# Supplementary Material A: List of games excluded from the review

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| **No.** | **Game Name** | **Authors/online reference** | **Players** | **Topic** | **Game purpose** | **Game purpose category** | **Reason for exclusion** |
| 1 | Aqua republica | UNEP-DHI Centre (https://www.unepdhi.org/aqua-republica/) | Students | Integrated Water Resource Management (IWRM) | To promote sustainable water resource management through experience gained by making decisions to manage a catchment in real life scenarios. | Decision-making, knowledge sharing (educative) | Three selection criteria not met: (1) The game focuses on water management at a catchment level with no explicit focus on urban areas/cities. (2) Not targeted at professionals (3) Non-academic game: information on game play and game design not available online |
| 2 | Aqualibrium | [Aqualibrium game (algorithmik.org.au)](http://www.algorithmik.org.au/apps/aqualibrium/) | Students | Water distribution system | To distribute a quantity of water equally between three points on a grid using a network of pipes. Teams are judged on how well they can achieve this task after a certain period of testing. | Knowledge sharing (educative) | Two selection criteria not met: (1) The game was primarily made as an educational tool and is not targeted at professionals (2) Non-academic game: information on game play and game design not available online |
| 3 | Atoll | Dray et al. (2006) | General public (residents of the atoll) | Groundwater management | To provide relevant information to local stakeholders to facilitate dialogue and devise sustainable water management practices. | Simulation, data exploration and collection | Three selection criteria not met: (1) focused on an island and not urban/peri-urban area (2) not targeted at professionals |
| 4 | CityOne | <http://gamesforcities.com/database/cityone-a-smarter-planet-game/> | Industry and business client | Sustainability, drinking water consumption | In the game, players transform cities by implementing alternatives in areas of energy, water, retail and banking. | Decision-making | One selection criteria not met: (1) Non-academic game: information on game play and game design not available online |
| 5 | Drop! H2O / Smart H20 | Novak et. al (2018) | General public (water consumers) | Reducing and monitoring drinking water consumption | Stimulate consumers to save water by changing their water consumption habits through their interaction with a behavioral change support system | Persuasive game (behavior change) | One selection criteria not met (1) Not targeted at professionals |
| 6 | EWAG survey | Aubert & Lienert (2019) | General public | Sustainable wastewater infrastructure planning | Provide information to players to understand the decision context of selecting decentralized vs centralized wastewater system and support construction of preferences. | Decision-making, data collection, knowledge sharing (informative) | One selection criteria not met (1) Not targeted at professionals |
| 7 | Floodplain Management Game | Stefanska et al. (2011) | Students and professionals (water managers, NGO, scientists) | River floodplain management; climate adaptation | To experience the challenges of policy-making for managing rivers as well as for floodplain agriculture and for scientists to examine how stakeholders make decisions about such alternatives | Simulation, data collection, knowledge sharing (informative), decision-making (problem solving) | One selection criteria not met: (1) The game is based on river sharing for only agricultural purposes and does not explicitly cover 'urban' water management |
| 8 | FloodSim | Rebolledo-Mendez et al. (2009) | Citizens | Fluvial flood policy | Raising awareness of issues surrounding flooding policy and citizen engagement in the UK. | Knowledge sharing (informative/raisng awareness) | One selection criteria not met: (1) Game not targeted at professionals |
| 9 | Hydro Hero | Appel et al. (2019) | Young citizens | Canal water maintenance | Improve knowledge and awareness about urban surface water maintenance so that citizens take on a proactive and responsible role | Knowledge sharing (informative), Motivation | One selection criteria not met: (1) Game not targeted at professionals |
| 10 | Nexus game | Mochizuki et al. (2021) | Professionals and researchers | Nexus; transboundary water sharing | Learn through experience how different water, energy, and food production, storage, and consumption technologies lead to the sustainable development of the respective countries. | Simulation, knowledge sharing (informative) | One selection criteria not met: (1) No explicit focus on urban areas |
| 11 | No game name | Predescu et al. (2021) | Citizens | Urban water infrastructure management | Bridge the gap between citizens and authorities to report and resolve infrastructure problems such as leak detection while providing entertainment-grade experience for the user | Data collection and exchange, motivation | One selection criteria not met: (1) The game is not targeted at professionals |
| 12 | No game name | ElSawah et al. (2015) | Professionals and general public | Water resources management, communication | Engage local residents to learn about water issues (in online mode) and facilitate dialogue among experts and users in public hearings and community gatherings (in collaborative mode) | Knowledge sharing (informative) | One selection criteria not met: (1) The paper only presents a simulation/gaming framework without a full-fledged game application. |
| 13 | NoMix tool | Pahl-Wostl et al. (2003) | Citizens | Sustainable nutrient recycling; urine separation technology | Information on the following topics is given in the tool: the content of nutrients and micropollutants (pharmaceuticals and hormones) in urine, the problems of collecting and storing urine in households, the possible technologies for transport and treatment of urine, and the concerns of agriculture. | Knowledge sharing (informative), Data collection | One selection criteria not met: (1) Although, the game has been mentioned in other review papers (Aubert et al, 2018), the authors do not claim it as a ‘game’ but call it an an ICT tool (the whole abstract does not mention the term ‘serious game’ or even ‘game’ a single time). |
| 14 | PIPES | Centre for Systems Solutions, (n.d.); Hamm & Mitchell, (2018) | Citizens and professionals | Drinking water quality and infrastructure management | Highlight decision-making challenges (e.g. lack of trust between stakeholders) and consequences of actions in the context of an aging drinking water infrastructure | Decision-making | One selection criteria not met: (1) Non-academic game: information on game play and game design not available online |
| 15 | Ravilla | Rusca et al. (2012) | Students | Intergated Water Resource Management (IWRM) | Provide hands-on experience with all important aspects of IWRM (i) understanding the system and its management, (ii) understanding the position of others, (iii) understanding the interaction between interest groups and (iv) experiencing different organizational and institutional settings. | Knowledge sharing (educative), training (negotiation skills, consensus building and working in teams) | One selection criteria not met: (1) Not targeted at professionals |
| 16 | ReNUWit Water/City Design Challenge | https://www.lawrencehallofscience.org/about/newsroom/in\_the\_news/renuwit\_water\_design\_challenge\_back\_ingenuity\_lab | Young citizens | Stormwater management | Create model cities, learn about permeable versus impermeable surfaces, and iterate designs to provide water for fish, prevent flooding, and promote infiltration of water into the ground | Knowledge sharing (educative) | One selection criteria not met: (1) Not targeted at professionals (2) Non-academic game: information on game play and game design not available online |
| 17 | Serious Sensor Placement | Rastburg et al (2020) | Students and general public | Optimal Sensor Placement | Place sensors in a water distribution system model, in order to improve their positions after they had been evaluated by a suitable algorithm. On the one hand, a minimum net coverage should be reached by the players, while on the other hand, a maximum number of placed sensors should not be exceeded. | Decision-making, knowledge sharing (educative) | One selection criteria not met (1) Not targeted at professionals |
| 18 | Shariva | Douven et al. (2014) | Professionals | Transboundary River Basin Cooperation | (1) Create awareness and upgrading knowledge amongst water and related professionals about cooperation and resolving transboundary river basin issues (2) practice related procedures and (3) test and review these procedures and provide recommendations for their improvement" | Knowledge sharing (informative), training | One selection criteria not met: (1) Game is focused on international river basin cooperation and not specifically on an urban area. |
| 19 | SIM4NEXUS | Sušnik et al. (2018) | Professionals and general public | Water-Energy-Food-Land-Climate Nexus | Enable stakeholders to understand and learn about the medium and long-term implications of nexus-related policies at a global/country/regional level. | Decision-making, learning | One selection criteria not met: (1)Game is not focused on a specific urban area rather case studies are focused on global, national or regional level (predominantly covering ruralareas/islands) which are outside the scope of this study |
| 20 | SimCity 4 | D’Artista & Hellweger (2007) | Students | Urban hydrology | Illustrate how water supply affects a city and vice versa | Knowledge sharing (educative) | Two selection criteria not met: (1)The authors only propose improvements to an existing entertainment game, SimCity4, but do not design the improved application (2) The game is not targeted at professionals |
| 21 | SimDelta | Rijcken et al.(2012) | Professionals (process managers, architects, water engineers) | Water infrastructure planning, flood risk management | A “SimDelta” would start with the current Dutch water system, and then present feasible solutions to problems showing up under various future scenarios. The game provides stakeholders and citizens insight into scenarios, problems and solutions, and also in other stakeholders. | Decision-making, data collection (crwodsourcing) | One selection criteria is not met: (1) The game is not a full-fledged application. The authors present an idea of what the game could be without implementing and testing it. |
| 22 | SOS mission eau | <https://www.dowino.com/en/realisations/serious-game-sos-mission-eau-2/> | Young audiences aged 7 to 11 years | IWRM (UWM) | Explain SEDIF’s business: the treatment and distribution of drinking water, from river to tap | Knowledge sharing (educative) | Two selection criteria not met (1) Non-academic game: information on game play and game design not available online (2) Not targeted at professionals |
| 23 | Unflushables | <https://www.ramjam.co.uk/project/the-unflushables/> | General public | Sewer waste | Learn about common misconceptions towards flushable items by sorting whether various items of sewage waste should be binned or flushed | Educative (informative) | Two selection criteria not met (1) Non-academic game: information on game play and game design not available online (2) Not targeted at professionals |
| 24 | Water Ethics Web Engine | Ewing & Demir (2021) | General public | Flooding, smart water systems, human-centred AI | Incorpoate voting-based ethical and normative preferences into water based decision support | Data collection, decision-making | One selection criteria not met (1) Not targeted at professionals |
| 25 | Water Wars | Hirsch (2010) | Citizens | Water scarcity | The game simulates realworld struggles over water in present-day New Mexico and highlights the challenges of economic, social, and environmental sustainability. | Simulation, knowledge sharing (informative) | One selection criteria not met (1) Not targeted at professionals: the game is categorized as a “civic game” - a class of socially-engaged games whose intent is to involve citizens in public affairs and democratic processes. |
| 26 | WaterArk | Cheng et al. (2019) | General public | Water resource adaptation | How to improve the public’s knowledge and ability to adapt water resources (WRs) as well as generate awareness of responsibility and willingness to do so are challenge issues | Knowledge sharing (educative) | One selection criteria not met (1) Not targeted at professionals |

# Supplementary material B: Mapping of serious games to decision-making phases

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| **Game no.** | **Game Name** | **Game contribution to DM** |
| 1 | Call for water | **Phase 4** (Participants are provided with information on latest observed reservoir volume, seasonal probabilistic forecasts on reservoir volumes and information about forecast performance in terms of sharpness (How confident is the forecast in predicting future outcomes?) and reliability (Can the player trust that the forecast range will contain the future scenario?) attributes) **Phase 5** (The main objectives in the game are to ensure that the town in the game has a secure water supply throughout the summer seasons while maintaining a budget. Players can choose to do nothing, call neighbors, sell surplus water, or wait and see. In the second round, participants have the possibility to pay for a subscription that provides reliable or sharp forecasts) **Phase 6** (Player's in-game decisions are monitored and characterized into perfect behavior - always securing water for the town while minimizing costs, safe behavior - risk averse behavior, passive behavior - never taking action regardless of reservoir conditions) |
| 2 | Invitational Drought Tournament (IDT) | **Phase 3** (Players consider conventional drought measures, e.g. water use restrictions, increasing irrigation efficiencies, promoting tourism or developing wetlands. They also develop their own solutions or strategies to manage droughts referred to as "innovations" in the game.) **Phase 4** (A systems dynamics model is used to demonstrate to the players the effects of their chosen drought mitigation alternatives and their resulting social, economic and ecological stresses during a simulated drought. The IDT model incorporates six connected sectors - population, water supply, municipal water use, agricultural water and land use, industrial water use and recreation.) **Phase 5** (Players have to meet the budget constraints while selecting their preferred drought management strategy and consider the impact of their choices on social, economic and environmental factors. Their drought management plans are then scored by an expert committee or in some setups scored involving other participants) |
| 3 | LA water game | **Phase 4** (The game has an underlying simulation model programmed in Vensim that allows players to adjust decision variables - money spent on infrastructure maintenance and fee charged to the public, and see its impact on the outcomes of concern. Participants can test their hypothesis regarding the system relationships by trying different combinations of the decision variables and receive feedback) **Phase 5** (Players evaluate tradeoffs on outcomes of quality, public opinion, and maintenance cost and decide accordingly) **Phase 6** (The game is player in rounds. 3 teams represent different generations and play subsequent rounds. The underlying simulation model allows the players to intervene at each time step, try a combination of decision variables and see instantly the impact of their choices on the indicator and get feedback for the next round) |
| 4 | Maintenance in Motion | **Phase 4** (Players are provided with tabular data about the financial and physical interactions between different infrastructures, e.g., street rehabilitation costs and impact of gas or sewer replacement on street deterioration. A Markov model is further used to mode infrastructure deterioration in the game) **Phase 5** (Players manage drinking water, gas, sewer, and street infrastructure and they need to balance their individual goal - cost effectiveness with their team goals - to increase infrastructure quality and minimize public costs under the uncertainties of no/perfect information about the current state of the object, unknown deterioration process, and unknown physical interactions among infrastructure and negotiation among players. In each round, players can choose to: inspect, replace or do nothing) **Phase 6** (Player's in-game decisions are recorded for further analysis to understand the relation between quality of information and the quality of rehabilitation decisions taken) |
| 5 | Management Game Asset Management | **Phase 1** (Players discuss the current state of the organization and discuss problems within different departments in the organization. The discussions that ensue in the game help players understand the difference in perceptions or knowledge on asset management)  **Phase 5** (Players choose to buy growth cards that stimulate investment in development programs such as ICT, training and communication, risk management or performance management. The money to buy these cards needs to provided by the Organization Manager and players must convince the manager or undertake debate challenges where they have to convince team members to be able to gain additional money) |
| 6 | Millbrook Serious Game | **Phase 4** (Players can change the level of drainage infrastructure investment and type of farming systems and they are provided feedback about their in-game decisions in the form of simulation results), **Phase 5** (Find the optimal combination of measures that leads to a solution that minimizes both damages and management costs) **Phase 6** (The Millbrook serious game uses a high-speed model that can quickly display numerous flood outputs resulting from different player inputs providing them with feedback on their decisions) |
| 7 | No game name | **Phase 1, 2, 3** (Primary data collection through field visits where interviews and group discussions were conducted to identify the main concerns of the stakeholders leading to identification of access to drinking water as the major concern. Furthermore relevant actors, their preferences, roles, actions, and resources were also mapped in this phase)  **Phase 4** (The game uses cooperative and non-cooperative game theory models which were used to define the players, their roles, actions, resources, and potential outcomes in the game) **Phase 5** (Players explore strategies that address their drinking water problems) **Phase 6** (Players test their strategies in multiple rounds, they implement a decision in the game world, see its outcome under uncertainty, then play the next round) |
| 8 | Perspective-based simulation game | **Phase 4** (Water management measures adopted by the player in the game are fed into an Integrated Assessment Meta Model to assess the implications of the decision under the climate change scenario and the results are presented to the players) **Phase 5** (Players implement flood prevention measures such as dike broadening, flood prevention, dike elevation, river widening, etc. and consider the implications of their choices on flooding, drought, nature development, and shipping) **Phase 6** (The game is played in rounds and players can get feedback on their collective decisions through the results of the IAMM model) |
| 9 | SeGWADE | **Phase 4** (The game used an EPANET based hydraulic simulation engine to simulate the results of the player's inputs) **Phase 5** (In the game, the player is challenged to find a solution that minimizes the cost of duplicated pipes while maintaining a minimum pressure in the water distribution system) **Phase 6** (Players test their solutions are provided continuous and instant feedback on the performance of their solution through the output of the hydraulic simulation model) |
| 10 | Ter' Aguas | **Phase 1, Phase 2, Phase 3** (Involvement of stakeholders through a companion modelling approach with 6 workshops to better identify the representation of local actor in environmental issues, development dynamics, urbanization process and their negotiation strategies with the water utility and governmental actors),  **Phase 4** (Underlying computer simulation assess the impact of players' choices on the quality of reservoir water, cash assets, and social indicators) **Phase 5** (Players experiment with multiple decisions in the game such as investment strategies in urban infrastructure, economic activities like buying and selling plots, licensing land use activities, and allocating land to migrant families in the area) **Phase 6** (The computer simulation assesses the impact of player's decision on the quality of reservoir water, cash assets of players and social indicators of municipality. Players reflect on the impact of one round of decision making, try to find a more collective strategy and implement it in the next round) |
| 11 | The Climate Game | **Phase 4** (Relevant information and value of each decision chosen by the player is calculated and presented on the computer screen that helps players to compare alternatives and make planning decisions) **Phase 5** (Players can choose from a list of decisions that are predefined in the game, e.g. improving housing conditions, developing more green areas, developing more water storage facilities or new waterworks and infrastructure. These decisions are taken to simultaneously achieve their individual and collective goals) **Phase 6** (Players reflect on the scores for their performance indicators such as livability, sustainability, finance, water storage facilities, etc, and play the next round) |
| 12 | Visimple | **Phase 4** (The game is based on a Geographic Information System (GIS) that is coupled with a Planning Support system (PUS). The interface between PUS and game transfers the results of hydraulic calculations and other values of the engineering tool to the game simulation. The outputs of the simulation show the impact of player's decision on the quality and sustainability of infrastructure) **Phase 5** (The possible actions are focused on adapting the water infrastructure components. Starting from a fixed urban development, players try to optimize the wastewater disposal and water supply of the city) **Phase 6** (Implicit: Although the game does not explicitly mentions number of rounds or trial and error sessions; it supports immediate system reactions which provide feedback to the players and allow them to find the most efficient strategy for converting a water infrastructure system) |
| 13 | Wastewater RPG | **Phase 4** (The game uses a simple model based on Excel spreadsheet that characterizes each element in the game by: flow rate and wastewater composition and applies matter balance to waste-water flow and pollutant concentration.) **Phase 5** (Players take decisions on optimizing resources available, e.g. industrial tanks, pluvial or storm tanks, bypass, or wastewater treatment plants, under the given scenario while balancing their own individual goals and collective goals) **Phase 6** (Players receive a positive/negative score if the water characteristics are below/above the legal limit) |
| 14 | Water Safety Plans | **Phase 4** (Players are provided with a water safety plan that maps the decision alternatives to the likelihood of occurrence, severity, risk, corresponding costs, risk level after implementing the control action, and stakeholders required to implement the action) **Phase 5** (Players are divided into 2 sub-groups and within each sub-group they need to decide how to spend the money over the next 10 years while keeping the 'risk' levels low. A few available alternatives they have include investing in advanced treatment systems at the drinking water plant, improving farming practices, closing of water storage tank, etc. However, players need to strategize their investment based on two constraints (1) limited budget (2) requirement of collaboration with stakeholders from the other sub-group to implement an intervention) |
| 15 | WATERSTORY | **Phase 1, 2, 3** (Stakeholders across various backgrounds and interests were involved in the group modeling sessions that helped identify key issues, prioritize intervention alternatives, and improve system understanding. Stakeholders were further involved in discussion that focused on possible alternatives that could ensure sustained availability of water for the Maui population), **Phase 4** (The information from Phase 1 and Phase 3 was used to develop a customized Systems Dynamics model relevant to the local content. The model incorporated the identified policy alternatives to analyze their social, economic and environmental impact across residential, commercial, industrial and agricultural sector) **Phase 5** (Players are encouraged to play with the model by changing model assumptions about precipitation, population and GDP and choosing the best combination of policy alternatives: increasing flow regulations, increasing water use efficiency or constructing a desalination plant) **Phase 6** (The user interface shows the impact of player's decisions on the water demand and supply of Maui) |

**References**:

Appel, Y., Dimitrov, Y., Gnodde, S., van Heerden, N., Kools, P., Swaab, D., … Bidarra, R. (2019). A serious game to inform young citizens on canal water maintenance. In A. Liapis, G. N. Yannakakis, M. Gentile, & M. Ninaus (Eds.), *Games and Learning Alliance* (pp. 394–403). Cham: Springer International Publishing.

Aubert, A. H., & Lienert, J. (2019). Gamified online survey to elicit citizens’ preferences and enhance learning for environmental decisions. *Environmental Modelling and Software*, *111*, 1–12. https://doi.org/10.1016/j.envsoft.2018.09.013

Cheng, P.-H., Yeh, T.-K., Tsai, J.-C., Lin, C.-R., & Chang, C.-Y. (2019). Development of an issue-situation-based board game: A systemic learning environment for water resource adaptation education. *Sustainability*, *11*(5), 1341. https://doi.org/10.3390/su11051341

D’Artista, B. R., & Hellweger, F. L. (2007). Urban hydrology in a computer game? *Environmental Modelling and Software*, *22*(11), 1679–1684. https://doi.org/10.1016/j.envsoft.2006.09.004

Douven, W., Mul, M. L., Son, L., Bakker, N., Radosevich, G., & Hendriks, A. (2014). Games to create awareness and design policies for transboundary cooperation in river basins: Lessons from the Shariva game of the Mekong River Commission. *Water Resources Management*, *28*(5), 1431–1447. https://doi.org/10.1007/s11269-014-0562-x

Dray, A., Perez, P., Jones, N., Le Page, C., D’Aquino, P., White, I., & Auatabu, T. (2006). The Atoll game experience: From knowledge engineering to a computer-assisted role playing game. *Journal of Artificial Societies and Social Simulation*, *9*(1), 1–11.

ElSawah, S., McLucas, A., & Mazanov, J. (2015). Communicating about water issues in Australia: A simulation/gaming approach. *Simulation and Gaming*, *46*(6), 713–741. https://doi.org/10.1177/1046878115580410

Ewing, G., & Demir, I. (2021). An ethical decision-making framework with serious gaming: A smart water case study on flooding. *Journal of Hydroinformatics*, *23*(3), 466–482. https://doi.org/10.2166/HYDRO.2021.097

Hirsch, T. (2010). Water wars: Designing a civic game about water scarcity. In *DIS 2010 - Proceedings of the 8th ACM Conference on Designing Interactive Systems* (pp. 340–343). New York, New York, USA: ACM Press. https://doi.org/10.1145/1858171.1858232

Mochizuki, J., Magnuszewski, P., Pajak, M., Krolikowska, K., Jarzabek, L., & Kulakowska, M. (2021). Simulation games as a catalyst for social learning: The case of the water-food-energy nexus game. *Global Environmental Change*, *66*, 102204. https://doi.org/10.1016/j.gloenvcha.2020.102204

Pahl-Wostl, C., Schönborn, A., Willi, N., Muncke, J., & Larsen, T. A. (2003). Investigating consumer attitudes towards the new technology of urine separation. *Water Science and Technology*, *48*(1), 57–65. https://doi.org/10.2166/wst.2003.0015

Predescu, A., Arsene, D., Pahont, B., Mocanu, M., & Chiru, C. (2021). A serious gaming approach for crowdsensing in urban water infrastructure with blockchain support. *Applied Sciences (Switzerland)*, *11*(4), 1–32. https://doi.org/10.3390/app11041449

Rebolledo-Mendez, G., Avramides, K., de Freitas, S., & Memarzia, K. (2009). Societal impact of a serious game on raising public awareness. In *Proceedings of the 2009 ACM SIGGRAPH Symposium on Video Games - Sandbox ’09* (pp. 15–22). New York, New York, USA: ACM Press. https://doi.org/10.1145/1581073.1581076

Rijcken, T., Stijnen, J., & Slootjes, N. (2012). “SimDelta”—Inquiry into an internet-based interactive model for water infrastructure development in the Netherlands. *Water*, *4*(2), 295–320. https://doi.org/10.3390/w4020295

Rusca, M., Heun, J., & Schwartz, K. (2012). Water management simulation games and the construction of knowledge. *Hydrology and Earth System Sciences*, *16*(8), 2749–2757. https://doi.org/10.5194/hess-16-2749-2012

Stefanska, J., Magnuszewski, P., Sendzimir, J., Romaniuk, P., Taillieu, T., Dubel, A., … Balogh, P. (2011). A gaming exercise to explore problem-solving versus relational activities for river floodplain management. *Environmental Policy and Governance*, *21*(6), 454–471. https://doi.org/10.1002/eet.586

Sušnik, J., Chew, C., Domingo, X., Mereu, S., Trabucco, A., Evans, B., … Brouwer, F. (2018). Multi-stakeholder development of a serious game to explore the water-energy-food-land-climate nexus: The SIM4NEXUS approach. *Water (Switzerland)*, *10*(2), 139. https://doi.org/10.3390/w10020139