# A serious gaming tool: Bow River Sim for communicating integrated water resources management

Mohammad Khaled Akhtar, Carmen de la Chevrotière, Shoma Tanzeeba, Tom Tang and Patrick Grover

## ABSTRACT

Serious games provide a way for stakeholders to become engaged in and understand the issues and constraints on a real-world system. An application of a serious game is explored, as a way to improve engagement and learning of participants in a water management planning process. Bow River Sim is a single-player game that helps the user to understand the Water Resources Management Model (WRMM) and to visualize the implications and impacts around system interactions in the basin. The Bow River Sim simulates water management decision-making based on maximizing social, economic, and environmental benefits while managing limited water supply. The game incorporates the principles of 'meaningful play' and provides a user-friendly interface, a fun game, and visual elements. The paper aims to (a) provide an overview of Bow River Sim, (b) illustrate how innovations such as serious games enhance learning processes for the user, and (c) illustrate the application of Bow River Sim and key learnings.

**Key words** | Bow River Sim, serious game, Unity game platform, water resources management model, WRMM

**Mohammad Khaled Akhtar** (corresponding author)
**Carmen de la Chevrotière**
Alberta Environment and Parks,
Government of Alberta,
Alberta, AB,
Canada
E-mail: *khalediwm@yahoo.com*; *Khaled.Akhtar@gov.ab.ca*

**Mohammad Khaled Akhtar**
(Mailing Address)
River Engineering and Technical Services,
11th Floor, Oxbridge Place, 9820 106 Street NW,
Edmonton, AB T5 K 2J6,
Canada

**Shoma Tanzeeba**
**Tom Tang**
Alberta Environment and Parks,
Government of Alberta,
Calgary, AB,
Canada

**Patrick Grover**
BGC Engineering Inc.,
Toronto, ON,
Canada

## INTRODUCTION

In 2017, Alberta Environment and Parks (AEP) developed a serious game using its decision support system model for the Bow River basin, called Water Resources Management Model (WRMM). The goal was to explore moving from the use of the decision support system model – for simulation along with communication and input through stakeholder workshops – to serious gaming. In this way, stakeholder engagement and learning could be improved. AEP is a ministry under the provincial government of Alberta and is responsible for licensing water use in the province, including water management planning. AEP was seeking an innovative way to communicate and engage with stakeholders of various backgrounds regarding decision support system simulations as a part of the water management planning process. The types of participants/stakeholders in these processes include water users (e.g. a city or large industry, small individual water users such as agricultural irrigators), indigenous organizations, government licensing staff, managers, legislative decision-makers, non-government organizations, and the general public with conservation concerns. A key challenge in water management planning processes is educating stakeholders/workshop participants on background and model assumptions, such as the complex legislative framework for water in Alberta, and water commitments outside of Alberta.

The serious game concept is not new; it evolved from war games in the Far East more than a hundred years ago. Modern war games originated by the end of the 18th century in Prussia as training tools for staff officers. For improved decision-making on current complex problems, it is essential

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to ensure better communication and information sharing to deal with sensitivity, complexity, and uncertainty. To achieve this balance, complementary tools to decision support system models are designed as 'serious games'. The fictional nature of the game is designed to relax the requirements and to provide information suitable for making 'defensible' decisions, allowing it to focus on presenting the data in a communicative and interactive way, to give stakeholders a better intuitive understanding of the complexity (Craven 2015). Such games can be of use to reach a young generation or to bring stakeholders into a dialogue (Medema et al. 2019). Evers (2017) indicates that serious games are the basis of a demand for incremental modifications (and experiments) of trial and error, as well as active learning of water governance systems. Serious games can be defined as the intersection between simulation, games, and learning (Figure 1). They should be attractive and engaging, although not necessarily fun, while learning may be implicit or explicit (Ulicsak & Wright 2010).

A serious game requires a game, simulation and learning aspect in almost equal measure. Combining a game and simulation, without learning, results in simulation games, which are purely for entertainment (Martens et al. 2008). Cognitive science has identified four main pillars of learning: attention, active learning, feedback, and consolidation (Esambert 2013; Drummond et al. 2017; Figure 1). The value of video games in these pillars is that they provide repetition, interaction, and feedback. The learning pillars should be carefully included in a serious game. Water allocation and management often require negotiating amongst different stakeholder interests, where a role-playing simulation, a simulation game, or a serious game may be useful. A case study conducted by Ferrero et al. (2018) demonstrated that a serious game helps players to understand the governance process and the negotiation that it requires among stakeholders to reach an agreement. Hill et al. (2014) found that participants in a role-playing water management game (drought tournament) desired realistic feedback on their water management strategies during gameplay. Susskind & Schenk (2014), negotiating experts, point out that role-playing simulations can only be used to intervene in real negotiations if they meet several criteria. The simulation is designed realistically and presented by an instructor/moderator who can guide the stakeholders/players/participants in the reflection of the results. The simulation must also use general instructions and confidential instructions so that the participants are more likely to follow the scenario. Finally, the participants must have a desire for a simulation to consider all options.

A simulation game can be used in water management planning to explore various possibilities of water licensing policy, reservoir system operations, and initiation of collaborative discussion among stakeholders of a basin (TGM 2012). AEP's water management processes, to date, likely fall into the realm of pure simulation or training exercises. While in these processes, stakeholders provide input to

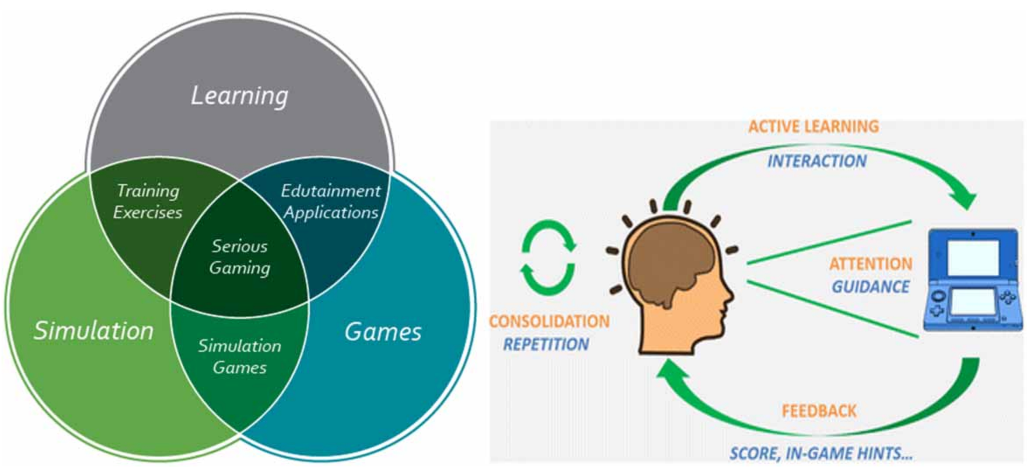


**Figure 1** | Superimposed area of serious gaming (left). Pillars of learning at right (active learning, attention, feedback, and consolidation) and the value of video games (interaction, guidance, score, and repetition) (Drummond et al. 2017).

generate scenarios to run, or tracking metrics to output, these do not necessarily have the requirements for a game, where a player or players have direct interaction with the simulation and are given the freedom to change parameters (within some designed limitations).

Games can be classified according to their type of gameplay, including goal-based (goals to reach or score) or play-based (no stated goals to reach); their purpose (educative message, informative message, and training); their market (entertainment, military, healthcare, scientific research, advertising, and environmental issues); and target audience (general public, professionals, and students). The gameplay in a serious game enables the active learning and feedback learning pillars, through the direct interaction with the game, and feedback (visual feedback or scoring).

Most currently available water management games have their own set of learning objectives and players in mind. SimBasin has turn-based, decision-based gameplay, to communicate conflicts and trade-offs in the basin, and facilitate workshops and discussions (Craven *et al.* 2017). WaterSim (Gober *et al.* 2010) is a water model with no extraneous gameplay elements but can provide a system level view. It explains how water data variables interact through visualization, allowing the players to view variables in a graphical form (charts and tables). Water Footprint Network developed a simplified game, Water Footprint Assessment Tool (Water Calculator) to provide clear insight into how water is appropriated and associated impacts resulting from those uses (https://waterfootprint.org/en/resources/interactive-tools/#CP). It assists companies, governments, NGOs, investors, consultants, researchers, and others to calculate and map a water footprint, assess its sustainability, and identify strategic actions to improve the sustainability, efficiency, and equitability of water use. Catchment Detox was developed in Australia to teach players about catchment ecosystems, water planning (including restrictions), and achieving healthy ecosystems. Catchment Detox is a game but not a scientific model. However, it is based on today's scientific understanding of water and catchment management issues (https://www.abc.net.au/science/catchmentdetox/files/faq.htm#faq2). Another Australian game is Run the River (https://www.mdba.gov.au/education/apps/run-the-river/teacher-guide), with an interactive tutorial. In this case, learning objectives are the elements of the water cycle, connections between the elements, and human impacts on the water cycle. Teaching the principles behind balancing the authorized purposes for operating a main stem inland waterway is embedded into the River Basin Balancer game where core controls are navigation, hydropower, recreation, water quality, and flood control (https://silverjackets.nfrmp.us/Portals/0/doc/presentations/Michelle_Schultz_slides.pdf). A few serious games focus on cross-border flood risk management and aim at training managers and decision-makers to deal with a flood-crisis situation. For example, the objective of the game Flood-Wise (Dewals & Fournier 2013) is to achieve a cross-border approach to flood risk management and to reinforce water management bodies' resilience to flood by simulating such circumstances. Another game, FloodSim, showed its potential to engage the public and raise awareness of societal issues by putting the player in control of flood policy in the UK (Rebolledo-Mendez *et al.* 2009). In this game, players decide how much money to spend on flood protection, how to keep the public informed, and where to build houses. Here, players must weigh the risk of flooding in different regions and the potential impact on the economy and the local population. DHI and the UNEP-DHI Centre for Water and Environment developed Aqua Republica to reflect the requirements of a serious game, by providing a learning platform for a sustainable river basin development. It requests the player to develop a prosperous river catchment, by generating a good economy to provide funds needed for development, having a steady food supply for the population and enough energy and water for the watershed. The game also includes a reward system to encourage learning, through the basin score (Chew *et al.* 2014, 2015). Laucelli *et al.* (2019) attempted to use serious gaming to help engineering students learn the complexities of designing water distribution networks and found that the gaming environment had value for learning such a complex system while facilitating an enjoyable experience. The study by Van der Wal *et al.* (2016) on water management also demonstrated the important role of serious games in social learning.

Research on the effectiveness of serious games is still underway, but it is almost impossible to draw any basic conclusions with the many facets that serious games can have. Even between similar games in the same type of comparison it is difficult and between different genres, it is almost impossible (Giessen 2014). It is assumed that the effectiveness of serious games is mixed with the design elements chosen for the game (Maheu-Cadotte *et al.* 2018), but the real meta-analysis confirms that serious games are generally more effective than conventional methods (Wouters *et al.* 2013). It is a collaborative planning approach that has proven to be an effective method for creating an attractive learning environment (Xu *et al.* 2020). Ke (2009) pointed out that, according to the conclusions of several game reviews, the empirical research on educational games is fragmented by research variables (research objective and methodology), administrative variables (learning environment), learning variables, procedural variables (e.g. game-based pedagogy), and game variables (e.g. genre and gaming media).

This paper presents a serious game application developed by AEP, named the 'Bow River Sim', along with the development process and lessons learned, to assist other water management teams and advisory councils, should they decide to apply serious gaming. While it is challenging to assess, an initial evaluation of its effectiveness is provided. Bow River Sim is a single-player water management serious game. It is separated into three components: a tutorial component, a play-based serious game, and a goal-based serious game. Serious games vary between highly accurate simulations, to games with entirely invented gameplay. In this case, the Bow River Sim is located towards the simulation spectrum but not like SimBasin or Water Footprint Assessment Tool (Water Calculator) as it blends Simulation (real water allocation model – WRMM) within a gaming environment. For AEP, it was a pilot exploring serious gaming as an engagement, communication, and learning tool for water resources management simulation.

## WATER RESOURCES MANAGEMENT IN ALBERTA

### Introduction of WRMM

Canada has a complex regulatory system for various aspects related to water resources management at federal, provincial/territorial, and municipal levels. The provinces have jurisdiction to license the use of natural water resources within provincial borders and to manage water shortage in years where natural water supplies are much below climate normals. The federal government provides monitoring of water flow and water levels through partnered funding with provinces and territories. Several transboundary water agreements exist between provinces and territories in Canada, which recognize the authority to manage resources within jurisdictional boundaries, while making commitments to downstream jurisdictions, for maintaining certain water quantity and quality objectives at borders.

Municipalities, large cities, and irrigation districts in Alberta manage drinking water and wastewater facilities, canals and distribution systems, and conservation and efficiency measures related to each of their water licences from the province. The timing for water demands varies according to the type of use, and the presence and size of water storage reservoirs.

It is in this complex water management context that AEP developed WRMM in the early 1980s as part of the South Saskatchewan River Basin (SSRB) planning program. The WRMM plays an important role in ensuring a balance of social, environmental, and economic benefits for various stakeholders in southern Alberta, within the provincial regulatory system. The WRMM allocates the available natural water supply to the various demands in order of Alberta Water Act (2000) licence priority and makes the best use of storage structures to mitigate shortages in times of low water supply and high demands. As a planning and long-term decision support model, it is used to run an entire historical time-series of natural water supply conditions (e.g. 1928–2001). The strength of the model is its capability to allocate water supplies according to the rules of the Alberta Water Act. Model results can be used to evaluate effects (risk) of new licence applications (e.g. irrigation expansion) or licence transfer applications on other existing water users and on conservation objectives for the aquatic environment. In addition, the results can also be used to assess whether a long-term assured supply is available for new water users under varying climate conditions. This helps with understanding and mitigating potential challenges in water management.

Previous WRMM applications range from local to regional, inter-provincial, and international scale water planning studies, including the South Saskatchewan Regional Plan (Alberta Government 2003, 2018), SSRB Approved Water Management Plan, Highwood Diversion Plan, Special Areas Water Supply Project, Acadia Irrigation Proposal, Meridian Dam Analysis, etc. WRMM has also been used to support:

- AEP and TransAlta agreement on a short-term 5-year plan,
- Water management infrastructure operations, design, and storage feasibility studies,
- The Montana-Alberta St. Mary and Milk Rivers Water Management Initiative,
- Cross-government and research institutions, and
- External stakeholders such as First Nations, Irrigation Districts, TransAlta, Consultants, Watershed Planning and Advisory Councils (WPACs).

In these types of model applications, communication, engagement, and education about the modelling process, potential scenarios, and simulation are achieved through an iterative process spanning many months or years, with a group of stakeholders representing multiple sectors (e.g. cities, rural municipalities, and agricultural producers). Feedback from participants is achieved through several workshops; however, models must be run by water resources engineering professionals and time spent in producing visualizations of results in between workshops. While this engages learners and stakeholders more than a lecture-style delivery, it is extremely time-consuming, requires repetition of key concepts as stakeholders change, and requires a level of trust that professionals are presenting results in an unbiased way.

## WRMM description

WRMM is a computer program that simulates water uses, water priorities, and remaining river flows (Figure 2). The application's primary use is to aid water management planning and long-term decision-making on water licences.

The WRMM is a steady-state surface water allocation model, which balances supply and demand optimally on short time steps over long periods of varying natural water supply conditions. In most of the past applications, the model runs on a weekly time step, but it can be set up to run monthly. One of its key features is its penalty point system, which can simulate the legal priority of demands in a particular river basin. In this way, the benefits or impacts to licensees, instream requirements, and other objectives can be evaluated over a long-term range of conditions. The model uses natural water supply and calculates shortages in each time step compared to demands. The model input data can be provided as cyclical (i.e. confined to one cycle, usually a year, and assumed to be repetitive) or as multi-cyclic (i.e. different in every cycle). Examples of cyclical input are municipal and industrial needs; examples of multi-cyclic data are natural flow or recorded flow, precipitation, evaporation, irrigation demand, hydropower demand, instream flow demand, and transboundary flow requirements (i.e. flow apportionment). Most of the time, irrigation demand data are generated by the Alberta Agriculture Irrigation Demand (IDM) model, whereas natural water supply is estimated by using natural flow models.

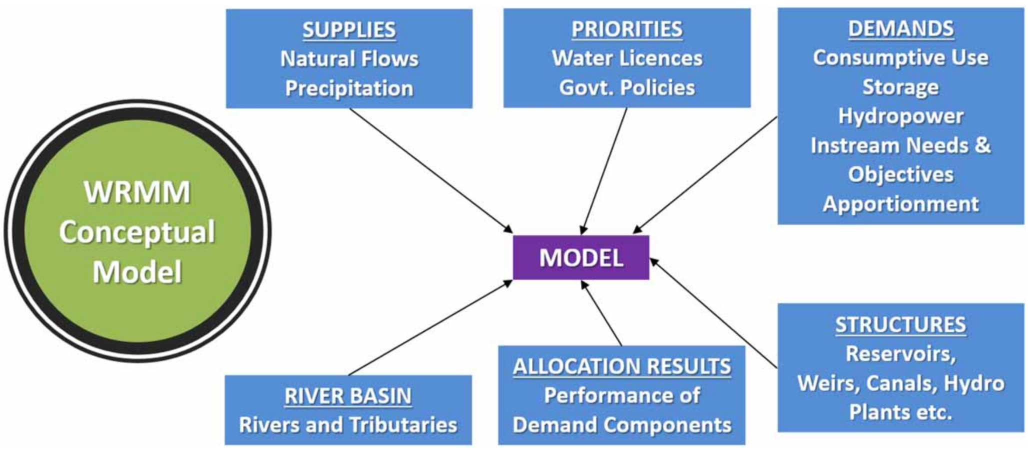


**Figure 2** | Water Resources Management Model (WRMM) components and connections.

The modelled region is translated into a network composed of nodes interconnected by flow links to represent physical channels. Nodes are used to represent points of inflow, diversion, storage, or consumption. Flow links define the direction of surface water movement from one location to another, e.g. river reaches, diversion canals, and return flow channels. The model components consist of (a) Inflows, (b) Natural Channels, (c) Diversion Channels, (d) Return Flows, (e) Reservoirs, (f) Hydropower, (g) Irrigation, (h) Non-Irrigation – Major/Minor Consumption, and (i) Apportionment.

The latest version of the WRMM is written in the C++ language and utilizes an improved Out-of-Kilter Algorithm (OKA) of Barr *et al.* (1974). In WRMM, all model data are converted into the basic variable: flow. The OKA is used to solve the 'minimum cost flow' problem. A feasible solution to the minimum cost flow problem is any set of arc flows which satisfies nodal continuity for every node and complies with the prescribed bounds on every arc. Each feasible solution incurs a total cost, defined as follows:

$$\text{Total cost} = \sum_{i=1}^{N} (Q_i C_i) \tag{1}$$

where $Q_i$ is arc flow (which must lie within the prescribed upper and lower bounds for the arc), $C_i$ is the arc cost (or penalty), and $N$ is the total number of arcs in the network.

Feasible solutions will have different values of the total cost. Therefore, the OKA searches the set of all feasible solutions (the feasible region) for the feasible solution with the minimum total cost. This is called the optimal solution.

The conceptual WRMM components (i.e. river basins, water supplies, demands, priorities, and structures) were applied to build a model of the full SSRB system. The SSRB WRMM has over 900 of those components and takes under 5 min to simulate a scenario with 74 years of data.

The SSRB is made up of several river sub-basins. The Bow River and the Oldman River join to form the South Saskatchewan River, and the Red Deer River joins the South Saskatchewan River just past the Alberta–Saskatchewan border. Alberta's transboundary flow commitment to Saskatchewan under the Master Agreement on Apportionment applies on the South Saskatchewan River downstream of the confluence with the Red Deer River and is of the highest priority to be met. The model simulates water distribution and shortages to various licences (e.g. city and irrigation district) based on the priority of their licence. The analysis of SSRB WRMM results helps all participants in the water management system understand the implications of the 'first in time, first in right' system over a large range of historical water supply conditions. Those involved in the water management system include water resource professionals providing advice to decision-makers on licence conditions, small business owners who hold a licence and must understand and follow those conditions, and stakeholders concerned with recreation and conservation who want to understand the impacts of water use on river flows.

While the simulation of the full SSRB system is necessary for decision-making, and the simulation runs fairly quickly, the whole system has many components and complex interactions that make game creation challenging. As the simulation is an important part of creating a serious game, a key decision was made to keep the WRMM intact. De-coupling of the WRMM simulation from the game also allows AEP the flexibility to apply other applications of WRMM, with minimal additional work, focused on game creation and artwork components. In this way, the resources to build the input data and basin components are not duplicated by building a new simulation integrated into the game itself.

## DESIGN AND DEVELOPMENT OF BOW RIVER SIM

Bow River Sim was designed and developed by a multi-disciplinary team (hydrologists, water modellers, game artists, game designers, programmers, and water managers). Professional staff from AEP's water management divisions directed the project and developed the simplified WRMM for the Bow River. AEP, along with an engineering firm, directed the game development team, which consisted of a game designer, a game artist, and a game developer to create a game around the WRMM. The game development team members were student interns. The game designer was responsible for overseeing the development of the gameplay, including the structure and rules of the game, and ensuring that the learning objectives were achieved. The game artist was responsible for creating the game art. Finally, the game developer developed the game software including the production of the user interface, coding of game rules, and pre- and post-processing of the WRMM.

## Bow River system simplified model

The Bow River portion of the SSRB WRMM contains a variety of water uses, including the City of Calgary and irrigation districts, and consists of about 350 components. While it is representative of various water management challenges and has considerably fewer components than the SSRB model, it was still too many components to introduce elements of gameplay. Model elements for the WRMM for Bow River Sim were reduced to 50 key water management elements shown in Figure 3.

The simplification was necessary to (i) reduce the complexity of the model to allow for learning, using play-based and goal-based gaming and (ii) reduce the model runtime. The simplified model has a reduced number of components from the original complex model: the number of diversions (5 from 114), natural channels (5 from 38), junctions (6 from 48), inflows (3 from 32), and return flows (3 from 25). However, the simplified model still contains key components of the conceptual model (e.g. supply and demand) and their functionality. The full 74 years of data for the reduced number of components was still kept, so that a large variety of low or high flow years can still be represented in the gameplay. The process of simplifying the model required a water resources modeller familiar with the SSRB WRMM to consolidate these components.

Model runs for the simplified version of the model were compared with the full Bow River system model during the development phase. While their results were not the same, the simplified version was representative enough for serious gaming purposes. Because of the simplicity, the model can

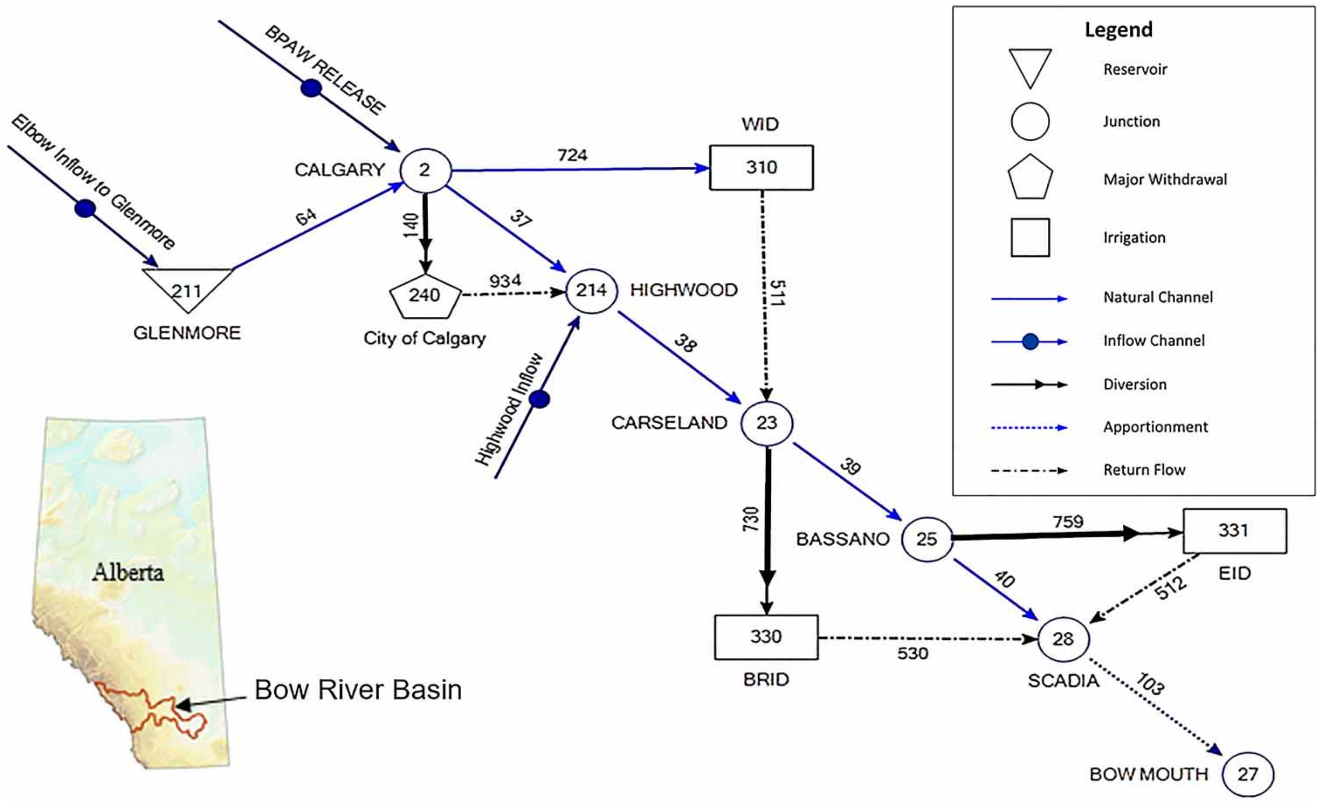


**Figure 3** | The WRMM (simplified version) of the Bow River basin developed by AEP for the Bow River Sim.

be executed on any regular desktop computer (i.e. Windows computer with 1.86 GHz dual-core processor and 4GB RAM). Run time of the simplified model is less than half a minute. Users/players are not required to use a gaming desktop or high configuration computer to carry out any of the tasks.

There are three inflow channels, which provide natural water supply into the model: the Bow River just downstream of the Bearspaw Dam, the Elbow River, and the Highwood River (Figure 3: BPAW Release, Elbow Inflow to Glenmore, and Highwood Inflow). The downstream end of the model is the junction with the Oldman River which then forms the South Saskatchewan River. The model includes the Glenmore Reservoir located on the Elbow River, upstream of the junction with the Bow River. The Glenmore Reservoir is the primary source of drinking water for the City of Calgary. Water demand elements in the model include the City of Calgary, three water irrigation districts with their inflow/outflow channels (the Western, Eastern, and Bow River Irrigation Districts), four natural channels which include instream flow requirements (minimum flow and percent of natural flow), and an apportionment channel at the downstream end which includes flow into the South Saskatchewan River as part of the total requirement for the transboundary agreement between Alberta and Saskatchewan.

The hydro-climatic time-series data used by both the full and simplified models are based on weekly historical natural streamflow, precipitation, and evaporation data between 1928 and 2001. In practice, the WRMM is not a historical simulation of the Bow River, but rather uses the historical range of natural water supply to explore the impact of various water management decision scenarios. Therefore, the irrigated area of the irrigation districts and the water demand for the City of Calgary do not change to reflect the historical growth but remain static. Players can, however, change the area of the irrigation districts and the water demand for the City of Calgary as part of the gameplay. Water demand for the three irrigation districts, which is based on the hectares of irrigated land, uses the Irrigation Demand Model, which generates water demand based on the crop type, historical precipitation, evaporation, and evapotranspiration data. Water demand for the City of Calgary is based on a single year (i.e. the water demand does not change year to year). Apportionment requirements for this simplified model are the estimated Bow River contributions to the transboundary agreement between Alberta and Saskatchewan.

## Game architecture

The Bow River Sim game architecture was designed to address several requirements: (a) able to be used by the public, (b) have a highly attractive (3D) and engaging user interface, and (c) be responsive and playable with minimal times. A major design consideration was how to interface with the WRMM. The WRMM EXE is a command-line interface (CLI) application that does not have a graphical user interface and instead uses text-based input and output files. CLI applications can easily be triggered to be run by other applications; however, this results in a turn-based gameplay style and slower runtimes. Another approach considered was to compile the WRMM code into a library (e.g. a dynamic-link library or DLL), which could then be directly called by the game and run in the computer's memory. This would have the advantage of allowing for greater control of the gameplay and faster interaction with the WRMM. The team selected to interact with the WRMM EXE as shown in Figure 4. While the choice to use the WRMM EXE was for simplicity, this solution provided a degree of transparency to the players as they can inspect the model input and output files and even run the WRMM EXE themselves.

The game platform shown in Figure 4 provides the user interface and (based on the user inputs) modifies the input files and triggers the WRMM EXE to run. Once completed, the game platform reads the output files from the WRMM EXE and presents the results to the user. The input files for the WRMM consist of two text files. The Simulation Control File (SCF), which defines the physical model, penalty system, water demand and supply, and the simulation parameters. The Hydrometeorological Database File (HDBF) contains the time-series data, including the natural inflows, evaporation and precipitation data, and irrigation water demands. The WRMM produces two output files: the Outid file, which contains the ideal flows that the water licensees requested; and the Outsim file, which contains the model's allocation of water to the licensees. The input

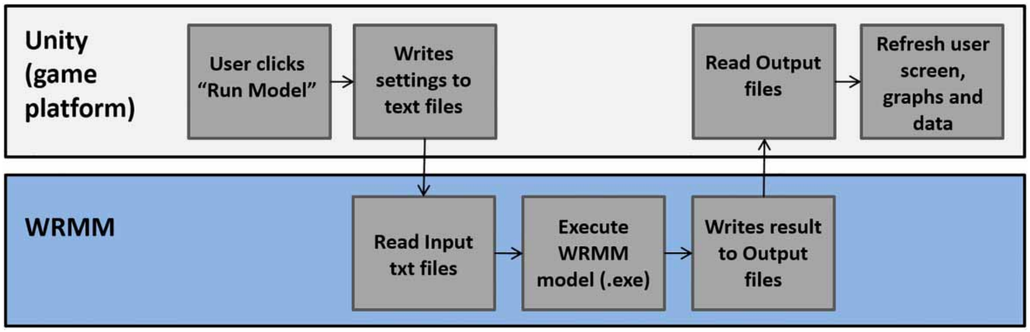


**Figure 4** | General approach for de-coupling the Unity (game platform) from the WRMM.

and output files are all small (i.e. <500 kb) due to the small size of the simplified WRMM of the Bow River basin. As the input and output files are well structured, a text parser was created to read and modify the input and output files.

The Unity Game Engine (Unity) was selected as the framework for the development of the game. Unity is a cross-platform gaming development framework and allows for the development of both 2D and 3D games and has extensive use within the gaming industry. It is an extremely popular platform for developing games with a large community of users and has extensive support. Unity has also been used to develop a number of applications outside entertainment, including serious games, engineering models, and advanced visualization. For example, Khalifa & Fayek (2015) leverage the advanced visualization capabilities built within Unity for visualization of real-world data. Sala (2018) used the advanced physics engines to simulate rockfall geohazards, allowing engineers and non-engineers alike to explore different mitigation designs in an intuitive and engaging way. The selection of a game engine allows non-entertainment developers to take advantage of the massive investment made by the platform developers and game companies. The Unity platform allows for a variety of game architectures, including desktop, mobile, and web-based deployments.

The game was written in C# and animated with the internal editor of Unity 3D. The three-dimensional characters, and representations such as pipelines of water going to a field, and the Wheaton character (a stock of wheat which interacts with players) were designed, edited, and revised based on team members' feedback in the Adobe Photoshop graphics editing software and then prepared for animation in 3DS Max and ZBrush. The operational flowchart of the Bow River Sim is shown in Figure 5. In this figure, 'moderator' is used considering game use in a workshop environment with a facilitator/moderator, but a 'single player/user' can replace the 'moderator' if the game is played alone.

## Game design

The design of the Bow River Sim serious game required several iterations to develop a playable and educational game, centred on the simplified WRMM. As discussed in the introduction, within serious games there is a continuum between a realistic simulation and a game. A simulation is designed strictly for evaluative or computational purposes, and accuracy is essential. A serious game, conversely is designed for an engaging educational experience, and clarity is important. As mentioned above, a key decision was made to use the numerical WRMM in the game. Most serious games for water management incorporate water management principles within the game logic but are not built around a specific engineering model, as their primary objectives are around teaching water management concepts. This placed constraints on the design of the gameplay. The WRMM for the Bow River basin is a numerical simulation designed for performing engineering analysis by trained water resource professionals. For the creation of the Bow River Sim serious game, the team members who were water modellers and water management professionals worked with the game designers on key learning outcomes in order to design

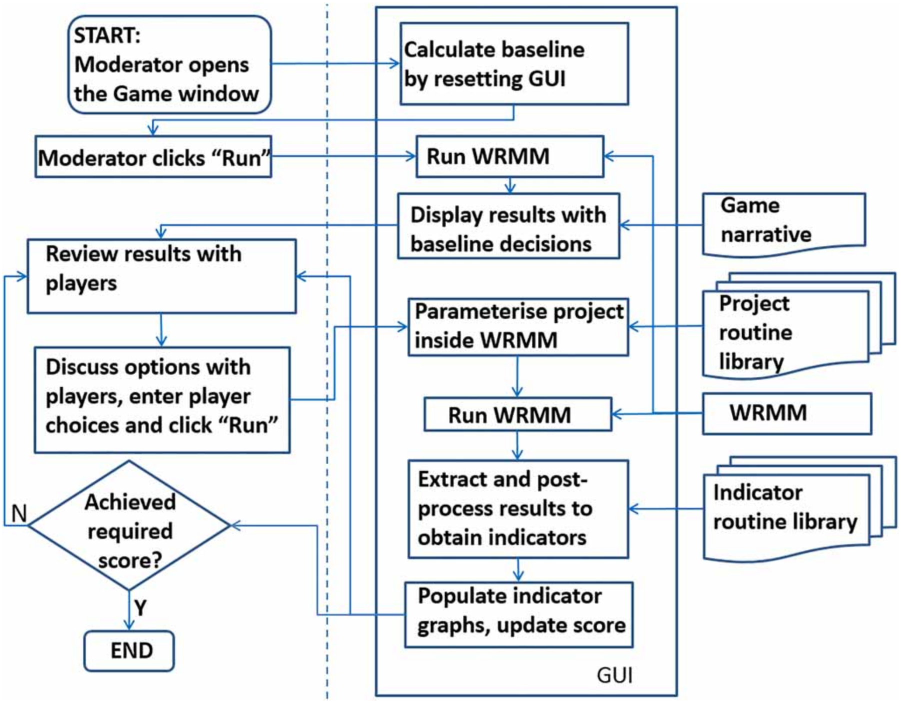


**Figure 5** | Bow River Sim operation flowchart.

the gameplay. Since the simplified Bow River system WRMM incorporates complex concepts of hydrology and water legislation as assumptions, some key concepts and background were required to be given to the serious game players. Therefore, it was decided to separate the Bow River Sim into three components: a Tutorial Mode and two separate game modes (Figure 6). The first game mode, 'WRMM Mode' is a play-based game that introduced ways for players to change the parameters of the Bow River system and receive visual feedback. The second game


**Figure 6** | Bow River Sim main menu showing the different options available for the gameplay.

mode, 'Challenge Mode' is a goal-based serious game, containing several challenges such as reaching a certain score by changing a particular system element.

## Tutorial Mode

The Tutorial Mode, on its own, likely fits into the category of 'Edutainment Application' rather than a serious game. It consists of two interactive tutorials. The first tutorial introduces the player to water management concepts, and the second tutorial introduces the player to the Bow River Sim. The tutorials are guided by 'Wheaton', an animated stalk of wheat who guides the player through the tutorials.

In the water concepts tutorial, Wheaton introduces the main concepts of water management that relate to the simplified Bow River System WRMM. It defines the role of inflows, minimum flows, apportionment, irrigation districts, and the Glenmore Reservoir. It also introduces the concept of consumptive versus non-consumptive water demands. In the how-to-play tutorial, Wheaton walks users through the Bow River Sim interface and how to operate the game. It requires players to perform certain actions to progress in the tutorial (i.e. Gating). It covers navigation, interpreting data, finding and changing sliders, finding and changing the priority (penalty) structure.

## WRMM Mode

The WRMM Mode allows stakeholders to play with selected parameters and settings to learn the basic WRMM structure and interactions between different components. The parameters for gameplay were selected to educate stakeholders on the differences that key parameters, such as increasing water flows or decreasing water use, make to the overall outcomes. The artistic design of the WRMM Mode provides the player with a simplified basin map with system elements, elements to change, and visual feedback of results (Figure 7).

Even though the Bow River WRMM was simplified, there are still a large number of inputs to the model. To simplify the options and yet provide opportunities to explore, the players are provided with controls to adjust

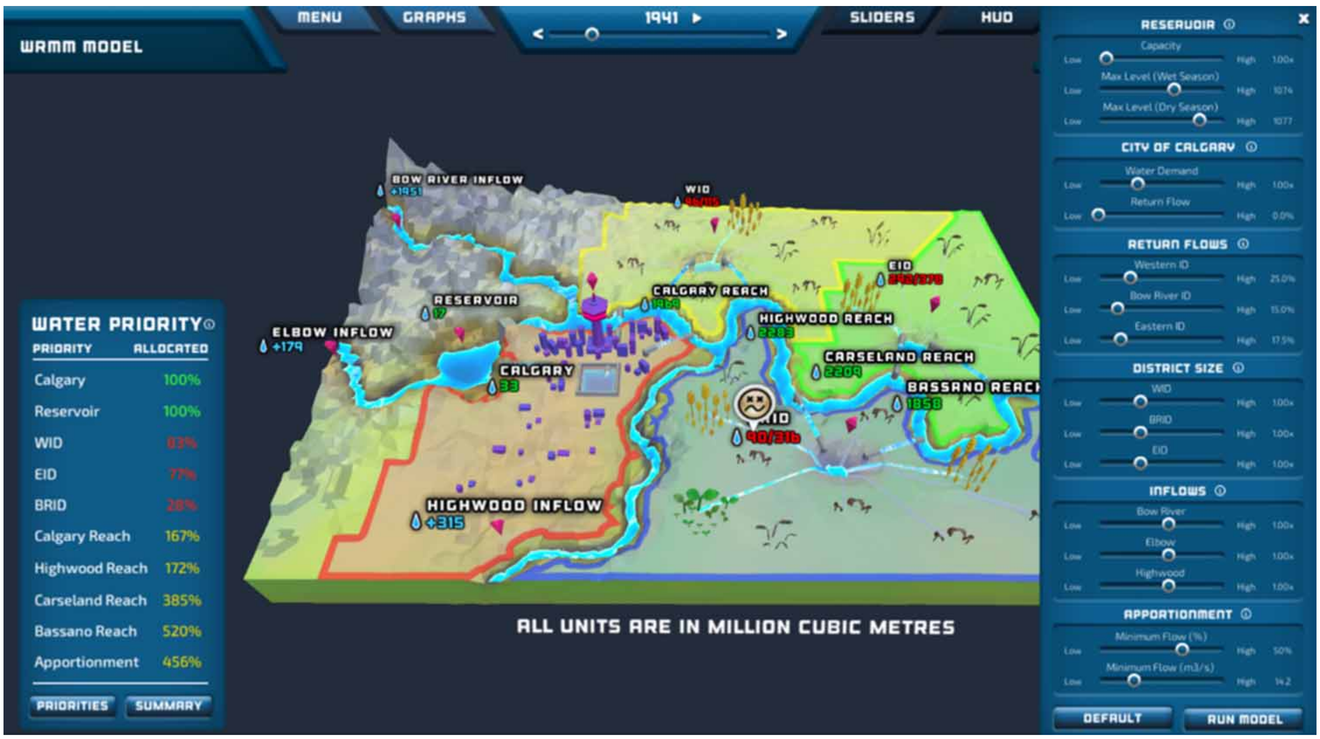


**Figure 7** | Bow River Sim WRMM Mode with sliders to change the parameters and the water licence priority.

the default values for selected major model parameters. The adjustable game parameters are described in Table 1. The players are provided slider controls to scale the default values for the parameters within a pre-set range of values (Figure 7). This approach provides several advantages: scaling of the parameter values by a multiplier or percent is more intuitive for non-technical stakeholders to understand, limiting the range of the parameter values prevents players from inputting values, which may generate errors in the WRMM, and it simplifies the gameplay testing. Players can also adjust the order of priority of the water licences by dragging and dropping them (Figure 7, Water Priority).

After the player makes their desired changes, they are provided visual feedback, as they move from year to year to review the results of their model run. If licensees' demands are met, happy faces and healthy looking crops appear. During water shortages, unhappy faces and unhealthy and dried up crops are displayed. Additionally, a window (textbox) on the left provides a summary of the allocated water for each component (Figure 7, Water Priority). Colours were assigned to the percentage allocated, to visually distinguish how closely the demand was met. Graphs are also available for each component to visualize its water demand versus supplied water.

An important part of creating a serious game is introducing a visual scoring system to provide feedback to players on the impacts of their decisions. Creating a scoring system, based on the output of the WRMM, was a challenge for the multi-disciplinary team due to the large output of each model run. The team developed an approach that provides a simplified summary of the model run for each year and an average for the entire period of the simulation, as well as an overall score. The Water Priority list (Figure 7) uses colour codes to convey the allocated water to each of the different components. Green indicates that the component received all the water volume it requested. Yellow indicates that it received more water volume than requested for the year, but demands were not met in some weeks (applies to the environmental constraints for the different water reaches). Finally, red means that the requested water licence volumes were not met for one or more weeks. The overall score is a percentage indicating how well the needs of the system components were met. The computation is carried out by dividing the total number of fully supplied weeks for all components (with the exception of the reservoir) by the total number of weeks for all years. A higher score means that more of the water demands were met. Providing a single score to summarize a simulation is extremely useful, as it allows players instantaneous feedback on the results of their simulation.

**Table 1** | Bow River Sim gameplay elements, parameters, and ranges

| Element | Element parameter | Ranges |
|---|---|---|
| Reservoir | Reservoir capacity | 0.8x to 4x the default capacity |
| | Maximum reservoir levels for wet season | 1,065–1,080 m |
| | Maximum reservoir level for dry season | 1,065–1,080 m |
| City of Calgary | Water demand | 0.1x to 3.0x the default water demand |
| | Return flows | 0–100% |
| Return flows from irrigation districts | Return flows from the Western, Eastern, and Bow River irrigation districts | 0–100% |
| Irrigation district size | Areas under irrigation for the Western, Eastern, and Bow River irrigation districts | 0x to 3x the historical water demand |
| Inflows | Inflows from the three tributaries: Bow River, Elbow River, and Highwood River | 0.5x to 1.4x the historical inflows |
| Apportionment | Percentage and volume of minimum flows | 1–100% of the minimum volume and flows |
| Priority | Rearranging the water licence priority order | |

### Challenge Mode

The Challenge Mode created three goal-oriented games, which helps players further explore and learn about the WRMM and water management concepts. In Challenge Mode, the parameters that could be changed were limited, and the challenges were crafted with specific learning objectives for the players. There are three challenges, introduced in this order: Reservoir Challenge, Calgary Challenge, and Priority Challenge.

In the Reservoir Challenge, stakeholders are instructed to reach an overall score of 98% while being restricted to adjusting only the capacity and maximum water level of the Glenmore Reservoir. The learning objective for this challenge is to educate game players on the purpose and operation of water reservoirs – storing water during wet periods for use during dry periods. In the second challenge, 'The Calgary Challenge', players need to score at least 97.7% by modifying the City of Calgary's water demand and return flows. The learning objective of the Calgary Challenge is to understand how water conservation can impact water allocated to downstream stakeholders. Finally, the Priority Challenge provides players with an opportunity to modify the Water Act licence priorities. Players are challenged to improve the water allocation of the basin by changing the existing priority order. The fundamental learning objective for the Priority Challenge is to educate players on the constraints of the current legislative system in Alberta regarding priorities of water uses, and the impacts on various elements of the system when priority is changed.

## Bow River Sim workshops

Two workshops were held with the purpose of collecting feedback from a range of different users/players. Four-hour sessions of serious gaming were allocated for participants' familiarization with the complexity of the water resources management of the basin. Staff members were available during the workshops for consultation on accessing the game (i.e. for technical issues and adaptation to special needs). Experienced water managers facilitated the sessions and held debriefings to discuss the experiences of gameplay, technology acceptance, and learning transfer to daily life. Similar sessions could be coordinated with an educational institution to include students in graduate or undergraduate studies.

The first workshop was held in Edmonton and participants consisted of various water management staff from the Government of Alberta. The second workshop was held in Calgary where participants were key water stakeholders within the Bow River, such as the City of Calgary and Irrigation Districts. Both workshops were structured in a similar fashion, even though they were in different locations to maximize the number of participants. At each workshop, an introductory session was first held which provided an overview of the Bow River Sim using the Tutorial Mode. Next, the WRMM Mode was introduced, and participants were allowed to play with different components of the basin and obtain feedback on their changes (e.g. happy faces). Later, the participants were split into several groups to play the Challenge Mode of the Bow River Sim, which contains three goal-based games (Reservoir Challenge, Calgary Challenge, and Priority Challenge, as described above). At the end of each challenge, scores were compared, and an open floor discussion was encouraged about the issues and challenges. After the event, participants answered evaluation questionnaires.

Feedback from the attendees during both workshops was positive, and the attendees took the challenges very seriously. It was noticed that the participants often underestimated the results of their changes to parameters, which were captured by the underlying WRMM and game feedback mechanisms.

The goal of the workshops was to bring participants together for a fruitful dialogue about their views and to generate interest and ideas on how to improve the game. It was observed during the workshops that because the participants were directly involved in running the simulation, and they had a goal-oriented challenge to complete, they were more engaged. This is an improvement compared to AEP's traditional processes where the decision support system model is run by experts with input from stakeholders. These problem-solving experiences in the game incorporate the four main pillars of learning (Figure 1: attention, active learning, feedback, and consolidation). Using the game in a workshop format helps people learn to express interests, understand others' perspectives, and facilitates dialogue and collaboration among all. Hence, the workshops designed around the Bow River Sim showed its potential as a tool to improve the integrated water management planning process.

## Evaluation of written feedback

Considering the background and involvement with the Bow River basin, the participants can be divided into three broad categories: 70% AEP staff (i.e. modeller, water manager, and dam operator), 27% stakeholders (i.e. representatives for the City of Calgary and three major Irrigation Districts), and 3% students (in this case, only one cooperative education student). Hence, most participants had both professional experience and some background knowledge of the basin. A questionnaire (Table 2) was circulated at the end of the workshops, which was designed to capture two aspects: game evaluation for use and requests for future improvements. There were over 30 participants in total over the two workshops.

**Table 2** | Workshop questionnaire for the Bow River Sim evaluation

| Questions | Rating (0–5) |
|---|---|
| **Game overview** | |
| Are the game elements well developed and appropriate for the game? | |
| Are the controls logical and easy to use? | |
| Is the game visually attractive? | |
| Do the setting and character seem to be appropriate for the game? | |
| **Educational overview** | |
| Are built-in support materials (i.e. description of gameplay and content description) sufficient? | |
| Is the background available for the game and the topics? | |
| Does a community exist where you can go for help and to share experiences? | |
| How well does the gameplay match the intended educational learning goals? | |
| Does the game engage you in solving real-world problems? Is the required operational learning appropriate for the game's intended purpose? | |
| Does the game demonstrate new knowledge to you? | |
| Does the game contain accurate information? | |
| What about the overall balance of the learning in the game in light of the intended application: is there an appropriate balance of learning and fun? | |

A structured analysis was performed based on the participant responses from both workshops utilizing the Four Pillars (Gameplay, Educational Content, Support, and Balance) of a Game-Based Learning (4PEG) approach (Becker 2015). Twelve elements/questions (a part of the approach), shown in Table 2, are addressed with a scoring system (excellent, good, okay, fair, poor, and missing), each containing a maximum score of 5 and a minimum of 0. Such scoring is useful to perform a structured analysis of the game to assess the potential of the game for use in a learning environment. The Bow River Sim was finally evaluated based on two higher-level criteria: Game Overview and Educational Overview (where educational content, support, and balance were merged together). Based on both workshops' participant feedback, the overall rating/score of the Bow River Sim is almost 3 (falls under 'okay') as per the 4PEG approach, which indicates that the game achieved its goal. However, there are still some potential areas for improvement to make the game an excellent tool for learning and engagement.

It is important to note that for the structured analysis, higher weighting was given to the educational aspects, as one of the main objectives of the Bow River Sim is to aid learning and engagement. Weighting was allocated based on a 4PEG approach where 'support' (i.e. user's guide, background material, and user's community) is a crucial item to consider (Table 3). The Bow River Sim did not do well in this section because it was not able to be packaged for download from the web, or distributed prior to the workshops.

**Table 3** | Initial structured analysis results adopted from the four pillars of game-based learning

| Main pillars and elements | Rating | Weighted % |
|---|---|---|
| **Game overview** | **3.2** | **30** |
| Gameplay | 3.2 | 15 |
| Art and audio | 3.3 | 15 |
| **Educational overview** | **2.9** | **70** |
| Support | 2.7 | 20 |
| Educational content | 3.1 | 30 |
| Balance | 2.8 | 20 |
| **Overall rating** | **3.0** | **100** |

Therefore, the only opportunity to learn from each other was at one of the workshops. However, a low score does not reflect the potential of the game as a learning tool. Becker (2015) defined her 4PEG analysis method as a subjective rating tool, and it is important to include additional comments whenever possible. Hence, once the game is available to the public and receives a sufficient number of ratings from various sources, further evaluation will be possible.

Feedback received from the workshops (see Table 4) on game improvements was also analysed as to the request type, the effort required to implement the request, whether the requirements are fully defined, the value the request would bring to the game, and any notes or observations. The request types are feature request (a request for new functionality in the game, i.e. something new that the game cannot currently do), enhancement (a request for modification to existing functionality resulting in some improvement), and bugs (errors in either the code or the functionality which produce an incorrect or unexpected result, or behave in unintended ways). The requests varied from very simple and well defined to more complex and less well defined (e.g. game needs more complexity for technical users).

Ideas for enhancements and functionality from the workshops included a request to improve the scoring mechanics of the game as the scoring system implemented was found to be simplistic. Additional technical information was also requested such as how the priority system works in practice. Improving the sensitivity of some of the gameplay elements, such as the reservoir, was also requested. Some players also expressed an interest in a more complex game, as they felt the current game was not detailed enough.

## LIMITATIONS, FUTURE IMPROVEMENTS, AND APPLICATIONS

### Limitations

Most of the effort of the project went towards the creation of the serious game; limited testing has been completed so far, with a limited number of participants. However, initial feedback shows that there is promise in the concept of a serious game as a communication, engagement, and educational tool.

The current version of the game does not support a multi-player option, and as such, collaboration and dialogue took place outside the gaming environment, within a workshop.

The game represents a simplification of the Bow River basin and the larger watershed (the SSRB). Some workshop participants thought this was a limitation; however, the simplification is likely necessary for wider application of the game. One possibility would be to use the Bow River Sim as a teaching tool about the complexity of the water management system, and for engagement and relationship building, rather than directly in the integrated water management process with a full decision support system model simulation. As a teaching tool, it could be used to introduce key features of the Alberta legislative system, the geographical system, and water resources modelling concepts to participants at the beginning of an Integrated Water Resources Management (IWRM) process. It could also be an effective way to review concepts and to introduce them to new participants entering in the middle of a process (as this can happen with turnover in organizations).

On the other side, the model simplification that took place was to consolidate the number of components, but it was still quite an accurate representation of the real Bow River basin. This limited the range of options that a stakeholder could explore in the game. For example, the size of the reservoir could be increased, but the effect of increasing its size was limited by its placement on the Elbow River and the flows of that river.

### Future improvements and potential applications

In order to enable further and wider testing of the effectiveness of the game for use in water resources management, Bow River Sim could be converted to a web-enabled version and at the same time ported to mobile devices.

For increasing its power for use in planning/decision-making processes, other possible new directions for improvement have been identified: (a) to introduce a multi-player option and multi-player gameplay, (b) to enrich the model by including more components from the full WRMM, (c) to collect feedback from an academic setting to improve the game and delivery method, (d) to refine the feedback by disaggregating the indicators for the aquatic

**Table 4** | Summary of the feedback on game improvement

| ID | Scenario | Request description | Type | Business value | Notes |
|---|---|---|---|---|---|
| F.AEP.1 | WRMM | Add a storage reservoir on the Bow River to better simulate impacts of large-scale storage | Feature request | High | Would need to modify the underlying model and update the design |
| E.WSP.1 | WRMM | Better explanation of the data used in the model | Enhancement | Medium | Perhaps provide a third tutorial which explains the data used in the model and the assumptions |
| E.WSP.3 | Water concepts | Provide more details on how the priority system works (first in time, first in right) | Enhancement | Medium | Documentation within the game design |
| E.WSP.4 | Reservoir challenge | Sensitivity to changing the reservoir properties is not high. The Glenmore Dam is not well suited to this challenge | Enhancement | Medium | This could be addressed by adding a storage reservoir on the Bow River |
| E.WSP.6 | Priority challenge | Reduce the number of reaches in the game as this biases the scoring in favour of prioritizing these since there are four | Enhancement | Medium | Related to the requests to revisit the scoring in the game |
| E.WSP.7 | WRMM | Improving the level of complexity of the game for technical users | Enhancement | Medium | Uncertain what this would require without doing further work to clearly define the requirements for this |
| E.WSP.8 | WRMM | Scoring system is simplistic and does not account properly for all of the 'business logic' related to things such as the apportionment | Enhancement | High | There are a number of related changes related to this one |
| F.WSP.1 | WRMM | Would be useful to have more tools to compare different model runs. For example, the ability to do a year by year comparison using tables and graphs would allow for a deeper understanding of the model | Feature request | High | This request came up often |
| F.WSP.2 | WRMM | Would be useful to be able to compare different years within a single model run | Feature request | High | This request came up often |
| F.WSP.3 | Priority challenge/ WRMM | Implement a scoring system which shows scores based on different factors such as environmental and economic | Feature request | High | There were a number of comments and discussions regarding the scoring with a number of different approaches. Would need to examine these and determine their impacts on playability |
| F.WSP.4 | WRMM | Would be interesting to add an industrial stakeholder and looking at scenarios which re-allocate water in a way which minimizes the stress of the system | Feature request | Medium | Would require modifications to the game board, WRMM, and development of scenarios |
| F.WSP.5 | WRMM | Examine other factors for the irrigation districts such as canal capacities | Feature request | Medium | Need to determine what this would look like and how it would impact the gameplay |
| F.WSP.6 | WRMM | Provide scenarios for simulating climate change | Feature request | Medium | Could be achieved by modifying the inflows and other meteorologically related inputs (evaporation, water demand, etc.) |

ecosystem, (e) to dynamically link other models, such as climate change scenarios with the underlying model of the game so that users can choose a scenario to visualize feedback, (f) to give users more freedom to explore strategies so that users can introduce interventions as per their needs (given that it is possible to model the intervention), and (g) to include more elements in the visual feedback.

The game also has future applications. There was a request to modify the game to match with the full Bow River System WRMM. It would also be possible to develop a wizard or developer's tool which would enable the game to be more easily translated to other built WRMMs. Simplified WRMMs, as used in this project, or further simplification could be considered for more academic settings, or for the general public to enhance knowledge of water resources management.

The creation of a serious game was a new undertaking for AEP water resources practitioners and modellers. It required outside expertise in game design, artwork, and development. The limited resources for this pilot effort limited the number of iterations in how to represent the components of the Bow River basin. This allowed quick development for the test phase, rather than focusing on iterations and learning between those knowledgeable on the Bow River basin and model, and those knowledgeable on game design and development.

The team would have benefited from expertise in education and/or communications. It was difficult for AEP water resource practitioners and modellers to design learning outcomes and gameplay (including scoring). There are likely improvements in the learning outcomes, the 'Challenge Mode' games, and the survey design that could be made with educational expertise. It was useful to have a game design team who were not familiar with the water basin involved.

## CONCLUSIONS

Designing appropriate serious games in water management for a wide range of users/players remains challenging. This paper tackled considerations in serious game design, the process of design, and the initial evaluation of a serious game, Bow River Sim. The game uses a simplified version of the WRMM developed in Alberta for the Bow River basin. A play-based game, a goal-based game, and a tutorial for education purposes were developed, with simplified system artwork and visual feedback. Since the main objective of the Bow River Sim is to enhance engagement in, and learning of, water resources management, it is important that elements such as water uses, water licence priorities under Alberta legislation, and remaining river flows are illustrated in the game so that the user/player has an active learning experience about these key learning outcomes. In the play-based 'WRMM Mode', the Bow River Sim contains the full functionality of the simplified Bow River System WRMM, with few constraints. In it, users can make changes to model parameters, within a certain range, and view results for each water user in the system by year, or display the total average data. Visual feedback was incorporated into the game, such as dying crops and unhappy faces. Three separate challenges were created for the goal-based gaming portion. Finally, the Tutorial Mode provides an educational walk-through of the basin, water management parameters, and key elements of the water management system in Alberta, with 'Wheaton', an animated stalk of wheat.

The beauty of the Bow River Sim is that it has an underlying powerful real water resources allocation model and can produce results close to reality within half a minute, along with incorporating gameplay and visual feedback. This is valuable, as the WRMM is actively in use, in various applications. The game shows promise for use by a variety of professional backgrounds (e.g. student, water decision-maker, and dam operator). The underlying model could be simplified further for an even wider range of players.

The game was developed for Desktop PCs with the help of the Unity engine but could be expanded to web and mobile devices. It was learned from the game development experience that the game is a promising tool in engaging stakeholders in water resources management. Educating through real-life examples helps water practitioners and water users apply different solutions to conflict situations in a learning environment. Medema *et al.* (2016) stated that serious gaming may be seen as a form of intervention that fosters collaboration in watershed management. The impacts of a future severe water shortage can be reduced substantially by altering reservoir operations, creating new storage, limiting new water uses, or increasing efficiency of current water uses. Innovative ways of sharing water during times of shortage are more likely to be enabled if stakeholders have a good understanding of each other's interests, the complexity of the system, and the impacts of potential solutions prior to the occurrence of a water shortage event. This is further enabled if the simulation is a realistic representation of the system, including real water flows and storage potential, for example.

Development of software, in particular, serious games, is challenging as it must balance a number of elements: simulation, learning, and gameplay. To handle the complexity of developing software, an incremental approach is used whereby the software is developed, released, and evaluated by users. Feedback from the users is then fed back into the development cycle to add new features, enhance existing features, and correct bugs or defects. It is also important to consider the trade-off between gameplay length and complexity. There are definite trade-offs between quick and simple games and games that take longer to run, but capture complexities of the science in more detail. As most were various professionals, the participants in the Bow River Sim development process favoured realism; hence, future improvements suggested were: a full model of the basin, disaggregating the indicators of impacts, and the ability to introduce interventions (given underlying models are available). Incorporating additional modules along with model domain expansion would satisfy the needs of multiple fields of expertise and enable deeper multi-disciplinary engagement. Additional stakeholder/player feedback in further testing could suggest which elements are the most important to model (e.g. economic and fisheries outcomes). These elements may be needed for the most effective gameplay and integrated water management. As learned in this project, the power and number of underlying models and the need for realistic decision support systems must be balanced with simplifications that are needed for creating engaging and educational games. Key learning outcomes should be discussed throughout development and tested for a variety of audiences/players with differing backgrounds.

Although historical data provide a wide range of conditions to consider, there is increasingly a need to incorporate the impacts of climate change. This may be an important additional model to include. The current version of the game has the potential to incorporate climate change impacts by manually modifying the inflows, irrigation requirements, and instream flow requirements. However, climate change scenarios would need to be dynamically tied to the gaming model so that users can choose a scenario to visualize the impacts. Hence, the implementation of climate change scenarios is currently listed under future development.

This project aimed to explore an innovative way to support water resources managers and modellers to engage stakeholders regarding water management planning issues that are complex and often frustrating. Bow River Sim shows promise as an engaging educational tool and for application in integrated water resources management decision-making processes.

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