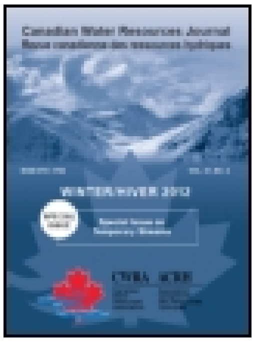

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Participatory water management modelling in the Athabasca River Basin

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ABSTRACT

Water is often used for a variety of conflicting purposes. Furthermore, as water is a dynamic resource, its equitable allocation across boundaries often poses problems for involved stakeholders. Integrated water resource management (IWRM) aims to promote the coordinated management of water across all boundaries. In theory IWRM is an effective solution to address multiple conflicting uses: however, in practice it is difficult to implement. This paper presents a case-study of an IWRM initiative in which the key component of participatory modelling is played out. Other important processes are integrated as well, such as problem structuring, social learning, and stakeholder engagement. In 2016-2017, approximately 30 stakeholders representing industry, municipalities, environmental NGOs, and federal/provincial government collaborated in order to explore opportunities to achieve sustainable watershed management in the Athabasca River Basin, Alberta Canada. Stress scenarios (including potential changes in climate, land use, and water use) were developed and used to test a series of water management strategies throughout the basin. These strategies were simulated within an integrated modelling tool in a live setting. Through this interactive process, promising strategies for sustainable water management were explored, and a series of recommendations for policy makers were identified. Recommendations include, but are not limited to, identifying areas for land conservation and reclamation priority, establishing in-stream flow need targets, and reducing water navigation limitations in the lower basin. Outlined through this paper, this case-study shows that examples of real-world participatory modelling efforts are in fact possible.

RÉSUMÉ

L'eau est souvent utilisé pour une variété d'objectif contradictoires. De plus, l'eau est une ressource dynamique, et donc son allocation équitable a traverse les frontieres pose souvent des problèmes aux parties impliquées. La gestion intégrée des ressources en eau (GIRE) vise à promouvoir le développement coordonné et la gestion de l'eau à travers des frontières. En théorie, la GIRE est une solution efficace, mais dans la pratique, il est souvent difficile à mettre en oeuvre. Cet article présente une étude de cas d'une initiative de GIRE réussie dans laquelle la modélisation en direct est emplois. Du plus, autres composants clés du processus sont intégrés, tels que la structuration des problèmes, l'apprentissage social, et l'engagement des intervenants. En 2016–2017, environ 30 intervenants représentant l'industrie, l'environnement, les municipalités, les ONG et les gouvernements fédéral et provinciaux ont collaboré afin d'explorer comment atteindre la gestion intégrée des ressources en eau dans le bassin de la rivière Athabasca, en Alberta, au Canada. Des scénarios de stress (comprenant les changements potentiels du climat, de l'utilisation des terres et de l'utilisation de l'eau) ont été construits et utilisés pour tester une série de stratégies de gestion de l'eau dans le bassin. Ces stratégies ont été simulées dans un outil de modélisation intégré dans un environnement réel. Grâce à ce processus interactif, des stratégies prometteuses pour une gestion durable de l'eau ont été explorées et une série de recommandations pour les législateurs ont été identifiées. Les recommandations incluent, mais ne sont pas limitées à, l'identification de sites hautement prioritaires pour la conservation et la remise en état, l'établissement d'objectifs de besoins en matière de débit dans le cours d'eau et la réduction des limitations de navigation dans le bassin inférieur. Décrite dans cet article, cette étude de cas montre qu'il est en fait possible de trouver des examples véritable de la modélisation en direct, dedans le context de GIRE .

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Integrated water resource management; participatory modelling; Athabasca River Basin; stakeholder engagement; social learning; problem-structuring

Introduction

Water is an integral and necessary resource for all life on earth. As a dynamic resource that moves through municipal, provincial, and international boundaries, its equitable allocation and management often pose challenges to local and regional stakeholders. In

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addition to transboundary issues, water uses may conflict, and environmental or social needs are sometimes overlooked. An integrated participatory approach to managing water is necessary in order to ensure equitable access for all users and a sustainable supply for future human and environmental needs. Additionally, such an integrated approach should also consider variability in future climate and land use, and their potential effects on water resources.

IWRM definitions

As defined by the Global Water Partnership (GWP), integrated water resource management (IWRM) is an iterative process that promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (Allan and Rieu-Clarke 2010). Other definitions explain IWRM as a process to "balance the competing demands and impacts of all [water] users to achieve sustainable development" (UN Environment 2018, 4), and "not a prescription, but rather an approach that offers a practical framework within which the problems of different communities and countries can be addressed" (Lenton and Muller 2009, 14). Conversely, Biswas (2004) argues that the definition of IWRM is amorphous, with no consensus on what aspects should be integrated and if such integration is even possible (Biswas 2004). Although there is divergence in the definition of IWRM, if integration is to be achieved, it should encompass the complex interactions among different environmental disciplines, and integrate them into the operational links between different sectors. As Quevauviller (2010, 178) has suggested, "sound decision making should strongly rely on scientific knowledge being integrated into the policy making process".

The IWRM concept, in theory, is a way in which water resources can be effectively and equitably managed; however, in practice, IWRM has proven difficult to implement (Biswas 2004). The necessary science-policy integration is a complex and difficult task (Quevauviller 2010). Proper communication and coordination between science and policy are often lacking and this leads to scientific research not being used and to policy research needs not being filled (Quevauviller 2010). Challenges also arise when integrating stakeholders in an open and collaborative manner into this science-policy interface. Although challenging, this participatory step in the process is essential to achieve IWRM.

Science-Policy-Stakeholder interface

Quevauviller (2010, 185) describes the science-policy interface as "an exchange platform through regular forums enabling both scientists and policy makers to discuss the corresponding research and policy agendas from the very beginning in order to ensure a more structured communication at all appropriate levels of policy formulation, development, implementation, and review". This paper argues that there are a few important elements missing from this definition. These elements include: the integration of watershed stakeholders into the exchange, thereby making it a science-policy-stakeholder interface; conducting these exchanges in a live setting, so that meaningful relationships can be developed and social learning can occur; and making this exchange an iterative process through multiple sessions so that context-specific problem structuring can first occur in order to inform the policy formulation. Work by Hassanzadeh et al. (2019) has shown that these missing components of the science-policy-stakeholder interface can be incorporated into water management efforts through the concept of participatory modelling. Applied in the Qu'Appelle River Basin, in Saskatchewan Canada, Hassanzadeh and others were able to explore the effects of stakeholder preferred best management practices on water pollution, through the use of a transparent and real-time water quality model (Hassanzadeh et al. 2019). They showed that participatory modelling is a key component of the necessary science-policy-stakeholder interface, and is integral to the concept of IWRM.

Social learning

Today, water resource management is defined by uncertainty, and in a fast-paced changing world water issues can be exacerbated and easily mismanaged by inflexible management processes (Pahl-Wostl 2002). Instead, approaches that consider barriers to human change must be considered when addressing uncertainty in water resources and environmental change (Pahl-Wostl 2002). Social learning can be an integral component to meaningful participation in IWRM, and may help foster both human and environmental change. Social learning, as defined by Keen, Brown, and Dyball (2005, 6), is "the collective action and reflection that occurs among different individuals and groups as they work to improve the management of human and environmental interrelations". This concept is integral to environmental management as it aims "to create learning partnerships, learning platforms, and learning ethics that support collective action towards a sustainable future" (Keen, Brown, and Dyball 2005, 3). Paul-Wostl and Hare (2004) suggest that social involvement is just as important in the process of water resource management as an improved knowledge of the watershed (Paul-Wostl and Hare 2004). Participatory modelling can serve as a tool of communication in such processes, and outcomes should not only come in the form of hard technical results, but also soft acquired skills, such as an improved ability for stakeholders in a basin to cooperate and solve conflict (Paul-Wostl and Hare 2004). According to Paul-Wostl and Hare (2004), key components in the social learning process include, stakeholder participation in model creation in order to gain trust, awareness of the basin as seen through the eyes of other participants, cooperation between participants, and problem-structuring. As will be shown in this paper, many of these components can be enabled through the processes of participatory modelling.

In the context of water resource management, social learning has been applied to real world cases, such as the co-management of New York's Eastern Lake Ontario basin (Schusler and Pfeffer 2003). Through that approach it was recognized that social learning is necessary for collaborative management, and was founded on the characteristics of open communication, diverse participation, unrestrained thinking, constructive conflict, democratic structure, multiple sources of knowledge, extended engagement, and facilitation (Schusler and Pfeffer 2003).

The Freshwater Integrated Resource Management with Agents project (FIRMA) also demonstrated the potentials of social learning, by investigating the effects of combining participatory approaches with agent-based social simulation in water resource management (Paul-Wostl and Hare 2004). A two-year process involving modellers, facilitators, and basin stakeholders, the FIRMA project goal was to bring participants together to generate new ideas which might be proposed to decision makers, in regards to overcapacity of water supply in a Swiss city. At the end of the process stakeholders reported a higher understanding and knowledge about the watershed system and other's perspectives within it (Paul-Wostl and Hare 2004).

Problem structuring

Finally, the concept of problem-structuring, in which stakeholders and experts alike actively participate in formulating the problem and its solutions, can be considered a key component of participatory modelling and IWRM (Vinke-de Kruijf, Hommes, and Bouma 2010). By formulating an agreed-upon problem, through iterative rounds of discussion, it can be possible to narrow in on preferred direction for solutions (Vinke-de Kruijf, Hommes, and Bouma 2010). Complex unstructured problems, which are often encountered in the realm of water resource management, frequently originate from divergent perceptions of stakeholders. As such, these problems arise not only due to lack of knowledge, but also due to social divergences and therefore approaches that pay attention to participation, communication, collaboration, and learning should be adopted (Hommes et al. 2007).

Such an approach was taken in a pilot-project in the Netherlands, where relevant actors were gathered and discussion was encouraged in order to achieve a more sustainable approach to freshwater management in the delta region (Hommes et al. 2007). Stormwater infrastructure in the delta region has removed the natural estuarine dynamics of freshwater-saltwater interactions, and has led to excessive algal blooms in some freshwater lakes. Re-establishment of estuarine dynamics would solve the algal problem; however, it would negatively impact other users of the lake as well, namely the agricultural users in the surrounding area (Hommes et al. 2007). The pilot project was initiated to address the conflicting perspectives on this water resources issue. Despite disagreement to a proposed solution, all actors were able to agree that they were indeed affected by the excessive algal growth, and therefore were able to formulate a common problem. After five rounds of interaction and discussion, participants reached a negotiated solution, which consisted of constructing an alternative freshwater supply prior to re-establishment of estuarine dynamics (Vinke-de Kruijf, Hommes, and Bouma 2010). The problem structuring process contributed to this negotiated agreement, by allowing interaction and exploration of stakeholders' diverging perceptions and connecting these perceptions to a shared knowledge base.

Case study

This paper presents a case study of the ARB Initiative (WaterSMART Solutions Ltd. 2018), an IWRM project carried out in the Athabasca River Basin (ARB) in Alberta, Canada. This project addressed water issues at a basin scale, employed a collaborative process where an inclusive Working Group simulated

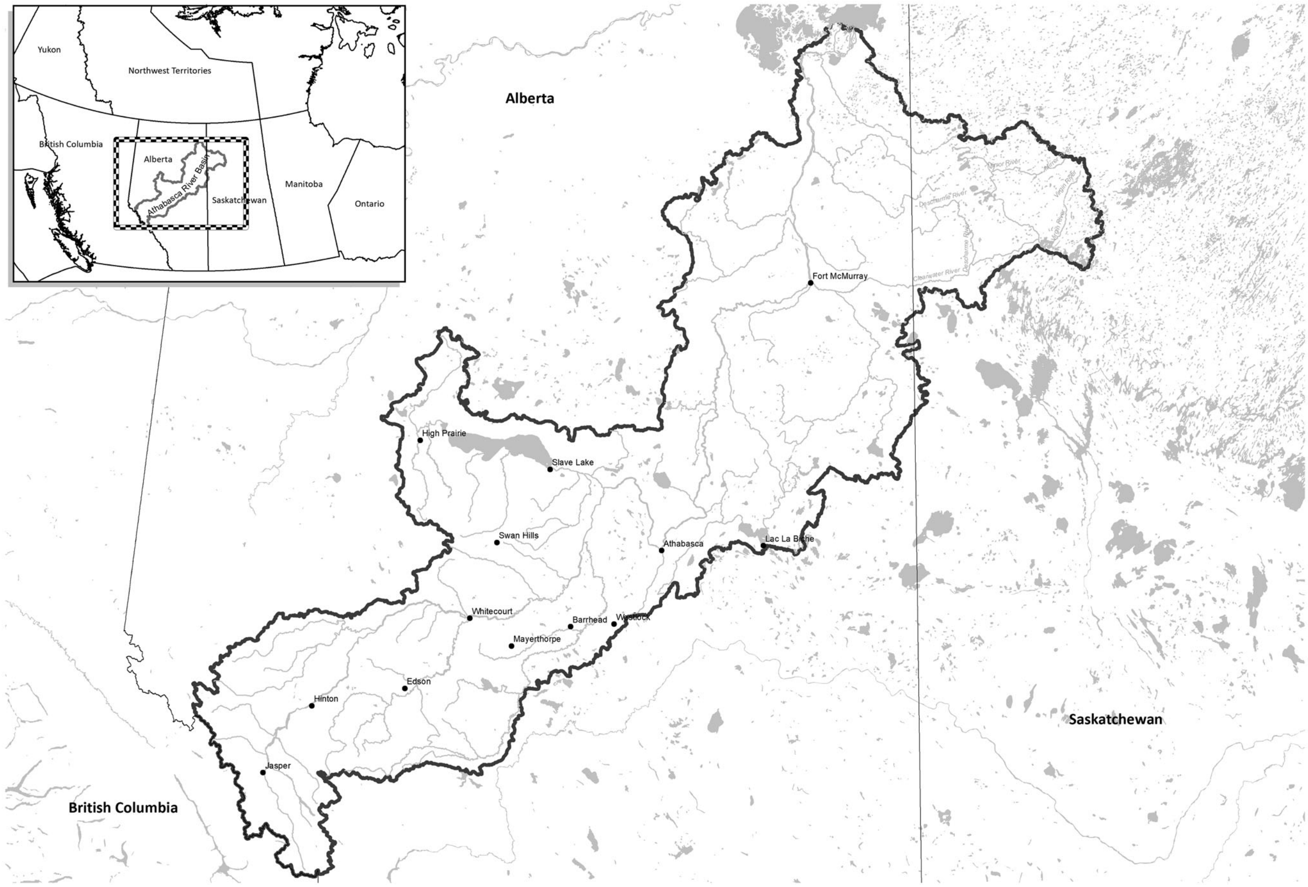

Figure 1. Athabasca River Basins in the province of Alberta. Source: Created by WaterSMART during the ARB Initiative project.

different water management strategies, used a scientifically sound model that integrated components of climate, hydrology, and water use, and discussed strategy outcomes (directed by local knowledge). Overall, this project aimed to support basin-wide water management to attain social, economic, and ecosystem goals. The foundation of the ARB Initiative was participatory modelling, as it incorporated stakeholder viewpoints into the model in real time during participatory workshops. The ARB Initiative was proposed by WaterSMART Solutions, driven by the reality that:

- Unpredictability of water supply coupled with a better understanding of environmental water needs and growing water demands is making IWRM across Alberta increasingly important.
- IWRM presented a near-term and implementable opportunity to identify and adapt to potential future climatic and environmental change.
- Stakeholders in the basin are driven by different needs, different legislation, and different business objectives, but commonly all need a well-managed water supply.

The Initiative aimed to provide a foundation for supporting cumulative effects assessments and adaptive management, while better understanding the basin in the context of water resource management, and facilitating respectful and collaborative discussions. Water management in the ARB can take many forms from the implementation of instream flows for environmental needs or navigation, to developing hydro-power potential, to water quality concerns and water availability in response to a changing climate. All these water management issues and concerns require an integrated, participatory approach to facilitate an equitable and transparent process. The process of collaborative water management in this Initiative is further described and key learnings are highlighted in order to understand the process of IWRM and participatory modelling more closely, enabling successful implementation in other areas in the future.

The ARB is large, covering approximately 25% of the province of Alberta, and draining approximately 165,000 km^2 in central and northern Alberta, as well as some northwest portions of Saskatchewan (Figure 1). The basin largely encompasses three different natural regions (the Rocky Mountains, the

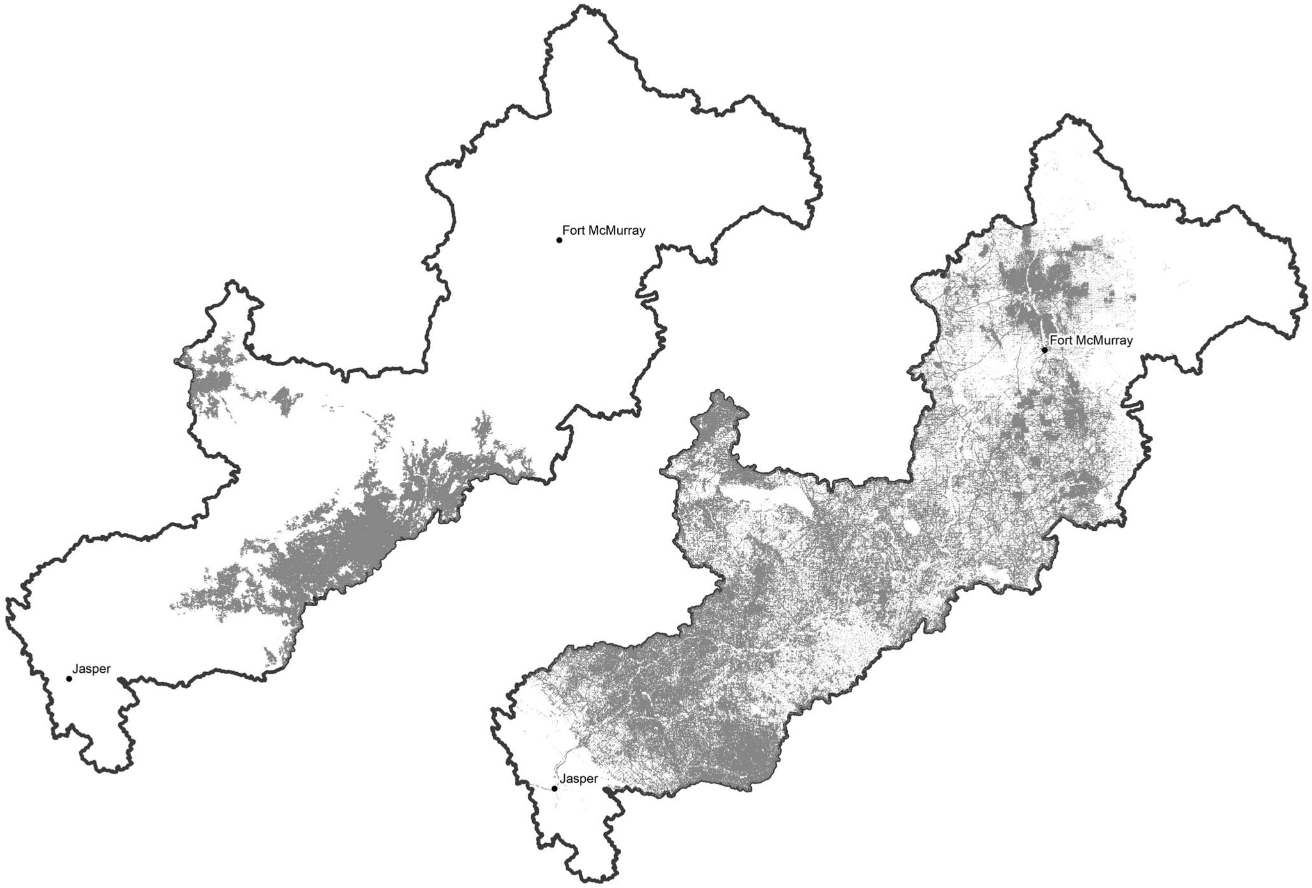

Figure 2. Agricultural land use footprint (left) and oil and gas land use footprint (right) in the ARB. NB: Footprint is displayed as a percent coverage of a 500 m pixel size. Source: Authors.

Foothills, and the Boreal Plains) distinct for their unique geology, landform, soils, and hydrology.

Hydrologic patterns in the ARB generally follow a snowmelt-dominated (nival) regime. Streamflow, usually low during the winter months, peaks during the spring due to snowmelt, and then gradually declines throughout the summer and fall as the snowpack and soil water storage become depleted. Most noticeably within the Rocky Mountain Natural Region, streamflow in the Athabasca River is supplemented during the late summer by glacier melt. Periodic increases in streamflow can occur during the summer due to large precipitation events – during late fall these precipitation events fall as snow and do not cause spikes in streamflow. Conversely, regions with low elevation gradients, such as parts of the Foothills and the Boreal Plains, demonstrate different streamflow patterns. In place of snowmelt, streamflow response is primarily driven by the amount of water stored in soils, wetlands, uplands, and groundwater (Devito et al. 2005). On a per-area basis, much of the water in the Athabasca River is generated in its headwaters, at high elevations in the Rocky Mountains.

Along with expected future changes in climate, may come resulting changes in streamflow across the ARB. As projected through Canadian Regional Climate Models (CRCM), a warmer climate would likely cause the headwaters to experience earlier spring melt and increased spring precipitation, causing higher spring peak flows. Summer flows are likely to decrease over the long-term, with increases from glacier melt in coming decades. Winter flows are likely to either remain relatively unchanged or increase slightly. Other recent studies have demonstrated similar decreases in summer streamflow (Eum, Yonas, and Prowse 2014), suggesting that the most challenging time for water availability and supply may be during the summer.

Not only does a changing climate affect water availability, but changes in land use should also be examined and addressed within the context of IWRM. With a diversity of land uses in the basin, water demands can often have conflicting purposes. In the upper and central portions of the ARB, agriculture represents the largest land use by area, while in the lower Athabasca oil and gas activities are the most significant land use (Figure 2). In the Foothills region linear features (including roads, seismic lines, pipelines, power lines, and railways) create the most land use pressure, and traditional uses of the land, including hunting and gathering, are still on-going and basin wide. All these differing land uses and their effects on the water balance can sometimes conflict and cause inequitable access to water, or insufficient water remaining for cultural, environmental and ecosystem needs. A participatory and collaborative approach between all land users is necessary to properly manage water resources and ensure all land uses are affecting water in a sustainable and fair manner.

Water allocation and use data were collected by sector, and from that consumptive use (i.e. return flows were accounted for) was analysed in order to identify any potential issues in the basin arising from conflicting users (industry, municipality, Indigenous communities, and the environment). Engagement and discussion with basin stakeholders were also undertaken to identify ARB specific water challenges that required active water management. The list of water challenges presented in the final report of the Initiative was developed with stakeholders and members of Indigenous communities in the first two Working Group meetings. The list provided a broad range of challenges that the Working Group felt were important to acknowledge and strive to improve as an outcome of the Initiative. This discussion built from prior conversation with Indigenous participants, and therefore aimed to identify Indigenous concerns as well. The key challenges that all stakeholders agreed upon included:

- Maintaining or improving water quality.
- Providing water supply certainty for development.
- Maintaining or improving ecosystem health.
- Minimizing the effect of the development footprint on basin hydrology.
- Accessing data and knowledge in the basin around water.
- Understanding the renewable energy potential of the basin.
- Ensuring sufficient flows for navigation.
- Limiting damage from floods or extreme events.
- Maintaining or improving the health of the Peace-Athabasca Delta.
- Addressing concerns around Indigenous rights.

A collaborative and open process was implemented to evaluate these challenges in which different stakeholder groups throughout the basin used an integrated water model that was built with the best available data to explore different 'what-if' scenarios concerning water management in a live setting. Throughout this participatory process, the integrated model was used as a boundary object to facilitate and direct discussion amongst stakeholders. Jakku and Thorburn (2009) define boundary objects as decision support systems that can temporarily bridge gaps between stakeholders, and encourage co-learning and cooperation. Through this approach a common understanding was developed for how water management decisions and actions would affect the basin and others in it. Perspectives were also learned and acknowledged, and different water management strategies were vetted in an open and respectful manner.

Case study process methodology

The ARB process was initiated by WaterSMART Solutions as there was a clear need for basin-wide discussion in the ARB. The terms of reference for this initiative was developed by WaterSMART Solutions, and involved creating a Working Group consisting of members from across the watershed, representing provincial and federal governments, environmental NGOs, industries, municipalities, and Indigenous communities. Participants were initially contacted and informed of the initiative via phone calls and in-person visits by the project team, with follow-up information provided through email. Approximately 30 stakeholders attended each of the Working Group sessions, with around 40% representing different levels of government (federal, provincial, municipal), 30% representing industry (all sectors working in the basin), 20% representing NGOs and academics, and 10% representing Indigenous communities. Such a group was gathered to ensure different perspectives were included in the process, as participants were driven by different water management goals, needs, and objectives. The group met eight times for Working Group meetings throughout a two-year period, where they first learned about the basin and opposing water resource perspectives, then identified water resource challenges. They then brainstormed different strategies to manage water resources in face of these challenges, and finally vetted these strategies through the model to explore each's intended and unintended effects and to test each under a series of potential future climates and land use scenarios. Figure 3 demonstrates the workflow and steps of the process and how they span out in the timeline of the eight Working Group sessions. Discussions were

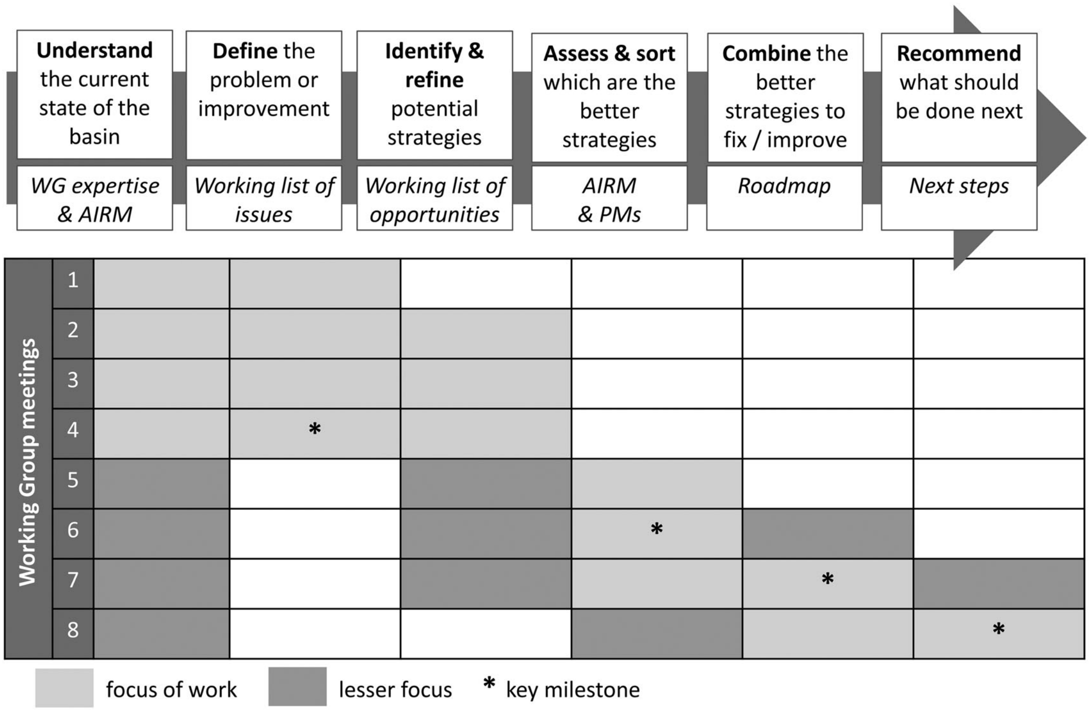

Figure 3. Schematic of the process that was employed in the ARB Initiative project. Source: WaterSMART Solutions Ltd.

participant led and facilitated by WaterSMART Solutions. Facilitation techniques such as breakout groups, flip charts, brainstorms, and friendly group competitions were used to entice and motivate participation in discussion and perspective sharing. The first four Working Group sessions had a strong focus on understanding the basin and other perspectives, while collaboratively defining a common problem and hearing out potential strategies to address the problem. The remaining four sessions focused on modelling the potential strategies, identifying the most promising, and finalizing recommendations for future work. To ensure the broader perspective of Indigenous communities were included in the process, an additional seven in-community sharing sessions were requested and conducted with communities in the lower part of the basin. For each of these sessions, the project team met with communities to provide an overview of the initiative and obtain feedback with respect to the range of water-related issues facing each community.

Case study modelling methods

It is essential to use reliable and scientifically robust information as a basis for IWRM. Such information is especially vital in the context of transboundary watersheds, as a model can represent a common and transparent knowledge-base for all parties (Stålnacke and Gooch 2010). The modelling tool that was used in the ARB Initiative was developed by incorporating the basin specific landscape, climate, hydrology, and river management components into a single integrated model, called the Athabasca Integrated River Model (AIRM; Figure 4). AIRM allows users to examine how changes to either the climate, the landscape, or the water management system (i.e. infrastructure or water usage) could affect streamflow and water availability in the entire ARB. A set of stress tests (historical, wet, and dry) were developed to test different water management strategies under a range of different conditions.

Historical conditions, represented by the basin from 1970 to 2015, used historical climate data with current landscape composition and current operating practices for water infrastructure. The wet conditions represented the effect of a substantially wetter and warmer climate in the ARB, using climate projections for 2040-2070 under moderate climate change, a large forest fire in the headwaters, moderate glacier recession to early 21st century levels, and doubling of industrial and municipal water use. The dry conditions, representing the effect of an extremely dry climate in the ARB, emulated an extended drought (Sauchyn et al. 2015), substantial glacier recession to late-21st century levels, substantial wetland degradation, and doubling of industrial and municipal water use. For further model and scenario details please

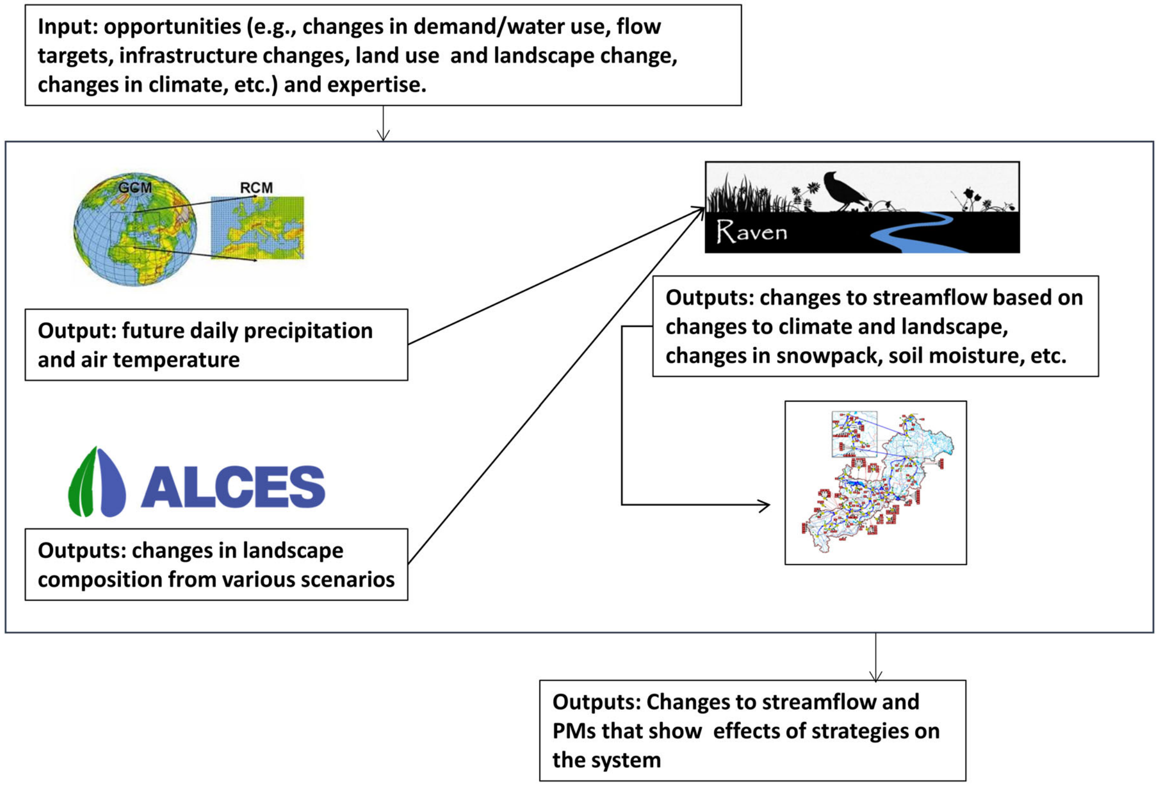

Figure 4. Schematic of the AIRM model and it's integrated components. Source: WaterSMART Solutions Ltd. (2018).

refer to the final report of the ARB Initiative (WaterSMART Solutions Ltd., 2018).

Performance Measures (PMs) for this work were developed by participants during the first few Working Group sessions. They were developed to be representative of the different values of water management, specifically ecological, economic, and social values, and are presented in Table 1 for the different strategies assessed. PMs considered include:

- Number of additional days for navigation by meeting the Aboriginal Extreme Flow (AXF), a pre-established flow value that is required for navigation in the lower reaches of the Athabasca River.
- Number of additional days with flow over the 1:100-year flood threshold (measured at different locations throughout the basin, but reported at Fort McMurray in Table 1).
- Number of additional days that violate in-stream flow need (IFN) targets (measured at the mouth of each tributary in the system, but reported as a sum of all tributaries in Table 1).
- Percent change in Walleye Recruitment Reduction (WRR) an indicator measured during summer in the lower reaches of the basin.
- Percent change in annual streamflow relative to naturalized flow.
- Additional water shortages incurred, measured in m^3/s and reported as a total for the whole system.

Case study strategies

Twelve strategies were developed and assessed by the Working Group and results were delivered in the form of performance measures (PMs) that related to the previously identified challenges in the basin. PMs were assessed in terms of their direction and magnitude of change, and were used as proxies to demonstrate if the strategy had the intended effect. The strategies that were assessed as part of this Initiative were all modelled separately and are illustrated in Figure 5 and described below:

- Effluent reuse: Enable reuse of industrial and municipal effluent in order to reduce reliance on freshwater. This strategy was simulated by redirecting the return flows of industrial and municipal demands to storage infrastructure and using this storage for other water withdrawals. Some participants commented that it may be '*somewhat challenging to implement as it would require a large infrastructure investment or involve high costs to haul water*'. From this, the group felt that this

Table 1. Matrix of model outcomes for all strategies analysed.

	Performance Measures					
Strategies	Added days meeting AXF	Added days over 1:100 flood at Ft Mac	Added days violating IFNs on all tribs	Change in Walleye Recruitment Reduction	% change in Annual streamflow	Added system water shortages - Annual
Effluent Reuse	0.0 Days	0.0 Days	−38 Days	1.4%	0.05%	0.0 m^3/s
Water Conservation	0.0 Days	0.0 Days	−63 Days	−7.5%	0.36%	−0.01 m^3/s
On Stream Storage (McLeod site, operating for navigation)	59 Days	0.0 Days	−1701 Days	2.54%	2.45%	0.0 m^3/s
Off Stream Storage (McMillan site, operating for navigation)	51.0 Days	0.0 Days	0 Days	1.17%	1.52%	0.0 m^3/s
Existing Infrastructure	−4.0 Days	0.0 Days	3357 Days	0.00%	−0.77%	−0.01 m^3/s
Environmental Flows	0.0 Days	0.0 Days	−2,215 Days	−7.15%	2.29%	23.96 m^3/s
Navigational Flows	6.0 Days	0.0 Days	− 1.0 Day	−0.48%	0.04%	1.07 m^3/s
Land Conservation (50% conservation)	−8.0 Days	0.0 Days	1306 Days	0.00%	0.26%	0.0 m^3/s
Forestry Practices	0.0 Days	0.0 Days	21 Days	0.00%	0.00%	0.0 m^3/s
Wetlands	1.0 Day	0.0 Days	−726.0 Days	0.00%	0.03%	0.0 m^3/s
Linear Connectivity	0.0 Days	0.0 Days	21 Days	0.00%	0.00%	0.0 m^3/s
Extraction Industry	Not Modeled	Not Modeled	Not Modeled	Not Modeled	Not Modeled	Not Modeled

strategy was more feasible to implement at the local level and required supporting policy.

- Water conservation: Continue to achieve water conservation and efficiency improvements with regional development. This strategy was simulated by reducing all municipal, industrial, and commercial demands throughout the basin by 10%. Participants agreed that this strategy was desirable since it reflected basin wide benefits, and that much is already being done to advance water conservation goals in the basin currently.
- On-stream storage: Explore new on-stream multi-purpose storage options. Three variations of this strategy were simulated, representing a tributary location, a mainstem location in the central basin, and another mainstem location in the lower basin. All three variations of this strategy operated to meet different objectives, and model results showed that based on the purpose of operation, benefits to the basin can vary substantially. This strategy proved to be quite contentious among stakeholders, with some maintaining that '*a dam would not be built to provide environmental benefits*', whereas others contended that '*having no reservoir reduces hydropower potential. There are more opportunities [for the basin] with a reservoir*'. In the end, participants concluded that the theme of on-stream storage had low feasibility of implementation, and only moderate benefits to the basin.
- Off-stream storage: Develop new and existing off-stream storage sites to meet multiple basin water management objectives. Two variations of this strategy were simulated, representing the same off-stream storage location yet different operating objectives. One was for meeting navigational flow needs and the other for meeting downstream water demands. Results showed that this strategy can in fact increase navigation potential in the lower Athabasca and decrease water shortages; however, some participants argued that '*new licensees need to plan for their own water needs regarding storage and use*'. After much discussion between participants this strategy was categorized as having moderate promise.
- Existing infrastructure: Alter existing water storage infrastructure and operations to meet multiple basin water management objectives. Alterations to the Paddle River Dam and the Lesser Slave Lake weir were modelled to meet minimum flows downstream. Based on group learnings it was concluded that altering the existing infrastructure on

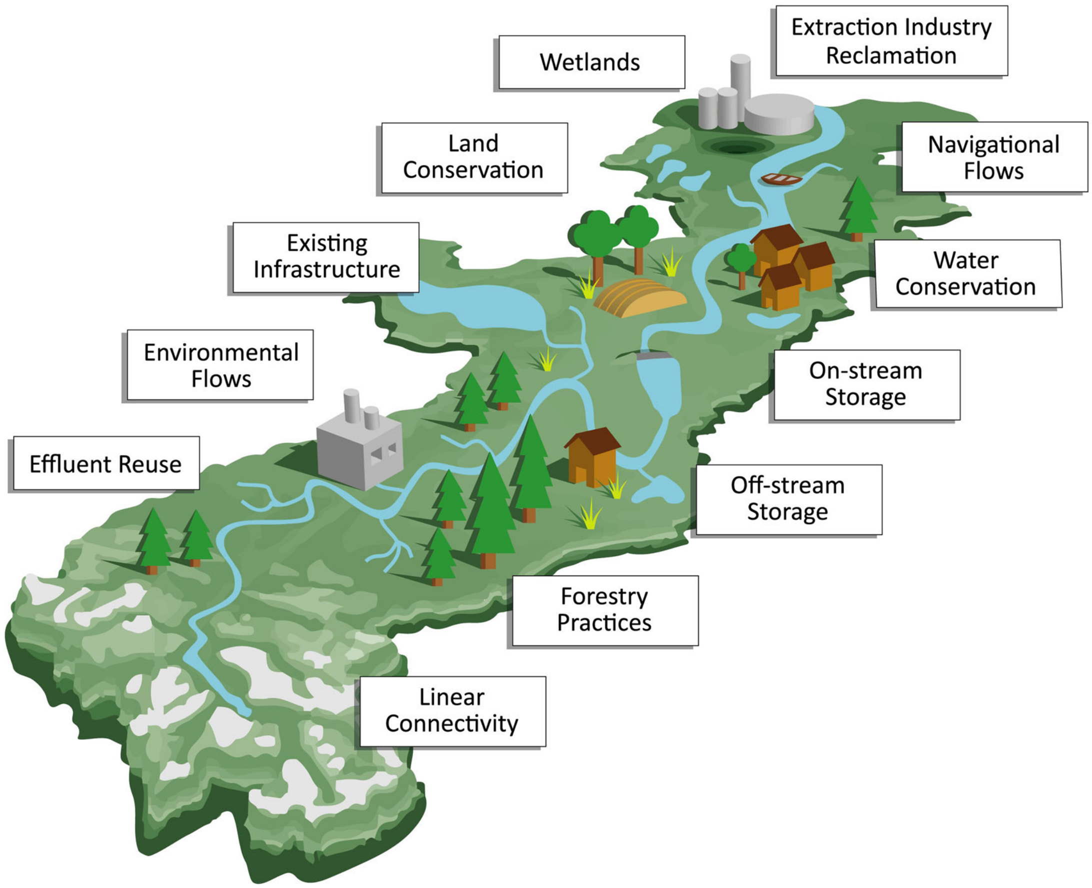

Figure 5. Schematic examples of water management strategies considered through the ARB Initative.

Lesser Slave Lake specifically would result in large negative impacts to the basin. It was unanimous that this strategy was least promising.

- Environmental flows: Establish in-stream flow needs (IFNs) or similar for all tributaries in the basin as a precautionary water management measure. IFN targets were set at the mouth of each tributary in the model. Results showed that although ecological benefits would be seen from reaching such targets, water shortages for users in the basin would occur. Participants all agreed that incurring shortages is not desirable, yet if this strategy is possible without large shortages, the benefits to the basin would be widespread.
- Navigational flows: Implement flows to improve navigation in the Lower Athabasca basin. Flow targets for navigation in the Lower Athabasca were added to the model for the open water season. Although model results showed that navigation would improve slightly under this strategy, the Working Group felt that the water shortages incurred were not worth the minimal improvement in navigation potential.
- Land conservation: Increase the quantity and improve the condition of conserved and restored land across the basin. This strategy was simulated by restoring a proportion of anthropogenic footprint to its natural state. It was noted by a participant that reclamation is not the same as restoration, and this led the group to suggest that conservation and restoration should be two separate strategies. The group consensus was that any amount of land conservation would be politically difficult to implement, yet the general ecological benefits to the basin would be high and would make this strategy worth exploring.
- Forestry practices: Support practices in Forest Management Agreements (FMAs) that minimize hydrologic change. This strategy was simulated by doubling the forest disturbance on the landscape relative to current day landcover, and results showed a notable increase in number of flood days throughout the basin. The Working Group agreed that supporting sustainable forestry practices is an integral component of a sustainable watershed management plan.

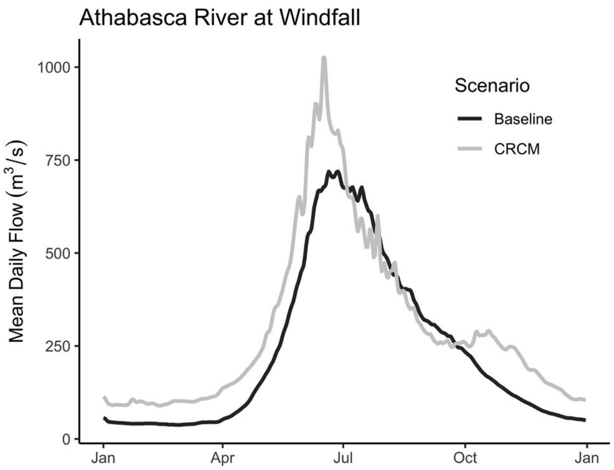

Figure 6. Average daily streamflow for baseline and climate scenarios on the Clearwater River in the Lower Athabasca Region.

- Wetlands: Avoid further wetland loss or functional impairment and promote more wetland restoration, education and best management practices focused on minimizing impacts. This strategy was simulated by a 30% relative decrease in wetland coverage in a subset of sub-basins to assess implications of wetland loss. Participants agreed that the ecological benefits to the basin would be great, but that further clarification was needed on how the strategy would specifically be implemented.
- Linear connectivity: Reclaim or deactivate linear features and reduce future linear disturbances in watersheds. This strategy was simulated by reclaiming 40% of linear features in a subset of sub-basins. Although the model showed limited benefits to the basin in terms of the PMs, participants agreed that this strategy would have other environmental and ecological benefits that are unrelated to water quantity. It was agreed that this strategy showed promise.
- Extraction industry reclamation: Continue to set and meet high standards of reclamation of extraction footprint to maintain or improve hydrological functions in a watershed. This strategy was not simulated in the model due to uncertainties in underlying assumptions; however, Working Group discussion resulted in consensus that companies should be held accountable to their reclamation plans.

Wherever possible, these strategies were discussed in terms of how they could fit in with actual existing or developing policies in the basin. In discussing these strategies and assessing model outcomes for each, the Working Group was able to better understand the hydrologic dynamics of the ARB, and strategy effects on their basin interests as well as the concerns of others in the basin. Through this process, a number of specific learnings about water management in the basin stood out for all participants.

Case study learnings

After vetting each strategy listed above through the model, the Working Group condensed a few important and agreed-upon learnings about sustainable water management in the basin. These learnings allowed for improved understanding of the current and potential future hydrology in face of changes in climate and land use, improved understanding of the current water uses in the basin, improved understanding of certain water management strategies, and identification of existing gaps in the data, processes, policy, and knowledge for the ARB.

Table 1 below demonstrates the PM results for the different strategies that were assessed through this work. PMs that move in a desirable direction are highlighted in green and PMs that move in an unfavourable direction are highlighted in red. From the PM results, participants were able to sort through the different strategies and discuss whether they seemed promising or not for sustainable water management in the ARB.

Through the collaborative Working Group sessions and the engaging use of the modelling tool to create informed dialogue, participants in this process were able to better understand the current hydrology in the basin and the distinctions in hydrologic regime between seasons and locations within the basin. For example, it was understood that the Rocky Mountain headwaters of the basin are snowmelt dominated, whereas the central and lower parts of the basin are mostly driven by groundwater dynamics and soil moisture conditions. With this in mind, and considering the potential future climate, it was learned that although streamflow during the summer and fall may decrease, there may be an overall increase in annual streamflow at the scale of the basin (Figure 6). Furthermore, higher glacial contribution may be expected within the next 50 years, followed by declining contribution thereafter as glacial ice recedes (Figure 7). Similarly, with potential future changes in land use, the Working Group learned that land use impacts on hydrology are mostly seen in local areas. When the interception and infiltration characteristics of a landscape are altered, changes in streamflow can result; however, at the scale of a basin as large as the

ARB, it is difficult to see significant effects on streamflow.

It was also discovered through this integrative process that the current total of all sectoral water allocations in the basin accounts for approximately 4% of the mean annual streamflow at the mouth of the Athabasca. 83% of human water use is allocated towards industrial uses.

Certain management strategies that were suggested prior to and during the course of the Working Group meetings were explored and shown to not be as promising as expected. Specifically, the notion of limiting all upstream water users in order to achieve a downstream minimum flow target for navigation proved to be relatively ineffective, although it did provide some benefits for summer walleye recruitment (Table 1). Participants voiced concerns over shortages, saying that "*we need to consider what kind of users are being shut off. Shutting off all licences is not realistic, but reducing shut offs would diminish the simulated benefits.*" This strategy does increase flows on the Athabasca River, but not to a level as to substantially improve navigation potential (Figure 8). Similarly, the notion of using alternatives to freshwater within in-situ oil sand facilities was not identified as a promising strategy. In the fourth Working Group meeting participants modelled these in-situ withdrawals to study the impact that alternatives would have on flow in the mainstem. After studying model results together, it was learned that very few surface water licences exist to divert water for this purpose, therefore, replacing this water use would not make a difference to streamflow on the Athabasca River (Figure 9).

Finally, through this interactive process, Working Group participants mutually identified a series of critical gaps concerning existing knowledge and data (lack of under ice flows, need for improved understanding of wetland hydrology, etc) in the ARB. One participant mentioned that they "*need to have more data from a water quality perspective*", while another focused on the lack of "tailings management plans for the oil sands mines". A final participant commented that "all this hinges on the awareness and ready access of data", and it was agreed upon that all models are only as useful as their input data; therefore, these gaps must be filled in order to move forward with sustainable water management in the basin.

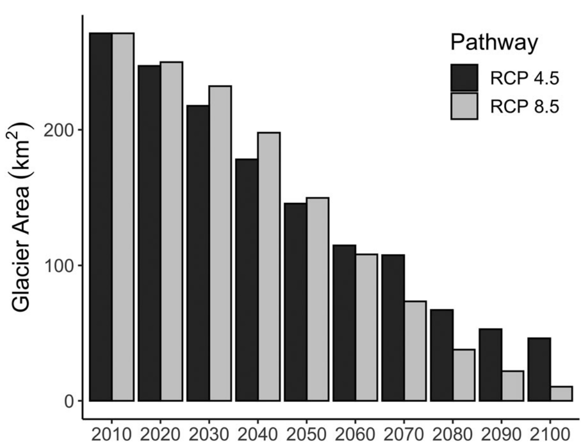

Figure 7. Simulated glacial area under climate scenarios between 2010 and 2100.

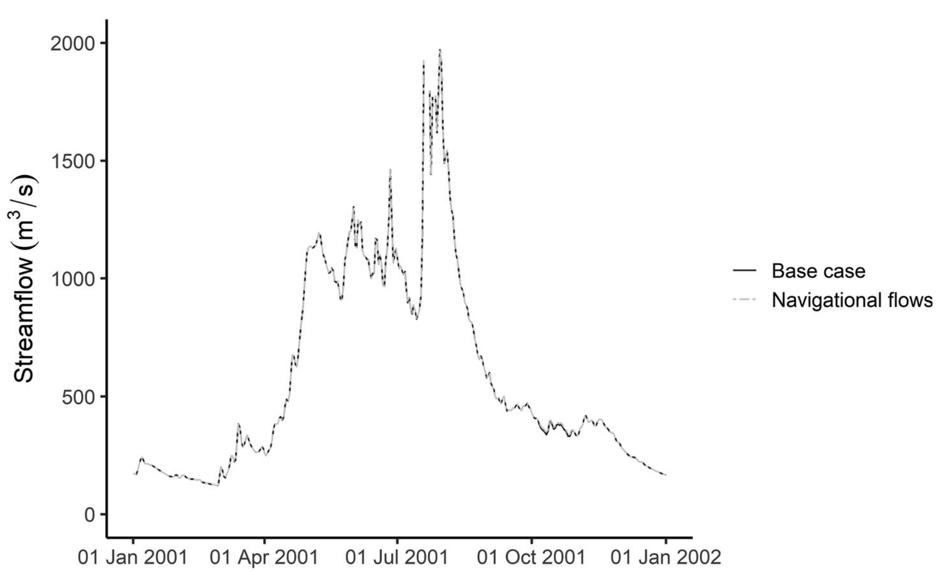

Figure 8. Streamflow on the Athabasca River below Firebag (for 2001) comparison between baseline and strategy of cutting off licences for navigation.

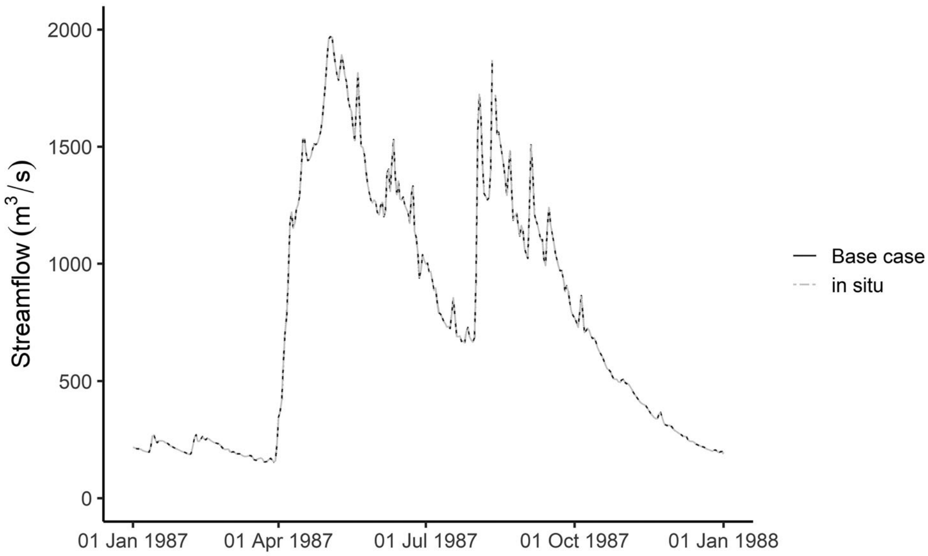

Figure 9. Comparison of daily average streamflow on the Athabasca River below Firebag between baseline and strategy of removing in-situ water withdrawal.

Discussion

The ARB Initiative is considered a successful and real-world example of participatory modelling in the context of IWRM. The success of this initiative was dependent on a number of key components, including but not limited to; the use of a robust and scientifically-backed model in a live setting; the inclusive Working Group which represented a diverse array of basin perspectives and inclusion of such local knowledge into the model; the respectful and open environment in which mutual learnings were made and dialogue was encouraged; and finally the ability to explore "what-if" scenarios and examine hypothetical water management strategies under current and potential future climate and land use conditions.

The use of a scientifically based model to support discussion concerning water management and policy is key to any IWRM undertaking. Ensuring that policy makers are informed of the most recent science, and that scientific research is in fact filling policy needs, is a necessary integration in successful water resource management (Quevauviller 2010). The ARB Initiative used an integrated, science-based model, and focused on representing the entire system at appropriate spatial and temporal scales to simulate the effects of different policy decisions or water management actions in the basin. Without such a tool to inform and drive the discussion a science-policy interface would be lacking in this process. Furthermore, using such a model in a live setting allows for questions to be asked, discussion to mature, and even changes to the model to be made on the spot in order to incorporate local stakeholder knowledge (Hassanzadeh et al. 2019). The modelling process undertaken within the ARB Initiative was transparent and informative. Knowledge from participants was incorporated into the model (for example: water use data, locations for optimal storage facilities, potential water reuse partnerships, and target areas for reclamation) and thus trust in the model was built.

Another component of IWRM is ensuring a representative group of stakeholders are involved in the process. This allows for the creation of a science-policy-stakeholder interface. The ARB Initiative Working Group had representatives from all stakeholder groups in the basin (including Indigenous groups), and sharing sessions were also held with Indigenous some communities that were not able to attend Working Group meetings. This allowed for diverse perspectives and knowledge to be incorporated into the model, and thus into the science-policy-stakeholder interface.

Social learning and problem structuring are also integral processes in the realm of participant driven environmental management. Social learning helps stakeholders better understand the basin from other perspectives (Pahl-Wostl 2002;Paul-Wostl and Hare 2004; Keen, Brown, and Dyball 2005), and problem structuring allows stakeholders to formulate a single common problem and come together on agreed solutions (Hommes et al. 2007; Vinke-de Kruijf, Hommes, and Bouma 2010). These processes are key to participation, cooperation, and coordination, concepts necessary for participatory modelling. Throughout the eight Working Group sessions of the ARB Initiative problem structuring and social learning were in fact experienced; a list of basin challenges (see list of challenges on page 6) was brainstormed together at the onset of work, and a series of mutual learnings about the basin was concluded by all stakeholders and formulated into a series of recommendations described below.

The discussion and learnings that were generated from the model outputs led to a series of recommendations for improved water management in the basin. These recommendations were developed by the stakeholders and were generated primarily through the learnings that were experienced. For example, one recommendation involved improving navigation potential in the lower basin. Shorting upstream water users in order to increase flow was initially assessed as a strategy but participants soon decided that the resulting increase in flow was not favourable over the shortages incurred. Other options to improve navigation were then discussed, including increasing water depth with in-stream structures or using alternative watercrafts that allow for better navigation in shallow waters.

The following list briefly describes the recommendations defined by the Working Group for a path towards sustainable water management in the ARB. It is important to note here that the ARB Initiative was not a legally binding process, and although these recommendations will be presented to government, they are not guaranteed to be adopted.

- Maintain or improve the natural hydrological function of the watershed
  - Do this by identifying sites of high conservation and restoration priority, improving knowledge about hydrologically sensitive wetlands, and filling data and science gaps
- Establish environmental flow needs for the Athabasca River and all tributaries
  - Do this by establishing IFN targets for all streams and rivers, and communicating these targets broadly and effectively.
- Reduce water navigation limitations in the lower basin
  - Do this by better understanding navigation channels and how they change through time, and investigating the potential for instream structures to increase water depth and/or alternative water crafts and year-round road access.
- Increase adaptive capacity of the basin
  - Do this by establishing multi-purpose objectives for new on or off stream storage projects to support basin flow needs
- Continue to develop the means to share and apply Traditional Knowledge
  - Sharing sessions were held as a part of the ARB Initiative; however, greater effort should be made to incorporate Traditional Knowledge into the process in the future. This can be done by developing and enabling meaningful processes that support the United Nations Declaration on the Rights of Indigenous Peoples and the Truth and Reconciliation Commission mandates, and collecting and sharing datasets of traditional uses in the ARB.
- Address the most critical gaps in water data, processes, policy, and knowledge
  - Do this by continuing to provide resources to Alberta Environment and Parks in its work to publicly and efficiently share already existing datasets, and resourcing and incentivizing basin wide water communications, and by closing the gaps between traditional knowledge, culture and society through Indigenous inclusion into policy.

Although some might consider this project a successful example of participatory modelling, a number of limitations were noted, which can be improved upon in future modelling efforts. These limitations include a need for improved hydrologic tools to model the Boreal Plains portion of the watershed, developing PMs that accurately reflect stakeholder concerns (i.e. water quality in addition to water quantity), and improve the resolution of the model to better simulate local scale dynamics.

Conclusion

Criteria for effective IWRM, as suggested by Allan and Rieu-Clarke (2010) include the concepts of equity, environmental accountability, stakeholder participation, transparency, and iterative self-improvement (Allan and Rieu-Clarke 2010). While perhaps not meeting all of these criteria, the ARB Initiative is a good example of what effective IWRM could look like through the participatory modelling approach, as it had a strong focus on stakeholder participation, transparency, and was an iterative process with a series of Working Group sessions.

The process outlined in the case study of the ARB Initiative is a template for the advancement of water resource management as it brings the concept of participatory modelling to another level. This novel approach integrates the platforms of robust and dynamic hydrologic, land use, and water management modelling with a diverse stakeholder Working Group in a live participant-led setting. To our knowledge, no such project has been previously undertaken at the scale of the entire ARB, or to the extent of integrating climate projections, land use projections, hydrologic modelling, and water management modelling. Having an inclusive group of basin stakeholders at the same table and using an interactive modelling tool to explore "what-if" scenarios allows for mutual learnings to be had and a range of water management strategies to be explored. This approach has been applied elsewhere (Sauchyn et al. 2016) in Canada; however, never at a scale as large as the Athabasca River. Applying an approach similar to the ARB Initiative has proven that by working collaboratively, knowledgeable and experienced stakeholders from across a watershed can identify opportunities to optimize and sustainably manage a basin's water supply.

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