Alberta Innovates

ARB Initiative Interim Report 1

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Contents

List of Figures

1. Introduction

Proactive and informed water management requires a clear understanding of how future climate and land use change may affect water resources, the users who depend on them, and the capacity within the watershed to respond and adapt. To add to the challenge, Alberta will continue to experience droughts, flooding, and increased pressure on surface water quantity due to population growth, economic development, and changing environmental management practices. The Sustainable Water Management in the Athabasca River Basin Initiative (ARB Initiative or Initiative) is a collaborative modelling project to examine opportunities and identify strategies to increase resilience and make the ARB more adaptable to climate variability and change.

This report provides an interim update on the ARB Initiative as it completes its first year of work. This interim update includes learnings and findings to date focused on the engagement of the Initiative, the development of the Athabasca Integrated River Model (AIRM), and the early development of the "basin story" including its current state, issues, challenges, and opportunities. This report is an interim product; therefore, any observations and findings are works in progress.

1.1 Project overview

The ARB Initiative aims to provide a foundation to support cumulative effects assessments, basin water management plans, adaptive and sustainable water management, and accessible and transparent information on basin water resources and management. Throughout this two-year Initiative, a set of participants (the Working Group) are brought together at eight Working Group meetings. At these meetings, a collaborative modelling process and an integrated modelling tool are used to inform and drive conversation regarding water management in the ARB. Through the Working Group meetings, strategies for sustainable water management in the ARB will emerge; these strategies will form a Roadmap for sustainable water management in the ARB.

The Working Group is an inclusive and diverse set of participants from across the basin made up of representatives from various industry sectors, including governments, municipalities, environmental non-governmental organizations (ENGOs), watershed planning and advisory councils, First Nations, and Métis. The Working Group members are driven by different water management goals, needs, and business objectives; as they participate in the Initiative, they are expected to share their viewpoints and discuss their ideas for a well-managed watershed in the ARB.

The collaborative modelling process brings together an integrated modelling tool and the Working Group in a transparent and open process to explore mitigation, adaptation, and management opportunities in response to a range of potential change in the ARB, such as changes in climate, land use, and development; all of these changes potentially mean changes for the rivers (e.g., timing or volume of flow) in the ARB. Changes are reflected in streamflow by changes in contribution (runoff) and water demands/use in the watershed. The collaborative modelling process enables Working Group members who may have disparate goals to assess and explore issues and opportunities, and to collaboratively develop solutions that mutually satisfy their objectives. The process brings together a wide range of basin perspectives with local and regional expertise to have an open, transparent conversation about basin-wide risks, concerns, and opportunities.

The integrated model, named the Athabasca Integrated River Model (AIRM), is a representation of the ARB water resource system; it incorporates the land use system, the hydrologic system, the climate system, and the river system. The AIRM can show the effects of changes in land use, climate, or water use on the water resources in the ARB. The AIRM has been developed with the Working Group specifically for the ARB Initiative. The AIRM builds on what has already been done in the basin by using existing knowledge, data, and tools to provide effective, science-based decision support for basin planning and management considerations. The AIRM is developed throughout the Initiative with the Working Group to create a transparent and accessible modelling tool that the Working Group understands, owns, and trusts. The AIRM is further discussed in Section 3.

Through the collaborative modelling process, the Working Group has the opportunity to use the AIRM to assess surface water quantity by modelling the current watershed and examining a range of potential impacts on water quantity, and to some degree water quality, from changes in climate and land use in the ARB. The model outputs are used to inform the Working Group discussion and to develop opportunities that address or support the challenges the group wants to focus on. The Working Group will use the collaborative process with a watershed focus, which will allow the Working Group to see their individual and collective interests on a larger, basin-wide scale. These opportunities will be refined, assessed, and sorted to develop strategies that will form the basis for a Roadmap for sustainable water management in the ARB. The Roadmap will be a compilation of the most promising strategies developed by the Working Group in the collaborative modelling process. This set of strategies, as well as associated practical actions, will serve as a recommended path toward sustainable water management in the basin. The Roadmap is intended to inform future planning and management efforts as they relate to water. The Initiative does not have any intention of prioritizing projects or laying out an implementation plan, but rather gaps will be identified and next steps will be recommended. The ARB Initiative Roadmap will be a guidance document, not a basin plan. It will reflect the discussions among those participating in the Working Group. Participation in the Working Group is not considered Consultation and is not a reflection of a decision-making body.

1.2 Engagement of the Working Group participants

Engagement for the ARB Initiative focused on creating an inclusive and diverse Working Group made up of participants from across the watershed with different perspectives. This approach was taken to have a diverse and informed group that could speak to the issues and opportunities around surface water flows and effects of change in the ARB on flows. The groups that were approached and invited to participate in the Working Group were:

- Federal and provincial governments and related agencies
- ENGOs/NGOs
- Indigenous representatives (First Nations and Métis)
- Industry (e.g., coal, oil and gas, forestry, oil sands, utility companies, agriculture)
- Municipalities (e.g., counties, municipal districts, towns, cities)
- Watershed planning and advisory councils (WPACs)

The ARB Initiative project team has been reaching out to groups, communities, and companies across the ARB since the fall of 2015 to introduce the Initiative and invite them to participate. This work to contact participants and build relationships has been carried out through email and phone conversations, in-person visits, and presentations to staff/organizations. The ARB is a very large and dynamic watershed in terms of its hydrology, geography, and demographics. There have been several challenges with engaging such a diverse group across the watershed, such as distance and capacity for participants to travel to attend the Working Group meetings. Time, personnel, and budgets have all been constraints in having participants from the uppermost and lowermost parts of the basin attend Working Group meetings. Email, phone calls, and a supplementary meeting in Fort McMurray have been used to try to keep these groups informed and engaged as much as possible. Engagement for everyone in the basin, including Indigenous communities, is ongoing and iterative to ensure that people are kept apprised of when Working Group meetings are being held, what is happening at the meetings, and how the work is advancing.

At four Working Group meetings held in Edmonton and one supplementary session held in Fort McMurray, representatives from all sectors have been in attendance, although not on a consistent basis in terms of who attends. Twenty-four representatives from six federal and provincial governments and related agencies have attended meetings, with 13 of those having consistent attendance (at least half of the meetings). Six representatives from five ENGOs/NGOs have attended, with all six representatives having consistent attendance. Sixteen representatives from nine companies or industry groups have attended meetings, with 10 of those having consistent attendance. Four representatives from three municipalities, counties, and districts have attended meetings, with three of those having consistent attendance. Two representatives from two WPACs have attended, with both representatives having consistent attendance.

There have also been challenges specific to Indigenous community engagement and having meaningful and consistent participation from Indigenous communities and groups. The ARB Initiative project team has been reaching out to engage Indigenous communities and groups that are located in or have traditional lands in the ARB. This includes 26 First Nations, 5 First Nation umbrella groups, and 12 Métis entities, which includes 3 Métis Settlements, the Métis Nation of Alberta (MNA), 4 MNA Regions, and 4 Métis Locals in the Wood Buffalo region of the basin. The engagement has been carried out through various means, including email and phone conversations, community visits, and presentations to staff, and in some cases, to chief or chair and council. Two of these presentations have been undertaken using remote conferencing, and 18 Indigenous groups have received presentations directly or through an umbrella organization to which they belong.

At the four Working Group meetings in Edmonton and the one supplementary session held in Fort McMurray, Indigenous representatives have been present at all meetings, although not on a consistent basis in terms of who has attended. Six First Nations and one umbrella group (representative of six First Nations) have attended, and seven Métis organizations have been in attendance at the Working Group meetings. The supplementary session held in the Fort McMurray area was well-attended by Indigenous groups, but not by the broader stakeholder members of the Working Group. Some Indigenous communities have attended the Working Group meetings without prior project team in-person visits to the reserve or community.

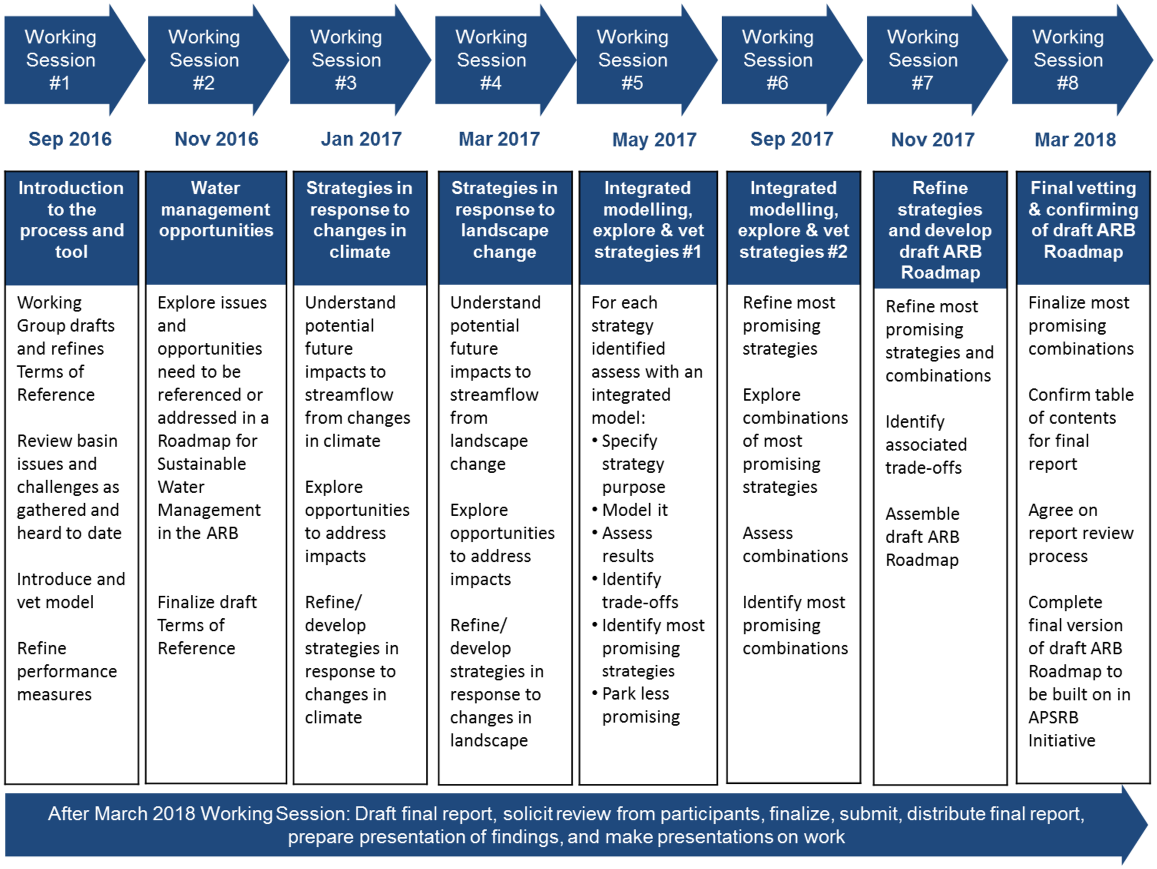
As part of the iterative engagement, the concept of sharing sessions was developed and has been offered to all Indigenous communities. Arrangements for sharing sessions to date have begun with two Métis Settlements and MNA Region 1, and also with three First Nations. Sharing sessions provide for discussions that will be undertaken by a subset of the project team; they involve travelling to an individual community to present project progress, providing an opportunity for focused dialogue to gain two-way understanding, and gaining insights into the community perspective. A sharing session agenda is planned to contain an overview of the project, a report on progress of the Working Group, a tour of the watershed as it is today (e.g., in terms of surface water use, landscape) through a demonstration of the AIRM, and an opportunity for discussion. It is expected that these will be half-day meetings and result in information sharing, relationship building, and potentially more robust project outcomes and Roadmap refinement.

Throughout the process of engaging participants from across the ARB, there have been several learnings about how to engage an inclusive and diverse group from across a geographically diverse area. These learnings are captured in Section 4 of this report so that they can be applied to future similar engagement-based projects in northern Alberta and elsewhere.

1.3 Working Group meetings

In Year 1 of the Initiative, four Working Group meetings were held in Edmonton and one supplementary Working Group meeting was held in Fort McMurray. The supplementary session was held primarily to accommodate interested parties and participants in the Fort McMurray area whose participation is otherwise hampered by capacity, budget, and travel constraints. Meeting summaries and the slides used in each of the Working Group meetings can be found online at http://albertawatersmart.com/featured-projects/collaborative-watershed-management.html.

Figure 1 shows the anticipated plan for the Working Group meetings for the ARB Initiative. The supplementary meeting in Fort McMurray was not part of the original project plan; therefore, it is not shown in this figure.



Working Session #1	Working Session #2	Working Session #3	Working Session #4	Working Session #5	Working Session #6	Working Session #7	Working Session #8
Sep 2016	Nov 2016	Jan 2017	Mar 2017	May 2017	Sep 2017	Nov 2017	Mar 2018
Introduction to the process and tool	**Water management opportunities**	**Strategies in response to changes in climate**	**Strategies in response to landscape change**	**Integrated modelling, explore & vet strategies #1**	**Integrated modelling, explore & vet strategies #2**	**Refine strategies and develop draft ARB Roadmap**	**Final vetting & confirming of draft ARB Roadmap**
Working Group drafts and refines Terms of Reference Review basin issues and challenges as gathered and heard to date Introduce and vet model Refine performance measures	Explore issues and opportunities need to be referenced or addressed in a Roadmap for Sustainable Water Management in the ARB Finalize draft Terms of Reference	Understand potential future impacts to streamflow from changes in climate Explore opportunities to address impacts Refine/ develop strategies in response to changes in climate	Understand potential future impacts to streamflow from landscape change Explore opportunities to address impacts Refine/ develop strategies in response to changes in landscape	For each strategy identified assess with an integrated model: • Specify strategy purpose • Model it • Assess results • Identify trade-offs • Identify most promising strategies • Park less promising	Refine most promising strategies Explore combinations of most promising strategies Assess combinations Identify most promising combinations	Refine most promising strategies and combinations Identify associated trade-offs Assemble draft ARB Roadmap	Finalize most promising combinations Confirm table of contents for final report Agree on report review process Complete final version of draft ARB Roadmap to be built on in APSRB Initiative

After March 2018 Working Session: Draft final report, solicit review from participants, finalize, submit, distribute final report, prepare presentation of findings, and make presentations on work

Figure 1: Chart outlining the plan for the Working Group meetings for the ARB Initiative.

The first Working Group meeting was held in Edmonton on September 22, 2016. The objectives for the first meeting were to introduce the Working Group; finalize the Terms of Reference for the Initiative; review and assess basin issues, challenges, and opportunities as gathered and heard to date; and confirm that the model is representative of the watershed today. Because this was the first time that the Working Group had formally met, this meeting gave participants the opportunity to meet and get to know each other. It also gave participants the opportunity to start to understand the model and the collaborative modelling process.

The second Working Group meeting was held in Edmonton on December 1, 2016. The overall objective for the second meeting was to develop a common basin understanding among the Working Group. At this meeting, the Working Group brainstormed about basin opportunities for water management and discussed issues and opportunities in water management and how these could be shown in the AIRM. The Working Group had a productive discussion and explored many basin water management opportunities; these opportunities were documented for exploration at future Working Group meetings.

A supplementary Working Group meeting was held in Fort McMurray on January 17, 2017. This meeting largely covered the same material that was covered at the second Working Group meeting in December in Edmonton. The meeting was held in Fort McMurray in order to engage communities and groups in the Fort McMurray area that had been unable to attend previous Working Group meetings. There was productive, open dialogue at this meeting, and many concerns were voiced by local communities. These concerns were documented for further conversations with the Government of Alberta (GoA) and were communicated to the broader Working Group at the third Working Group meeting.

The third Working Group meeting was held in Edmonton on January 26, 2017. At this meeting, the effects of changes in climate and climate variability on streamflow were introduced. Working Group participants discussed these effects and opportunities to address them. The issues and opportunities were documented for exploration at future Working Group meetings.

The fourth Working Group meeting was held in Edmonton on March 14, 2017. At this meeting, the effects of landscape changes on water in the ARB were discussed; in addition, the effects of landscape change on issues and opportunities that had been discussed in previous meetings were examined. The process being followed to develop the ARB Roadmap was also reviewed, as was a very preliminary draft of the basin story: current state, issues and opportunities (Section 2). The Working Group also systematically refined the list of opportunities identified to date and then determined as a group what the ARB Roadmap will focus on.

During Year 2 of the Initiative, four more Working Group meetings will be held in Edmonton. At these meetings, the Working Group will further examine the opportunities for water management in the ARB and will develop these opportunities into water management strategies that will form the ARB Initiative Roadmap.

1.4 Work completed in Year 1 of the ARB Initiative

This section provides a high-level overview of the work completed over the first year of the ARB Initiative. The objectives for Year 1 of the Initiative were to form and bring together the Working Group, identify the opportunities and challenges in the ARB that the group wanted to focus on, build the AIRM, and introduce the Working Group to the model to set the stage for refining opportunities and creating the Roadmap in Year 2.

The ARB Initiative is divided into six coordinated streams of activity that are based on the six tasks outlined in the original proposal and funding agreement. The six streams of work are outlined and described below; key activities that were performed in each of the six streams during Year 1 of the Initiative are highlighted.

1. Iterative communication and engagement

   Throughout the project, there is ongoing communication and engagement with the Working Group and members of the water community in the basin who were invited to participate in the ARB Initiative; this activity stream takes place throughout Year 1 and Year 2 of the Initiative. The engagement efforts include, but are not limited to, Working Group meetings with summaries, a project webpage, and additional Indigenous engagement meetings.

   - Iterative work has been ongoing to increase the number of Working Group participants and the diversity of participants attending Working Group meetings. Attendance is never guaranteed, but with many personal phone calls and some one-on-one meetings, the project team has been making an effort to increase attendance.

   - Four Working Group meetings were held in Edmonton: September 22, 2016; December 1, 2016; January 26, 2017; and March 14, 2017. Meeting summaries and slides were distributed to the entire Working Group and posted on the ARB Initiative website. Follow up on action items from these meetings has been completed or is in progress.

   - One supplementary meeting was held on January 17, 2017, in Fort McMurray. A meeting summary and slides were distributed to the entire Working Group and posted on the ARB Initiative website. Follow up on action items from this meeting has been completed or is in progress.

   - Sharing sessions for Indigenous communities have been conceptualized, developed, and offered to all Indigenous communities within the geographic scope of the Initiative. Arrangements for sharing sessions have begun with interested communities.

- The Terms of Reference have been drafted and updated based on feedback from Working Group meetings and follow-up written submissions via email. The Terms of Reference have been distributed to the entire Working Group and posted on the ARB Initiative website.

2. Develop the ARB river system model and climate scenarios

   The second activity stream includes building a comprehensive mass balance river system model for the ARB and developing climate variability scenarios for use with the hydrologic model; this work took place primarily in Year 1 of the Initiative. This stream of work includes introducing the Working Group to the various components of the AIRM and how to use the model to explore and refine opportunities.

   - The river system model has been developed and is a credible and useful tool. The model is representative of the ARB system and can be used with participants to provide a basis for informed discussion.

   - Performance measures (PMs) have been drafted based on participant input and interests in the basin.

   - Three climate change scenarios were developed and incorporated into the hydrologic model inputs. The climate change scenarios are warm-wet, median, and cool-dry. The scenarios were developed using downscaled Regional Climate Models (RCMs) at a daily time step (daily air temperature and precipitation estimated for grid cells across the whole ARB).

   - Issues discussed during Working Group meetings have been compiled into an issues document. The list of issues is provided in Appendix A.

   - Opportunities discussed during Working Group meetings have been compiled into a list of opportunities. Throughout Year 2 of the Initiative, these opportunities will continue to be explored and will eventually become the strategies that are included in the ARB Initiative Roadmap. The list of opportunities is provided in Appendix B.

3. Develop the ARB land use and hydrologic models

   The third activity stream includes the development and use of basin-scale hydrologic and land use models; this work took place primarily in Year 1 of the Initiative. The models were built to simulate the effects of changes in land use, natural disturbance, and climate on streamflow in the ARB. A primary objective of the Initiative is to use an integrated model with land use, hydrologic, and river system simulation capabilities in a workshop setting where Working Group participants can examine scenarios live. In addition, an objective of this work is to simulate relevant hydrologic processes for the entire ARB, allowing for robustness and confidence in hydrologic response to changes in climate and land use/natural disturbance.

   - The land use model was fully attributed with available land use and landscape data for the entire ARB and is ready to conduct simulations.
   - The hydrologic model calibration and verification were completed for the full ARB.
   - The hydrologic and land use models were then coupled with the river system model, and this model is ready to be used with the Working Group.

4. Develop the ARB integrated model

   The fourth activity stream includes developing the ARB integrated model that combines the ARB river system, climate scenarios, land use, and hydrologic models. This work will primarily take place in Year 2 of the Initiative because most of this stream of work involves using the integrated model with the Working Group. The integrated model will be used collaboratively to identify and assess water management issues and develop water management, mitigation, and adaptation strategies in a workshop setting. Collaborative modelling harnesses the best knowledge and expertise across the basin to develop a common basin understanding and implementable strategies. The findings of the collaborative work will be broadly communicated to water users, managers, decision makers, the broader water community, and the Alberta public under the recommendations and documentation activity stream.

   - A beta version of the AIRM consisting of climate, land use, hydrologic, and river system models has been completed. See more detail on AIRM in Section 3.
   - The linkages between the land use model, the hydrologic model, and the river system model were made, and the user interface that links the models with the PMs has been developed.

5. Recommendations and documentation

   The fifth activity stream includes project documentation and work that will advance the implementation of recommendations; most of this work will take place in Year 2 of the Initiative. Final documentation of the Working Group modelling results will be prepared and communicated during Year 2 of the ARB Initiative; this includes communicating and presenting final results.

   - There were no activities in this stream of work in Year 1 of the ARB Initiative.

6. Implementation, Logistics and Administration Committee management, and Phase 4 planning

   The sixth activity stream includes project management and oversight of the Logistics and Administration Committee (LAC). This activity stream will take place throughout Years 1 and 2 of the Initiative; there will be several LAC meetings throughout the Initiative. The LAC is comprised of project funders and WPACs in the ARB; the committee is meant to review overall project details, schedules, and finances. This stream also includes raising matching funds and considering future work in the ARB (what was to be Phase 4) or the bigger Slave River Basin.

   - Fundraising for matching funds has been completed.
   - Project tracking and management has been ongoing throughout Year 1 of the Initiative.
   - Contract updates with contributing partners to meet project cash-flow needs and matching contributions have been ongoing throughout Year 1 of the Initiative.
   - Two LAC conference calls were held in Year 1 of the Initiative. These calls included discussions on project plans, timelines, funding, deliverables, diversifying the attendance at Working Group meetings, and overall Indigenous engagement.

2. The basin story: current state, issues, and opportunities

2.1 Basin story as heard from the Working Group meetings so far

Throughout the Working Group meetings, a story of the ARB started to emerge that reflects the current state, issues, and opportunities in the basin. Understanding the story of the ARB equips the Working Group with insight to decide where this group should focus its efforts and provides the basin context for the Working Group's discussions and findings.

A range of water management challenges exist in the basin that emerged as issues that should be addressed or as improvements that should be made to the current state of water or water management in the basin. Based on the issues identified, opportunities began to emerge; these opportunities resolved issues or helped improve aspects of water management in the watershed. These opportunities will develop into strategies throughout the Initiative and will become a key part of the Roadmap for sustainable water management in the ARB.

The Athabasca River headwaters begin at the Columbia Glacier in Alberta's Jasper National Park, and the river travels more than 1,500 km to its outlet into Lake Athabasca located in the northeastern corner of Alberta, forming part of the Peace-Athabasca Delta (PAD), which is a UNESCO heritage site. The Athabasca watershed is a large basin, covering nearly 25 percent of Alberta. There are four distinct natural regions in the basin: the Rocky Mountains, Foothills, Prairies, and Boreal Plain. Each region is unique and has diverse hydroclimate characteristics, geologic characteristics, natural resources, and ecosystems. The basin is interconnected hydrologically as water flows through its river network—the mainstem, tributaries, and wetlands—from the headwaters to the Delta.

Development across the basin comes from many different sectors, and development intensity varies across the basin; there are many municipalities, Aboriginal populations, and economic activities. Economic activities include agriculture, forestry, coal mining, oil and gas, and oil sands development. In the upper and central portions of the basin, the most significant development in terms of total footprint is from agriculture and forestry; in the lower portion of the basin, oil and gas (including mining) activity represents the most significant development.

In the future, the ARB may be challenged by constrained water resources due to changes in climate, changes in land use, increases in economic growth, and subsequent cumulative effects on the surrounding environment. The Working Group expressed concerns about the effect of human development on the basin and surrounding environment; the issues were captured and provided the basis for the challenges that the group wanted to focus on for the remainder of the ARB Initiative. These challenges are outlined in the following section of this report.

2.2 Challenges the Working Group wants to focus on

Over the course of Year 1 of the Initiative, the Working Group developed a working list of issues related to water in the ARB. An issue was defined as an important concern or problem related to water in the basin that warrants attention; an issue can be current or future, and it can be specific to a sub-basin or basin-wide.

To understand the water-related issues in the ARB, a desktop study was completed by reviewing publicly available documents (*Summary of issues, interests, and opportunities in the Athabasca River Basin, April 2016*). The information provided in the initial desktop study has been developed, refined, and enhanced through dialogue with Working Group participants; the complete working list of issues is provided in Appendix A.

To focus the Working Group discussion and understand the Working Group's goals and focus for the Initiative, the working list of issues was grouped into 10 broader water challenges facing the ARB. These challenges were presented to the Working Group during the fourth Working Group meeting (March 14). At this meeting, the Working Group participants were asked to determine which challenges they felt the ARB Initiative's work and Roadmap deliverable should focus on given the participants in the group, the tools available in the project, and the project scope and timeline. Working Group members were given nine stickers that they used to indicate which water challenge(s) they felt the ARB Initiative's work and Roadmap deliverable should focus on. Participants placed the stickers on challenge(s), that were posted on the wall, that they felt should be a focus. There was no limit to the amount of stickers that participants could place on any given challenge. This was a necessary step given the significant range of issues and perspectives in the basin; the focus of work had to be narrowed to enable meaningful exploration and assessment of water management strategies. Based on the feedback from the Working Group, there was an interest in focusing on the following challenges for the remainder of the ARB Initiative:

- Maintaining or improving water quality
- Providing water supply certainty for development
- Maintaining or improving ecosystem health
- Minimizing the effect of development footprint on basin hydrology
- Accessing data and knowledge in the basin around water

It was determined that the following issues, although important, would not be a focus or would be less of a focus for the remainder of the ARB Initiative:

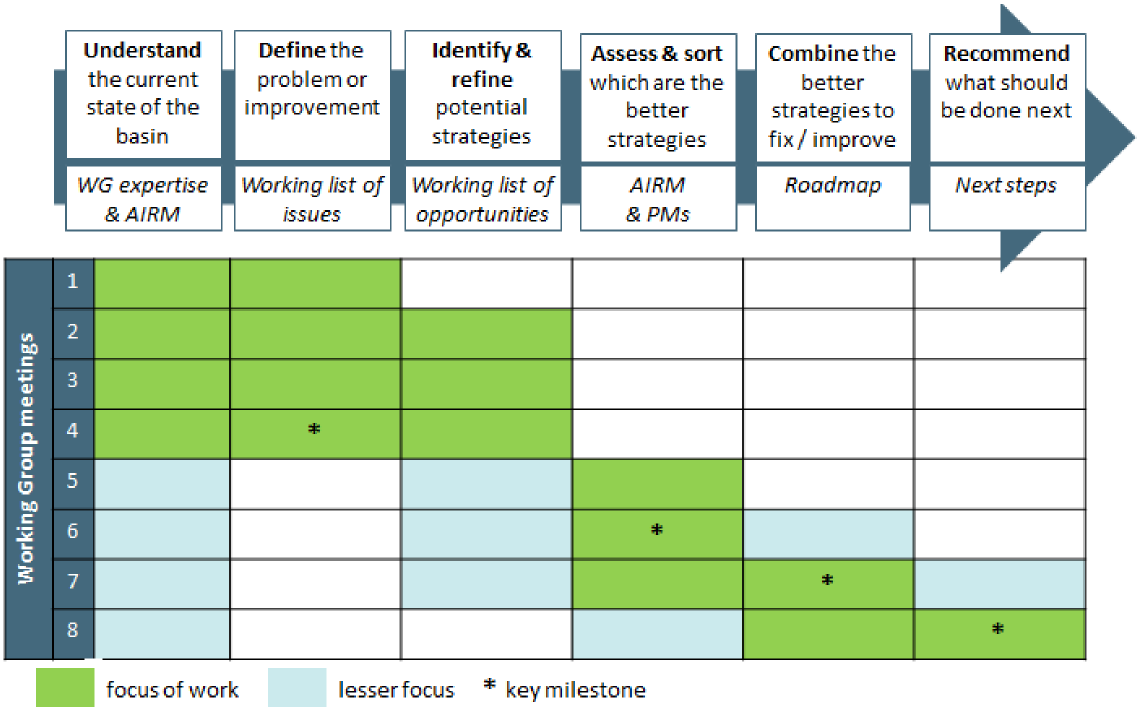
- Understanding the renewable energy potential of the basin
- Ensuring sufficient flow for navigation
- Limiting damage from floods or extreme events
- Maintaining or improving the health of the PAD
- Addressing the concerns around treaty rights

The Working Group will focus its efforts in Year 2 on the first five challenges above; the other five issues are recognized and respected but will not be a direct focus of this work.

2.3 Opportunities developed to date

Over the course of Year 1, the Working Group developed a long list of opportunities. Opportunities are defined as ideas or specific actions that could be implemented to address surface water management issues in the basin or to make surface water management improvements on a sub-basin or basin-wide scale.

The extensive list of opportunities developed in Year 1 of the Initiative will be refined into strategies, and ultimately into the ARB Roadmap, through modelling and discussion. The process of refining the strategies is not about assigning a rank or outlining which strategies have more value than others. The process of refining the list of opportunities involves assessing and sorting of the opportunities by the Working Group participants in the Working Group meetings. This process is illustrated in Figure 2 and Figure 3.



Working Group meetings	**Understand** the current state of the basin	**Define** the problem or improvement	**Identify &** **refine** potential strategies	**Assess & sort** which are the better strategies	**Combine** the better strategies to fix / improve	**Recommend** what should be done next
	WG expertise & AIRM	*Working list of issues*	*Working list of opportunities*	*AIRM & PMs*	*Roadmap*	*Next steps*
1	🟩	🟩				
2	🟩	🟩	🟩			
3	🟩	🟩	🟩			
4	🟩	🟩 *	🟩			
5	🟦		🟦	🟩		
6	🟦		🟦	🟩 *	🟦	
7	🟦		🟦	🟩	🟩 *	🟦
8	🟦			🟦	🟩	🟩 *

🟩 focus of work 🟦 lesser focus * key milestone

Figure 2: The process of how the Working Group will go from an understanding of the basin to the Roadmap.

Figure 3: Details of how the Working Group will "assess and sort" from the box in Figure 2.

The Working Group reviews model results and refines opportunities in Working Group meetings based on simulations in the model and discussions around each opportunity. As participants refine opportunities into strategies, the least promising strategies and the most promising strategies will begin to be identified; these strategies will then be confirmed by the Working Group. The strategies will also be examined in combinations to analyze the cumulative potential of combined strategies for water management in the basin. The full list of individual and combined strategies will be provided in the Roadmap report; the report will discuss strategies that are most promising, those that show some promise, and those that are least promising. It will also discuss gaps in water data, knowledge, and processes that were identified.

The opportunities were grouped into three regions, which are used as the three breakout tables in the Working Group meetings: upper ARB, central ARB, and lower ARB; these regions are shown in Figure 4. For each of these regions, opportunities were placed into one of three categories: supply and demand; regulatory; or lands and ecosystem use. Following input from the Working Group at the fourth Working Group meeting (March 14), all opportunities that were considered to be of interest basin-wide were sorted into one of the three regions, or into one of the three additional groupings: gaps in water data, knowledge, and processes; additional potential opportunities or actions; or parked (do not pursue).

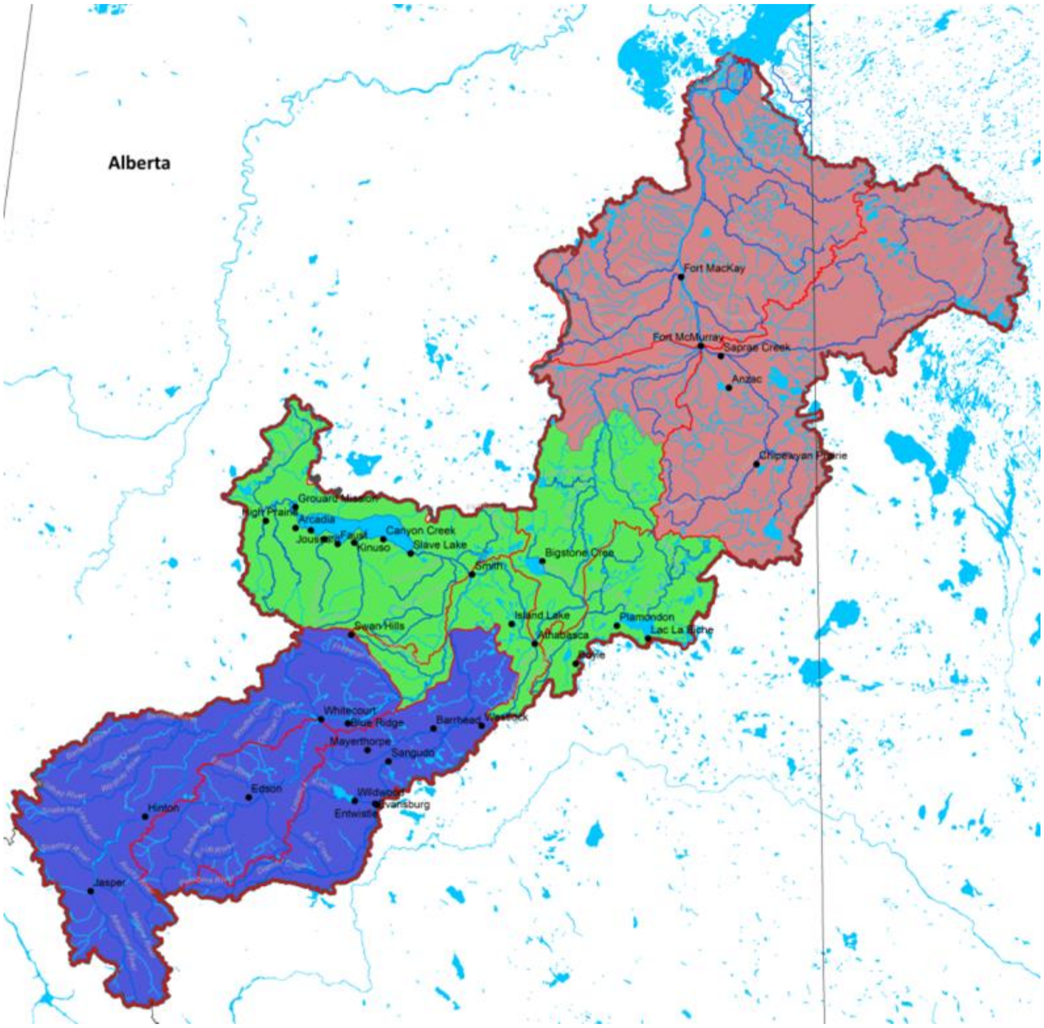


Figure 4: The three regions of the ARB that were used as breakout tables in the Working Group meetings to discuss opportunities and issues in the different regions in the ARB. The upper region is shown in blue, the central region is shown in green, and the lower region is shown in red.

A full list of the opportunities identified in each of the three regions of the ARB, as well as the opportunities in each of the additional three groupings, is provided in Appendix B.

3. Development of the Athabasca Integrated River Model (AIRM)

3.1 Components of the AIRM

The AIRM was developed during Year 1 of the ARB Initiative. The AIRM is an integrated model with four components: climate, land use, hydrology, and river system (see Figure 5). These distinct components are coupled for use in the collaborative modelling process during Working Group meetings. This section summarizes each of the components of the AIRM; additional details regarding each component can be found in Appendices C, D, and E of this report.

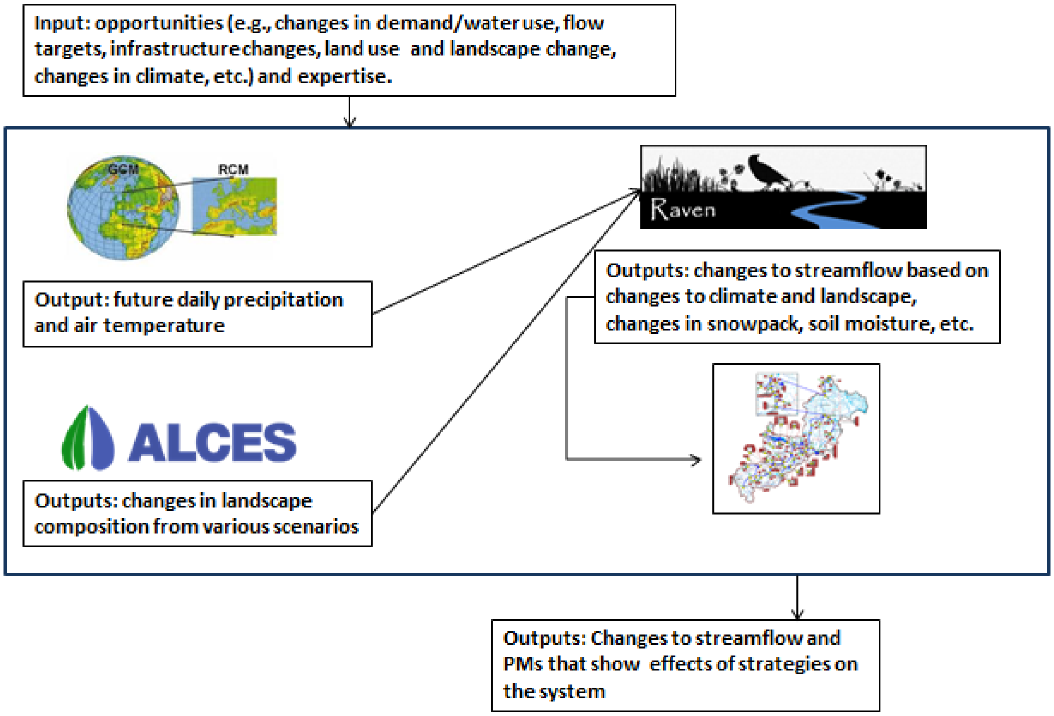


Figure 5: The AIRM and its components, the flow of how they fit together, and inputs and outputs relative to use with the Working Group.

3.1.1 Landscape simulator development and input to AIRM

ALCES Online is the basis for land use modelling in the AIRM (see Figure 6). It is used to simulate changes in landscape and land use across the ARB. These changes in landscape will be run through the hydrological model, as described in Section 3.1.2, to enable dynamic simulations of how changes on the land impact hydrology, and hence streamflow, in the ARB. ALCES Online is a cell-based representation of today’s landscape and can be used to conduct user-defined scenarios of the future or past. These scenarios can be defined to differ with respect to the rate and spatial pattern of future or past development and natural disturbance. The simulation engine can incorporate numerous drivers, such as forestry, mining, settlements, oil and gas exploration, agriculture, transportation networks, fire, pests, climate change, and reclamation. The flexible simulation engine and relative ease at which scenarios can be defined make it possible to explore the outcomes of numerous scenarios to develop an understanding of the range of land use options and uncertainties that exist. Simulation outcomes in terms of changes in the abundance, location, and age of natural and anthropogenic land cover types are applied to create maps of future landscape composition and indicators of interest.

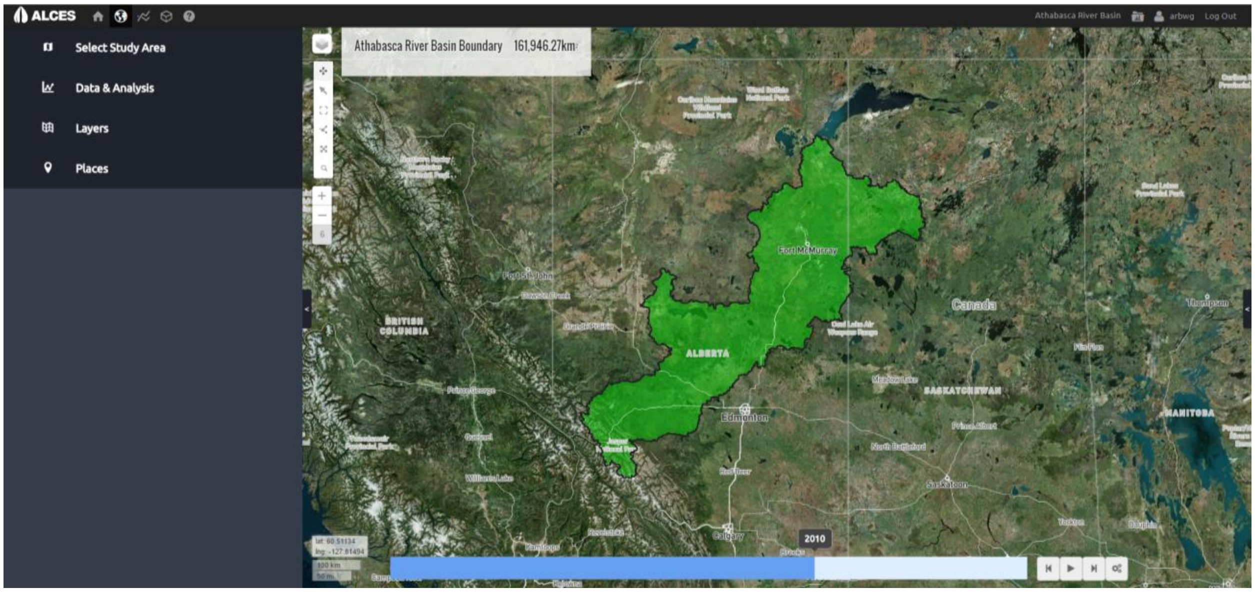


Figure 6: ALCES Online component of the AIRM.

Completing the scenario analysis with ALCES Online required the following steps: integrating data layers to assess current composition of the landscape; simulating changes to landscape composition under a range of scenarios that differ with respect to development rate, management practices, and natural disturbance; and assessing the consequences of the scenario to hydrology through the RAVEN hydrologic model (see Section 3.1.2). Detailed information on the datasets integrated into ALCES Online is provided in Appendix C. Any potential future land use scenarios will be developed by the Working Group based on interests and assumptions about future landscape changes in the ARB.

3.1.2 Hydrological model development for AIRM

The hydrological component of the AIRM is a built using the RAVEN modelling platform. RAVEN is used to simulate daily streamflow in the ARB by representing physical hydrological processes and producing streamflow as an output. Climate and landscape changes from the climate scenarios and ALCES Online are fed into RAVEN, which simulates the subsequent changes in streamflow and then inputs that into the river system component of the AIRM. RAVEN is a semi-distributed hydrological model with modifications to a “level 1 (near–perfect) emulation” (Craig et al., 2015) of the HBV–EC hydrologic model. The HBV-EC model is a Canadian version of the original Scandinavian watershed model (Bergström, 1992; Canadian Hydraulics Centre, 2010) and has been used extensively to model mountain streamflow in British Columbia and Alberta (e.g., Stahl et al., 2008; Jost et al., 2012; Mahat et al. 2015). For detailed information on the RAVEN model, including the data used, calibration and verification details, and simulated processes, see Appendix C.

To account for the substantial range of landscapes within the ARB, the watershed was split into five individual sub-models approximating the natural regions present in the watershed: Headwaters, Foothills, Prairie, Lesser Slave, and Boreal Plain. Each model was driven by a universal set of weather sites, and differences between the sub-models were due to different parameter sets and processes. The models were connected by a series of inflows, which deliver streamflow from the outlet of the upstream model to the furthest upstream sub-basin in the subsequent model.

Hydrologic Response Units (HRUs) define the spatial representation of the landscape in the model and are areas assumed to have a uniform hydrologic response to meteorological inputs. This method of spatial aggregation reduces computational cost without reducing modelled watershed complexity relative to fully distributed (gridded) methods. HRUs were delineated for each sub-basin using elevation (100 m elevation bands), sub-basins split by orientation, and nine land use types (coniferous forest, deciduous forest, cut/burned forest, grassland, wetland, mine [oil sand and coal], disturbed [hard surface], alpine, and glacier) dictated by ALCES Online. Within each sub-basin, the proportion of each combination of land use, elevation band, aspect, and slope were calculated to form a unique HRU. In total, the ARB was divided into 29,788 HRUs, and 18,234 were located in the Headwaters model.

The vegetation and soil classes for each HRU are tied to each land use type. The model is then driven by daily air temperature (minimum, maximum, and average) and precipitation, which were spatially distributed using inverse-distance weighting and routed through the forest canopy and soils based on physically explicit processes (e.g., infiltration, interception, and evaporation).

To fit simulated streamflow to observed values, the parameters in each of the five hydrological sub-models were individually calibrated. Parameter calibration was achieved by first identifying sensitive parameters and then grouping and calibrating process-related parameters in a step-like fashion, broadly following Stahl et al. (2008). For each sub-model, parameter calibration was evaluated using two hydrometric gauges with good long-term records and available data from 2003 to 2013. Once calibration steps were complete, performance was evaluated for each model using available streamflow measurements for gauges not used in calibration, and for all available gauges from 1986 to 2003 (i.e., outside the calibration period). Model verification was supplemented by comparing simulated snow water equivalent (SWE), monthly precipitation, and daily air temperatures to independent climate stations and snow survey sites.

Model performance (based on statistics, including the Nash–Sutcliffe model efficiency coefficient [NSE], used to assess the predictive power of hydrological models, with a value of 1 corresponding to a perfect match) was highest in the Headwaters model, and along the mainstem of the Athabasca River. Generally, performance was good to excellent in upstream regions (monthly NSE of >0.93 in the Headwaters and 0.77–0.94 in the Foothills). Performance was more varied further downstream; some sub-basins had good performance (monthly NSE = 0.70–0.80), but others had only satisfactory or marginal performance (monthly NSE = 0.40–0.60). In many cases, sites with the lowest monthly NSE values were regions that are either heavily influenced by industrial activity or have small watershed areas (<100 km^2).

3.1.3 River system model development for AIRM and performance measures

The river system model component of AIRM is a water balance model that functions on a daily time step and is built on the OASIS modelling platform (see Figure 7). It is operating-rule driven and can be used to test different water management scenarios. It is built to be an interactive model and allows for stakeholder-driven development of opportunities and strategies. It receives daily streamflow simulated in the RAVEN model, which includes any changes in landscape or climate. The river system model then simulates effects of human influences on streamflow (e.g., water withdrawals, return flows, diversions, flow targets, changes to existing or new infrastructure) and shows how these effects could impact water-related values of Working Group participants.

Output from the AIRM is then fed into performance measures (PMs), which are any visual that shows the status of an interest to a Working Group participant (e.g., fish species, navigation, streamflow, security of supply). Issues and challenges that the Working Group would like to see changed or improved are reflected in the PMs. PMs therefore show the direction and magnitude of change on an issue of interest in response to a simulated change in the system. The Working Group informed the PMs that have been developed to date (see details in Appendix D); these PMs are categorized as water management, ecological, and social.

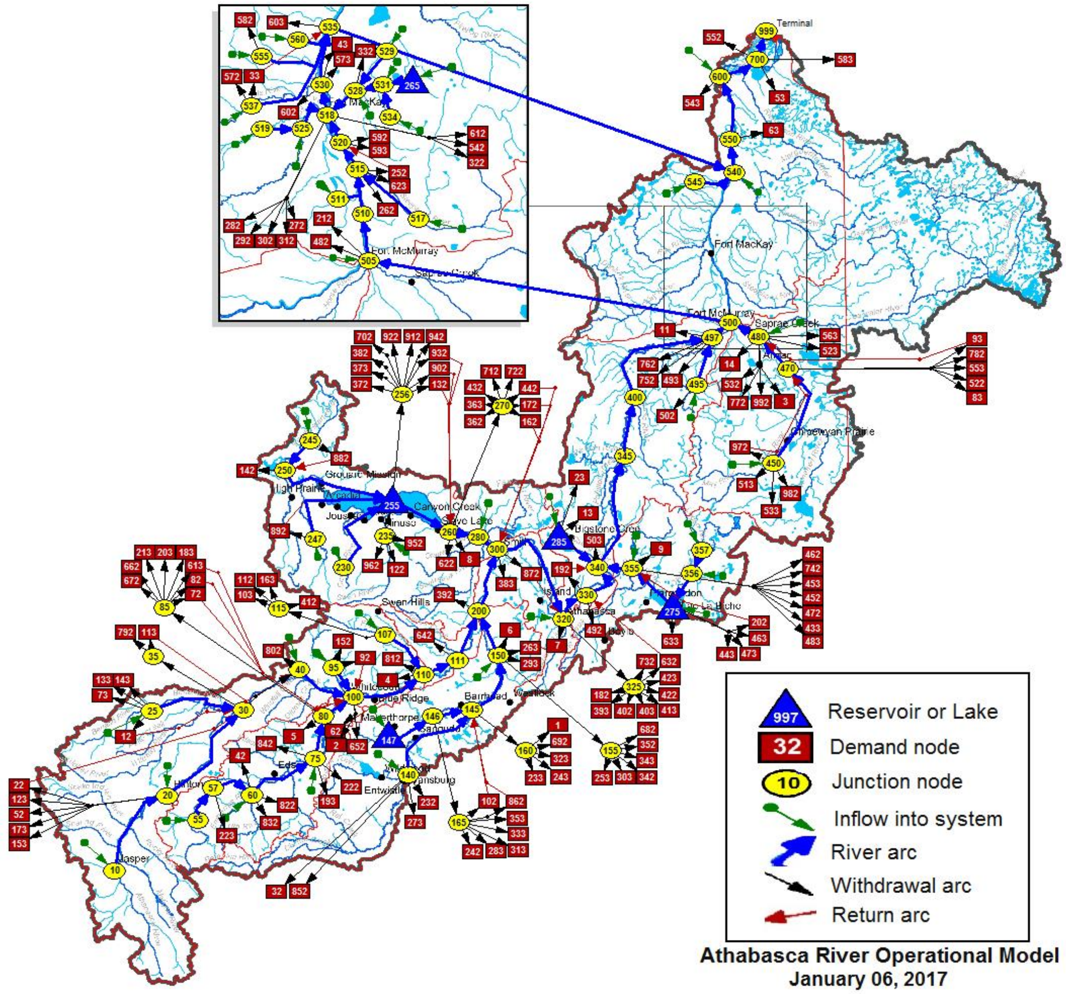


Figure 7: Schematic of the river system component of the AIRM, built on the OASIS modelling platform.

OASIS models operate under a few basic assumptions. Mass balance is always preserved by having water enter the model only at nodes with inflows and exit only through demands, evaporation, or a terminal junction node. Water is also, in the general sense, allocated to each “use” (e.g., minimum flows, water-use demands, reservoir storage) through a weighting system; that is, higher weighted uses get water first. These weights can be modified in various alternatives to increase the priority of one use over another, but the fundamental concept is applied regardless. Primary inputs include simulated inflows from the RAVEN hydrological model, licensed allocation for the whole system or consumptive use (in some cases actual use numbers were provided), return flows, and physical data for diversions and reservoirs or lakes, with associated operations. For detailed information on input datasets and assumptions, see Appendix C.

3.1.4 Climate scenarios: development and inputs to AIRM

One objective of the ARB Initiative is to propose adaptive and robust water management strategies that account for the regional impacts of climate variability and change, collectively referred to as changes in climate. To do this, a scientifically valid set of possible future conditions needed to be developed to enable the Working Group to test water management alternatives under a range of potential future climate and hydrological scenarios.

The innovative approach to developing the climate scenarios is described in detail in Appendix E and is summarized here. This aspect of the work was led by the Prairie Adaptation Research Collaborative using innovative methods that 1) incorporate the forcing and modes of variability in the regional hydroclimate and 2) are applicable to adaptation planning in the basin. For the ARB Initiative, data from Regional Climate Models (RCMs) were used as they have much higher spatial resolution, with a 50 km grid typical of RCMs compared to a 250 x 250 km Global Climate Model (GCM) cell. The RCMs provide data for 65 points in the ARB as opposed to climate projections for parts of three 3 or 4 GCM grid cells. The higher resolution of the RCMs enables the simulation of climate with greater topographic complexity and finer-scale atmospheric dynamics, providing climate change data suitable for regional impact studies.

Data from 10 RCM experiments were used. These RCM data consisted of historical runs for the baseline period 1971–2000 and simulations of the climate of the future period 2041–2070. The driving GCMs, in which the RCMs are nested, were part of Phase 3 of the Coupled Model Intercomparison Project (Meehl et al., 2007; IPCC, 2013). These GCMs were forced for the 21st century by the relatively high A2 greenhouse gas (GHG) emission scenario from the Special Report on Emissions Scenarios (Nakicenovic et al., 2000). Given recent emissions of GHGs at a rising rate (World Meteorological Organization, 2014), A2 is increasingly the most realistic emission scenario.

The historical and future weather generated by a RCM was saved at three-hour intervals for each of the points in the grid. These data were converted to daily values—precipitation (mm/day) and mean air temperature (°C)—by averaging the three-hour output. To illustrate trends and projected climate changes, we plotted mean monthly, seasonal, and annual data. Data from three of the 10 models were used to capture and provide a range of projections of future climate. Figure 8 illustrates how these three models were chosen from a scatterplot of the changes in annual precipitation and air temperature projected by the 10 RCM experiments. The circled RCMs project the least, median, and most changes in air temperature and precipitation.

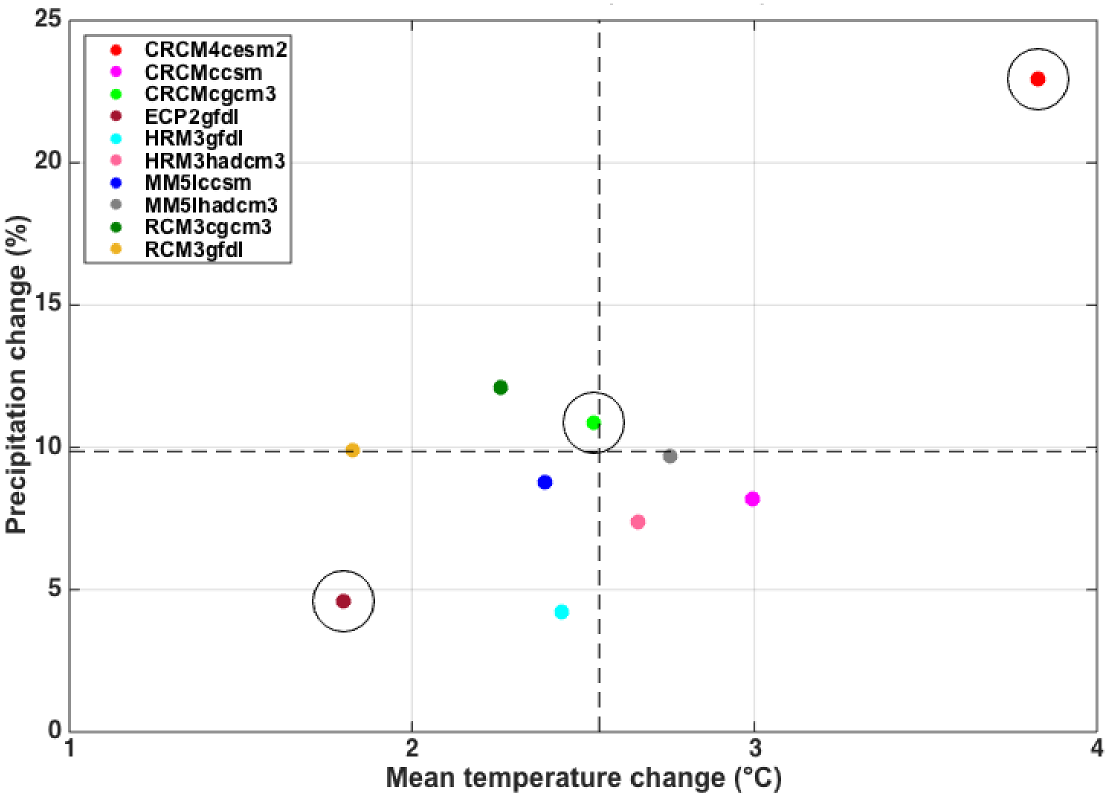


Figure 8: A scatterplot of the 10 RCM climate change scenarios. The changes are the difference in annual precipitation and temperature between 1971–2000 and 2041–2070. The scatterplot is used to identify the circled RCMs that simulate the least, median, and most changes in temperature and precipitation.

These three climate scenarios from the RCMs were used for the ARB Initiative to provide a range of potential future climates for the ARB. To provide a robust Roadmap best tested against a range of climates, three final climate scenarios were developed based on outputs from the RCMs, the historical streamflow record, and the tree-ring information showing natural variability in prehistoric river flows greater than what has been seen in the historical streamflow record. The three scenarios that went into AIRM to provide a range of future climate were:

1. Wetter scenario: climate scenario from RCMs

   This scenario was developed to show what would happen under a future climate if there were more water in the ARB, or a “wetter” scenario. It uses information based on the most recent regional climate modelling. Based on the RCM outputs, precipitation will generally increase (more in the spring and summer, and less in the headwaters during winter), and air temperatures will generally increase. Daily air temperature and precipitation values are from RCMs:

   - CRCM4_cesm2 – CanRCM4: 25 km^2 spatial resolution, representing the greatest increase in air temperature and precipitation
   - CRCM_cgcm3: 50 km^2 spatial resolution, representing moderate increases in air temperature and precipitation
   - ECP2_gfdl: 50 km^2 spatial resolution, representing the least increase in air temperature and precipitation

   Outputs from any of the three RCMs can be simulated in AIRM to show the effects of a wetter period of record (30 years) in the ARB and what that means for streamflow and water use in the basin.

2. Recent scenario: historical (1971–2000) streamflow data

   This scenario was developed to show what would happen if the future climate were similar to what was experienced in the recent past (i.e., if there were a similar amount of water in the ARB to the recent past). It provides perspective under historical conditions and provides a meaningful baseline, represented by the period from 1971 to 2000. It assumes the future will replicate the recent past.

3. Drier scenario: drought scenario from paleo climate analysis

   This scenario was developed to show what would happen under a future climate if there were less water in the ARB, or a “drier” scenario. This scenario provides a stressful water management scenario that is based on evidence of past droughts (Sauchyn et al. 2015). The drought scenario is a 30-year time series based on streamflow records from 1971 to 2000 with a 17-year drought period starting in 1974 that was spliced into the streamflow record to simulate the effects of a long-term, severe drought. Individual years when low mean annual streamflow had been observed (2000, 2002, 2003, 2006, and 2009) were spliced into the 1971–2000 record.

These potential future scenarios present a credible and useful set of scenarios under which opportunities and strategies from the Working Group can be tested against to make them as robust as possible. These scenarios also provide an opportunity to identify adaptation options and build resiliency to respond to future changes in climate.

3.2 AIRM and its representation of the ARB today

Once the AIRM was developed, a “base case” was established upon which scenarios of change in the system could be modelled and differences between the base case and a given scenario could be evaluated. The base case is a representation of the watershed and river system function today. It includes “current operations,” for which the model simulates current operating practices, modelled as rules based on licensed priorities and water management plans and frameworks. The base case is applied to the naturalized historical flows from 1970 to 2015. The base case AIRM implies that all current infrastructure and demands were present in the basin for the entire period of record (i.e., infrastructure, operations, and developed land remain constant).

The AIRM represents the basin today, based on available data and information to date. As with all models, the phrase “All models are wrong, some are useful” applies to the AIRM too; however, the project team believes the AIRM is a useful representation of the ARB watershed. Base case results were verified against historical streamflow and lake level records, and were seen to generally match river flow at several locations over the historical period. The NSE for the Athabasca mainstem at the end of the system, including all operations and streamflow simulations, is approximately 0.7. The AIRM and the PMs that have been developed show direction and magnitude of hydrologic change within the basin. Small refinements in the model are expected as the Working Group uses the AIRM over the next four Working Group meetings; however, the AIRM is built and ready for use.

4. Learnings from Year 1 of the ARB Initiative

Collaborative water management projects differ from one another because pressures, perspectives, and interests are different in every basin. There are some fundamental components that are critical to these projects being as useful and successful as possible; however, each new basin where this type of work is undertaken provides new learnings on successfully running a collaborative modelling project. Several learnings from Year 1 of the Initiative are noteworthy and may apply to other watershed-based projects in the future, especially in northern Alberta. These learnings are outlined below, with a note about how each learning can be applied to similar work in the future.

4.1 Working Group engagement and participation

The time required to develop the collaborative modelling process and common understanding of the basin with the Working Group

There has been and continues to be keen interest in this type of work in the ARB; however, the basin is massive and diverse. To date, there have been few opportunities to come together and have basin-wide discussions. There is a large diversity in backgrounds in the Working Group, and the pace and structure of the meetings needed to be slowed down and modified. Many of the Working Group members had not worked together before the ARB Initiative; therefore, educating the Working Group about the collaborative modelling process and building a common understanding of the basin itself required more time and effort than expected; these activities will require additional time for the remainder of the Initiative.

As the Working Group began to develop a common understanding of the basin, their collective goals became more focused, and the work and project goals evolved. The need for flexibility to meet the Working Group’s goals while still providing a structured path forward became apparent; in response to this need, the project team laid out the process for developing the ARB Roadmap, which is illustrated in Figure 2 and Figure 3 in Section 2.3 of this report. Over Year 1, there was a focus on developing a shared understanding of the ARB among the Working Group; this understanding of the basin was developed by encouraging communication between Working Group members during facilitated breakout sessions and through project team presentations that showed an overview of the basin and its diversity.

The need to answer Working Group questions about how this project fits with other processes

Throughout the Initiative, the Working Group has expressed concern regarding how the work completed throughout the Initiative fits into other ongoing processes—government processes or otherwise—taking place within the basin. There is further concern that the lack of clarity regarding where this process fits into other ongoing processes is impeding First Nations and Métis from participating fully in the Initiative. Answering the question of where this process fits into other ongoing processes would be valuable not only to Indigenous participants but also to the rest of the Working Group.

The project team has worked with the GoA to draw a picture of the ARB Initiative and how it fits in with other water management pieces in the basin. The project team has suggested that this collaborative water management project has the ability to bring some of Alberta's key water management tools and information together, creating a shared platform for discussion. Among the existing water management tools information are licenses, legislation, policies, operations, infrastructure, regulations, and modelling tools. These tools are reflected in the AIRM used in the collaborative water management process in the ARB. During this process, the diverse basin-wide Working Group uses the tools and information to identify, simulate, and discuss basin-wide water management issues and opportunities. This work can support GoA processes such as water management planning and implementation, and discussions are ongoing about how this work can further support GoA processes.

There are many First Nations and Métis communities in the basin. The broader Working Group has expressed that First Nations and Métis involvement in the Initiative is necessary to provide a complete basin perspective. First Nations and Métis communities have expressed interest in participating in the ARB Initiative; however, Indigenous participation in the Initiative is complicated due to circumstances outside the control and scope of this Initiative. These circumstances include historical events, and planning processes such as LARP (Lower Athabasca Regional Plan) that were not seen to be inclusively supported in the basin. In addition, the United Nations Declaration on the Rights of Indigenous Peoples, with Canada being a recent signatory, leaves some uncertainty regarding guidance for engagement and decision-making around natural resources management in general as this implementation is evolving. The United Nations Reactive Monitoring Mission to Wood Buffalo National Park taking place in the basin has been in the spotlight, and previous court rulings also in the basin, where participation or a chance at participating in a collaborative manner was later regarded as Consultation, were cited as concerns.

To provide clarity and build trust among First Nations and Métis communities and the broader Working Group, the Working Group has requested clarification from the GoA on four points that would allow for understanding of how the Working Group efforts play into the bigger water management picture in Alberta. These points are:

- The perception that this process is Consultation and this role belongs to government.
- There is no guarantee that recommendations identified through this process will be used.
- The need to understand how this Initiative fits into overall water management processes.
- There is no forum for dialogue with GoA on these matters of water management and underlying issues of infringements on treaty rights.

WaterSMART has formally communicated the above request for clarity to the GoA through GoA Working Group participants, members of the Logistics and Administrative Committee, and through the AEP branches that provided financial contributions to the ARB Initiative. The conversation between GoA and WaterSMART is ongoing. The lack of clarity as to how the Initiative fits in with other water management pieces in the basin has slowed progress in Working Group development, which has slowed progress in Year 1 of the Initiative. In future work of this sort, particularly in northern Alberta, it is suggested that the picture of how the work fits in with other water management initiatives in the basin be formed earlier in the process with GoA.

The need to provide funding and capacity for some participants

When the Initiative was scoped, funding was not provided to directly support participation in the Initiative by any specific group. It was felt that paying for people, or any subset of the Working Group, to participate may be seen as unfair and may send the wrong message about a collective group coming together to support and improve water resource management in the basin. Lack of resources was a barrier for some communities and groups in being able to participate in the Working Group meetings. This was sometimes a function of limited funds to allow for travel or limited capacity of a group to have personnel available to go, or both. While it is beyond the scope of work such as this to provide personnel capacity to organizations, these types of basin-wide projects could plan to budget for assistance with direct costs (e.g., travel, accommodations), where needed, to attend meetings.

The benefits of direct initial contact instead of umbrella groups

Direct contact rather than indirect contact by going through umbrella groups or industry associations is the most effective means to promote participation for communities. Organizations should be contacted individually. If companies or communities are contacted through an association or umbrella group, follow up with individual companies should be done. Direct contact not only serves to establish relationships early on, but also allows for the project to be explained first-hand by the project team rather than through the filter of another organization.

The need to ensure clarity and consistency in project messaging

Messaging regarding the current scope and potential future phases of work evolved over time through varied thoughts from supporters of the work, needs identified by the Working Group, and modelling capability. In some instances, as the messaging evolved, it created confusion about the goals and outcomes of the work and who was leading the work. There was and continues to be a perception by some that this is a government-led project or a Consultation process. This has not been messaged and is not the case, but it continues to be perceived based on how the work has evolved.

When messaging large initiatives like this with many perspectives involved, neutral language should be used to frame the project to avoid unnecessary confusion. To gain interest, the messaging should emphasize specific benefits to communities, organizations, or companies. An effective Terms of Reference document can be used to communicate the scope and intent of the work early on. The Terms of Reference should be drafted before beginning community engagement, and they should be discussed at engagement meetings and updated with input from any potential participant or participating group.

The delivery and accessibility of technical information
When a large amount of technical information is being used and disseminated to a large and diverse group of participants who have different knowledge on water in the basin, it is vital to ensure that delivery and accessibility of the information is appropriate. Technical information should be presented and accessible in plain language, where possible, in recognition of the diversity of a large basin-wide working group. This is important to ensure understanding of material by the working group.

Email communications, phone calls, and access to meeting materials and Initiative documents via a project website serve as an effective means to access project materials and for groups to share materials with other staff and consultants. For Indigenous groups, this can help support the translation of this information for internal decision-making purposes.

The gaps in attaining and incorporating traditional knowledge
In the ARB, it has been noted that integration of traditional knowledge into the modelling work is lacking. It has been a challenge to have Indigenous participants bring aspects of traditional knowledge to the table that could be used in the modelling process because of a lack of trust and other difficulties that accompany the sharing of traditional knowledge. Holding meetings within a community and pursuing the question of how to best use observation-based data and traditional knowledge as part of this work is an opportunity that has been proposed for relationship building and moving beyond this challenge. A suggestion to hold a Working Group meeting on “the land” rather than in Edmonton has been proposed; however, considerations have to be made for the majority of participants and logistics, which is why the meetings are held in Edmonton.

The value in following up on meeting invitations and responses
Meetings are typically scheduled two to four months in advance to provide participants with adequate notice to plan and prepare; an important learning over the first year of the Initiative has been to check in with those who do not respond to meeting requests to ensure there is an opportunity for them to participate if they wish to do so. Some potential participants do not respond to email but will communicate verbally. Some organizations do not provide direct email accounts for all potential participants within the organization or community, and some have only a general voicemail box or none at all.

4.2 Model development

The time needed to overcome unanticipated challenges in the integration of multiple models
The integration of multiple models has been a successful but challenging part of the Initiative. Much has been learned regarding how to integrate tools that have different technical requirements in a relatively seamless manner. However, not all challenges were anticipated, particularly data manipulation and processing requirements. The modelling platform was built to meet the needs of the work by being open, transparent, flexible, and able to be integrated with other modelling platforms in the future (e.g., water quality, groundwater). Future projects of this nature should consider expanding the scope of the modelling work to account for unforeseen challenges that inevitably accompany model integration.

The best approaches to simulating large-scale watersheds
The ARB is an extremely diverse system, and substantial hydrologic process work was required to understand how best to simulate this dynamic watershed. In addition, the size of the watershed was challenging to work with. Tools were developed that operate extremely quickly at these scales, and these tools will continue to be refined over the next year. Developing these tools to be efficient in a way that properly represented the basin was challenging. Through overcoming these challenges, much was learned about the system and about how to simulate large-scale watersheds. This learning, as reflected in the AIRM, can be applied to other watershed models and modelling work in northern Alberta to improve simulated hydrological processes for research or regulatory needs.

5. Concluding remarks

In Year 1 of the Initiative, WaterSMART was able to support the Working Group in coming together to begin discussions regarding water in the ARB—what issues and opportunities exist to move toward sustainable water management in the ARB. Over the past year, we have collectively:

- Held four full-day Working Group meetings at which participants representing communities and organizations across the basin engaged in dialogue to build a common understanding of the ARB and identify issues and opportunities around surface water in the ARB.

- Maintained a working list of the water-related issues and a working list of water-related opportunities in the ARB.

- Built the AIRM, which represents the basin today based on the best available data and information to date. The AIRM simulates the interactions between climate, landscape, hydrological processes (e.g., evaporations, interceptions, runoff), river flow, and human interactions in the watershed (e.g., water withdrawals, water storage). The AIRM shows the direction and amount of change to streamflow within the basin.

- Received presentations from experts on changes in climate and landscape, and what these might mean for streamflow in the ARB.

- Decided to focus the remaining work on five key basin challenges based on the scope of the Initiative and Working Group interest:

    - Maintaining or improving water quality (temperature and dissolved oxygen)
    - Providing water supply certainty for municipalities and 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

In the second year of the Initiative, we will collectively:

- Hold four additional full-day Working Group meetings to develop and test strategies using AIRM.

- Build the most promising strategies into a Roadmap.

- Develop a set of practical actions to advance the Roadmap.

- Hold sharing meetings to ensure that effective engagement and two-way communication with Indigenous groups occurs. It is hoped that these meetings will create opportunities for dialogue, information sharing, progress reporting, and a clear understanding of the ARB Initiative.

This Roadmap will be a set of strategies and practical actions that will serve as a recommended path toward sustainable water management in the basin. It is intended to inform future planning and management efforts as they relate to water. The strategies may include capturing gaps in data, knowledge, policy and tools, and processes that could contribute to more informed and inclusive decision-making in the future.

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7. Appendices

APPENDIX A Working list of surface water quantity issues in the ARB

This list of surface water quantity-related issues in the Athabasca River Basin (ARB) has evolved based on background information collected in the form of a desktop study of issues in the basin *(Summary of issues, interests, and opportunities in the Athabasca River Basin, April 2016)*. The information provided in the initial desktop study informs this document and has been further developed and enhanced through dialogue with Working Group participants. This list will be continually updated based on discussions at Working Group meetings over the course of the ARB Initiative.

Colored text indicates discussions captured from breakout tables at Working Group meetings based on geography in the basin: upper part of the basin in blue; central part of the basin in green; and lower part of the basin in red. Black text represents issues that were gathered as part of the desktop study and relate to the current ARB Initiative scope of work.

Issues: Supply and demand (e.g., licences/changes in supply/demand/infrastructure)

- Reduced streamflow downstream due to municipal and industrial withdrawals.
- Meeting instream flow needs (IFNs): Is there a formula used to calculate IFN for temporary diversion licences? Could this be included in basin-wide IFN calculations or on all the major tributaries?
- Changes in water temperature and possible reduction in dissolved oxygen from industrial activities or warmer/lower summer flows.
- Declining water levels inhibiting boat transportation. Navigation is an issue in specific parts of the basin (downstream of Fort McMurray, in the Peace-Athabasca Delta [PAD], at the mouth of some tributaries, and at Lesser Slave Lake). Navigation is an issue on smaller tributaries in some areas of the central portion of the basin. This is due to many factors and may become more problematic in the future with potentially drier conditions.
- Declining water levels, which results in sediment being drawn in during water intake.
- Impact of current allocations on treaty rights; also, how that may change under future scenarios.
- Risk of water shortages to water licence holders.
- Risk of insufficient storage to water licence holders.
- Human-caused impacts on the PAD. How will we know if the opportunities counteract human-caused degradation to the PAD?
- Erosion of streambanks and loss of infrastructure: Town of Whitecourt/Millar Western Plant – spurs have been added in the river to prevent erosion; there is worry that the mill will be washed away. Beaver Creek used to flow through a channel where the mill is now located.
- Lake-level decline seems to be an issue in a number of lakes in the ARB that are being monitored.

- Reuse of water runoff should be examined as an issue to be addressed.
- Less frequent flooding in the PAD (e.g., ice jams).
- More frequent conditions under which ice jams form at Athabasca and Fort McMurray.
- Change in water quantity due to climate change:
  - Timing (start and end) of annual freshet.
  - Changes in snowpack and effects on seasonal and annual flows.
  - Changes in water levels and soil moisture regimes resulting in dry creeks and dry wetlands.
  - How longer climate cycles (e.g., 60 years) could change seasonal and annual flow conditions.
  - How snowmelt, glaciers, and baseflow contributions to streamflow may change.
- The lack of conversation surrounding treaty rights has been an ongoing issue in the basin. There is a need for the Government of Alberta to have one-on-one conversations regarding treaty rights with First Nations and Métis communities.
- Decreased soil moisture content may be linked to an increase in the occurrence or intensity of forest fires.
- Many waterbodies that were protected before changes to the *Navigable Water Protection Act* in 2012 are no longer protected and are at risk.

Issues: Regulatory (e.g., policy, regulations, legislation)

- Clear policy and regulations on water reuse are needed to match quality to use and be more efficient in the use of water in the basin. Need to understand how integrated water management, in particular water reuse and water return policy, could impact the basin once the policy mechanisms are specified.
- Spill tracking records system and reporting requirements along with monitoring is needed to inform cumulative effects over time. Build datasets and trust over time for improved water planning and management.
- The compensation for fish habitat loss is not effective: compensation lakes affect terrestrial ecosystems and are not an adequate replacement for culturally significant traditional fishing.

Issues: Lands and ecosystems

- Shoreline development on the south shore of Lesser Slave Lake and on the shores of some smaller lakes in the central basin.
- Winagami Lake with South Heart Dam has poor water quality with decreased dissolved oxygen as a result of agricultural runoff. The Peavine community lost land due to the dam and reservoir. Blue-green algae are a problem in this reservoir and other stagnant waterbodies and lakes.
- How often the current surface water allocations could prevent the ability to meet minimum surface water flows required to maintain healthy aquatic environments.
- Lack of flooding has resulted in increased willow growth and island formation.

- Reduction in sustainability of fish populations due to reduced flow, flow instability, water temperature, and compromised link between ARB and PAD.
- Declining fish populations are harming waterfowl populations and traditional use.
- Impact of withdrawals (e.g., coal mines) on the health of headwater tributaries.
- The sustainability of fish populations and availability of fish habitat.
- Maintenance of ecosystem health.
- Hydrological impacts on peatland wetlands due to fragmentation from road crossings and recreation.
- Lack of environmental baseflows throughout the basin. These flows need to be defined to address aquatic health and, in particular, the effect on fish populations, which have been and continue to be impacted (e.g., whitefish and walleye; northern pike throughout the basin; and Arctic grayling at Swan River and Sawridge Creek).
- Beaver management on small tributaries is needed to ensure flows exist for water supply and aquatic health (identified as community-based issues at Gift Lake and Bigstone Cree communities).
- Reduction in water quantity due to landscape changes:
  - How wetland loss and retention influences hydrology and streamflow.
  - Effect of large-scale forest disturbance on hydrology and streamflow.
- Low or changing water flows and water-table levels in the Gift Lake and Gift Lake River areas.
- Large-scale forest disturbance could lead to increased volatility in water flows.
- Development has increased the frequency/volume of flash flooding in Lesser Slave Lake area.
- Private land practices are adding to sedimentation: lack of buffers and riparian areas degradation are contributing to sedimentation and poorer water quality.
- Protection of wetlands and wetland complexes, such as those near Buffalo Bay, is needed. Recognize the importance of wetland connectivity and relationship to hydrologic function and flow in tributaries and the river.
- Hydrological impacts on peatland wetlands due to fragmentation from road crossings and recreation.

Issues: Data and knowledge

- There is a need to manage and make information accessible to community-level decision makers and at other scales.
- There is a lack of understanding of the groundwater processes in the basin.
- There is a lack of knowledge surrounding locally important sensitive areas; for example, in the Lower Athabasca there are many large fens upstream that contribute to water supply.

Other water-related issues captured in Working Group meetings for future work or consideration

- Phosphorus loadings from agriculture runoff: impacts in the South Heart River.
- Oil and gas development (cumulative impacts of spills) impacts on Swan River.
- Sedimentation at water intake points. It was recognized that we are not modelling sediment, and the breakout table agreed that this is likely a reflection of design/maintenance issues rather than a basin water management issue.
- Fish and terrestrial animals are not consumable and/or are less available due to water and land impacts.

APPENDIX B Working list of opportunities (potential strategies) in the ARB (Updated April 6, 2017)

Potential Strategies: Upper Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
Supply and Demand (SD)	1	Reuse of industrial or municipal effluent (BW)	Return flows from industry and other operations that create contaminants should be repurposed for other industry use (reuse by industry).	• For example, Swan Hills was considering selling this water to industry or pulp mills sending effluent companies for hydraulic fracturing. • Benefits of a basin wide water reuse policy involve considering the tradeoff and impacts on water reuse applications and on water withdrawals/returns. Another benefit would be reducing water use intensity. An example of basin wide water reuse was the purple pipes project from RMWB to Anzac. These are regional water supply lines for municipal needs. • Developing collaborative collection and storage of water available for reuse at various locations to be used by industry users that reply on TDLs. Collaborative grey water collection and storage-Grey water could be storage at various key locations and used by Industry users that rely on TDLs. Grey water could be used at times of low flow instead of taking the water from the river. The grey water could be what is typically returned to the water by other license holders.

Potential Strategies: Upper Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
				POTENTIAL ACTION: Need to change, clarify, or make new clear policies for decisions on water, specifically regarding reuse and re-connecting industrial land pieces post reclamation. The existing *Water Act* covers the legislation to enable policy, but the policy needs to be cleared up. Municipal to industrial reuse, industrial to industrial reuse. Need for a basin wide (even provincial wide) water reuse policy. **POTENTIAL ACTION**: Water use education. Awareness and education are important for conservation, water use efficiency and management. **POTENTIAL ACTION**: Develop policy for water reuse, policy should address acceptable water quality for reuse as well as storage options. Using treated industrial effluent from ANC for use in hydraulic fracturing. ANC Treated effluent to hydraulic fracturing companies. Alberta Newsprint Company is treating effluent for use in hydraulic fracturing in the Athabasca and Peace basins. Treated effluent could come from industrial and municipal sources; it could be used in fracking operations in the upper Athabasca or Peace River basins.

Potential Strategies: Upper Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	2	Limit TDLs in tributaries that have habitat at risk	Develop a database of this knowledge. Limit temporary diversion licences (TDLs) where species at risk are identified and restrict activities in those areas.	• Tributaries that have sensitive habitats can be identified and withdrawals can be limited from those tributaries. • Tributaries could be limited by stream order.
	3	Explore new and existing on stream and off stream hydropower sites for both hydropower and water storage	Explore hydropower facility development in the Athabasca to support increased economic development and the Alberta government's Climate Change Plan. • Astoria site • Labyrinth site • Pinto Creek site • Berland site • Oldman site • Image Rock site • McLeod site • McLeod Valley site • Pembina site	Recognized benefits of this opportunity included a renewable energy source that aligns with the Climate Change Leadership Plan, flood control, and water storage. Challenges to this opportunity were raised and included impacts on natural flows in the system (i.e., freshet), impacts to riparian functions, and impacts to fish habitat. Hatch published a report in 2010 that outlined all of the potential hydropower sites throughout the province. Sites were identified based on hydropower potential, there were 17 sites identified on the Athabasca and its major tributaries. There was concern expressed over the impacts that hydropower facilities can have on a river (e.g., fish passage, changes in flow, etc.). All energy development will have its trade-offs; with hydropower the trade-off discussion should include both positive and negative tradeoffs as facilities can often be multipurpose (e.g., flood control, storage, low flow augmentation, etc.), depending on the type of facilities (e.g., large storage versus run of river). These should be multi-use facilities, have fish passage and be developed to enable preservation of river function.

Potential Strategies: Upper Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
				Obed site: run of the river solution: A former coal licence is looked at for use to generate electricity by running water through an existing storage off-stream and hydro turbines.
	4	Explore setting precautionary water withdrawal limits (BW)	This could be considered to limit impact on water-based recreation and navigational uses of the Athabasca River.	Propose IFNs on tributaries as needs dictate . Define instream flow needs (IFNs) on a seasonal basis what is needed in terms of quantity for the watershed and manage water resources accordingly. Implement environmental baseflows. Environmental baseflows are needed to be identified and enforced throughout the basin. These flows need to be defined so as to address aquatic health, and in particular effect on fish as populations have been and continue to be impacted. Fish populations include, whitefish and walleye, northern pike throughout the basin, and Arctic grayling at Swan River and Sawridge Creek.
	5	Water conservation, and water efficiency improvements (BW)	Improve municipal water management practices. This could include metering, stormwater use, lawn watering, low flush toilets, general conservation, etc.	This provides an opportunity to educate and address each individual's actions and practices Monitor and create ways to manage water use (e.g., municipalities could incentivize conservation). **POTENTIAL ACTION**: Water use education. Awareness and education are important for conservation, water use efficiency and management.

Potential Strategies: Upper Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
Regulatory (R)				
Lands and Ecosystem Use (LE)	1	Establish parks or conservation areas	Look at conserving areas with high biodiversity / hydrological importance (e.g. CPAWS high conservation areas for biodiversity).	A suggestion was made for a conservation area in the Gregg River area. **POTENTIAL ACTION:** Set up a fund to support initiatives and habitat conservation rather than simply allocating funding to habitat offsetting. There is a significant allocation of funds to habitat offsetting that may be better served as a long-term fund that provides resources for habitat conservation and other initiatives. Identify and conserve and restoration areas for source water protection. Maybe work off of pilot in the Bow Basin from the WRRP work on identifying high value restoration and conservation projects.
	2	Alter forest harvest regimes in some watersheds and limit forestry in hydrologically sensitive watersheds		Increase harvest level to simulate the effects of increased footprint of harvesting and forest fire. For example, speed up the cut of older pine forests to simulate the increased harvest of older pine (pine beetle prevention).
	3	Increase to agricultural land (forest conversion)		Simulate increase of agricultural land (grassland)

Potential Strategies: Upper Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	4	Address access management and linear disturbances (BW)	Access management to help address linear disturbances was another opportunity that was mentioned. This includes planning, minimizing disturbances, minimizing crossings, and mandating "best-practices" in order to have the least impact on hydrology.	For example, building access roads in order to optimize reclamation, or proactive designation of trails and recreational areas. Road sharing and decommissioning (e.g., revegetate redundant roads) are needed to reduce linear disturbance and resultant impacts on water flow, infiltration, and quality, particularly in the Swan Hills area.
	5	Prioritize reclamation through strong reclamation modelling (BW)	Prioritizing reclamation through strong reclamation modelling was another potential opportunity.	For example, identifying sites of highest priority that may have the greatest positive impact on peatland complexes, tributaries, and connectivity is a big opportunity in the basin. There is potential there to build off the work from a recent WRRP project in the Bow Basin that used ALCES to identify restoration projects of greatest value hydrologically in the Bow Basin.

Potential Strategies: Central Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
Supply and Demand (SD)	1	Irrigation agriculture	Climate change could mean more arid conditions, and with warmer temperatures, resulting in longer growing season; this could result in the need or opportunities to use irrigation for farmland (not done currently in this area of the basin).	This potential future need should to be addressed. Add a demand node. Pembina sub-basin has been included here with demand node. Check on model results within the growing season timeframe identified, rather than assessing for the entire year, since the irrigation water demand would not apply outside of the growing season months. This should be applied to the land that is currently classed as agriculture and determine what a maximum amount of irrigation on that land would actually be.
	2	Use the weir at Lesser Slave Lake to manage lake levels.	Look at managing lake levels to ensure flows are adequate and desirable for aquatic health and community needs downstream of the Lake.	Examine the balance between flood protection and aquatic health, as well as navigation considerations. Model can examine lake levels established between 575.5 and 577.5 m., with consideration for fluctuations between these levels.
	3	Potential hydropower sites	• Mirror site • Moose Portage site	Mirror site was examined and more is needed, and Moose Portage site is yet to be discussed by the group. **Clarify if these are run of the river and how much power they would generate**. There are fisheries concerns about these. Based on Hatch (2010) report it seems as though Mirror site would not be run of river, and could generate just under 2,000 GWh/year, and has 72 m of gross head.

Potential Strategies: Central Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	4	Re-evaluate water storage options off stream	Evaluate options in the basin to allow for industrial water supply, flow augmentation and regulation, and possible hydropower.	Evaluate options in the basin to allow for industrial water supply, flow augmentation and regulation, and possible hydropower. Lesser Slave Lake option: rehabilitate the current weir at LSL and raise it by 30 cm that would produce 100M m^3 of additional storage in LSL.
	5	Explore setting precautionary water withdrawal limits (BW)	This could be considered to limit impact on water-based recreation and navigational uses of the Athabasca River.	Propose IFNs on tributaries as needs dictate . Define instream flow needs (IFNs) on a seasonal basis what is needed in terms of quantity for the watershed and manage water resources accordingly. Implement environmental baseflows. Environmental baseflows are needed to be identified and enforced throughout the basin. These flows need to be defined so as to address aquatic health, and in particular effect on fish as populations have been and continue to be impacted. Fish populations include, whitefish and walleye, northern pike throughout the basin, and Arctic grayling at Swan River and Sawridge Creek.

Potential Strategies: Central Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	6	Reuse of industrial or municipal effluent (BW)	Return flows from industry and other operations that create contaminants should be repurposed for other industry use (reuse by industry).	• For example, Swan Hills was considering selling this water to industry or pulp mills sending effluent companies for hydraulic fracturing. • Benefits of a basin wide water reuse policy involve considering the tradeoff and impacts on water reuse applications and on water withdrawals/returns. Another benefit would be reducing water use intensity. An example of basin wide water reuse was the purple pipes project from RMWB to Anzac. These are regional water supply lines for municipal needs. • **POTENTIAL ACTION**: Need to change, clarify, or make new clear policies for decisions on water, specifically regarding reuse and re-connecting industrial land pieces post reclamation. The existing *Water Act* covers the legislation to enable policy, but the policy needs to be cleared up. Municipal to industrial reuse, industrial to industrial reuse. Need for a basin wide (even provincial wide) water reuse policy. • **POTENTIAL ACTION**: Water use education. Awareness and education are important for conservation, water use efficiency, and management.

Potential Strategies: Central Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	7	Water conservation, and water efficiency improvements (BW)	Improve municipal water management practices. This could include metering, stormwater use, lawn watering, low flush toilets, general conservation, etc.	This provides an opportunity to educate and address each individual's actions and practices Monitor and create ways to manage water use (e.g., municipalities could incentivize conservation). **POTENTIAL ACTION**: Water use education. Awareness and education are important for conservation, water use efficiency and management.
Regulatory (R)	1	Water management for lakes	There is a need to implement better water management for lakes that is similar to the management of rivers.	This is related to allocation limits. Applying the same rules as rivers (similar to IFN). Basin size, precip, etc., to create lake water balances.
Lands and Ecosystems Use (LE)	1	Ensure adequate reforestation and buffer requirements for logging activities	Reforestation and buffer requirements are needed to reduce sedimentation, and these best management practices both offer other habitat and water quality and quantity (hydrological connection) benefits.	See linear disturbances (6) and benefits to identifying logging roads to be restored. Need to have better enforcement and the timing of reforestation. Simulate logging BMPs or buffer?

Potential Strategies: Central Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	2	Understand the opportunity around natural water storage and how this has changed relative to pre-industrial landscape	Natural water storage offers a wide range of benefits. It would be helpful to understand what this storage could be under a pre-industrial landscape.	Particularly important for wetland policy. Need to have rationale and arguments for protecting wetlands. Beaver dams and detention storage. Quantify the loss to date, then use as a scenario to evaluate the rate of loss over the next few decades. Evaluate the effect of wetlands on flow, baseflow, etc. Implement land use planning restrictions to limit residential development impacts on lakes and wetlands. Another opportunity could be land use planning restrictions to limit residential development impacts on lakes and wetlands. Specifically, in the Lac La Biche area
	3	Identify and conserve and restoration areas for source water protection.	Maybe work off of pilot in the Bow Basin from the WRRP work on identifying high value restoration and conservation projects.	This may be accomplished through a land use plan. **POTENTIAL ACTION**: Set up a fund to support initiatives and habitat conservation rather than simply allocating funding to habitat offsetting. There is a significant allocation of funds to habitat offsetting that may be better served as a long-term fund that provides resources for habitat conservation and other initiatives.

Potential Strategies: Central Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	4	Reclaim roads that are no longer needed	What is the hydrologic impact? Should maybe as a starting point just reclaim all of the ‘trails’ and see what happens hydrologically in the model. It would be a good indication of what road reclamation would do. Clarify the policy that exists around road reclamation.	• Access management to help address linear disturbances was another opportunity that was mentioned. This includes planning, minimizing disturbances, minimizing crossings, and mandating “best-practices” in order to have the least impact on hydrology. For example, building access roads in order to optimize reclamation, or proactive designation of trails and recreational areas. Road sharing and decommissioning (e.g., revegetate redundant roads) are needed to reduce linear disturbance and resultant impacts on water flow, infiltration, and quality, particularly in the Swan Hills area. • The Athabasca River Basin is a convergence zone of linear disturbance pressures, with recreational pressures coming from the south and industrial pressures coming from the north. It is important to recognize both of these pressures as this relates to future projections and cumulative effects in the area • Other “linear disturbances” include channelized and straightened channels for water conveyance designed to get water off the land efficiently; this is an opportunity to re-naturalize the channels and the river system. Get impacting companies to synergize their efforts to remedy the impacts.

Potential Strategies: Central Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	5	Opportunity to make any future new farm land (converting land into farm land) that is developed to have no new net impact to the existing issue of sediment and nutrient runoff		e.g., larger buffers around waterbodies, best farming practices, etc.). Education is needed, incentives work well such as technical assistance (e.g., grants for implementing BMPs) for farmers, and enforcement of a policy/regulation like this would be good.
	6	Prioritize reclamation through strong reclamation modelling (BW)	Prioritizing reclamation through strong reclamation modelling was another potential opportunity.	For example, identifying sites of highest priority that may have the greatest positive impact on peatland complexes, tributaries, and connectivity is a big opportunity in the basin. There is potential there to build off the work from a recent WRRP project in the Bow Basin that used ALCES to identify restoration projects of greatest value hydrologically in the Bow Basin.

Potential Strategies: Lower Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
Supply and Demand (SD)	1	Potential hydropower sites	• Moberly Rapids hydro site • Crooked Rapids hydro site • Brule Point hydro site • Pelican Rapids hydro site • Grand Rapids hydro site	Potential reservoir site: Grand Rapids (Indicative size from 2008 AEP report: 400,000 cdm) Potential to offer: • Hydropower generation • Storage for flow augmentation • Supply for licence use Option: Use a new reservoir upstream of Fort McMurray (#346 in the model, approximately the Grand Rapids site location and volume) to release water as needed to meet the AXF below the confluence with Firebag River. Option: Estimate how much more withdrawal capacity (i.e., for additional licences) the upstream reservoir would create, over and above making releases to meet the AXF.
	2	Re-evaluate water storage options off stream	Evaluate options in the basin to allow for industrial water supply, flow augmentation and regulation, and possible hydropower.	Evaluate options in the basin to allow for industrial water supply, flow augmentation and regulation, and possible hydropower. McMillan Lake: The lake is a closed lake system with a small drainage area, and is currently a brine lake, not really any fish. The lake drains through sub-surface muskeg area surrounding it. Idea would be to build a 5 m berm and increase the capacity of the lake to 100M m^3. Water would be pumped up 100 m into the lake in the spring when flows are high, and then release the water as needed. Might be possible that oxygenated return flows to river could help with DO sag in river, but likely no fish compensation benefit.

Potential Strategies: Lower Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	3	Find alternatives to freshwater use in SAGD facilities.	Find alternatives to freshwater use in SAGD facilities.	Very few SAGD licences if any draw from freshwater sources. They typically use groundwater saline sources. Therefore the impact of this opportunity would be minimal. Should it be removed from the list? • Most SAGD operations use groundwater however there are a small number that have licenses to withdraw freshwater from the river. It would be informative to model these withdrawals and see the flow impact of eliminating them. • Separately, there may be a Regulatory strategy or gap related to the outstanding for a clear and useful definition of "near fresh" or brackish groundwater vs. saline groundwater.
	5	Reuse of industrial or municipal effluent (BW)	Return flows from industry and other operations that create contaminants should be repurposed for other industry use (reuse by industry).	• For example, Swan Hills was considering selling this water to industry or pulp mills sending effluent companies for hydraulic fracturing. • Benefits of a basin wide water reuse policy involve considering the tradeoff and impacts on water reuse applications and on water withdrawals/returns. Another benefit would be reducing water use intensity. An example of basin wide water reuse was the purple pipes project from RMWB to Anzac. These are regional water supply lines for municipal needs. • **POTENTIAL ACTION**: Need to change, clarify, or make new clear policies for decisions on water, specifically regarding reuse and re-connecting industrial land pieces post reclamation. The existing *Water Act* covers the legislation to enable policy, but the policy needs to be cleared up. Municipal to industrial reuse, industrial to industrial reuse. Need for a basin wide (even provincial wide) water reuse policy.

Potential Strategies: Lower Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
				• **POTENTIAL ACTION**: Water use education. Awareness and education are important for conservation, water use efficiency and management.
	6	Water conservation, and water efficiency improvements (BW)	Improve municipal water management practices. This could include metering, stormwater use, lawn watering, low flush toilets, general conservation, etc.	This provides an opportunity to educate and address each individual's actions and practices Monitor and create ways to manage water use (e.g., municipalities could incentivize conservation) **POTENTIAL ACTION**: Water use education. Awareness and education are important for conservation, water use efficiency and management.
Regulatory (R)	1	Implement an Aboriginal Base Flow (ABF) or Aboriginal Extreme Flow (AXF)	AXF: minimum 400 cms in the river below the confluence with Firebag River during open water season (April 16 to October 28 = 196 days).	Purpose: to set the minimum water level/flow in the mainstem and tributary mouths required for treaty rights and traditional uses, primarily navigation. This was put forward to the Phase 2 Surface Water Quantity Framework in the As Long as the River Flows document. The document identified 400 cms as a minimum and ~1,600 cms as the ideal. The flow in the mainstem is largely driven by natural dynamics. Licence withdrawals for the total oil sands vary but are limited 4.4 cms, during low flow periods (<87 cms). That is relatively small compared to a flow target of 400 cms.

Potential Strategies: Lower Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
				One option is to put in a dam upstream and operate it to meet AXF. Alternatives to implementing a minimum flow could be: • Dredge the river to remove sediment and increase depth. – It was recognized the model developed for this project represents flow, not depth. However, an existing flow-depth-navigation relationship can be used to infer effect that different flow levels will have on navigation. • Changing vessels to use those that require less water depth, e.g., air boats. – Conceptually, options can be considered as either build the river for the boat or build the boat for the river. Using different boats is an example of the latter. • Use structures to create depth in navigation pinch points. • Develop a navigation model, using bathymetry to understand navigation channels and their changes through time to assess options. A potential opportunity could be re-dredging of the lower Athabasca River to enable navigation (access) to First Nations and Métis communities and traditional territories. An opportunity here could be to better develop navigation modelling, using bathymetry to understand navigation channels and their changes through time. Alternative means of navigation were suggested to avoid dredging activities, for example the use of different water crafts that can maneuver in shallower waters, or road navigation by building an all-season permanent road to Fort Chipewyan.

Potential Strategies: Lower Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
				Under the climate scenarios, in the Wetter scenario, temperatures would be higher therefore the open water season could be longer. This may create demand for a longer navigation window e.g. 256 days instead of 196 days.
	2	Explore an Ecosystem Base Flow (EBF)	Explore an Ecosystem Base Flow (EBF) in the Athabasca River.	Will need to know location of EBF, flow target, and duration. This is not established yet. Could there be a development of a functional flow for the Lower Athabasca?
	3	Explore the creation of a policy or directive to enable oil sands to treat and release water.		Oil sands operations need a specific policy/directive with alignment from the federal and provincial governments to enable OSPW water release. A standard of water quality needs to be defined and agreed upon in terms of the level of treatment that is required for release. Estimate the impact on river flows of having return flows from oil sands operations. This could show the water quantity impacts, not the water quality impacts. • This is already being examined by a working group including government and industry. • Water quality is a major concern with the concept of treat and release and this project cannot speak to that therefore perhaps this strategy should not be further explored. • However, it would be informative for this project to look at the potential augmentation offered from controlled releases from a flow volume perspective. We would need to assume that water quality guidelines are met.

Potential Strategies: Lower Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
				• Would need to know how much is being returned, from what license, and following what yearly pattern.
Lands and Ecosystems Use (LE)	1	Reclamation requirements, practices and implementation for hydrology. & Priority reclamation	Reduces linear fragmentation causing interruptions in hydrological connectivity.	This is an issue throughout the oil sands area Primary causes are roads and pipelines (and compacted seismic lines but hard to know which are compacted) Prioritize reclamation through strong reclamation modelling. Prioritizing reclamation through strong reclamation modelling was another potential opportunity. For example, identifying sites of highest priority that may have the greatest positive impact on peatland complexes, tributaries, and connectivity is a big opportunity in the basin. There is potential there to build off the work from a recent WRRP project in the Bow Basin that used ALCES to identify restoration projects of greatest value hydrologically in the Bow Basin. **POTENTIAL ACTION**: Increase reclamation compliance. An opportunity could be to revisit older reclamation plans and match their intent and details with current policy goals and practices.
	2	Restoration requirements e.g., for cut lines	Reduces linear fragmentation causing interruptions in hydrological connectivity.	This is an issue throughout the oil sands area This is relevant to cut lines

Potential Strategies: Lower Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	3	Surface disturbance limits	Reduces linear fragmentation causing interruptions in hydrological connectivity.	This is a “front end” opportunity. Examples include: • Pooling leases • Nodes of disturbance e.g. long distance directional drilling • Common infrastructure e.g. roads • Best Management Practices e.g. for well pads Identify and conserve and restoration areas for source water protection. Maybe work off of pilot in the Bow Basin from the WRRP work on identifying high value restoration and conservation projects. This may be accomplished through a land use plan. Address access management and linear disturbances Access management to help address linear disturbances was another opportunity that was mentioned. This includes planning, minimizing disturbances, minimizing crossings, and mandating “best-practices” in order to have the least impact on hydrology. For example, building access roads in order to optimize reclamation, or proactive designation of trails and recreational areas. Road sharing and decommissioning (e.g., revegetate redundant roads) are needed to reduce linear disturbance and resultant impacts on water flow, infiltration, and quality, particularly in the Swan Hills area. To what % will we limit surface disturbance to?

Potential Strategies: Lower Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	4	Road and seismic line BMPs and monitoring their effectiveness	road and seismic line BMPs and monitoring their effectiveness	
	5	Provide more information on which wetland areas are more sensitive" (or more significant) from a hydrological perspective and an isolated/local/regional scale	Reduce or avoid key hydrology features being intersected by land use features resulting in disrupted hydrology.	Challenge is in defining "key hydrology features". How do you determine which are hydrologically sensitive? Example: wetlands - overall, fens (connected to groundwater) may be more sensitive than bogs (typically the driest), swamps (depressions holding precipitation) and marshes. However, the value of the fen would depend on its class, its rich/poor, its location in the watershed, its connectivity. Which wetlands? Which disturbance features (seismic lines okay, but roads not?). Do we reclaim all of these intersections or a certain proportion of them?
	6	Impose requirements on mining operations to maintain watershed functions target ranges.	Hydrological impacts from mining e.g. channel rerouting and diverting changes stream flow and structure	Example area: Muskeg River Basin where ~30-40% of the land is or has been a mine pit. Reclaimed landscapes have proven difficult to recreate the original peat wetland functions. The Muskeg River Watershed Integrity Management Framework is working to do this. Which mining footprint to reclaim? How much of it? Reclaim it back to what landscape? (i.e. peatlands are hard to recreate)

Potential Strategies: Lower Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	7	Maintain the wetland network in the region to offer key functions associated with fires	Through water quantity, address two main ways that fire impacts water: • Increases runoff • Creates water quality problems	Key wetland functions associated with fires: • Water storage in the basin to keep the system wet • High flow mitigation and buffering post fire • Sinks for water quality contaminants post fire Where do we decrease the wetland (randomly) and by how much %? Which wetlands types to decrease? All?
	8	Fire suppression in hydrologically sensitive areas	Reduce negative impacts of fires on hydrology	Depends on the nature of the fire suppression, e.g., forest clearing to create burn barrier would not be positive. How much % higher? And how much % lower? Will randomly distribute the fires across the landscape.
	9	Don't know yet – needs discussion	Land impact of new reservoirs (area directly flooded)	
	10	Protect specific caribou range areas beyond LARP protection.	Another opportunity that was suggested was protection of specific caribou range areas beyond LARP protection.	Specific examples included areas west of Fort McMurray, east of Athabasca River, Richardson, McClelland/Fort Hills area, and the Lake Athabasca Valley.
	12	Explore different compensation mechanisms other than compensation lakes in the ARB		Examples: a fish hatchery, create a list of hanging culverts and other fish connectivity issues that industry could use these as "low hanging fruit" for fish compensation, create a fund with the money that is traditionally used for compensation lakes and use the money to enhance fisheries or study fisheries and develop a deeper understanding.

Potential Strategies: Lower Basin

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	12	Apply "Room for the River" philosophies and principals in communities within the ARB	There could be an opportunity to apply Room for the River philosophies and principals in communities within the ARB.	For example Fort McMurray could apply these practices to reduce the risk of flood damage, especially with amplified risk from climate change. We could ensure that municipal planning incorporates Room for the River practices.

Gaps in Water Data, Knowledge and Processes

Group	ID	Opportunity	Description / Rationale /Details	Commentary
Gaps in Data and Knowledge	1	Address how to measure, model and manage tributaries without gauge stations		
	2	Understand the linkage between hydrology (soil moisture) and wildfire	There appears to be lower soil moisture lately and there is a need to understand the linkage between this and wildfire occurrence.	
	3	Find a technology for real-time measurement of winter flows	There is a big data gap, therefore big opportunity in the basin to find a technology for real-time measurement of winter flows, typically under ice.	It is crucial to get actual flow data during low flow periods – currently we only have one measurement per month to approximate flows during the winter period.
	4	Improve actual water use data for allocation management	Look at improvements to actual water use and data availability through the water use reporting system.	Better actual water use reporting and data will help in allocation management and understanding that water licence holders may not be using their full allocated amount. If actual water use was known for all users future licensing could be better understood.
	5	Enhance monitoring & data collection of hydrological data in the upper portions of the ARB	It would be beneficial to have more data and monitoring and to have it shared and available to everyone.	*******Need specifics********* Flow (mainstem? Tribs?), temperature, precip, snow (all higher elevations)

Gaps in Water Data, Knowledge and Processes

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	6	Find and include any DFO issued diversion licences	Determine where there are previously existing, but no longer used, DFO diversions from tributaries. Review the licences to know where water could still legally be diverted; this information is stored in a federal database. Compile this information and ensure any active licences are included that aren't in the provincial database.	********Remove if this is confirmed they don't exist***********
	7	Include water incident related reporting and monitoring (industrial incidents) in water data		Currently these don't go into any databases. These reports contain a great deal of data, and are often relevant for longer than just when the incident was reported.
	8	Spill tracking records system and reporting requirements	Spill tracking records system and reporting requirements along with monitoring is needed to inform cumulative effects over time.	Build datasets and trust over time for improved water planning and management.
	9	Map areas of hydrologic sensitivity in the basin that supply water to sub-basins and are locally important to communities.		This is an opportunity to enhance community based monitoring, and to identify water volumes in these systems (data gap) and how they are changing.

Gaps in Water Data, Knowledge and Processes

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	10	Continue to develop indicators that correlate changes in flow and impacts in ecosystems		On the mainstem and tributaries, there is no system in place to measure impacts of changes in flow on the aquatic ecosystem. Identify indicators/thresholds OR take the ones that were fleshed out in the P2FC, and incorporate the instream flow needs (IFN) discussions, and pull these together to measure impacts from surface water quantity to the ecosystem.
	11	Groundwater withdrawal reporting is lacking	There needs to be a system in place for reporting and tracking groundwater withdrawals as they can have effects on surface water.	

Additional Potential Opportunities or Actions

ID	Opportunity	Description / Rationale /Details	Commentary
1	Sub-basin planning for water management	Sub-basin planning is needed to better manage water in the central part of the basin and throughout the watershed.	This would include holistic water management planning and regulation that recognizes water connectivity through small tributaries and wetlands. Water management is needed for lakes as well as rivers. Create implementation plans for holistic water management. This may include managing flow and lake levels (e.g., restrict flows into and out of lakes/reservoirs for water management and instream flow requirements)
2	Recognize and address Infringements on treaty rights: Create trust and path forward through addressing underlying issues.		Dialogue is needed on "where do we go from here?" - needed as a step in the "Roadmap": need a table to address these issues in order to move forward. Opportunity to provide a level playing field and dialogue regarding social license, and treaty rights. This is the difference between making a good water management plan and addressing treaty rights in this context. Need to involve Aboriginal people in getting development done sustainably in the context of treaty rights.
3	Use environmental thresholds for planning rather than commodity production.	There was discussion about looking at the LARP and seeing if there would be a difference in outcomes if environmental thresholds and indicators were applied rather than using commodity production as the primary driving indicator.	

Additional Potential Opportunities or Actions

ID	Opportunity	Description / Rationale /Details	Commentary
4	Consider the water aspects in developing a system of Ecosystem Management that also considers Traditional Knowledge and Use		
5	Better water management information system to support regulatory decision making and policy	There was unanimous agreement concerning the need for a better water management information system to support regulatory decision making and policy setting.	For example, specific lakes may have certain designations that might impacts TDL rulings. Furthermore, it is critical to achieve better real-time flow measurements during low flow winter periods. Finally, install gauge stations on more tributaries, and make the data accessible. Data gaps (accessibility, or lack of data) is a big challenge in the Lac La Biche area.
6	Examine cumulative impacts of actions on water	Hydrological change may bring a stronger need to examine cumulative impacts of actions on water.	Examine the changes to the hydrological regime over the past 100 years and use to predict future changes and their cumulative effects.
7	'Water needs assessment' with First Nations communities	A long-term needs assessment, (e.g., 50-year time frame), to understand future infrastructure needs & plan for water mgmt. during times of drought.	These have been done in Southern Alberta; assessments in the north could follow a similar template. These assessments help to develop a community water profile.
8	Compile and apply the knowledge from TLU and TEK studies	Compile the knowledge from TLU and TEK studies that have been done by industry all along the Athabasca River. Capture the information in a central, publically accessible way for planning and management considerations.	With leadership changes in First Nations communities sometimes the transfer of this knowledge is a challenge. It may be a possibility to look at leveraging the commitment from the Alberta-NWT bilateral agreement on how to do this.

Additional Potential Opportunities or Actions

ID	Opportunity	Description / Rationale /Details	Commentary
9	Perform a community water audit	This could be done using tools for source water protection as previously used with INAC (Indigenous and Northern Affairs Canada). The tools allow for an audit for communities/industry to understand water diversions and uses and how to improve water use (e.g., CEP plans).	Water audit needs to address water use and losses (leaks, etc.), to improve the system. There was a suggestion to expand the audit to consider ecosystem needs as well.
10	Identification of waters of cultural significance not only for water supply but also for navigation and access to traditional lands, as in accordance with treaty rights.		Protection of more waterbodies. Include more waterbodies in Environmental Assessments (EAs) Protected water supplies more probable prior to changes to *Navigable Water Protection Act* in 2012 through omnibus bill. Métis study shows waters no longer protected; these waters should be included again.

Park - Do Not Pursue (from the February 23 version)

Group	ID	Opportunity	Description / Rationale /Details	Commentary
Supply and Demand (SD)	1	Re-naturalize or dredge Buffalo Bay.	C	It was decided not to pursue this opportunity as it was outside the scope of this work; however it was noted that actions upstream to limit or reduce sediment loading would help with this opportunity.
	2	Look at alternatives to dams for electrical generation (e.g. nuclear?).	BW	It was decided not to pursue this opportunity as it was outside the scope of this work.
	3	Account for water collection at local sites in rural areas.	C	It was decided not to pursue this one as the information isn't there to really speak to it, and the scale at which this concern might be happening and where it is happening would not be well represented in the model.
	4	Potential actions to help mitigate the drying of the Peace-Athabasca Delta (PAD).	L	The PAD itself is not within the geographical scope of this project therefore weirs etc. in the PAD are out of scope. Instead, this project should maintain a Performance Measure that reflects the flows delivered from the Athabasca River to the PAD and as strategies are explored upstream, this PM should be checked to ensure flows to the PAD are not unintentionally impacted. In addition, augmenting flows for the PAD could be a driver of operations for upstream infrastructure therefore should be added to the list of potential objectives for upstream reservoirs. PM should be "% change in flow to PAD relative to naturalized"

Park - Do Not Pursue (from the February 23 version)

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	5	Strategic, efficient, and purposeful water allocation	The water licensing system should connect where and how water is used – it is important over the long term to be more strategic, efficient, and purposeful in the allocation and use of water. (BW)	It was decided not to pursue this opportunity as it was outside the scope of this work as this is done through the current allocation system.
	6	Decommissioning old/no longer used basin infrastructure (e.g., dams, culverts, diversions, etc.).	BW	It was decided not to pursue this opportunity as there was not enough larger infrastructure in the basin that isn't being used or could be simulated in AIRM as it was not part of the scope.
	7	Install weirs to raise the lake levels for ecological and traditional uses.	L	It was decided not to pursue this opportunity.
	8	Mitigate ice-jam flooding in Fort McMurray.	L	Instead, this project should maintain a Performance Measure that reflects the flows through Fort McMurray and indicates whether any changes in those flows from upstream strategies may increase the conditions conducive to ice jamming. Need a correlation between flows and ice-jam formation specific for the Fort McMurray location. As far we are aware this does not exist.

Park - Do Not Pursue (from the February 23 version)

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	9	Explore alternate methods of transportation on the river to access traditional fishing and hunting areas.	L	This is now included as an option that is captured under another opportunity (Implement an Aboriginal Base Flow (ABF) or Aboriginal Extreme Flow (AXF)). It should be noted that minimizing disturbance to fish habitat should be a key consideration for looking at alternative transportation vessels and dredging.
	10	Explore temporal changes for withdrawals to limit stress on the aquatic system.	L	At a seasonal scale, this is already in place for new off-stream facilities in the region.
Regulatory (R)	1	Consider how to meet the current Water Management Framework in the Lower Athabasca.	L	The current framework is already being met through the water sharing agreement between oil sands operators. There may be an opportunity to be more transparent on this agreement and how it works; however, it also uses information and data considered sensitive by the participating companies.
	2	Revisit policy around sand and gravel extraction in flood plains.	BW	It was decided not to pursue this opportunity as it was outside the scope of this work.
	3	Enable transfers of old unused licences.	BW	It was decided not to pursue this opportunity as the basin is still open to new licences, and in order to transfer licences you need a water management plan.

Park - Do Not Pursue (from the February 23 version)

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	4	Develop a basin wide water management plan.	BW	It was decided not to pursue this opportunity as this work can't create a water management plan, but it can certainly inform a plan and can be used to help in the creation of one.
	5	Explore creating a threshold for groundwater withdrawals.	BW	There is not a good understanding on what the effect of groundwater withdrawals is on water in the ARB –and the cumulative effects are unknown. The SWQMF has a limit for surface water withdrawals; however, there is no such limit or threshold in place for groundwater, and there isn't a mechanism to cumulatively manage it.
	6	Share datasets.	C	It was decided not to pursue this opportunity as it was discussed that this is outside the scope of this work; however it was noted that this work encourages and supports the sharing of datasets, and that over the course of the Initiative data gaps or access to data issues will be flagged.
Lands and Ecosystem Use (LE)	1	Advance recreational opportunities in the basin.	BW	It was decided not to pursue this opportunity as it was outside the scope of this work.
	2	Identify alternate sources of fish for food supply.	BW	It was decided not to pursue this opportunity as it was outside the scope of this work.

APPENDIX C Modelling components of the AIRM

C.1 RAVEN hydrological model

C.1.1 Data

Daily streamflow data (m^3/s) were obtained for six Water Survey of Canada (2016) hydrometric gauges along the mainstem of the Athabasca River, and 33 major tributaries (Table C-1). Along the Athabasca River mainstem, hydrometric data were available from 1970 to 2014 at Jasper, Hinton, and Fort McMurray; from 1970 to 2013 at Windfall and Athabasca; and from 1971 to 1984 at Embarras, located immediately above the Athabasca River Delta. In addition, stage measurements were available for large lakes: Lesser Slave Lake (07BJ006) from 1979 to 2013 and Lac La Biche (07CA004) from 1970 to 2012.

Table C-1: Water Survey of Canada hydrometric gauges in the Athabasca River Basin.

Model	Station Name	Station Code	Period	Drainage Area (km^2)
Headwaters	Whirlpool River Near The Mouth	07AA009	1966–1996	598
	Miette River Near Jasper*	07AA001	1914–2012	629
	Maligne River Near Jasper	07AA004	1916–1997	908
	Snake Indian River Near The Mouth	07AB002	1971–1993	1,580
	Athabasca River Near Jasper	07AA002	1913–2014	3,873
	Athabasca River At Hinton*	07AD002	1961–2014	9,765
Foothills	Gregg River Near The Mouth	07AF015	1985–2012	384
	Mcleod River Above Embarras River*	07AF002	1954–2013	2,562
	Berland River Near The Mouth*	07AC007	1986–2013	5,655
	Athabasca River Near Windfall	07AE001	1960–2013	19,600
Prairie	Paddle River Near Rochfort Bridge	07BB004	1963–2012	617
	Paddle River At Barrhead	07BB006	1972–2013	2,368

Table C-1: Water Survey of Canada hydrometric gauges in the Athabasca River Basin.

Model	Station Name	Station Code	Period	Drainage Area (km^2)
	Pembina River Near Entwistle*	07BB002	1914–2012	4,402
	Mcleod River Near Rosevear	07AG007	1984–2012	7,143
	Mcleod River Near Whitecourt*	07AG004	1968–2013	9,109
	Pembina River At Jarvie	07BC002	1957–2013	13,104
Lesser Slave	Swan River Near Swan Hills	07BJ003	1970–2014	155
	Driftpile River Near Driftpile	07BH003	1972–1986	835
	Sakwatamau River Near Whitecourt*	07AH003	1972–2013	1,145
	West Prairie River Near High Prairie	07BF002	1921–2012	1,152
	East Prairie River Near Enilda	07BF001	1921–2013	1,467
	Freeman River Near Fort Assiniboine	07AH001	1965–2014	1,662
	Swan River Near Kinuso*	07BJ001	1915–2012	1,900
	Driftwood River Near The Mouth	07BK007	1968–2013	2,100
	South Heart River Near Big Prairie Settlement	07BF905	2005–2012	6,001
	Lesser Slave River At Slave Lake	07BK001	1915–2012	13,567
	Lesser Slave River At Highway No 2A	07BK006	1962–1988	14,400
	Athabasca River At Athabasca	07BE001	1913–2013	74,602
Boreal Plain	Poplar Creek Near Fort McMurray	07DA007	1972–1986	151
	Calumet River Near Fort Mackay	07DA014	1975–1977	183

Table C-1: Water Survey of Canada hydrometric gauges in the Athabasca River Basin.

Model	Station Name	Station Code	Period	Drainage Area (km^2)
	Unnamed Creek Near Fort Mackay	07DA011	1975–1993	274
	Tar River Near Fort Mackay	07DA015	1975–1977	301
	Logan River Near The Mouth	07CA012	1984–2013	425
	House River At Highway No 63	07CB002	1982–2012	781
	Hangingstone River At Fort McMurray*	07CD004	1965–2014	962
	Dover River Near The Mouth	07DB002	1975–1977	963
	Steepbank River Near Fort McMurray	07DA006	1972–2014	1,320
	Muskeg River Near Fort Mackay	07DA008	1974–2014	1,461
	Horse River At Abasands Park	07CC001	1930–1979	2,130
	Ells River Near The Mouth	07DA017	1975–1986	2,450
	Owl River Below Piche River	07CA013	1984–2013	3,078
	La Biche River At Highway No 63	07CA011	1982–1995	4,860
	Christina River Near Chard*	07CE002	1982–2014	4,863
	Mackay River Near Fort Mackay	07DB001	1972–2014	5,569
	Firebag River Near The Mouth*	07DC001	1971–2014	5,988
	Clearwater River Above Christina River	07CD005	1966–2014	17,023
	Clearwater River At Draper	07CD001	1930–2014	30,799
	Athabasca River Below Fort	07DA001	1957–2014	132,588

Table C-1: Water Survey of Canada hydrometric gauges in the Athabasca River Basin.

Model	Station Name	Station Code	Period	Drainage Area (km^2)
	McMurray			
	Athabasca River At Embarras Airport	07DD001	1971–1984	155,000
* Hydrometric gauge used in model calibration				

Daily climate data (maximum, minimum, and mean air temperature, and net precipitation) to drive the hydrologic model were obtained for seven Environment Canada (2016) climate stations: Mica, Cariboo, Jasper, Hinton, Whitecourt, Slave Lake, and Fort McMurray. Data were available from 1970 to 2015 (Table C-2); however, gaps in the datasets necessitated imputation using nearby climate stations. Air temperature data were imputed using linear regression with an adjacent site. Although seasonal regressions were tested, they offered no discernible improvement in fit. Net precipitation data were imputed using precipitation events at an adjacent site, scaled by the relative difference in monthly precipitation totals for overlapping events. Air temperature regressions for all sites exhibited strong fit (r^2 = 0.90–0.98), while relationships for net precipitation were more modest (r^2 = 0.40–0.50).

Table C-2: Observed Environment Canada and synthetic PRISM climate stations used in this study.

Data Source	Name	Longitude	Latitude	Elevation (m)
Environment Canada	Cariboo	-119.47	52.72	1,080
	Hinton	-117.71	53.37	1,010
	Jasper	-118.08	52.88	1,010
	Whitecourt	-115.69	54.14	782
	Slave Lake	-114.77	55.29	582
	Mica	-118.59	52.05	579
PRISM	Azure Lake	-119.00	53.46	2,030
	Columbia Icefield	-117.21	52.22	1,981

Table C-2: Observed Environment Canada and synthetic PRISM climate stations used in this study.

Data Source	Name	Longitude	Latitude	Elevation (m)
	Cadomin	-117.32	53.05	1,511
	Snake Indian Basin	-118.40	53.37	1,400
	Wildhay	-117.56	53.86	1,147
	Roche Miette	-117.98	53.15	1,100
	Embarras	-116.90	53.30	1,060
	Drayton Valley	-114.98	53.22	880
	Fox Creek	-116.81	54.40	831
	House Mountain Heli	-115.52	55.03	830
	Chip Lake	-115.48	53.70	790
	Salteaux	-114.78	54.92	730
	Behan	-111.43	55.28	670
	Conklin Lookout	-111.18	55.62	670
	Peavine	-116.26	55.84	664
	Clyde	-113.64	54.15	650
	East Prairie	-116.15	55.18	650
	Goose Mountain	-116.33	54.74	630
	Triangle	-116.72	55.43	607
	Big Point	-115.39	55.48	582
	Wabasca	-113.83	55.96	579
	Athabasca	-113.29	54.72	563

Table C-2: Observed Environment Canada and synthetic PRISM climate stations used in this study.

Data Source	Name	Longitude	Latitude	Elevation (m)
	Beaver Lake	-111.77	54.68	561
	Pelican Portage	-112.62	55.80	530
	Algar Lake	-112.30	56.32	527
	Anzac	-111.04	56.45	500
	Fort McMurray	-111.38	56.73	369
	Horizons	-111.90	57.35	350
	Cascade Rapids	-110.28	56.70	270

To more fully represent the spatial variability in air temperature and precipitation within the watershed, 35 synthetic weather stations within the basin were generated (Table C-2). Daily climate data for all sites were found using monthly PRISM normals from 1961 to 1990 (Daly, 2002a; Daly, 2002b). Scaling factors were derived by comparing monthly climate variables for all synthetic sites against PRISM normals from the closest observed climate station. Scaling factors for temperature were calculated as the absolute difference, while factors for precipitation were calculated as the percent difference. Monthly scaling factors were interpolated to a daily resolution using a cubic spline in R (R Core Team, 2015), and synthetic daily climate data were generated by correcting observed climate data from the closest station with daily scaling factors.

Additional Environment Canada (2016) climate stations were used as independent means of verifying temperature and precipitation lapse rates and interpolation routines. As such, these sites were excluded from data imputation routines. These stations (Table C-2) span from 1970 to 2015 and cover a range in elevation and spatial variability, from the high alpine to low boreal regions. Modelled meteorology was also verified using automated British Columbia Ministry of Environment (2016) and Government of Alberta (2016) snow pillow and snow course data from several sites.

C.1.2 Model methods

Daily streamflow in the Athabasca River Basin (ARB) watershed was modelled using semi–distributed hydrological model RAVEN with modifications to a “level 1 (near–perfect) emulation" (Craig et al., 2016) of the HBV–EC hydrologic model to account for varied hydrologic processes across the ARB. The HBV-EC model is a Canadian version of the original Scandinavian watershed model (Bergström, 1992; Canadian Hydraulics Centre, 2010) and has been used extensively to model mountain streamflow in British Columbia and Alberta (e.g., Stahl et al., 2008; Jost et al., 2012; Mahat and Anderson, 2013). The model’s algorithms use a combination of empirical and physically based parameterizations; major processes are described in Section C.1.2.2, and all model algorithms are described in further detail in Stahl et al. (2008) and Canadian Hydraulics Centre (2010).

To account for the substantial range of landscapes within the ARB, the watershed was split into five individual sub-models, approximating the natural regions present in the watershed: Headwaters, Foothills, Prairie, Lesser Slave, and Boreal Plain. Each model was driven by a universal set of weather sites, and differences were due to different parameter sets and hydrologic processes. The models are connected by a series of inflows, which deliver streamflow from the outlet of the upstream model to the furthest upstream sub-basin in the subsequent model.

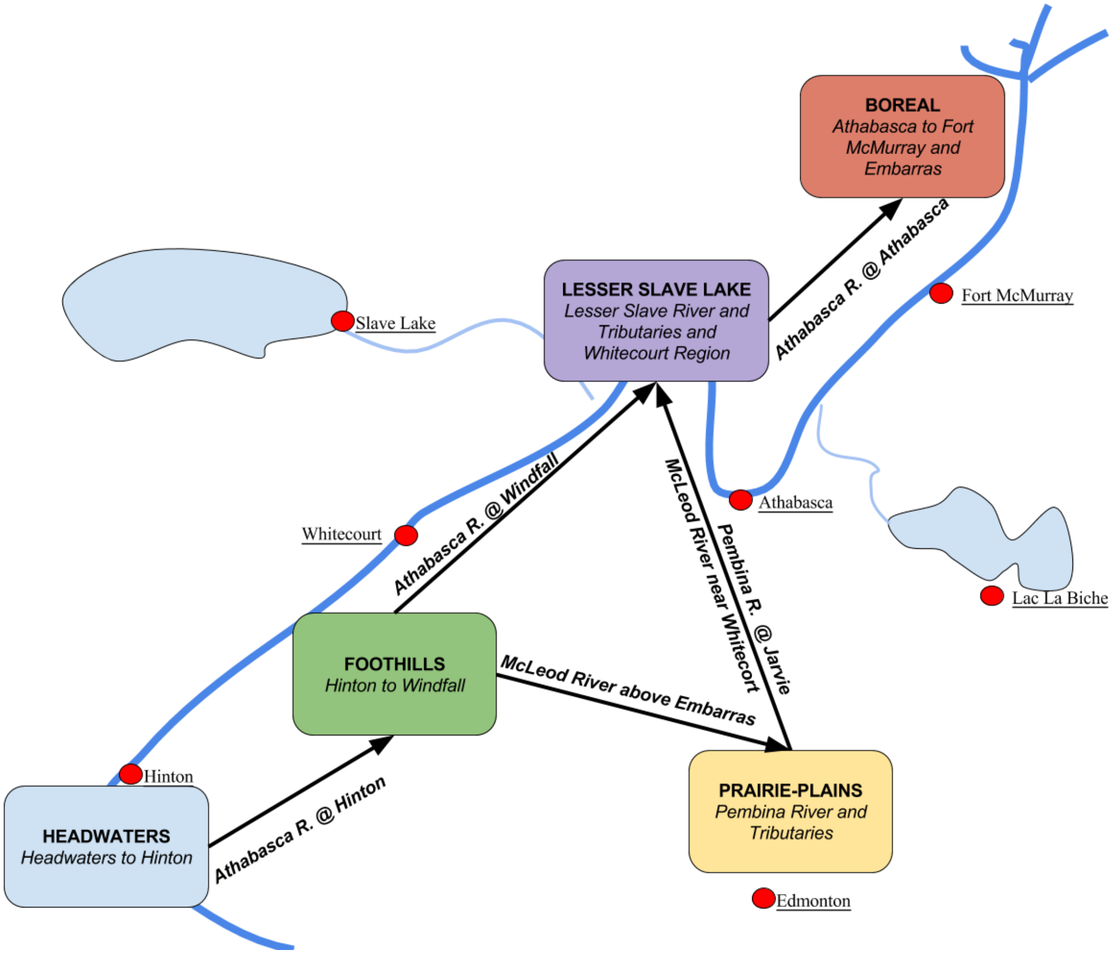


Figure C-1: Schematic showing the connection between sub-models used to simulate the ARB.

C.1.2.1 Hydrologic Response Units

Areas of similar character and location were lumped together into Hydrologic Response Units (HRUs) (e.g., Stahl et al., 2008; Jost et al., 2012): areas assumed to have a uniform hydrologic response to meteorological inputs. This method of spatial aggregation reduces computational cost without a reduction in modelled watershed complexity relative to fully distributed (gridded) methods. HRUs are delineated by first delineating each sub-basin into 100 m elevation bands, four aspect classes, three slope classes, and nine land use types (Coniferous Forest, Deciduous Forest, Cut Forest, Grassland, Wetland, Mine, Disturbed [Urban], Alpine, and Glacier). Within each sub-basin, the proportion of each combination of land use, elevation band, aspect, and slope was calculated to form a unique HRU. In total, the basin was divided into 29,788 HRUs, and 18,234 were located in the Headwaters model.

For model input, the area, elevation, land use class, vegetation class, soil profile, slope, and aspect were obtained for each HRU. Elevation, slope, and aspect were obtained from the mean value in each HRU, and land use was obtained from the mode. The vegetation and soil classes for each HRU were tied to each land use type.

C.1.2.2 Model processes

The model is driven by daily air temperature (minimum, maximum, and average) and net precipitation, which were spatially distributed across the catchment using inverse-distance weighting. Initially, water delivered as precipitation is routed through the forest canopy. Precipitation that is not intercepted within the forest canopy reaches the surface as rain or snow. Snowmelt was calculated using a spatially corrected temperature index model (Hock, 2003; Jost et al., 2012). Glacier melt is simulated using a degree day approach (Craig et al., 2016).

Rain and snowmelt are routed into the soil as infiltration, or evaporate. Once water enters the three-layer soil, it moves downwards through percolation and upwards by capillary rise. Soil water returns to the surface from the middle soil layer through a faster two-parameter power-law baseflow response, whereas a slower response in the deepest soil layer was simulated using the Variable Infiltration Capacity (VIC) routine (Clark et al., 2008).

Routing between sub-basins was calculated as a diffusive wave, where the flood wave propagates through the reach. The mean travel time of the wave signal is controlled by the channel length, as well as the mean channel slope, bed geometry, and Manning’s *n* of each sub-basin (Craig et al., 2016). The mean channel length, slope, and width were measured for each sub-basin, and sub-basins were grouped into thematic groups with similar channel geometries, slope, and Manning’s *n*. Given that HRUs are treated as non-contiguous in RAVEN, routing between HRUs within a sub-basin is not considered, and water released from HRUs is received at the sub-basin outlet following a delay defined by a triangular unit hydrograph (Craig et al., 2016). Further work is ongoing with respect to HRU-scale routing within RAVEN.

C.1.3 Model calibration and verification

To fit simulated streamflow to observed values, the parameters in each of the five hydrological models were individually calibrated. Parameter calibration was achieved by first identifying sensitive parameters and then grouping and calibrating process-related parameters in a step-like fashion, broadly following Stahl et al. (2008); the overarching method is outlined in Table C-3. Initial parameter sets were input as a guided “first estimate" and manually adjusted to roughly emulate the shape and structure of the annual hydrograph. The complete sets of parameters were then calibrated using the Levenberg-Marquardt algorithm (200 iterations) and a relatively broad range of parameter values. The sensitivity of each parameter was determined within OSTRICH using composite scaled sensitivities (*CCS*) (Matott, 2005; Hill, 2000), and insensitive parameters (*CSS* ≈ 0) were excluded from further calibration steps.

Table C-3: Framework for parameter calibration, where the subscript *Q* represents daily streamflow and *MAF* designates mean annual flow.

Guiding Principle		Parameters	Criteria/Objective
1)	Isolate and exclude insensitive parameters	All	$CSS \approx 0$ ("not calculated")
2)	Ensure correct volume of water in catchment	T, P lapse rates, Interception, glacier melt	minimize $PBIAS_Q$, maximize E_{MAF}
3)	Ensure correct freshet timing	T lapse rate, melt factors	maximize E_Q, ensure SWE timing
4)	Calibrate routing, sensitivity, and baseflow	Soil routing parameters	maximize E_Q
5)	Approximate parameter uncertainty	All	Obtain parameter *SE*

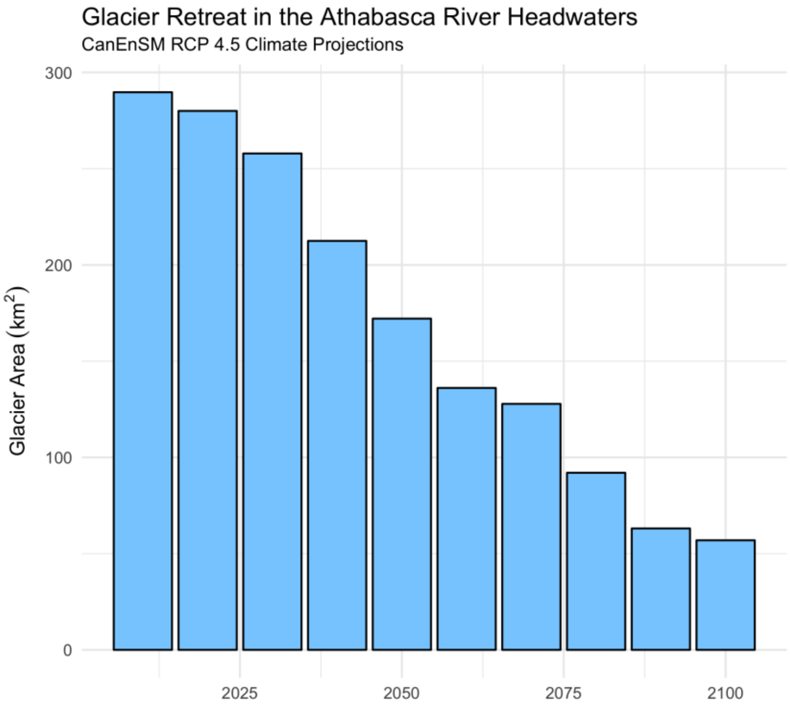
Calibration for sensitive parameters was executed in process-based groups using the DDS algorithm. First, the simulated annual water yield in the catchment was corrected to mean annual flow (MAF) by calibrating water balance parameters such as the precipitation and air temperature lapse rates, canopy interception, and glacier melt (only in the Headwaters model). Second, freshet timing was calibrated to daily streamflow by calibrating the air temperature lapse rate and melt parameters for each land use type. In addition, the melt timing and peak snow water equivalent (SWE) values were compared to independent SWE observations, while an additional qualitative inspection was carried out over a range of HRUs (selected to span elevations and aspects) to ensure realistic accumulation and disappearance dates. Finally, water routing and streamflow responsiveness was calibrated using routing parameters. Steps 2 through 4 were repeated as necessary until satisfactory model performance was met.

Once an adequate model solution was found, a final refinement calibration run was implemented for all sensitive parameters using the Levenberg-Marquardt algorithm in order to derive uncertainty statistics such as the standard error. Model fit was evaluated during calibration runs using the Nash-Sutcliffe Efficiency (*E*) (Nash and Sutcliffe, 1970) as the objective function, and the (absolute) percent bias (*PBIAS*) was also evaluated.

For each model, parameter calibration was evaluated using two hydrometric gauges with good long-term records and available data from 2003 to 2013 (see Table C-4). Once calibration steps were complete, performance was evaluated for each model using available streamflow measurements for gauges not used in calibration, and for all available gauges from 1986 to 2003 (i.e., outside the calibration period). Model verification was supplemented by comparing simulated SWE, monthly precipitation, and daily air temperatures to independent climate stations and snow survey sites.

C.1.4 Climate change scenarios in AIRM

To account for the effect of climate change on simulated streamflow, the calibrated models were re-run for a 30-year period under two climate scenarios. In the first scenario, the CRCM4 climate change model was implemented. Gridded historical data were bias-corrected using Empirical Quartile Weighting: each climate station used in the ARB models was compared with the nearest grid cell. Bias-corrected precipitation and air temperature data were derived for each climate station for a daily 30-year period. In addition, glacier retreat was accounted for by dynamically changing glacier HRUs to alpine within the Headwaters model at a decadal time step. Future glacier coverage data were obtained from Clarke et al. (2015) (see Figure C-2).



Data are obtained from Clarke, G. K., Jarosch, A. H., Anslow, F. S., Radić, V., & Menounos, B. (2015). Projected deglaciation of western Canada in the twenty-first century. Nature Geoscience, 8(5), 372-377.

Figure C-2: Change in glacier area within the ARB from 2005 to 2100 using CanEnSM RCP 4.5 climate change projection.

In the second climate change scenario, a historical period was spliced together to simulate the effects of a long-term, severe drought. Individual years where low mean annual streamflow had been observed (2000, 2002, 2003, 2006, and 2009) were spliced into the 1970–2015 record, replacing high-flow years from 1980–1986 and 2001–2003.

C.2 Results

C.2.1 Model performance

Model performance was highest in the Headwaters model, and along the mainstem of the Athabasca River. Generally, performance was good to excellent in upstream regions (monthly NSE of >0.93 in the Headwaters and 0.77–0.94 in the Foothills). Performance was more varied further downstream; some sub-basins had good performance (monthly NSE = 0.70–0.80), but others had only satisfactory or marginal performance (monthly NSE = 0.40–0.60). In many cases, sites with the lowest monthly NSE values were regions that are heavily influenced by industrial activity or are small areas (<100 km^2).

Table C-4: Model performance statistics for calibration (2003–2013) and verification (1986–2002) periods, where *NSE* is the monthly Nash-Sutcliffe Efficiency and *PBIAS* is the percent bias.

Model	Site	Calibration		Verification	
		NSE	*PBIAS*	*NSE*	*PBIAS*
Headwaters	Athabasca River At Hinton	0.97	-7%	0.95	4%
	Athabasca River Near Jasper	0.95	-13%	0.98	-6%
	Miette River Near Jasper	0.93	-1%	0.95	5%
	Whirlpool River Near The Mouth	–	–	0.76	-22%
Foothills	Athabasca River Near Windfall	0.94	-3%	0.92	8%
	Berland River Near The Mouth	0.77	2%	0.75	17%
	Gregg River Near The Mouth	0.81	-5%	0.64	1%
	Mcleod River Above Embarras River	0.80	2%	0.68	11%
Prairie	Mcleod River Near Rosevear	0.81	11%	0.73	10%
	Mcleod River Near Whitecourt	0.78	3%	0.69	9%

Table C-4: Model performance statistics for calibration (2003–2013) and verification (1986–2002) periods, where *NSE* is the monthly Nash-Sutcliffe Efficiency and *PBIAS* is the percent bias.

Model	Site	Calibration		Verification	
		NSE	*PBIAS*	*NSE*	*PBIAS*
	Pembina River Near Entwistle	0.75	9%	0.67	10%
Lesser Slave	Athabasca River At Athabasca*	0.82	23%	0.80	27%
	Driftwood River Near The Mouth	0.63	36%	0.39	21%
	East Prairie River Near Enilda	0.72	-1%	0.49	8%
	Freeman River Near Fort Assiniboine	0.82	22%	0.54	26%
	Sakwatamau River Near Whitecourt	0.78	20%	0.59	33%
	Swan River Near Kinuso	0.73	-6%	0.63	7%
	West Prairie River Near High Prairie	0.57	44%	0.40	50%
Boreal Plain	Athabasca River Below Fort McMurray*	0.74	28%	0.61	33%
	Christina River Near Chard	0.59	6%	–	–
	Clearwater River At Draper	0.70	-3%	–	–
	Firebag River Near The Mouth	0.65	-6%	0.32	17%
	Hangingstone River At Fort McMurray	0.59	6%	0.42	34%
	House River At Highway No 63	0.54	-1%	0.32	26%

Simulated SWE, net monthly precipitation, and mean daily temperatures showed good fit with observed records in the basin (Table C-5). In general, air temperatures were well reproduced, with correlation coefficients (r^2) over 0.86, and with values consistently over 0.90 in flat, low-elevation sites. Net precipitation and SWE were well reproduced, with better performance outside the mountains, likely due to less topographic complexity.

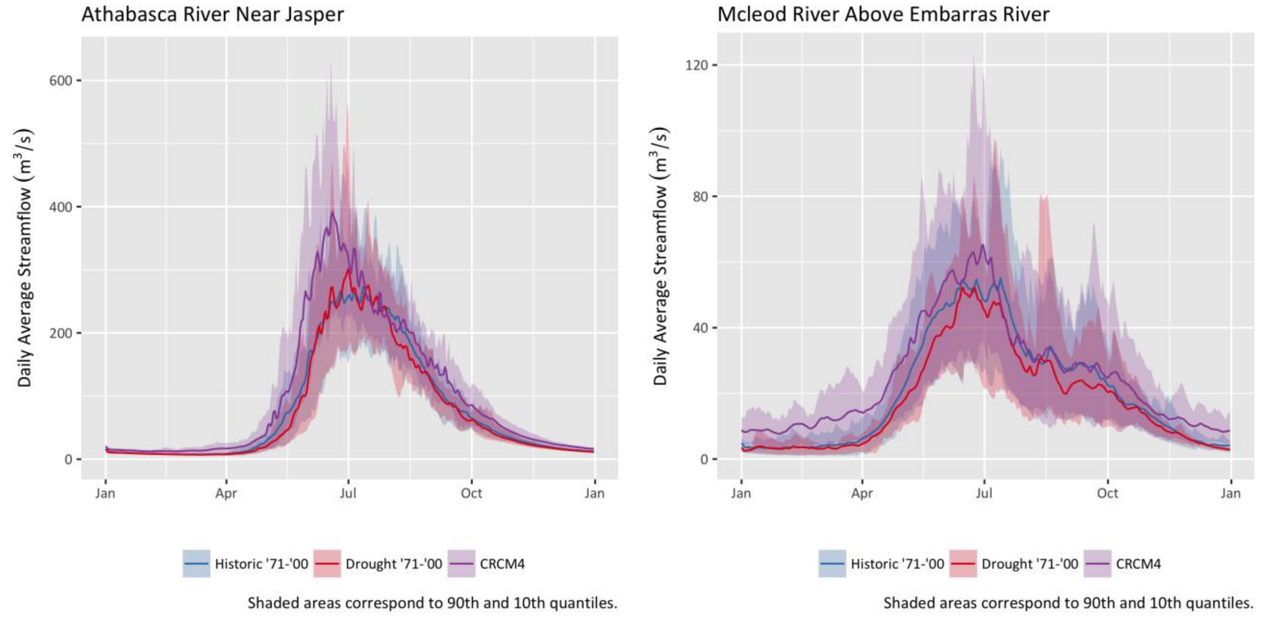
Table C-5: Performance statistics for simulated meteorological variables air temperature (T), net monthly precipitation (P), and snow water equivalent (SWE).

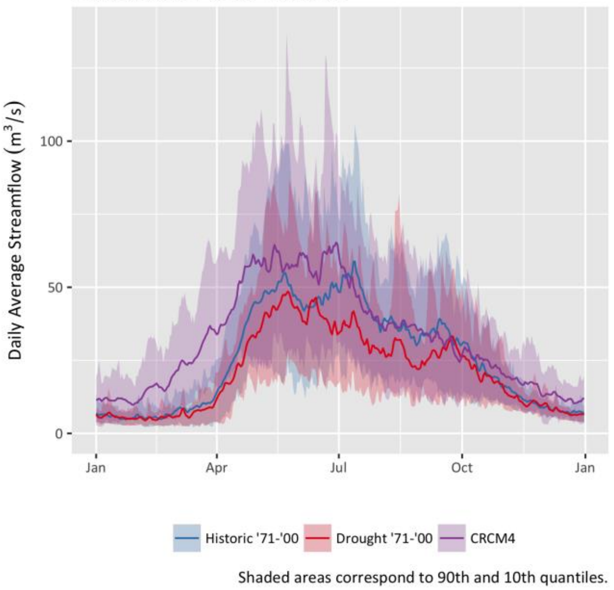
Site	Network	Latitude	Longitude	Elevation (m)	r^2		
					T	*P*	*SWE*
Sunwapta	EC, ABGov	52.54	-117.65	1,416	0.87	0.10	0.63
Columbia Icefield	EC, ABGov	52.23	-117.17	1,982	-	-	-
Edson	EC, ABGov	53.58	-116.21	900	0.98	0.76	0.78
Twin Lakes	ABGov	54.06	-114.79	655	-	-	0.78
Barrhead CS	EC	55.13	-114.19	589	0.97	0.64	-
High Prairie	EC, ABGov	55.40	-116.45	595	0.97	0.64	0.75
Swan Dive Lookout	EC, AgriAB	54.73	-115.22	1,036	0.92	0.67	0.68
Gordon Lake Lookout	EC, AgriAB	56.62	-110.48	514	0.92	0.82	0.83
Ells Lookout	EC	57.18	-112.33	573	0.89	0.45	-
Livock Lookout	EC, AgriAB	56.47	-113.18	579	0.86	0.69	0.83

C.2.2 Climate change scenarios in the AIRM

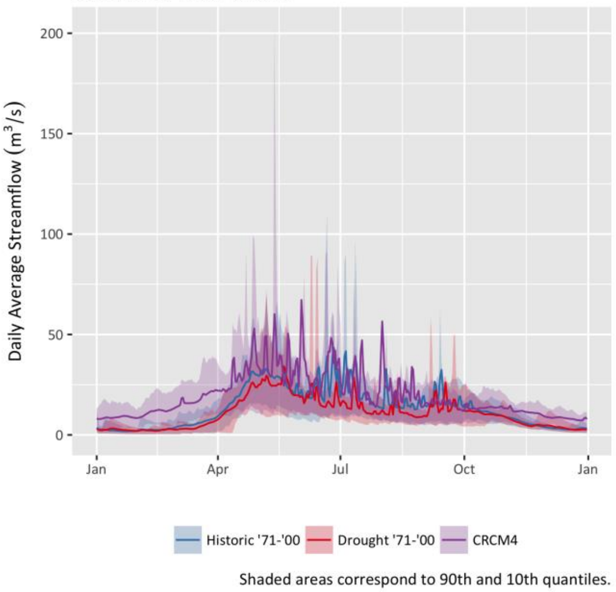
Climate change scenarios showed significant changes in streamflow regimes, though the magnitude and direction of these changes varied by each model (Figure C-3). In the Headwaters model, Athabasca River Near Jasper showed increased July flow under the drought scenario, and marginally lower flows during the late summer relative to the historical period. This was likely due to enhanced glacier melt (due to a lower snowpack and earlier ice exposure). Under the CRCM4 climate change scenario, freshet occurred earlier in the year and was substantially higher than the historical period. Conversely, no meaningful change in late summer or fall streamflow was observed. An earlier and larger freshet was due to higher air temperatures leading to earlier melt, and a substantially larger snowpack was due to increased winter precipitation.

Streamflow in the Foothills model (McLeod River Above Embarras River) showed a marked decrease in summer and fall flow under the drought scenario, whereas winter flows remained unchanged. Conversely, under the CRCM4 climate change scenario, streamflow was significantly elevated during the winter season, likely due to periodic winter snowmelt events and possible rain events, both driven by increased air temperatures. Similar to the Headwaters model, spring freshet occurred earlier, and was more severe under the future climate scenario, due to earlier snowmelt and greater winter snowpack.

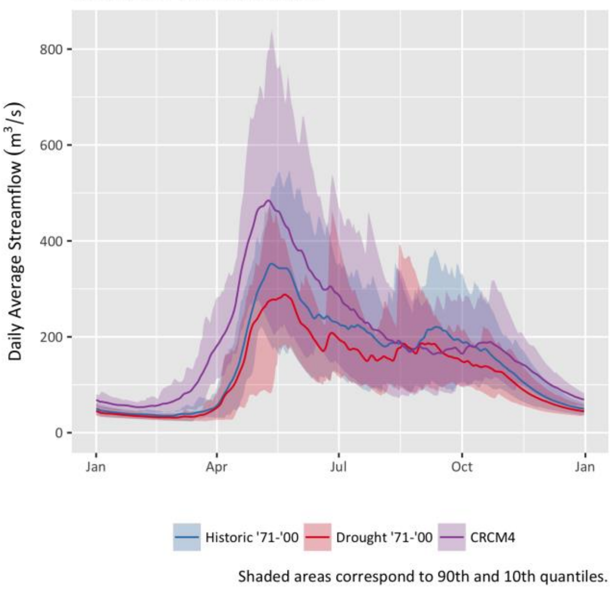



Pembina River Near Entwistle

Shaded areas correspond to 90th and 10th quantiles.


Swan River Near Kinuso

Shaded areas correspond to 90th and 10th quantiles.


Clearwater River At Draper

Shaded areas correspond to 90th and 10th quantiles.

Figure C-3: Average daily hydrographs for five Athabasca River sub-basins, one from each model, under the historical 1970–2000 period, drought scenario, and CRCM4 climate change scenario.

The streamflow response in the Prairie model (Pembina River Near Entwistle) to climate scenarios was similar to the Foothills. The future climate scenario led to a significantly larger and earlier freshet, and winter flows were also substantially elevated. The drought scenario resulted in a decreased, and marginally later, freshet. Notably, the decrease in the streamflow for the drought scenario was substantially greater than observed in the Foothills or Headwaters models, suggesting that the region is particularly prone to water deficits during dry years.

The streamflow response in the Lesser Slave model (Swan River Near Kinuso) broadly followed the trends in the Foothills and Prairie models. Under the drought scenario, summer streamflow showed a modest decrease, particularly during the late summer, due to the lack of larger summer storms providing a flashy streamflow response. The streamflow response to the future climate scenario CRCM4 was more pronounced. Flow remained elevated throughout the entire winter period, suggesting periodic mid-winter snowmelt events. In addition, freshet was much less pronounced, with only a modest spike during April, suggesting that the winter snowpack was less pronounced, and therefore snowmelt had a smaller impact on spring water timing. Most notably, streamflow was significantly more variable under the CRCM4 scenario and was punctuated by large singular events throughout the summer months. This suggests that streamflow in the region was driven by large precipitation events (likely summer convective storms), which are projected to be more severe under this climate scenario, in turn presenting a potentially increased risk of stochastic high flows and flooding.

In the Boreal model (Clearwater River At Draper), streamflow followed a strong annual trend, where streamflow was low (or dry in some smaller sub-basins) throughout the winter months, peaked sharply during spring runoff, and tapered off gradually throughout the summer. Under the drought scenario, this timing was not disrupted, though peak flow was reduced by approximately 20% on average. This decrease persisted throughout the summer months, while there was a modest decrease in winter streamflow. Conversely, the CRCM4 climate change scenario exhibited large increases in peak flow (~30%) and higher winter flows. Though the timing of spring freshet did not change, flow increased earlier in the spring. Because of the cold air temperatures in this region, it is likely that increased winter air temperatures did not meaningfully alter the rain-snow precipitation state throughout the winter months, though it may have had a more pronounced effect during the spring snowmelt period. In addition, increased winter precipitation led to a large increase in snowpack, which melted rapidly during the long late-spring days. The lack of variability in late-summer streamflow is likely a reflection of the relatively arid conditions in the region and lack of widespread large convective storms under these climate scenarios.

C.3 River system modelling

The river system model component of the AIRM is a water balance model that functions on a daily time step. It is operating-rule driven and can be used to test different water management scenarios at a screening level. It is built to be an interactive model and allows for stakeholder-driven development of alternatives. The following section describes the methods used to build this component of the AIRM.

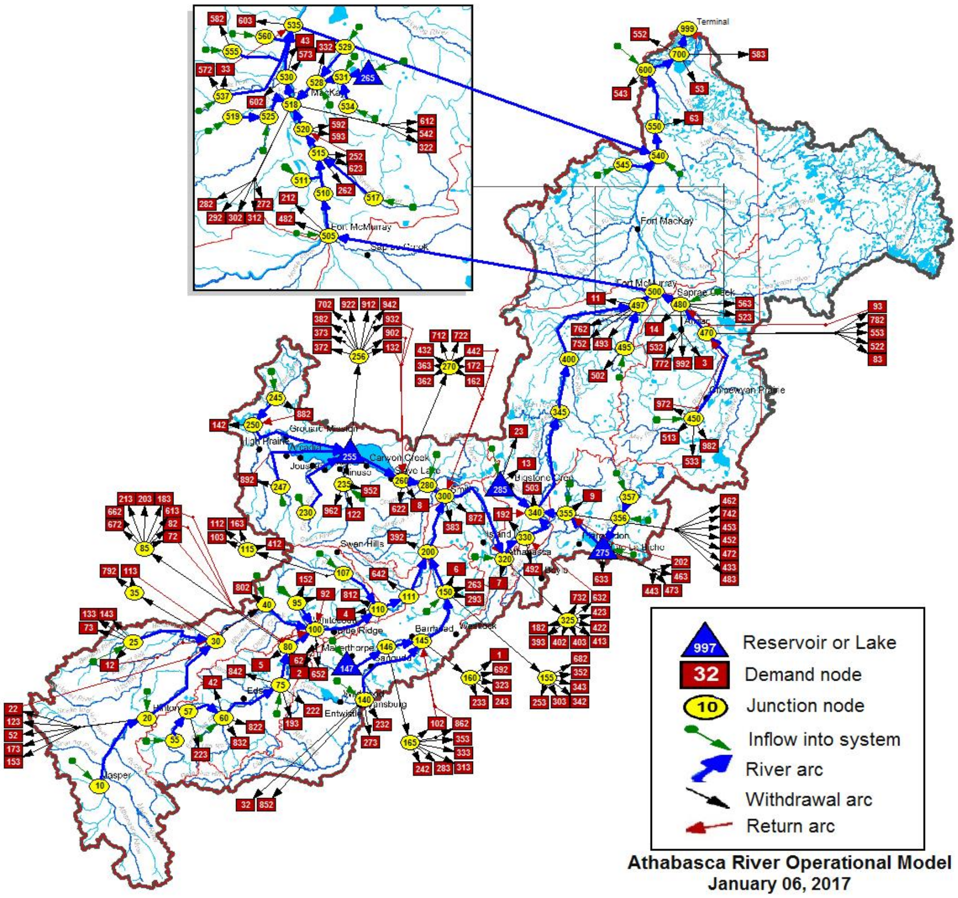


Figure C-4: The river system model schematic.

C.3.1 Data

Water licence data were obtained from the Alberta Environment and Parks (AEP) Water Licence Database and were filtered for licences within the ARB. Further filtering for surface water licences and for currently active or renewable licences, there were a total of 1,045 eligible licences in the basin (Table C-6). These licences were then grouped into demand nodes in the model rather than being explicitly modelled individually. Additional data on licence volume, location, owner, and type were accounted for when grouping licences into different demand nodes.

C.3.2 Grouping demands

A first pass at dividing up the licences into different demand nodes involved splitting based on volume. All licences above 1 million cubic meters (m^3) were termed "high volume" licences and were further grouped by their approval holder and their geographic location. For example, if there were two licences that were both above 1 million m^3, both owned by the same company, and both drawing from the Athabasca River downstream of the confluence with the Muskeg River, those two licences would be grouped into one single demand node in the model. Indigenous community licences are counted in part of the high volume licences.

All other remaining licences (under 1 million m^3) were termed "low volume" licences and were grouped by their industry type and their location. For example, if there were two licences that were both under 1 million m^3, both of "municipal" type, and both drawing from the Paddle River, they would be grouped into one single demand node in the model. Municipal, environmental, commercial and industrial, agricultural and irrigation make up the low volume licences.

Finally, all temporary diversion licences (TDLs) were grouped by industry type and geographic location, similar to the low volume licences above. The high volume, low volume, and TDLs comprise all of the surface water licences in the ARB that are consumptive.

Table C-6: Grouping of licences in the model.

Type	Number of Licences	Volume (m^3)	% by Volume
High volume	60	**800,692,016**	**96**
• First Nations	8	838,000	
Low volume	651	**32,116,155**	**3.8**
• Municipal	51	9,017,936	
• Environmental management	64	9,090,616	
• Commercial and industrial	303	10,477,726	
• Agricultural and irrigation	233	3,529,876	
TDLs	334	**1,537,547**	**0.2**
TOTAL	1,045	**834,345,718**	

C.3.3 Assigning priority

It is necessary to assign priority to the demand nodes in order to tell the model which demand node gets water first in the case of a drought or water shortage. In the case where the system runs out of water and there is not enough for all demands, the model will not give any water to the demand nodes that have the lowest priority.

For the "high volume" demand nodes, First Nations demands were given highest priority. The remaining "high volume" demand nodes were then assigned priority based on the oldest licence date within each node, where older dates are given higher priority over more juvenile ones. For demand nodes that have most of their water drawn from a more juvenile licence, that more juvenile date is used instead.

Priority was then assigned to the remaining "low volume" licences based purely on licence type and not date. Priority was based on the following sequence: municipal demand nodes > environmental management demand nodes (i.e., management of fish, management of wildlife, habitat enhancement, and water management) > commercial and industrial demand nodes > agriculture and irrigation demand nodes.

Finally, all TDL demand nodes were assigned the lowest priority in the model.

C.3.4 Creating patterns

Although it is not necessary, assigning monthly patterns to different demand nodes and return flows can help the model perform more accurately. Patterns help inform the model of any seasonal changes in demands and/or return flows. For example, a demand node might withdraw all of its yearly licence volume within a three-month period over the spring and withdraw nothing for the remainder of the year. If a pattern is not specified in this case, the model will assume a stable withdrawal rate for the entire year.

Data were acquired and processed for two different scenarios to simulate. One scenario runs off actual reported usage data and reflects the most up-to-date and accurate version of the system, whereas the other scenario runs off allocated volumes and therefore reflects the system at a more stressed state in which all licences are using their maximum allowable volume every year.

C.3.4.1 Actual use demand patterns

To create a demand pattern that reflects the actual withdrawal rates for each licence, reported water usage data were retrieved from the AEP Water Licence Database. The most recent five years of data were extracted for each licence, and usage data were scaled down to cubic meters per second (cms). The mean usage for each month for each licence was calculated, and then these mean values were summed by their corresponding demand node numbers in the model to get a monthly pattern of actual mean usage for each demand node in the model.

C.3.4.2 Allocation demand patterns

To create the full allocation demand patterns, the volume for each licence was scaled down to cms and then summed by demand node number in the model to get an average annual rate of allocated withdrawal in cms for each demand node. The actual use pattern was then scaled in proportion to the average annual withdrawal rate to get a pattern that reflected the monthly actual usage but still simulated the full allocation volume for the year.

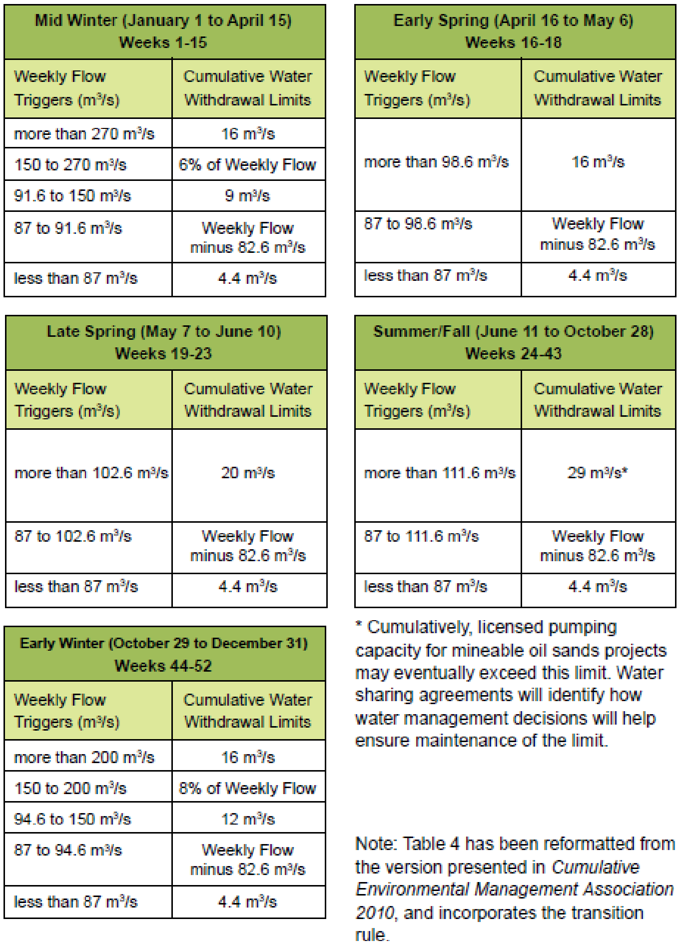
C.3.4.3 Return flow patterns (actual use vs. allocation)

Some licences are obliged to return a specific amount of water to the system after they have withdrawn it for their licensed purposes. It is therefore important to specify patterns for return flows as well. The same process was followed as above for establishing these patterns. Actual return data were used to derive a monthly actual return pattern, which was then used in conjunction with allocated returns to derive an allocated return pattern. These patterns were also expressed as a proportion of the demand in the model so that if the demand was to increase or decrease for whatever reason, the return would adjust proportionally.

C.3.5 Operating rules

C.3.5.1 Minimum flows

Certain minimum flows have been incorporated into the model as simple operating rules. One of these is a minimum flow of 6 cms on Lesser Slave River. Another more complex operating rule is the incorporation of the Surface Water Quantity Management Framework (SWQMF) rules into the model. The SWQMF specifies different limits to cumulative oil sands withdrawal based on time of year and flow in the Athabasca at Fort McMurray (Figure C-5). These limits have been incorporated into the model.



Mid Winter (January 1 to April 15) Weeks 1-15	
Weekly Flow Triggers (m^3/s)	Cumulative Water Withdrawal Limits
more than 270 m^3/s	16 m^3/s
150 to 270 m^3/s	6% of Weekly Flow
91.6 to 150 m^3/s	9 m^3/s
87 to 91.6 m^3/s	Weekly Flow minus 82.6 m^3/s
less than 87 m^3/s	4.4 m^3/s

Early Spring (April 16 to May 6) Weeks 16-18	
Weekly Flow Triggers (m^3/s)	Cumulative Water Withdrawal Limits
more than 98.6 m^3/s	16 m^3/s
87 to 98.6 m^3/s	Weekly Flow minus 82.6 m^3/s
less than 87 m^3/s	4.4 m^3/s

Late Spring (May 7 to June 10) Weeks 19-23	
Weekly Flow Triggers (m^3/s)	Cumulative Water Withdrawal Limits
more than 102.6 m^3/s	20 m^3/s
87 to 102.6 m^3/s	Weekly Flow minus 82.6 m^3/s
less than 87 m^3/s	4.4 m^3/s

Summer/Fall (June 11 to October 28) Weeks 24-43	
Weekly Flow Triggers (m^3/s)	Cumulative Water Withdrawal Limits
more than 111.6 m^3/s	29 m^3/s*
87 to 111.6 m^3/s	Weekly Flow minus 82.6 m^3/s
less than 87 m^3/s	4.4 m^3/s

Early Winter (October 29 to December 31) Weeks 44-52	
Weekly Flow Triggers (m^3/s)	Cumulative Water Withdrawal Limits
more than 200 m^3/s	16 m^3/s
150 to 200 m^3/s	8% of Weekly Flow
94.6 to 150 m^3/s	12 m^3/s
87 to 94.6 m^3/s	Weekly Flow minus 82.6 m^3/s
less than 87 m^3/s	4.4 m^3/s

* Cumulatively, licensed pumping capacity for mineable oil sands projects may eventually exceed this limit. Water sharing agreements will identify how water management decisions will help ensure maintenance of the limit.

Note: Table 4 has been reformatted from the version presented in *Cumulative Environmental Management Association 2010*, and incorporates the transition rule.

Figure C-5: Surface Water Quantity Management Framework cumulative oil sands withdrawal limits.

C.3.5.2 Reservoirs

Simple operating rules have been incorporated for the Paddle River Dam based on guidance from AEP hydrologists and reservoir operators. The two larger systems, Lac La Biche and Lesser Slave Lake, were also included.

C.3.6 Scenario development

In consulting with the Working Group, certain water management scenarios were identified for further investigation in the model. These scenarios involved adding on-stream storage infrastructure, scaling up specific demands, and implementing minimum flows in specific locations. All these scenarios have been built in the model and simulated in the model. Some require simple changes, such as changing existing scaling factors, whereas others require more in-depth adjustments, such as coding for minimum flows in conjunction with adding on-stream storage.

C.4 Land use modelling

C.4.1 Data

ALCES Online uses unity indicators, which are a collection of non-overlapping land use classes assigned to the entire surface of a study area. Any given point on the surface of the study area is assigned one class only. The unity dataset for ARB was built by combining portions of two provincial unity datasets: Alberta and Saskatchewan. Data sources varied between the two provincial datasets, but the general approach was the same.

Data were generalized into two categories: landscape types (natural states) and footprint types (human-caused states). Data quality, completeness, and age were considered in selecting the best compromise between time allotted and final data robustness. Desired land use categories were identified, and the data sources were prepared.

Land use features were broadly organized into "assemblies" as follows:

Landscape Assemblies:

- Land cover
- Water
- Wetlands
- Agriculture

Footprint Assemblies:

- Roads
- Pipelines
- Transmission lines
- Seismic lines
- Wellsites
- Feedlots
- Rail
- Mines
- Airports
- Recreation
- Residential/urban areas
- Industry and other polygonal footprints
- Edmonton and Calgary detailed urban land use polygons

Within each assembly, a hierarchy was assigned for precedence setting where features overlap. Often, assemblies were constructed from individual spatial features taken from multiple sources. Individual sources were organized in a hierarchy so as to select the most accurate and most current spatial data. In general:

- Newer sources were selected over older sources.
- Photo-interpreted sources were selected over satellite classification.
- Agriculture and Agri-Food Canada (AAFC) agriculture satellite classification was chosen over EOSD (Earth Observation for Sustainable Development of Forests) and LCC2000.
- Specific-built spatial products were chosen over generalized spatial categories. For example, the Edmonton land use product supersedes EOSD Urban and Developed.
- Land cover data gaps (e.g., due to cloud and shadow) were filled with alternate EOSD satellite categories or were filled with closest neighbour categories.

Each assembly was built by starting with the most general source and then systematically “stamping” the next hierarchy priority source on top. The end result was an assembly layer with no overlap and priorities assigned.

C.4.1.1 Alberta data sources

Land Cover

The default source for land cover was the Alberta Biodiversity Monitoring Institute (ABMI) 2010 Land Cover layer. Developed and Exposed Land categories were erased and filled with closest neighbours along areas known to be roads to prevent overestimation of the footprint.

The ABMI product did not contain wetlands, so the Alberta Merged Wetland Inventory was used. In areas where the wetlands inventory was absent (i.e., national parks), EOSD Land Cover tiles were used to define wetlands. In areas covered by the Grassland Vegetation Inventory (GVI), detailed wetlands and land cover categories superseded ABMI. Areas dominated with agriculture used the AAFC Crop Inventory 2014 product for land cover classification (AAFC is a refinement of the source data used to build the ABMI layer and adds finer detail in agricultural areas).

Water

The Alberta provincial base layers were used to define water features. Lakes, glaciers, and large polygonal rivers were derived from AltaLIS BF-Hydro Polygon. Smaller, linear water features were derived from AltaLIS BF-SLNET. A random sample of feature types were measured from satellite images to calculate a mean width for each feature type. Buffers were applied to create polygonal features.

Agriculture

Agriculture types were derived from the AAFC_30m_EOSD_2014 Crop Inventory product. This product is a refinement of the EOSD satellite classification used for the ABMI Land Cover. Therefore, it added finer detail to all land cover classes in and around farm fields, and was used in areas where agriculture dominates the landscape.

The GVI is a photo-interpreted dataset covering the southern agriculture regions of Alberta. Agriculture definitions for grassland, pasture, and crops were used in this inventory. Crop types within a crop polygon used the AAFC definitions.

Human Footprints

Footprint was derived from many sources. Alberta sources (AltaLIS, Alberta Energy Regulator [AER]) were preferred if available but often were not. In those cases, the Canadian Government CanVec data was heavily used. Information from Open Street Map, National Rail Network, municipalities, and other organizations were used where available.

C.4.1.2 Saskatchewan data sources

Land Cover

Land cover was built by combining two sources. EOSD Land Cover tiles were used in the northern (non-agricultural region) half of the province. AAFC_30m_EOS_2014 Crop Inventory product was used in the southern half of the province. Developed and Exposed Land categories were erased and filled with closest neighbours along areas known to be roads to prevent overestimation of the footprint. Gaps in satellite cover were filled with closest non-water natural land cover type neighbours.

Water

Water was defined using the National Hydro Network 1:50,000 products. Lakes and large polygonal rivers were derived from the waterbody layer. Smaller, linear water features were derived from the watercourse layer. A random sample of feature types were measured from satellite images to calculate a mean width for each feature type. Buffers were applied to create polygonal features.

Agriculture

Agriculture types were derived from the AAFC_30m_EOS_2014 Crop Inventory product.

Human Footprints

Footprint was derived primarily from national sources and included the following:

- CanVec Land, Transportation, Natural Resources
- Open Street Map
- Geologic Atlas of Saskatchewan

C.5 Model parameters

Table C-7: Description of hydrological model parameters.

Variable	Description	Units
ALapse	Adiabatic temperature lapse rate	C/km
PLapse	Precipitation lapse rate	mm/km
Snw1	Temperature range at which precipitation is a mix of rain and snow	C
Snw2	Midpoint temperature at which precipitation is a mix of rain and snow	C
K_factor	Snow melt factor	mm/C
Min_melt	Minimum seasonal melt rate	mm/C
Refreeze	Snow refreeze factor	mm/C
Acor	Snow melt correction for HRU aspect and slope	none
K_glacier	Melt correction factor for glacier over exposed ice	none
Conif_corr	Melt factor correction for coniferous forest	none
Decid_corr	Melt factor correction for deciduous forest	none
Wetl_corr	Melt factor correction for wetland	none
Cut_corr	Melt factor correction for a recently harvested forest	none
Conif_Cov	Fractional vegetation cover in coniferous forest	%
Wetl_Cov	Fractional vegetation cover in wetland	%

Table C-7: Description of hydrological model parameters.

Variable	Description	Units
Decid_Cov	Fractional vegetation cover in deciduous forest	%
Cut_Cov	Fractional vegetation cover in a recently harvested forest	%
Grass_Cov	Fractional vegetation cover in grassland	%
Conif_LAI	Leaf-Area-Index for coniferous forest	none
Wetl_LAI	Leaf-Area-Index for wetland	none
Decid_LAI	Leaf-Area-Index for deciduous forest	none
Cut_LAI	Leaf-Area-Index for a recently harvested forest	none
Grass_LAI	Leaf-Area-Index for grassland	none
HBV_B0	Infiltration coefficient	none
Perc0	Percolation rate for surface soil layer	mm
Cap0	Capillary rise rate for top soil layer	mm
Base_N1	Upper soil layer baseflow rate (exponent)	none
Base_K1	Upper soil layer baseflow rate	none
Perc1	Percolation rate for middle to deep soil layer	mm
Cap1	Capillary rise rate for middle soil layer	mm
Base_N2	Baseflow rate for deep soil layer	none
Base_MAX2	Maximum baseflow rate for deep soil layer	mm

Table C-8: Model parameters, standard errors (SE), and composite scaled sensitivities (CSS) for all models.

	Headwaters			Foothills			Prairie			Lesser Slave			Boreal		
Variable	Value	SE	CSS	Value	SE	CSS	Value	SE	CSS	Value	SE	CSS	Value	SE	CSS
ALapse	6.51	0.02	601.1	4.60	0.62	7.2	6.00	1.67	5.4	4.30	0.95	7.8	5.60	4.15	8.5
PLapse	0.30	0.01	46.7	1.15	0.22	5.6	0.10	0.25	0.5	0.70	0.18	3.1	1.14	0.59	12.5
Snw1	2.27	0.06	49.4	1.40	0.31	2.1	2.00	0.42	3.3	3.00	0.42	9.6	1.60	0.67	6.3
Snw2	2.90	0.42	5.9	1.30	1.20	0.6	2.00	2.26	0.5	0.41	1.45	0.2	2.30	2.39	1.8
K_factor	2.56	0.01	292.9	0.85	0.07	8.9	1.00	0.08	11.1	1.55	0.18	14.7	0.91	0.03	78.6
Min_melt	1.66	0.02	85.7	0.20	0.08	1.1	0.50	0.10	3.5	0.15	0.11	0.9	0.20	0.05	8.8
Refreeze	0.65	0.26	2.4	0.90	1.40	0.3	0.50	3.34	0.1	1.00	20.32	0.0	1.40	25.27	0.1
Acor	0.37	0.03	16.3	0.21	0.12	0.9	0.25	0.12	1.3	0.17	0.11	0.9	0.00	0.25	0.0
K_glacier	3.66	0.12	36.6	-	-	-	-	-	-	-	-	-	-	-	-
Conif_corr	0.90	0.12	11.2	0.76	0.07	4.8	0.70	0.24	2.9	0.63	0.13	4.3	0.64	0.22	15.2
Decid_corr	0.90	0.38	3.4	0.86	0.29	1.6	0.90	0.21	4.8	0.72	0.21	4.7	0.81	0.53	4.1
Cut_corr	0.99	6.39	0.1	0.98	1.97	0.2	0.80	1.38	0.5	0.85	0.66	1.1	0.71	1.38	1.5
Wetl_corr	-	-	-	-	-	-	-	-	-	-	-	-	0.62	0.24	9.6

Table C-8: Model parameters, standard errors (SE), and composite scaled sensitivities (CSS) for all models.

	Headwaters			Foothills			Prairie			Lesser Slave			Boreal		
Variable	Value	SE	CSS	Value	SE	CSS	Value	SE	CSS	Value	SE	CSS	Value	SE	CSS
Conif_Cov	0.84	0.11	58.4	0.77	0.07	20.0	0.80	0.19	16.0	0.76	0.11	10.0	0.73	0.28	83.6
Wetl_Cov	0.21	1.44	0.3	0.47	0.22	2.2	0.50	0.16	8.7	0.45	0.18	2.2	0.43	0.10	38.5
Decid_Cov	0.67	0.22	12.6	0.79	0.21	6.8	0.80	0.25	7.3	0.78	0.13	8.4	0.73	0.46	22.5
Cut_Cov	0.66	9.91	0.1	0.56	0.79	0.6	0.50	1.28	1.1	0.33	0.40	0.9	0.49	0.98	4.8
Grass_Cov	0.08	1.27	0.1	0.22	0.99	0.1	0.68	0.12	4.7	0.30	0.52	0.7	0.40	0.79	3.7
Conif_LAI	2.10	1.35	12.4	4.90	2.02	3.1	4.30	6.05	2.2	3.00	2.28	1.8	2.70	5.10	14.9
Wetl_LAI	5.40	33.55	0.2	6.50	9.39	0.6	6.00	6.25	1.9	6.40	3.57	1.9	6.40	4.65	9.6
Decid_LAI	7.80	10.97	1.9	7.20	6.83	1.2	7.20	9.57	1.4	6.70	4.29	1.7	7.40	14.21	3.9
Cut_LAI	1.39	65.47	0.0	3.50	24.63	0.1	3.00	25.65	0.3	3.70	2.04	0.9	2.20	11.79	1.4
Grass_LAI	5.25	45.65	0.1	4.10	38.41	0.1	5.00	2.17	1.4	5.00	20.54	0.3	4.50	18.24	1.1
HBV_B0	0.93	0.23	5.2	0.81	2.19	0.2	1.00	1.48	0.5	0.54	0.12	4.0	1.29	2.65	1.0
Perc0	5.13	0.37	24.1	6.30	1.58	3.8	3.34	0.59	5.7	4.57	0.48	9.2	8.90	3.13	24.4
Cap0	19.40	4.70	5.4	13.90	3.24	2.9	8.80	1.80	3.7	4.20	1.24	3.1	3.30	4.65	5.8

Table C-8: Model parameters, standard errors (SE), and composite scaled sensitivities (CSS) for all models.

Variable	Headwaters			Foothills			Prairie			Lesser Slave			Boreal		
	Value	SE	CSS	Value	SE	CSS	Value	SE	CSS	Value	SE	CSS	Value	SE	CSS
Base_N1	2.15	5.33	0.8	1.55	0.11	58.0	1.83	0.37	24.5	1.05	0.06	63.1	1.22	0.06	203.5
Base_K1	0.77	3.29	0.5	0.01	0.01	8.5	0.00	0.00	3.2	0.70	0.16	15.9	0.01	0.00	45.6
Perc1	14.20	0.53	30.2	5.30	0.64	5.4	5.70	0.92	5.5	3.37	0.31	9.4	1.51	0.18	68.1
Cap1	-	-	-	-	-	-	-	-	-	-	-	-	1.28	0.18	56.6
Base_N2	5.24	0.19	45.3	1.64	0.19	11.5	2.00	0.30	11.8	1.16	0.21	10.9	1.66	0.31	23.8
Base_MAX2	8.05	0.51	17.2	45.90	12.80	5.0	42.00	13.75	5.6	25.80	12.08	4.3	8.60	6.04	6.9

C.6 Model parameter composite scaled sensitivities

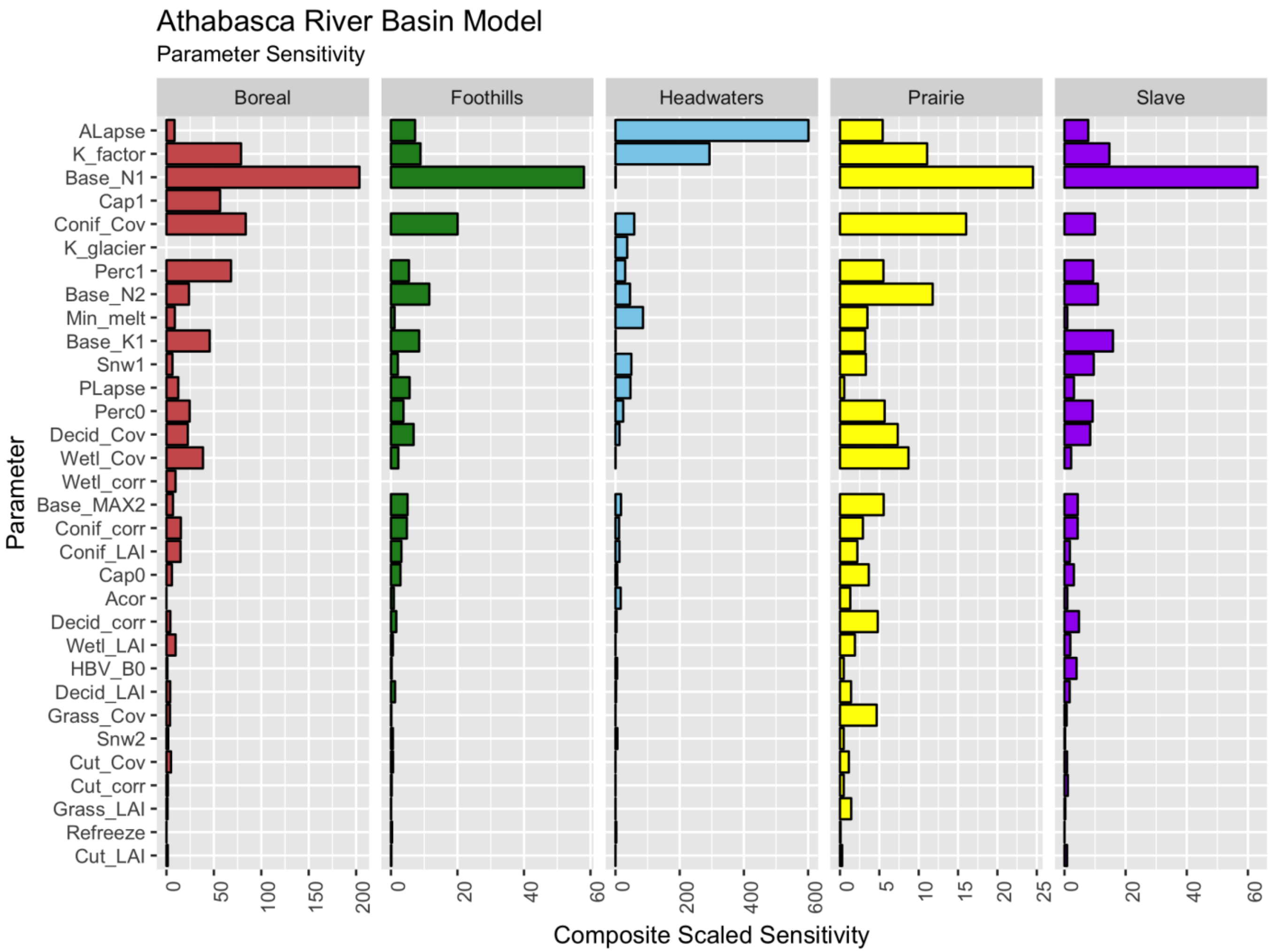


Figure C-6: Composite scaled sensitivities for all calibrated model parameters.

C.7 ALCES Online data

ARB Indicator	Data Source Alberta	Data Source Saskatchewan
Water Undifferentiated	ABMI, AAFC, EOSD	AAFC, EOSD
Snow Ice	ABMI, AAFC, EOSD	AAFC, EOSD
Rock Rubble	ABMI, AAFC, EOSD	AAFC, EOSD
Exposed Land	ABMI, AAFC, EOSD	AAFC, EOSD
Developed Undifferentiated	ABMI, AAFC, EOSD	AAFC, EOSD
Shrubland	ABMI, AAFC, EOSD	AAFC, EOSD
Wetlands land Undifferentiated	AAFC, EOSD	AAFC, EOSD
Water Oxbow Recurring	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	na
Water Ditch	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	NHN 50K watercourse
Water Canal	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	NHN 50K watercourse
Water Aquaduct	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	NHN 50K watercourse
Water Stream Indefinite	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	na
Water Stream Recurring	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	NHN 50K watercourse
Water Spillway	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	na

ARB Indicator	Data Source Alberta	Data Source Saskatchewan
Water Stream Permanent	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	NHN 50K watercourse, NHN 50K waterbody
Water Lake Recurring	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	NHN 50K waterbody
Water Quarry	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	na
Water Lagoon	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	NHN 50K waterbody
Water Ice Field	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	na
Water Dugout	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	NHN 50K waterbody
Water Canal	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	NHN 50K waterbody
Water Oxbow Permanent	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	na
Water Lake Permanent	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	NHN 50K waterbody
Water Reservoir	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	NHN 50K waterbody
Water River Major	AltaLIS BF-Hydro Polygon, AltaLIS BF-SLNET	NHN 50K waterbody
Grassland	GVI, AAFC, EOSD	AAFC, EOSD
Agriculture Undifferentiated	AAFC, ABMI, EOSD	AAFC, EOSD
Agriculture Forage	AAFC	AAFC

ARB Indicator	Data Source Alberta	Data Source Saskatchewan
Agriculture Fallow	AAFC	AAFC
Agriculture Cereal Barley	AAFC	AAFC
Agriculture Cereal Oats	AAFC	AAFC
Agriculture Cereal Grain Rye	AAFC	AAFC
Agriculture Cereal Grain Triticale	AAFC	AAFC
Agriculture Cereal WWheat	AAFC	AAFC
Agriculture Cereal OWheat	AAFC	AAFC
Agriculture Corn	AAFC	AAFC
Agriculture Oils Borage	AAFC	AAFC
Agriculture Oils Canola	AAFC	AAFC
Agriculture Oils Flaxseed	AAFC	AAFC
Agriculture Oils Mustard	AAFC	AAFC
Agriculture Oils Safflower	AAFC	AAFC
Agriculture Oils Sunflowers	AAFC	AAFC

ARB Indicator	Data Source Alberta	Data Source Saskatchewan
Agriculture Oils Soybeans	AAFC	AAFC
Agriculture Pulses Peas	AAFC	AAFC
Agriculture Pulses Beans	AAFC	AAFC
Agriculture Pulses Lentils	AAFC	AAFC
Agriculture Vegetables Potatoes	AAFC	AAFC
Agriculture Vegetables Sugarbeets	AAFC	AAFC
Agriculture Vegetables Other	AAFC	AAFC
Agriculture Herbs	AAFC	AAFC
Agriculture Canary Seeds	AAFC	AAFC
Agriculture Hemp	AAFC	AAFC
Agriculture Other Crops	AAFC	AAFC
Forest Coniferous	GVI, AAFC, EOSD, ABMI	AAFC, EOSD
Forest Deciduous	GVI, AAFC, EOSD, ABMI	AAFC, EOSD
Forest Mixed	GVI, AAFC, EOSD, ABMI	AAFC, EOSD

ARB Indicator	Data Source Alberta	Data Source Saskatchewan
Wetlands Bog	Combined Wetlands Inventory, GVI	na
Wetlands Fen	Combined Wetlands Inventory, GVI	na
Wetlands Marsh	Combined Wetlands Inventory, GVI	na
Wetlands Swamp	Combined Wetlands Inventory, GVI	na
Wetlands Water	Combined Wetlands Inventory, GVI	na
Wetlands Treed	Combined Wetlands Inventory, GVI, EOSD	AAFC, EOSD
Wetlands Herb	GVI, EOSD	AAFC, EOSD
Wetlands Shrub	GVI, EOSD	AAFC, EOSD
Wetlands Alkali	GVI	na
Wetlands Temporary	GVI	na
Agriculture Crop Undifferentiated	GVI	na
Agriculture Pasture	GVI	na
Commercial Business Services	City of Edmonton Land Use Map	na
Commercial Finance Insurance Real Estate	City of Edmonton Land Use Map	na

ARB Indicator	Data Source Alberta	Data Source Saskatchewan
Commercial Food	City of Edmonton Land Use Map	na
Commercial General	City of Edmonton Land Use Map	na
Commercial Home Improvement	City of Edmonton Land Use Map	na
Commercial Professional Services	City of Edmonton Land Use Map	na
Commercial Retail	City of Edmonton Land Use Map	na
Commercial Services	City of Edmonton Land Use Map	na
Commercial Vehicles	City of Edmonton Land Use Map	na
Commercial Entertainment	City of Edmonton Land Use Map	na
Commercial Hospitality	City of Edmonton Land Use Map	na
Commercial Office	City of Edmonton Land Use Map	na
Commercial Other	City of Edmonton Land Use Map	na
Commercial Service	City of Edmonton Land Use Map	na
Commercial Shopping Centre	City of Edmonton Land Use Map	na
Community Facility	City of Edmonton Land Use Map	na

ARB Indicator	Data Source Alberta	Data Source Saskatchewan
Education	City of Edmonton Land Use Map	na
Entertainment	City of Edmonton Land Use Map	na
Industry Extractive	City of Edmonton Land Use Map	na
Industry NonDurable Goods	City of Edmonton Land Use Map	na
Industry Other	City of Edmonton Land Use Map	na
Industry Storage	City of Edmonton Land Use Map	na
Infrastructure Parking	City of Edmonton Land Use Map	na
Infrastructure Road Other	City of Edmonton Land Use Map	na
Institutional	City of Edmonton Land Use Map	na
Medical	City of Edmonton Land Use Map	na
Membership Organizations	City of Edmonton Land Use Map	na
Military	City of Edmonton Land Use Map	na
Prison	City of Edmonton Land Use Map	na
Residential Collective Dwelling	City of Edmonton Land Use Map	na

ARB Indicator	Data Source Alberta	Data Source Saskatchewan
Residential Mobile Home	City of Edmonton Land Use Map	na
Residential Multi-Unit	City of Edmonton Land Use Map	na
Residential One-Unit	City of Edmonton Land Use Map	na
Residential Other	City of Edmonton Land Use Map	na
Residential Two-Unit	City of Edmonton Land Use Map	na
Right-of-Way	City of Edmonton Land Use Map	na
Telecom Other	City of Edmonton Land Use Map	na
Transportation	City of Edmonton Land Use Map	na
Utility Power	City of Edmonton Land Use Map	na
Utility Sewage	City of Edmonton Land Use Map	na
Utility Waste	City of Edmonton Land Use Map	na
Utility Water	City of Edmonton Land Use Map	na
Seismic Line	AltaLIS BF_Cutline_Trail	CanVec Land
Towers	Canvec Land	Canvec Land

ARB Indicator	Data Source Alberta	Data Source Saskatchewan
Rural Acreage Undifferentiated	ABMI, GVI	Canvec Land
Rural Farm Undifferentiated	ABMI, GVI	Canvec Land
Rural Residence Undifferentiated	ABMI, GVI	Canvec Land
Urban Undifferentiated	EOSD, AAFC, ABMI, AltaLIS	AAFC, EOSD
Parks Hard Surface	City of Calgary	na
Trail ATV	TransCanada Trail, QuadSquad, Open Street Map, HikeAlberta, City Data, AltaLIS BF_Cutline_Trails, AB Parks	na
Trail Bike	TransCanada Trail, QuadSquad, Open Street Map, HikeAlberta, City Data, AltaLIS, AB Parks	na
Trail Footpath	TransCanada Trail, QuadSquad, Open Street Map, HikeAlberta, City Data, AltaLIS, AB Parks	na
Trail Horse	TransCanada Trail, QuadSquad, Open Street Map, HikeAlberta, City Data, AltaLIS, AB Parks	na
Trail Ski	TransCanada Trail, QuadSquad, Open Street Map, HikeAlberta, City Data, AltaLIS, AB Parks	na
Trail Undifferentiated	TransCanada Trail, QuadSquad, Open Street Map, HikeAlberta, City Data, AltaLIS, AB Parks	CanVec Transportation, Open Street Map

ARB Indicator	Data Source Alberta	Data Source Saskatchewan
Pipeline	Alberta Energy Regulator; AltaLIS	CanVec
Industrial Agriculture Processing	AltaLIS, CanVec, GVI	na
Industrial High Density	AltaLIS, CanVec, GVI	na
Industrial Low Density	AltaLIS, CanVec, GVI	na
Industrial Processing	AltaLIS, CanVec, GVI	na
Industrial Undifferentiated	AltaLIS, CanVec, GVI	CanVec
Recreation SportRink Undifferentiated	Open Street Map, City of Edmonton	na
Recreation SportField Undifferentiated	Open Street Map, City of Edmonton	na
Recreation SportCentre Undifferentiated	Open Street Map, City of Edmonton	na
Recreation SportStadium Undifferentiated	Open Street Map, City of Edmonton	na
Recreation SportTrack Undifferentiated	Open Street Map, City of Edmonton	na
Recreation Campground	Open Street Map, City of Edmonton	na
Recreation Picnic	Open Street Map, City of Edmonton, ESRI Basemap, CanVec, AltaLIS	na

ARB Indicator	Data Source Alberta	Data Source Saskatchewan
Recreation SkiHill	Open Street Map, City of Edmonton, ESRI Basemap, CanVec, AltaLIS	na
Recreation Zoo	Open Street Map, City of Edmonton, ESRI Basemap, CanVec, AltaLIS	na
Recreation Golf Course	Open Street Map, City of Edmonton, ESRI Basemap, CanVec, AltaLIS	na
Recreation Golf Mini	Open Street Map, City of Edmonton, ESRI Basemap, CanVec, AltaLIS	na
Recreation Golf DrivingRange	Open Street Map, City of Edmonton, ESRI Basemap, CanVec, AltaLIS	na
Recreation Playground	Open Street Map, City of Edmonton, ESRI Basemap, CanVec, AltaLIS	na
Recreation IndoorOther	Open Street Map, City of Edmonton, ESRI Basemap, CanVec, AltaLIS	Open Street Map
Recreation OutdoorOther	Open Street Map, City of Edmonton, ESRI Basemap, CanVec, AltaLIS	Open Street Map
Rec Park	Open Street Map, City of Edmonton, ESRI Basemap, CanVec, AltaLIS	Open Street Map

ARB Indicator	Data Source Alberta	Data Source Saskatchewan
Powerline	AltaLIS, CanVec	CanVec
Feedlot Beef	NRCB, ABMI, GVI, County Grande Prairie	na
Feedlot Bison	NRCB, ABMI, GVI, County Grande Prairie	na
Feedlot Cervid	NRCB, ABMI, GVI, County Grande Prairie	na
Feedlot Dairy	NRCB, ABMI, GVI, County Grande Prairie	na
Feedlot Horse	NRCB, ABMI, GVI, County Grande Prairie	na
Feedlot Multi	NRCB, ABMI, GVI, County Grande Prairie	na
Feedlot Poultry	NRCB, ABMI, GVI, County Grande Prairie	na
Feedlot Sheep	NRCB, ABMI, GVI, County Grande Prairie	na
Feedlot Swine	NRCB, ABMI, GVI, County Grande Prairie	na
Feedlot Undifferentiated	GVI	na
PetroWell Undifferentiated Abandoned	ABMI, AER	na
PetroWell GasCapped	ABMI, AER	na
PetroWell CBMAbandoned	ABMI, AER	na

ARB Indicator	Data Source Alberta	Data Source Saskatchewan
PetroWell GasAbandoned	ABMI, AER	na
PetroWell OilAbandoned	ABMI, AER	na
PetroWell Undifferentiated	ABMI, AER	CanVec Resource Management, Open Street Map Man Made
PetroWell CBM	ABMI, AER	na
PetroWell Gas	ABMI, AER	na
PetroWell Oil	ABMI, AER	na
PetroWell WaterAbandoned	ABMI, AER	na
PetroWell Water	ABMI, AER	na
Sump	ABMI	na
Oil and Gas Facility	AltaLIS, CanVec, AER	CanVec
Wind Turbine	ABMI, CanVec	CanVec
Power Plant Coal	AltaLIS	CanVec
Power Plant Gas	AltaLIS	CanVec
Power Plant Undifferentiated	AltaLIS	CanVec

ARB Indicator	Data Source Alberta	Data Source Saskatchewan
PowerTransformer Station	CanVec	CanVec
LumberMill	CanVec	CanVec
Landfill	ABMI	Open Street Map Man Made, Open Street Map Landuse, CanVec Man Made
Mine OilSands Disturbed NoVegetation	AEP, ABMI, AltaLIS, CanVec, GVI	na
Mine OilSands Pit Lake	AEP, ABMI, AltaLIS, CanVec, GVI	na
Mine Tailing Pile	AEP, ABMI, AltaLIS, CanVec, GVI	na
Mine OilSands Disturbed Vegetation	AEP, ABMI, AltaLIS, CanVec, GVI	na
Mine Coal	AEP, ABMI, AltaLIS, CanVec, GVI	CanVec, Saskatchewan Energy and Resources
Mine Peat	AEP, ABMI, AltaLIS, CanVec, GVI	CanVec, Saskatchewan Energy and Resources
Mine Gravel	AEP, ABMI, AltaLIS, CanVec, GVI	CanVec, Saskatchewan Energy and Resources
Mine Quarry	AEP, ABMI, AltaLIS, CanVec, GVI	CanVec, Saskatchewan Energy and Resources
Mine Sand	AEP, ABMI, AltaLIS, CanVec, GVI	CanVec, Saskatchewan Energy and Resources
Mine Clay	AEP, ABMI, AltaLIS, CanVec, GVI	CanVec, Saskatchewan Energy and Resources
BorrowPit	AEP, ABMI, AltaLIS, CanVec, GVI	CanVec, Saskatchewan Energy and Resources

ARB Indicator	Data Source Alberta	Data Source Saskatchewan
Dugout	AEP, ABMI, AltaLIS, CanVec, GVI	CanVec, Saskatchewan Energy and Resources
Lagoon Mine	AEP, ABMI, AltaLIS, CanVec, GVI	CanVec, Saskatchewan Energy and Resources
Lagoon Waste Water	AEP, ABMI, AltaLIS, CanVec, GVI	CanVec, Saskatchewan Energy and Resources
Lagoon Undifferentiated	AEP, ABMI, AltaLIS, CanVec, GVI	CanVec, Saskatchewan Energy and Resources
Rail Operational Main	Open Street Map, National Railway Network, AltaLIS, City of Calgary, City of Grande Prairie	Open Street Map
Rail Passenger Train	Open Street Map, National Railway Network, AltaLIS, City of Calgary, City of Grande Prairie	Open Street Map
Rail Operational Yard	Open Street Map, National Railway Network, AltaLIS, City of Calgary, City of Grande Prairie	Open Street Map
Rail Operational Siding Spur	Open Street Map, National Railway Network, AltaLIS, City of Calgary, City of Grande Prairie	Open Street Map
Rail NonOperational	Open Street Map, National Railway Network, AltaLIS, City of Calgary, City of Grande Prairie	Open Street Map
Rail ROW	Open Street Map, National Railway Network, AltaLIS, City of Calgary, City of Grande Prairie	Open Street Map
Rail Other	Open Street Map, National Railway Network, AltaLIS, City of Calgary, City of Grande Prairie	Open Street Map

ARB Indicator	Data Source Alberta	Data Source Saskatchewan
Cemetery	CanVec	na
Road Truck Trail	Open Street Map, AltaLIS	Open Street Map Highway
Road Winter Road	Open Street Map, AltaLIS	Open Street Map Highway
Road Access Road	Open Street Map, AltaLIS	Open Street Map Highway
Road Service Road	Open Street Map, AltaLIS	Open Street Map Highway
Road Residential Road	Open Street Map, AltaLIS	Open Street Map Highway
Road Quaternary Highway	Open Street Map, AltaLIS	Open Street Map Highway
Road Tertiary Highway	Open Street Map, AltaLIS	Open Street Map Highway
Road Secondary Highway	Open Street Map, AltaLIS	Open Street Map Highway
Road Primary Highway	Open Street Map, AltaLIS	Open Street Map Highway
Road Core Highway	Open Street Map, AltaLIS	Open Street Map Highway
Airport Terminal	Open Street Map, AltaLIS, CanVec, ESRI Basemap, City of Edmonton	Open Street map Aeroway, CanVec Transportation
Airport Hangar	Open Street Map, AltaLIS, CanVec, ESRI Basemap, City of Edmonton	Open Street map Aeroway, CanVec Transportation

ARB Indicator	Data Source Alberta	Data Source Saskatchewan
Airport Building	Open Street Map, AltaLIS, CanVec, ESRI Basemap, City of Edmonton	Open Street map Aeroway, CanVec Transportation
Airport Apron	Open Street Map, AltaLIS, CanVec, ESRI Basemap, City of Edmonton	Open Street map Aeroway, CanVec Transportation
Airport Helipad	Open Street Map, AltaLIS, CanVec, ESRI Basemap, City of Edmonton	Open Street map Aeroway, CanVec Transportation
Airport Runway	Open Street Map, AltaLIS, CanVec, ESRI Basemap, City of Edmonton	Open Street map Aeroway, CanVec Transportation
Airport Greenspace	Open Street Map, AltaLIS, CanVec, ESRI Basemap, City of Edmonton	Open Street map Aeroway, CanVec Transportation
Airport Other	Open Street Map, AltaLIS, CanVec, ESRI Basemap, City of Edmonton	Open Street map Aeroway, CanVec Transportation

Data Source	Description	Source Link
AAFC	In 2014, the Earth Observation Team of the Science and Technology Branch (STB) at Agriculture and Agri-Food Canada (AAFC) repeated the process of generating annual crop inventory digital maps using satellite imagery to for all of Canada, in support of a national crop inventory. A Decision Tree (DT) based methodology was applied using optical (Landsat-8) and radar (RADARSAT-2) based satellite images, and having a final spatial resolution of 30 m. In conjunction with satellite acquisitions, ground-truth information was provided by provincial crop insurance companies and point observations from the BC Ministry of Agriculture and our regional AAFC colleagues.	http://open.canada.ca/data/en/dataset/ae61f47e-8bcb-47c1-b438-8081601fa8fe
ABMI Footprints	The ABMI 2012 Wall-to-Wall Human Footprint is the latest of a series of wall-to-wall footprint maps produced by the ABMI (previous versions: 2010, 2007). These maps provide the most comprehensive representation of human footprint in Alberta. The human footprint information is compiled to generate inventory that includes human footprint attributes and features related to the energy, forestry, and agriculture industries, as well as urban development. All of the inventory features were created and/or verified using a heads-up digitizing of all the human footprint attributes manually interpreted from satellite imagery.	http://www.abmi.ca/home/products-services/Products/Human-Footprint-Map.html
ABMI Land Cover	The ABMI Wall-to-Wall Land Cover 2010 dataset provides Alberta-wide, polygon-based representations of provincial land cover circa year 2010, respectively. It is based on the digital classification of 30 meter resolution Landsat satellite images, and enhanced using GIS datasets provided by the Government of Alberta. The land cover product contains approximately 1 million polygons and comprise 11 classes, including water, shrubland, grassland, agriculture, exposed land, developed land and different forest types.	http://www.abmi.ca/home/products-services/Products/Land-Cover.html

Data Source	Description	Source Link
AEP	The Alberta Human Footprint Monitoring Program (AHFMP) Footprint Sublayers 2014	http://aep.alberta.ca/forms-maps-services/maps/resource-data-product-catalogue/land-use.aspx
AER	This Spatial information consists of both Abandoned Well data and Revised Abandoned Well Location data.	http://www1.aer.ca/ProductCatalogue/510.html
AER	The ST37: List of Wells in Alberta Monthly report is available in PDF, TXT, and Shapefile format.	http://www.aer.ca/data-and-publications/statistical-reports/st37
AER	This dataset contains all AER-approved oil and gas pipelines in Alberta. This data represents the best information available to the AER at the date of publication. Specific pipeline location information should be obtained from the survey plans, owners, and field observation. This dataset excludes low pressure distribution lines.	http://www1.aer.ca/ProductCatalogue/557.html
AltaLIS	AltaLIS 20K Base Features	http://www.altalis.com/products/base/20k_base_features.html
AltaLIS BF-Hydro Polygon	AltaLIS 20K Base Features - 20K polygon water features	http://www.altalis.com/products/base/20k_base_features.html
AltaLIS BF-SLNET	AltaLIS 20K Base Features - 20K line water features	http://www.altalis.com/products/base/20k_base_features.html

Data Source	Description	Source Link
CanVec Land	Land Features entities are: Island, Shoreline, Wooded Area, Saturated soil, Landform Feature (esker, sand…), and Cut Line. CanVec is a digital cartographic reference product of Natural Resources Canada (NRCan). It originates from the best available data sources covering Canadian territory, offers quality topographical information in vector format, and complies with international geomatics standards. CanVec is a multi-source product coming mainly from the National Topographic Data Base (NTDB), the Mapping the North process conducted by the Canada Centre for Mapping and Earth Observation (CCMEO), the Atlas of Canada data, the GeoBase initiative, and the data update using satellite imagery coverage (e.g. Landsat 7, Spot, Radarsat, etc.).	http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/4182012b-e8b6-4ee8-8bc9-5f954580d628.html
CanVec Man Made	Man-made Features entities are: Dam, Protection Structure (breakwater, dike/levee), Liquid Storage Facility (basin, swimming pool…), Tank, Building, Delimiting Structure (fence, wall…), Landmark Feature (cross, radar, crane, fort…), Chimney, Tower, Sewage Pipeline, Conduit Bridge, Waste, Leisure Area, Residential Area, Commercial, and Institutional Area and Ritual Cultural Area (shrine, cemetery…). CanVec is a digital cartographic reference product of Natural Resources Canada (NRCan). It originates from the best available data sources covering Canadian territory, offers quality topographical information in vector format, and complies with international geomatics standards. CanVec is a multi-source product coming mainly from the National Topographic Data Base (NTDB), the Mapping the North process conducted by the Canada Centre for Mapping and Earth Observation (CCMEO), the Atlas of Canada data, the GeoBase initiative, and the data update using satellite imagery coverage (e.g. Landsat 7, Spot, Radarsat, etc.).	http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/4182012b-e8b6-4ee8-8bc9-5f954580d628.html

Data Source	Description	Source Link
CanVec Transportation	Transport Features is composed of, among others, the National Road Network (NRN) and the National Railway Network (NRWN). Transport Features entities are: Nautical Facility, Track Segment, Track Junction, Railway Station, Track Crossing, Track Marker Post, Track Structure, Rail Ferry, Road Segment, Road Ferry, Road Junction, Blocked Passage, Toll Point, Aerial Cableway, Footbridge, Trail, Navigational Aid, Marina, and Runway. CanVec is a digital cartographic reference product of Natural Resources Canada (NRCan). It originates from the best available data sources covering Canadian territory, offers quality topographical information in vector format and complies with international geomatics standards. CanVec is a multi-source product coming mainly from the National Topographic Data Base (NTDB), the Mapping the North process conducted by the Canada Centre for Mapping and Earth Observation (CCMEO), the Atlas of Canada data, the GeoBase initiative and the data update using satellite imagery coverage (e.g. Landsat 7, Spot, Radarsat, etc.).	http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/4182012b-e8b6-4ee8-8bc9-5f954580d628.html
CanVec, Saskatchewan Energy and Resources	Geological Atlas of Saskatchewan - Mine Locations	http://www.infomaps.gov.sk.ca/website/SIR%5FGeological%5FAtlas/viewer.htm
City of Calgary	City of Calgary land use features	https://data.calgary.ca/OpenData/Pages/DatasetDetails.aspx?DatasetID=PDC0-99999-99999-00101-P(CITYonlineDefault)
City of Edmonton Land Use Map	A detailed map of land use categories by land parcel for the city of Edmonton.	https://data.edmonton.ca/Thematic-Features/City-of-Edmonton-Land-Use/rezv-ns5t

Data Source	Description	Source Link
Combined Wetlands Inventory	The Alberta Merged Wetland Inventory depicts wetlands within the province of Alberta for the period 1998 to 2009 classified to the five major classes in the Canadian Wetland Classification System (CWCS): marsh, bog, fen, swamp, and open water. There are 30 component wetland inventories that were merged to create this wetland inventory product. These individual wetland inventories utilized four different wetland classification systems with different source imagery and different resolutions. They have been reclassified to the CWCS five major classes. Information on the component wetlands can be found in the Alberta Merged Wetland Inventory Status attribution.	http://aep.alberta.ca/forms-maps-services/maps/resource-data-product-catalogue/biophysical.aspx
EOSD	The Earth Observation for Sustainable Developments of Forests (EOSD) project is a partnership project between the Canadian Forest Service (CFS) and the Canadian Space Agency (CSA), with provincial and territorial participation and support. An element of EOSD is the development of a land cover map of the forested area of Canada reflective of circa 2000 conditions. Including image overlap outside of the forested area of Canada, over 475 Landsat-7 ETM+ images were classified, over 80% of Canada was mapped, and over 600 1:250,000 map sheet products were developed for unfettered sharing.	https://ca.nfis.org/index_eng.html
GVI	Alberta Grassland Vegetation Inventory covers the Grassland Natural Region of the province. It provides mapped information of landscape scale soil/landform features and vegetation cover for use in planning and management of rangelands, wildlife, wetlands, land use planning, and reclamation in native grasslands	http://aep.alberta.ca/forms-maps-services/maps/resource-data-product-catalogue/forest-vegetation-inventories.aspx

Data Source	Description	Source Link
National Railway Network	The National Railway Network (NRWN), version 1.0 focuses on providing a quality geometric description and a set of basic attributes of Canadian rail phenomena. The NRWN product is distributed in the form of eleven provincial or territorial datasets and consists of one linear feature (Track), four punctual features (Junction, Crossing, Marker Post, and Station), and one linear or punctual feature (Structure) with which is associated a series of descriptive attributes such as, among others: Track Classification, Track Name, Track Operator, Track User, Gauge, Number of Tracks, Electrification, Design Speeds, Subdivision Name; Junction Type; Level of Crossing, Crossing Type, Warning System, Transport Canada Identifier; Station Name, Station Type, Station User, Number of platforms; Structure Type. The available output file format for the product are: GML (Geography Markup Language) in ASCII and SHAPE (ESRI - TM) and KML (Keyhole Markup Language).	http://open.canada.ca/data/en/dataset/ac26807e-a1e8-49fa-87bf-451175a859b8
NHN 50K waterbody	Hydro Features is composed of the network of Canadian surface waters. Hydro Features entities are: Watercourse, Water Linear Flow, Hydro Obstacle (falls, rapids…), Waterbody (lake, watercourse…), Permanent Snow and Ice, Water Well, and Spring. CanVec is a digital cartographic reference product of Natural Resources Canada (NRCan). It originates from the best available data sources covering Canadian territory, offers quality topographical information in vector format, and complies with international geomatics standards. CanVec is a multi-source product coming mainly from the National Topographic Data Base (NTDB), the Mapping the North process conducted by the Canada Centre for Mapping and Earth Observation (CCMEO), the Atlas of Canada data, the GeoBase initiative, and the data update using satellite imagery coverage (e.g. Landsat 7, Spot, Radarsat, etc.).	http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/93b9a6e6-1264-47f6-ad55-c60f842c550d.html

Data Source	Description	Source Link
NHN 50K watercourse	Hydro Features is composed of the network of Canadian surface waters. Hydro Features entities are: Watercourse, Water Linear Flow, Hydro Obstacle (falls, rapids…), Waterbody (lake, watercourse…), Permanent Snow and Ice, Water Well, and Spring. CanVec is a digital cartographic reference product of Natural Resources Canada (NRCan). It originates from the best available data sources covering Canadian territory, offers quality topographical information in vector format, and complies with international geomatics standards. CanVec is a multi-source product coming mainly from the National Topographic Data Base (NTDB), the Mapping the North process conducted by the Canada Centre for Mapping and Earth Observation (CCMEO), the Atlas of Canada data, the GeoBase initiative, and the data update using satellite imagery coverage (e.g. Landsat 7, Spot, Radarsat, etc.).	http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/93b9a6e6-1264-47f6-ad55-c60f842c550d.html
NRCB, ABMI, GVI, County Grande Prairie	Spatial locations of feedlot operations from various sources were edited and digitized by ALCES staff.	WWW.alces.ca
Open Street Map	OpenStreetMap (OSM) is a collaborative project to create a free editable map of the world. The creation and growth of OSM has been motivated by restrictions on use or availability of map information across much of the world, and the advent of inexpensive portable satellite navigation devices. OSM is considered a prominent example of volunteered geographic information.	http://download.geofabrik.de/north-america/canada/alberta.html
TransCanada Trail, QuadSquad, Open Street Map, HikeAlberta, City Data, AltaLIS, AB Parks	Trails map manually edited and partially manually digitized by ALCES staff. All available Alberta sources were pulled together and near coincidences were edited to remove duplication.	www.alces.ca

C.8 References

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APPENDIX D Current list of performance measures (PMs) with descriptions

Naturalized streamflow: Streamflow values in the absence of withdrawals from the system. These are calculated as the total of all inflows to the basin.

Simulation time period: The simulation time period refers to the length of time between the start and the end of the simulation. The current simulation time period is from 1971 to 2015 (45 years).

dam^3= cubic decameters; **cms**= cubic meters per second

Water Management PMs:

1. Seasonal system shortages (dam^3)
    a. This PM shows the basin-wide water shortages by season over the simulation time period.
    b. The map for this PM is broken up by sub-basin. The sub-basins are colored to indicate shortages (red is high, green is low, and clear is no shortage). The user can select sub-basins to evaluate the total shortage volume of that sub-basin for each season.
2. Net water use upstream of Fort McMurray
    a. This PM shows net water use upstream of Fort McMurray. The black line on the graph refers to the threshold of (60,000 dam^3) established by the Surface Water Quantity Management Frameworks for the Lower Athabasca River.
3. Annual total system shortages (dam^3)
    a. This PM shows the total annual shortages for all of the demands in the system over the simulation time period.
4. Lesser Slave Lake elevation
    a. This PM shows the water elevation at Lesser Slave Lake at a daily time step throughout the simulation time period.
5. Water demand and delivery
    a. This PM measures the water demand (cms) and the delivery (cms) at specific demand nodes. This PM is shown on a daily time step over the simulation time period.

Ecological PMs:

1. Annual number of days at or below Ecosystem Baseflow (87 cms)
   a. This PM shows the number of days in any given year where the flow on the mainstem of the Athabasca River below Fort McMurray is 87 cms or less.
   b. Walleye recruitment reduction
   c. This PM shows an estimate of the reduction in walleye population recruitment at the Peace-Athabasca Delta (PAD) during the summer fry period (weeks 18–43). Walleye population recruitment is a measure of how well the population can be sustained. This PM is derived from a relationship with streamflow into the PAD and is referenced from previous work by Paul (2013).
2. Seasonal streamflow as a percentage of naturalized streamflow
   a. This PM shows the seasonal streamflow relative to naturalized streamflow. It is intended to evaluate the deviation from naturalized streamflow as an indication of ecosystem health and water supply.
   b. The map for this PM shows the relative difference in streamflow as a percentage of naturalized streamflow for each sub-basin and for each season, indicated by change in colors. The user can click on each sub-basin to obtain the percentage of naturalized streamflow.
3. Athabasca River contribution to the PAD as a percentage of naturalized streamflow
   a. This PM shows the percentage of naturalized flow that the Athabasca River contributes to the PAD.
4. Days below the chronic dissolved oxygen (DO) threshold in the Athabasca River at Fort McKay
   a. This PM shows the number of days per year where the simulated DO levels on the Athabasca mainstem near Fort McKay are 6 mg/L or less. The value of 6 mg/L is defined as the chronic threshold by the Alberta Provincial Guidelines for the Protection of Aquatic Life. In the model, DO is calculated using a linear relationship between stream temperature, streamflow, and DO. The data for the calculation was obtained from the Joint Oil Sands Monitoring Program (JOSM).
5. Days where stream temperature is above 20°C on the Athabasca River mainstem at Fort McKay
   a. This PM shows the number of days in any given year that the stream temperature in the Athabasca River at Fort McKay is estimated to be 20°C or more. The 20°C value is intended to indicate stressful conditions for fish. Stream temperature is estimated using the relationship between air temperature and streamflow, and uses data obtained from JOSM.

6. Daily streamflow

    a. This PM shows streamflow at specific locations throughout the basin. Flow is measured at a daily time step throughout the entire simulation time period. Specific locations are listed below (as examples):

        - Athabasca River downstream of Fort McMurray
        - Lesser Slave River above the Athabasca confluence
        - McLeod River above the Athabasca

Social PMs:

1. Percent change in fall Aboriginal Navigation Index (ANI) in the Athabasca River below Fort McMurray

    a. This PM shows the weekly calculated change in the fall (weeks 34–43) ANI as a result of flow and withdrawals for industrial use. The weekly change is shown as a percentage.

2. Number of days over 1:100 flood thresholds

    a. This PM shows the number of days over the entire simulation period where the 1:100 flood flow thresholds are exceeded at a number of locations across the basin. The following locations are represented; corresponding 1:100 flood flow thresholds are indicated.

        - Athabasca River at Fort McMurray (5,809 cms);
        - Lesser Slave River below Lesser Slave Lake (152 cms);
        - Athabasca River at Whitecourt (2,898 cms);
        - McLeod River at Whitecourt (2,672 cms);
        - Athabasca River at Athabasca (5,846 cms);
        - Athabasca River at Hinton (1,425 cms), and
        - Pembina River at Sangudo (1,160 cms).

    The 1:100 year flood flow threshold values were obtained from the 2014 Feasibility Study - Athabasca River Basins (IBI Group and Golder Associates), prepared for the Government of Alberta - Flood Recovery Task Force.

D.1 References

Paul, A. 2013. Environmental flows and recruitment of walleye (Sander vitreus) in the Peace–Athabasca Delta. Can. J. Fish. Aquat. Sci. 70: 307–315 (2013) dx.doi.org/10.1139/cjfas-2012-0279

APPENDIX E Methodology and development of climate scenarios for use in the AIRM

The scientific objective of producing climate scenarios for the Athabasca River Basin (ARB) Initiative was to develop scenarios of projected changes in the climate of the ARB using innovative methods that 1) incorporate the forcing and modes of variability in the regional hydroclimate and 2) are applicable to adaptation planning in the basin. The climate projections and our novel methodology provide scenarios to assess practical adaptive strategies for water management under climate change. These scenarios will be used by the Working Group, which is comprised of municipal, provincial, and federal governments; industry; non-governmental organizations; and Indigenous participants.

The climate of northern Alberta is changing. It is getting much less cold, as shown in Figure E-1, which is a plot of mean minimum winter temperature at Fort McMurray from 1915 to 2011. There is considerable variability from year to year but also a significant upward trend. The horizontal bars on the figure, representing 25-year mean values, show that in recent years minimum winter temperatures were five degrees higher than during the first 25 years of the weather record. A warming winter has significant ecological and hydrological implications.

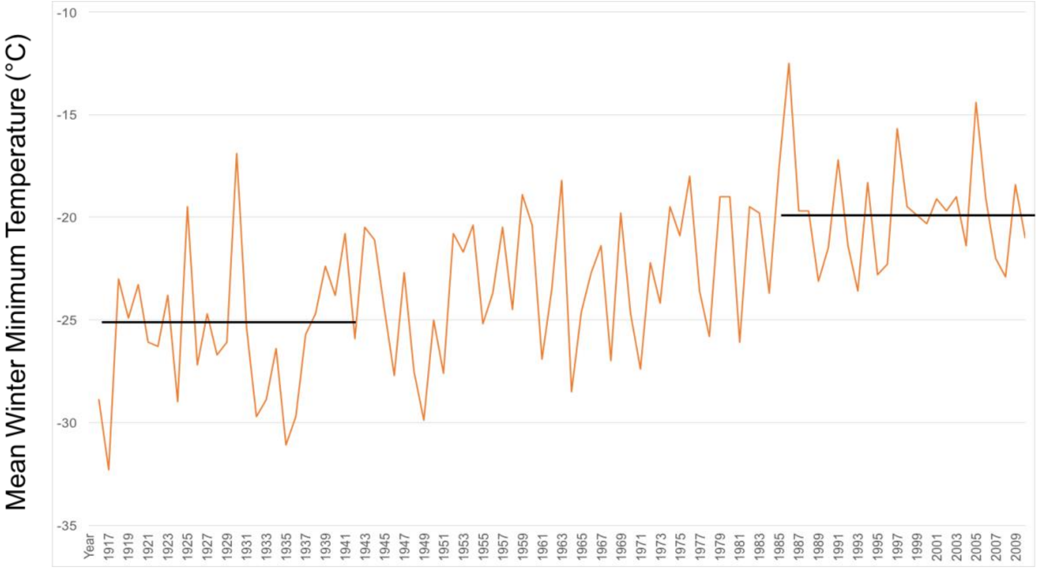

Figure E-1: Mean minimum winter temperature (°C) at Fort McMurray from 1915 to 2011. The horizontal bars depict mean values for the first and last 25 years of this period.

This historical trend in winter temperatures is consistent with Global Climate Model (GCM) projections of the future climate of northern Alberta. Figure E-2 presents the output from a large number of GCMs in terms of projected changes in mean temperature and total precipitation for winter (left) and summer (right). The large scatter of projections reflects the uncertainty arising from the use of different numerical models and greenhouse gas (GHG) emission scenarios, plus simply the internal natural variability of the climate system. Despite this uncertainty, all models project higher temperature and most suggest more precipitation. This increase in temperature and precipitation is more pronounced in winter. A median change in summer precipitation of about +5% suggests that surface and soil conditions could be largely unchanged, or possibly drier, given that higher temperatures will lead to an increase in moisture loss by evapotranspiration.

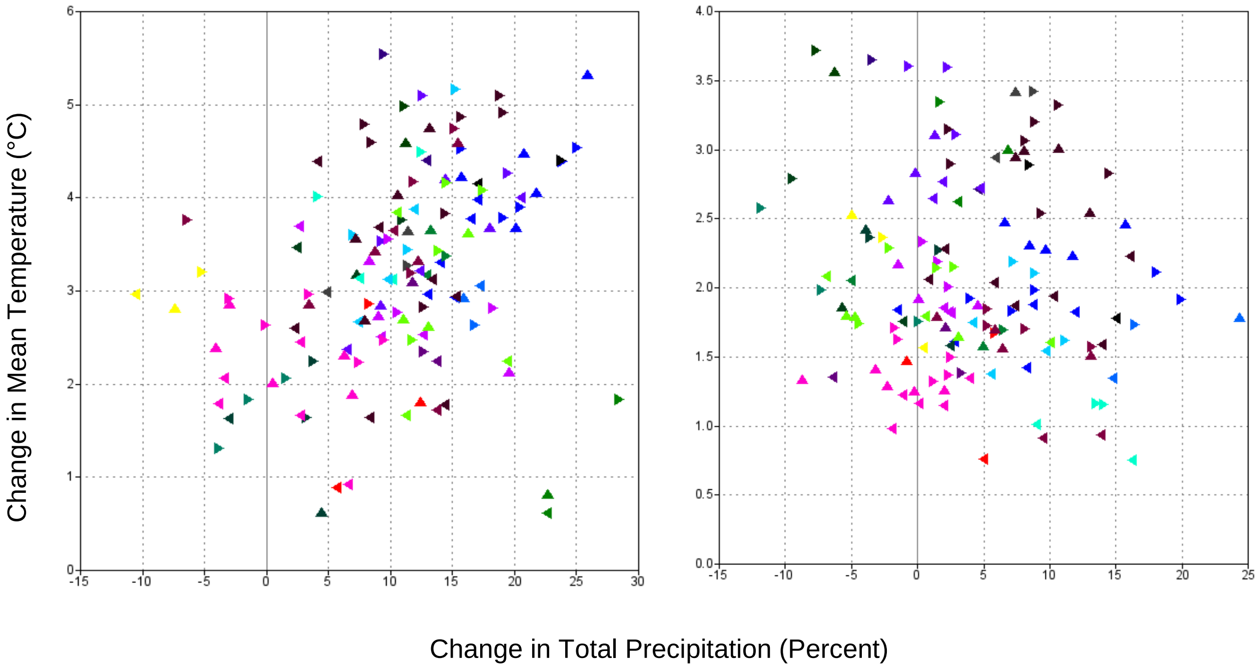

Figure E-2: Climate change projections for winter (left) and summer (right) for northern Alberta for periods 2040–69 versus 1961–90 (Source of data: Pacific Climate Impacts Consortium).

Figure E-2 is the only use of output from GCMs for this project. These data are suitable for generating broad climate change scenarios for an area as large as or larger than northern Alberta; however, for this work, data from Regional Climate Models (RCMs) of much higher spatial resolution are used. Figure E-3 shows the boundary of the ARB with the 50 km grid typical of RCMs. Superimposed on the figure is a single 250 x 250 km GCM cell. The RCMs provide data for 65 points in the ARB as opposed to climate projections for parts of 3 or 4 GCM grid cells.

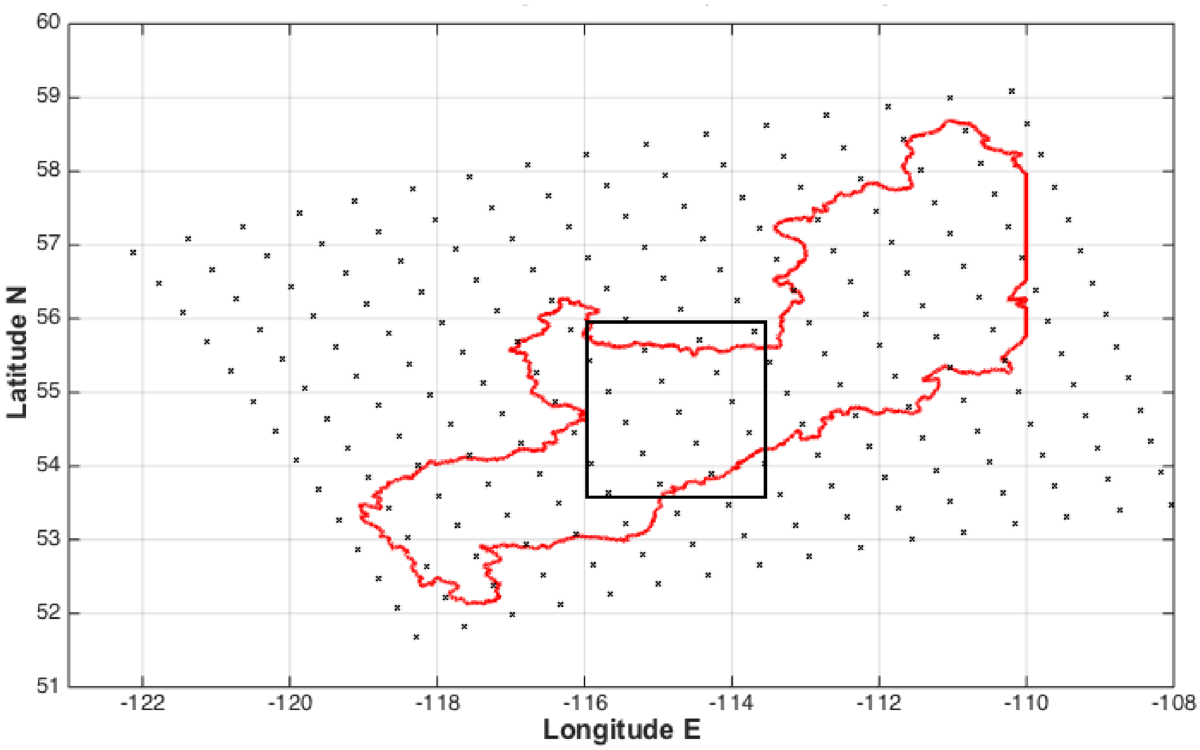

Figure E-3: The boundary of the ARB in red with the 50 km grid typical of RCMs; superimposed is a single 250 x 250 km GCM cell.

Regional climate modelling represents the dynamically downscaling of output from GCMs. The higher resolution of the RCMs enables the simulation of climate with greater topographic complexity and finer-scale atmospheric dynamics, providing climate change data suitable for regional impact studies (Barrow and Sauchyn, in press). A new generation of RCMs includes advanced land surface schemes and the coupled simulation of regional climate and watershed hydrology. With their limited spatial domain, RCMs are fed boundary conditions from GCMs, which simulate the atmosphere-ocean circulation patterns that drive the inter-annual to decadal variability of the regional hydrologic regime. This mode of variability is important for distinguishing anthropogenic climate change from low-frequency natural variability and for water resource planning and management for infrequent events, such as sustained drought. Inter-annual variability and extreme hydrologic events, rather than long-term trends in mean runoff, present most of the challenge for managing watersheds and for designing and maintaining water conveyance and storage structures.

Data were used from 10 RCM experiments. Nine are from the North American Regional Climate Change Assessment Program (NARCCAP; narccap.ucar.edu), which produced a set of RCM simulations of the climate of the United States and most of Canada at a spatial resolution of 50 km (Table E-1). These RCM data consist of historical runs for the baseline period 1971–2000 and simulations of the climate of the future period 2041–2070. The driving GCMs were part of Phase 3 of the Coupled Model Intercomparison Project (CMIP3; Meehl et al., 2007; IPCC, 2013). These GCMs were forced for the 21st century by the relatively high A2 GHG emission scenario from the Special Report on Emissions Scenarios (SRES; Nakicenovic et al., 2000). Given recent emissions of GHGs at a rising rate (World Meteorological Organization, 2014), A2 is increasingly the most realistic emission scenario.

Table E-1: The nine North American Regional Climate Change Assessment Program RCMs and driving GCMs. Each regional climate simulation is labeled according to the "RCMgcm."

	Driving GCM				Acronym for RCMgcm pair
RCM	ccsm	cgcm3	gfdl	Hadcm3	
CRCM	x	x			CRCMccsm, CRCMcgcm3
ECP2			x		ECP2gfdl
HRM3			x	x	HRM3gfdl, HRM3hadcm3
MM5I	x			x	MM5Iccsm, MM5Ihadcm3
RCM3		x	x		RCM3cgcm3, RCM3gfdl

In addition to the nine NARCCAP RCM experiments, data from one run of the Canadian Regional Climate Model Version 4 (CRCM4) was used, which covers the North American region at a spatial resolution of approximately 25 km (Figure E-4). CRCM4 was nested within the Canadian Centre for Climate Modelling and Analysis Earth Systems Model Version 2 (cesm2). The cesm2 GCM was forced for the 21st century by RCP8.5, a Representative Concentration Pathway comparable to the SRES A2 GHG emission scenario. The CRCM4cesm2 run is part of the Coordinated Regional Climate Downscaling Experiment (CORDEX; Giorgi et al., 2009). CORDEX is the successor framework to NARCCAP, using the most recently developed RCMs and GCMs. The CORDEX GCMs are part of Phase 5 of the Coupled Model Intercomparison Project (CMIP5), a later generation of GCMs (Taylor et al., 2012).

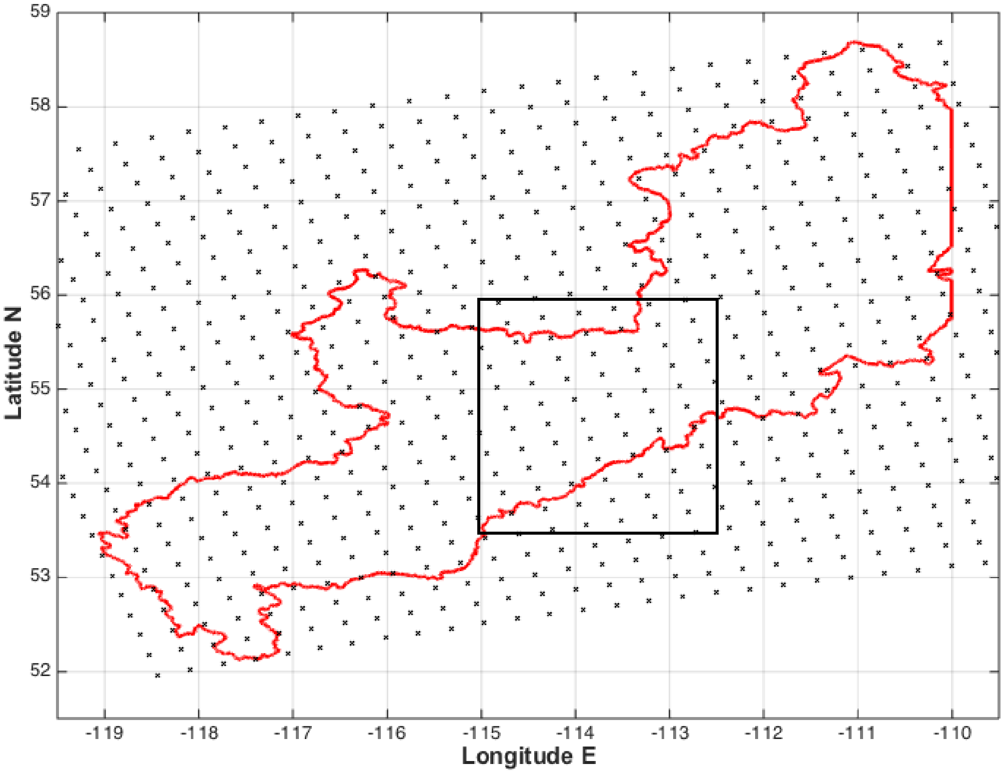

Figure E-4: The boundary of the ARB in red and the CRCM4 grid with a resolution of 25 km. Superimposed is a single 250 x 250 km GCM cell.

The historical and future weather generated by a RCM is saved at three-hour intervals for each of the points in the 50/25 km grid. The first stage of the study was to download the very large amount of data available for each of the RCMs over the 30-year historical (1971–2000) and future (2041–2070) periods. From this, matrix data were extracted for the grid points, shown in Figures E-3 and E-4, that fall within the boundaries of the ARB. These data were converted to daily values (precipitation in mm/day and mean temperature in °C) by averaging the three-hour output. This appendix presents climate change scenarios from the 10 RCM runs by plotting mean monthly, seasonal, and annual temperature and precipitation, and comparing the historical, future, and observed climates.

Figures E-5 and E-6 show output from the 10 RCM experiments in the form of two scatterplots, showing the projected differences in mean precipitation and temperature between1971–2000 and 2041–2070 for winter (Figure E-5) and summer (Figure E-6). Consistent with the historical trend plotted in Figure E-1, there is more warming in winter than summer. Both seasons are wetter. Only one of the nine models (but a different model in each season) projects less precipitation. As with the GCM climate change scenarios in Figure E-2, the range of projections in Figures E-5 and E-6 reflect differences between climate models and the internal natural variability in the regional climate regime. Unlike the GCM scenarios, however, all of the RCM simulations are based on the same or similar GHG emission concentrations (SRES A2 or RCP8.5).

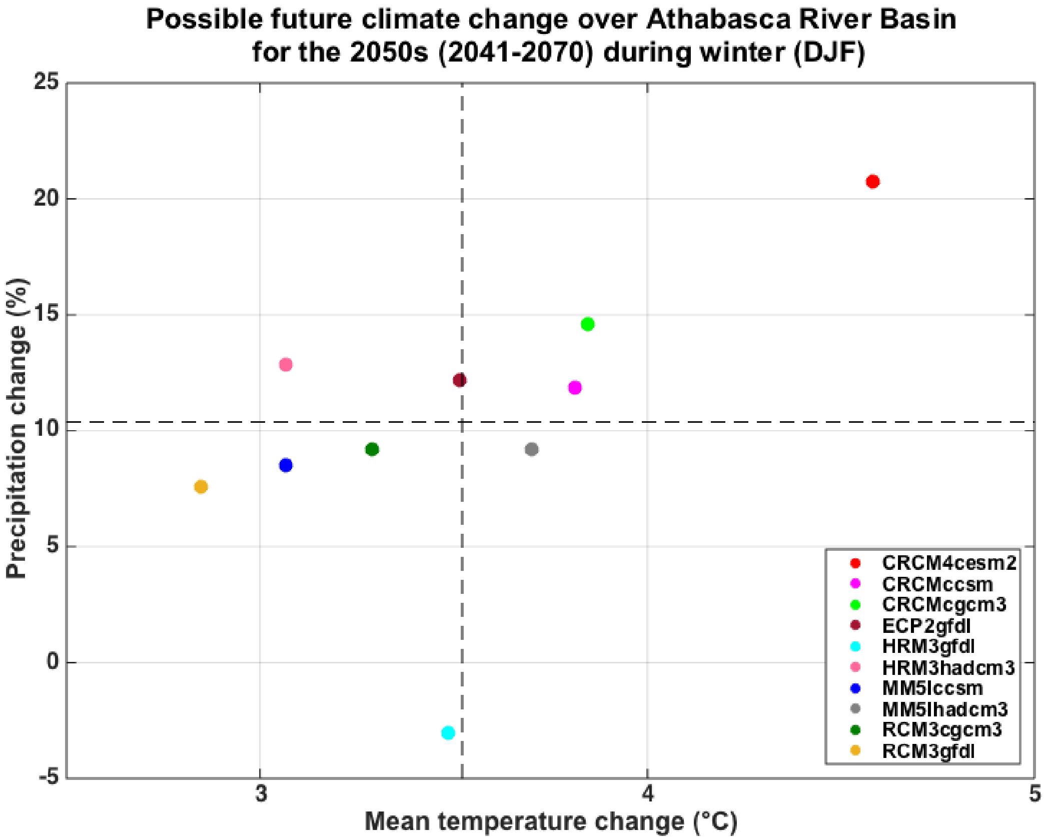

Figure E-5: A scatterplot of the 10 RCM climate change scenarios for the winter season. The changes are the difference in mean precipitation and temperature between 1971–2000 and 2041–2070.

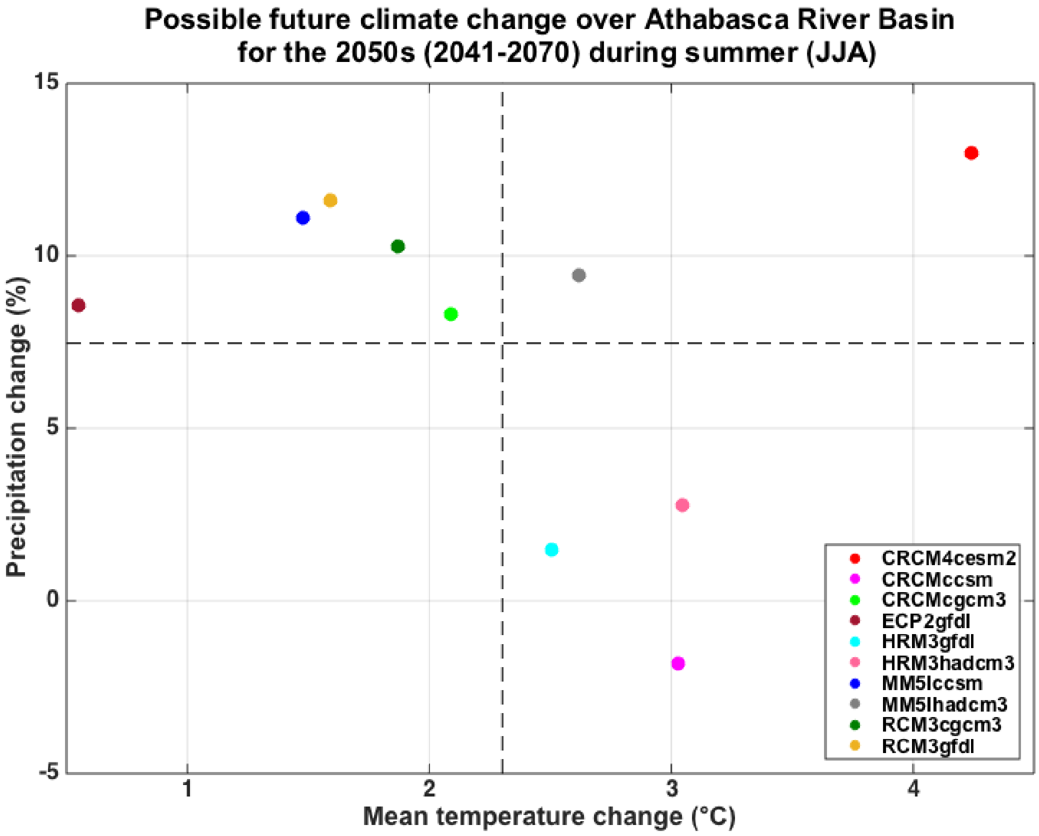

Figure E-6: A scatterplot of the 10 RCM climate change scenarios for the summer season. The changes are the difference in mean precipitation and temperature between 1971–2000 and 2041–2070.

Figures E-7 to E-10 are plots of mean monthly precipitation and temperature for the baseline and future 30-year periods. Also plotted is weather observations for the baseline period 1971–2000. These observed data were derived from the Canadian Gridded Climate Data (CANGRID, McKenney et al., 2011), a dataset that consists of temperature and precipitation observations interpolated from weather stations onto a 0.5° (~50 km) grid. Figure E-7 indicates that the RCMs are able to reasonably simulate the annual temperature cycle. More models underestimate monthly temperatures than overestimate them. A comparison of Figures E-7 and E-8 reveals higher future temperatures, particularly in the colder months (November–February) when all models but one project higher mean temperatures than observed in the recent past and simulated by the RCMs for the baseline period.

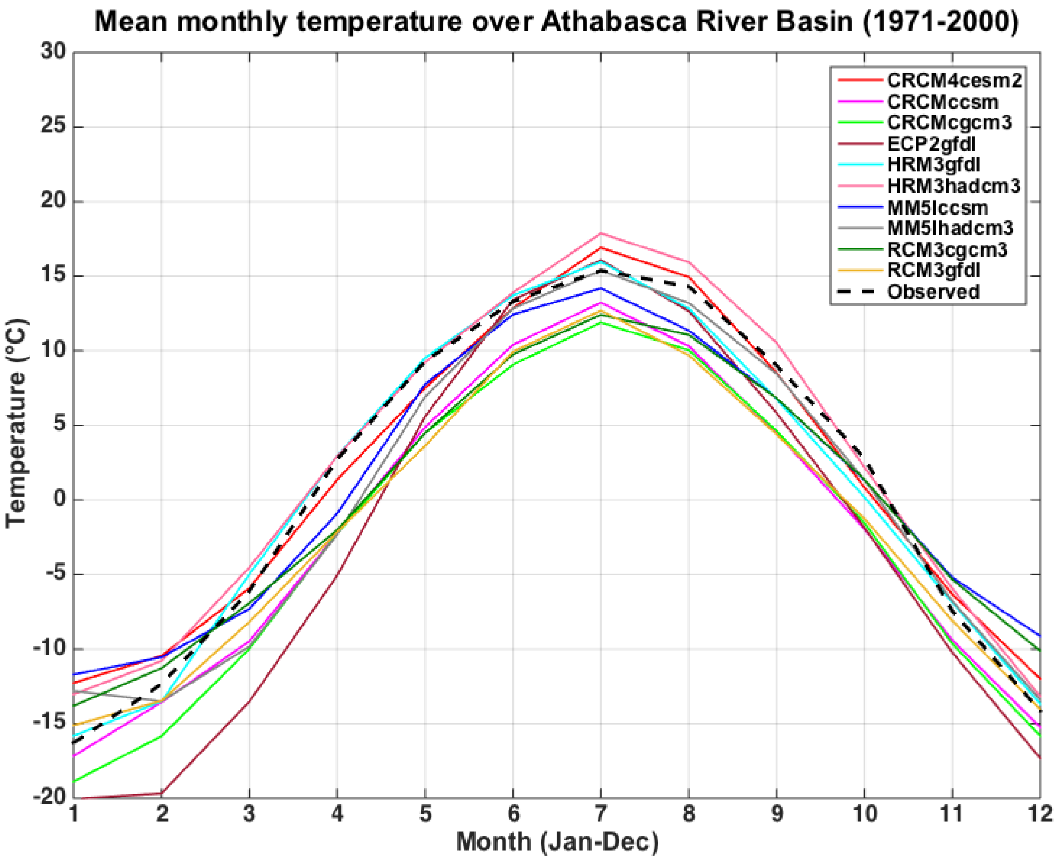

Figure E-7: Mean monthly temperature over the ARB recorded at weather stations (dashed line) and simulated by the 10 RCMs (colored lines) for the baseline period 1971–2000.

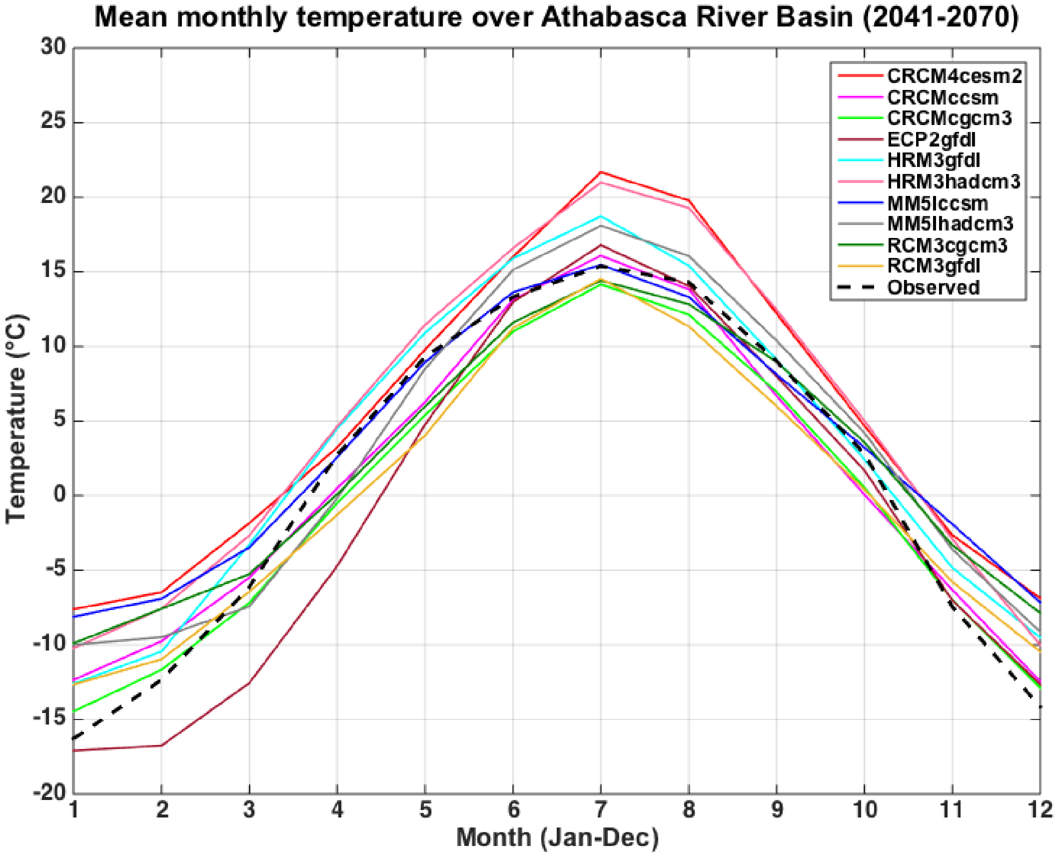

Figure E-8: Mean monthly temperature over the ARB recorded at weather stations (dashed line) and simulated by the 10 RCMs (colored lines) for the future period 2041–2070.

Figure E-9 demonstrates that the RCMs have difficulty simulating mean monthly precipitation (mm/day). This is common to all climate models, not just RCMs. Whereas mean temperatures are directly related to the earth's energy balance, and the anthropogenic forcing imposed by a change in the concentration of GHGs, precipitation is a process very much linked to the coupled dynamics of the ocean and atmosphere. Also regional precipitation is very much driven by the internal natural variability of the climate system and the large-scale circulation of the ocean and atmosphere—phenomena like the El Niño Southern Oscillation. The RCMs do capture the seasonal cycle of precipitation in the ARB, but they all overestimate winter snowfall, and some of the models significantly underestimate summer rainfall. Given this uncertainly in the modelling of regional precipitation, a climate change scenario should be based only on the relative differences between runs of the same model. A comparison of model outputs between Figures E-9 and E-10 indicates that the RCMs project more precipitation in all months, but especially in winter and early spring. There is also a shift in maximum monthly precipitation to June from July.

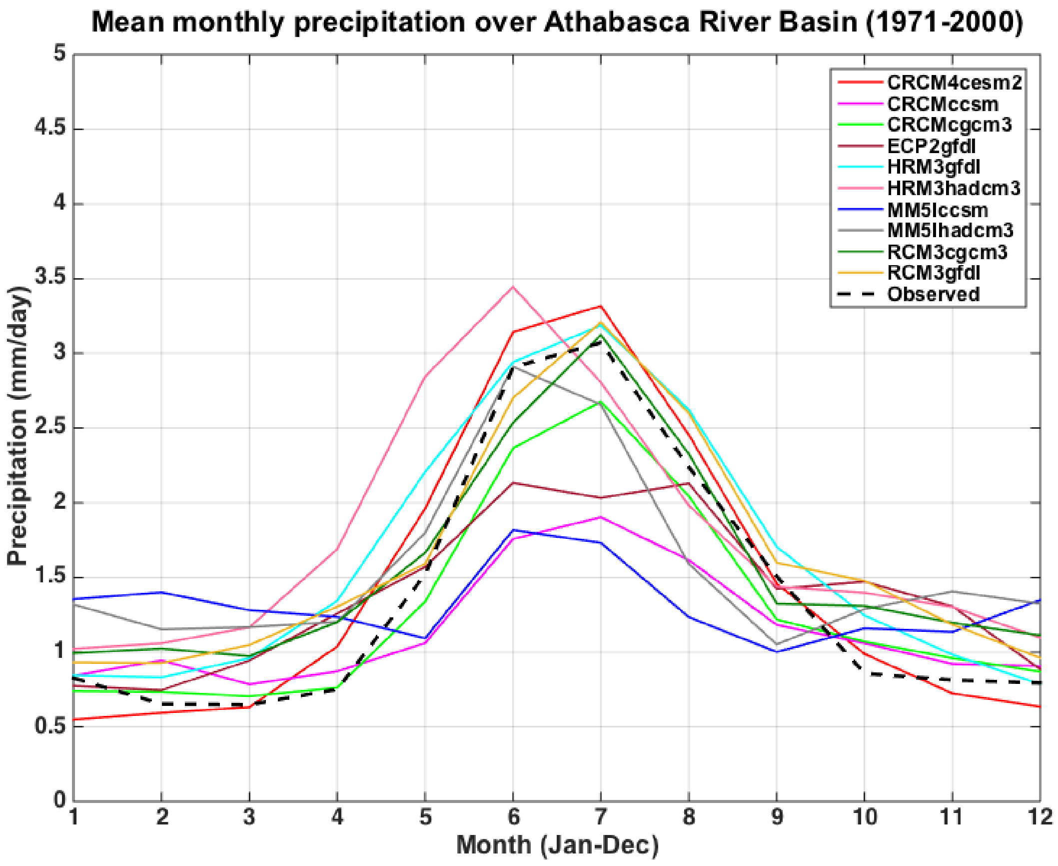

Figure E-9: Mean monthly precipitation over the ARB recorded at weather stations (dashed line) and simulated by the 10 RCMs (colored lines) for the baseline period 1971–2000.

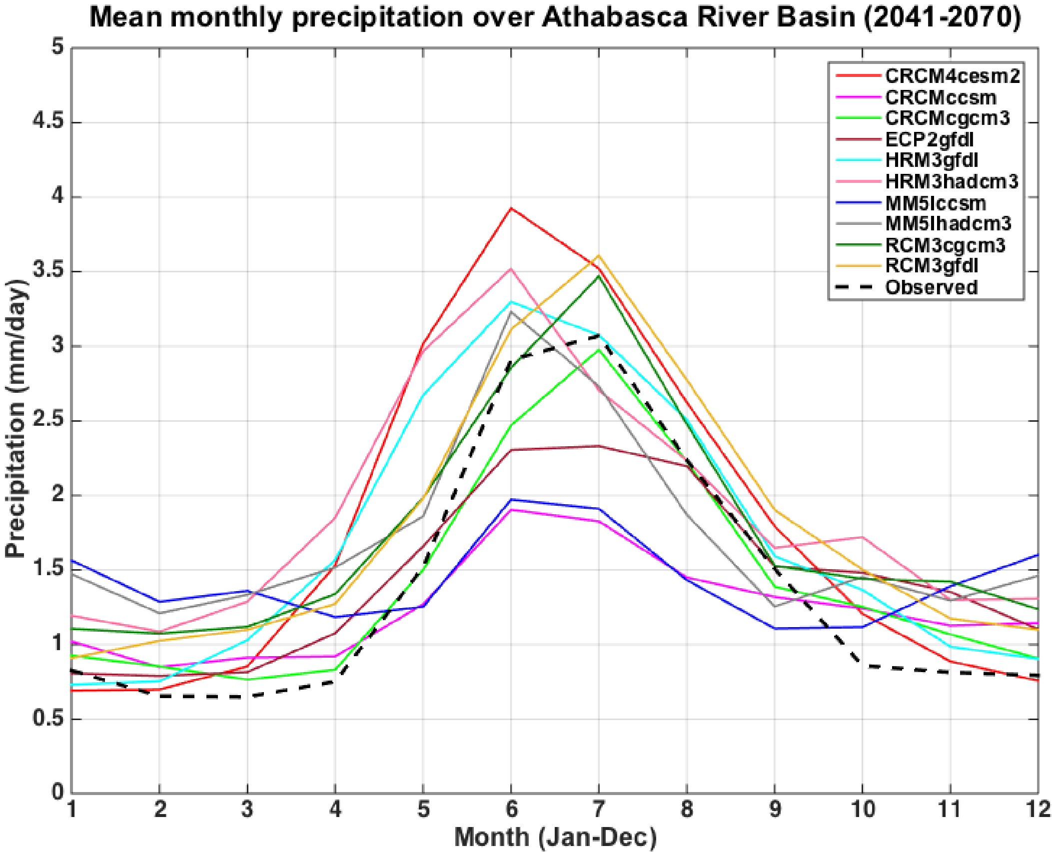

Figure E-10: Mean monthly precipitation over the ARB recorded at weather stations (dashed line) and simulated by the 10 RCMs (colored lines) for the future period 2041–2070.

This appendix has presented outputs from 10 RCM/GCM experiments for the ARB. To illustrate trends and projected climate changes, mean monthly, seasonal, and annual data were plotted. Data from three of the 10 models were used to capture and provide a range of projections of future climate. Figure E-11 illustrates how these three models were chosen from a scatterplot of the changes in annual precipitation and temperature projected by the 10 RCM experiments. The circled RCMs project the least, median, and most changes in temperature and precipitation.

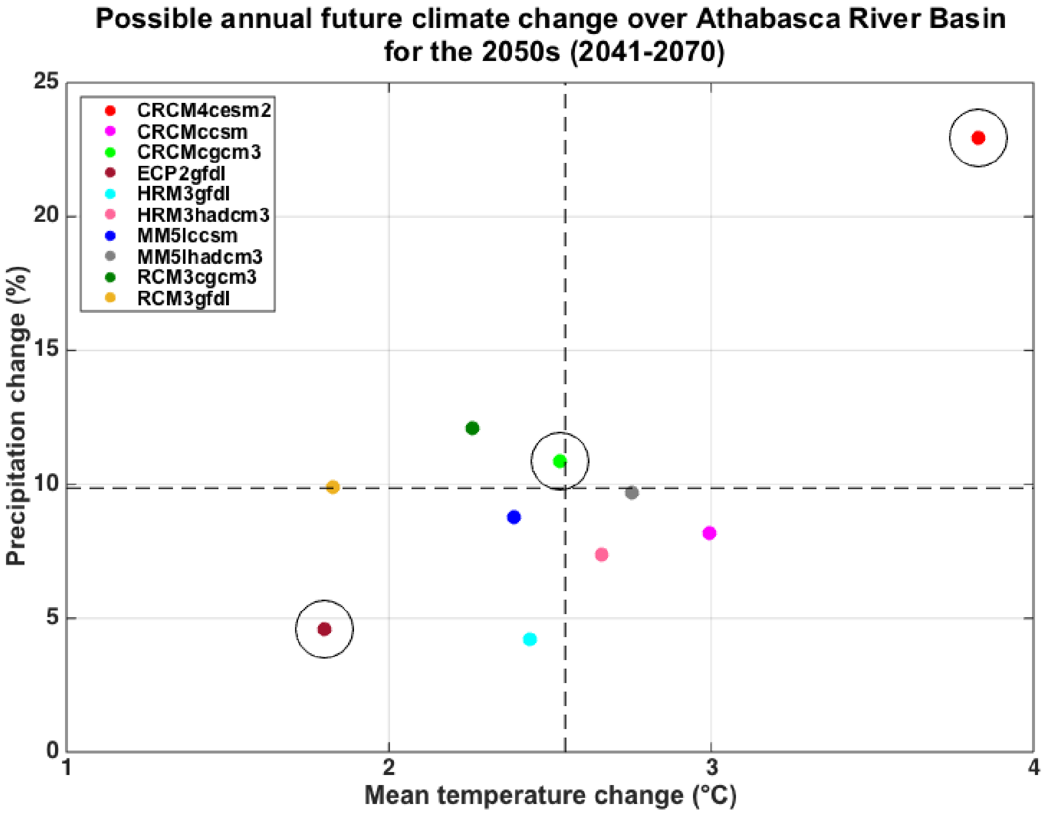

Figure E-11: A scatterplot of the 10 RCM climate change scenarios. The changes are the difference in annual precipitation and temperature between 1971–2000 and 2041–2070. The purpose of this scatterplot was to identify the circled RCMs that simulate the least, median, and most changes in temperature and precipitation.

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