Alberta Innovates

A Roadmap for Sustainable Water Management in the Athabasca River Basin

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List of Acronyms

AEP	Alberta Environment and Parks
AI	Alberta Innovates
AIRM	Athabasca Integrated River Model
ARB	Athabasca River Basin
AUC	Alberta Utilities Commission
AXF	Aboriginal Extreme Flow
BMP	Best Management Practice
CAPP	Canadian Association of Petroleum Producers
CEP	Conservation, Efficiency and Productivity
m^3/s	Cubic meters per second
COSIA	Canadian Oil Sands Innovation Alliance
CPAWS	Canadian Parks and Wilderness Society
dam^3	Cubic decameter
DUC	Ducks Unlimited Canada
FMA	Forest Management Agreement
GoA	Government of Alberta
IFN	Instream Flow Needs
LAR	Lower Athabasca Region
LARP	Lower Athabasca Regional Plan
NPV	Net present value
PAD	Peace-Athabasca Delta
PM	Performance Measure
SWQMF	Surface Water Quantity Management Framework
TDL	Temporary Diversion Licence
TRC	Truth and Reconciliation Commission
UNDRIP	United Nations Declaration on the Rights of Indigenous Peoples
WPACs	Watershed Planning and Advisory Councils
WRPP	Watershed Resilience and Restoration Program

Executive Summary

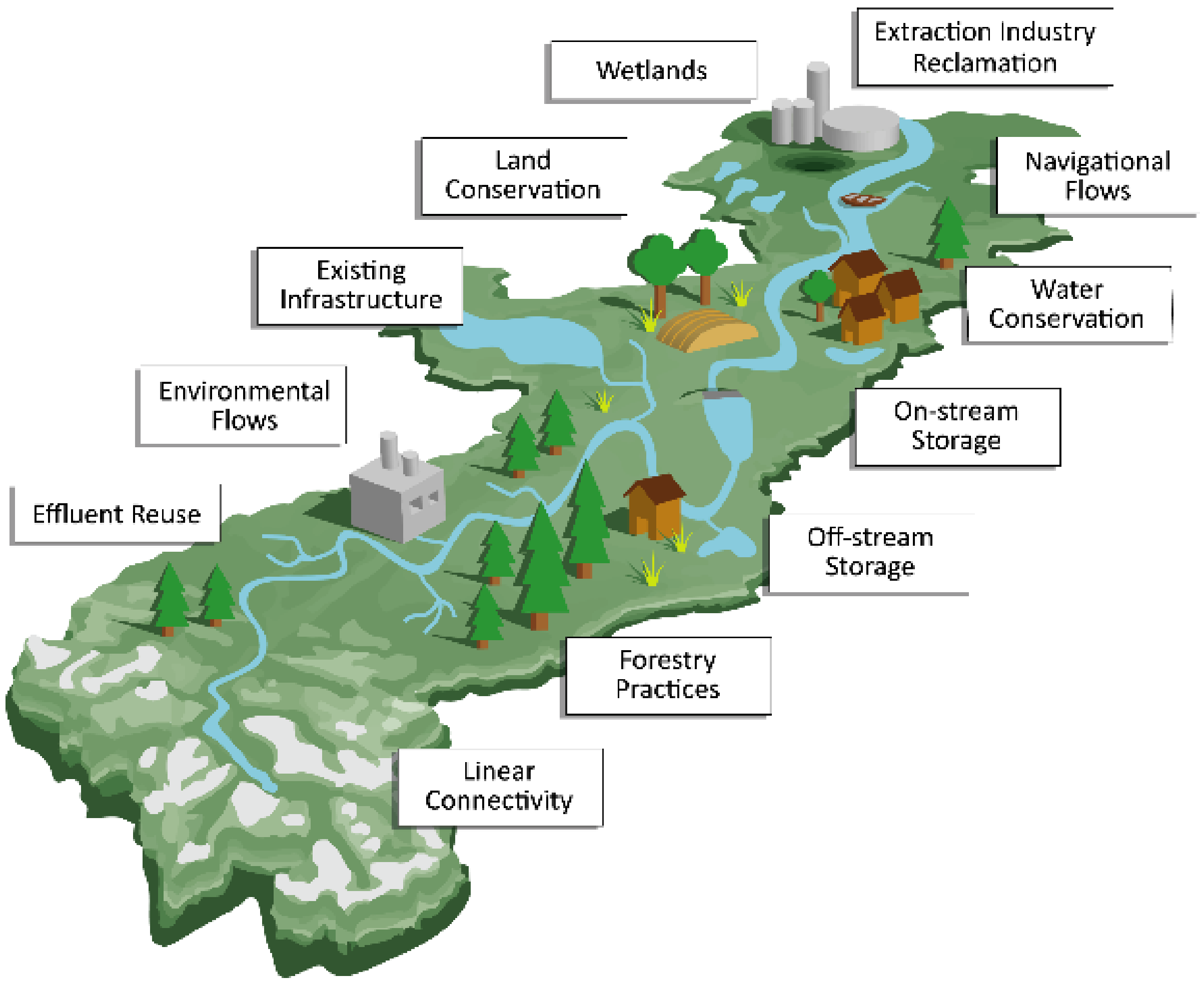
The Sustainable Water Management in the Athabasca River Basin Initiative (the ARB Initiative, or Initiative) was designed to identify water management issues, assess opportunities, and propose ways to build resilience to change. It examined the quantity of surface water in the Athabasca River mainstem and major tributaries, considering the potential implications of changes in basin landscape and changes in climate on streamflow. Although water quantity is not presently a high-profile issue in the ARB, that does not mean the watershed isn't under pressure or at risk. Without active and ongoing management of human activities, the basin cannot escape the effects of climate change or the negative cumulative impacts of landscape change.

The natural attributes and resources of the ARB have long attracted settlement and development. They represent a rich and diverse ecological heritage and many of these features are important to the region's identity. Industrial development, including agriculture, urbanization, livestock production, forestry, coal mining, oil and gas, and oil sands has occurred across the ARB, with varied intensity. The total footprint of these human activities shows the most extensive activity in the Pembina River area, the Lesser Slave Lake area, and the Fort McMurray area. For centuries, the ARB has been home to and of importance to Indigenous Peoples. Traditional uses of the land include hunting, gathering, community development, and ceremony.

The Athabasca River system is large and complex, passing through four distinct Natural Regions. The basin is interconnected hydrologically as water flows through its river network from the headwaters to the Peace-Athabasca Delta. Streamflow in the ARB generally follows a snowmelt-dominated regime. Streamflow is low during the cold winter months, peaks during the spring due to snowmelt, and tapers off throughout the summer and into the fall as the winter snowpack and soil water storage are depleted. Although streamflow is naturally variable, it has generally declined over recent decades. Potential future climate change in the form of changing patterns in precipitation and air temperature poses a challenge for water management in the basin. Scenarios suggest that the timing of spring streamflow will shift to earlier in the season and that there may be a general increase in annual streamflow, although with reductions during the summer and fall. Glaciers are an important late-season source of water for the Athabasca River, but over the long term, they will contribute less and less as the ice recedes. Overall, the longer-term hydrologic regime in the ARB is likely to be different from today and water management strategies must be adapted to these potential future conditions.

An inclusive and diverse Working Group comprising representatives from across the basin openly shared knowledge, experience, perspectives, and ideas for a well-managed watershed in the ARB. They used a collaborative modelling process and an integrated modelling tool (the Athabasca Integrated River Model, or AIRM) to inform and drive the discussion. The AIRM enabled the Working Group to explore mitigation, adaptation, and management opportunities in response to a range of potential climate, land use, and development changes in the ARB. Participants, many of whom had disparate goals and interests, could examine how individual or cumulative changes in land use, climate, and river systems affected water availability, and identify strategies that satisfied their objectives. Performance measures developed by the Group were used to review the modelling results and assess the strategies.

The Working Group identified 10 challenges facing the region and subsequently proposed 12 strategies to address them. The modelling was used to illustrate the strategy and results and to support discussion on the benefits, trade-offs, implementation feasibility, and an assessment as to whether the strategy was most promising, least promising, or uncertain. The 12 strategies are shown schematically and listed below; they were not ranked or prioritized.



Effluent reuse: Enable reuse of industrial or municipal effluent to reduce reliance on freshwater
Water conservation: Continue to achieve water conservation and efficiency improvements as communities develop
On-stream storage: Explore new on-stream multi-purpose storage options
Off-stream storage: Develop new and existing off-stream storage sites to meet multiple basin water management objectives
Existing infrastructure: Alter existing water storage infrastructure and operations to meet multiple basin water management objectives

Environmental flows: Establish instream flow needs or similar targets for all tributaries in the basin as a precautionary water management measure
Navigational flows: Implement minimum flows to improve navigation in the lower Athabasca basin
Land conservation: Increase the quantity and improve the condition of conserved and restored land across the basin
Forestry practices: Support practices in Forest Management Agreements that minimize hydrologic change
Wetlands: Avoid further wetland loss and functional impairment and promote more wetland restoration, education, and best management practices focused on minimizing impacts
Linear connectivity: Reclaim or deactivate linear features and reduce future linear disturbances in watersheds
Extraction industry reclamation: Continue to set and meet high standards of reclamation of extraction footprint to maintain or improve hydrological functions in a watershed

Through informed discussions with the Working Group, a number of related learnings emerged and were explored. These learnings were facts or observations about the basin and water management that either supported or provided a counterpoint to commonly held perceptions. For example, there is a commonly held perception that industry withdraws and consumes a large portion of the water in the Athabasca River and its tributaries every year. In fact, of the approximately 19.5 billion m^3 that flows annually in the Athabasca River (based on data from 1971 to 2015,) only up to ~835 million m^3 of water can be withdrawn across the ARB from surface water sources (rivers, streams, lakes) in a year. Through more than a thousand water diversion licences, these withdrawals support a range of uses including industrial, commercial, agricultural, municipal and others. These learnings add to the information and platform of knowledge that offers a reference point for water questions in the basin.

The Working Group concluded its activity by proposing six recommendations for sustainable water management in the ARB.

1. **Maintain or improve the natural hydrological functions of the watershed**
   - ***to protect water supply, water quality, and watershed health***
   - ***by embedding hydrological priorities in land use planning and enforcement at the regional, sub-regional, and local scales.***

   Implementable actions:
   - Identify sites of highest conservation and restoration priority that would have the greatest positive impact on peatland complexes, tributaries, and connectivity
   - Improve understanding of the location and overall function of hydrologically sensitive wetlands
   - Fill data and science gaps by increasing the understanding of how changes in hydrologic connectivity affect water volumes
   - Support and inform conservation and restoration areas in future land use plans and ongoing planning

2. **Establish environmental flow needs for the Athabasca River and all tributaries**
   - ***to clarify flows needed for watershed health and volumes available for use***
   - ***by calculating and publicly communicating reach-specific IFNs or similar targets.***

   Implementable actions:
   - Establish IFN targets for all streams and rivers, likely using a modified Alberta Desktop Method
   - Communicate broadly, in an accessible way, all IFNs that are calculated for the ARB

3. **Reduce water navigation limitations in the lower basin**
   - ***to maintain traditional access and activities***
   - ***by recognizing that further minimum flow targets are unlikely to provide navigational flows and, instead, employing a suite of alternative methods.***

   Implementable actions:
   - Investigate potential for instream structures to increase water depth in specific locations
   - Better understand navigation channels and their changes through time and consider select channel management including targeted dredging
   - Investigate the potential for investment in alternate water craft and provision of year-round road access

4. **Increase the adaptive capacity of the basin**
   - ***to be more resilient to climate change impacts on water supply while meeting multiple basin needs***
   - ***by investigating multi-purpose infrastructure to manage the flow regimes of the Athabasca River and major tributaries.***

   Implementable actions:
   - Establish multi-purpose objectives for new projects to understand and inform how future storage could support basin flow needs

5. **Continue to develop the means to share and apply Traditional Knowledge**
   - ***to lend the experience and expertise of Indigenous Peoples to formal sustainable water management in the basin***
   - ***by developing and enabling meaningful processes that support the UNDRIP and TRC mandates.***

   Implementable actions:
   - Example: collect and share a dataset of traditional sites in the ARB

6. **Address the most critical gaps in water data, processes, policy, and knowledge**
   - ***to better inform sustainable water management***
   - ***by prioritizing and closing gaps most critical to the ARB.***

   Implementable actions:
   - Continue to provide resources, budget, and mandate to AEP in its work to publicly and efficiently share already existing water data

- Find and invest in the instrumentation solution to provide near real time measurements under ice flow
- Complete and implement the provincial water reuse policy that is currently under development to change, clarify, or create clear direction for decisions on water reuse
- Resource and incentivize water communication to inform sustainable water management decisions individually, organizationally, and collectively
- Close the gaps between Traditional Knowledge, culture, and society through inclusion of Traditional Knowledge into policy

Collectively, these six recommendations touch on each of the water challenges identified by the Working Group, as seen in the table below.

Challenges	**Recommendation**					
	1	**2**	**3**	**4**	**5**	**6**
Maintaining or improving ecosystem health	√	√		√	√	√
Providing water supply certainty for development		√		√		
Minimizing the effect of the development footprint on basin hydrology	√	√			√	√
Ensuring sufficient flow for navigation			√		√	
Limiting damage from floods or extreme events				√		
Maintaining or improving the health of the Peace-Athabasca Delta		√		√	√	√
Addressing concerns around Indigenous rights		√	√		√	
Accessing water-related data and knowledge in the basin					√	√
Maintaining or improving water quality	√	√				√
Understanding the renewable energy potential of the basin				√		

The ARB Initiative provides a foundation for improved dialogue and more adaptive, sustainable, and holistic watershed planning and management, including both water and land use. It supports cumulative effects assessments and accessible and transparent information on basin water resources and management. The resulting strategies, recommendations and practical actions form a Roadmap for Sustainable Water Management in the ARB to inform and guide planning and future management efforts in the basin.

Many individuals and organizations feel an urgency to address water challenges in the basin and to be more proactive with future approaches to water management. Decisions, actions, and inactions today are affecting the long-term sustainability of the basin; there is a need to determine what is wanted for the basin in the long term, and act accordingly.

1.0 Introduction

1.1 Context

Proactive and informed water management requires a clear understanding of how future climate and land use changes can affect water resources, the users who depend on them, and Alberta's ability to respond and adapt. To add to the challenge, Alberta will continue to experience droughts, flooding, and increased pressure on surface water and groundwater quality and supplies due to population growth, economic development, and changing environmental management practices.

Through this Initiative, ten challenges to surface water management in the Athabasca River Basin (ARB) were identified:

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

Decisions and actions today are likely to impact the long-term sustainability of the basin; there is an opportunity to get ahead of the curve and provide the information and knowledge to determine what is wanted for the long-term needs of the basin and those who use it. Addressing water challenges is urgent and requires being proactive based on what is known about the current situation and planning for the future, while keeping in mind the ongoing needs in the basin. The urgency to take action on sustainable water management in the ARB is driven in part by several recent factors:

- Long-term regional land use plans are being developed for the ARB.
- The global shift to a low-carbon economy is forcing diversification, beyond oil and gas, throughout the province.
- Municipalities and Indigenous communities continue to seek residential, commercial, and industrial growth.
- Alberta's Climate Leadership Plan is pressing for more renewable energy and the ARB offers substantial hydro-electric energy potential.
- Regulatory frameworks are demanding that reclamation plans for oil sands be set and begun early in a project's life cycle.
- The Joint Reactive Monitoring Mission to Wood Buffalo National Park by UNESCO World Heritage Centre and the International Union for Conservation of Nature and subsequent reports.

- Mandates related to the United Nations Declaration on the Rights of Indigenous Peoples and the Truth and Reconciliation Commission are shifting Indigenous involvement and expectations including capacity, consultation on their traditional lands of the watershed, and opportunities for growth.

Decisions, actions, and inactions today are affecting the long-term water resource sustainability of the basin. There is a need to determine the long-term vision of water management held by basin residents and stakeholders. The Sustainable Water Management in the Athabasca River Basin Initiative (the ARB Initiative or Initiative) was a proactive project that used a collaborative process with an inclusive Working Group to simulate and discuss strategies that would support basin-wide water management. Through the lens of sustainable water management, the project began to answer the question: Considering the many interests and perspectives in the basin, how do we move forward as a basin to have sustainable water resources for all in the future?

1.2 Project overview

The ARB Initiative was an innovative project to identify water management issues, assess opportunities, and propose strategies to build resilience to change. This process has been used in other river basins in Alberta and it is envisioned that, following this project, the whole Slave River system (Athabasca, Peace, and Slave River Basins) could be examined in a similar manner. This work was done to provide a foundation for improved dialogue and more holistic watershed planning, recognizing that water and land management and planning go hand in hand.

The scope of the ARB Initiative was surface water quantity in the Athabasca River mainstem and major tributaries. It considered the implications of changes in streamflow, focusing on water management within the context of landscape and climate change. Although water quantity is not presently seen by many as a significant issue in the ARB, that does not mean the watershed isn't under pressure or at risk. Without active and ongoing management of human activities, the basin cannot escape the effects of climate change or the cumulative effects of landscape change due to forestry, agriculture, urban development, mining, oil and gas, and hydroelectric development. Further, the spatial footprint of these activities does not directly reflect the impact on hydrology and water quality throughout the basin and over time.

The ARB Initiative aimed to provide a foundation for supporting cumulative effects assessments, adaptive and sustainable basin water management and planning, and accessible and transparent information on water resources and management. The Working Group used a collaborative modelling process and an integrated modelling tool to inform and drive conversations regarding water management in the ARB. The resulting strategies and practical actions offer a Roadmap for Sustainable Water Management in the ARB, which is intended to inform planning and future management efforts.

The Roadmap, once published, is expected to be of value to the broad water community in the basin, including the Government of Alberta, Indigenous communities, and other water users. It is the hope and expectation of everyone involved in this project that the outcomes will serve to further the development and ongoing improvement of planning, policy, and management of water in the ARB by government, industry, organizations, and communities.

Watershed health is inextricably linked to the ability to be resilient under changing climate and landscape conditions. The ARB will be challenged by converging interests due to changes in climate and land use, economic growth, and subsequent cumulative effects in the basin. Although this work focused on the entire basin, with proper resources this modelling approach can be used to examine smaller spatial scales as well.

1.3 Process methodology for the ARB Initiative

1.3.1 Process

Engagement in the ARB Initiative focused on creating an inclusive and diverse Working Group made up of participants from across the watershed with different perspectives (see Appendix A). This approach established a diverse and informed group that could speak to the issues and opportunities around surface water quantity and effects of change in the ARB on water supply and demand. The following were invited to participate in the Working Group:

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

The eventual Working Group included representatives from across the basin from various industry sectors, governments, municipalities, environmental non-governmental organizations, WPACs, First Nations, and Métis. Participants were driven by different water management goals, needs, and business objectives but all openly shared their knowledge, experience, perspectives, and ideas for a well-managed watershed in the ARB.

The collaborative approach exposed the Working Group to an integrated modelling tool in a transparent and open process to explore mitigation, adaptation, and management opportunities in response to a range of potential climate, landscape, and development changes in the ARB. These changes potentially mean streamflow changes for the rivers in the basin (e.g., more variable timing or volume of flow), which are reflected by changes in contribution (runoff), water demands, and water use. The collaborative modelling process enabled Working Group members with disparate goals to assess and explore issues and opportunities and develop solutions that mutually satisfied their objectives.

The integrated model, named the Athabasca Integrated River Model (AIRM), is a representation of the ARB water resource system. It incorporates the landscape system, the hydrologic system, the climate system, and the river management system, and 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 can be used to demonstrate the effects of changes in land use, climate, or water use on the water resources in the ARB and was used throughout the Initiative with the Working Group to create a transparent and accessible modelling tool that the Working Group could understand, access, and trust.

Through the collaborative modelling process, the Working Group used the AIRM to simulate the current basin condition and examine a range of potential effects on water quantity, and to some degree water quality, from changes in climate and landscape in the ARB. This process enabled participants to see their individual and collective interests reflected on a larger, basin-wide scale. The model outputs were used to inform the discussion and develop opportunities that addressed or supported the challenges the group wanted to focus on. These opportunities were refined, assessed, and sorted to develop strategies that shaped the Roadmap for Sustainable Water Management in the ARB. Many ideas were not evaluated further because they were deemed outside of the scope of this work, or there was not sufficient data or resources to explore them (see Appendix D). The Initiative did not prioritize strategies or projects or lay out an implementation plan, but rather has identified gaps and next steps for sustainable water management in the ARB. The Roadmap is a guidance document, not a basin plan, and reflects the discussions of the Working Group. Participation in the Working Group is not considered consultation and the outcomes are not a reflection of a decision-making body.

1.3.2 Meetings

The Working Group met eight times between December 2016 and March 2018, coming together to understand the scope of work, discuss and simulate challenges and opportunities, and work towards a Roadmap for sustainable water management in the ARB.

The meetings were structured to first create an understanding of the basin today and to identify and assess challenges and opportunities as gathered and heard to date, including potential effects of changes in climate and effects of landscape changes on streamflow in the ARB. Subsequent meetings allowed for the assessment of opportunities and their subsequent refinement into strategies, which were then categorized as having more or less promise. The Roadmap was framed and drafted, and recommendations developed and vetted by the group in the final meeting. The process is summarized in Figure 1.

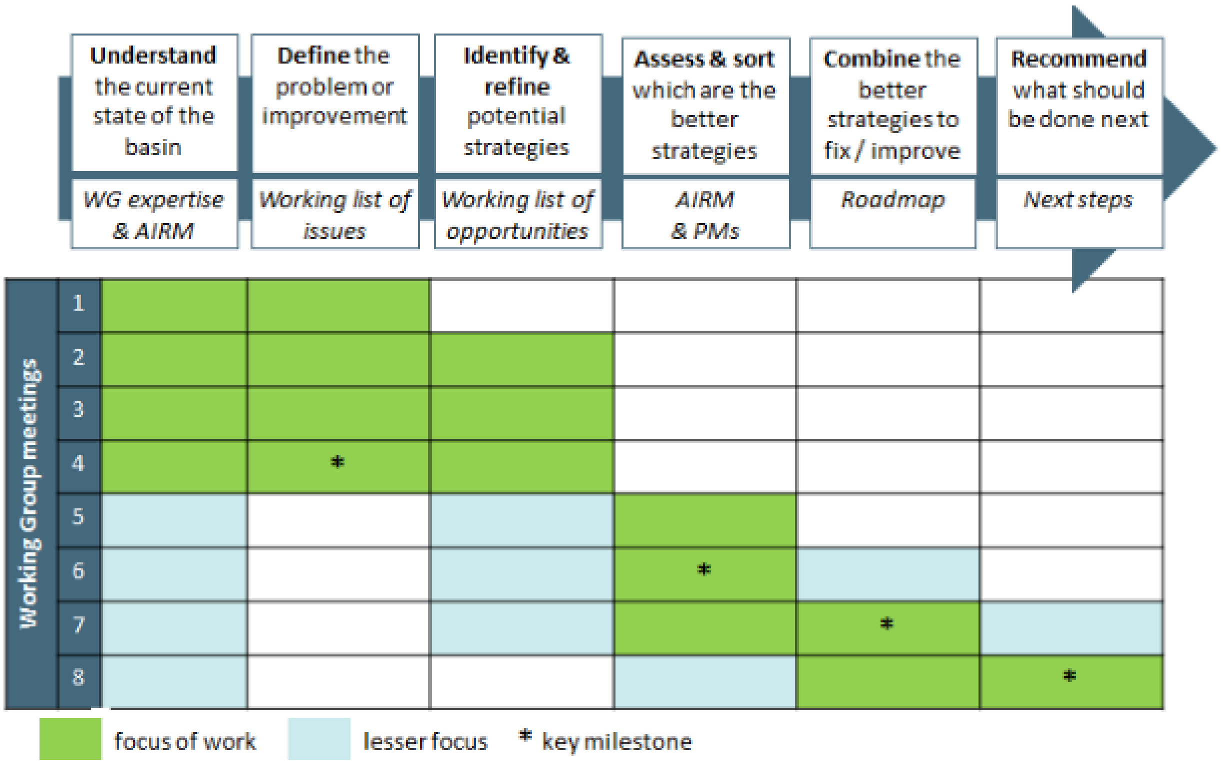


Figure 1: The process of how the Working Group went from an understanding of the basin to the Roadmap.

1.3.3 Additional engagement with Indigenous communities

To include broader perspectives of First Nations and Métis communities and capture their water issues through the ARB Initiative process, invitations for sharing sessions were extended to these groups within the ARB, to be scheduled as in-community sessions in the spring and summer of 2017 and 2018. Seven sessions were requested and conducted with representatives in the lower part of the basin. Sessions took place in the Fort McMurray, Fort Chipewyan, and Lac La Biche areas. These included conversations with Métis groups from three different communities and a session with three First Nations. Some of the 2018 sharing sessions were held to follow up with the same communities from the first set of sharing sessions in 2017.

In these sessions, community representatives presented their water-related concerns. The concerns fell broadly into three categories: water quantity, water quality, and ecosystem health. The latter two topics were arguably the overarching areas of concern with respect to water; similar concerns were raised during Working Group sessions, but these were not the focus for the ARB Initiative.

Regarding water quantity, sharing session participants brought up their concerns for instream flow needs for fish habitat and navigation. These quantity issues were linked to water quality concerns in that low flows were recognized as exacerbating water quality problems in some geographical areas. Further, it was noted that streamflow data were unavailable in areas around Fort Chipewyan, with community members citing the lack of local streamflow gauges and monitoring of lake levels in the area.

Other specific local issues were highlighted and included concerns for access to fish and, in the case of Fort Chipewyan, the loss of the commercial fishery was conveyed as a major concern along with frustration at the lack of information regarding reasons for its official closure. Lake levels were also reported to be dropping and were associated with degraded water quality and unhealthy fish populations; communities have described mass fish die-offs. Also associated with water quality is concern about a lack of trust in the quality of drinking water. In the case of Fort Chipewyan, community members linked the rare cancers found in their community to the water supply and advised against consuming local water. Overall ecosystem health was of concern, with specific mention of impacts from changes in water quality on fisheries and on ungulate health; members of the Fort Chipewyan community explained that government officials are now advising against the consumption of organ meat of hunted species. Others noted the observed changes over time in the loss of species along trap lines in portions of the lower Athabasca watershed, indicating an issue with unhealthy food or water sources for these species.

Along with providing more detail and insight into the water concerns of the communities, these conversations supplemented and substantiated the information collected for further exploration by the Working Group. Concerns about water quality and ecosystem health were most often cited. The communities shared their observations of changes in their environment over time, many of which were also noted by Working Group participants. Flow and water levels of local tributaries and lakes were of concern for navigation and for access to land and food-based resources. Discussions also highlighted the need to have comprehensive, trusted, and comparable data sets to provide information for better water management in the basin.

1.4 The Athabasca Integrated River Model (AIRM)

The AIRM is an integrated model that links climate, landscape, hydrologic, and river system modelling to water supply and demand in the Athabasca River (see Figure 2). The integration of these distinct components allows for changes in one component, or multiple components, to affect water availability. This tool enabled the Working Group to design any number of strategies to examine how individual or cumulative changes in land use, climate, and river system management (such as changes to infrastructure or water usage) affected water availability in the ARB. Please see Appendix B for summaries of each of the components of the AIRM.

While this integrated modelling approach offers considerable flexibility, the AIRM has several important limitations:

- The AIRM simulates surface water quantity and cannot simulate the effects of potential changes to deeper groundwater flows, water quality, and ecosystem health, among others.
- The AIRM was designed to provide high-level estimates of regional water supply and demand and provides simulations at pre-determined points of interest along the Athabasca River and major tributaries.
- Given the large geographic extent of the ARB, AIRM was designed to simulate larger sub-basins and the mainstem of the Athabasca River.

- The AIRM employs a sub-basin routing approach, which means that it does not account for the movement of water within a sub-basin, only between sub-basins. Thus, the model does not account for localized processes that affect water flow and routing such as hydrological connectivity, ice jams, beaver dams, and road network fragmentation.

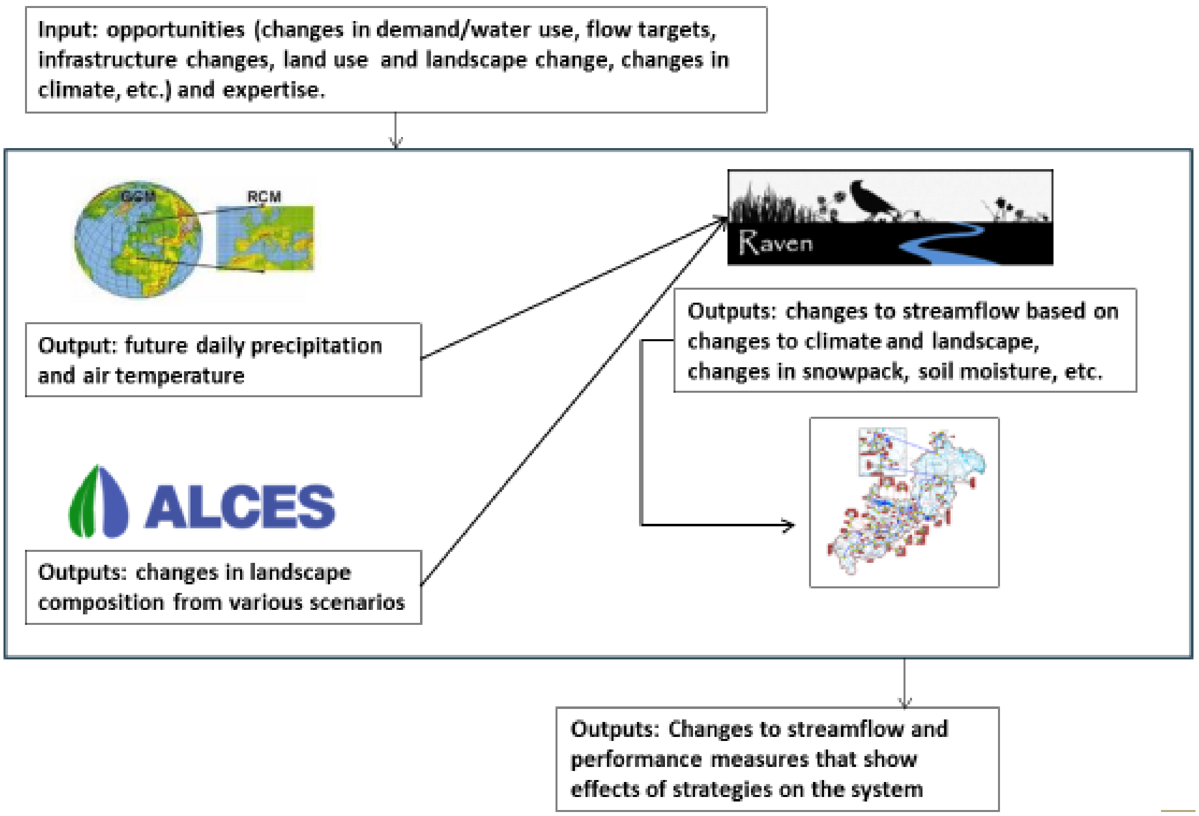


Figure 2: The AIRM and its components, how they fit together, and inputs and outputs relative to use by the Working Group.

1.4.1 Base case

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 explored. The base case represents the existing watershed, incorporating current landscape composition and operating practices. It was modelled using rules based on licensed priorities and water management plans and frameworks, and historical climate data from 1971 to 2015 (45 years). The base case AIRM implies that all current infrastructure and demands were present in the basin for the entire period from 1971 to 2015 (i.e., infrastructure, operations, and developed land remain constant).

The AIRM represents the basin today, based on available data and information to date. Base case simulations were verified against historical streamflow and lake level records, and generally displayed good agreement at several locations over the historical period (see Appendix B, Section B.3, Table B-4 for a full list of model evaluation statistics). The model performance was deemed adequate for the purposes of this project, demonstrated with a Nash-Sutcliffe Efficiency for the Athabasca River mainstem at the end of the system (Athabasca River at Embarras), including all operations and streamflow simulations, of approximately 0.7. The AIRM and the performance measures that were developed provide a robust means of evaluating direction and magnitude of hydrologic change within the basin, a primary focus of this work.

1.4.2 Stress tests

Two stress tests were designed to test how sensitive the strategies were to changes from the base case conditions. These two tests, Dry Scenario and Wet Scenario, simulated extreme conditions relative to the base case that would have a large effect on streamflow, and therefore stress the natural function and infrastructure within the ARB. Due to the length of simulated climate change data, these stress tests were run for a period of 30 years and were compared to a historical period (1986 – 2015).

The Dry Scenario was designed to simulate the effect of extremely dry conditions in the ARB. This scenario consisted of altering the climatology to emulate an extended drought similar to what was outlined in Sauchyn et al. (2015), simulating severe glacier recession to late-21st century levels, simulating substantial wetland degradation, and doubling industrial and municipal water usage.

The Wet Scenario was designed to simulate the effect of substantially wetter and warmer conditions in the ARB. This scenario consisted of altering the climatology to reflect the mid-21st century (2040 – 2070) climate under moderate climate change (see Appendix B), simulating a large forest fire in the Athabasca River headwaters upstream of Hinton, simulating moderate glacier recession to early 21st century levels, and doubling industrial and municipal water use.

2.0 Facts about the ARB

The Athabasca River headwaters begin at the Columbia Icefield in Jasper National Park (Figure 3). The river travels more than 1,500 km to Lake Athabasca in the northeastern corner of Alberta through four distinct Natural Regions: the Rocky Mountains, Foothills, Boreal, and Canadian Shield (Figure 4). Each region is unique and has diverse hydroclimatic characteristics, geologic characteristics, natural resources, and ecosystems. The basin is interconnected hydrologically as water flows through its river network—the mainstem, tributaries, lakes and wetlands—from the headwaters to the Peace-Athabasca Delta.

The ARB is a massive and complex basin in terms of its geography, hydrology, development, and management.

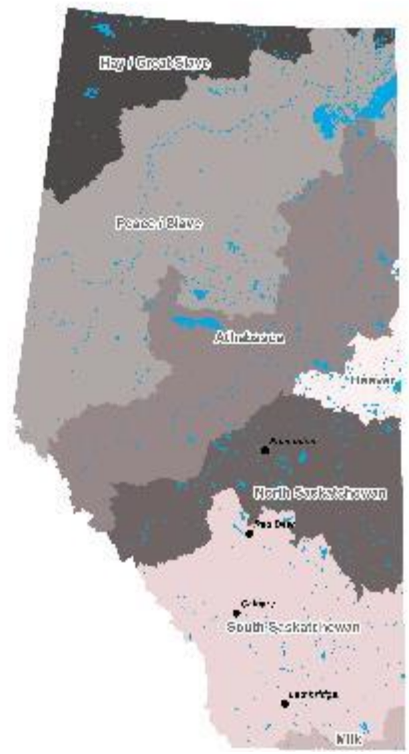


Figure 3: Major river basins in Alberta.

2.1 Geography

The ARB study area drains approximately 165,000 km^2 of central and northern Alberta, as well as the northwest margins of Saskatchewan. It covers nearly 25% of Alberta.

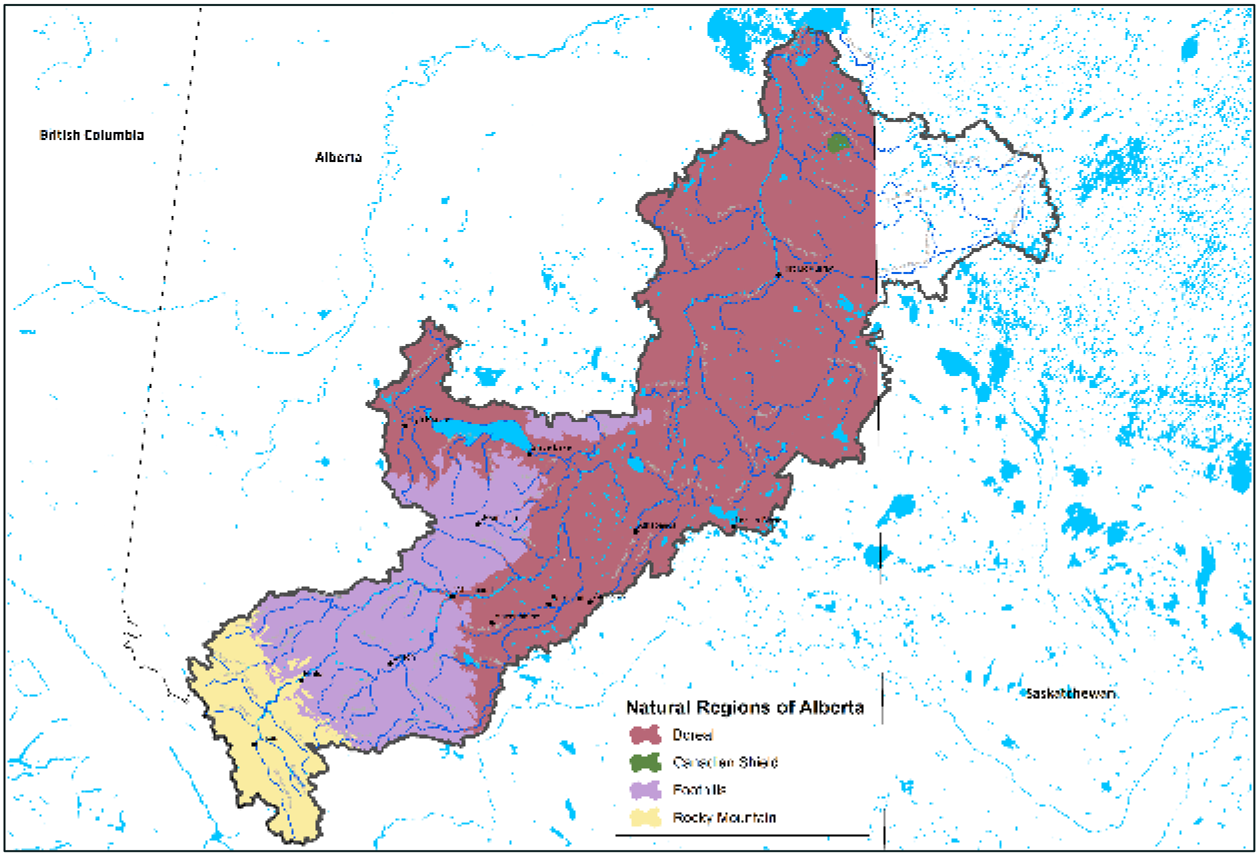


Figure 4: Athabasca River Basin and the Natural Regions of Alberta.

Note: The Natural Regions are only for Alberta; the portion in Saskatchewan is a combination of Boreal and Canadian Shield.

Upstream of Hinton, the Athabasca River is fed by major tributaries including the Sunwapta, Maligne, and Whirlpool rivers flowing from the south, with the Snaring and Snake Indian rivers flowing from the north. These rivers pass through the Rocky Mountain Natural Region, which is characterized by steep topography, high elevations (up to approximately 3700 m above sea level), large glaciers, high winter snowpack, and widespread coniferous forests (Natural Regions Committee, 2006). This natural region is largely within Jasper National Park and the Willmore Wilderness Area; as such, the landscape has experienced relatively little anthropogenic disturbance, which is limited to coal mining, some forestry, several highways, and several settlements, including the towns of Jasper and Hinton.

Between Hinton and Whitecourt, the Athabasca River passes through the Foothills Natural Region, gaining water from major tributaries such as the Berland and McLeod rivers. The Foothills also extend northward to the Swan Hills, where tributaries, including the Freeman and Swan rivers, originate. The Foothills are the interface between the Rocky Mountains and Boreal, characterized by variable topography with undulating terrain. Forests are often mixed and are dominated by lodgepole pine (Natural Regions Committee, 2006). This region has extensive forestry and oil and gas development, and while it is occupied by relatively few people it is important to understand the significance of the area because it is traditional land for many First Nations.

For over half of its length, the Athabasca River passes through the Boreal Natural Region from Lesser Slave Lake and the Pembina River watershed through to Lake Athabasca. Several major tributary watersheds comprise this region, characterized by relatively flat topography with a mosaic of lakes, interspersed uplands, and extensive wetlands. Vegetation is typically deciduous mixed wood and coniferous forest. Climate in this region is similar to the rest of the basin, with short summers and cold winters (Natural Regions Committee, 2006). This area has been extensively developed through agriculture, oil and gas, and forestry activities, and has a larger human population than the Foothills.

A small portion of Canadian Shield lies between Fort McMurray and Fort Chipewyan, viewed as an outlier relative to the larger Canadian Shield Natural Region. This region is characterized by exposed bedrock and hummocky topography. There are some bogs and fens within this region and, where soils permit, open coniferous or mixed forest stands (Natural Regions Committee, 2006). This region is not intensely developed and forms only a very small portion of the ARB.

The Athabasca River drains into Lake Athabasca in northeast Alberta. With the Peace River joining from the north, this area is known as the Peace-Athabasca Delta (PAD), a prized ecological area and a UNESCO World Heritage Site. The PAD is also partially within Wood Buffalo National Park. The PAD is formed by three smaller deltas (the Athabasca River Delta, the Peace River Delta, and the Birch River Delta). This area is very sensitive to changes in Lake Athabasca water level, which plays a large role in maintaining the ecologic functions of the PAD (RAMP, 2018).

2.2 Hydrology

Streamflow in the ARB generally follows a snowmelt-dominated flow regime. Streamflow is low during the cold winter months, peaks during the spring due to snowmelt, and tapers off throughout the summer and into the fall as the winter snowpack and soil water storage are depleted. The Athabasca River is supplemented during the late summer by glacier melt, although this does not dramatically affect streamflow in any major tributaries outside of the Rocky Mountain Natural Region. During the late summer and fall, streamflow periodically increases due to large summer precipitation events, but generally decreases until late fall when precipitation typically falls as snow and does not immediately contribute to streamflow.

This general streamflow pattern is typical of the hydrology of continental basins but there are several notable variations in this pattern between regions of the ARB. In the mountainous parts of the basin (generally upstream of Hinton), high snowpacks, high glacier coverage, and a large elevation gradient make for a highly seasonal pattern. In this region, the volume of water stored in winter snowpack and the timing of spring snowmelt are the primary factors driving streamflow. These factors generate a hydrograph that has a large spring runoff, moderate flows during the late summer due to release of water from soil moisture and glacial melt, and low flows during the cold winter months, which are governed by groundwater.

Conversely, regions with low elevation gradients, such as the Pembina watershed and most of the northern Boreal forest, have a much less seasonally dominant hydrograph. In these areas, snowpack is often substantially lower and melt occurs early in the spring. This leads to a quick peak in streamflow (typically in April), followed by relatively large sporadic increases in streamflow following summer precipitation events. This part of the basin is also subject to the interaction between a sub-humid (water deficit) climate with annual and decadal cycles and a diverse geologic setting (Devito et al., 2012). The amount of water stored in soils, wetlands, uplands, and groundwater ultimately dictates how streamflow responds to precipitation events on both short and long-time scales.

Overall, streamflow increases further downstream along the Athabasca River from a mean annual flow of 170 m^3/s at Hinton to 616 m^3/s at Fort McMurray and 930 m^3/s at Embarras, where the river reaches the PAD. Approximately 19% of annual average streamflow in the Athabasca River originates upstream of Hinton, while 28% originates between Athabasca and Fort McMurray (Figure 5). However, when corrected for the relative gross drainage area of each point of interest, approximately 58% of the Athabasca River streamflow by area occurs upstream of Hinton, and 38% occurs upstream of Jasper. This suggests that on a per-area basis, much of the water in the Athabasca River is generated in its headwaters, at high elevations in the Rocky Mountains.

This pattern of fractional contributions to Athabasca River flow varies by season. While the area upstream of Hinton contributes about 50% of the streamflow by area during the winter months, during April it only contributes 25%, and from May to July it is responsible for almost 75%. This means that during this period, approximately 30% of the total streamflow in the Athabasca River originates in the Rocky Mountains, despite this area comprising only about 6% of the ARB (Figure 6).

More information on how hydrology was modelled and analyzed is available in Appendix B.

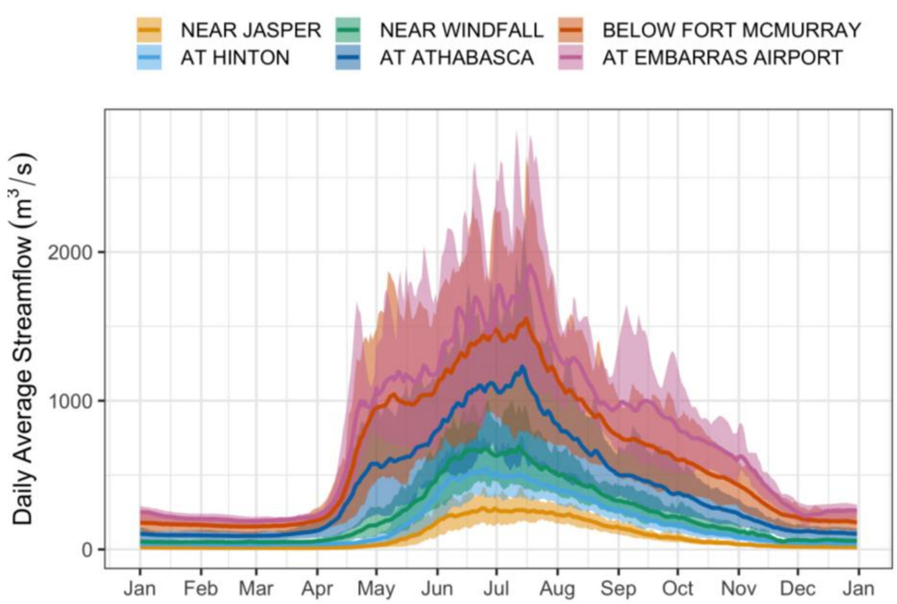


Figure 5: Observed average daily streamflow for six Water Survey of Canada hydrometric gauges along the Athabasca River. Shaded areas correspond to 10 and 90% quantiles.

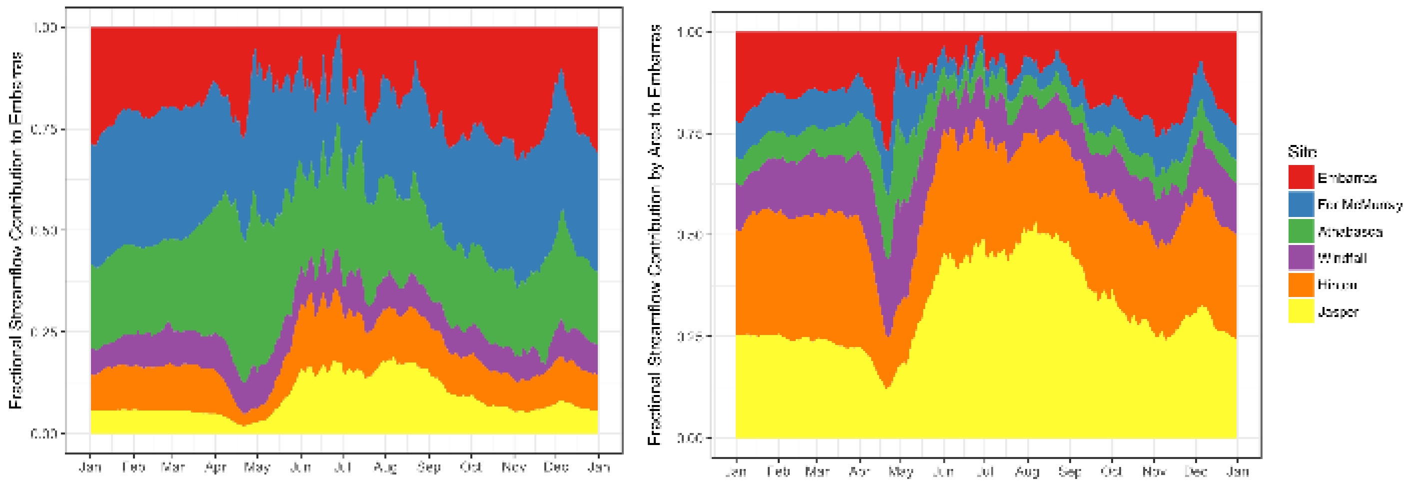


Figure 6: Fractional streamflow contributions for various points of interest on the Athabasca River mainstem.

2.3 Climate change

There has been a statistically significant trend towards declining streamflow in the Athabasca River over recent decades (Sauchyn et al., 2015). However, analysis from a 900-year reconstruction of water-year flow (October 1 -September 30) using tree rings demonstrates there is higher natural variability in water availability than has been observed in the last 100 years (Figure 7). This long-term analysis demonstrates that repeated decadal droughts are relatively common in the ARB. Likewise, there have been periods much wetter than those observed in the last 100 years. Water management decisions should account for this natural variation (Sauchyn et al., 2015).

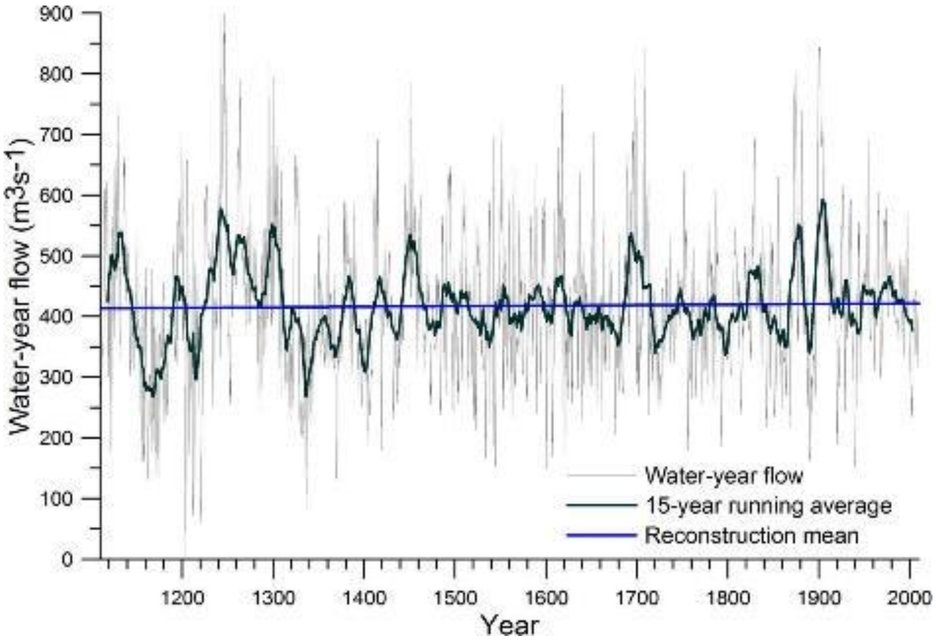


Figure 7: 900-year reconstruction of water-year flow.

Source: Sauchyn et al., 2015.

Potential future climate change poses a challenge for water management in the ARB, as snowmelt timing is expected to shift substantially in the future, resulting in longer snow-free periods. This has implications for the hydrologic regime of the ARB and is likely to significantly affect soil moisture conditions (Dibike et al., 2018). The potential future climate scenarios evaluated through this study[1] suggest that precipitation will likely increase during the winter across much of the ARB, with the exception of the headwaters (Figure 8). Air temperature is likely to increase in the spring under all potential future climate scenarios except the ECP2 Scenario (Figure 9). These air temperature changes are relatively extreme on a monthly basis and demonstrate that substantial change may be expected in the ARB.

[1] These scenarios are identified as CRCM, CRCM4, ECP2, RCP4.5 and RCP8.5.

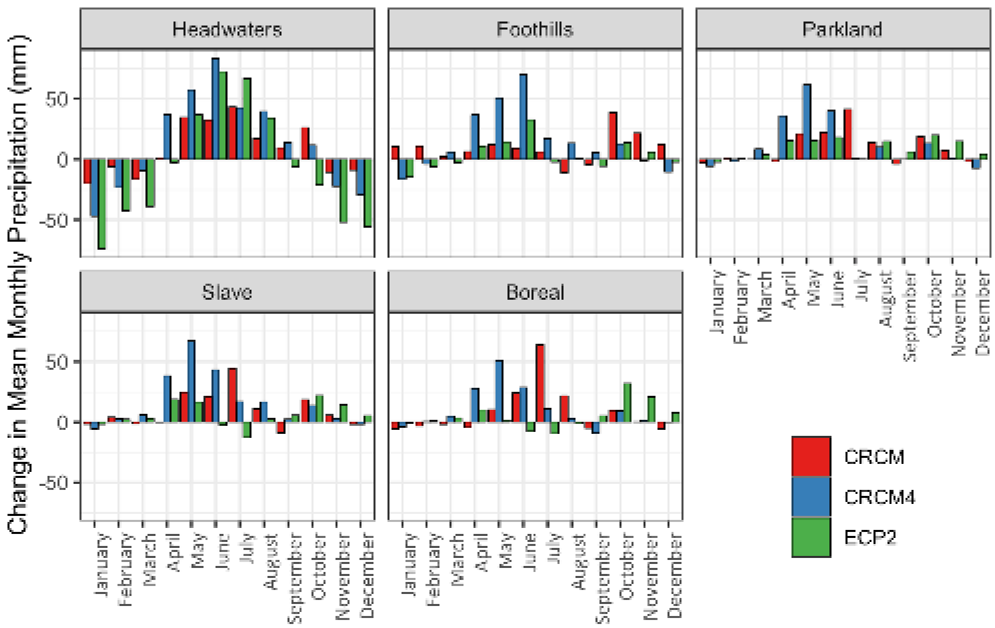


Figure 8: Future change in precipitation for sub-regions of the ARB.

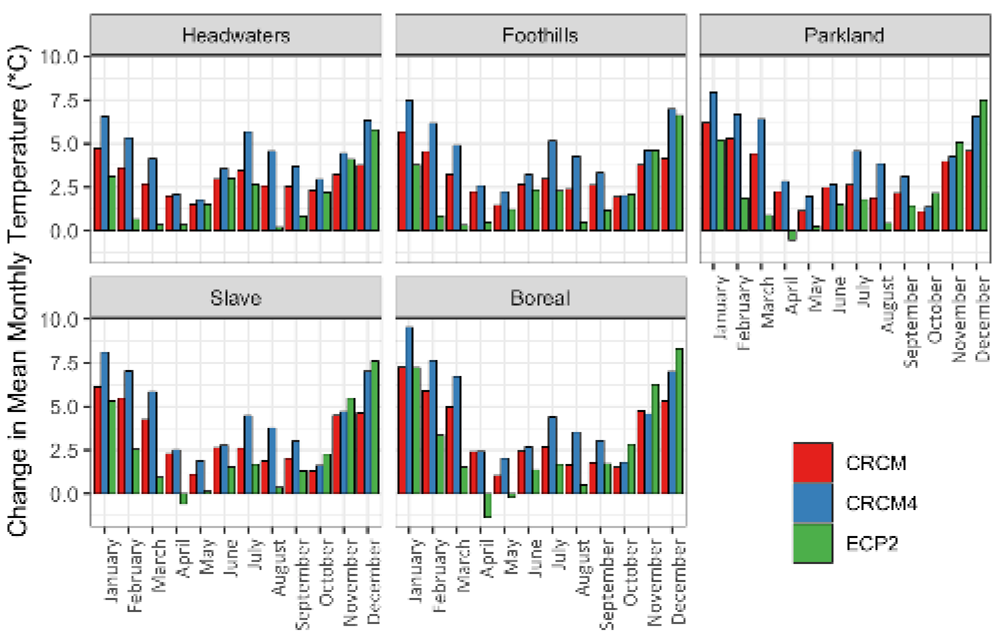


Figure 9: Future change in air temperature for sub-regions of the ARB.

Ultimately, these changes in climate are likely to result in substantial changes in streamflow across the ARB. For example, the headwaters are likely to experience earlier spring snowmelt, with higher freshets from higher spring precipitation. Summer flows are likely to decrease, and winter flows are likely to remain relatively unchanged or increase slightly (Figure 10).

These scenarios also suggest that the timing of spring streamflow will shift to earlier in the season and that there may be an overall increase in annual streamflow, although with reductions during the summer and fall (Figures 10 and 11). These results are consistent with other studies, suggesting the most challenging time for water supply is likely to be the summer given that studies suggest summer streamflow is likely to decline in the future, while spring and winter flows could increase (Eum et al., 2014).

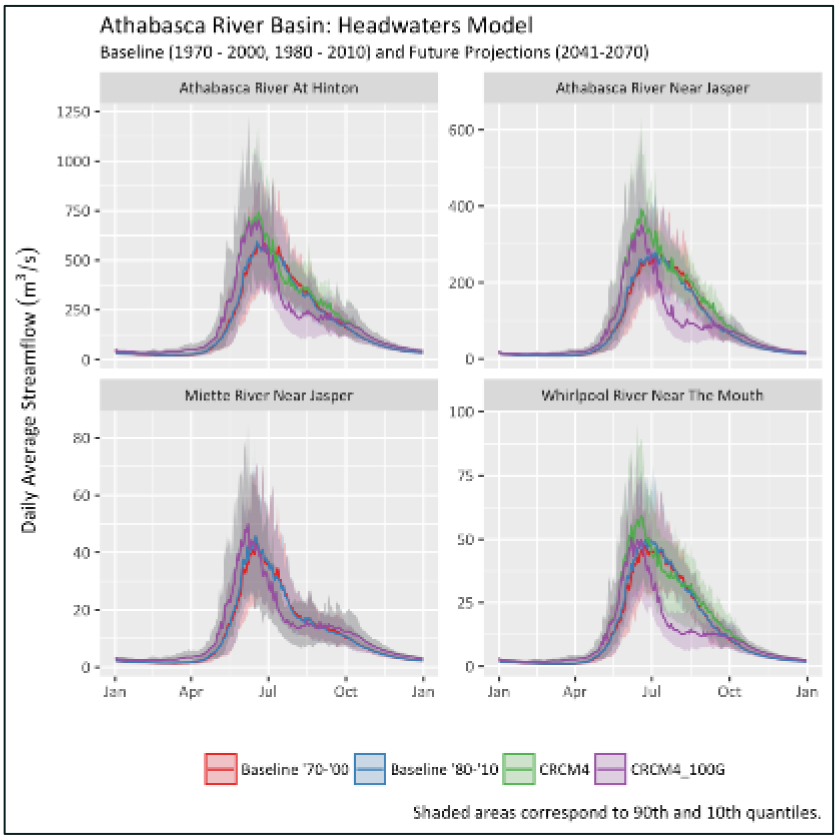


Figure 10: Average daily streamflow for 30-year periods in the headwaters.

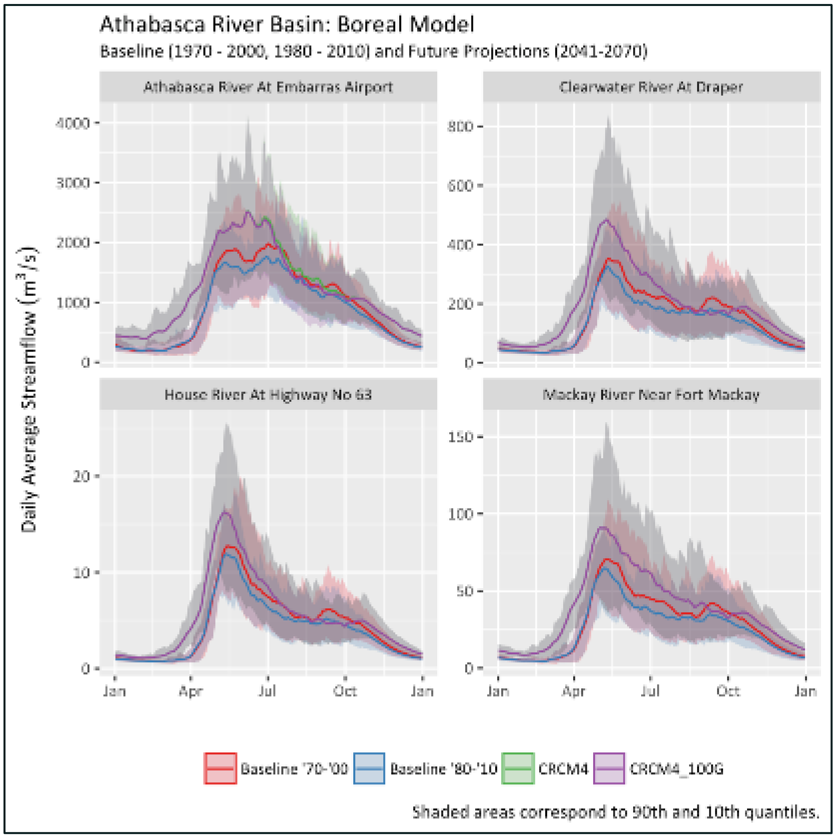


Figure 11: Average daily streamflow for 30-year periods in the lower basin.

Glaciers provide an important late-season source of water for the Athabasca River, with larger proportions of glacial contribution to streamflow occurring further upstream (currently approximately 5% of the annual streamflow). Future changes in climate are likely to result in higher glacial contribution to streamflow over the medium term (next 50 years or so) from higher ice melt. Over the long term (in the next 100 years), glaciers will contribute less and less to streamflow in the Athabasca as glacier ice recedes substantially, as shown in Figure 12 (Chernos et al., 2017).

Overall, these analyses demonstrate that the hydrologic regime in the ARB is very likely to be different from what has been observed over the last several decades. Water management can be adapted to these potential future conditions to provide reliable water supply (Eum et al., 2014). However, thoughtful planning is required to ensure environmental, social, cultural, and economic effects of climate change are not exacerbated by anthropogenic influence.

More information on how the potential climate change impacts were modelled and analyzed is available in Appendices B and C.

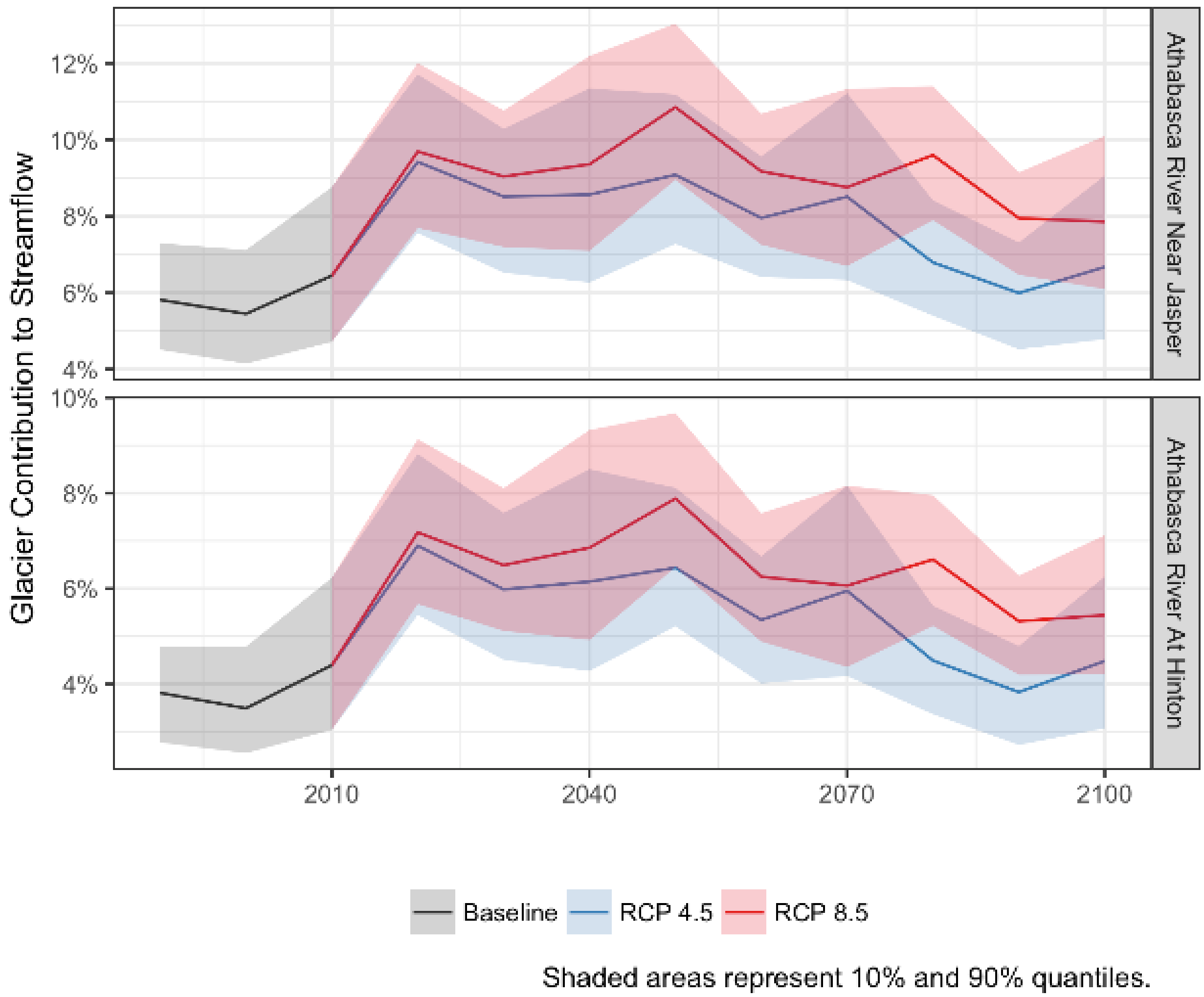


Figure 12: Simulated glacier contribution to total annual streamflow in the Athabasca River at Jasper and Hinton from 1980 to 2100 under two potential future climate change scenarios.

Source: Chernos et al. 2017.

2.4 Human activity

Industrial development has occurred in many sectors across the ARB, with varied intensity. Many municipalities and Indigenous populations are present in the ARB as well. The total footprint of these human activities shows the most extensive activity in the Pembina River area, the Lesser Slave Lake area, and the Fort McMurray area (Figure 13). Development activities include agriculture, urbanization, livestock production, forestry, coal mining, oil and gas, and oil sands.

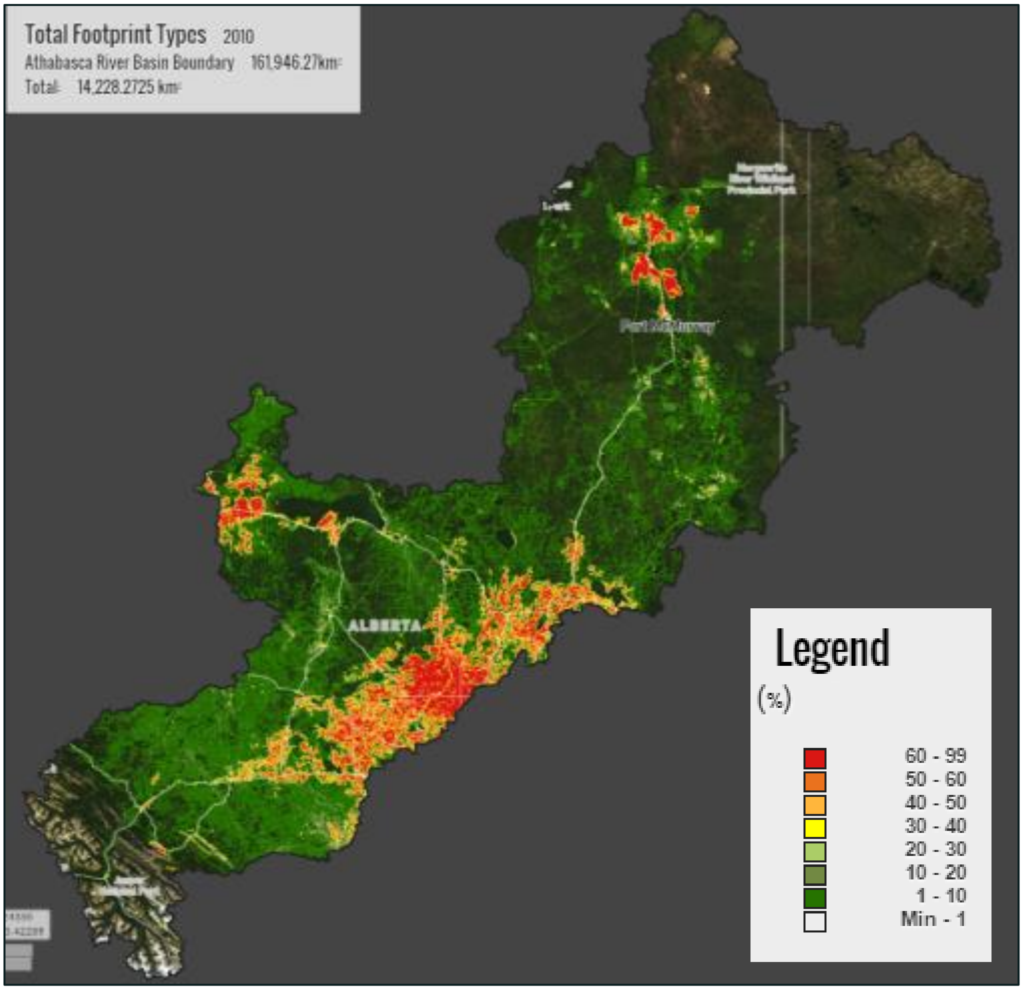
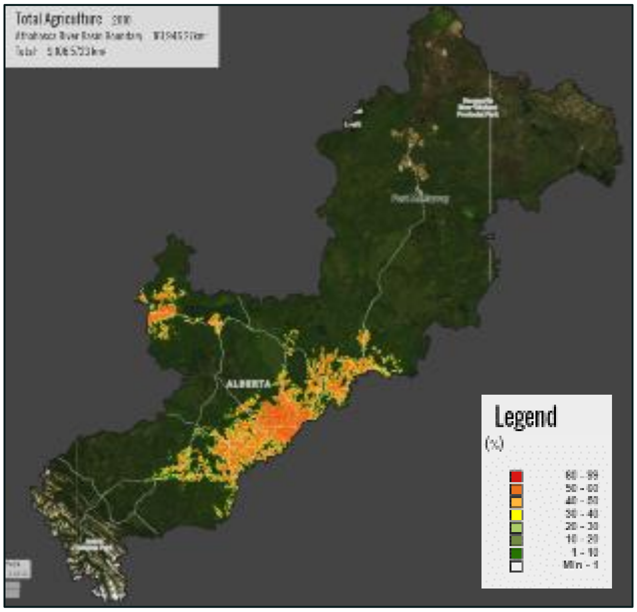


Figure 13: Total permanent footprint across the ARB, where red indicates high density footprint and green indicates low density footprint.

In the upper and central portions of the basin, the most significant development in terms of total area footprint is from agriculture and forestry. Agriculture represents the largest overall land use by area and has converted vegetation from natural mixed wood forest to seasonal single crop types. This reduction in forest cover means more water reaches the ground (because of less interception and less evapotranspiration) and runoff is typically higher. Crop type, farming practices and irrigation practices also largely determine how much water is used and retained in the area (Figure 14).



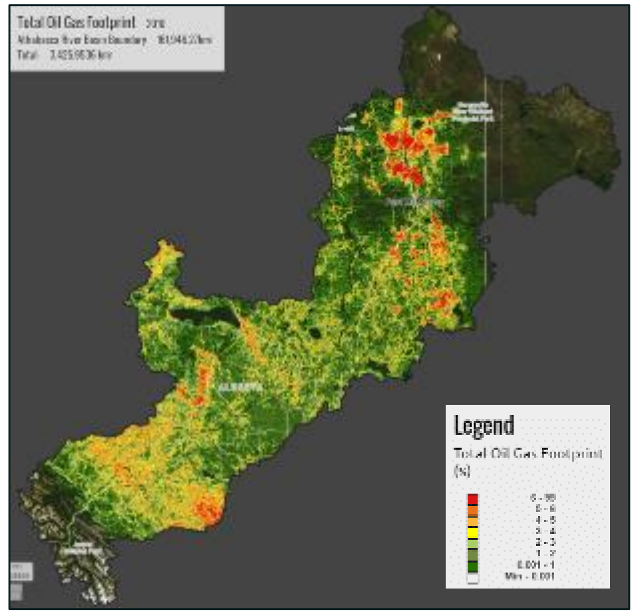


Figure 14: Total agriculture (left) and total oil and gas footprint (right), where red represents high and green represents low.

Forest harvesting is distributed throughout the basin within Forest Management Agreement (FMA) boundaries (Figure 15). The harvesting and replanting of trees changes the age structure of the forest. Younger forests have lower interception rates than older forests, with more rain and snow reaching the soil surface. Younger forests are often less water efficient and can actually use more water. Lower amounts of shade cover can result in higher evaporation from the soil in the summer and faster or earlier snowmelt in the winter and spring.

In addition to forest harvest, wildfire and pests can substantially disturb forested areas. Large wildfires have been observed historically in the ARB and are likely to persist into the future. Mountain pine beetle and other pests have altered forest structure in several stands in the ARB. Cumulatively, the effects of forest harvest and natural disturbance can alter the hydrologic regime of a basin, with a wide range of potential downstream implications.

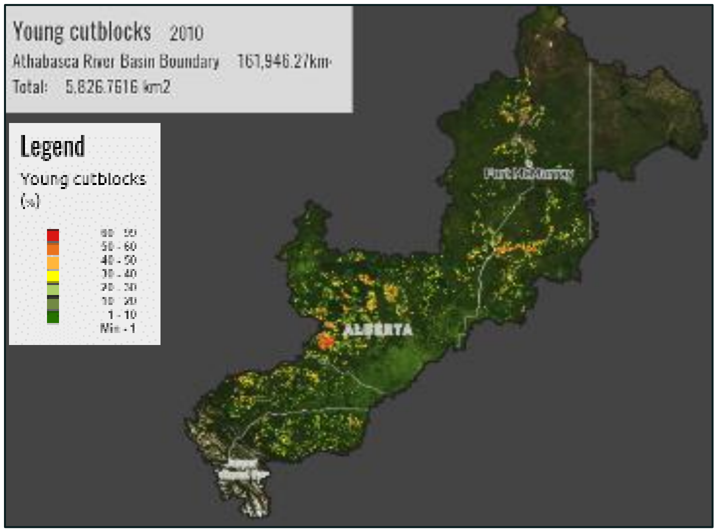


Figure 15: Cut blocks younger than 30 years old, where red represents high amounts of cutblock and green represents low amounts of cutblock.

In the lower part of the basin, oil and gas activities, including mining and in-situ operations, are the most significant development in terms of total footprint area. Conventional oil and gas activities, including wells, lines, and pipelines, are distributed at low intensities throughout the basin. Water is managed carefully on these sites, often using closed systems. Vegetation is typically removed during site construction, resulting in faster runoff and earlier snowmelt (as seen with forest harvesting), and reduced natural connectivity of the watershed, resulting in altered drainage patterns.

Other developments in the basin related to human activity include homes, businesses, roads, and power lines. The Athabasca State of the Watershed Report (Fiera, 2012) drew from scientific literature to develop pressure thresholds for these types of activities in the basin (Table 1).

Table 1. Indicators for which pressure ratings were developed based on thresholds from the scientific literature.

Indicator	Unit	High Pressure	Moderate Pressure	Low Pressure
Road Density	km/km^2	≥0.5	>0.1 to 0.5	0 to 0.10
Seismic, Pipeline, Power Line & Railroad Density	km/km^2	>3	>1.2 to 3	0 to 1.2
Large Patches of Natural Vegetation	% aerial coverage of tertiary watershed with large patches	≤30%	<30 – 65%	>65%
Stream Crossing Density	# of road crossings/km^2	>0.6	>0.4 – 0.6	≤0.4
Human Population Density	Growth rate by tertiary watershed (%)	>5.67	>0 to 5.67	≤0
Human Land Use - Agriculture	% aerial coverage of tertiary watershed	>60	>25 to 60	≤25

Source: Adapted from Fiera, 2012

Using these thresholds, it is evident that road density and seismic lines, pipelines, power lines and rail density create the most pressure in the Foothills (Figure 16). This is an area with higher densities of forestry and oil and gas activities. Linear features can reduce the connectivity of the watershed and alter drainage patterns, resulting in changes in streamflow. In addition to hydrologic function, linear features can affect terrestrial and aquatic ecosystems.

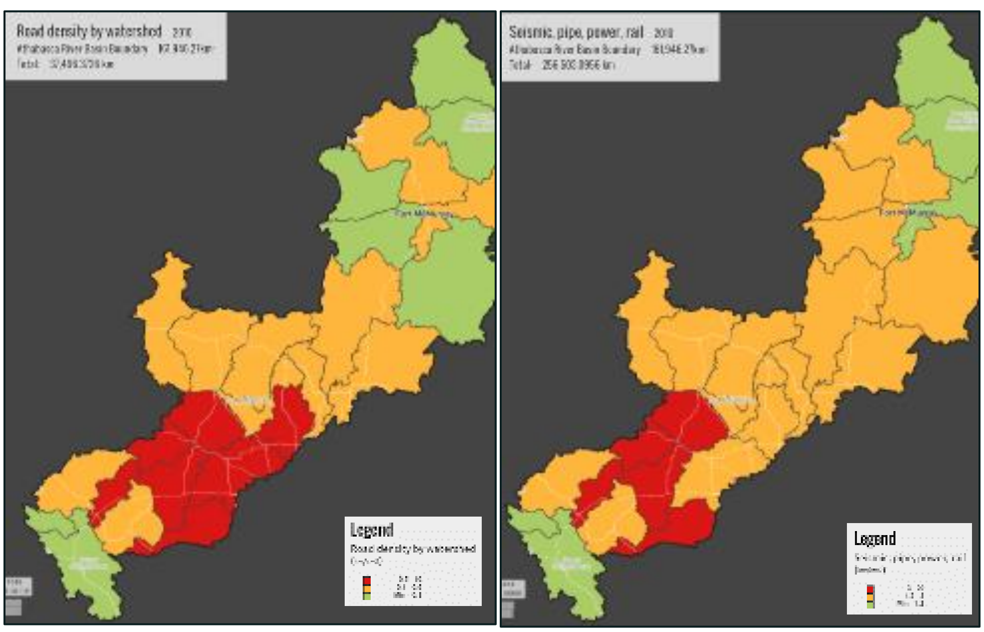


Figure 16: Road density (left) and other linear feature density (right) expressed using thresholds established by the 2012 Athabasca State of the Watershed report.

For centuries, the ARB has been home to many Indigenous Peoples. Traditional uses of the land include hunting, gathering, community development, and ceremony. These areas are still important to Indigenous Peoples and, with a changing landscape of watershed and land use planning, educating decision makers on the main issues that are related to watershed planning is important for change and innovation to ensure sustainable use for all who live in, operate in, or visit the basin.

More information on how the land uses in the basin were modelled and analyzed is available in Appendix B.

2.5 Water management

The natural attributes and resources of the ARB have long attracted settlement and development and represent a rich and diverse ecological heritage. Many of these features are important to the region's identity. This has driven the development of policy and legislation to provide the broader context and necessary frameworks for water management in the basin. Some of these policy and legislative elements are briefly described below.

In 1894, before Alberta became a province, the federal government passed the *North West Irrigation Act*, which allowed allocation of water by the government for irrigation and other purposes.[2] Water was allocated based on the seniority of the licence, which meant that in times of shortage, the holder of an older licence could divert water ahead of a more junior licence-holder. This priority system (referred to as "first in time, first in right" or FITFIR) was affirmed by the Government of Alberta (GoA) in the 1931 *Water Resources Act* and the more recent *Water Act,* proclaimed in 1999.

In 2003, the GoA published *Water for Life: Alberta's Strategy for Sustainability* (Alberta Environment, 2003), which has been the vehicle for managing Alberta's water resources since then. The GoA affirmed its commitment to this approach for managing water quantity and quality when it renewed the strategy in 2008.[3] The strategy's three goals of safe, secure drinking water; healthy aquatic ecosystems; and reliable, quality water supplies for a sustainable economy are being met through knowledge and research, partnerships, and water conservation.

The Water Conservation and Allocation Policy for Oilfield Injection[4] and its corresponding Guideline were released in 2006 to support the conservation and management of water and prevent excess use of water during enhanced oil recovery operations. The Policy and Guideline include specific environmental outcomes that support the goals of the Water for Life strategy. An updated version of this Policy that would apply to all upstream oil and gas operations has been under development and review for many years and is now slated for completion by 2020 based on the current government's priorities and

[2] See Alberta Environment and Parks, http://aep.alberta.ca/water/education-guidelines/legislative-history-of-water-management-in-alberta.aspx
[3] See http://aep.alberta.ca/water/programs-and-services/water-for-life/default.aspx
[4] See https://open.alberta.ca/publications/0778531447

timelines. The updated version is expected to put greater emphasis on the use of alternatives to high-quality non-saline sources and to provide more detail on the assessment of cumulative effects for all upstream operations including oil sands mining, in-situ, enhanced oil recovery, and multi-stage hydraulic fracturing operations.

The Lower Athabasca Regional Plan (LARP) was completed in 2012 under the GoA's *Alberta Land Stewardship Act* and the Land Use Framework[5]. Regional plans set out a new approach for managing land in each region to achieve environmental and economic goals. The Lower Athabasca Region (LAR) covers the area from the south edge of the Municipal District of Bonnyville to Alberta's northern border; it includes Fort McMurray, Cold Lake, and Lac La Biche. The LARP is the regional plan that sets the stage for the next 50 years, concentrating on environmental, economic, and social actions by setting regional environmental limits for air quality and surface water quality and implementing a groundwater management framework; establishing six conservation areas; addressing infrastructure challenges; developing tailings, biodiversity, and surface water quantity frameworks; working with indigenous communities; providing certainty for industry development in the oil sands; and supporting diversification of the economy. In accordance with the Land Use Framework, LARP was subject to review five years after its approval and implementation; that review is underway.

The Upper Athabasca Regional Plan has not yet formally started. Once launched, the regional planning process will begin by gathering data and assessing input and advice from stakeholders to develop the Plan. A Regional Advisory Council will be established to develop recommendations for the region and to conduct consultations.

The Lower Athabasca Region Groundwater Management Framework was released in 2012 by Alberta Environment and Sustainable Resource Development.[6] The Framework will enhance the existing system to manage non-saline groundwater resources across the LAR including management of potential cumulative effects on these resources. It establishes indicators of groundwater quality and quantity and a method for developing triggers and limits. Goals include: establishing baseline groundwater conditions and range of natural variability in the LAR to facilitate enhanced knowledge and detection for change; providing a consistent approach to understanding potential effects from all development activities on the surrounding environment; facilitating projections of change based on future scenarios, such as expanding development or climate variability and change; and supporting and supplementing the current pollution prevention and risk management principles as part of groundwater quality and quantity management.

[5] See https://open.alberta.ca/dataset/37eab675-19fe-43fd-afff-001e2c0be67f/resource/a063e2df-f5a6-4bbd-978c-165cc25148a2/download/5866779-2012-08-lower-athabasca-regional-plan-2012-2022.pdf

[6] See https://open.alberta.ca/publications/9781460105344

The Alberta Wetland Policy was released in September 2013 and full implemented in 2016 for the full province. It is intended to minimize the loss and degradation of wetlands, while allowing for continued growth and economic development in the province[7]. The goal of the Policy is to conserve, restore, protect, and manage Alberta's wetlands to sustain the benefits they provide to the environment, society, and economy. The Policy reflects that not all wetlands are of equal value and provides the methodology to assess the form, function, use, and distribution criteria and assign a wetland value. The Policy promotes avoidance, followed by minimization and, finally, replacement.

The Tailings Management Framework was released in 2015 to help address the accumulated fluid tailings in the LAR and provides additional management requirements for oil sands mine operators[8]. Highlights include requirements to set limits on the amount of tailings that can be accumulated; investment in new technologies; establishment of firm thresholds to identify when companies must take action to prevent harm to the environment; requirements for companies to post additional financial security to manage potential remediation issues; and methods to ensure tailings are progressively treated and reclaimed throughout the project life cycle, and are also ready to fully reclaim within 10 years of the end of mine life of that project.

Also aligned with the LARP, the Surface Water Quantity Management Framework (SWQMF) was released in 2015 by Alberta Environment and Parks (AEP). Its objective is to manage cumulative oil sands mining water withdrawals to support both human and ecosystem needs, while balancing social, environmental, and economic interests. The SWQMF requires most of the water withdrawals by existing operators and all water used by new operators to stop during low flow periods and sets water withdrawal limits for all mineable oil sands operators during moderately low flow periods. It also establishes metrics to detect when flow conditions are moving outside of the modelled conditions that were used to inform the withdrawal limits. One of these metrics is the Aboriginal Navigation Index, which uses the Aboriginal Extreme Flow and Aboriginal Base Flow from Candler et al. (2010).

The Water Reuse and Stormwater Use Policy for Alberta has been under development for a number of years but, at the time of writing, had not been released. It is expected to define how alternative water sources including stormwater, municipal wastewater, household greywater, rooftop collected water, and other such sources might be used to offset freshwater use and augment existing water supplies. This approach should save energy, reduce treatment requirements, and increase resiliency to climate change. A guidebook is being prepared to provide instructions on the risk-based approach that is expected to be used for regulation and approvals.

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[7] See http://aep.alberta.ca/water/programs-and-services/wetlands/alberta-wetland-policy.aspx

[8] See http://aep.alberta.ca/land/programs-and-services/land-and-resource-planning/regional-planning/lower-athabasca/documents/LARP-TailingsMgtAthabascaOilsands-Mar2015.pdf

The Athabasca River Basin affects not only Alberta; it receives water from and contributes water to other jurisdictions, crossing a number of boundaries and making it necessary for jurisdictions to work together. For example, the governments of Canada, British Columbia, Alberta, Saskatchewan, the Northwest Territories, and Yukon entered into the Mackenzie River Basin Transboundary Master Agreement in July 1997. This Agreement committed the parties to create a cooperative forum to inform about and advocate for the maintenance of the ecological integrity of the entire Mackenzie River watershed.[9] The Mackenzie River Basin Board was established to implement the Master Agreement. The Agreement requires neighboring jurisdictions to negotiate detailed bilateral water management agreements to address water issues at jurisdictional boundaries on transboundary streams and to provide parameters on the quality, quantity, and flow of water. In March 2015, Alberta and the Northwest Territories announced a bilateral water management agreement[10] to protect the integrity of water flowing downstream from Alberta to the Northwest Territories. This agreement focuses on aquatic ecosystems in the Mackenzie River Basin and commits both governments to co-operatively manage water resources in the basin, which is the largest river system in Canada.

3.0 Strategies for sustainable water management

3.1 Water challenges in the ARB

To begin to understand the water-related issues in the ARB, a desktop review of publicly available documents was completed. The information gathered was refined and enhanced through dialogue with Working Group participants who developed a list of water issues. An issue was defined as an important concern or problem related to water in the ARB that warrants attention; an issue can be historic, current, or future, and it can be specific to a sub-basin or basin-wide.

Appendix E contains the full list of surface water quantity issues and interests in the ARB gathered through the desktop study and in discussion with the Working Group participants at group and individual meetings. This list was summarized into a set of water challenges:

- Maintaining or improving ecosystem health
- Providing water supply certainty for development
- Minimizing the effect of the development footprint on basin hydrology
- Ensuring sufficient flow for navigation
- Limiting damage from floods or extreme events
- Maintaining or improving the health of the Peace-Athabasca Delta
- Addressing concerns around Indigenous rights

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[9] See http://aep.alberta.ca/water/education-guidelines/mackenzie-river-basin-bilateral-water-management-agreements.aspx

[10] See http://aep.alberta.ca/water/education-guidelines/documents/MackenzieBasinAgreement-AB-NWT-Feb2015.pdf

- Accessing water-related data and knowledge in the basin
- Maintaining or improving water quality
- Understanding the renewable energy potential of the basin

The Working Group discussion showed that, like all watersheds, there are many water challenges in the ARB and it is important to proactively address them. The Working Group focused its discussion and modelling on challenges it thought the ARB Initiative and eventual Roadmap should emphasize, given the tools available and the project scope and timeline.

3.2 Strategy assessment through modelling and dialogue

Over the course of the Initiative, the Working Group identified and assessed strategies for current and future actions for sustainable water management across the whole ARB. As potential strategies and options began to emerge, WaterSMART Solutions Ltd. (WaterSMART) compiled the modelling output and documented findings in a neutral transparent manner for review by all Working Group participants. This information is presented in the following sections in summary tables for each strategy. The entire Working Group did not have to agree with a specific strategy; this report reflects that the strategy was assessed and if the group thought it was valid, it is included.

The AIRM was used to assess strategies where possible, and to provide quantitative results that indicated direction and magnitude of the strategy's effect on water supply and demand. The Working Group also developed Performance Measures (PMs) to use in reviewing the modelling results. Each PM was associated with a specific water challenge and the PMs served as proxies to show whether the strategies being explored were having the intended impact with no unintended consequences. When using the PMs to assess strategies and their effects, the Working Group focused on the direction and magnitude of the modelled change rather than the specific numerical change, as this was intended to be a screening level analysis.

The PMs that were predominantly used are shown in Table 2. For the PM "Change in annual instream flow needs violations," results reflect how instream flow needs (IFN) violations are calculated, where it is assumed that flow reductions relative to the base case are not desired. The model assumes the base case to be the most desirable streamflow condition relative to IFN and this is held constant in the simulations; when that condition is not met in the model it comes up as an IFN violation because the IFN was not met on that day.

Table 2: Performance measures for sustainable water management.

PM	Associated water challenge
Change in seasonal system shortages (m^3/s)	Provide water supply certainty for municipalities and development
Change in seasonal streamflow as a percentage of naturalized streamflow	Minimize the effect of development footprint on basin hydrology
Change in walleye recruitment reduction	Maintain or improve ecosystem health
Change in annual instream flow needs violations	Maintain or improve ecosystem health
Change in number of days over 1:100 flood thresholds	Limit damage from floods
Change in number of days meeting Aboriginal Extreme Flow	Ensure sufficient flow for navigation

3.3 Summary of strategies

The goal of this Initiative was to create a Roadmap with strategies, information, and actions that can be implemented by communities, industries, and government decision makers for long-term sustainable water management in the ARB. Strategies were discussed at each Working Group meeting in breakout groups to capture dialogue and thinking around each one. Twelve strategies were developed and are summarized in this report:

1. Effluent reuse: Enable reuse of industrial or municipal effluent to reduce reliance on freshwater
2. Water conservation: Continue to achieve water conservation and efficiency improvements as communities develop
3. On-stream storage: Explore new on-stream multi-purpose storage options
4. Off-stream storage: Develop new and existing off-stream storage sites to meet multiple basin water management objectives
5. Existing infrastructure: Alter existing water storage infrastructure and operations to meet multiple basin water management objectives
6. Environmental flows: Establish IFNs or similar targets for all tributaries in the basin as a precautionary water management measure
7. Navigational flows: Implement minimum flows to improve navigation in the lower Athabasca basin
8. Land conservation: Increase the quantity and improve the condition of conserved and restored land across the basin
9. Forestry practices: Support practices in Forest Management Agreements (FMAs) that minimize hydrologic change
10. Wetlands: Avoid further wetland loss or functional impairment and promote more wetland restoration, education, and best management practices focused on minimizing impacts

11. Linear connectivity: Reclaim or deactivate linear features and reduce future linear disturbances in watersheds
12. Extraction industry reclamation: Continue to set and meet high standards of reclamation of extraction footprint to maintain or improve hydrological functions in a watershed

The 12 strategies are not ranked or prioritized in any way; rather, they are summarized based on modelling results and on feedback and discussion from the Working Group and are documented at a screening level. Some strategies have been assessed more than others. In some cases, the strategies cover multiple areas of the basin. Figure 17 illustrates in general the 12 strategies and where they fit in the overall picture of water management in the watershed.

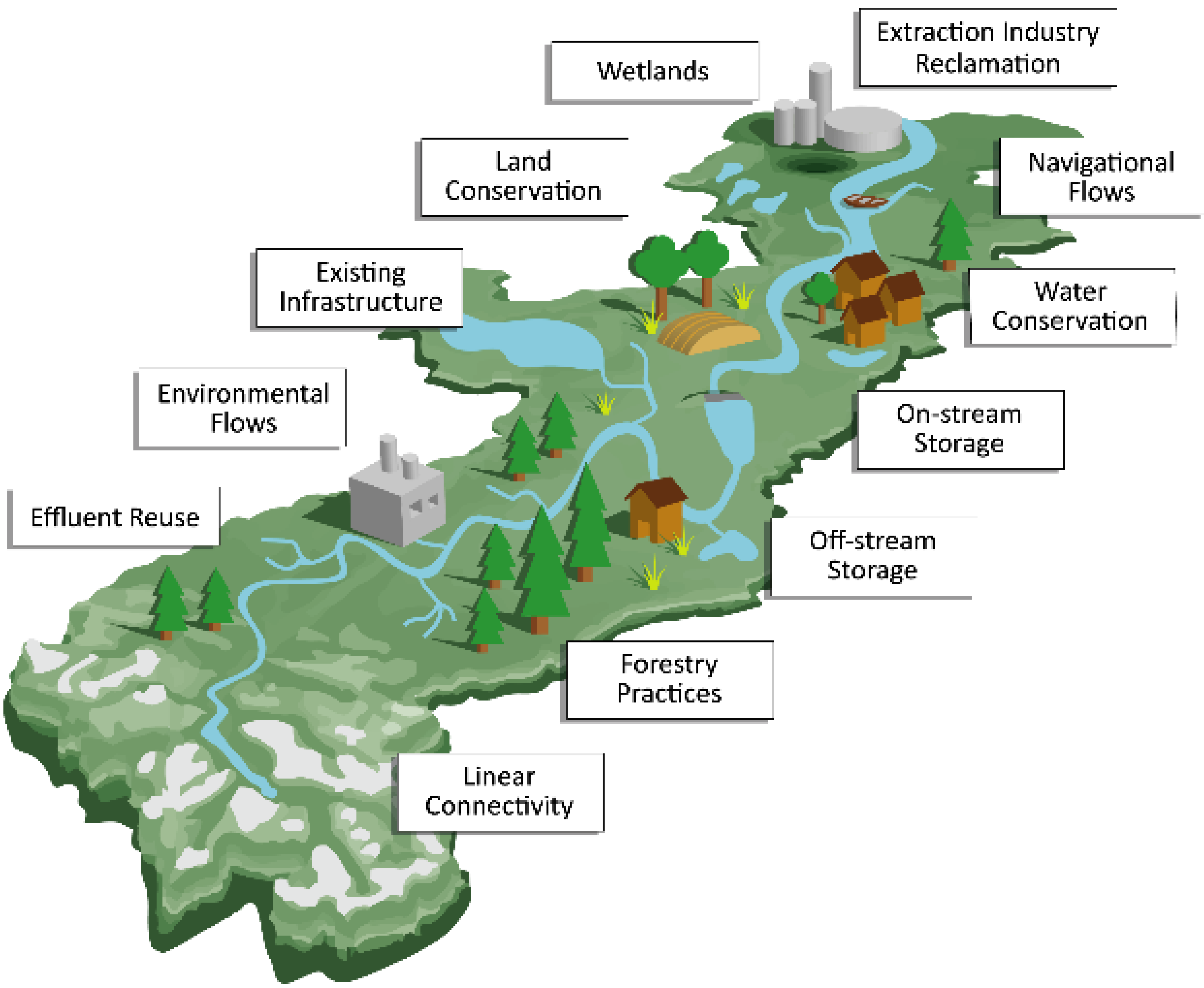

Figure 17: A conceptual schematic of the ARB, outlining strategies developed by the Working Group for sustainable water management.

This work focused on water quantity, in terms of streamflow, in the mainstem and the tributaries. The modelling component looked at streamflow and water quantity, but when these were discussed, aspects of water quality, biodiversity, landscape health, and other elements inevitably came up. In this report, references to these other aspects (e.g., water quality, biodiversity) are based on dialogue from the Working Group meetings.

In the following sections, each strategy is summarized with a description of the strategy and examples of the strategy in the basin today. The modelling was used to illustrate the strategy and results, and to support discussion on the benefits, trade-offs, implementation feasibility, and an assessment as to whether the strategy was most promising, least promising, or if the group was unsure.

It is envisioned that, in response to current and future development and climate change, these strategies will serve as a starting point for planning and water management in the ARB. The strategies can be reviewed and considered by organizations and communities in accordance with their interests and concerns, and to the level deemed applicable for their programs, projects, and planning. While these water management strategies were being developed, gaps in data and information also became apparent. The strategies should be considered along with the gaps, which are described in Section 4.

3.3.1 *Effluent reuse:* Enable reuse of industrial or municipal effluent to reduce reliance on freshwater

3.3.1.1 Strategy overview

This strategy is intended to take return flows (treated effluent) from industrial, municipal, or commercial operations and reuse that water for other industrial purposes. This approach would support development without needing to withdraw additional freshwater, while also reducing release of treated effluent back into the river. This strategy has potential application at local levels throughout the basin. This strategy discusses reuse as a consideration, as opposed to recycling; a participant noted that recycling is often defined as reusing water for a single use by one user whereas reuse is defined as a second water user reusing discharged water from another user.

Specific examples of this strategy already in place or being considered include:

- Interim guidance from the GoA exists in "The Interim Guidance to Authorize Reuse of Municipal and Industrial Wastewater[11]" (December 2015), and there are many examples of work underway in different sectors. One driver is the Draft Water Conservation Policy for Upstream Oil and Gas Operations (October 2016)[12], which encourages upstream oil and gas operators to explore alternate water sources before using high quality non-saline water for operations.
- Alberta Newsprint Company is considering supplying companies with effluent water for the use of hydraulic fracturing.
- The Regional Municipality of Wood Buffalo has investigated the option of sending treated wastewater to industrial users.
- Industry-to-industry reuse is taking place between the Suncor base mine and the Suncor Firebag SAGD operation. Starting in February 2013, Suncor implemented a process to send tailings water from its oil sands base plant through an existing pipeline to its in-situ operation (Firebag), to use as make-up water (CAPP, 2017).
- The Oil Sands Leadership Initiative (predecessor to the Canadian Oil Sands Innovation Alliance, or COSIA), has looked at a number of opportunities for reusing water regionally since 2008.

Higher flows would be expected in stream locations where licence holders used reused water rather than water from the stream, thus supporting instream flows at that location.

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[11] See https://open.alberta.ca/publications/interim-guidance-to-authorize-reuse-of-municipal-and-industrial-wastewater

[12] See https://www.capp.ca/~/media/capp/customer-portal/publications/280937.pdf

3.3.1.2 Modelling done to test this strategy and modelling results

For this strategy, return flows from industrial and commercial demands in the upper ARB were simulated to no longer return to the river, but instead flow to off-stream storage. Temporary Diversion Licences (TDLs) in the upper ARB would then draw from this off-stream storage instead of withdrawing freshwater. The maximum storage is set at 100,000 dam^3; volumes in excess of this would flow out of storage back to the mainstem Athabasca River. In addition to the water necessary to support TDLs, water may also be drawn from this storage to meet the downstream SWQMF flows when necessary.

Flows immediately downstream of the return outfalls would remain mostly unchanged with slightly lower flows on some days. Figure 18 shows mostly similar flows on the Athabasca River downstream of the Berland River under the reuse strategy (blue), relative to the base case (orange) under historical conditions. These results show that storing reuse water does not negatively affect flows downstream of the return outfall. To visualize the changes from this strategy, Figure 18 depicts a particular timeframe within the overall 30-year simulation (Jan 1 to Mar 1 of 1986), as this is a lower flow year.

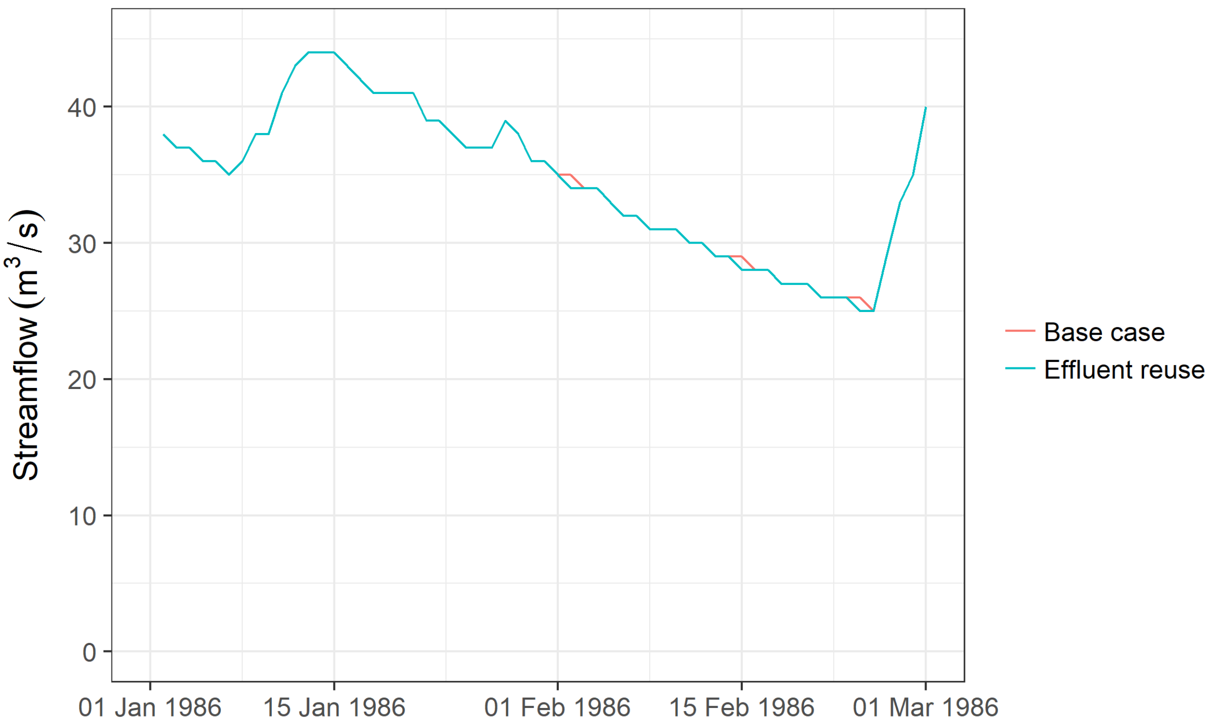

Figure 18: Historical conditions on the Athabasca River downstream of the Berland River confluence, under the base case (orange) and effluent reuse strategy (blue), between Jan 1 and Mar 1 of 1986.

Under this reuse strategy, less water would be used directly from smaller tributaries because TDLs would now take water from off-stream storage. This would increase streamflow slightly in those streams relative to the base case under historical conditions. An example of this can be shown on the Freeman River where flows are higher than the base case because TDLs would no longer withdraw freshwater from this stream. To illustrate this example, Figure 19 shows flow in the Freeman River under the base case (orange) and under the effluent reuse strategy (blue) under historical conditions. Similar to Figure

18, this figure depicts a particular timeframe (Jan 1 to Apr 1, 1987) within the overall 30-year simulation, in order to effectively visualize the changes from this strategy.

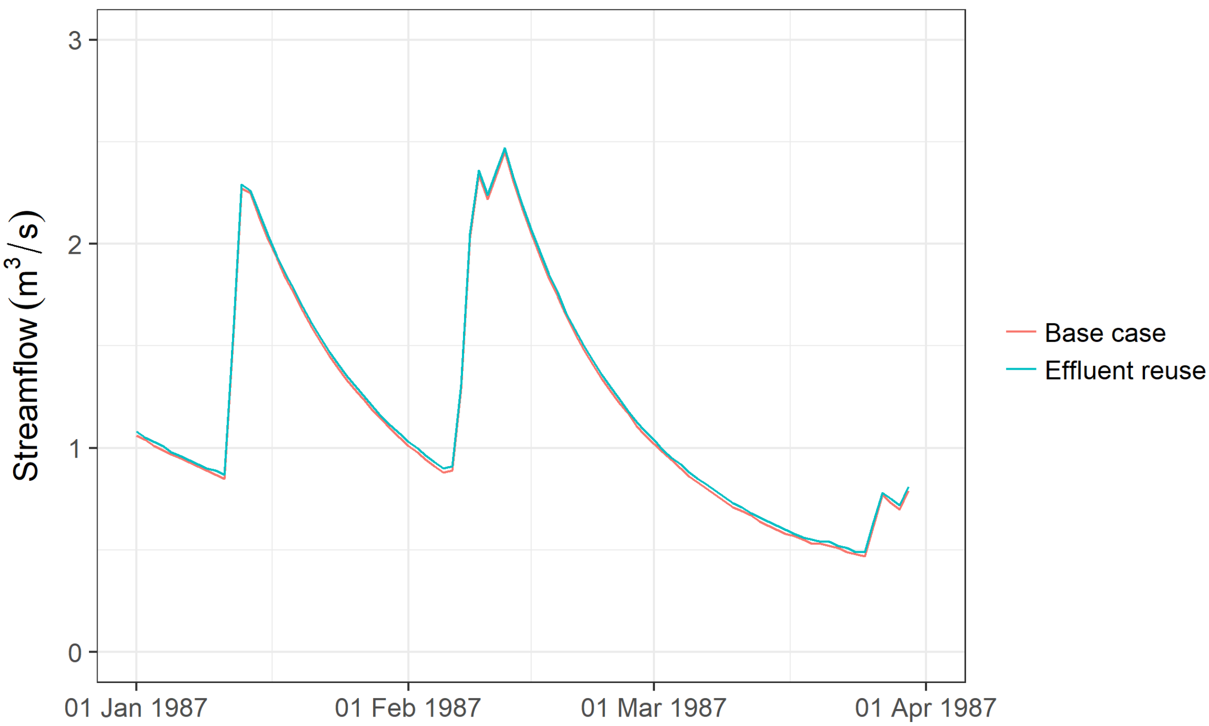

Figure 19: Historical conditions on the Freeman River under the base case (orange) and effluent reuse strategy (blue), between Jan 1 and Apr 1 of 1987.

The difference in average daily streamflow of the Freeman River and Athabasca River below the Berland River under the base case (orange) and reuse strategy (blue) is indistinguishable under all three conditions (Historical, Wet, and Dry). Average daily streamflow in the Freeman River for the reuse strategy looks similar to the base case under all three conditions as well. The effect of the reuse strategy may be undetectable when looking at flow in the river, but PMs were affected (see Table 3 at the end of this section).

The effluent reuse strategy as modelled performs similarly under all three conditions. Table 3 summarizes the overall model results seen by looking at the PMs for the strategy. The first column in the table describes the PM. The second column displays the relative difference in results for the strategy relative to base case operations under the dry condition. The third column displays the results of the strategy relative to the base case under the historical condition. The last column displays the results of the strategy relative to the base case under the wet condition.

The tributaries (e.g., Freeman River) could have higher flows under this strategy, leading to fewer days per year where the IFN for that sub-basin is not met.[13] This situation could occur in the Pembina sub-basin and to a lesser extent in the McLeod sub-basin (Figure 20), because TDLs would no longer take water from those sub-basins. In Figure 20, the orange line is barely visible because it is overlapped so much by the blue, showing very small differences between the base case and the strategy on these two rivers. Instead, water users would reuse water that has already been withdrawn from other locations. This strategy would reduce water use pressure on the smaller streams, thus reducing the number of IFN violations in some sub-basins and improving the general ecological health of those areas. Because transport trucks would now take water from storage infrastructure rather than pulling up next to a stream, there would be less riparian disturbance and damage; this in turn could be expected to improve water quality as less sediment is generated. This strategy would also see less effluent discharge as effluent is reused and disposed of rather than released back to the river. This improved water quality, over time, would likely provide long-term cumulative benefits to the basin.

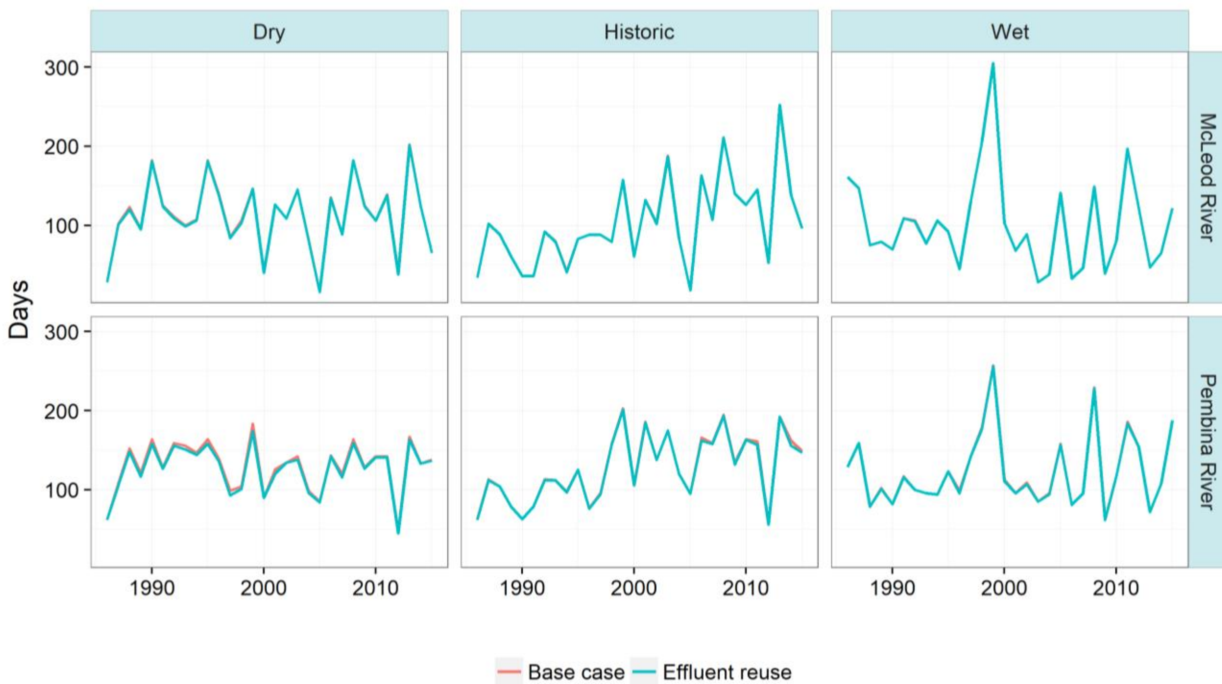

Figure 20: Total IFN violations over the dry, historic, and wet conditions, under the base case (orange) and effluent reuse strategy (blue), within the McLeod and Pembina sub-basins.

[13] IFN is defined as a flow threshold established for different streams to support and maintain the ecological health of the river. It should be noted that results in the IFN PM reflect how IFN violations are calculated, where it is assumed that flow reductions relative to the base case are not desired. IFNs are calculated based on the Desktop Method for the base case period. Reductions in streamflow relative to this base case period will result in IFNs not being met or violated.

This strategy could reduce winter water shortages for some licence holders and other downstream users (especially under dry hydrologic conditions) because the stored water would sometimes be released to supplement flows at Fort McMurray and thus meet the flow targets set out by the SWQMF (Figure 21).

Figure 21: Seasonal basin-wide water shortages under dry, historic, and wet conditions, with base case (orange) and effluent reuse strategy (blue).

Effluent reuse: Enable reuse of industrial or municipal effluent to reduce reliance on freshwater

Table 3: Summary of PM results for the reuse strategy relative to the base case under historic, wet, and dry conditions for a 30-year period.

Period and Location	Dry - Effluent reuse	Historic - Effluent reuse	Wet – Effluent reuse
Change in number of days meeting Aboriginal Extreme Flow. *Challenge: Ensure sufficient flow for navigation*			
Annual - below Firebag confluence	0.0 Days	0.0 Days	0.0 Days
Change in number of days over 1:100 flood thresholds. *Challenge: Limit damage from floods*			
Annual - Athabasca River at Athabasca	0.0 Days	0.0 Days	0.0 Days
Annual - McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca upstream of Whitecourt	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca River at Hinton	0.0 Days	0.0 Days	0.0 Days
Annual - Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Pembina River at Sangudo	0.0 Days	0.0 Days	0.0 Days
Annual - Ft. McMurray	0.0 Days	0.0 Days	0.0 Days
Change in annual instream flow needs violations. *Challenge: Maintain or improve ecosystem health*			
Annual - Mouth of the Lac La Biche River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the McLeod River	-24.0 Days	-5.0 Days	-1.0 Days
Annual - Mouth of the Clearwater River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Pembina River	-88.0 Days	-33.0 Days	-19.0 Days
Change in walleye recruitment reduction. *Challenge: Maintain or improve ecosystem health*			
Annual - below Ft. McMurray	1.59%	1.40%	0.63%
Change in seasonal streamflow as a percentage of naturalized streamflow. *Challenge: Minimize the effect of development footprint on basin hydrology*			
Summer - at the Mouth	0.02%	0.01%	0.02%
Spring - at the Mouth	0.02%	0.00%	0.00%
Fall - at the Mouth	0.03%	0.02%	0.03%
Winter - at the Mouth	0.34%	0.02%	0.03%
Change in seasonal system shortages (m^3/s). *Challenge: Provide water supply certainty for municipalities and development*			
Spring - whole system	0.0 m^3/s	-0.0 m^3/s	0.0 m^3/s
Winter - whole system	-0.35 m^3/s	0.0 m^3/s	-0.02 m^3/s
Fall - whole system	0.0 m^3/s	0.0 m^3/s	0.0 m^3/s
Summer - whole system	0.0 m^3/s	0.0 m^3/s	0.0 m^3/s

3.3.1.3 Benefits and trade-offs

This strategy simply changes the source of TDL water withdrawals from freshwater to treated effluent, thereby allowing more freshwater to remain in the river, which in turn may take water use pressure away from the smaller streams. The strategy could result in minor flow increases in the smaller streams and thereby reduce the number of IFN violations in some sub-basins. This strategy has limited impact on flow at a basin scale but has visible benefits on smaller rivers and may have benefits to water quality through reduced loading from nutrients and other constituents on tributaries and the mainstem; water quality benefits cannot be demonstrated through the modelling.

The benefits seen in this strategy depend on time and location of the original withdrawal and the location of the water reuser. For example, if water that was originally withdrawn from the mainstem Athabasca was reused instead of taking freshwater from a tributary, the tributary would benefit; however, if water that was originally withdrawn from the mainstem of the Athabasca was reused instead of pulling freshwater from the Athabasca, there would be no net change to surface water quantity.

The effects of this strategy are localized to tributaries that are important components of the aquatic ecosystem, providing habitat for different life cycle stages for aquatic species. Therefore, the benefits of this strategy may be higher for the aquatic ecosystem, relative to other PMs such as navigation.

As modelled, a trade-off of this strategy is the slight negative effect it could have on walleye recruitment. When the off-stream storage was initially filling, the reservoir would hold back water, and therefore the flows downstream in the Athabasca River would be lower than usual, as that treated effluent would normally have been discharged into the river. PM results suggest this would lead to slightly less walleye recruitment. If this strategy were implemented it would likely be at a smaller, more local level. Local implementation would likely not involve a large reservoir, and thus not have the slight negative effect on walleye recruitment in the mainstem of the Athabasca River.

As it is modelled, stored effluent could provide a back-up water source when surface water systems are stressed or not available. Effluent reuse could also create an economic incentive for effluent suppliers as it may save on water treatment. Many large users withdraw water from the mainstem while TDLs tend to withdraw from tributaries. As modelled, storing and distributing wastewater for reuse may not necessarily result in net environmental benefit. Reusing treated wastewater, which usually goes back to the river as return flows in licences, may impact the quantity of water available for downstream water users.

3.3.1.4 Implementation challenges and actions

Although modelled with a large storage structure and infrastructure to transport water from the effluent source to the storage location then to a location where it would be reused, the Working Group thought it would be more feasible to implement this strategy at the local level with a network of smaller storage facilities, thus minimizing transportation distances. Collaborative grey water[14] collection and

[14] Grey water is defined as wastewater generated from homes or offices that is free of fecal contamination. Sources usually include sinks, showers, and washing machines, but exclude toilets.

storage from municipal and community uses could be included. Grey water could be stored at various key locations and used by nearby TDL licence holders or during times of low flow instead of withdrawing from the river.

Other challenges to implementation include ensuring acceptable quality of the water for reuse, depending on the end use. For example, reusing water for agricultural purposes would require a different quality of water than water being reused for hydraulic fracturing. There could also be a water supply risk for companies that rely on another company or municipality for reused water.

A provincial water reuse policy is being developed and implementation of this strategy may be more feasible once that policy is released. Developing a policy that applied to all of Alberta despite vastly different water management considerations in northern, central, and southern basins has been a challenge. The conditions in the ARB are different than in central or southern Alberta, so the same water reuse policy may not be as appropriate in the ARB as in the South Saskatchewan River Basin, for example.

Two key actions could help move this strategy forward:

- Continue to develop and implement a basin-wide or province-wide water reuse policy. Such a policy should change, clarify, or create clear direction for decisions on water reuse. It should address acceptable water quality for reuse as well as appropriate storage options. The existing *Water Act* covers the legislation to enable reuse, but the policy needs clear articulation and direction.
- Create incentives for water reuse (e.g., opportunity for a company to report through a sustainability index).

3.3.1.5 Screening assessment

This strategy was identified as a most promising strategy.

However, ease of implementation of this strategy is contingent on a water reuse policy being developed and implemented to allow users to begin the reuse process. This may start with many small water exchanges that develop over time into a larger water reuse network. This strategy has limited impact on flow at a basin scale but has visible benefits on smaller rivers and may have benefits to water quality.

3.3.2 *Water conservation:* Continue to achieve water conservation and efficiency improvements as communities develop

3.3.2.1 Strategy overview

This strategy is intended to promote conservation and efficiency practices for municipal, community, industrial, and commercial water use, thereby supporting future regional development without increasing demand for freshwater. This strategy is applicable across the entire ARB. Municipal use typically sees a relatively high return rate so reductions in municipal water use, while beneficial, would have less effect on river flow. Thus, this strategy should focus heavily on industrial and commercial uses.

Specific examples of water conservation that are already in place include:

- Water Conservation Policy
    - The GoA's *Draft Water Conservation Policy* was released in October 2016. This policy expands on the 2006 *Water Conservation and Allocation Policy for Oilfield Injection* and the accompanying *Water Conservation and Allocation Guideline for Oilfield Injection,* which presented a guideline for the use and conservation of non-saline water for conventional water flooding and oil sands thermal in-situ operations. This new draft policy emphasizes the use of alternatives to high-quality non-saline sources, such as industrial or municipal wastewater and low-quality non-saline groundwater. The updated policy provides specific water policy and direction for oil sands mining operations, oil sands thermal in-situ operations, enhanced oil recovery and cold bitumen enhanced recovery operations, and multi-stage hydraulic fracturing operations in horizontal wells.
- Industry freshwater use
    - Industry has set goals to decrease freshwater use individually and through groups such as COSIA and the Canadian Association of Petroleum Producers (CAPP). In some in-situ projects freshwater use has been entirely replaced with alternate water sources; for example, Devon's Jackfish oil sands project uses only brackish water to create the steam needed to separate oil from sand (CAPP, 2018).
- Water for Life Conservation, Efficiency and Productivity Plans
    - As part of the Water for Life strategy the Alberta Water Council examined the objective of improving water conservation, efficiency, and productivity (CEP). In 2008, the Council produced recommendations for CEP planning, and outlined a planning process to be followed by the seven major water using sectors in the province. Progress has occurred and been reported by these sectors (Alberta Water Council, 2017).
    - Progress under CEP planning in the oil and gas sectors (CAPP, 2016):
        - Water productivity has exceeded the Water for Life Strategy's provincial target of a 30% improvement from 2005 to 2015 in the following sub-sectors: oil sands mining, oil sands in-situ, conventional oil, well drilling, and gas plants.

        - Bitumen production from oil sands mines increased by 68% from 2002 to 2014. Over the same period, non-saline water use productivity improved such that total non-saline water use for the oil sands mining sub-sector increased by only 16%.
        - Non-saline groundwater use has increased over the past decade due to a reduction in fresh water use. The proportion of total oil sands mining non-saline water withdrawals from groundwater has increased from 1% during the baseline period (2002-2004) to about 6% in 2014.
    - Progress under CEP planning in the forest sector (Alberta Forest Products Association, 2015):
        - Alberta Newsprint Company (ANC) at Whitecourt has installed and is operating a dispersed aeration system. The dispersed air flotation system selectively removes contaminants from wastewater streams from the paper machine, allowing reuse of these streams in the process, thereby decreasing water usage. As of 2015, ANC is evaluating a new sludge dewatering technology that uses 1000 fewer litres per minute of water than the current dewatering system.
    - Progress under CEP planning in the municipal sector:
        - Examples of municipal water conservation measures include water metering, stormwater collection and use, lawn watering restrictions, and low-flush or low-flow plumbing fixtures. Many municipalities in the basin (e.g., Town of Jasper) have already implemented water conservation and efficiency programs, in part due to the Water for Life CEP plan requirements.

Higher flows would be expected as a result of this strategy due to decreased withdrawals from the river. This strategy would bring instream flows closer to natural and thereby support overall aquatic ecosystem health. The relative effect of demands on streamflow is quite small so the expected increase in flow from this strategy would be small as well. However, PMs that directly depend on demands would show a greater change.

3.3.2.2 Modelling done to test this strategy and modelling results

This strategy was simulated by reducing all municipal, industrial, and commercial demands throughout the basin by 10%. If a 10% decrease is not achieved, the benefits, as reflected in the model, would not be realized. The Working Group discussed that a 10% overall reduction is probably unachievable with expected growth, due in part to water CEP actions having been implemented already. The Working Group considered that a "10% reduction in water use intensity," although not modelled that way, was maybe more achievable. This strategy provides an opportunity to address each water user's actions and to monitor and create ways to better manage water use in the ARB.

Under this strategy, 10% less water would be withdrawn from the system by the existing municipal, industrial, and commercial water licences. This would increase streamflow relative to the base case operations under all conditions. Figure 22 shows slightly higher flows on the Athabasca River at the mouth under the conservation strategy (blue) relative to base case (orange), during one year in the historic simulation.

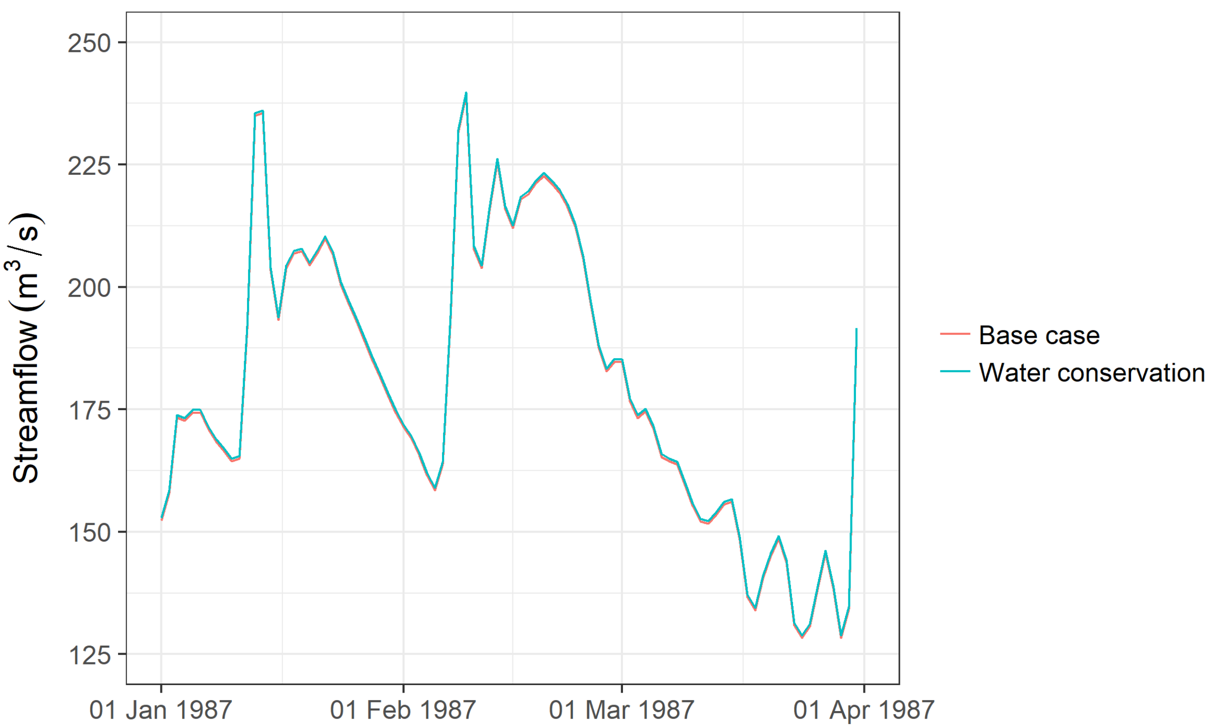

Figure 22: An example of streamflow in 1987 on the Athabasca River at the mouth under base case operations (orange) and water conservation strategy (blue).

The relative effect of demands on streamflow would be quite small; as expected, the increase in streamflow under this strategy would be barely detectable at the scale of the Athabasca River, and under a range of dry, historic, and wet conditions. Although the relative effect of demands on streamflow at the scale of the Athabasca River is quite small, many PMs are directly related to demands and would thus show a greater change under this strategy. Table 4 at the end of this section displays the PM results for the strategy relative to base case operations, under all three conditions.

Walleye recruitment reduction could decrease slightly under a conservation strategy due to higher summer flows at the mouth, which are close to natural flow (Figure 23). Likewise, there could be a decrease in IFN violations as more water is retained in-stream.

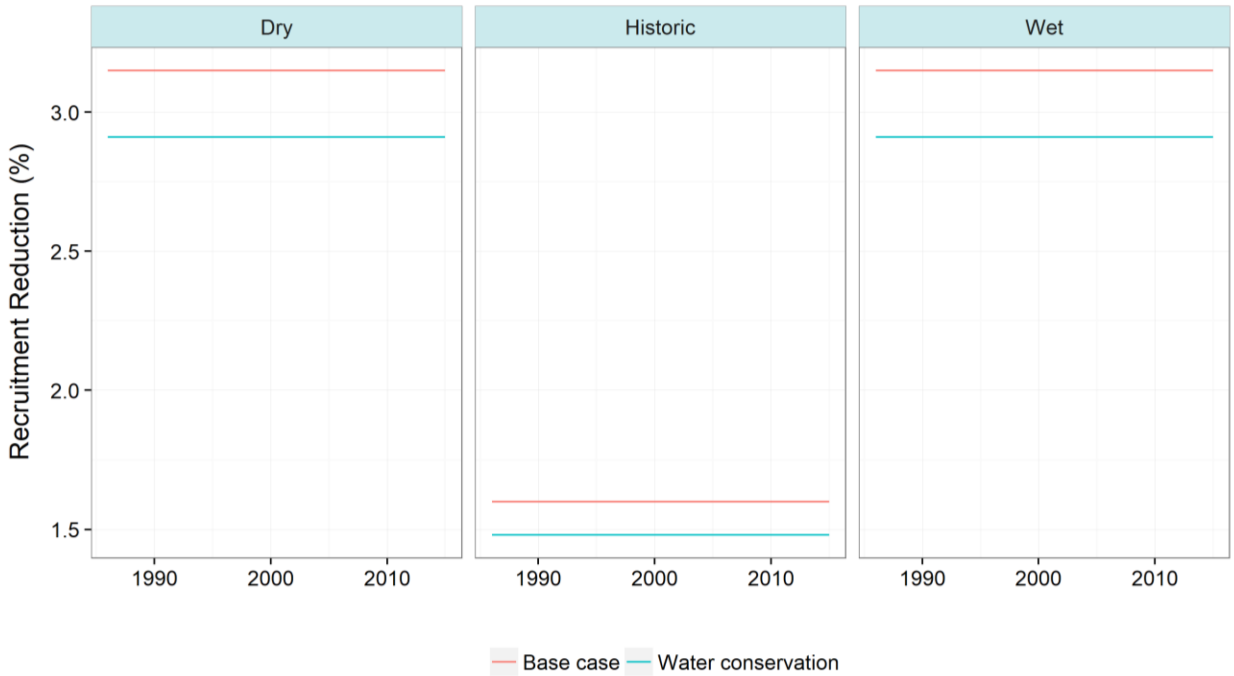

Figure 23: Annual walleye recruitment reduction (%) over dry, historic, and wet conditions, under base case operations (orange) and water conservation strategy (blue).

Shortages would decrease under a water conservation strategy. Since users are not asking for as much water, the relative proportion that they would miss during a shortage would be smaller (Figure 24). This strategy could potentially offset expected water needs from future population growth. The Working Group noted that a 10% flat decrease in water use does not allow for growth; the Water for Life strategy discusses a decrease in water use intensity as opposed to an absolute decrease, which has more potential to allow for growth.

Figure 24: Seasonal system shortages over dry, historic, and wet conditions, under base case operations (orange) and water conservation strategy (blue).

Table 4: Summary of PM results for the conservation strategy relative to the base case under historic, wet, and dry conditions for a 30-year period.

Period and Location	Dry – Water conservation	Historic – Water conservation	Wet – Water conservation
Change in number of days meeting Aboriginal Extreme Flow. *Challenge: Ensure sufficient flow for navigation*			
Annual - below Firebag confluence	1.0 Days	0.0 Days	0.0 Days
Change in number of days over 1:100 flood thresholds. *Challenge: Limit damage from floods*			
Annual - Athabasca River at Athabasca	0.0 Days	0.0 Days	0.0 Days
Annual - McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca upstream of Whitecourt	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca River at Hinton	0.0 Days	0.0 Days	0.0 Days
Annual - Lesser Slave River	0.0 Days	2.0 Days	0.0 Days
Annual - Pembina River at Sangudo	0.0 Days	0.0 Days	0.0 Days
Annual - Ft. McMurray	0.0 Days	0.0 Days	0.0 Days
Change in annual instream flow needs violations. *Challenge: Maintain or improve ecosystem health*			
Annual - Mouth of the Lac La Biche River	-3.0 Days	0.0 Days	-2.0 Days
Annual - Mouth of the McLeod River	-54.0 Days	-20.0 Days	-17.0 Days
Annual - Mouth of the Clearwater River	-20.0 Days	-3.0 Days	-3.0 Days
Annual - Mouth of the Lesser Slave river	-40.0 Days	-34.0 Days	-48.0 Days
Annual - Mouth of the Pembina River	-8.0 Days	-6.0 Days	-5.0 Days
Change in walleye recruitment reduction. *Challenge: Maintain or improve ecosystem health*			
Annual - below Ft. McMurray	-7.62%	-7.50%	-7.62%
Change in seasonal streamflow as a percentage of naturalized streamflow. *Challenge: Minimize the effect of development footprint on basin hydrology*			
Summer - at the Mouth	0.10%	0.05%	0.07%
Spring - at the Mouth	0.16%	0.08%	0.08%
Fall - at the Mouth	0.13%	0.06%	0.09%
Winter - at the Mouth	0.25%	0.17%	0.20%
Change in seasonal system shortages (m3/s). *Challenge: Provide water supply certainty for municipalities and development*			
Spring - whole system	-0.88 m3/s	-0.01 m3/s	-0.02 m3/s
Winter - whole system	-3.21 m3/s	-0.0 m3/s	-0.06 m3/s
Fall - whole system	-0.02 m3/s	0.0 m3/s	0.0 m3/s
Summer - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s

3.3.2.3 Benefits and trade-offs

The benefits from this strategy are seen across most PMs and are proportional to the degree of conservation practiced. Such benefits included increased walleye recruitment, reduced shortages, and reduction in IFN violations. The reduction in shortages is because water users in the modelled scenario are asking for 10% less water.

The trade-offs to this strategy include the expense and effort required to implement conservation programs and initiatives throughout the basin. All sectors have been working towards CEP plans of 30% conservation targets; a further 10% reduction, as modelled, may be impossible. Reductions beyond 30% may provide diminishing returns, and some sectors could experience more difficulties than others in implementing additional reductions.

3.3.2.4 Implementation challenges and actions

This strategy could be relatively straightforward to implement. Examples of success stories in other jurisdictions prove that water conservation as a strategy is possible. The Working Group thought that education and awareness was a big factor in the success of the strategy, and substantial effort should focus on informing residents, industry, and business owners of the importance of water conservation. Effective outreach is likely one of the biggest challenges to this strategy. The Working Group also noted that the cost of new technologies to achieve further water conservation could be very high. A great deal of progress has been made through CEP plans, but gaps in the data surrounding water use and water use changes for the seven major water-using sectors in the province make it hard to measure increased conservation and hard to encourage more conservation.

Several actions that could move this strategy toward implementation include:

- Implement outreach and education programs in all municipalities and communities and for all industrial and commercial developments, given that awareness and education are vital for a conservation strategy to succeed.
- Provide capacity and resources to ensure education and enforcement programs in AEP related to water use reporting and quality control of reported data is done effectively.
- Establish clear objectives for water conservation for the ARB.
- Encourage and support water conservation through incentive programs, such as:
    - Tax breaks for meeting water conservation objectives
    - A sliding rate so users pay more per unit of water consumed after a certain level
    - Community-scale incentives for municipal users (like water metering)
- Enforce stricter water use regulations and higher water rates to complement incentive programs.
- Establish legislation that encourages water reuse.

3.3.2.5 Screening assessment

This strategy was identified as having some promise.

This strategy was considered to be highly feasible economically and to yield moderate net benefits for the basin. This strategy is also socially feasible, and much is already being done to advance water conservation goals. Adopting water conservation as a strategy aligns with many community values and the Water for Life strategy.

3.3.3 *On-stream* storage: Explore new on-stream multi-purpose storage options

3.3.3.1 Strategy overview

This strategy explores options for on-stream storage in the ARB, which would serve multiple purposes, including but not limited to:

- Augmenting flows to meet downstream needs; e.g., aquatic health, riparian health, and navigation
- Supplying water supply for licensed demands
- Mitigating floods
- Generating hydropower as a renewable energy source

This strategy offers a better understanding of how on-stream storage infrastructure could affect the timing of flows in the river to serve the purposes noted above, and a better understanding of the trade-offs involved; for example, implementing this strategy could create barriers to fish passage, water temperature changes, altered sediment and nutrient regimes, changes to ice cover, and possible infringement on Indigenous harvest rights.

There are currently no on-stream storage facilities on the Athabasca River mainstem. A number of potential hydropower sites have been identified in Alberta, including 17 sites in the ARB (Alberta Utilities Commission (AUC), 2010). Hydropower discussions have arisen in recent years in part due to Alberta's Climate Leadership Plan, which established aggressive targets for renewable energy. Applications were made in 2017 for two on-stream run-of-river hydropower sites on the mainstem of the Athabasca River: the Pelican Renewable Generating Station Project and Sundog Renewable Generating Station Project upstream of Fort McMurray (Ingram, 2018). However, the applicant subsequently informed the Canadian Environmental Assessment Agency that it was not proceeding with the two projects, and the Environmental Assessment process for both projects was terminated on February 14, 2018.

A number of outcomes are possible for this strategy, depending on the size and operating rules of the storage facility. Many potential benefits and trade-offs could arise from on-stream storage. It is assumed that a full analysis of benefits and trade-offs would be addressed through detailed environmental assessments for any proposed projects; they are not explored fully in this Initiative.

3.3.3.2 Modelling done to test this strategy and modelling results

Three on-stream storage sites identified in the 2010 AUC report were simulated in the AIRM to explore the effects of on-stream storage at different locations in the basin: the McLeod site, the Mirror site, and the Grand Rapids site (see Figure 25).

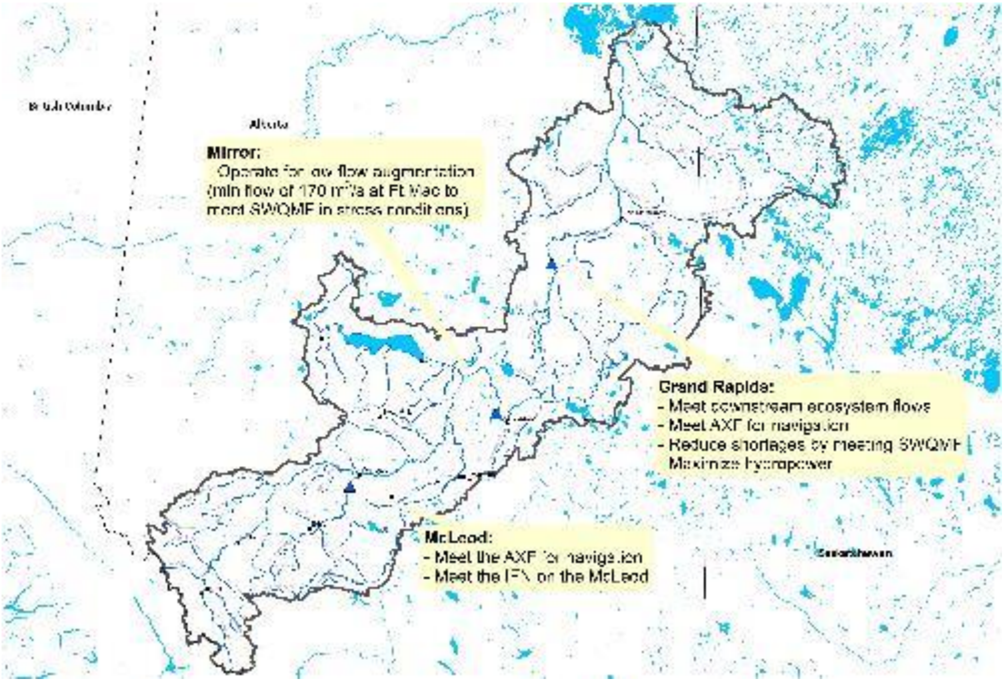

Figure 25: Three on-stream storage sites simulated in AIRM to help explore on-stream storage.

Each site was simulated for multi-purpose operations and for operations focused solely on hydropower, so the operational differences could be compared. The multi-purpose operating objectives were varied for each site to provide insight into different types of objectives that could be met with an on-stream storage facility. The following model runs were simulated in AIRM:

- On-stream tributary facility - McLeod site
  This reservoir would have a maximum storage of 694,000 dam^3 and would operate to meet downstream flows for navigation and IFN flows on the McLeod River. The reservoir would only release water when it is needed for these purposes. The McLeod reservoir could also be simulated to operate for hydropower purposes only. Results for the two McLeod simulations are compared below.
- On-stream mainstem facility - Mirror site
  This reservoir would have a maximum storage of 1,899,600 dam^3 and would operate for low flow augmentation and hydropower production. The Mirror reservoir could also be simulated to operate for hydropower purposes only. Results for the two Mirror simulations are compared below.
- On-stream mainstem downstream facility - Grand Rapids site
  This reservoir would have a maximum storage of 407,000 dam^3 and would operate to meet the following objectives in priority order: 1) meet downstream ecosystem flows, 2) meet navigational flow requirements, 3) reduce shortages, and 4) maximize hydropower. The Grand Rapids reservoir could also be simulated to operate for hydropower purposes only. Results for the two Grand Rapids simulations are compared below.

Results: On-stream tributary facility - McLeod site

In the first variation of this strategy, a McLeod reservoir would release water only when it is needed downstream for navigational purposes (measured on the Athabasca River) or to meet IFN targets on the McLeod River. The minimum flow for navigation was set to 400 m^3/s downstream of the Firebag confluence from April 15th to October 28th each year. The IFN target on the McLeod River was set to the greater of either a 15% instantaneous reduction from natural flow or the 80% exceedance of natural flow based on a weekly timestep. If the natural flow went below either of these thresholds (for example in October of 2001), the McLeod reservoir would release water to keep flows at 400 m^3/s for navigation (Figure 26), and above the IFN target on the McLeod River. Any year that the reservoir requires refilling, it would do so primarily during the peak summer flows; therefore, under this strategy, peak spring-summer flows are lower. In this variation, the reservoir was not operated with hydropower as a priority, but hydropower could be generated.

In the second variation (McLeod hydro), when operated for hydropower only, the reservoir does not aim to meet the navigational flow or IFN requirement, and water was released only for hydropower purposes, slightly augmenting low flows and slightly dampening peak flows (Figure 26).

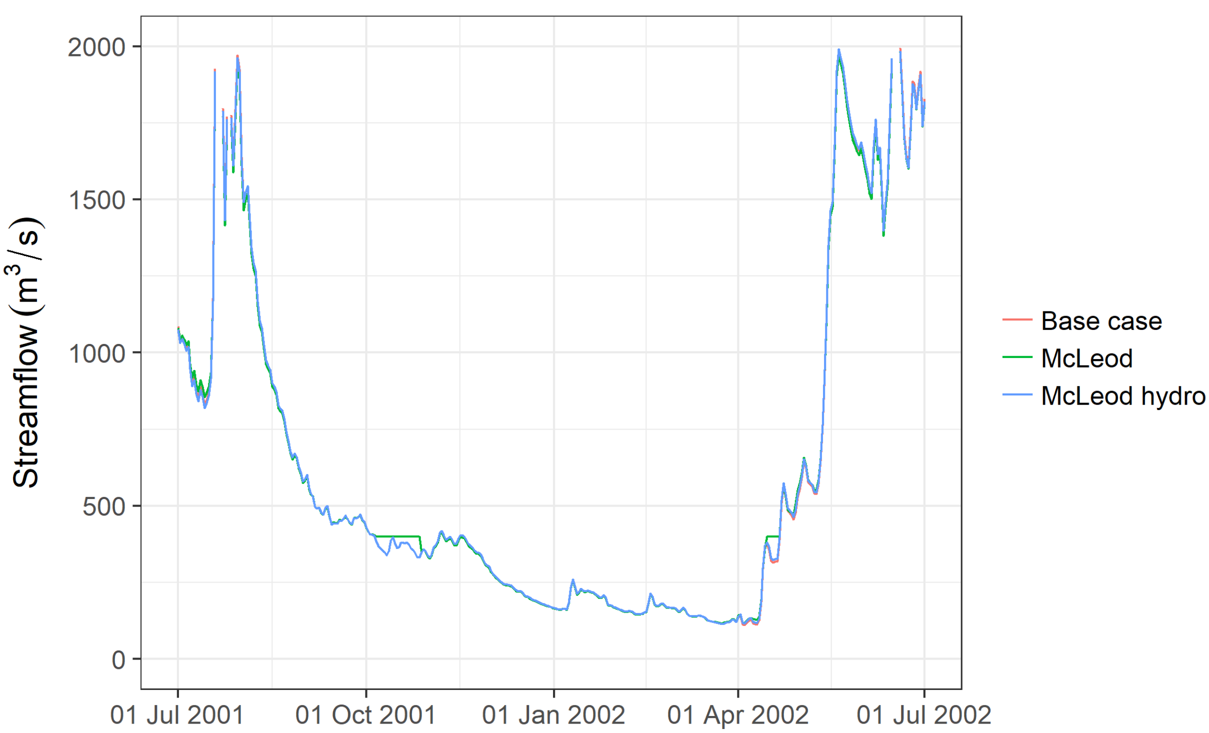

Figure 26: Historical conditions (2001) on the Athabasca River downstream of the Firebag confluence, under base case (orange), McLeod storage strategy (green), and McLeod hydro strategy (blue). The 2001-2002 year is shown to help visualize effects of the strategy during a timeframe when flow augmentation is necessary.

Table 5 and Table 6 at the end of this section display the PM results for both variations of the McLeod reservoir strategy under all three conditions relative to base case.

The Aboriginal Extreme Flow (AXF) target of 400 m^3/s would be met 100% of the time under the first variation of this strategy, due to the augmented flows from the on-stream reservoir (Table 5). This would occur under the historic conditions as well as the dry conditions. The wet conditions would not exhibit any days below the AXF threshold, thus flow augmentation would not be necessary. Results suggest one more day of navigational flow under both the historic and dry conditions when operated for hydropower only. This is because simulated hydropower operations would increase baseflows and dampen peak flows, but not to the same degree as with a minimum flow target.

In both variations, summer flows would decrease, which could negatively affect walleye recruitment since walleye fry rely on natural summer flows at the mouth. This effect could be greater under the hydropower-only variation since the reservoir would require refilling every summer (Figure 27). When operated for non-hydro purposes, the reservoir would not need refilling in some years, lessening the negative impact on walleye recruitment.

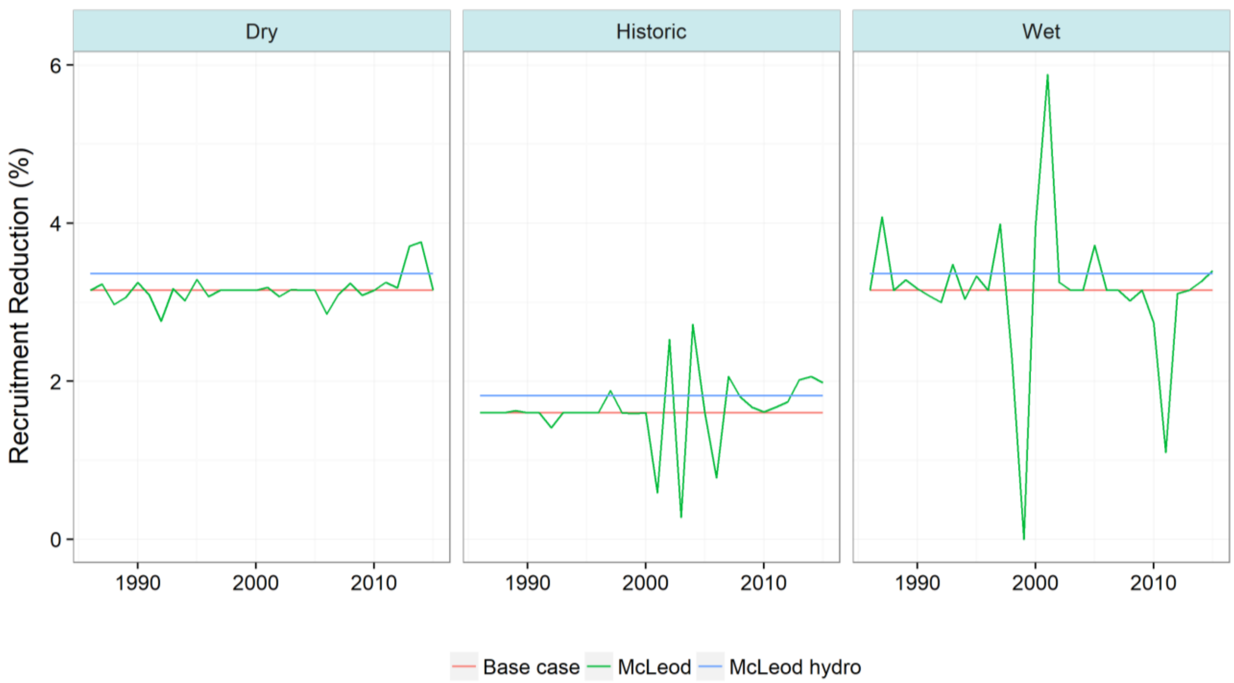

Figure 27: Annual walleye recruitment reduction (%) over dry, historic, and wet conditions, under base case operations (orange), McLeod storage strategy (green), and McLeod hydro strategy (blue).

An on-stream tributary facility at the McLeod site showed some promise in the screening assessment, described further at the end of this strategy. Working Group members agreed it would show more promise if the reservoir did not refill during the walleye recruitment window.

Results: On-stream mainstem facility - Mirror site

A Mirror reservoir on the mainstem of the Athabasca River, if operated for low flow augmentation, would dampen peak flows and augment low flows in the basin. This change in flow would be demonstrable down to the mouth, making it detectable at large scales, and would occur most noticeably under the historic and dry conditions (Figure 28). When operated purely for hydropower, low flow would not be augmented to the same degree (Figure 28).

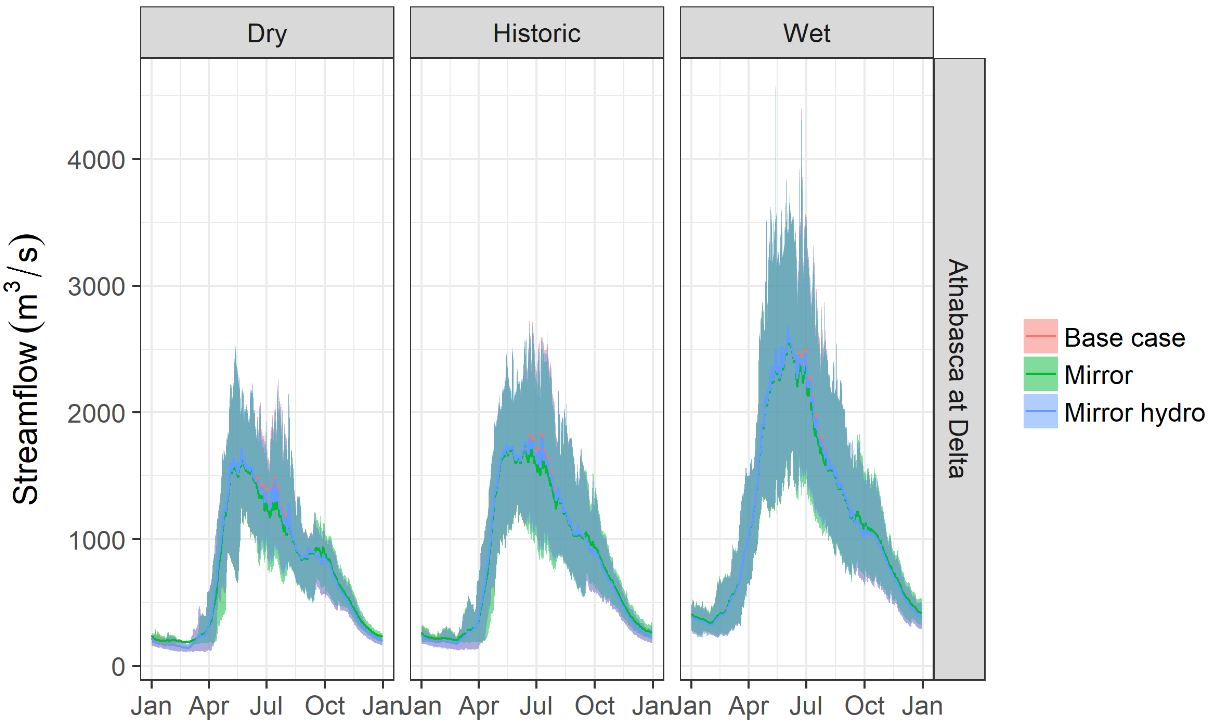

Figure 28: Average daily streamflow in the Athabasca River at the mouth, with base case operations (orange), Mirror reservoir strategy (green), and Mirror hydro strategy (blue), under dry, historic, and wet conditions.

Tables 7 and 8 display the difference in PM results for the Mirror reservoir strategy (both variations) relative to base case operations, under all three conditions.

Operation of the Mirror reservoir for low flow augmentation could have a relatively large negative impact on walleye recruitment due to the damped summer flows at the mouth each year (Figure 29). Since walleye rely on natural flows, this could decrease their recruitment potential. Operating for hydropower only could also decrease recruitment, but to a lesser extent (Figure 29) because the reservoir would not draw down as low and would not require as much refilling during spring-summer peak flows.

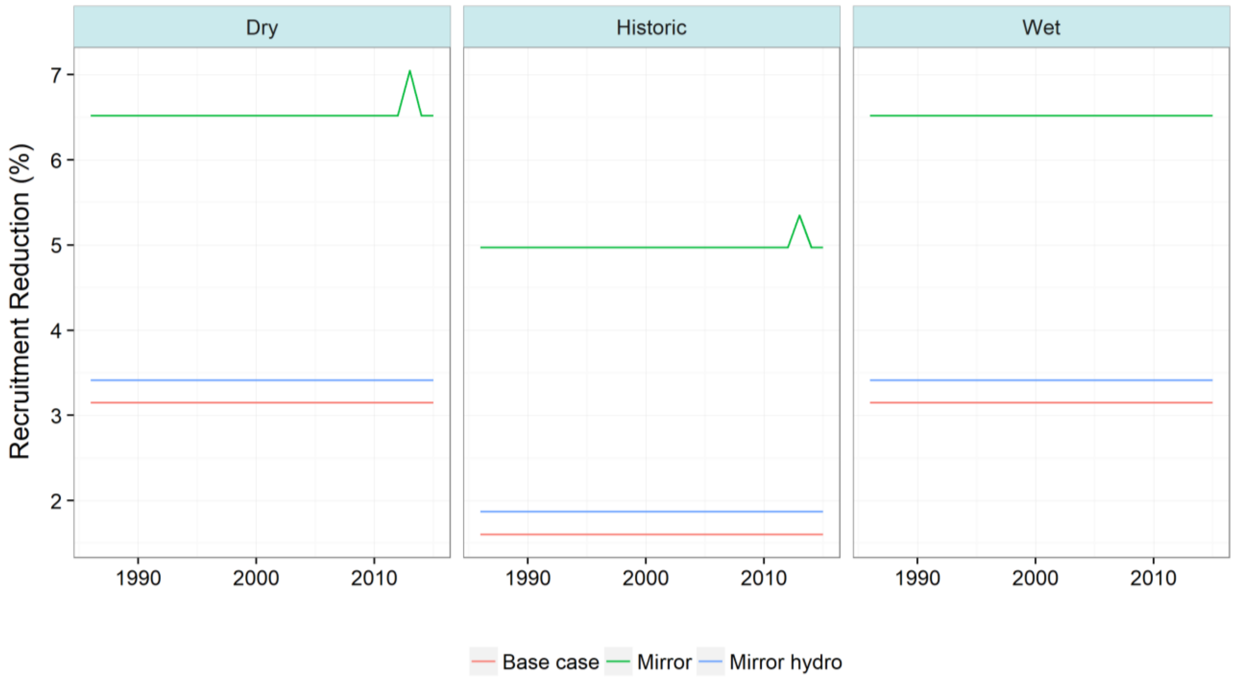

Figure 29: Annual walleye recruitment reduction (%) over dry, historic, and wet conditions, under base case operations (orange), Mirror storage strategy (green), and Mirror hydro strategy (blue).

Similarly, under the Mirror reservoir low-flow augmentation operations, there could be fewer days meeting the AXF navigation flow target relative to the base case (Table 7). However, this PM is improved under the hydropower option, showing an increase in the number of days meeting the navigation flow target relative to the base case (Table 8).

During dry conditions, winter shortages could decrease substantially under the Mirror reservoir low-flow augmentation operations. The reservoir would augment low winter flows and thus avoid triggering the SWQMF (Figure 30). Under hydropower-only operations, winter flows decrease and cause more shortages relative to base case (Figure 30).

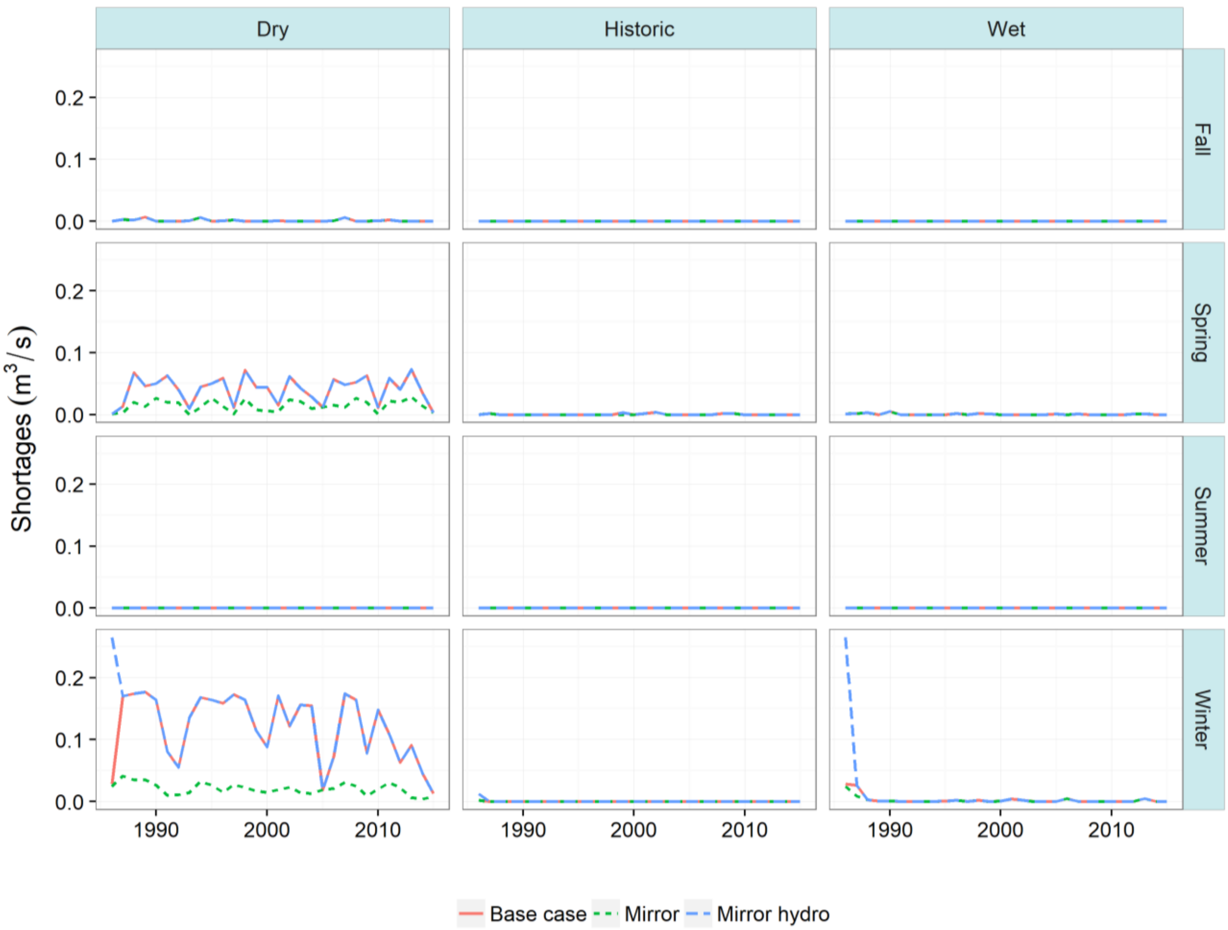

Figure 30: Basin-wide seasonal shortages during dry, historic, and wet conditions, under base case (solid orange), Mirror storage strategy (dashed green), and Mirror hydro strategy (dashed blue).

As currently modelled, the Mirror reservoir exhibits some promise as a strategy for flexible water management in the ARB.

Results: On-stream mainstem downstream facility - Grand Rapids site

In general, a Grand Rapids reservoir on the mainstem of the Athabasca River could result in higher flows during open water season to meet the navigational flow requirement of 400 m^3/s and the SWQMF flow requirements. Figure 31 depicts an increase in winter flow under the Grand Rapids option to meet the SWQMF targets and avoid shortages. Later in the year, the flow is sustained at 400 m^3/s to meet the navigation target and refill the reservoir. Operating a Grand Rapids reservoir solely for hydropower could result in slightly higher baseflows in late spring but would not meet the navigational flow target and would not decrease any shortages caused through the SWQMF (Figure 31). It is important to note that Figure 31 depicts a particular timeframe (01 Jan 2003 to 01 Jan 2004) within the overall 30-year simulation in order to effectively visualize the changes from this strategy.

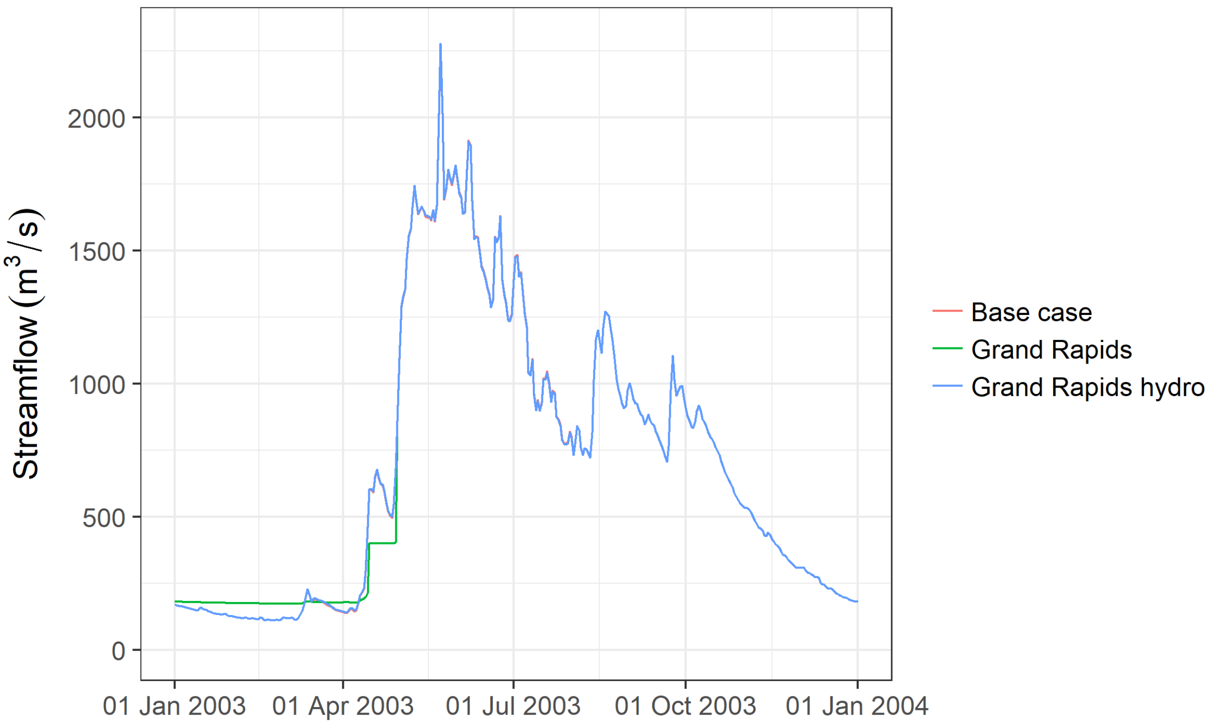

Figure 31: Dry conditions on the Athabasca River downstream of the Firebag confluence, in 2003, under base case operations (orange), Grand Rapids reservoir strategy (green), and Grand Rapids hydro strategy (blue).

Tables 9 and 10 present the difference in PM model results for the Grand Rapids reservoir strategy (both variations) relative to base case operations, under all three conditions.

Operating this strategy for multiple purposes other than hydropower could dampen peak flows and augment low flows to meet navigational requirements or the SWQMF flows whenever necessary. AXF days could increase under historic and dry conditions (Figure 32). There would be no increase under wet conditions because 100% of the days already meet the target. This strategy could also lead to fewer shortages compared to the base case.

Operating for hydropower purposes only would likely result in a small increase in days where the AXF is not met (Figure 32). This operation assumed run-of-river, where water would essentially pass through the reservoir.

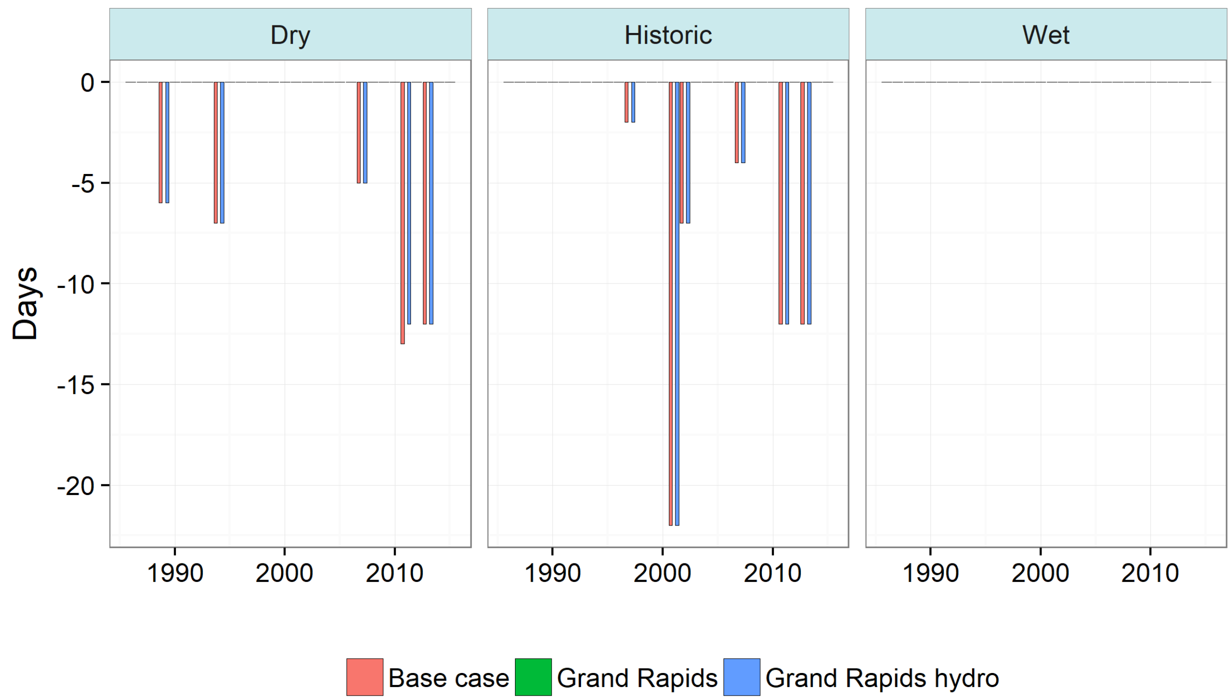

Figure 32: Number of days not meeting the AXF flow target over dry, historic, and wet conditions, under base case (orange), Grand Rapids storage strategy (green), and Grand Rapids hydro strategy (blue).

Operating a Grand Rapids reservoir for hydropower purposes only could have less negative impact on the walleye recruitment PM than operating it as a multi-purpose reservoir (Figure 33). This is because in the multi-purpose strategy, the reservoir would require more refilling when it is used for navigation and to fulfill the SWQMF.

Figure 33: Annual walleye recruitment reduction (%) over dry, historic, and wet conditions, under base case operations (orange), Grand Rapids storage strategy (green), and Grand Rapids hydro strategy (blue).

The Grand Rapids reservoir strategy was assessed as having moderately high benefits given its potential to meet basin objectives that may include environmental flows, increased navigation, hydropower, and water supply for future users.

Table 5: Summary of PM results for McLeod on-stream storage strategy, relative to base case, under historic, wet, and dry conditions for a 30-year period.

Period and Location	Dry - McLeod	Historic - McLeod	Wet - McLeod
Change in number of days meeting Aboriginal Extreme Flow. *Challenge: Ensure sufficient flow for navigation*			
Annual - below Firebag confluence	43.0 Days	59.0 Days	0.0 Days
Change in number of days over 1:100 flood thresholds. *Challenge: Limit damage from floods*			
Annual - Athabasca River at Athabasca	0.0 Days	0.0 Days	0.0 Days
Annual - McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca upstream of Whitecourt	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca River at Hinton	0.0 Days	0.0 Days	0.0 Days
Annual - Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Pembina River at Sangudo	0.0 Days	0.0 Days	0.0 Days
Annual - Ft. McMurray	0.0 Days	0.0 Days	-2.0 Days
Change in annual instream flow needs violations. *Challenge: Maintain or improve ecosystem health*			
Annual - Mouth of the Lac La Biche River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the McLeod River	-1904.0 Days	-1701.0 Days	-1640.0 Days
Annual - Mouth of the Clearwater River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Pembina River	0.0 Days	0.0 Days	0.0 Days
Change in walleye recruitment reduction. *Challenge: Maintain or improve ecosystem health*			
Annual - below Ft. McMurray	0.38%	2.54%	0.05%
Change in seasonal streamflow as a percentage of naturalized streamflow. *Challenge: Minimize the effect of development footprint on basin hydrology*			
Summer - at the Mouth	0.26%	0.37%	0.68%
Spring - at the Mouth	1.16%	1.10%	0.77%
Fall - at the Mouth	0.25%	0.66%	0.56%
Winter - at the Mouth	0.35%	0.32%	0.65%
Change in seasonal system shortages (m3/s). *Challenge: Provide water supply certainty for municipalities and development*			
Spring - whole system	-0.01 m3/s	-0.0 m3/s	0.0 m3/s
Winter - whole system	-0.0 m3/s	0.0 m3/s	-0.01 m3/s
Fall - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s
Summer - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s

Table 6: Summary of PM results for the McLeod strategy for hydro, relative to the base case, under historic, wet, and dry conditions for a 30-year period.

Period and Location	Dry – McLeod hydro	Historic – McLeod hydro	Wet – McLeod hydro
Change in number of days meeting Aboriginal Extreme Flow. *Challenge: Ensure sufficient flow for navigation*			
Annual - below Firebag confluence	1.0 Days	1.0 Days	0.0 Days
Change in number of days over 1:100 flood thresholds. *Challenge: Limit damage from floods*			
Annual - Athabasca River at Athabasca	0.0 Days	0.0 Days	0.0 Days
Annual - McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca upstream of Whitecourt	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca River at Hinton	0.0 Days	0.0 Days	0.0 Days
Annual - Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Pembina River at Sangudo	0.0 Days	0.0 Days	0.0 Days
Annual - Ft. McMurray	0.0 Days	0.0 Days	-1.0 Days
Change in annual instream flow needs violations. *Challenge: Maintain or improve ecosystem health*			
Annual - Mouth of the Lac La Biche River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the McLeod River	15.0 Days	-7.0 Days	32.0 Days
Annual - Mouth of the Clearwater River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Pembina River	0.0 Days	0.0 Days	0.0 Days
Change in walleye recruitment reduction. *Challenge: Maintain or improve ecosystem health*			
Annual - below Ft. McMurray	6.67%	13.75%	6.67%
Change in seasonal streamflow as a percentage of naturalized streamflow. *Challenge: Minimize the effect of development footprint on basin hydrology*			
Summer - at the Mouth	-0.77%	-0.69%	-0.55%
Spring - at the Mouth	1.11%	0.99%	0.61%
Fall - at the Mouth	0.00%	0.00%	0.00%
Winter - at the Mouth	0.00%	0.00%	0.00%
Change in seasonal system shortages (m3/s). *Challenge: Provide water supply certainty for municipalities and development*			
Spring - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s
Winter - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s
Fall - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s
Summer - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s

Table 7: Summary of PM results for Mirror on-stream storage strategy, relative to the base case, under historic, wet, and dry conditions for a 30-yr period.

Period and Location	Dry - Mirror	Historic - Mirror	Wet - Mirror
Change in number of days meeting Aboriginal Extreme Flow. *Challenge: Ensure sufficient flow for navigation*			
Annual - below Firebag confluence	-28.0 Days	-4.0 Days	0.0 Days
Change in number of days over 1:100 flood thresholds. *Challenge: Limit damage from floods*			
Annual - Athabasca River at Athabasca	0.0 Days	0.0 Days	0.0 Days
Annual - McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca upstream of Whitecourt	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca River at Hinton	0.0 Days	0.0 Days	0.0 Days
Annual - Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Pembina River at Sangudo	0.0 Days	0.0 Days	0.0 Days
Annual - Ft. McMurray	0.0 Days	0.0 Days	-3.0 Days
Change in annual instream flow needs violations. *Challenge: Maintain or improve ecosystem health*			
Annual - Mouth of the Lac La Biche River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Clearwater River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Pembina River	0.0 Days	0.0 Days	0.0 Days
Change in walleye recruitment reduction. *Challenge: Maintain or improve ecosystem health*			
Annual - below Ft. McMurray	107.54%	211.42%	106.98%
Change in seasonal streamflow as a percentage of naturalized streamflow. *Challenge: Minimize the effect of development footprint on basin hydrology*			
Summer - at the Mouth	-11.52%	-13.42%	-7.95%
Spring - at the Mouth	20.49%	16.95%	0.41%
Fall - at the Mouth	8.53%	8.43%	6.16%
Winter - at the Mouth	50.03%	29.01%	6.66%
Change in seasonal system shortages (m3/s). *Challenge: Provide water supply certainty for municipalities and development*			
Spring - whole system	-0.79 m3/s	-0.0 m3/s	0.0 m3/s
Winter - whole system	-2.98 m3/s	0.0 m3/s	-0.02 m3/s
Fall - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s
Summer - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s

Table 8: Summary of PM results for the Mirror strategy for hydro, relative to the base case, under historic, wet, and dry conditions for a 30-year period.

Period and Location	Dry – Mirror hydro	Historic – Mirror hydro	Wet – Mirror hydro
Change in number of days meeting Aboriginal Extreme Flow. *Challenge: Ensure sufficient flow for navigation*			
Annual - below Firebag confluence	2.0 Days	2.0 Days	0.0 Days
Change in number of days over 1:100 flood thresholds. *Challenge: Limit damage from floods*			
Annual - Athabasca River at Athabasca	0.0 Days	0.0 Days	0.0 Days
Annual - McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca upstream of Whitecourt	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca River at Hinton	0.0 Days	0.0 Days	0.0 Days
Annual - Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Pembina River at Sangudo	0.0 Days	0.0 Days	0.0 Days
Annual - Ft. McMurray	0.0 Days	0.0 Days	-1.0 Days
Change in annual instream flow needs violations. *Challenge: Maintain or improve ecosystem health*			
Annual - Mouth of the Lac La Biche River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Clearwater River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Pembina River	0.0 Days	0.0 Days	0.0 Days
Change in walleye recruitment reduction. *Challenge: Maintain or improve ecosystem health*			
Annual - below Ft. McMurray	8.25%	16.88%	8.25%
Change in seasonal streamflow as a percentage of naturalized streamflow. *Challenge: Minimize the effect of development footprint on basin hydrology*			
Summer - at the Mouth	-2.57%	-2.93%	-1.54%
Spring - at the Mouth	1.03%	1.08%	0.85%
Fall - at the Mouth	0.00%	0.00%	0.00%
Winter - at the Mouth	-1.06%	-1.02%	-1.04%
Change in seasonal system shortages (m3/s). *Challenge: Provide water supply certainty for municipalities and development*			
Spring - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s
Winter - whole system	0.24 m3/s	0.01 m3/s	0.24 m3/s
Fall - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s
Summer - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s

Table 9: PM summary results for Grand Rapids on-stream storage strategy, relative to the base case, under historic, wet, & dry conditions for a 30-yr period.

Period and Location	Dry – Grand Rapids	Historic – Grand Rapids	Wet – Grand Rapids
Change in number of days meeting Aboriginal Extreme Flow. *Challenge: Ensure sufficient flow for navigation*			
Annual - below Firebag confluence	43.0 Days	59.0 Days	0.0 Days
Change in number of days over 1:100 flood thresholds. *Challenge: Limit damage from floods*			
Annual - Athabasca River at Athabasca	0.0 Days	0.0 Days	0.0 Days
Annual - McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca upstream of Whitecourt	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca River at Hinton	0.0 Days	0.0 Days	0.0 Days
Annual - Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Pembina River at Sangudo	0.0 Days	0.0 Days	0.0 Days
Annual - Ft. McMurray	0.0 Days	0.0 Days	-1.0 Days
Change in annual instream flow needs violations. *Challenge: Maintain or improve ecosystem health*			
Annual - Mouth of the Lac La Biche River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Clearwater River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Pembina River	0.0 Days	0.0 Days	0.0 Days
Change in walleye recruitment reduction. *Challenge: Maintain or improve ecosystem health*			
Annual - below Ft. McMurray	14.85%	10.96%	4.44%
Change in seasonal streamflow as a percentage of naturalized streamflow. *Challenge: Minimize the effect of development footprint on basin hydrology*			
Summer - at the Mouth	-1.79%	-1.44%	-1.22%
Spring - at the Mouth	16.18%	4.48%	1.17%
Fall - at the Mouth	0.00%	-0.02%	0.00%
Winter - at the Mouth	75.90%	0.00%	0.04%
Change in seasonal system shortages (m3/s). *Challenge: Provide water supply certainty for municipalities and development*			
Spring - whole system	-0.79 m3/s	-0.0 m3/s	0.0 m3/s
Winter - whole system	-2.94 m3/s	0.0 m3/s	-0.02 m3/s
Fall - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s
Summer - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s

Table 10: PM summary results for Grand Rapids strategy for hydro, relative to the base case, under historic, wet, and dry conditions for a 30-year period.

Period and Location	Dry - Grand Rapids hydro	Historic – Grand Rapids hydro	Wet – Grand Rapids hydro
Change in number of days meeting Aboriginal Extreme Flow. *Challenge: Ensure sufficient flow for navigation*			
Annual - below Firebag confluence	1.0 Days	0.0 Days	0.0 Days
Change in number of days over 1:100 flood thresholds. *Challenge: Limit damage from floods*			
Annual - Athabasca River at Athabasca	0.0 Days	0.0 Days	0.0 Days
Annual - McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca upstream of Whitecourt	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca River at Hinton	0.0 Days	0.0 Days	0.0 Days
Annual - Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Pembina River at Sangudo	0.0 Days	0.0 Days	0.0 Days
Annual - Ft. McMurray	0.0 Days	0.0 Days	-1.0 Days
Change in annual instream flow needs violations. *Challenge: Maintain or improve ecosystem health*			
Annual - Mouth of the Lac La Biche River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Clearwater River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Pembina River	0.0 Days	0.0 Days	0.0 Days
Change in walleye recruitment reduction. *Challenge: Maintain or improve ecosystem health*			
Annual - below Ft. McMurray	4.44%	9.38%	4.44%
Change in seasonal streamflow as a percentage of naturalized streamflow. *Challenge: Minimize the effect of development footprint on basin hydrology*			
Summer - at the Mouth	-1.79%	-1.44%	-1.22%
Spring - at the Mouth	3.31%	2.99%	1.17%
Fall - at the Mouth	0.00%	0.00%	0.00%
Winter - at the Mouth	0.00%	0.00%	0.00%
Change in seasonal system shortages (m3/s). *Challenge: Provide water supply certainty for municipalities and development*			
Spring - whole system	-0.02 m3/s	-0.0 m3/s	0.0 m3/s
Winter - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s
Fall - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s
Summer - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s

3.3.3.3 Benefits and trade-offs

The benefits of this strategy accrue to the basin from changing the natural flow regime of the river on which the storage is built. There are potentially large benefits to the basin from on-stream reservoirs; the nature of the benefits would depend on what objectives the storage facility is built and operated to meet.

On-stream storage would allow for storage of water during periods of high flow and releases during low flow periods. This could be used to help meet navigational flows more often, reduce shortages to licensed demands, and reduce downstream IFN violations (if storage were on the major tributaries). Flow regulation or augmentation may offer potential for managing ice jams and could result in fewer flood days for communities by capturing and storing peak flows. Having on-stream storage would create more flexibility to deal with changing flows due to climate change. The climate change adaptation benefit from on-stream storage could help manage shifts in hydrologic conditions that are likely to result from longer, warmer summers.

The operating objectives for an on-stream project should include basin objectives and hydropower generation objectives; the balance of these two is key in supporting water management while still having an economically viable project. The Working Group noted that introducing on-stream storage could have the unintended consequence of de-incentivizing industrial, municipal, and agricultural improvements in water efficiency practices. That said, having both the certainty from on-stream storage and improvements in water efficiency together might make Alberta industries that much more competitive.

On-stream storage could have large impacts on environmental factors and traditional communities. For example, this strategy was shown to have negative impacts on walleye recruitment during the summer period, as walleye rely on naturalized summer flows for recruitment. On-stream storage may have negative effects on Indigenous communities, land uses and cultural sites. Other cultural and recreational uses of the river, such as canoeing, may be negatively affected by this strategy, but in some instances these same uses have seen benefits from flow augmentation from storage. Other potential trade-offs include changes in flow to the PAD, sediment transport from trapping of sediment in the reservoir, possible reduction in spring and summer peak flows (due to reservoir filling) with associated implications for riparian health and impacts on fish migration as a result of the dam being a barrier. There would likely be consequences for terrestrial and aquatic habitat and potentially for communities upstream as well.

3.3.3.4 Implementation challenges and actions

This strategy will be challenging to implement as it would involve substantial costs to develop, build, and operate large storage infrastructure as well as undertake numerous feasibility studies and impact assessments. Objectives can often be conflicting, and the facility would need to create a revenue stream to be economically viable. A challenge in implementing on-stream storage is establishing a shared vision of the structure’s purpose. There is also an operational challenge to proactively timing releases from a reservoir to meet flow objectives hundreds of kilometers away. This is much easier to do in a model than in real time but can be done with appropriate tools and knowledge.

Environmental concerns would need to be identified and addressed for an on-stream storage project to proceed, including flows to the PAD, terrestrial and aquatic habitat loss, geomorphologic function, fish passage, and ice-jamming; these should be managed through federal and provincial environmental assessment and mitigation measures.

Some Working Group members believe such facilities should be developed to maintain river function. Others are of the view that because the inevitable adverse environmental impacts cannot be adequately mitigated, these facilities should not be built. The appetite for on-stream (and off-stream) projects is ultimately influenced by government priorities and policy direction. There appears to be greater willingness to discuss on-stream dams and reservoirs today than there was even five years ago.

Actions that could be undertaken to move this strategy toward implementation include:

- Develop clear purposes for any potential on-stream storage facility; should a project be advanced, it should meet specific basin objectives in addition to energy generation.
- Perform site selection, project feasibility and environmental assessments in the context of defined basin purposes.
- Align with best practice guidelines through up-front engagement and consultation and conduct such activities in accordance with federal and provincial regulations.

3.3.3.5 Screening assessment

Views on this strategy varied considerably. Overall, this strategy was viewed as being least promising to having some promise.

The strategy was considered to have low feasibility (contingent on-site selection, feasibility studies, environmental assessments, adequate engagement, and adequate financial support), with high potential benefit, but also high trade-offs.

Some in the Working Group felt that the greatest overall benefit of this strategy is management of downstream water quantity (flow).

3.3.4 *Off-stream storage*: Develop new and existing off-stream storage sites to meet multiple basin water management objectives

3.3.4.1 Strategy overview

This strategy is intended to develop new and existing off-stream storage sites to meet multiple basin water management objectives, such as enhancing industrial water supply, regulating flow for aquatic health, improving riparian health or navigation, and generating hydropower.

Two types of existing off-stream storage were explored to differing degrees. The first was McMillan Lake in the LAR (Figure 34). McMillan Lake is a closed lake system with a small drainage area and is a non-fish-bearing brine lake. The lake drains through the sub-surface area surrounding it. This strategy would involve building a five-meter berm and increasing the capacity of the lake to 100,000 dam^3. Water would be pumped 100 meters up into the lake in the spring when river flows are high and released as needed downstream.

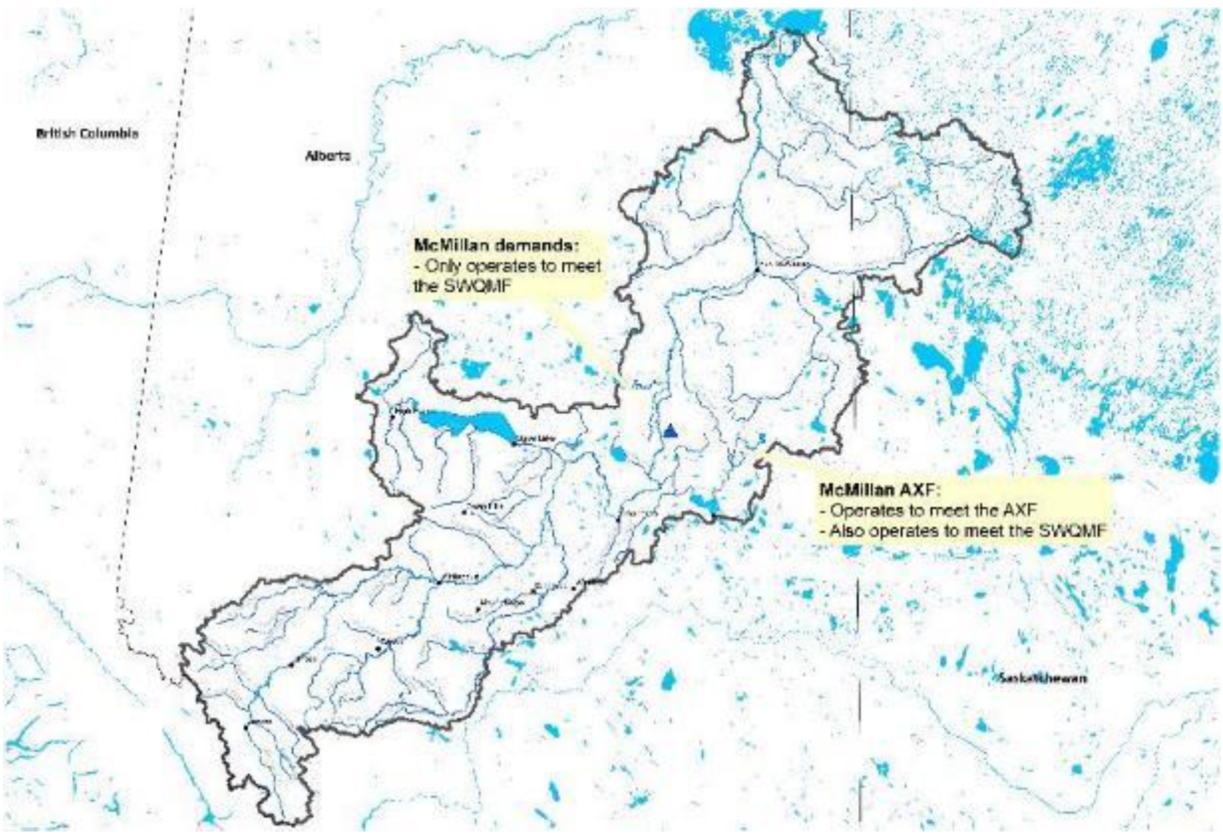

Figure 34: Off-stream storage site that was simulated in AIRM to help explore off-stream storage as a strategy.

The second option reflected that several oil sands sites in the ARB already have off-stream freshwater storage. For example, Imperial Oil's Kearl site has storage capacity for make-up water for a 30-day period. These sites mean that operators do not need to divert water during low flow periods. Although the sites were not built and designed to meet multiple basin water management objectives, the Working Group discussed how existing storage in ponds now holding raw water or tailings might offer another form of off-stream storage for future water management purposes; these sites were discussed but not simulated as there was recognition that another working group was looking at release of treated tailings water from ponds. As companies design their operation and reclamation plans, these assets (both the facilities and the water they hold) could be viewed as opportunities to be leveraged for water management. Generally, it is assumed that the impact to the natural flow regime of the source river will be affected less by off-stream storage than on-stream storage.

Augmented low flows, decreases in shortages, and/or improvements in downstream navigation are possible outcomes of this strategy. Hydropower could be generated as water is released from the reservoir. In the case of McMillan Lake, energy would be required to pump water up to the lake and there are some environmental concerns about wetland and habitat loss related to this site that would need to be better understood.

3.3.4.2 Modelling done to test McMillan Lake off-stream storage and modelling results

Two model runs were done to test this strategy:

McMillan demands: This model run assumes both a maximum and initial storage of 100,000 dam^3 in McMillan Lake. Water would only be pumped out of the lake when necessary to meet downstream licence demands.

McMillan AXF: This run assumes both a maximum and initial storage of 100,000 dam^3 in the lake. Water would be pumped out of the lake to a) meet the AXF navigation flow target downstream, and b) meet any downstream licence demands.

McMillan demands

> Operation of McMillan Lake to meet downstream demands would augment low flows at Fort McMurray to meet the SWQMF flow thresholds. The lake would then refill immediately after these flows have been met. These higher flows would enable oil sands users in the Lower Athabasca to withdraw greater volumes of water to meet their demands. Figure 35 shows the cumulative water withdrawal from oil sands operators in the Lower Athabasca. During late winter the cumulative withdrawal under the strategy (blue line) is greater than the withdrawal under the base case (orange line) due to the augmented flows that are coincident in timing.

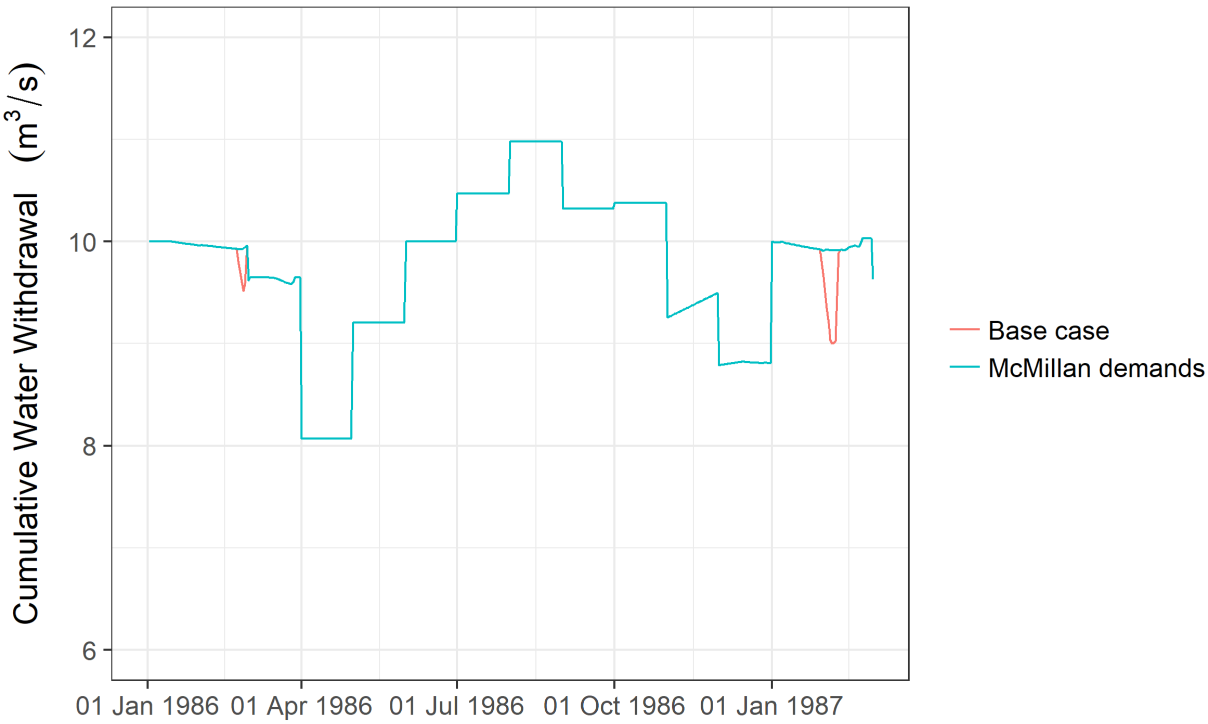

Figure 35: Cumulative oil sands water withdrawal under wet conditions in 1986, in the Lower Athabasca, under base case operations (orange) and McMillan demands strategy (blue).

Table 11 presents the PM model results for the McMillan demands strategy relative to base case operations under dry, historic, and wet conditions.

Winter water shortages could decrease relative to base case, especially under dry conditions (Figure 36). This would be at the expense of other PMs such as navigation since McMillan Lake would refill and decrease flow during the navigation window (Figure 37).

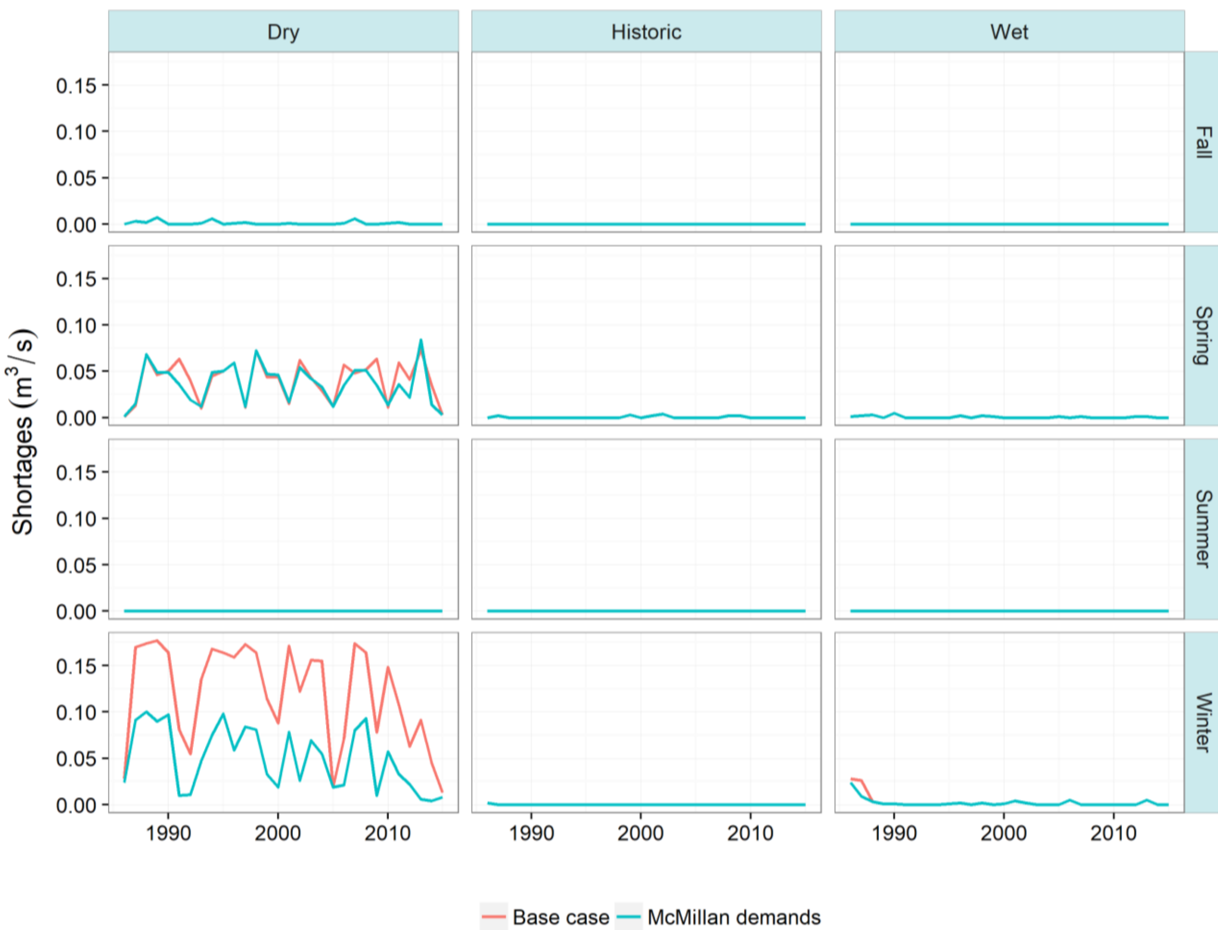

Figure 36: Seasonal basin-wide winter shortages over dry, historic, and wet conditions, under base case (orange), and the McMillan demands strategy (blue).

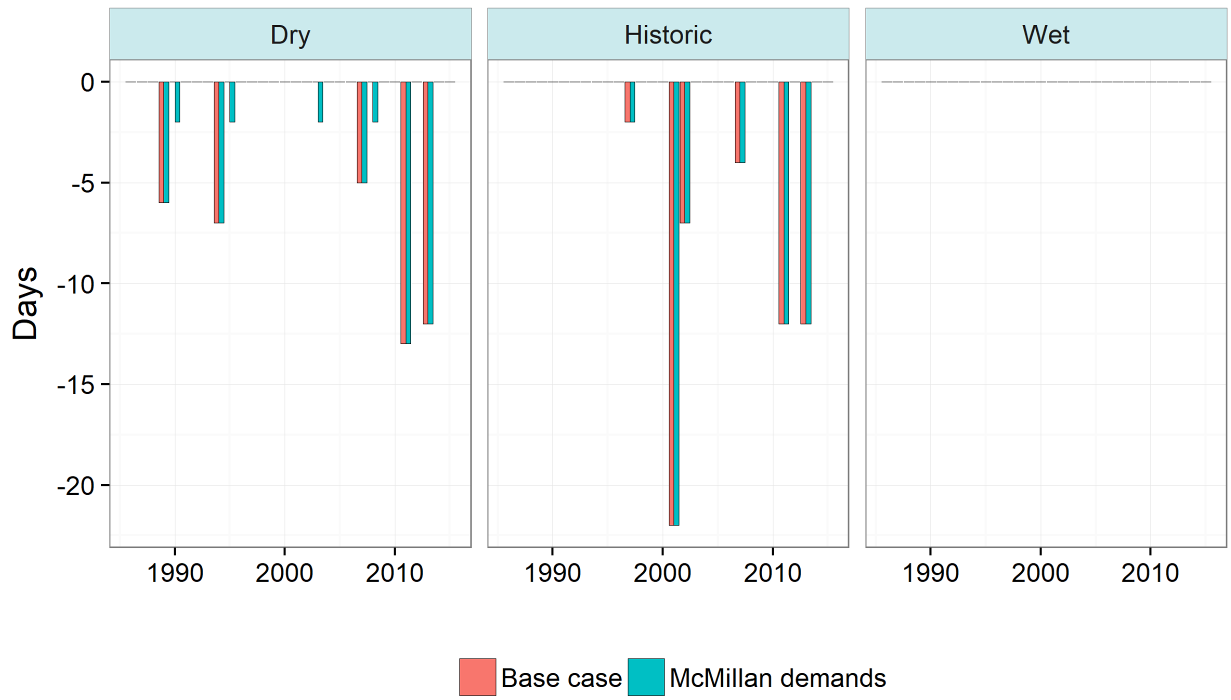

Figure 37: Number of days not meeting the AXF flow target over dry, historic, and wet conditions, under base case (orange) and McMillan demands strategy (blue).

McMillan AXF

Operation of McMillan Lake to meet the AXF flow target downstream would perform similarly to the McMillan demands variation above; however, the lake would now pump water out to meet the navigation target as well. Figure 38 shows how the McMillan AXF strategy, under dry conditions in 2010-2011, sustains a flow of 170 m^3/s to meet the SWQMF, and then later in the year sustains a flow of 400 m^3/s to meet the navigational flow requirements.

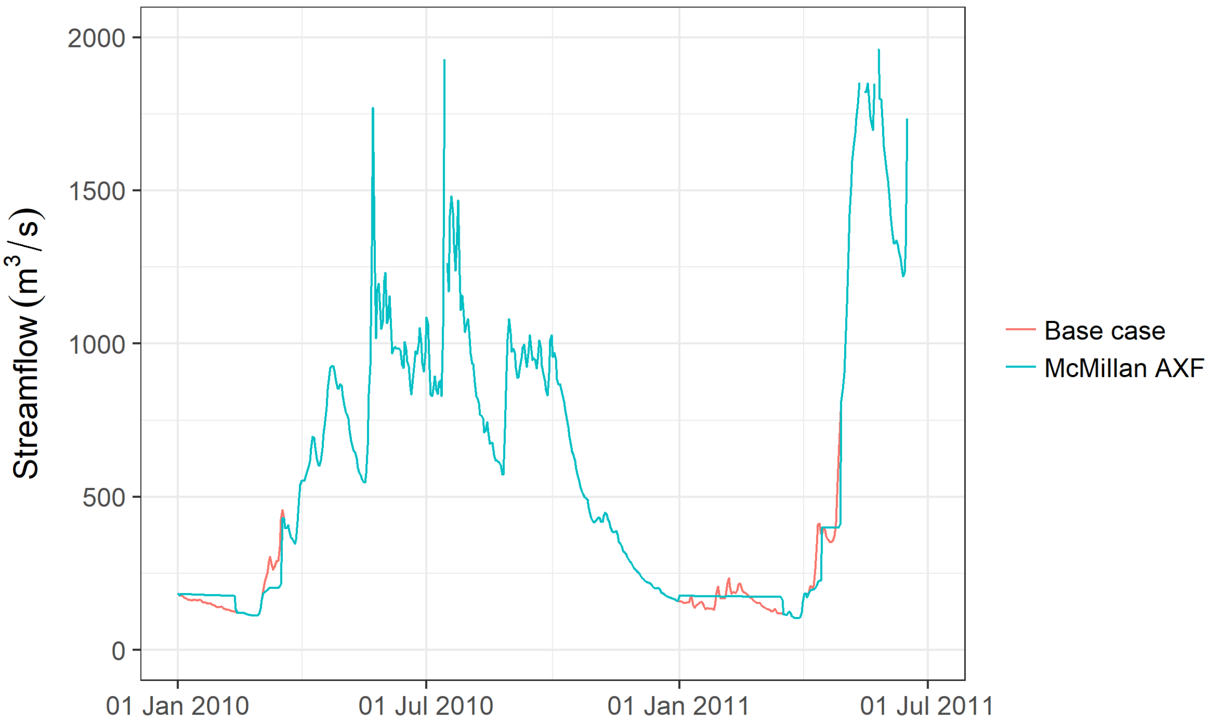

Figure 38: Dry conditions on the Athabasca River below the Firebag confluence, under base case operations (orange) and McMillan AXF strategy (blue), between Jan 1, 2010 and Jul 1, 2011.

Table 12 shows the PM model results for the McMillan AXF strategy relative to base case operations under all three conditions.

Results suggest operating McMillan Lake for navigation and to meet water demands could increase the number of navigable days relative to base case because water would be pumped out of the lake to supplement flow during the navigation window (Figure 39). This would occur at the expense of walleye recruitment because the lake would refill in the summer and cause lower than natural streamflow during the summer fry period.

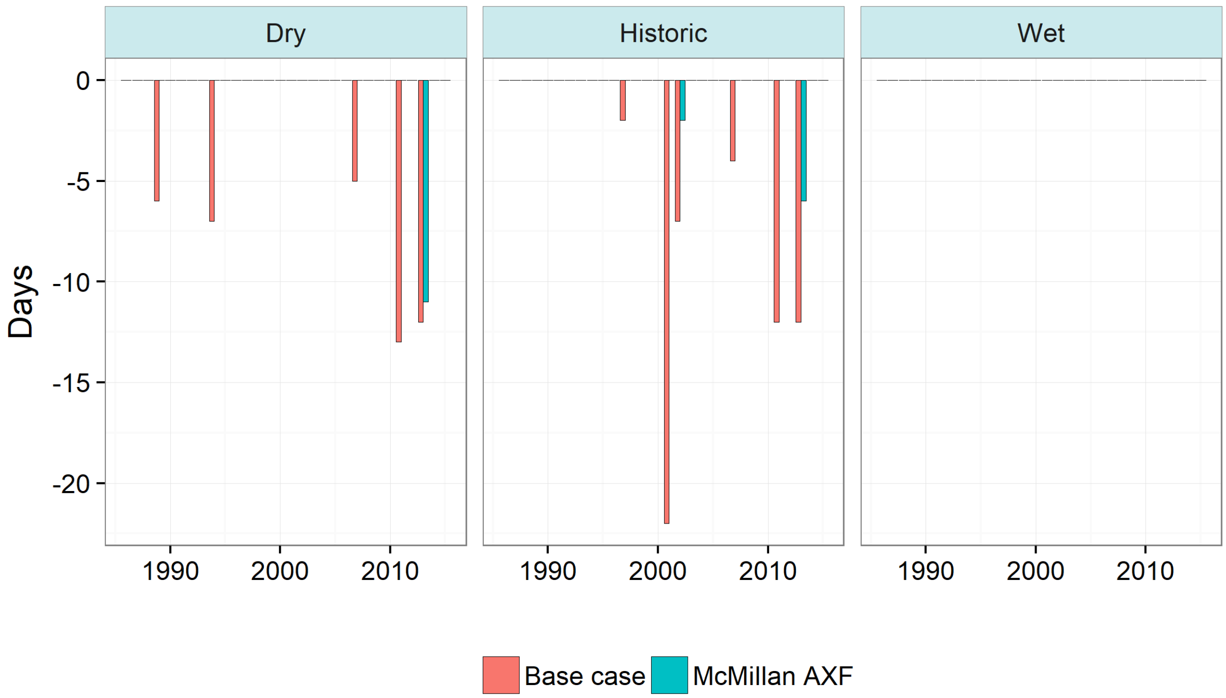

Figure 39: Number of days not meeting the AXF flow target over dry, historic, and wet conditions, under base case (orange) and McMillan for AXF strategy (blue).

If McMillan Lake is used for off-stream storage to augment low flows, the SWQMF flow thresholds and the navigational flow targets could be met more often relative to base case. As a trade-off, walleye recruitment would likely be negatively affected due to the lake refilling during the summer period.

Table 11: PM results for McMillan off-stream storage for demands, relative to the base case, under historic, wet, and dry conditions for a 30-year period.

Period and Location	Dry – McMillan demands	Historic – McMillan demands	Wet – McMillan demands
Change in number of days meeting Aboriginal Extreme Flow. *Challenge: Ensure sufficient flow for navigation*			
Annual - below Firebag confluence	-8.0 Days	0.0 Days	0.0 Days
Change in number of days over 1:100 flood thresholds. *Challenge: Limit damage from floods*			
Annual - Athabasca River at Athabasca	0.0 Days	0.0 Days	0.0 Days
Annual - McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca upstream of Whitecourt	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca River at Hinton	0.0 Days	0.0 Days	0.0 Days
Annual - Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Pembina River at Sangudo	0.0 Days	0.0 Days	0.0 Days
Annual - Ft. McMurray	0.0 Days	0.0 Days	0.0 Days
Change in annual instream flow needs violations. *Challenge: Maintain or improve ecosystem health*			
Annual - Mouth of the Lac La Biche River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Clearwater River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Pembina River	0.0 Days	0.0 Days	0.0 Days
Change in walleye recruitment reduction. *Challenge: Maintain or improve ecosystem health*			
Annual - below Ft. McMurray	0.00%	0.00%	0.00%
Change in seasonal streamflow as a percentage of naturalized streamflow. *Challenge: Minimize the effect of development footprint on basin hydrology*			
Summer - at the Mouth	0.00%	0.00%	0.00%
Spring - at the Mouth	-13.45%	0.00%	0.00%
Fall - at the Mouth	0.00%	0.00%	0.00%
Winter - at the Mouth	36.91%	0.00%	0.04%
Change in seasonal system shortages (m3/s). *Challenge: Provide water supply certainty for municipalities and development*			
Spring - whole system	-0.13 m3/s	0.0 m3/s	0.0 m3/s
Winter - whole system	-2.09 m3/s	0.0 m3/s	-0.02 m3/s
Fall - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s
Summer - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s

Table 12: PM results for McMillan off-stream storage for AXF, relative to the base case, under historic, wet, and dry conditions for a 30-year period.

Period and Location	Dry – McMillan AXF	Historic – McMillan AXF	Wet – McMillan AXF
Change in number of days meeting Aboriginal Extreme Flow. *Challenge: Ensure sufficient flow for navigation*			
Annual - below Firebag confluence	32.0 Days	51.0 Days	0.0 Days
Change in number of days over 1:100 flood thresholds. *Challenge: Limit damage from floods*			
Annual - Athabasca River at Athabasca	0.0 Days	0.0 Days	0.0 Days
Annual - McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca upstream of Whitecourt	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca River at Hinton	0.0 Days	0.0 Days	0.0 Days
Annual - Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Pembina River at Sangudo	0.0 Days	0.0 Days	0.0 Days
Annual - Ft. McMurray	0.0 Days	0.0 Days	0.0 Days
Change in annual instream flow needs violations. *Challenge: Maintain or improve ecosystem health*			
Annual - Mouth of the Lac La Biche River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Clearwater River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Pembina River	0.0 Days	0.0 Days	0.0 Days
Change in walleye recruitment reduction. *Challenge: Maintain or improve ecosystem health*			
Annual - below Ft. McMurray	0.96%	1.17%	0.00%
Change in seasonal streamflow as a percentage of naturalized streamflow. *Challenge: Minimize the effect of development footprint on basin hydrology*			
Summer - at the Mouth	0.00%	0.00%	0.00%
Spring - at the Mouth	-12.45%	1.02%	0.00%
Fall - at the Mouth	0.03%	0.49%	0.00%
Winter - at the Mouth	36.91%	0.01%	0.04%
Change in seasonal system shortages (m3/s). *Challenge: Provide water supply certainty for municipalities and development*			
Spring - whole system	-0.14 m3/s	-0.0 m3/s	0.0 m3/s
Winter - whole system	-2.09 m3/s	0.0 m3/s	-0.02 m3/s
Fall - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s
Summer - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s

3.3.4.3 Benefits and trade-offs

The benefits to the basin from off-stream reservoirs would depend on what objectives the storage facility is built and operated to meet. Some possible benefits include potential reduction in shortages to water users, more days meeting desired navigational flow targets, and higher winter streamflow to augment low flows; hydropower generation may be possible depending on how the facility is built. Off-stream storage could create water temperature and water quality concerns depending on the site selected and operating parameters. This strategy should ensure that McMillan Lake does not refill during the summer period, which is the walleye fry window, that the brine concentration in the lake does not create unwanted water quality impacts, and that releases do not create unwanted impacts on water temperature.

3.3.4.4 Implementation challenges and actions

As modelled at McMillan Lake, this strategy may be moderately feasible to implement. It would require building a five-meter berm to increase storage capacity of the lake, as well as pumping water up 100 meters into the lake during spring high flows and out of the lake as needed during low flows.

Overall, off-stream storage options may be a moderately expensive undertaking relative to some of the more passive strategies considered through this Initiative; however, off-stream projects are likely smaller and more feasible than a large-scale, on-stream storage facility.

Using industrial ponds that now hold raw water or tailings water will encounter additional implementation challenges as uncertainty remains regarding the necessary treatment and end state of the water held in these reservoirs. The concept of stored tailings water being treated and released is being examined by an industry and government working group, and COSIA is doing detailed modelling to support the discussion. Oil sands operations need a specific policy or directive that aligns with federal and provincial government policy to regulate oil sands process water release, and a standard of water quality would need to be defined in terms of the level of treatment that is required.

Two potential actions would help move this strategy toward implementation:

- Develop potential purposes for an off-stream storage facility in the ARB. The purposes or objectives of having an off-stream storage facility need to be clearly defined.
- Undertake feasibility and engineering studies and an environmental assessment to identify any negative consequences to the environment or Indigenous values and rights in the area. Consideration of the surrounding areas near McMillan Lake is recommended to identify any specific Indigenous rights. The impacts on downstream fisheries due to timing of flows and water quality should also be considered.

3.3.4.5 Screening assessment

This strategy was viewed as having some promise.

The Working Group reflected that if a location for off-stream storage can be identified, potential consequences to nature can be mitigated, and the facility shows a positive cost-benefit, it should be considered. This strategy is moderately feasible to implement and the benefits to the basin could be significant depending on how the facility is designed, built, and operated.

3.3.5 *Existing infrastructure*: Alter existing water storage infrastructure and operations to meet multiple basin water management objectives

3.3.5.1 Strategy overview

This strategy is intended to alter existing water storage infrastructure and operations to meet multiple basin objectives for flexible water management. While many small weirs and structures exist in the ARB, only two are of sufficient size to potentially offer basin-scale water management benefits. Therefore, this strategy explores altering operations on the Paddle River Dam and altering the weir infrastructure on Lesser Slave Lake. These modifications may help meet multiple objectives in the basin, including storage for flow augmentation and to meet licence use, flood mitigation, and restoring natural flow regimes downstream.

The Paddle River Dam is used for flood control and recreation. It contains a relatively small reservoir with some capacity to capture freshet under current conditions. Its effect on downstream flows is minimal. The weir on Lesser Slave Lake was installed in 1983 to reduce fluctuation of lake water levels and diminish flood hazard in the area.

Improvements to downstream flows might be possible with dynamic operation of the Lesser Slave Lake weir and the Paddle River Dam. Changes to the fishery of the Paddle River Dam reservoir would be expected with operational changes and is an important aspect to consider.

3.3.5.2 Modelling done to test this strategy and modelling results

Alterations to the Paddle River Dam and the Lesser Slave Lake weir were modelled together. Paddle River Dam operations were modified so that downstream users could withdraw water from the reservoir during low flow periods when they need it. The weir on Lesser Slave Lake was raised by 30 cm to simulate increased storage in the lake.

Two variations of this strategy were modelled: Variation 1 included downstream minimum flows to meet the SWQMF flow targets (shown in Figure 40 as “Existing infrastructure”), and Variation 2 included a simple minimum flow of 15 m^3/s on Lesser Slave River (shown in Figure 40 as “Existing infrastructure without SWQMF). When needed, water would be drawn from Lesser Slave Lake to meet these downstream minimum flows.

This strategy could result in lower baseflows on the Lesser Slave River because the lake would be able to store more water (that is, discharge less) with the weir raised by 30 cm. However, since the lake level could be kept at a higher elevation through the winter, at the onset of freshet it would discharge more water relative to base case operations making peak flows higher under this strategy (Figure 40). Simple operations were implemented in the model, with Lesser Slave Lake discharging water to meet the SWQMF minimum flows (Variation 1). These simple operations resulted in very high flows during the winter under the dry condition (Figure 40). This would essentially cause winter flooding which is not natural, desirable, or realistic. Variation 2 of this strategy simulates a simple minimum flow in Lesser

Slave River and would provide a more realistic operation (Figure 40).

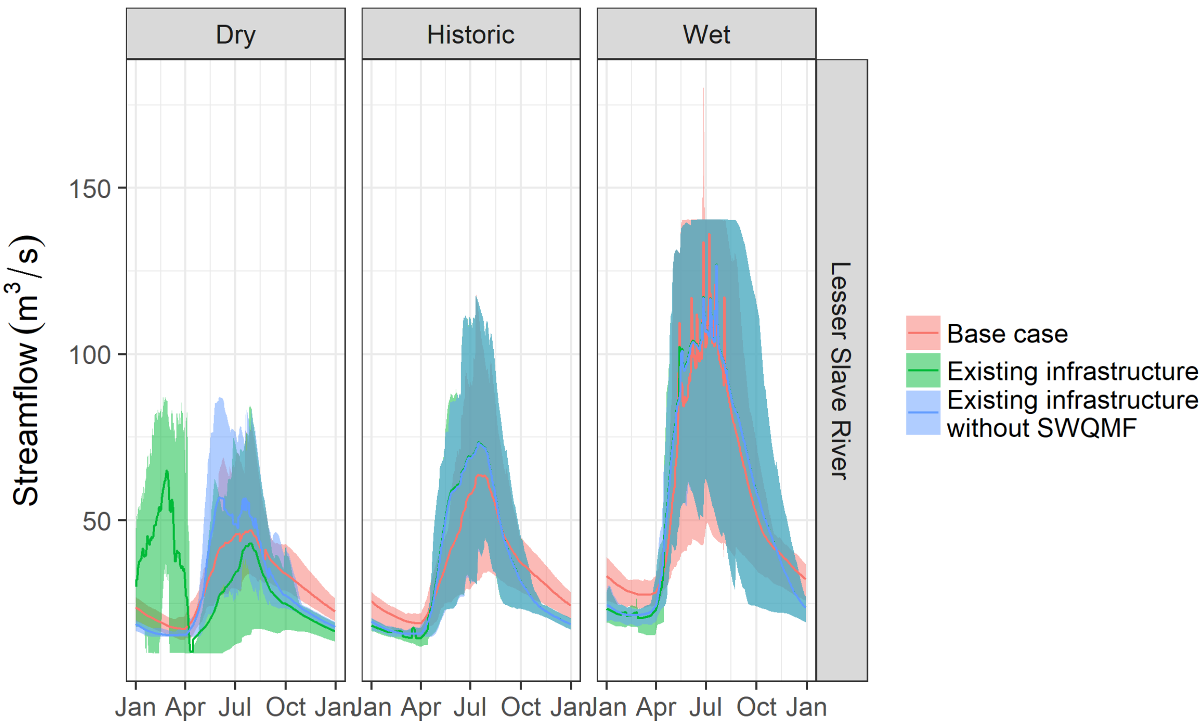

Figure 40: Average daily streamflow in the Lesser Slave River, with base case operations (orange), existing infrastructure strategy (green), and existing infrastructure strategy without SWQMF (blue), under dry, historic, and wet conditions.

Tables 13 and 14 at the end of this section show the PM results for the existing infrastructure strategy (both variations) relative to base case operations under all three conditions.

This strategy could lead to fewer navigation days relative to base case because of the lower baseflows that are coming into the Athabasca River from Lesser Slave River and the Paddle River under both simulations. This simulation could also lead to more IFN violations in these sub-basins under historical and wet conditions, but fewer violations in the Lesser Slave sub-basin under dry conditions (Figure 41). Under the SWQMF variation of this strategy (Variation 1), the flow in the Athabasca at Fort McMurray would require augmentation every year; therefore, the discharges from Lesser Slave Lake would be higher relative to base case. From this, there would likely be fewer IFN violations under the dry conditions in the Lesser Slave sub-basin.

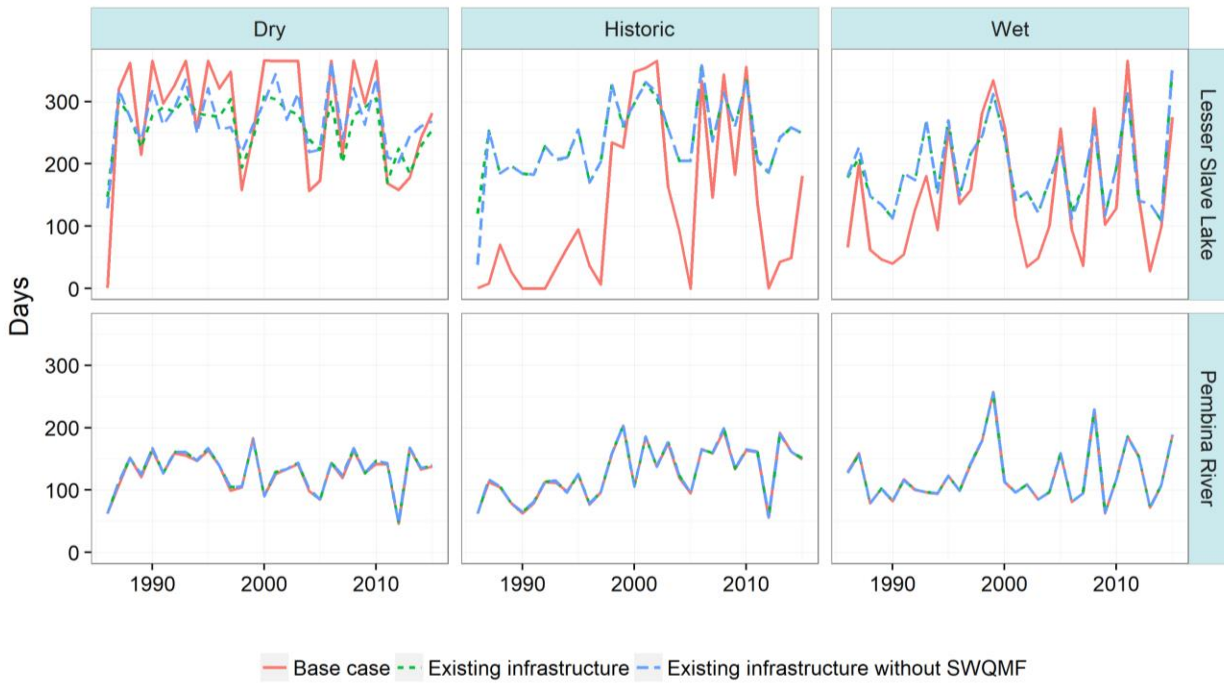

Figure 41: Total IFN violations over the dry, historic, and wet condition, under the base case (solid orange), existing infrastructure strategy (dashed green), and existing infrastructure strategy without SWQMF (dashed blue), within the Lesser Slave Lake and the Pembina sub basins.

The SWQMF variation of this strategy could substantially reduce downstream winter shortages, especially under dry conditions, because of the augmented low flows on Lesser Slave River to meet the SWQMF targets. Without the SWQMF rules, winter shortages could increase substantially (Figure 42); even though a minimum flow exists for the Lesser Slave River, it is not high enough to meet the SWQMF. Furthermore, the SWQMF would be triggered more often and would restrict withdrawals because of the decreased baseflow from Lesser Slave Lake.

Figure 42: Seasonal basin-wide seasonal shortages over dry, historic, and wet conditions, under base case (orange), existing infrastructure strategy (dashed green), and existing infrastructure strategy without SWQMF (dashed blue).

The higher peak flows that could occur on the Lesser Slave River result in more flood days relative to base case under all three conditions and under both variations of the model run (Figure 43).

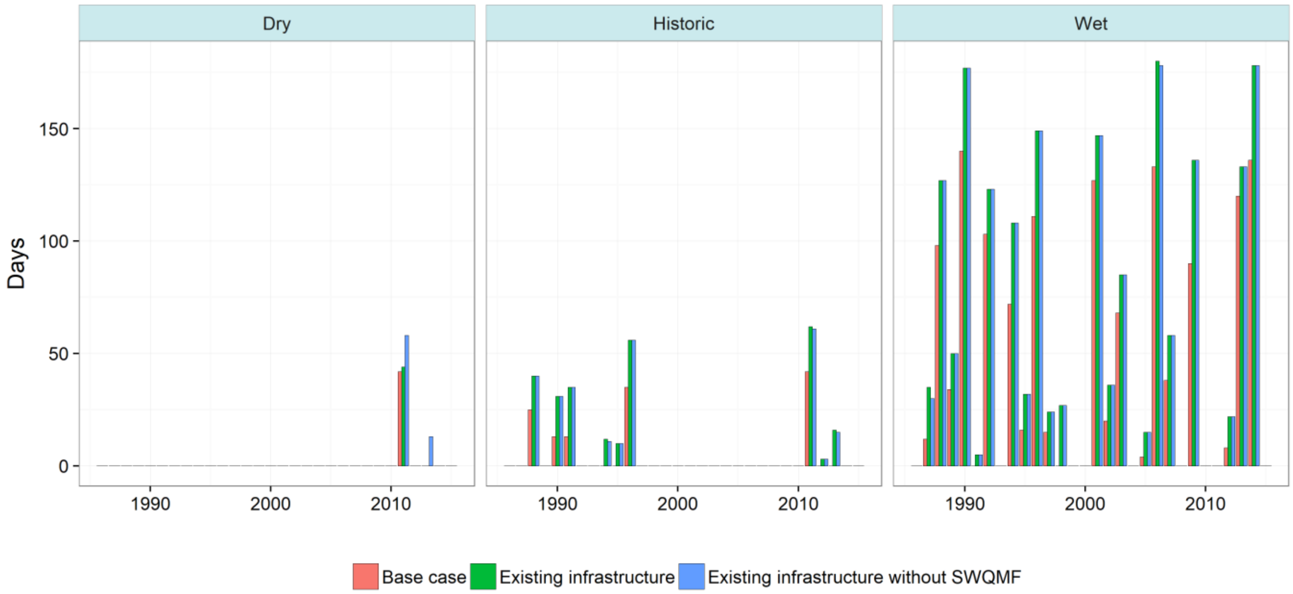

Figure 43: Number of days per year where the 1:100 flood flow thresholds are exceeded at Lesser Slave River below Lesser Slave Lake, over dry, historic, and wet conditions, under base case (orange), existing infrastructure strategy (green), and existing infrastructure strategy without SWQMF (blue).

In summary, raising the weir at Lesser Slave Lake would likely lower winter flows; however, the need to also meet the SWQMF would likely increase flow in the Lesser Slave River intermittently during the winter. This result may not be realistic, and a more plausible strategy is to implement a higher minimum flow rather than simply trying to meet the SWQMF.

With a raised weir, flood hazard on the Lesser Slave River would likely increase. This would be especially noticeable during spring freshet under wet conditions. This strategy may increase erosion and sedimentation of the lake and river channel, which is already an issue. Local communities in the Lesser Slave region may potentially be affected by this increased flood hazard.

The change in streamflow from this strategy could also have a considerable impact on IFN violations as streamflow deviates substantially from the base case.

This strategy demonstrates the need for careful lake management in the ARB. By manipulating the existing infrastructure on Lesser Slave Lake, substantial changes in the current flow regime can likely be achieved. The learnings from this strategy can help us move toward better water management for lakes and reservoirs, in terms of establishing lake level needs (similar to IFN for rivers).

Aquatic health impacts (e.g., riparian habitat, fish habitat and movement, channel maintenance, sediment transport) for both lakes and downstream flow, should be considered in effective lake management, although they are not easily modelled in this exercise. Flood and drought protection, ecosystem health, and navigation considerations should also be prioritized.

Table 13: PM results for the existing infrastructure (with SWQMF) relative to base case, under the historic, wet, and dry conditions for a 30-year period.

Period and Location	Dry – Existing infrastructure	Historic – Existing infrastructure	Wet – Existing infrastructure
Change in number of days meeting Aboriginal Extreme Flow. *Challenge: Ensure sufficient flow for navigation*			
Annual - below Firebag confluence	-9.0 Days	-4.0 Days	0.0 Days
Change in number of days over 1:100 flood thresholds. *Challenge: Limit damage from floods*			
Annual - Athabasca River at Athabasca	0.0 Days	0.0 Days	0.0 Days
Annual - McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca upstream of Whitecourt	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca River at Hinton	0.0 Days	0.0 Days	0.0 Days
Annual - Lesser Slave River	2.0 Days	137.0 Days	502.0 Days
Annual - Pembina River at Sangudo	0.0 Days	0.0 Days	0.0 Days
Annual - Ft. McMurray	0.0 Days	0.0 Days	-6.0 Days
Change in annual instream flow needs violations. *Challenge: Maintain or improve ecosystem health*			
Annual - Mouth of the Lac La Biche River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Clearwater River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Lesser Slave River	-606.0 Days	3327.0 Days	1315.0 Days
Annual - Mouth of the Pembina River	55.0 Days	30.0 Days	3.0 Days
Change in walleye recruitment reduction. *Challenge: Maintain or improve ecosystem health*			
Annual - below Ft. McMurray	0.00%	0.00%	0.00%
Change in seasonal streamflow as a percentage of naturalized streamflow. *Challenge: Minimize the effect of development footprint on basin hydrology*			
Summer - at the Mouth	-0.74%	0.06%	0.03%
Spring - at the Mouth	-1.02%	-0.14%	-0.18%
Fall - at the Mouth	-0.68%	-0.23%	-0.16%
Winter - at the Mouth	0.08%	-0.40%	-0.62%
Change in seasonal system shortages (m3/s). *Challenge: Provide water supply certainty for municipalities and development*			
Spring - whole system	-0.8 m3/s	-0.01 m3/s	-0.0 m3/s
Winter - whole system	-2.93 m3/s	0.0 m3/s	-0.02 m3/s
Fall - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s
Summer - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s

Table 14: PM results for existing infrastructure (without SWQMF) relative to base case, under the historic, wet, and dry conditions for a 30-year period.

Period and Location	Dry – Existing infrastructure without SWQMF	Historic – Existing infrastructure without SWQMF	Wet – Existing infrastructure without SWQMF
Change in number of days meeting Aboriginal Extreme Flow. *Challenge: Ensure sufficient flow for navigation*			
Annual - below Firebag confluence	-6.0 Days	-4.0 Days	0.0 Days
Change in number of days over 1:100 flood thresholds. *Challenge: Limit damage from floods*			
Annual - Athabasca River at Athabasca	0.0 Days	0.0 Days	-1.0 Days
Annual - McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca upstream of Whitecourt	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca River at Hinton	0.0 Days	0.0 Days	0.0 Days
Annual - Lesser Slave River	29.0 Days	134.0 Days	495.0 Days
Annual - Pembina River at Sangudo	0.0 Days	0.0 Days	0.0 Days
Annual - Ft. McMurray	0.0 Days	0.0 Days	-6.0 Days
Change in annual instream flow needs violations. *Challenge: Maintain or improve ecosystem health*			
Annual - Mouth of the Lac La Biche River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Clearwater River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Lesser Slave River	-262.0 Days	3262.0 Days	1325.0 Days
Annual - Mouth of the Pembina River	55.0 Days	30.0 Days	3.0 Days
Change in walleye recruitment reduction. *Challenge: Maintain or improve ecosystem health*			
Annual - below Ft. McMurray	-0.12%	-0.06%	0.00%
Change in seasonal streamflow as a percentage of naturalized streamflow. *Challenge: Minimize the effect of development footprint on basin hydrology*			
Summer - at the Mouth	0.13%	0.06%	0.03%
Spring - at the Mouth	1.21%	0.40%	-0.02%
Fall - at the Mouth	-0.43%	-0.23%	-0.16%
Winter - at the Mouth	0.80%	-0.07%	-0.51%
Change in seasonal system shortages (m3/s). *Challenge: Provide water supply certainty for municipalities and development*			
Spring - whole system	14.69 m3/s	5.55 m3/s	0.4 m3/s
Winter - whole system	15.73 m3/s	3.16 m3/s	0.67 m3/s
Fall - whole system	0.02 m3/s	0.0 m3/s	0.0 m3/s
Summer - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s

3.3.5.3 Benefits and trade-offs

The potential benefits to the basin would depend on what objectives the revised operations of the existing infrastructure are intended to meet. The modelling and discussion conducted in this project suggest little benefit could be achieved by changing the existing operations that are focused on flood control, recreation, and lake stability.

The trade-offs from introducing additional objectives include increased flooding hazard on Lesser Slave River and on Slave Lake due to higher peak flows and increased lake elevation. Decreased water quality may be expected as increased erosion and sedimentation could result from higher peak flows. Lower winter flows would also be expected on Lesser Slave River that would create more IFN violations and could potentially increase shortages.

3.3.5.4 Implementation challenges and actions

As modelled, this strategy may be challenging to implement as there would be negative social and recreational impacts associated with a change in water level on Lesser Slave Lake and the Paddle River Reservoir. The operational changes proposed in this strategy may not be feasible or useful given the few benefits that were identified.

A key priority reinforced by this strategy is to develop and implement a lake management plan for the Lesser Slave Lake region. This plan should create clear management objectives for lake levels, water allocations, and downstream flows on Lesser Slave River to optimize aquatic health, flood mitigation, and recreational and navigational opportunities.

3.3.5.5 Screening assessment

This strategy was identified as a least promising strategy.

As it was modelled, the effect of modifying existing infrastructure and operations in the basin may not be socially or ecologically feasible due to increased flooding risk and increased IFN violations.

3.3.6 *Environmental flows*: Establish IFNs or similar targets for all tributaries in the basin as a precautionary water management measure

3.3.6.1 Strategy overview

This strategy looks at setting IFN or similar flow targets (e.g., environmental flow needs) on some larger tributaries in the basin as a precautionary water management measure using the existing Alberta Desktop Method (Alberta Environment, 2011). To examine this strategy and its potential effect, the Working Group looked at how often the IFN flow targets would be violated if a minimum flow were implemented and all upstream users were denied water, and the volume of shortages that would result in such a case. This strategy is intended to proactively manage ecosystem health and can be used to help inform a modified desktop method that is being developed to guide water allocations and maintain ecosystem health.

Examples of established minimum flows in the basin:

- The Lower Athabasca Region SWQMF
    - The objective of the SWQMF (Alberta Environment and Parks, 2015) is to manage cumulative oil sands mining water withdrawals to support both human and ecosystem needs, while balancing social, environmental, and economic interests. The SWQMF requires most of the water withdrawals by existing operators and all water withdrawals by new operators to stop during low flow periods and sets water withdrawal limits for all mineable oil sands operators during moderately low flow periods. It also establishes metrics designed to detect when flow conditions are moving outside of the modelled conditions that were used to inform the withdrawal limits. One of these metrics is the Aboriginal Navigation Index, which uses the Aboriginal Extreme Flow and Aboriginal Base Flow from Candler et al. (2010).
- Water sharing agreements between oil sands operators
    - An important part of the SWQMF in the LAR is water-sharing agreements between oil sands operators. The overall (cumulative) withdrawal limit is identified within the Framework, but the companies work out among themselves exactly how to share it. This concept was used in the “Phase 1” version as well, and it effectively overrides the maximum instantaneous withdrawal rates specified in each company’s licence. The Oil Sands Water Management Agreements focus on the winter weeks because the withdrawal limits for the open water period are high enough that no coordination between the companies is yet required. In addition, the companies collaborate on a weekly email report on their withdrawals that tracks their compliance with the agreement and the limits.
- All new TDLs issued are subject to IFNs as calculated using the Alberta Desktop Method
    - All new TDLs that are issued in the ARB are subject to IFNs as calculated using the Alberta Desktop Method (Alberta Environment, 2011). The Alberta Desktop Method is a method to balance water use for human consumption with water needed to maintain

healthy aquatic ecosystems; it is used where site-specific information to establish an environmental flow is absent. IFNs are science-based quantities and qualities of water to sustain the ecological integrity of riparian systems. By staying within recommended limits, there is a low probability of ecological effects. The level of environmental flow recommended by the Alberta Desktop Method is the greater of either (i) a 15% instantaneous reduction from natural flow, or (ii) the lesser of either the natural flow or the 80% exceedance of natural flow based on a weekly or monthly timestep.

- The modified desktop method now being developed will make it mandatory to consider environmental flows when allocating new licences
    - AEP is working on a modified desktop method (referred to as the Surface Water Allocation Directive in the Working Group meetings), which will provide a province-wide, consistent approach to help determine water withdrawal applications, and may enhance, expand, or replace the Alberta Desktop Method. This modified method is intended to guide establishment of water allocations so that ecosystem health can be maintained and would likely not apply to waterbodies already covered by an existing Water Management Plan or Water Conservation Objective.

This strategy would result in a more natural hydrograph and may support improved ecosystem health.

When simulated in the AIRM, this strategy demonstrates how often the IFN flow targets would be met if a minimum flow were implemented and the shortages that would arise if licences were cut off under historical, wet, and dry conditions.

3.3.6.2 Modelling done to test this strategy and modelling results

The Alberta Desktop Method was applied to five tributaries in the model (McLeod, Pembina, Lesser Slave, Lac La Biche, and Clearwater) to set an IFN minimum flow target at the mouth of each tributary. Upstream demands were shorted to meet the IFN whenever necessary.

Results demonstrate that this strategy would increase flows, primarily during low flow periods, in the major tributaries where IFN targets are set (Figure 44) by causing upstream shortages.

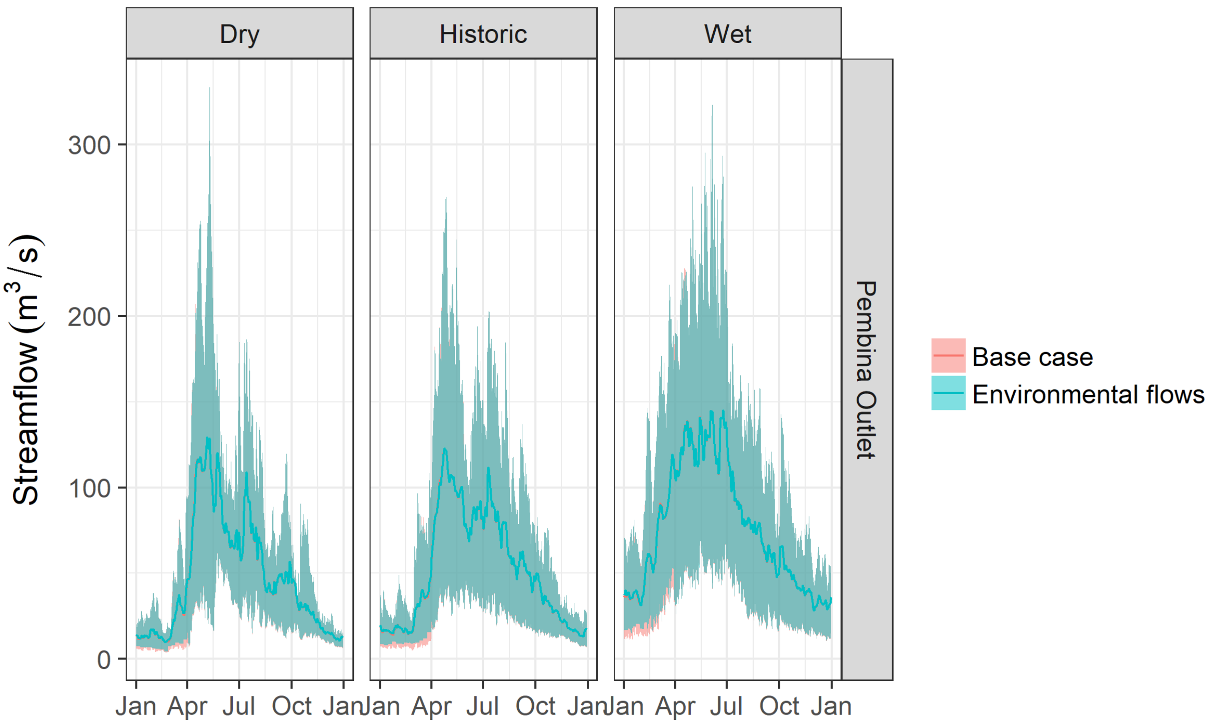

Figure 44: Average daily streamflow at the mouth of the Pembina River, with base case operations (orange) and IFN strategy (blue), under dry, historic, and wet conditions.

Table 15 shows the PM results for the IFN strategy relative to base case operations under all three conditions. This strategy performs the best under dry conditions, where there is the greatest increase in number of days that the IFN is met. Under dry conditions this strategy also increases the days where navigation is possible at the Firebag confluence by three days.

This strategy could decrease IFN violations in all sub-basins under all conditions; two sub-basins are illustrated in Figure 45. As Figure 46 shows, the natural hydrograph that is supported under this strategy has a positive effect on walleye recruitment. Overall, it was identified that implementing environmental flows is important. These flows need to be defined on a seasonal basis to address aquatic health and fish population viability. However, because the mechanism to achieve these results is by shutting off upstream water users, this strategy could increase basin-wide shortages in all seasons (Figure 47). Therefore, it will be important to evaluate trade-offs between ecosystem and human water needs.

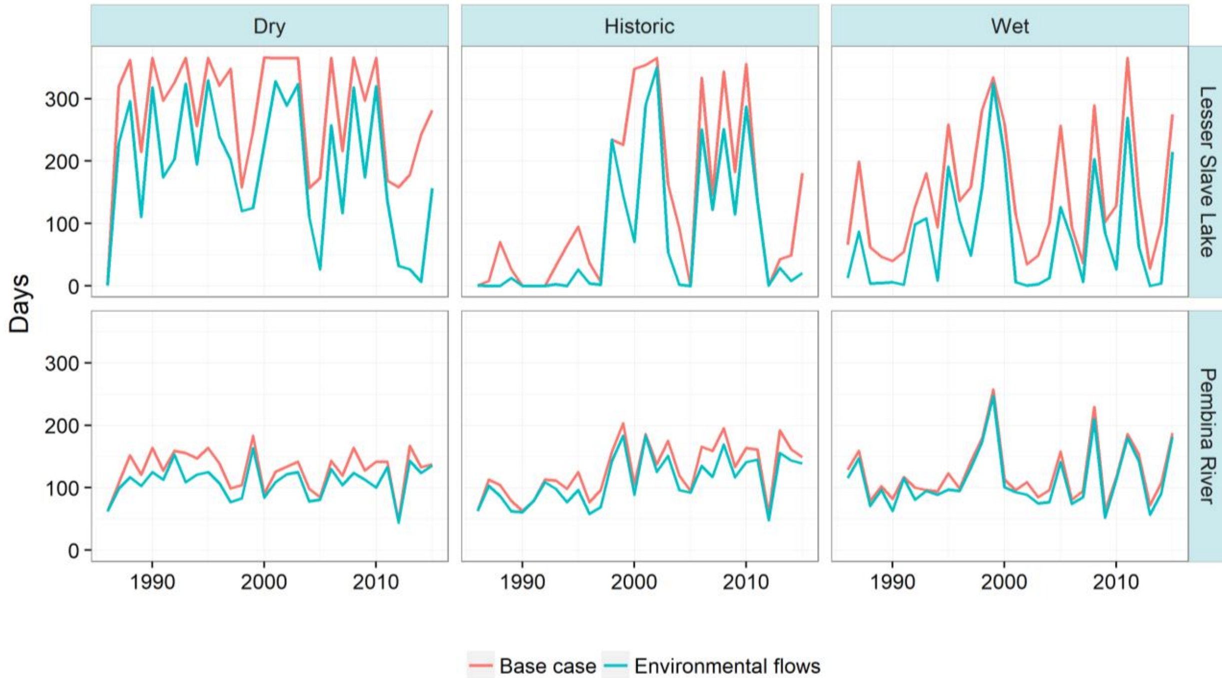

Figure 45: Total IFN violations over the dry, historic, and wet condition, under the base case (orange) and environmental flows strategy (blue), within the Lesser Slave Lake and Pembina sub-basins.

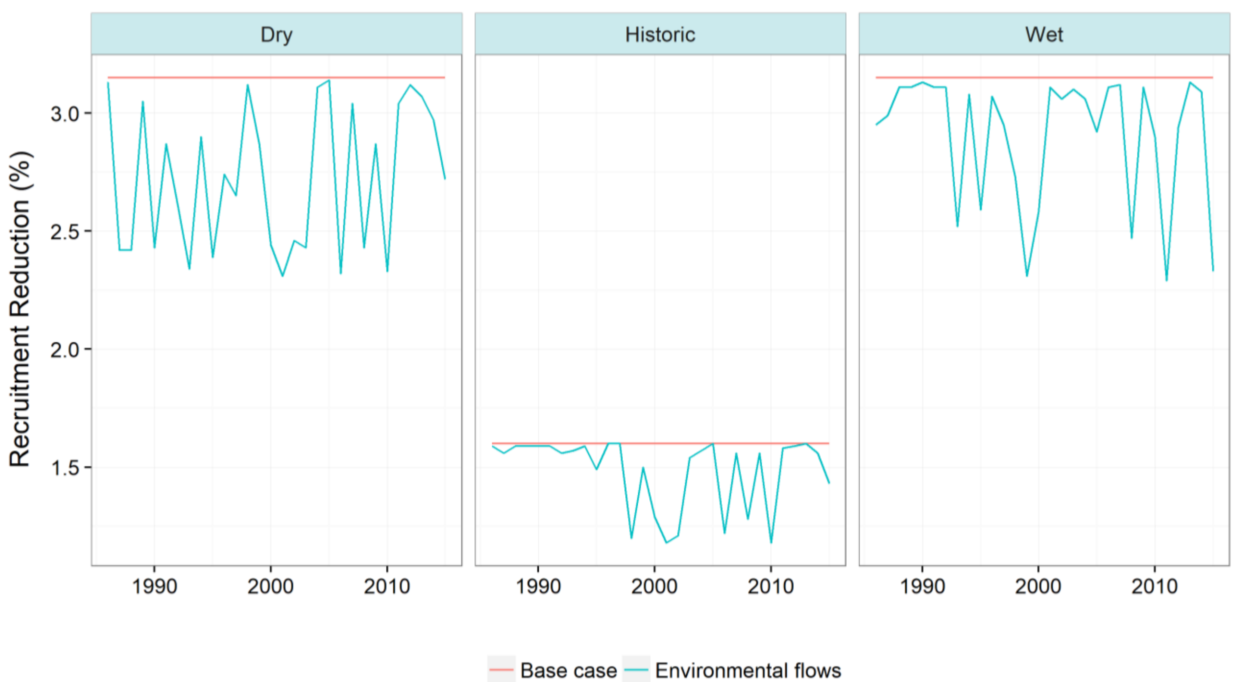

Figure 46: Annual walleye recruitment reduction (%) over dry, historic, and wet conditions, under base case operations (orange) and environmental flows strategy (blue).

Figure 47: Seasonal basin-wide seasonal shortages over dry, historic, and wet conditions, under base case (orange), and the environmental flows strategy (blue).

Table 15: Summary of PM results for the IFN strategy relative to base case, under the historic, wet, and dry conditions for a 30-year period.

Period & Location	**Dry – Environmental flows**	**Historic – Environmental flows**	**Wet – Environmental flows**
Change in number of days meeting Aboriginal Extreme Flow. *Challenge: Ensure sufficient flow for navigation*			
Annual - below Firebag confluence	3.0 Days	0.0 Days	0.0 Days
Change in number of days over 1:100 flood thresholds. *Challenge: Limit damage from floods*			
Annual - Athabasca River at Athabasca	0.0 Days	0.0 Days	0.0 Days
Annual - McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca upstream of Whitecourt	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca River at Hinton	0.0 Days	0.0 Days	0.0 Days
Annual - Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Pembina River at Sangudo	0.0 Days	0.0 Days	0.0 Days
Annual - Ft. McMurray	0.0 Days	0.0 Days	0.0 Days
Change in annual instream flow needs violations. *Challenge: Maintain or improve ecosystem health*			
Annual - Mouth of the Lac La Biche River	-30.0 Days	-16.0 Days	-20.0 Days
Annual - Mouth of the McLeod River	-470.0 Days	-177.0 Days	-156.0 Days
Annual - Mouth of the Clearwater River	-189.0 Days	-37.0 Days	-56.0 Days
Annual - Mouth of the Lesser Slave River	-2661.0 Days	-1481.0 Days	-1953.0 Days
Annual - Mouth of the Pembina River	-577.0 Days	-504.0 Days	-328.0 Days
Change in walleye recruitment reduction. *Challenge: Maintain or improve ecosystem health*			
Annual - below Ft. McMurray	-13.50%	-7.15%	-7.85%
Change in seasonal streamflow as a percentage of naturalized streamflow. *Challenge: Minimize the effect of development footprint on basin hydrology*			
Summer - at the Mouth	0.70%	0.24%	0.34%
Spring - at the Mouth	1.91%	0.73%	0.69%
Fall - at the Mouth	1.23%	0.31%	0.47%
Winter - at the Mouth	2.48%	1.01%	1.18%
Change in seasonal system shortages (m^3/s). *Challenge: Provide water supply certainty for municipalities and development*			
Spring - whole system	18.88 m3/s	5.88 m3/s	13.59 m3/s
Winter - whole system	28.38 m3/s	7.09 m3/s	13.66 m3/s
Fall - whole system	23.02 m3/s	5.45 m3/s	10.31 m3/s
Summer - whole system	16.32 m3/s	5.54 m3/s	11.28 m3/s

3.3.6.3 Benefits and trade-offs

This strategy would likely result in fewer IFN violations throughout the basin and would likely increase seasonal naturalized streamflow, therefore increasing walleye recruitment and suggesting an improvement to fishery health. Under dry conditions this strategy could also result in slightly more days meeting the navigational flow target. The trade-off to this strategy is likely a substantial increase in water shortages to all users over all seasons as licences are shorted to meet IFNs. Working Group participants suggested it would be beneficial to look at this strategy along with other strategies, such as storage. Increasing water shortages to upstream users may or may not be an acceptable trade-off. It remains important to balance environmental and other objectives, and this strategy can help inform the modified desktop method currently being drafted, to achieve such objectives.

3.3.6.4 Implementation challenges and actions

In the absence of a water management plan for the ARB that speaks directly to IFNs, this strategy would be moderately difficult to implement. However, with the completion of a modified desktop method, this strategy (or a variation of it) may be more feasible to implement in the near future.

Challenges related to this strategy would likely include some resistance from senior licence holders if new IFN conditions were applied to their existing licences. Water supply certainty would be another challenge, as senior licence holders may be worried that their licences would be cut off.

The Working Group noted several actions that could move this strategy toward implementation, including:

- Establish IFNs in an approved water management plan by exploring the potential of using a modified desktop method to establish the IFN targets.
- Develop a database of tributaries that have habitat at risk and/or species at risk and limit water allocations, implement IFNs, and/or restrict activities in those areas.
- Determine watershed withdrawal limits based on environmental factors (e.g., fish habitat needs) and manage licences with that limit in mind.
- Communicate broadly, in an accessible way, when IFNs are implemented on a licence or a specific stream.

3.3.6.5 Screening assessment

This strategy was identified as a most promising strategy.

This strategy would likely have positive net benefits and high feasibility. The AIRM could be used to determine where this strategy would have the highest impact by applying the Alberta Desktop Method (or a modified desktop method) to see where the pressures are for water supply. This can be used to illustrate and quantify supply risks to the “next person in the licence queue.” The Working Group questioned whether this strategy should apply only to new licences or also to existing licences. If all licences are subject to minimum flows there would be greater benefit for the basin; however, it is important to remember the volume of licence shortages that this strategy would create when considering trade-offs. It was acknowledged in the Working Group meetings that the approach of applying IFN conditions to new licences and TDLs is already being done by AEP and the Alberta Energy Regulator.

3.3.7 *Navigational flows*: Implement minimum flows to improve navigation in the lower Athabasca basin

3.3.7.1 Strategy overview

This strategy would implement minimum flows to improve navigation on the Athabasca River downstream of the Firebag River confluence during the open water season. The minimum flow is based on the AXF, a flow established for navigation in the Candler et al. (2010) report "As Long as the River Flows." The AXF defines a minimum flow of 400 m^3/s in the Athabasca River below the confluence with the Firebag River between April 16 and October 28 (total of 196 days). In this strategy, upstream licence demands are shorted to meet the AXF flow target whenever necessary.

The Working Group noted that the navigational flows are not met naturally in many cases. This strategy explored the idea of meeting navigational flows more often through management.

At present, there is no established minimum flow for navigational purposes in the ARB. Communities are collecting data through an Indigenous navigation app to help determine the navigational pinch points.

This strategy is expected to increase flows on the Lower Athabasca River, which would improve navigation for Indigenous peoples, allowing them to practise their traditional activities more freely and without restriction. To achieve these higher flows, the strategy would increase shortages upstream of the Firebag confluence.

3.3.7.2 Modelling done to test this strategy and modelling results

Based on the flow and timing suggested by the AXF, the model applies a minimum flow target of 400 m^3/s downstream of the confluence with the Firebag River, between April 16 and October 28 of each year. It was assumed that the model will short upstream licensees during that period to keep flow in the river and reach the 400 m^3/s target.

The volume of demands is small relative to the flow in the Athabasca River, so this strategy would not substantially increase streamflow in the Athabasca mainstem. During dry years (e.g., 2001) the target of 400 m^3/s is not attainable, even by shorting all upstream water users (Figure 48).

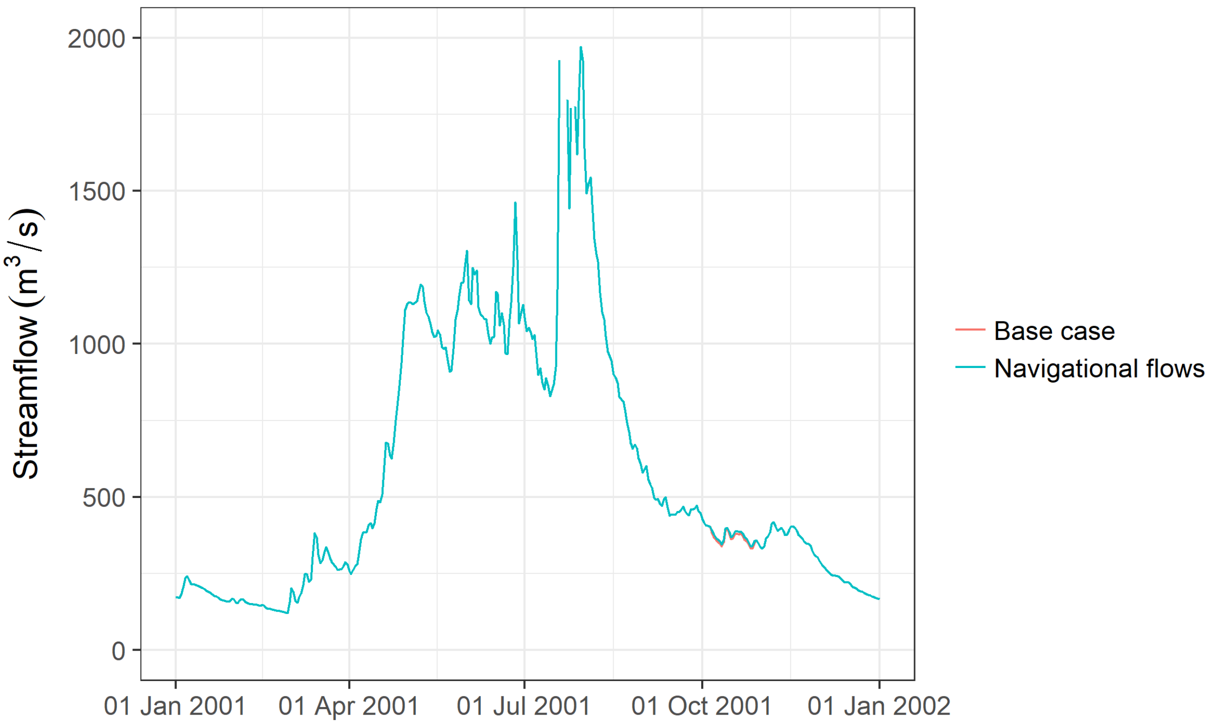

Figure 48: Historic conditions on the Athabasca River below the Firebag confluence during a dry year (2001), under base case operations (orange) and navigational flows strategy (blue).

Table 16 shows the PM results for the navigation strategy relative to base case operations under all three conditions. This strategy performs the best under dry conditions, showing the greatest increase in navigation days and the fewest IFN violations.

By shorting all upstream users, six additional days under historic conditions and 13 additional days under dry conditions could meet the navigational minimum flow requirements (Figure 49). This represents a small increase in navigation because it is expressed over the entire 30-year timeseries. Although it is a small change, this strategy shows that water can be made available without building large storage infrastructure.

This strategy should consider which users are being shut off. Realistically, all water licences upstream of the minimum flow should not and would not be shut off. It is more likely they would be reduced or a subset of licences would be shut off, but this approach would diminish the simulated benefits to the AXF.

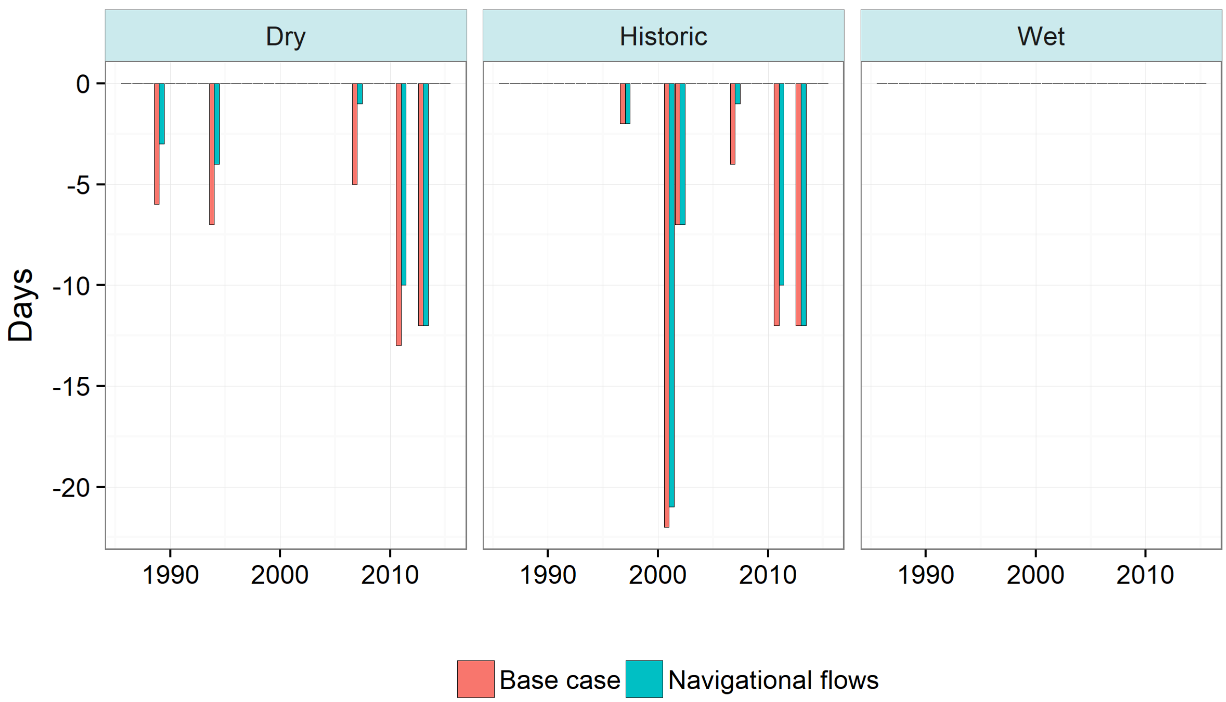

Figure 49: Number of days not meeting the AXF flow target over dry, historic, and wet conditions, under base case (orange) and navigational flows strategy (blue).

It was discussed in the Working Group meetings that if demands could not be managed to meet navigational flows, then a suite of alternatives could be examined. Alternative means to enable navigation could include:

- Using alternative water vessels that could operate in shallower depths, similar to the air boats that are used in Fort Chipewyan.
- Dredging channels to create boat passage. Dredging was done in the past on the Athabasca River for barges. This ended when the winter road was built and since then, sand bars have developed that impede boat passage. This option should consider the associated disturbance to fish and fish habitat of dredging.
- Building structures to create depth at navigation pinch points.
- Building an off-stream storage facility and operating it to meet the AXF.
- Increasing road navigation by building an all-season permanent road to Fort Chipewyan. However, an all-season road would significantly worsen certain environmental impacts, such as those to wildlife and wetlands.

As Figure 50 shows, shorting upstream licences (typically during spring and fall) would result in more flow in the Athabasca River but would not be sufficient to reach the 400 m^3/s target all the time.

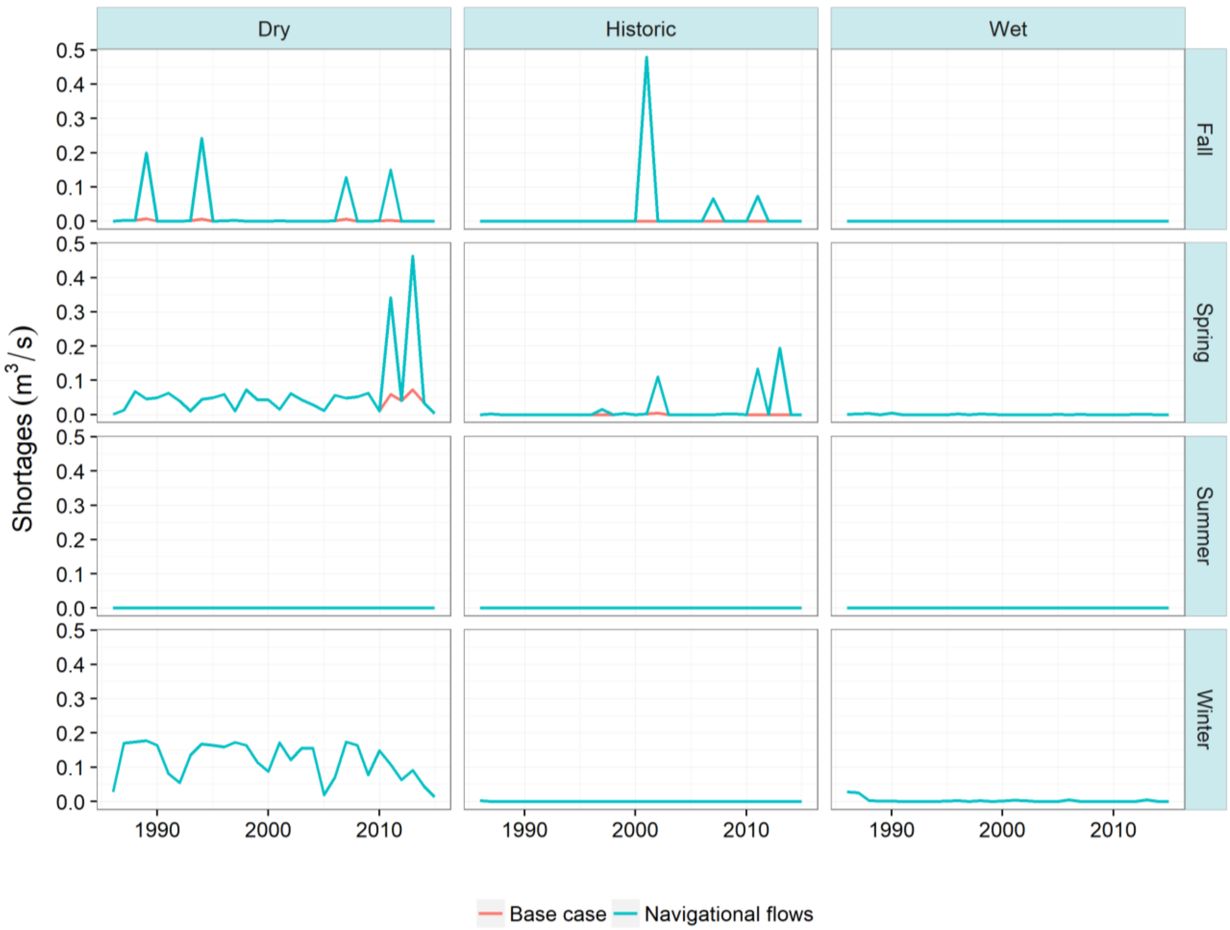

Figure 50: Basin-wide seasonal shortages over dry, historic, and wet conditions, under base case operations (orange) and navigational flows strategy (blue).

Table 16: Summary of PM results for the navigation strategy relative to base case, under the historic, wet, and dry conditions for a 30-year period.

Period and Location	Dry – Navigational flows	Historic – Navigational flows	Wet – Navigational flows
Change in number of days meeting Aboriginal Extreme Flow. *Challenge: Ensure sufficient flow for navigation*			
Annual - below Firebag confluence	13.0 Days	6.0 Days	0.0 Days
Change in number of days over 1:100 flood thresholds. *Challenge: Limit damage from floods*			
Annual - Athabasca River at Athabasca	0.0 Days	0.0 Days	0.0 Days
Annual - McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca upstream of Whitecourt	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca River at Hinton	0.0 Days	0.0 Days	0.0 Days
Annual - Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Pembina River at Sangudo	0.0 Days	0.0 Days	0.0 Days
Annual - Ft. McMurray	0.0 Days	0.0 Days	0.0 Days
Change in annual instream flow needs violations. *Challenge: Maintain or improve ecosystem health*			
Annual - Mouth of the Lac La Biche River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the McLeod River	-1.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Clearwater River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Lesser Slave River	-10.0 Days	-1.0 Days	0.0 Days
Annual - Mouth of the Pembina River	0.0 Days	0.0 Days	0.0 Days
Change in walleye recruitment reduction. *Challenge: Maintain or improve ecosystem health*			
Annual - below Ft. McMurray	-0.29%	-0.48%	0.00%
Change in seasonal streamflow as a percentage of naturalized streamflow. *Challenge: Minimize the effect of development footprint on basin hydrology*			
Summer - at the Mouth	0.00%	0.00%	0.00%
Spring - at the Mouth	0.03%	0.02%	0.00%
Fall - at the Mouth	0.02%	0.02%	0.00%
Winter - at the Mouth	0.00%	0.00%	0.00%
Change in seasonal system shortages (m3/s). *Challenge: Provide water supply certainty for municipalities and development*			
Spring - whole system	0.67 m3/s	0.45 m3/s	0.0 m3/s
Winter - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s
Fall - whole system	0.7 m3/s	0.62 m3/s	0.0 m3/s
Summer - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s

3.3.7.3 Benefits and trade-offs

Under dry conditions this strategy provides 13 more days where the navigational flow targets are met, whereas under historic conditions the navigational flow targets are met six more days. This strategy increases walleye recruitment because of higher streamflow during the open water season which overlaps with the walleye recruitment window. This strategy also decreases the number of days when the IFN is violated in some sub-basins by a small amount.

In this strategy, upstream water users would be shorted during the spring and fall. They would be shorted in a priority sequence, but all could experience a shortage.

3.3.7.4 Implementation challenges and actions

Several implementation challenges with this strategy were identified:

- Implementation would require a greater understanding of navigational needs along different reaches in the Lower Athabasca River, at different temporal scales. This involves understanding what constitutes minimum acceptable conditions and optimal conditions for navigation.
- A better understanding of the effects of climate change on navigational requirements would facilitate implementation. For example, under wet conditions temperatures may be warmer, potentially extending the open water season. This may create demand for a longer navigation window, and the minimum flow should adjust to reflect that demand.
- There is no water management plan in place that defines minimum flows for optimal and sub-optimal navigation.

The Working Group thought it would be beneficial to look at this strategy in conjunction with other strategies, such as off-stream storage (i.e., the McMillan Lake strategy). Storing water in off-stream natural lakes during times of surplus would decrease the need to short upstream water licences and diminish the need for large infrastructure.

Actions that could help move this strategy toward implementation:

- Develop a navigation model to understand navigation channels and their changes through time. Ensure that this model considers possible future changes in streamflow and geomorphic conditions.
- Develop a navigation model to understand navigation channels and their changes through time; this model should consider possible future changes in streamflow.
- Develop a better understanding of navigation challenges experienced by communities, which would fill gaps and enable a better understanding of how to approach this strategy; e.g., where are communities experiencing pinch points? As noted, data are already being collected on navigational pinch points through an Indigenous navigation app.
- Assess means of obtaining minimum flows for navigation or alternate navigation.
- Develop a binding water management plan that defines minimum flows for optimal and sub-optimal navigation, which vary by season and location within the basin. Associated with such a plan is a need to specify a clear and concise way to meet these minimum flows, such as shorting all or some upstream users.

3.3.7.5 Screening assessment

This strategy was identified as a least promising strategy (as it is modelled).

Most Working Group participants thought this strategy would have little benefit and that it would be reasonably difficult to implement, especially when it came to cutting off all water licences upstream. However, it was widely noted that minimum flows for navigation should be implemented in conjunction with other water management strategies, such as off-stream storage. Combining this strategy with others could maximize the benefits and make implementation more feasible.

3.3.8 *Land conservation*: Increase the quantity and improve the condition of conserved and restored land across the basin

3.3.8.1 Strategy overview

This strategy aims to increase the amount and improve the condition of conserved and restored[15] land across the basin, particularly in areas of high biodiversity or hydrologic importance. This strategy is intended to maintain and improve hydrologic function and watershed health through land conservation. It has potential throughout the entire basin, but this analysis focused on the upper and central portions of the watershed. Under LARP, approximately 16% of the Lower Athabasca's land base is managed as new conservation areas in addition to the 6% already protected as wildland provincial parks.

Other areas for conservation and restoration have been identified by the Canadian Parks and Wilderness Society (CPAWS), the Alberta Wilderness Association (AWA), and Ducks Unlimited Canada (DUC). Example areas of conservation within the ARB include the CPAWS high conservation areas for biodiversity, the CPAWS Net Present Value model areas (Figure 51), the AWA areas of concern, and the DUC key wetland areas.

This strategy minimizes the lost opportunity cost of protecting an area by identifying areas that have a lower value for resource development but still meet biodiversity targets. It focuses on the hydrological changes, such as streamflow and water quality, that can occur when areas with high biodiversity and hydrologic importance are conserved, while providing for a well-managed and intact landscape that can help to mitigate flooding, etc.

[15] Restoration is not the same as reclamation. Reclamation is putting the land back to an “equivalent land capability,” meaning that the ability of the land to support various land uses after conservation and reclamation is similar to the ability that existed prior to an activity being conducted on the land, but that the individual land uses will not necessarily be identical. Restoration could be used in some cases to return the land to its original natural state, but this is very difficult. This strategy should ensure that the challenges regarding restoration are recognized before development takes place. From the model’s perspective, simulations assumed land would be restored by converting human footprints back to their natural state (as if development never happened in the first place). Reclamation (not restoration) is the legal requirement for many kinds of disturbance.

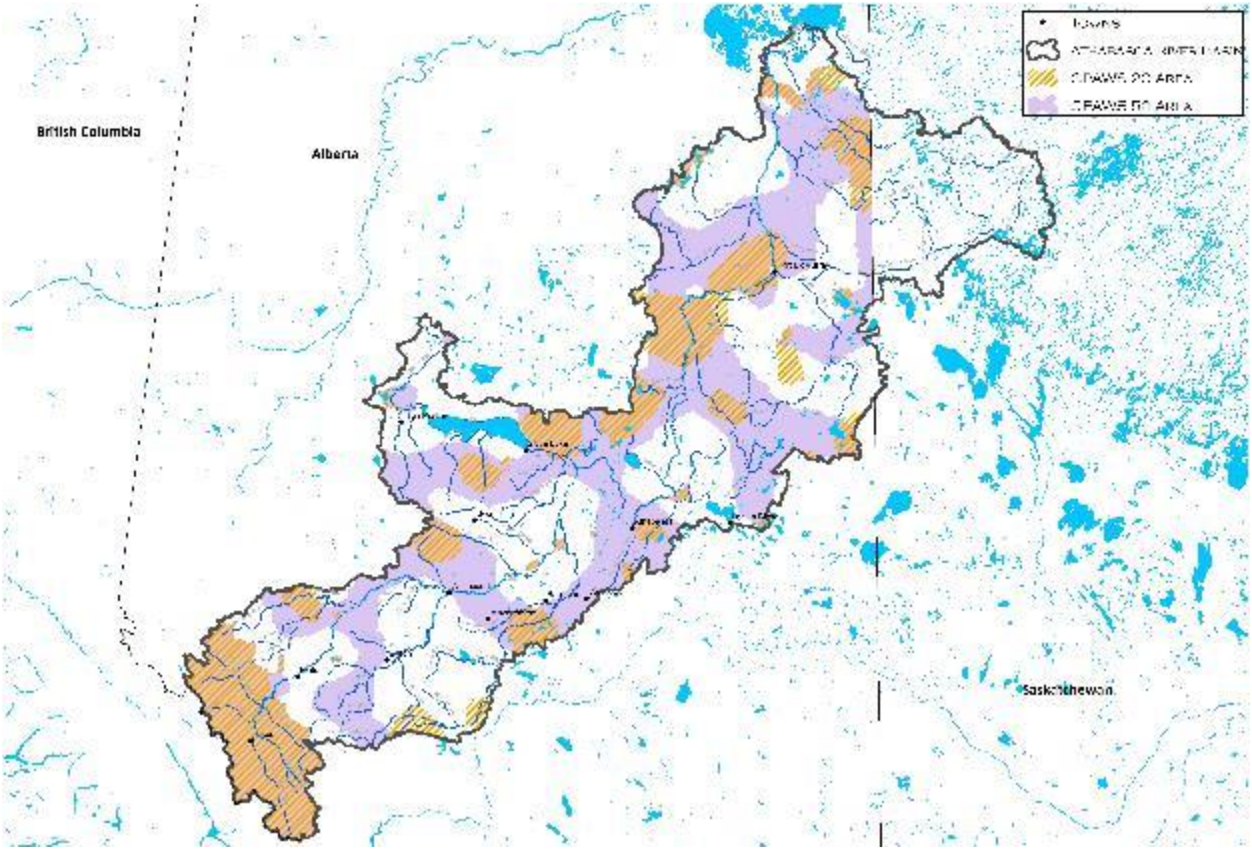

Figure 51: CPAWS20 and CPAWS50 areas identified through the Net Present Value (NPV) analysis.

3.3.8.2 Modelling done to test this strategy and modelling results

Modelling for this strategy relied on previous modelling work conducted in the development of the Conservation Blueprint of Northern Alberta (CPAWS, 2015). This work suggests that for Alberta to meet acceptable levels of conservation there must be a commitment to protect at least 20% of the land base by 2020 and 50% of the land base forever. Areas of high conservation value were determined using a combination of irreplaceability, rarity, diversity, and richness indicators.

Through this strategy, human-made footprints were simulated as being restored to a natural land cover in areas identified in the CPAWS20 and CPAWS CPAWS50 analyses (Figure 51). Footprints to be restored included agriculture, mines, small roads, pipelines, seismic lines, and powerlines. Features to be excluded from restoration included urban areas, major roads, recreation areas, and trails. In the model, fires were suppressed and would not be active in the conserved landscape. This approach was taken to isolate the effect of conserving land without other confounding factors.

In general, peak streamflow decreased under this strategy. As agricultural and other disturbed land is re-vegetated, a higher proportion of precipitation is assumed to be intercepted and thus does not contribute to streamflow. As modelled, conservation scenarios would lead to a net zero change in streamflow because, by definition, they have no change in land cover relative to current day. To model the effects of conservation, the run would have to be compared with an estimate of future land cover change with and without conservation (i.e., against a business as usual development scenario).

This strategy demonstrates the effect of scale and local variation in streamflow response. Since landscape change is not uniform across the whole basin, results can be more demonstrable at local scales. For example, streamflow in the Swan River does not show substantive change under this strategy given that there is limited area to restore or reclaim in that sub-basin (Figure 52). Streamflow in the Clearwater River, on the other hand, shows notable reductions in spring freshet due to the large areas that were identified to be restored in that sub-basin (Figure 53).

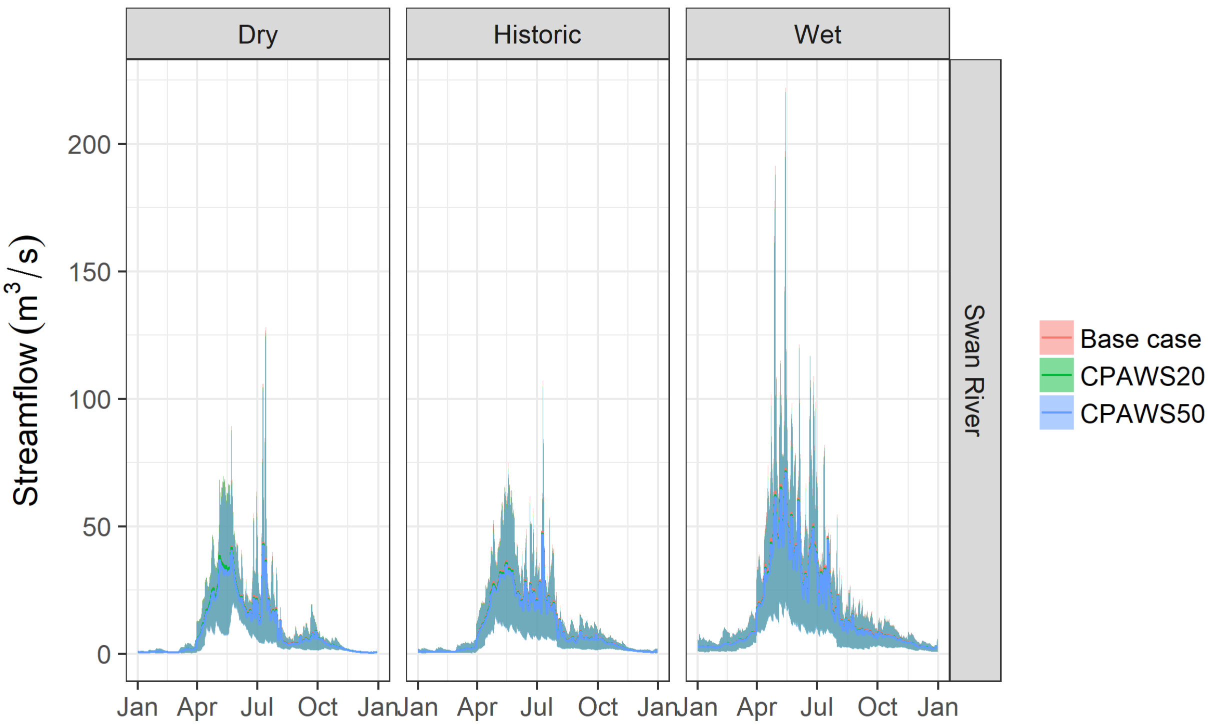

Figure 52: Average daily streamflow in the Swan River near Kinuso, with base case operations (orange), CPAWS20 strategy (green) and CPAWS50 strategy (blue), under dry, historic, and wet conditions.

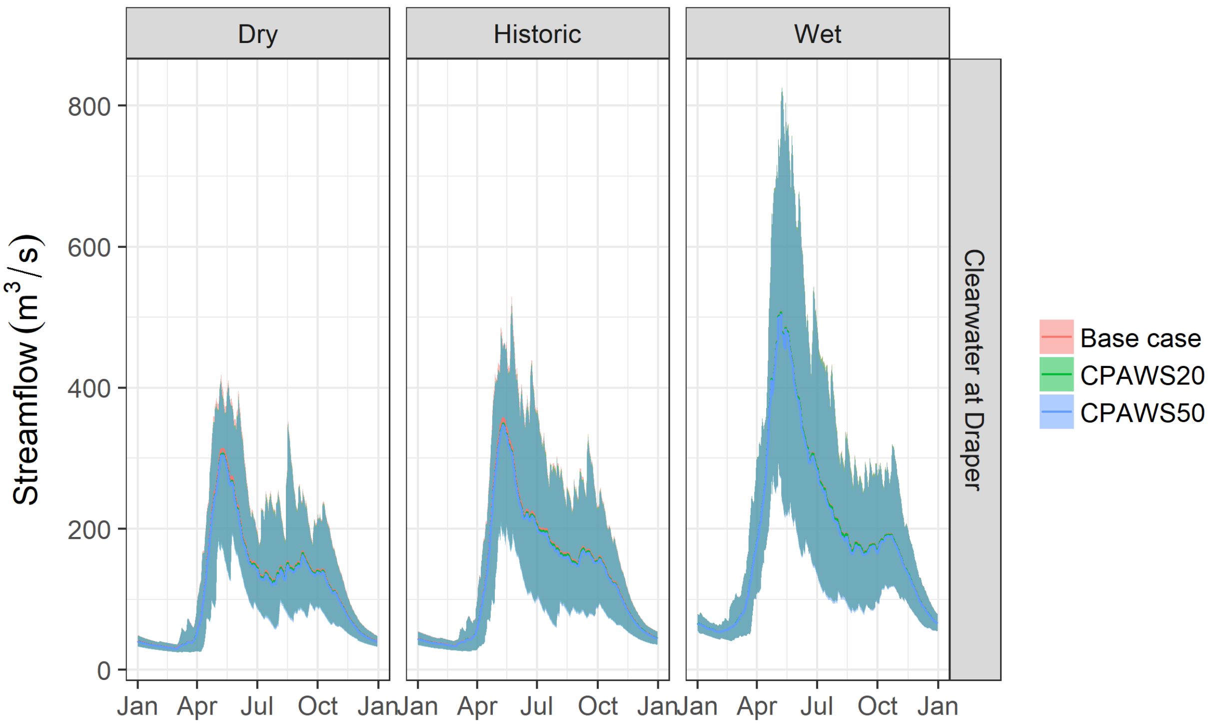

Figure 53: Average daily streamflow in the Clearwater River at Draper, with base case operations (orange), CPAWS20 strategy (green), and CPAWS50 strategy (blue), under dry, historic, and wet conditions.

Overall, this strategy could result in more IFN and navigational flow violations given that streamflow would likely be reduced relative to the base case due to larger amounts of water being stored on the landscape (Table 17 and Table 18). Contrary to this overall finding, the Pembina sub-basin could have fewer IFN violations (Figure 54, Table 17, and Table 18). This is because the Pembina is an area of concentrated agricultural activity; when agricultural land is reforested, the soils retain water longer, which increases recharge and supplements late-season streamflow. These results reflect how IFN violations are calculated, where it is assumed that flow reductions relative to the base case are not desired. This is confounded by the fact that the base case does not assume a natural landscape.

The dampening effects of forest cover on streamflow are demonstrated through reductions in peak streamflow. As a result, this strategy could decrease flood days, particularly in the Lesser Slave sub-basin (Figure 55).

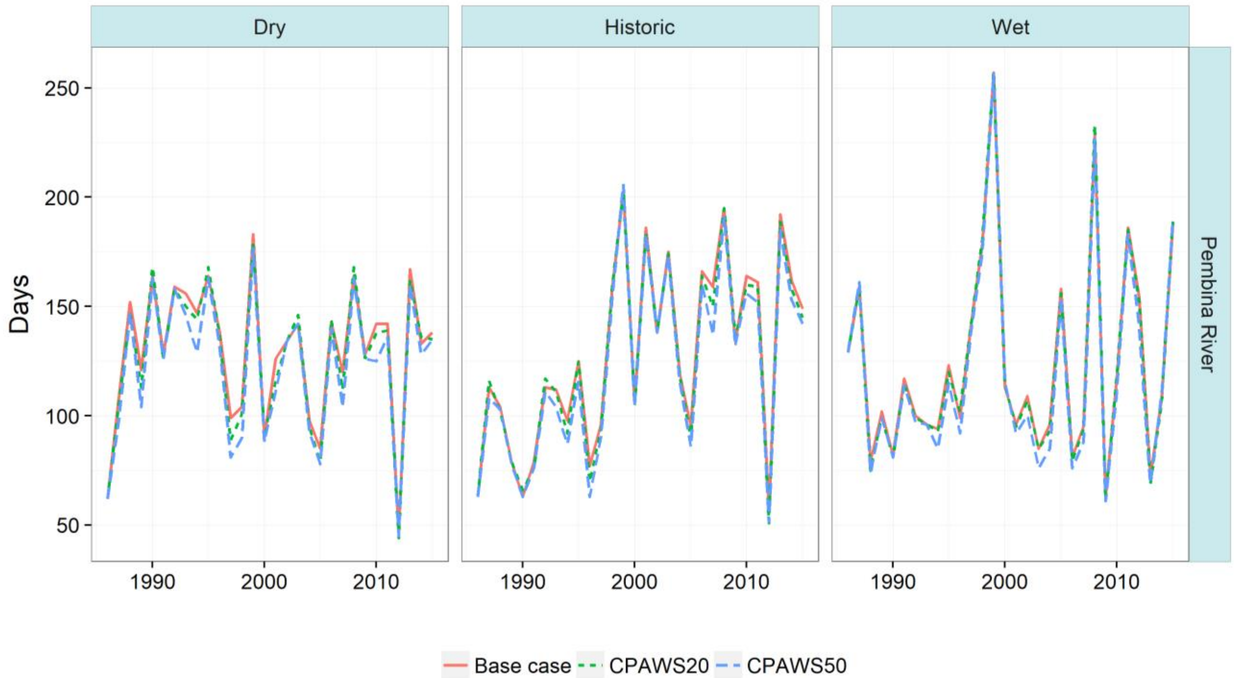

Figure 54: Total IFN violations over the dry, historic, and wet condition under the base case (solid orange), CPAWS20 strategy (dashed green), and CPAWS50 strategy (dashed blue), within the Pembina sub basin.

Figure 55: Total number of days over the entire simulation period where the 1:100 flood flow thresholds are exceeded at Lesser Slave River below Lesser Slave Lake, over dry, historic, and wet conditions, under base case (orange), CPAWS20 strategy (green), and CPAWS50 strategy (blue).

Although this strategy could lead to a decrease in streamflow relative to the base case, there would be no associated increase in shortages except under the dry condition, and the shortages are small.

Table 17: Summary of PM results for the CPAWS20 strategy relative to base case, under the historic, wet, and dry condition for a 30-year period.

Period and Location	Dry - CPAWS20	Historic - CPAWS20	Wet - CPAWS20
Change in number of days meeting Aboriginal Extreme Flow. *Challenge: Ensure sufficient flow for navigation*			
Annual - below Firebag confluence	-3.0 Days	-3.0 Days	0.0 Days
Change in number of days over 1:100 flood thresholds. *Challenge: Limit damage from floods*			
Annual - Athabasca River at Athabasca	0.0 Days	0.0 Days	0.0 Days
Annual - McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca upstream of Whitecourt	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca River at Hinton	0.0 Days	-3.0 Days	1.0 Days
Annual - Lesser Slave River	-1.0 Days	-4.0 Days	-23.0 Days
Annual - Pembina River at Sangudo	0.0 Days	0.0 Days	0.0 Days
Annual - Ft. McMurray	0.0 Days	0.0 Days	-1.0 Days
Change in annual instream flow needs violations. *Challenge: Maintain or improve ecosystem health*			
Annual - Mouth of the Lac La Biche River	94.0 Days	56.0 Days	7.0 Days
Annual - Mouth of the McLeod River	1.0 Days	5.0 Days	5.0 Days
Annual - Mouth of the Clearwater River	311.0 Days	200.0 Days	36.0 Days
Annual - Mouth of the Lesser Slave River	59.0 Days	144.0 Days	118.0 Days
Annual - Mouth of the Pembina River	-73.0 Days	-52.0 Days	-21.0 Days
Change in walleye recruitment reduction. *Challenge: Maintain or improve ecosystem health*			
Annual - below Ft. McMurray	0.00%	0.00%	0.00%
Change in seasonal streamflow as a percentage of naturalized streamflow. *Challenge: Minimize the effect of development footprint on basin hydrology*			
Summer - at the Mouth	-0.02%	-0.02%	-0.01%
Spring - at the Mouth	0.05%	-0.04%	-0.01%
Fall - at the Mouth	-0.04%	-0.01%	-0.02%
Winter - at the Mouth	-0.03%	-0.01%	-0.02%
Change in seasonal system shortages (m3/s). *Challenge: Provide water supply certainty for municipalities and development*			
Spring - whole system	0.02 m3/s	0.0 m3/s	0.0 m3/s
Winter - whole system	0.04 m3/s	0.0 m3/s	0.0 m3/s
Fall - whole system	-0.0 m3/s	0.0 m3/s	0.0 m3/s
Summer - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s

Table 18: Summary of PM results for the CPAWS50 strategy relative to base case, under the historic, wet, and dry condition for a 30-year period.

Period and Location	Dry - CPAWS50	Historic - CPAWS50	Wet - CPAWS50
Change in number of days meeting Aboriginal Extreme Flow. *Challenge: Ensure sufficient flow for navigation*			
Annual - below Firebag confluence	-11.0 Days	-8.0 Days	0.0 Days
Change in number of days over 1:100 flood thresholds. *Challenge: Limit damage from floods*			
Annual - Athabasca River at Athabasca	0.0 Days	0.0 Days	-1.0 Days
Annual - McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca upstream of Whitecourt	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca River at Hinton	0.0 Days	-3.0 Days	2.0 Days
Annual - Lesser Slave River	-4.0 Days	-22.0 Days	-68.0 Days
Annual - Pembina River at Sangudo	0.0 Days	0.0 Days	0.0 Days
Annual - Ft. McMurray	0.0 Days	0.0 Days	-5.0 Days
Change in annual instream flow needs violations. *Challenge: Maintain or improve ecosystem health*			
Annual - Mouth of the Lac La Biche River	503.0 Days	404.0 Days	407.0 Days
Annual - Mouth of the McLeod River	176.0 Days	128.0 Days	137.0 Days
Annual - Mouth of the Clearwater River	546.0 Days	333.0 Days	153.0 Days
Annual - Mouth of the Lesser Slave River	322.0 Days	601.0 Days	382.0 Days
Annual - Mouth of the Pembina River	-199.0 Days	-160.0 Days	-115.0 Days
Change in walleye recruitment reduction. *Challenge: Maintain or improve ecosystem health*			
Annual - below Ft. McMurray	0.00%	0.00%	0.00%
Change in seasonal streamflow as a percentage of naturalized streamflow. *Challenge: Minimize the effect of development footprint on basin hydrology*			
Summer - at the Mouth	-0.14%	-0.05%	-0.09%
Spring - at the Mouth	-0.16%	-0.09%	-0.05%
Fall - at the Mouth	-0.12%	-0.05%	0.01%
Winter - at the Mouth	-0.19%	-0.07%	-0.07%
Change in seasonal system shortages (m3/s). *Challenge: Provide water supply certainty for municipalities and development*			
Spring - whole system	0.04 m3/s	0.0 m3/s	0.0 m3/s
Winter - whole system	0.1 m3/s	0.0 m3/s	0.0 m3/s
Fall - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s
Summer - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s

3.3.8.3 Benefits and trade-offs

This strategy would have many benefits that cannot be assessed by looking only at streamflow; e.g., potential improvements in water quality, a more natural landscape with potentially higher biodiversity, and potentially less alteration to the hydrologic regime of the basin. The modelling results suggest that this strategy could result in fewer flood days on the Lesser Slave River, and fewer IFN violations in the Pembina sub-basin. However, if large areas of land are conserved or restored, industrial activity may move from inside the conserved or restored areas to other parts of the ARB, potentially increasing the industrial footprint in other regions of the basin. Alternatively, concentrating or centralizing development while maintaining larger areas of intact land could have positive effects overall.

The model also highlighted some trade-offs: more days where flow is below the navigational target because water is being stored rather than contributing to runoff, and more IFN violations in all other sub-basins. However, this is confounded by the current IFN calculation given that the IFN comparison assumes streamflow reductions relative to the base case are not favorable even though the base case is likely less of a "natural" state. The modelling done for this strategy also resulted in more shortages under dry conditions because more water is being retained on the landscape.

3.3.8.4 Implementation challenges and actions

An increase in land set aside for conservation is likely to present political challenges given that human populations and subsequent recreation and resource extraction are increasing. An important point relative to this simulation is that the largest areas restored comprised agricultural land use. Although it is unlikely that agricultural lands will be restored to their natural state, incentives could be implemented to help conserve land with high ecological or hydrological value in an agricultural setting. Funding should be available to support these types of initiatives and a good example of this type of funding is AEP's Watershed Resilience and Restoration Program (WRRP). To aid in implementing this strategy, land use plans should be developed across the basin to ensure clear targets are in place for conservation areas. A clear and concise management policy should also be developed for these areas, and regular monitoring should be undertaken to evaluate its effectiveness.

Identifying sites of highest conservation and restoration priority that would have the greatest positive impact on peatland complexes, tributaries, and connectivity is a big opportunity in the ARB. There is potential to build on work from a recent WRRP project in the Bow River Basin, which used the ALCES land use model to identify restoration projects of greatest hydrological effect in the basin. Defining a systematic approach to site identification is imperative for successful implementation of this strategy.

3.3.8.5 Screening assessment

This strategy was identified as having some promise.

Considering that the LARP sets aside 16% of the land in that region for conservation, a CPAWS 20% conservation target may be achievable. A 50% target would be more challenging. As mentioned above, achievable targets should be set out in land use plans across the basin.

3.3.9 *Forestry practices*: Support practices in Forest Management Agreements (FMAs) that minimize hydrologic change

3.3.9.1 Strategy overview

Timber harvest has the potential to alter hydrologic regimes given that forest canopies play a role in the interception and subsequent evapotranspiration of precipitation, affect snow accumulation and ablation, and can influence soil water storage. (Buttle, 2011; Carrera-Hernandez et al., 2011; Green and Alila, 2012). Therefore, managing forests to maintain critical hydrologic features and connectivity while preserving spatial heterogeneity and diversity in hydrologic function is important in terms of a long-term strategy for promoting watershed health (Creed et al., 2011). This strategy envisions sustainable forest management and stewardship, focusing on practices that minimize hydrologic change. Examples of such practices include:

- Completing Detailed Forest Management Plans and Sustainability Plans
- Assessing harvest levels relative to their influence on streamflow; an indicator that can be used for this type of assessment is Equivalent Clearcut Area
- Maintaining riparian reserve zones and management areas
- Deactivating roads
- Wet area mapping
- Collaborations such as the Foothills stream crossing partnership

FMAs established in the ARB include Forest Management Plans that are implemented to assure sustainable management of forests and other values. The provincial government is responsible for preparing Forest Management Plans in areas not covered by FMAs. These plans are developed on a 10-year time frame and follow the process set out in the Alberta Forest Management Planning Standard (Alberta Sustainable Resource Development, 2006).

If implemented, forest management aimed at reducing hydrologic change should result in a minimally altered flow regime. Improved water quality would also be expected, as best management practices (BMPs) that minimize erosion and other water quality impacts would be implemented.

This Initiative did not evaluate future land use trajectories so did not attempt to evaluate the effectiveness of implementing different forestry-related practices. Rather, modelling conducted for this strategy was done to demonstrate the role of forest cover on the hydrologic regime of the ARB by removing forest cover in the model.

3.3.9.2 Modelling done to test this strategy and modelling results

The model was used to evaluate the potential effect of harvest on streamflow and assumed an approximate doubling of young-seral forest (forest less than five years old) relative to current levels, given that young forests are assumed to have lower hydrologic functions. This leads to approximately 28,000 km^2 of young forest relative to base case. This was done to demonstrate an effect since the scale of this modelling work is very large and hydrologic effects from harvest are typically most visible at smaller spatial scales (Green and Alila, 2012).

Doubling the amount of young forest on the landscape led to higher streamflow as there would be less forest canopy to intercept precipitation. Changes in streamflow would not be uniform across the landscape, with greater changes occurring in regions where large areas of young forest occur, or where forested area comprises a large proportion of a watershed. The East Prairie River watershed, for example, had a high level of disturbance in this scenario and was heavily forested, resulting in a substantial change in streamflow, primarily during the spring period (Figure 56). Conversely, the Berland River would likely experience a smaller change in streamflow (Figure 57) due to the scale of the watershed and relatively low level of forest disturbance occurring in this simulation.

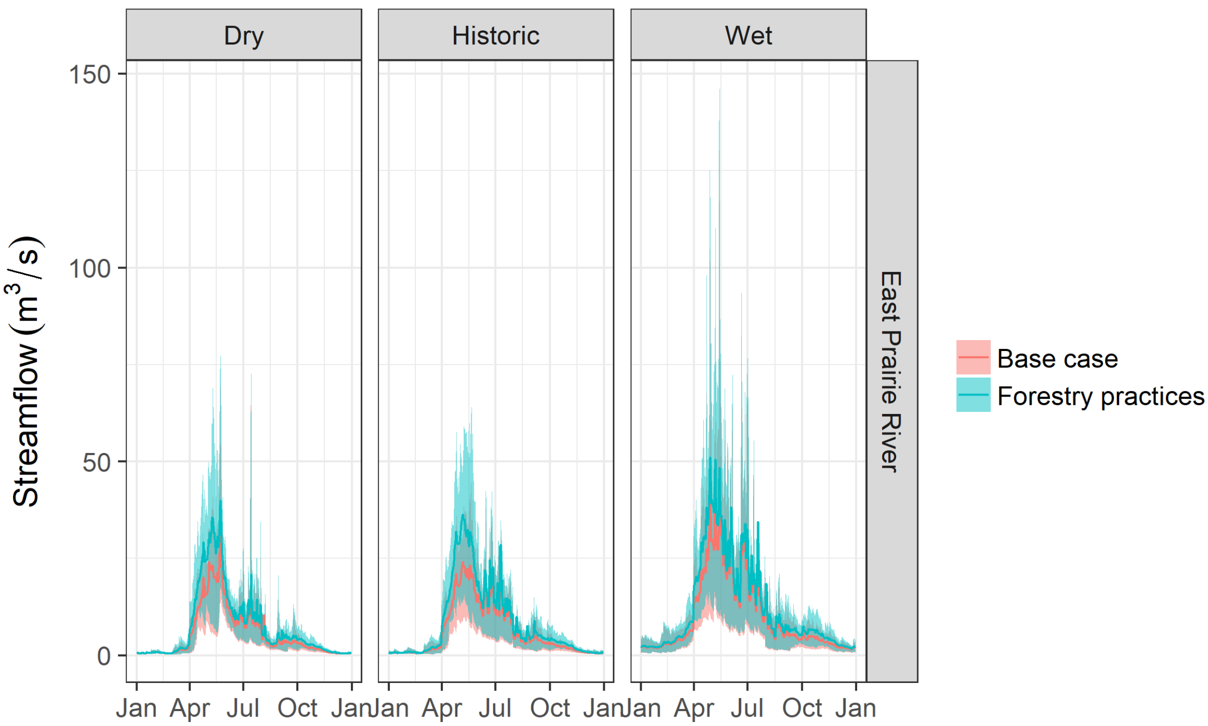

Figure 56: Average daily streamflow in the East Prairie River near Enilda, with base case operations (orange) and forestry practices strategy (blue), under dry, historic, and wet conditions.

These results demonstrate that forest canopies can play a substantial role in governing the water balance. The analysis also demonstrates that the scale of disturbance ultimately determines the hydrologic response of a given watershed. This suggests managing the level of forest disturbance in the ARB is important for minimizing hydrologic change.

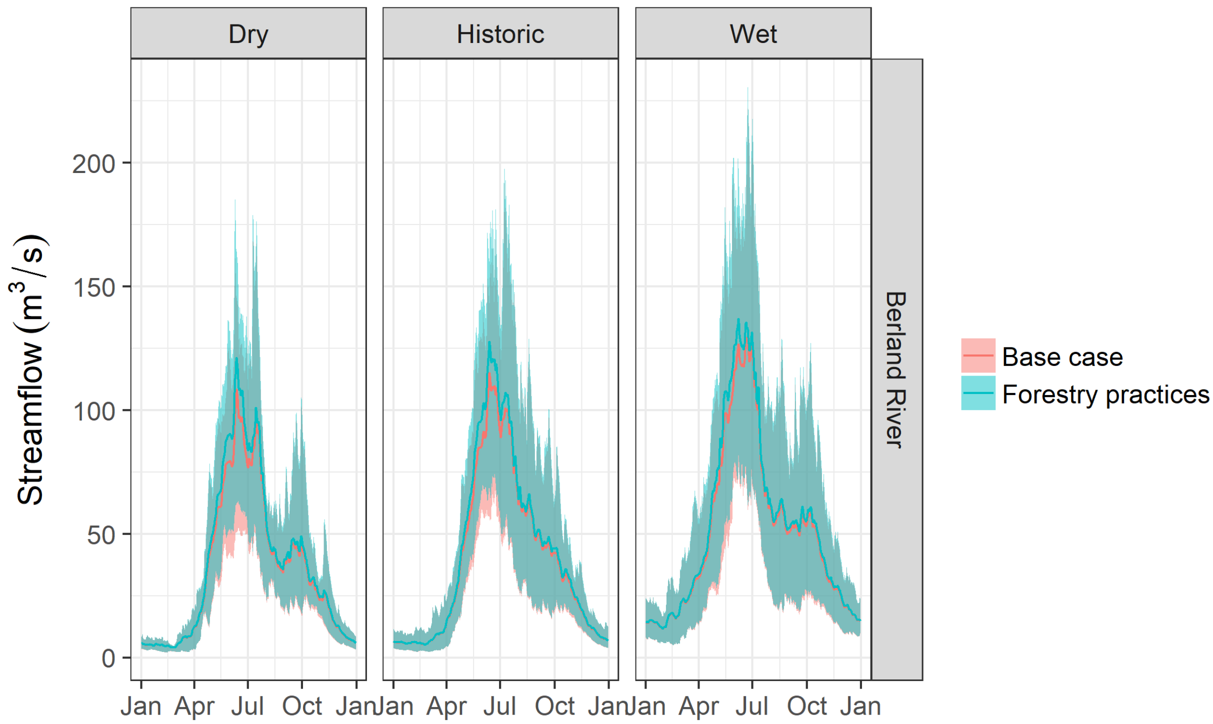

Figure 57: Average daily streamflow in the Berland River near the mouth, with base case operations (orange) and forestry practices strategy (blue), under dry, historic, and wet conditions.

3.3.9.3 Benefits and trade-offs

Benefits would be most noticeable in smaller watersheds that have higher relative levels of disturbance and more forest cover, as opposed to the entire basin. The results demonstrate that increasing the level of forest disturbance does affect streamflow; therefore, a benefit of managing disturbance levels is reducing the potential to alter streamflow regimes.

There are continual challenges with managing forests in a sustainable and economically viable way. Trade-offs such as changes to timber supply should be evaluated when determining how forest harvest regimes could be modified to minimize effects on streamflow. These types of trade-offs are difficult to quantify at the screening level given that efficiencies and innovative practices can play a role in offsetting the effects of reduced timber supply.

3.3.9.4 Implementation challenges and actions

Implementation of this strategy relies largely on each operator's Forest Management Plans. Hydrologic values are typically described in these plans and a shift towards explicitly managing for the strategy's values would be beneficial. Forest Management Plans typically include watershed disturbance assessments. However, there is no clear definition of the most appropriate spatial scale for assessment nor are there well-defined targets in terms of disturbance levels associated with scale. Implementing this strategy should clearly define spatial scales for assessment and disturbance levels. Implementation should also ensure adaptive management is applied as new science and information become available.

Actions that could help implement this strategy include:

- Completing detailed watershed assessments to identify potential for hydrologic alteration
- Altering harvest regimes in some watersheds
- Limiting harvest in hydrologically sensitive watersheds
- Improving compliance and application of forestry BMPs, such as those noted below, and others

Incentivizing BMPs, broader education, and raising awareness are other means to improve forest management in the ARB. Examples of BMPs include:

- Harvest in a manner that focuses on desynchronizing runoff from the watershed[16]
- Aggressively deactivate logging roads
- Continue to retain riparian reserves and management zones around lakes, wetlands, and streams

BMPs can help mitigate the hydrologic effects of forest disturbance at all scales but they are not always put in place. As well, deviations can be granted to Operating Ground Rules with little transparency. Although provincial standards are in place, riparian area management varies from one FMA to another and forestry activities are not regulated on private land. As such, clearly defining priorities to maintain consistency across the ARB is necessary.

3.3.9.5 Screening assessment

This strategy was identified as having some promise.

This strategy is easy to implement and would yield moderate benefit, with higher benefits at smaller spatial scales. Implementation may be feasible with increased effort by government and industry, and the environmental and ecological benefits to the basin would be worth the effort. However, advancements in technology to reduce timber demand would be required should harvest levels be dramatically altered. This strategy is generally seen as an integral and necessary step to achieving sustainable and flexible water and watershed management in the ARB.

[16] The concept of watershed synchronization considers the distribution of elevation zones in a watershed and the effect that different elevations have on the rate and timing of flow generation. For example, a flat watershed mostly within the same elevation zone will generate peak flows from different sources at a similar time.

3.3.10 *Wetlands*: Avoid further wetland loss or functional impairment and promote more wetland restoration, education, and best management practices focused on minimizing impacts

3.3.10.1 Strategy overview

This strategy focuses on avoiding wetland loss or functional impairment and promoting wetland restoration through the continued refinement, implementation, and enforcement of related legislation, policies, and mechanisms such as the Alberta Wetland Policy. Wetlands create unique and diverse habitats for a wide range of organisms, serving a vitally important role on the landscape. The rationale for this strategy is to maintain or improve the hydrological benefits of wetlands, including groundwater recharge, sustained baseflow, water quality, flow attenuation, and others. The strategy would be most effective in the central and lower portions of the basin where wetlands play a larger role on the landscape.

Apart from the provincial Wetland Policy, there is no wetland conservation and restoration plan in place and specific to the ARB. DUC, Alberta-Pacific Forest Industries Inc., Forest Products Association of Canada, Canadian Forest Products Ltd., Millar Western Forest Products Ltd., Tolko Industries Ltd., West Fraser, and Weyerhaeuser Company are engaged in a three-year collaboration focused on Boreal forest wetland conservation. This collaboration – the Forest Management and Wetland Stewardship Initiative[17] – is integrating wetland and waterfowl conservation into forest management planning and operations. In the oil sands region, Suncor and Syncrude have active wetland reclamation projects. Suncor has reclaimed approximately 48 hectares of wetlands and lakes, with recent innovation in reconstructing swamps, marshes, and fens. Likewise, Syncrude has implemented a 54-hectare wetland research project focused on fens. These projects all point to the importance of wetlands in terms of hydrologic and ecologic function and demonstrate more work is needed to improve wetland construction techniques that enable natural wetland functions.

It is expected that wetland loss would result in lower baseflows, higher peak flows, and decreased water quality. This strategy would encourage sustained baseflows, improved water quality, and peak flow attenuation wherever wetlands are conserved or restored.

3.3.10.2 Modelling done to test this strategy and modelling results

To test this strategy, modelling was done to evaluate the effect of wetland removal, assuming there would be a 30% decrease in wetland coverage in the following sub-basins:

- Athabasca River (between Athabasca and Fort McMurray)
- Lac La Biche
- House River
- Christina River

This represents approximately 458 km^2 of wetlands converted to disturbed (non-permeable) land.

[17] See http://boreal.ducks.ca/about-us/collaborate/forest-management-wetland-stewardship-initiative-fmwsi/

Using the Lac La Biche sub-basin as an example, modelling results demonstrate that the wetland loss under this scenario would lead to more water in the Lac La Biche River (Figure 58). Under this scenario, precipitation falling on disturbed areas would run off more quickly due to reduced permeability, as would spring snowmelt; under the base case, runoff from these events would be absorbed by wetlands and subsequently released.

The modelling was relatively high level and did not account for the effects of wetland connectivity or the influence of groundwater-surface water interactions that could be altered through wetland loss. However, results do demonstrate that wetland area can play an important role hydrologically, and changing these areas is likely to have a substantial effect on the hydrologic regime. It is also likely that wetland loss will result in lower late-season streamflow, particularly during dry periods. The simulation demonstrates this effect in that there was no change in streamflow for the Dry Scenario, suggesting the effect of lower infiltration is outweighed by a reduction in total storage.

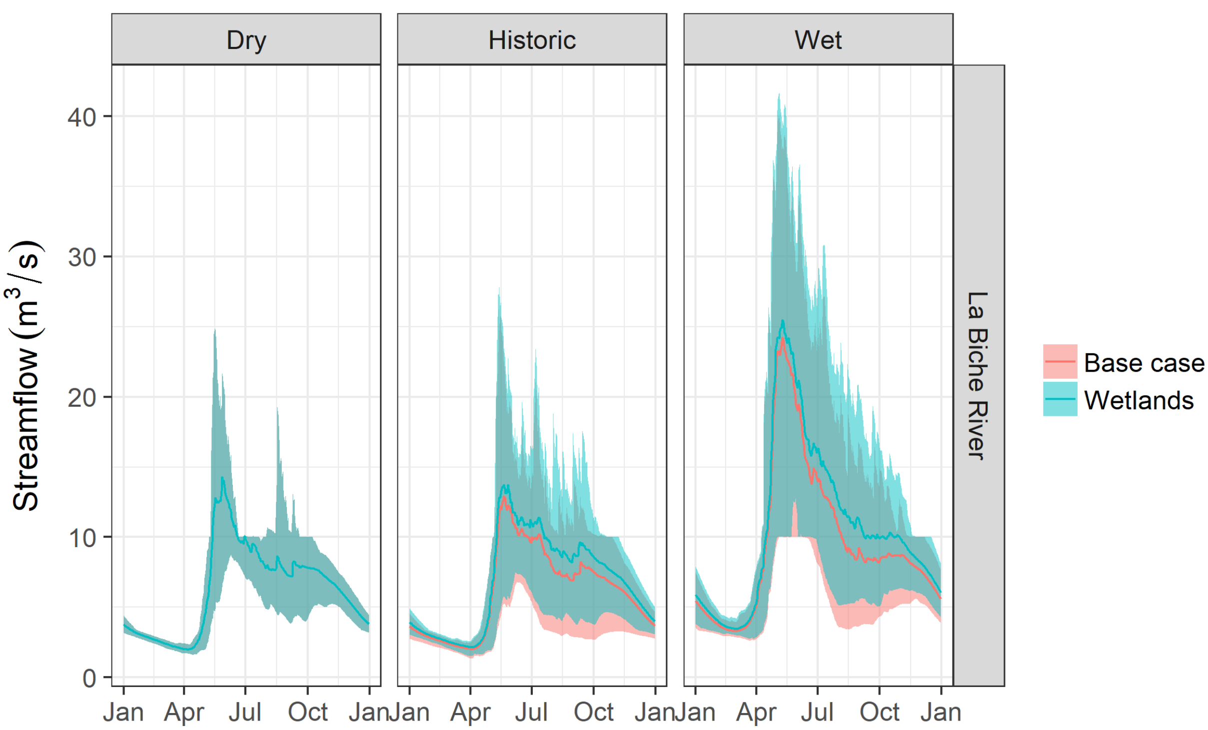

Figure 58: Average daily streamflow in the La Biche River below Lac La Biche, with base case operations (orange) and wetlands strategy (blue), under dry, historic, and wet conditions.

Note: This strategy has not been tested under the dry condition, as wetland disruption is already included in this stress condition.

3.3.10.3 Benefits and trade-offs

Simulation results suggest there could be higher streamflow as a result of less storage of water in wetlands. Conserving and restoring wetlands and maintaining their function can increase overall ecosystem health, providing habitat for wildlife, hydrologic connectivity, and diversity across the landscape.

This strategy has the potential to add challenges to future development by creating additional challenges that development would need to overcome in order to proceed. Also, the cost of reclaiming wetlands can be quite large.

3.3.10.4 Implementation challenges and actions

This strategy would benefit from a deeper understanding and classification of wetland types and associated hydrological sensitivities. For example, fens (which are connected to groundwater) may be more sensitive than bogs, swamps, or marshes. This sensitivity might also depend on the wetland class, degree of richness, location in the watershed, and connectivity. While classification is being done by AEP and DUC, Traditional Knowledge could be another valuable resource for better understanding wetlands and their role and the need to protect and conserve them. Traditional Knowledge should be used at the discretion of the First Nation providing it, following proper cultural protocol and knowledge transfer laws.

A number of key actions would help move this strategy toward implementation:

- Implement restrictions to limit development and its impacts on lakes and wetlands. The Lac La Biche area was identified as a specific area of concern relative to residential development.
- Improve understanding of hydrologically sensitive wetlands. Work conducted by DUC, industry, and the University of Alberta should be incorporated. Additional data and modelling are likely also needed to support this.
- Undertake additional research:
    - about how changes in hydrologic connectivity affect streamflow to better inform this strategy.
    - on wetland construction methods that result in natural wetland function is still required.
    - to fill gaps on effects on wetland function and restoration techniques.
- Make wetland monitoring (e.g., tracking loss of wetlands, functional impairment, best management practice and restoration effectiveness) a priority.
- The Wetland Policy should be adequately implemented in the Boreal region.
- Wetland BMPs should be implemented and adopted as standard operations, and the Wetland Policy adhered to in terms of avoidance of wetland loss and functional impairment. BMP examples include:
    - Ensuring crossings and road design account for hydrologic connectivity
    - Limiting peat harvest, especially around the McMillan Lake area
    - Limiting wetland fragmentation and maintaining connectivity

3.3.10.5 Screening assessment

This strategy was identified as having some promise.

This strategy would provide moderate benefits with a number of positive impacts on water quality, streamflow, and ecosystems. Implementation would be fairly easy if it simply means following the Alberta Wetland Policy more rigorously. Alternatively, if it means that all wetlands in the ARB must be preserved, implementation would be much more challenging.

3.3.11 *Linear connectivity*: Reclaim or deactivate linear features and reduce future linear disturbances in watersheds

3.3.11.1 Strategy overview

This strategy was intended to reduce the total linear footprint on the landscape by 40% through mechanisms such as road and trail deactivation, seismic line reclamation, and restrictions on off-highway vehicle use. Linear features fragment the landscape and have the potential to interrupt hydrologic functions and ultimately affect streamflow, although industry does reclaim features such as roads where possible. This strategy reduces this interruption and aims to determine the hydrological impact of linear disturbances in terms of changes to streamflow. This strategy has potential application for the whole basin.

The ARB is a convergence zone of linear disturbance pressures, with recreational pressure coming from the south and industrial pressure coming from the north. These pressures have implications for projections of future disturbance and cumulative effects in the area. Primary issues from linear disturbances are fragmentation from roads, pipelines, and compacted seismic line; channelization of rivers and creeks for water conveyance can also disturb the landscape. This strategy is an opportunity to identify areas of high priority for linear reclamation and thereby re-naturalize the landscape by a) identifying areas that are beneficial to hydrological processes, and b) emphasizing the importance of reclamation from a hydrological standpoint and encouraging the enforcement of reclamation.

This strategy may also help inform current reclamation requirements, which allow for a range of end states. Today's reclamation requirements highlight a number of BMPs related to conserving or restoring hydrological processes, but many are not being followed. Implementing these BMPs is an important step in this strategy, as is monitoring their effectiveness. COSIA has a few major initiatives to address linear disturbances, including the Algar Historic Restoration Project, Linear Deactivation Project, and the Cenovus Caribou Habitat Restoration Project. As well, an integrated land management plan outlined in LARP strongly emphasizes timely restoration of linear disturbances.

It is expected that reclamation of linear features would decrease spring flows given that precipitation would not run off as quickly and there would be a secondary effect of increased interception from vegetation regrowth. That said, due to the narrow nature of the linear features, a 40% reduction in those features would only affect about 0.6% of the area of the basin. A possible increase in baseflow due to higher infiltration and connectivity would be expected, but increased evapotranspiration could counteract this effect.

3.3.11.2 Modelling done to test this strategy and modelling results

This strategy was tested by reclaiming 40% of linear features (trails, minor roads, seismic lines, pipelines) in the following regions:

- Christina River (15 km^2 reclaimed)
- Hangingstone River (4 km^2 reclaimed)
- Muskeg River (20 km^2 reclaimed)
- MacKay River (8 km^2 reclaimed)

The AIRM replaces disturbed features, which are characterized by surfaces with low permeability and no vegetation, with forest (higher soil permeability and vegetation). Many of the linear features in the basin are not "hard surfaces," and have varying degrees of permeability due to differences in cover (asphalt, gravel, earthen) and compaction (high use to low use). Flow interruption and changes in runoff routing were not simulated in the model so these effects are not captured.

Table 19 presents the PM results for the linear feature strategy relative to base case operations, under all three conditions. The magnitude of change in streamflow from this strategy would likely be small at the basin scale. However, in smaller regional watersheds with very dense linear features, the strategy could result in a noticeable, more localized response.

Table 19: Summary of PM results for the linear feature strategy relative to base case, under the historic, wet, and dry conditions for a 30-year period.

Period and Location	Dry – Linear connectivity	Historic – Linear connectivity	Wet – Linear connectivity
Change in number of days meeting Aboriginal Extreme Flow. *Challenge: Ensure sufficient flow for navigation*			
Annual - below Firebag confluence	0.0 Days	0.0 Days	0.0 Days
Change in number of days over 1:100 flood thresholds. *Challenge: Limit damage from floods*			
Annual - Athabasca River at Athabasca	0.0 Days	0.0 Days	0.0 Days
Annual - McLeod River	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca upstream of Whitecourt	0.0 Days	0.0 Days	0.0 Days
Annual - Athabasca River at Hinton	3.0 Days	0.0 Days	0.0 Days
Annual - Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Pembina River at Sangudo	0.0 Days	0.0 Days	0.0 Days
Annual - Ft. McMurray	0.0 Days	0.0 Days	-1.0 Days
Change in annual instream flow needs violations. *Challenge: Maintain or improve ecosystem health*			
Annual - Mouth of the Lac La Biche River	1.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the McLeod River	-4.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Clearwater River	38.0 Days	21.0 Days	21.0 Days
Annual - Mouth of the Lesser Slave River	0.0 Days	0.0 Days	0.0 Days
Annual - Mouth of the Pembina River	0.0 Days	0.0 Days	0.0 Days
Change in walleye recruitment reduction. *Challenge: Maintain or improve ecosystem health*			
Annual - below Ft. McMurray	0.00%	0.00%	0.00%
Change in seasonal streamflow as a percentage of naturalized streamflow. *Challenge: Minimize the effect of development footprint on basin hydrology*			
Summer - at the Mouth	0.00%	0.00%	0.00%
Spring - at the Mouth	0.01%	0.00%	0.00%
Fall - at the Mouth	0.00%	0.00%	0.00%
Winter - at the Mouth	0.00%	0.00%	0.00%
Change in seasonal system shortages (m3/s). *Challenge: Provide water supply certainty for municipalities and development*			
Spring - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s
Winter - whole system	-0.0 m3/s	0.0 m3/s	0.0 m3/s
Fall - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s
Summer - whole system	0.0 m3/s	0.0 m3/s	0.0 m3/s

3.3.11.3 Benefits and trade-offs

Based on the modelling, there is a low net benefit to streamflow at the scale of the basin, since hydrologic change is often proportional to the area disturbed and linear features do not represent a large area in and of themselves. From an ecosystem perspective, reclaiming linear features can help improve water quality by reversing habitat fragmentation effects on wildlife.

Although more water is held on the landscape, resulting in slightly higher IFN violations, this is again a function of the way the IFN violations are calculated. Reductions in streamflow relative to base case are assumed to be negative for IFNs and do not necessarily represent a more natural condition. There is the potential for this strategy to add challenges to future development from limiting linear disturbance. There is also a large cost to reclaim existing linear features.

3.3.11.4 Implementation challenges and actions

This strategy should be viewed as an opportunity to be more proactive in reducing linear disturbance of development. The focus should be first on conservation of natural landscapes and then on reclamation or deactivation of linear features. Techniques to reduce linear disturbance in development include pooling leases, encouraging common infrastructure, implementing BMPs, and sharing and decommissioning of roads (e.g., revegetating redundant roads).

Several actions could help move this strategy toward implementation:

- Develop policy that describes appropriate levels of linear development. An example of this is the draft Livingstone-Porcupine Hills Land Footprint Management Plan for southwest Alberta (AEP, 2018).
- Reduce linear disturbance of development by encouraging industry to collaborate and minimize disturbance.
- Increase reclamation compliance by revisiting old reclamation plans and matching their intent and details with current policy goals and practices, and by improving enforcement and timing of reclamation.
- Address access management by improving land use management to minimize the impact of all types of access on the landscape.
- Target priority reclamation sites modelled after the WRRP work in the Bow Basin for identifying high value restoration and conservation sites.
- Fill data and science gaps by increasing understanding of how changes in hydrologic connectivity affect streamflow and by acquiring data about which seismic lines are and are not compacted in the basin.

3.3.11.5 Screening assessment

This strategy was identified as having some promise.

Although the overall net benefit is low at the scale assessed in this analysis, the strategy would be feasible and easy to implement. It would likely have environmental and ecological benefits that are unrelated to water quantity, such as improved water quality and aquatic health, improved wildlife habitat and connectivity, and improved biodiversity. There is already a push for linear reclamation in the ARB and this strategy could be part of a greater conservation and reclamation land use strategy.

3.3.12 *Extraction industry reclamation:* Continue to set and meet high standards of reclamation of extraction footprint to maintain or improve hydrological functions in a watershed

3.3.12.1 Strategy overview

This strategy is intended to support continued reclamation practices and enforcement in the resource extraction sector. It aims to ensure mines and pits are reclaimed in a manner that restores or improves watershed functions and would apply wherever there is an extraction footprint in the basin.

There are examples of this type of reclamation already in the basin today. Individual oil sands and coal mining facilities are each required to develop and implement extensive reclamation plans as part of their regulatory approval processes and commitments to stakeholders. The Muskeg River Watershed Management Framework (Alberta Environment, 2008) specifies water quantity and quality limits in an area with extensive extraction activity and reclamation.

Re-establishing hydrological functions and, potentially, returning the watershed to a near-natural state are the expected outcomes of this strategy. It has been difficult for reclaimed landscapes to recreate swamp, peatland, and wetland functions. The strategy may have a relatively small impact on water quantity but improvements to water quality would be expected.

3.3.12.2 Modelling done to test this strategy and modelling results

No modelling was done for this strategy directly as detailed facility-scale water management was outside the scope of the project.

If this strategy were modelled, it would need to be simulated at a much more local scale, with finer details and assumptions. Detailed modelling assumptions that are required include:

- Which areas should be reclaimed?
- How much of these areas should be reclaimed?
- What landscape should it be reclaimed back to?

This strategy is closely related to the land-based strategies explored in this initiative, including wetlands, forestry, conservation, and linear connectivity, and the modelling from those strategies provides the logic to support this strategy.

3.3.12.3 Benefits and trade-offs

One potential benefit is the re-establishment of hydrologic functions. Extraction disturbance can dramatically alter hydrologic function through site-scale water management. Although this site-scale management is important during operations, there may be opportunities to re-establish hydrologic functions during closure, resulting in more natural streamflow regimes. From a basin-wide perspective, there would be social benefits and potential water quality impacts following implementation of this strategy.

A trade-off would be potential decreases in streamflow as a result of increased interception on the landscape.

3.3.12.4 Implementation challenges and actions

End-of-life reclamation plans should already be in place for existing operations in the basin. Companies are required to carry out reclamation in their closure plans. The timing typically depends on the rate of development and the life of the project. Progressive reclamation is becoming more common as companies, regulators, and investors prefer staged reclamation throughout the life of the facility. This restores the hydrologic functions sooner and allows companies to reach natural certification sooner.

3.3.12.5 Screening assessment

This strategy was identified as having some promise.

However, detailed modelling should be conducted to thoroughly and more confidently screen the degree of promise that this strategy holds.

4.0 Additional learnings about the ARB

Through informed discussions with the Working Group, a number of related learnings emerged and were explored. These learnings were not strategies for sustainable water management; instead, they were facts or observations about the basin and water management that either supported or provided a counterpoint to commonly held perceptions. These learnings are included here to add to the information and platform of knowledge that offers a reference point for water questions in the basin.

4.1 Where does the water in the ARB come from?

Commonly held perception: *The water in the Athabasca River and its tributaries comes from multiple sources, mainly glaciers, melting snow, and rainfall.*

Learnings from this project:

Generally, streamflow in the ARB follows a snowmelt-dominated flow regime. Streamflow is low during the winter months, peaks during the spring due to snowmelt, and tapers off into the fall as the winter snowpack is depleted. The Athabasca River is supplemented during the late summer by glacier melt and groundwater. During the spring, summer, and fall, streamflow periodically increases due to large summer precipitation events.

More specifically, the pattern of contributions to Athabasca River flow varies by season and between regions. In the mountainous parts of the basin (generally upstream of Hinton), high snowpack, high glacier coverage, and a large elevation gradient make for a highly seasonal pattern. In this region, the volume of winter snowpack and the timing of spring snowmelt are the primary factors driving streamflow. These factors generate a hydrograph that has a large spring runoff, moderate flows during the late summer, and low flows during the winter months.

Conversely, regions with low elevation gradients, such as the Pembina watershed and most of the Boreal Region, have a much less seasonally dominant hydrograph. In these areas, snowpack is often substantially lower, and melts out early in the spring. This leads to a quick peak in streamflow (typically in April), followed by relatively large sporadic increases in streamflow following summer precipitation events. These areas are more affected by non-topographically-driven hydrologic processes such as wetland connectivity and antecedent moisture conditions. A more detailed description of surface water hydrology is provided in Section 2.

4.2 Where does the water in the ARB go?

Commonly held perception: *Industry withdraws and consumes a large portion of the water in the Athabasca River and its tributaries every year.*

Learnings from this project:

In any river basin, water "goes" to many different uses and leaves the basin a number of different ways. Natural uses include evaporation (rising of vapor), transpiration (movement through plants), infiltration (seepage into soils), and percolation (trickling into groundwater reserves). In any season, some of the water in the basin is going through these natural processes to either leave the basin or be stored in natural forms. Human uses are, for the most part, managed through a system of water diversion licences issued by AEP under the *Water Act*. Municipalities, companies, individuals, and others can hold a licence to divert a specified volume of water at a specified time and rate from a specified location for a specified use.

Currently, more than a thousand water diversion licences allow up to ~835 million m^3 of water to be withdrawn from the ARB surface water sources (rivers, streams, lakes) in a year. These licences authorize withdrawals for a range of uses, as shown in Table 20.

Table 20: Summary of water licences held in the Athabasca River Basin by allocation volume and type of user.

Type	# Licences	Withdrawal volume	% by volume
Higher volume licences	57	733,428,757 m^3	88%
Agricultural & Irrigation	1	1,800,000 m^3	
Commercial & Industrial	36	682,795,155 m^3	
Environmental Management*	3	11,103,400 m^3	
First Nation	8	838,000 m^3	
Municipal	9	36,892,202 m^3	
Lower volume licences	651	32,116,155 m^3	3.8%
Agricultural & Irrigation	233	3,529,876 m^3	
Commercial & Industrial	303	10,477,726 m^3	
Environmental Management	64	9,090,616 m^3	
Municipal	51	9,017,936 m^3	
TDLs	336	68,800,806 m^3	8.2%
TOTAL	1045	834,345,718 m^3	100%

*e.g., lake control structures and Ducks Unlimited pond enhancements (attempting to account for evaporative loss)

The question then becomes: how much of the water in the ARB goes to these human uses? The simplest answer would be to look at the average annual flow in the mainstem of the Athabasca River. If it is measured at Embarras, just upstream of Lake Athabasca, the average annual volume in the Athabasca River is approximately 19.5 billion m^3 (based on data from 1971 to 2015) and it follows the seasonal pattern shown in the hydrograph below (Figure 59).

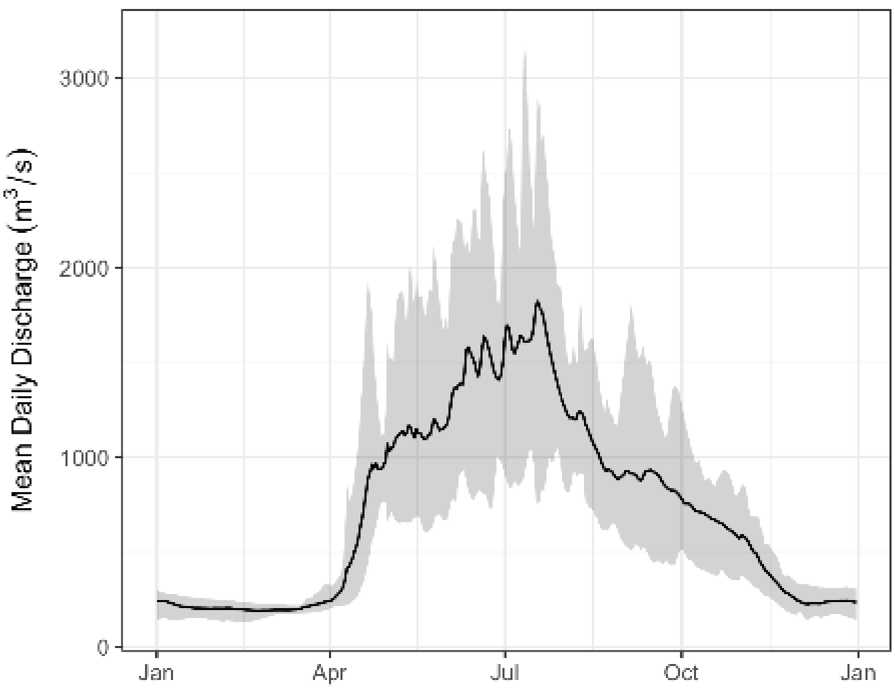

Figure 59: Daily average streamflow (1971 – 2015) for the Athabasca River at Embarras (WSC: 07DD001).

Source: Water Survey of Canada, 2018

This suggests that over an average year, with ~19.5 billion m^3 of water flowing in the Athabasca River at Embarras, all of the water licence withdrawal allocations, that is ~834 million m^3, would account for ~4% of the water in the Athabasca River. Of this, 83.1% goes to industrial uses; therefore, industrial use accounts for ~3.5% of the annual flow in an average year at Embarras. Municipal uses amount to 5.5% of allocations, or ~0.24% of the annual flow in an average year at Embarras. Another 0.6% of the allocation goes to agricultural uses, accounting for ~0.26% of the annual flow in an average year at Embarras.

This is a very simple view of how much water "goes" to human uses. It does not consider how much of this withdrawal allocation is actually taken nor does it factor in how much of the withdrawal is fully consumed instead of being used then treated and returned to the river as return flow. It also doesn't consider individual tributaries or the seasonal distribution of withdrawal. In a basin as large and diverse as the ARB, it is important to look at how much water is actually allocated, withdrawn, and consumed at a number of points throughout the basin.

4.3 What will climate change likely mean for water supply in the ARB?

Commonly held perception: *Climate change will typically mean less precipitation (snow and rain) each year and warmer temperatures causing earlier melting of glaciers and snow. All of this means less water supply in most years.*

Learnings from this project:

As explained in Section 2.3, the scenarios modelled in this study suggest that spring streamflow timing will shift to earlier in the season and there may be an overall increase in annual streamflow, with reductions in streamflow during the summer and fall (Figures 10 and 11). These results are consistent with other recent studies, suggesting the most challenging time for water supply is likely to be the summer given that studies suggest summer streamflow is likely to decline in the future, while spring and winter flows could increase (Eum et al., 2014).

4.4 How might melting glaciers affect long-term water supply in the ARB?

Commonly held perception: *Glaciers worldwide are melting faster now than historically due to warmer air temperatures from climate change. This is expected to be the case for glaciers in the ARB as well, meaning that glacier water supply will be depleted in the not-too-distant future.*

Learnings from this project:

As explained in Section 2.3, future changes in climate are likely to result in higher glacial contribution to streamflow over the medium term (next 50 years or so) from higher ice melt. This will increasingly deplete the volume of water stored in the glaciers. Over the long term (in the next 100 years), glaciers will contribute less and less to streamflow in the Athabasca as glacier ice recedes substantially.

4.5 How might changes in land use affect water supply in the ARB?

Commonly held perception: *Changes in how land is used (natural areas, forestry, farming, resource extraction, towns, etc.) and what covers the land (forest, rangeland, crops, cut lines, trails, paved surface, etc.), can significantly change the amount of water that flows in the ARB's rivers.*

Learnings from this project:

The impact of land use on the hydrological functions in a watershed is increasingly better understood and documented. If surfaces are hardened (e.g., changed from grass to pavement), less water infiltrates the soil and more water drains off the area. If trees and shrubs are removed, less snow is intercepted, less water can be lost to evapotranspiration, and snow melts and drains faster. If waterbodies are intersected by linear features such as roads, trails, seismic lines, and cut lines, natural drainage patterns are changed resulting in water typically running off the landscape faster.

Each of these dynamics, and the many other and often more complex hydrological dynamics resulting from changes in land use, are typically seen and managed most effectively in local areas. This reflects the layers of planning that occur in the ARB, including sub-regional and municipal planning that are better suited to manage the changes at the smaller scales.

Over the scale of a basin as large as the ARB, it is difficult to see significant effects on streamflow from changes in land use. That was the case in this work (Figure 60); the AIRM was used to simulate the effect of wetland reduction, changes in linear footprint, and forest cover reduction. In all of the modelling results, the changes in flow in the mainstem of the Athabasca River were directionally intuitive but barely discernible given that the scale is so large. Figure 60 also demonstrates that the smaller the spatial scale (e.g., the Gregg River near the mouth), the larger the potential effect of changes in land use.

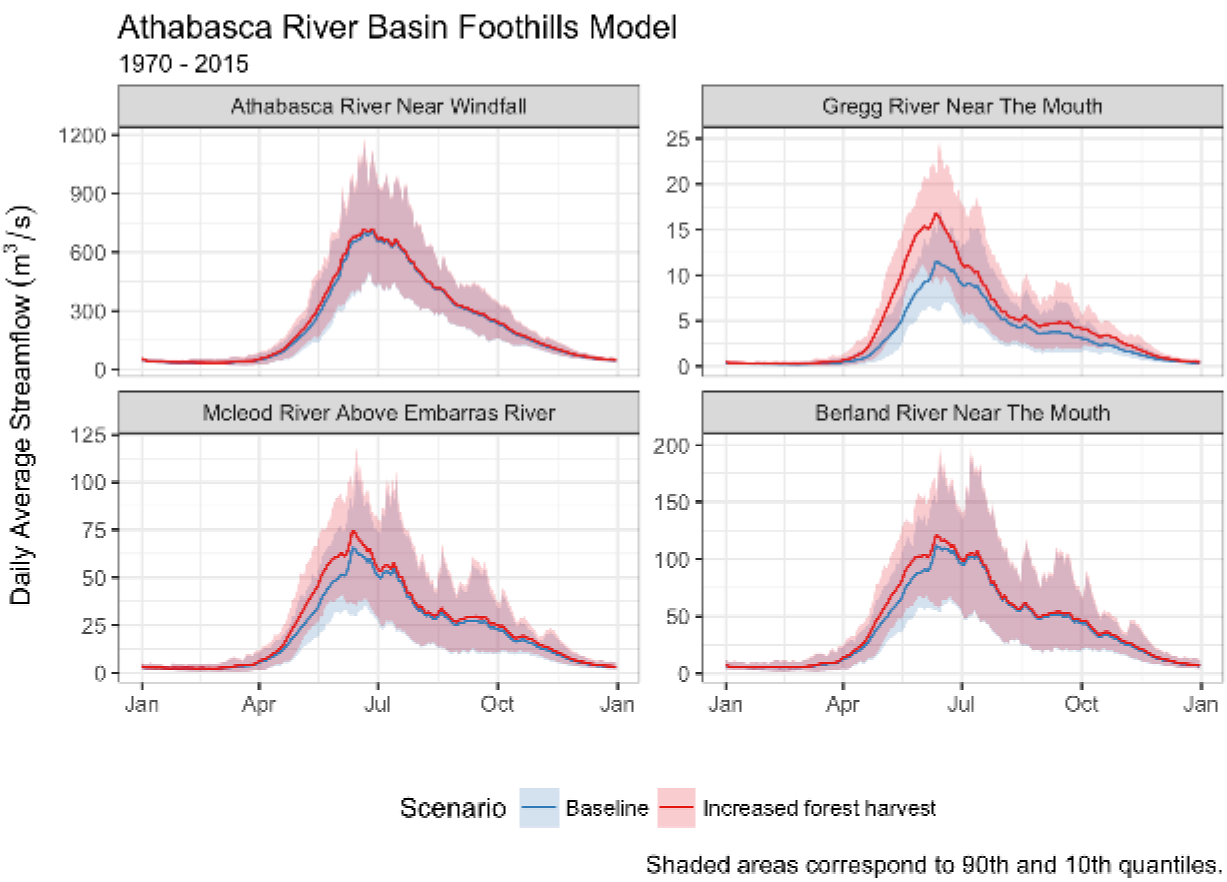

Figure 60: Daily average streamflow at four locations under baseline (1970 -2015) and under 50% higher forest harvest.

4.6 Which has greater potential effect on surface water quality and quantity: converting land into farmland or increasing irrigation?

Commonly held perception: *Developing new farmland will cause water quality problems due to sediment and nutrient runoff. Increasing irrigation will create higher water demand leading to water quantity problems*.

Learnings from this project:

Using AIRM, a 30% increase in agricultural area was simulated by replacing forest stands with crops. Results suggest this would not have a substantial effect on surface water quantity at the scale assessed. However, there is still a need to minimize the effects on water quantity at smaller spatial scales and to limit the effects of agriculture on water quality. There may be changes in streamflow at smaller spatial scales and issues with sediment and nutrient runoff, which could potentially be mitigated with BMPs.

It was also discussed that due to a warmer climate there may be an opportunity to irrigate new areas of farmland. Simulations doubled water use for existing agriculture licences in the ARB during the growing season. The results did not show substantial changes to water quantity; rather, with increased agricultural demand, water quality may be more affected than water quantity.

If agriculture were to expand its land or water use in response to a changing climate (warmer air temperatures and longer growing season), the main consideration is likely the impact of runoff into river systems. Increased demand would be small as current demands are small, so even with a doubling of those demands, shortages aren't expected to increase based on the modelling.

The Working Group discussed that if new farmland were developed or irrigated, it should have no net impact on sediment and nutrient runoff; such impacts can be managed through larger riparian buffers around waterbodies and use of best farming practices, for example. Education is needed, and incentives such as grants to farmers and ranchers for implementing BMPs have worked well in the past.

4.7 Will using alternatives to freshwater in in-situ facilities make a noticeable difference in flow in the Athabasca River?

Commonly held perception: *In-situ facilities currently use a lot of freshwater in their operations and asking industry to change to alternative processes or non-freshwater sources will result in less water being diverted from the Athabasca River and its tributaries.*

Learnings from this project:

Very few in-situ facilities hold surface water licences to divert freshwater and of them, very few, if any, actively draw from freshwater sources. These operations typically use saline water from groundwater wells. Because a small number have licences to withdraw freshwater, the Working Group used AIRM to model these licensed withdrawals to see the impact on flow of eliminating them. The licences included in this analysis are shown in Table 21.

Table 21: Licences in the ARB for in-situ freshwater use.

Approval ID Number	Approval Holder	Water Source	Quantity
00325409-00-00	ATHABASCA OIL CORPORATION	Unnamed Lake	41,500 m^3
00325602-00-00	ATHABASCA OIL CORPORATION	Unnamed Lake	267,500 m^3
00325644-00-00	ATHABASCA OIL CORPORATION	Unnamed Lake	263,000 m^3
00368511-00-00	ATHABASCA OIL CORPORATION	Unnamed Lake	30,000 m^3
00076176-00-00	ATHABASCA OIL CORPORATION	Unnamed Lake	32,000 m^3
00031488-00-00	ATHABASCA OIL CORPORATION	Unnamed Lake	50,000 m^3
00029559-00-00	ATHABASCA OIL CORPORATION	Unnamed Lake	75,000 m^3

Source: AEP Water Licence Database

As seen in Figure 61, the simulation showed no detectable difference in flow in the mainstem by using alternatives to freshwater use in currently licensed in-situ facilities.

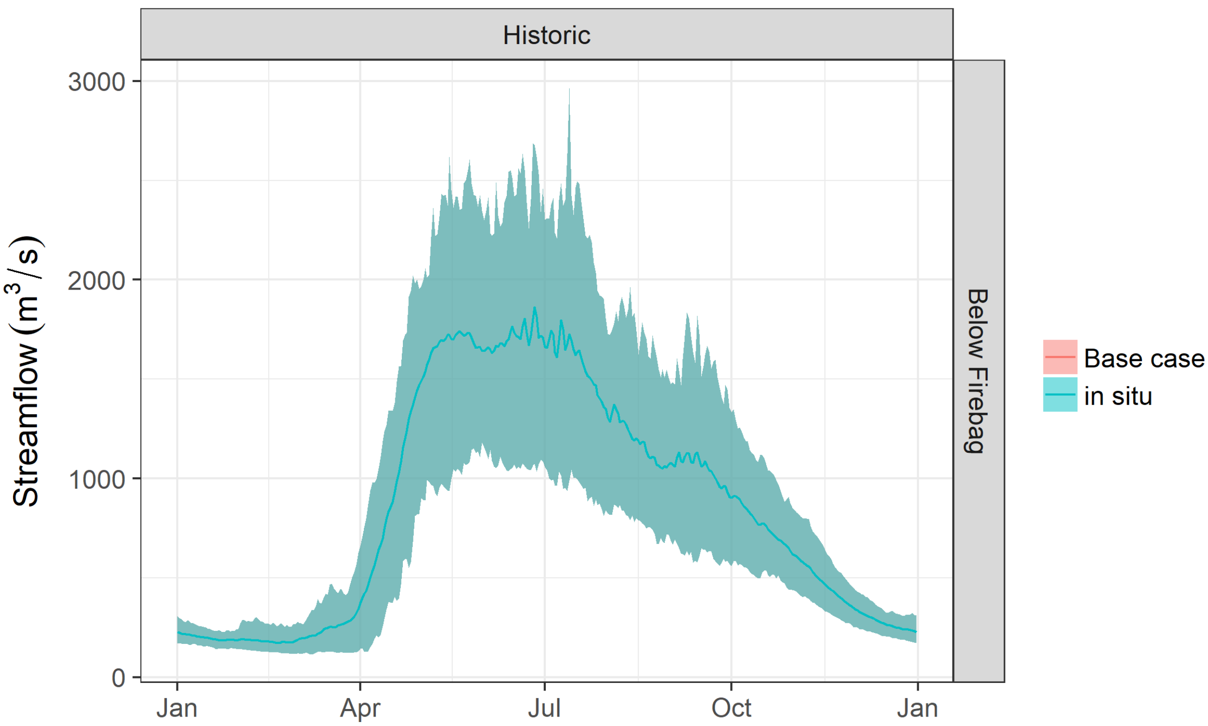

Figure 61: Comparison of average daily streamflow for the Athabasca River below Firebag during base case and removing in-situ withdrawal.

4.8 Can shutting off water licence withdrawals improve navigation on the Athabasca River?

Commonly held perception: *Industrial water withdrawals are high. If they are shut off, higher flows would substantially help navigation in the lower basin.*

Learnings from this project:

The SWQMF supports minimum flow targets in the Lower Athabasca by setting withdrawal limits on industry during times of low flow. Licence withdrawals for the total oil sands vary but are limited to 4.4 m^3/s during low flow periods, defined as <87 m^3/s in the Athabasca River at Fort McMurray.

The report “As Long as the River Flows” (Candler et al, 2010) suggested 400 m^3/s as a minimum extreme flow (AXF) and ~1,600 m^3/s as an ideal flow (called the Aboriginal Base Flow) that would support Aboriginal navigation and access to traditional lands in the lower basin.

The Working Group explored the potential for improvements in flow for navigation purposes in the AIRM by applying a minimum flow target of 400 m^3/s downstream of the confluence with the Firebag River, between April 16 and October 28 (open water season) of each year, then shorting upstream licences to try to meet the target minimum (Figure 62). The results showed that by doing this, flows generally increased on the Athabasca River downstream of the Firebag confluence during the open water season but not substantially, and the 400 m³/s target was not achieved all the time even when all upstream licences were shorted. Figure 62 shows that the navigational flows and the base case overlap almost all the time, with a few minor exceptions.

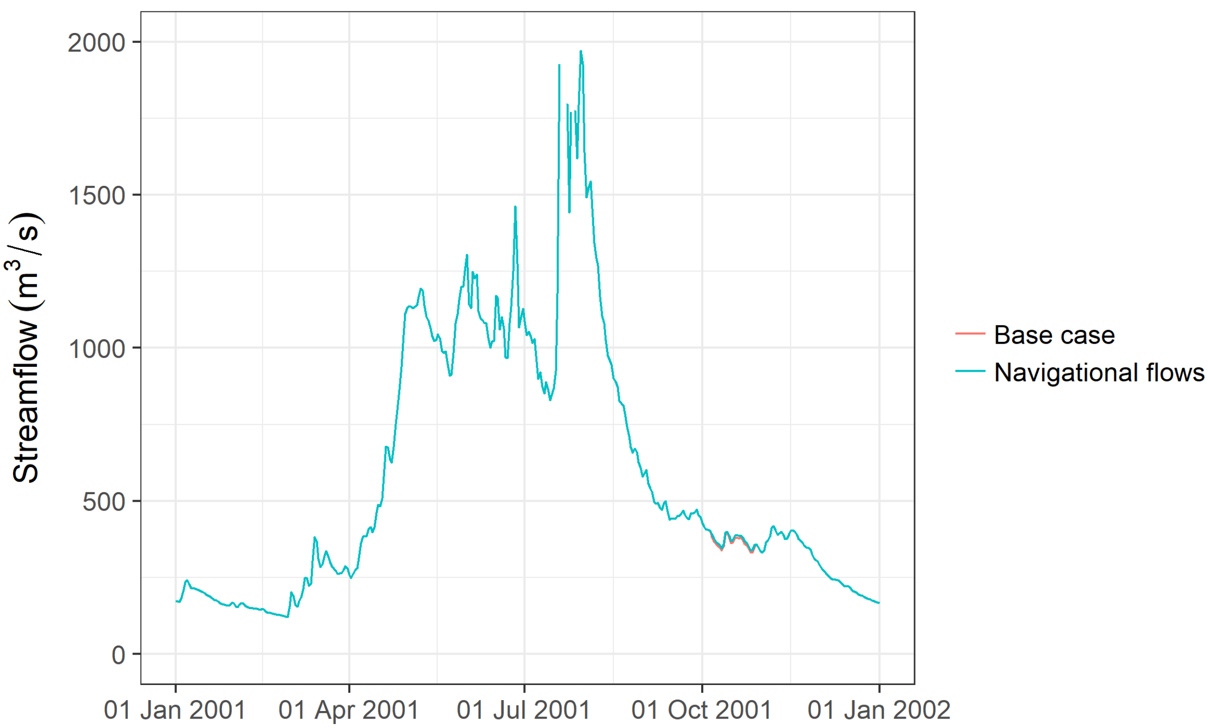

Figure 62: Example of water year 2001 under the base case and shorting water licences to meet navigational flows.

Recognizing the limited contribution that stopping licensed withdrawals could make to achieving higher flows in the lower basin to support navigation, the Working Group identified potential alternatives to a minimum flow. These might include:

- Construction of instream structures to increase water depth in locations identified as navigation pinch points.
- Construction of an upstream dam and reservoir designed and operated to store, and release water as needed to meet the AXF or similar minimum flow for navigation.
- Better stream channel data and navigation models to understand navigation channels and their changes through time to assess options for the lower basin. This may lead to suggestions for channel management including targeted dredging in the lower Athabasca River as has been done in the past.

- Investment in alternate transportation including replacement of water craft by those that can maneuver in shallower waters and changing to road navigation by building an all-season permanent road to Fort Chipewyan and other areas in the lower basin.

4.9 What critical gaps exist in water related data, processes, policy, and knowledge for the ARB?

Commonly held perception: *There are many gaps in what we need to know to properly manage water in the ARB. While much has been and continues to be done towards sustainable water management, gaps exist in data collection and access, fundamental science, formal and informal processes, provincial and local policies, and individual and collective knowledge.*

Learnings from this project:

Throughout this project, participants and interviewees were asked to identify the gaps they have encountered in their work and discussions related to sustainable water management in the ARB. The list of gaps, while neither exhaustive nor comprehensively vetted, was lengthy. It is shown in Appendix F.

Table 22 summarizes gaps that were identified during the project, and this summary was shared with the Working Group.

Table 22: Summary list of data, knowledge, process and policy gaps identified in this project.

Data	Knowledge	Processes	Policy
Technology for real-time measurement of winter flows Monitoring and data collection of snowpack, tributary streamflow, and meteorological data in the upper portion of the ARB Awareness of and ready access to all public datasets (e.g., snow surveys) Spill tracking records system and reporting requirements Groundwater withdrawal reporting All water use data for allocation management	Understanding the linkage between hydrology, soil moisture and wildfires Mapping of hydrologically sensitive areas in the basin that supply water to sub-basins and are locally important to communities Development of indicators that correlate changes in flow and ecosystem effects Understanding of the hydrological effect of watershed and local scale connectivity Understanding of the effect of oil sands mining on sub-basin hydrology	Address how to manage tributaries where there is currently no flow data Include water incident-related reporting and monitoring (industrial incidents) in water data Prioritize reclamation through comprehensive reclamation modelling Understand more of the specific concerns around Traditional Knowledge (TK) and implementing TK into policy. Require TK in the process of policy development	Implement a basin-wide water re-use policy Establish a water conservation objective for the basin Establish a water management plan for the basin focusing efforts on greatest risks

The Working Group could not identify which of these gaps would be considered most critical as it would likely vary between groups depending on needs and perspectives. That said, an underlying theme for addressing many of these gaps is awareness and ready access to data. There are instances where significant investment and effort have gone into developing datasets that are not productively used as they are not known or cannot be readily accessed.

5.0 Sustainable water management in the ARB

This Roadmap is a set of strategies and practical actions, developed by a collaborative and inclusive Working Group, that serves as a recommended path toward sustainable water management in the ARB. It is intended to inform future planning and management efforts as they relate to water. The set of strategies are:

1. Effluent reuse: Enable reuse of industrial or municipal effluent to reduce reliance on freshwater
2. Water conservation: Continue to achieve water conservation and efficiency improvements as communities develop
3. On-stream storage: Explore new on-stream multi-purpose storage options
4. Off-stream storage: Develop new and existing off-stream storage sites to meet multiple basin water management objectives
5. Existing infrastructure: Alter existing water storage infrastructure and operations to meet multiple basin water management objectives
6. Environmental flows: Establish IFNs or similar targets for all tributaries in the basin as a precautionary water management measure
7. Navigational flows: Implement minimum flows to improve navigation in the lower Athabasca basin
8. Land conservation: Increase the quantity and improve the condition of conserved and restored land across the basin
9. Forestry practices: Support practices in Forest Management Agreements (FMAs) that minimize hydrologic change
10. Wetlands: Avoid further wetland loss and functional impairment and promote more wetland restoration, education, and best management practices focused on minimizing impacts
11. Linear connectivity: Reclaim or deactivate linear features and reduce future linear disturbances in watersheds
12. Extraction industry reclamation: Continue to set and meet high standards of reclamation of extraction footprint to maintain or improve hydrological functions in a watershed

These strategies were developed in response to the basin challenges that were brought up in the first few Working Group meetings; these challenges included:

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

- Maintaining or improving water quality
- Understanding the renewable energy potential of the basin

This project was not designed to solve any one problem in the basin, or to recommend action in any particular time frame. Nevertheless, many individuals and organizations feel an urgency to address water challenges in the basin now, and to be more proactive with future approaches to water management. Decisions, actions, and inactions today are affecting the long-term sustainability of the basin; there is a need to determine what is wanted for the basin in the long term, and act accordingly.

Alberta's Climate Leadership Plan is pressing for more renewable energy and there is interest in hydro potential in the ARB to provide renewable capacity. Lower energy prices are forcing diversification throughout the provincial economy, so how might that change water use and water needs in the basin? Municipalities continue to seek residential, commercial, and industrial growth. Regulatory frameworks are demanding reclamation plans be set and begun early in project life cycles, and long-term land use plans are being prepared for the basin. Mandates of the UN Declaration on the Rights of Indigenous Peoples (UNDRIP) and the Truth and Reconciliation Commission (TRC) are shifting Indigenous involvement and expectations on natural resource decisions. From a sustainable water management perspective, considering the many interests and perspectives in the basin, how do we collectively want to move forward? What does this mean for the basin?

With those issues in mind, below are six recommendations based on the outcomes from this project that will serve as a path toward sustainable water management in the ARB. The purpose and approach for each recommendation is noted in italics, and each recommendation is accompanied by practical actions to advance implementation.

5.1 Recommendations for sustainable water management in the ARB

1. **Maintain or improve the natural hydrological functions of the watershed**
   - ***to protect water supply, water quality, and watershed health***
   - ***by embedding hydrological priorities in land use planning and enforcement at the regional, sub-regional, and local scales***.

   Implementable actions:
   - Identify sites of highest conservation and restoration priority that would have the greatest positive impact on peatland complexes, tributaries, and connectivity
   - Improve understanding of the location and overall function of hydrologically sensitive wetlands
   - Fill data and science gaps by increasing the understanding of how changes in hydrologic connectivity affect water volumes
   - Support and inform conservation and restoration areas in future land use plans and ongoing planning

2. **Establish environmental flow needs for the Athabasca River and all tributaries**
   - ***to clarify flows needed for watershed health and volumes available for use***
   - ***by calculating and publicly communicating reach-specific IFNs or similar targets.***

   Implementable actions:
   - Establish IFN targets for all streams and rivers, likely using a modified Alberta Desktop Method
   - Communicate broadly, in an accessible way, all IFNs that are calculated for the ARB

3. **Reduce water navigation limitations in the lower basin**
   - ***to maintain traditional access and activities***
   - ***by recognizing that further minimum flow targets are unlikely to provide navigational flows and, instead, employing a suite of alternative methods.***

   Implementable actions:
   - Investigate potential for instream structures to increase water depth in specific locations
   - Better understand navigation channels and their changes through time and consider select channel management including targeted dredging
   - Investigate the potential for investment in alternate water craft and provision of year-round road access

4. **Increase the adaptive capacity of the basin**
   - ***to be more resilient to climate change impacts on water supply while meeting multiple basin needs***
   - ***by investigating multi-purpose infrastructure to manage the flow regimes of the Athabasca River and major tributaries.***

   Implementable actions:
   - Establish multi-purpose objectives for new projects to understand and inform how future storage could support basin flow needs

5. **Continue to develop the means to share and apply Traditional Knowledge**
   - ***to lend the experience and expertise of Indigenous Peoples to formal sustainable water management in the basin***
   - ***by developing and enabling meaningful processes that support the UNDRIP and TRC mandates.***

   Implementable actions:
   - Example: collect and share a dataset of traditional sites in the ARB

6. **Address the most critical gaps in water data, processes, policy, and knowledge**
   - ***to better inform sustainable water management***
   - ***by prioritizing and closing gaps most critical to the ARB.***

   Implementable actions:
   - Continue to provide resources, budget, and mandate to AEP in its work to publicly and efficiently share already existing water data

- Find and invest in the instrumentation solution to provide near real time measurements under ice flow
- Complete and implement the provincial water reuse policy that is currently under development to change, clarify, or create clear direction for decisions on water reuse
- Resource and incentivize water communication to inform sustainable water management decisions individually, organizationally, and collectively
- Close the gaps between Traditional Knowledge, culture, and society through inclusion of Traditional Knowledge into policy

Collectively, these six recommendations touch on each of the water challenges identified by the Working Group, as seen in Table 23. Appendix F lists the gaps identified through work and discussions related to sustainable water management in the ARB Initiative.

Table 23: Water challenges in the ARB.

Challenges	**Recommendation**					
	1	**2**	**3**	**4**	**5**	**6**
Maintaining or improving ecosystem health	√	√		√	√	√
Providing water supply certainty for development		√		√		
Minimizing the effect of the development footprint on basin hydrology	√	√			√	√
Ensuring sufficient flow for navigation			√		√	
Limiting damage from floods or extreme events				√		
Maintaining or improving the health of the Peace-Athabasca Delta		√		√	√	√
Addressing concerns around Indigenous rights		√	√		√	
Accessing water-related data and knowledge in the basin					√	√
Maintaining or improving water quality	√	√				√
Understanding the renewable energy potential of the basin				√		

5.2 Closing statement

The findings of this project reflect the importance of thinking about and planning a response to future change in the ARB. They provide a Roadmap to move us towards new and enhanced approaches to water and watershed management in the basin that can be implemented before facing imminent crises of flood, drought, overallocation, or stalled development. Decisions, actions, and inactions today are affecting the sustainability of the basin, and this Roadmap can help determine what we want the basin to look like in the long term, so we can act accordingly.

The strategies and recommendations present what can be done in the near term to build the adaptive capacity of the water management system in the ARB. This Roadmap is intended to stimulate investment in resilience and adaptive capacity and raise awareness of potential water quantity risks to encourage water management preparedness efforts and arrangements, all to better equip the basin to respond to the range of potential future water situations and challenges.

Many activities are already in progress to make the ARB more resilient and to address specific issues and concerns. Water management decisions are informed by risk and hazard assessments, regulations, science, political decision making, and economic conditions. Working collaboratively, knowledgeable and experienced water users and managers from across the ARB reaffirmed and identified opportunities to optimize and build on the programs, regulatory frameworks, and physical infrastructure already in place to manage the basin's water supply to support continued population and economic growth with improved environmental health. All of these elements will need to align to see a true shift in the adaptive capacity of the basin.

Participants contributed an enormous amount of time and expertise to this initiative. Their insight and knowledge were invaluable to the success of the project, and their enthusiasm for the collaborative process was remarkable. WaterSMART is deeply grateful to the individuals and organizations that played a part in building this Roadmap for sustainable water management in the ARB.

WaterSMART hopes that all readers will consider the findings of this report and how they may contribute to implementing its recommendations. We are hopeful that the outcomes from this work will be woven into policies, plans and strategies that are influencing water management in the ARB (e.g., land use plans). We hope individual water managers, watershed groups, and water users will act on this opportunity to champion and support the advancement of effective water management strategies for their stakeholders and their watersheds.

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Appendix A: Project Participants

Listed below are the organizations and communities that generously gave time, energy, and expertise to this work by attending at least one of the Working Group meetings. Being on this list does not mean that they necessarily supported all the individual strategies. Any errors or omissions are those of the authors, not the participants.

Alberta Agriculture and Forestry
Alberta Energy Regulator
Alberta Environment and Parks
Alberta Forest Products Association
Alberta Innovates
Alberta Newsprint Company
Alberta Pacific Forest Industries
Alberta Wilderness Association
Alexander First Nation
Aspen Regional Water Services Commission
ATCO
Athabasca University
Athabasca Watershed Council
Bigstone Cree Nation
Canadian Parks and Wilderness Society
Conklin Integrated Environmental Services
Driftpile First Nation
Ducks Unlimited Canada
Environment and Climate Change Canada
Fisheries and Oceans Canada
Fort McKay First Nation #468
Fort McKay Métis
fRI Research
Frog Lake First Nation
Gift Lake Métis Settlement
Heart Lake First Nation
Lac La Biche County
Lesser Slave Watershed Council
McMurray Métis (Wood Buffalo Métis Locals)
Métis Nation of Alberta Region 1
Northern Lights Fly Fishers
Peavine Métis Settlement
Regional Municipality of Wood Buffalo
Repsol Oil and Gas Canada Ltd.
Shell Canada
Sucker Creek First Nation
Suncor Energy
Teck Resources Ltd.
Town of Athabasca
Trout Unlimited Canada
University of Regina
West Central Forage Association
West Fraser - Hinton
Westmoreland Coal Company
Yellowhead Tribal Council

Appendix B: Modelling components of the AIRM

B-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 B-1). 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 the climate scenarios developed for this work can be found in Appendices C.

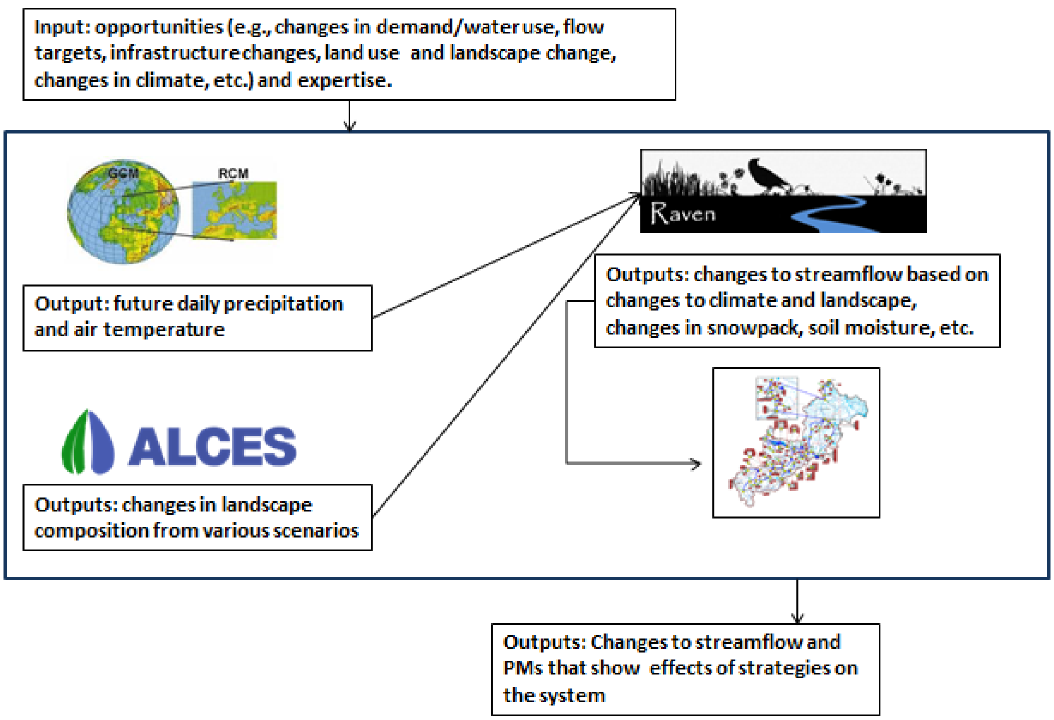


Figure B-63: The AIRM and its components, the flow of how they fit together, and inputs and outputs relative to use with the Working Group.

B.1.1 Landscape simulator development and input to AIRM

ALCES Online is the basis for land use modelling in the AIRM (see Figure B-2). 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 B.2, to enable dynamic simulations of how changes on the land affect hydrology, and hence streamflow, in the ARB. ALCES Online is a cell-based representation of today's landscape and can be used to construct 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 with which scenarios can be defined make it possible to explore the outcomes of numerous scenarios and 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.

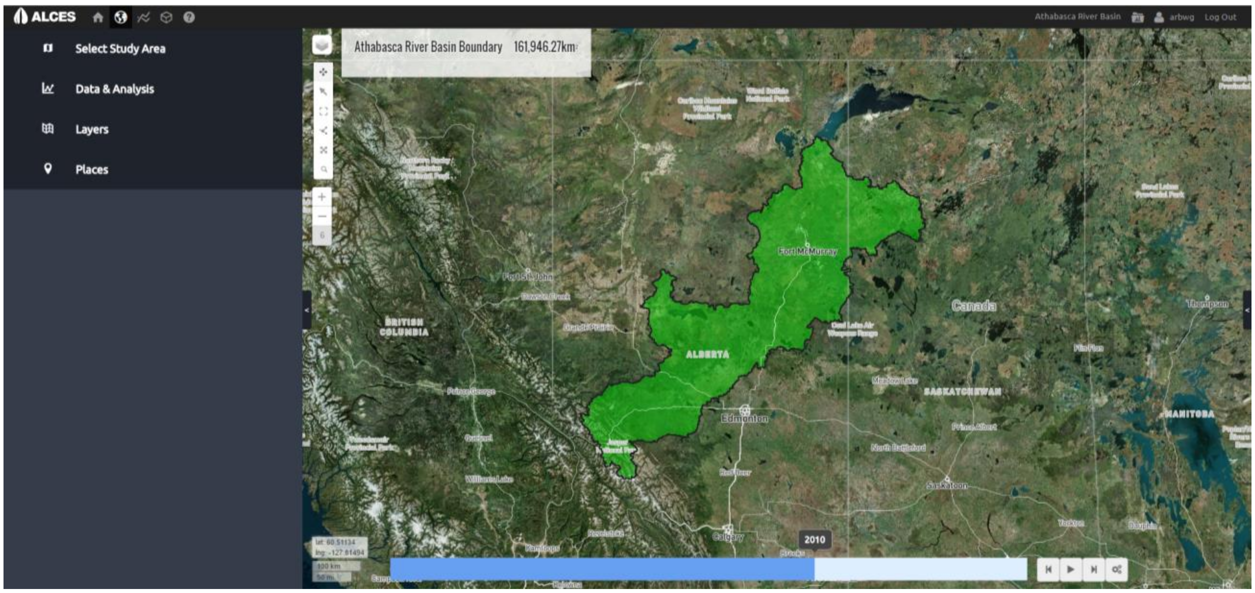


Figure B-64: ALCES Online component of the AIRM.

Completing the scenario analysis for this project 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 B.2). Detailed information on the datasets integrated into ALCES Online is provided in Table B-8 of this Appendix. 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.

B.1.2 Hydrological model development for AIRM

The hydrological component of the AIRM is built using the Raven hydrologic modelling platform. Raven was 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 data 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., 2016) 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., 2013). For detailed information on the RAVEN model, including the data used, calibration and verification details, and simulated processes, see Section B. 2 and B.3 of this appendix.

B.1.3 River system model and performance measure development for AIRM

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 B-3). 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.

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 alternative scenarios 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 later on in this appendix.

Output from the AIRM is then fed into performance measures (PMs), which are any graphical visual that shows the status of an interest (e.g., fish species, navigation, streamflow, security of supply) to a Working Group participant. 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 discussion informed the PMs that have been developed to date; these PMs are categorized as water management, ecological, and social.

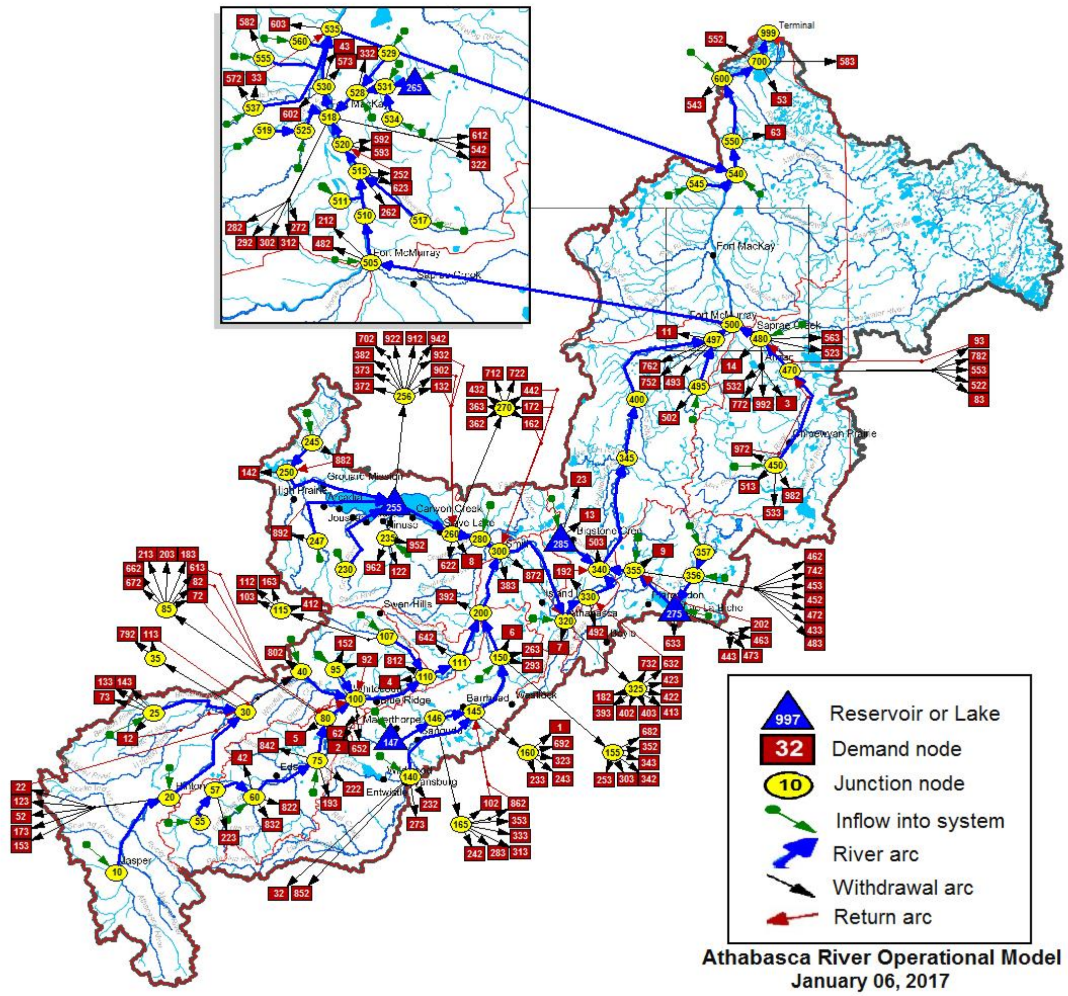


Figure B-65: Schematic of the river system component of the AIRM, built on the OASIS modelling platform.

B.1.4 Climate scenarios: development and inputs to AIRM

One objective of the ARB Initiative was 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 C 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 or four 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 an 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, 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 B-4 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.

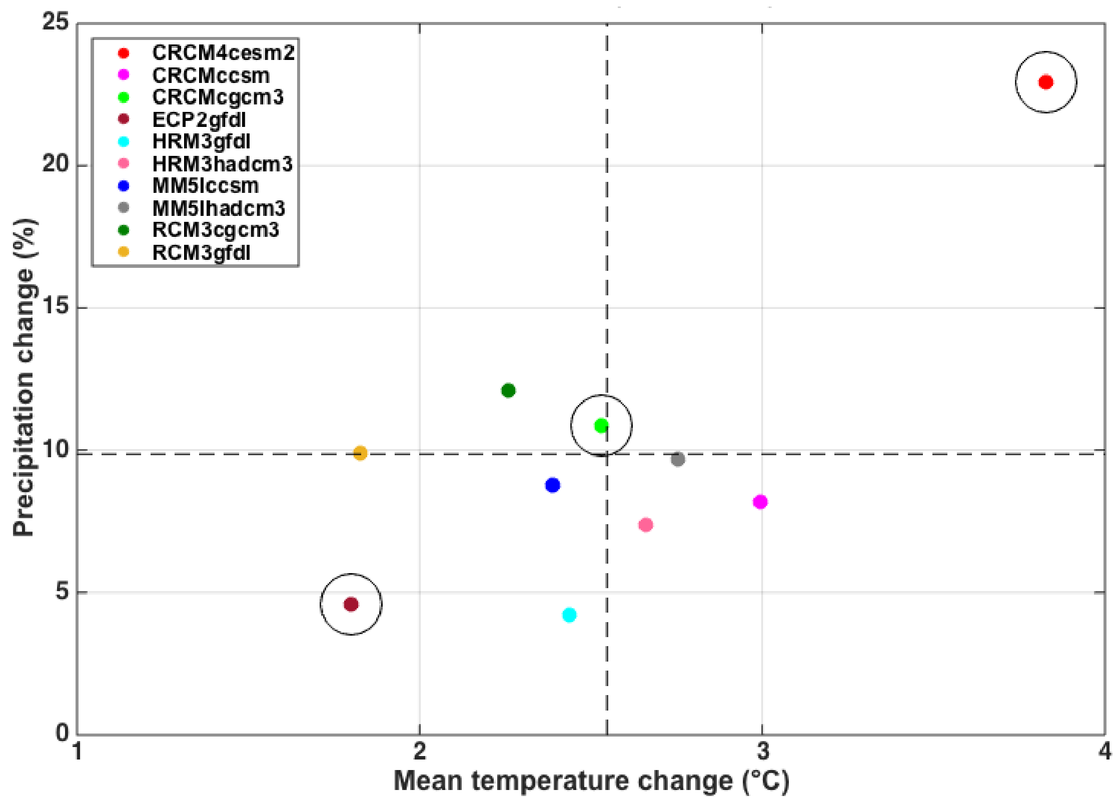


Figure B-66: A scatterplot of the 10 RCM climate change scenarios. The changes are the difference in annual precipitation and temperature between 1971–2000 and 2041–2070. The scatterplot is used to identify the circled RCMs that simulate the least, median, and most changes in temperature and precipitation.

These three climate scenarios from the RCMs were used 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 against which opportunities and strategies from the Working Group can be tested 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.

B.2 Raven hydrological modelling framework

B.2.1 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 B-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 B-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
	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	07AH003	1972–2013	1,145

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

Model	Station Name	Station Code	Period	Drainage Area (km²)
	Whitecourt*			
	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
	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

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

Model	Station Name	Station Code	Period	Drainage Area (km^2)
	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 McMurray	07DA001	1957–2014	132,588
	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 B-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 B-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
	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

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

Data Source	Name	Longitude	Latitude	Elevation (m)
	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
	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 B-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 B-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.

B.2.2 Model Methods

Daily streamflow in the ARB 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. All model algorithms are described in more 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. 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 B-5).

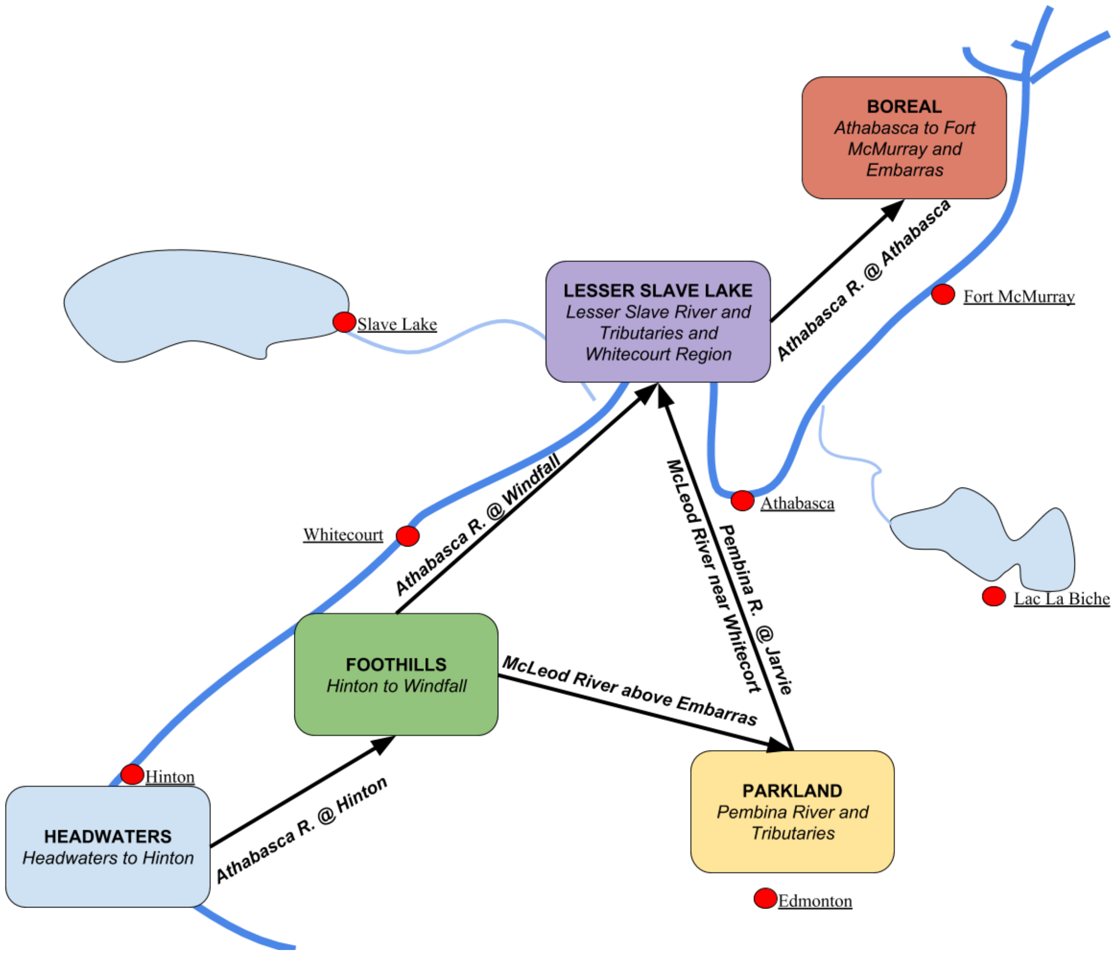


Figure B-67: Schematic showing the connection between sub-models used to simulate the ARB.

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) dictated by ALCES Online. 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 from ALCES Online 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.

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 by 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.

B.2.3 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 B-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 B-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 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 B-4 in the next section). 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.

B.2.4 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 B-6).

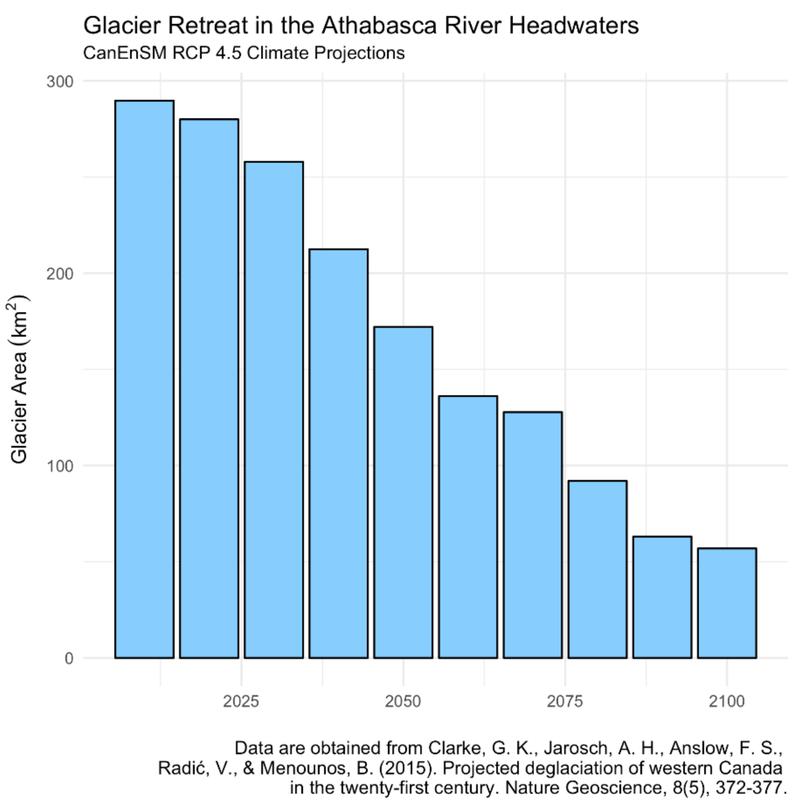


Figure B-68: Change in glacier area within the ARB from 2005 to 2100 using CanEnSM RCP 4.5 climate change projection.

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.

B.3 Results

B.3.1 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 B-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%
Parkland	McLeod River near Rosevear	0.81	11%	0.73	10%
	McLeod River near Whitecourt	0.78	3%	0.69	9%
	Pembina River near Entwistle	0.75	9%	0.67	10%
Lesser Slave	Athabasca River at Athabasca*	0.82	23%	0.80	27%

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

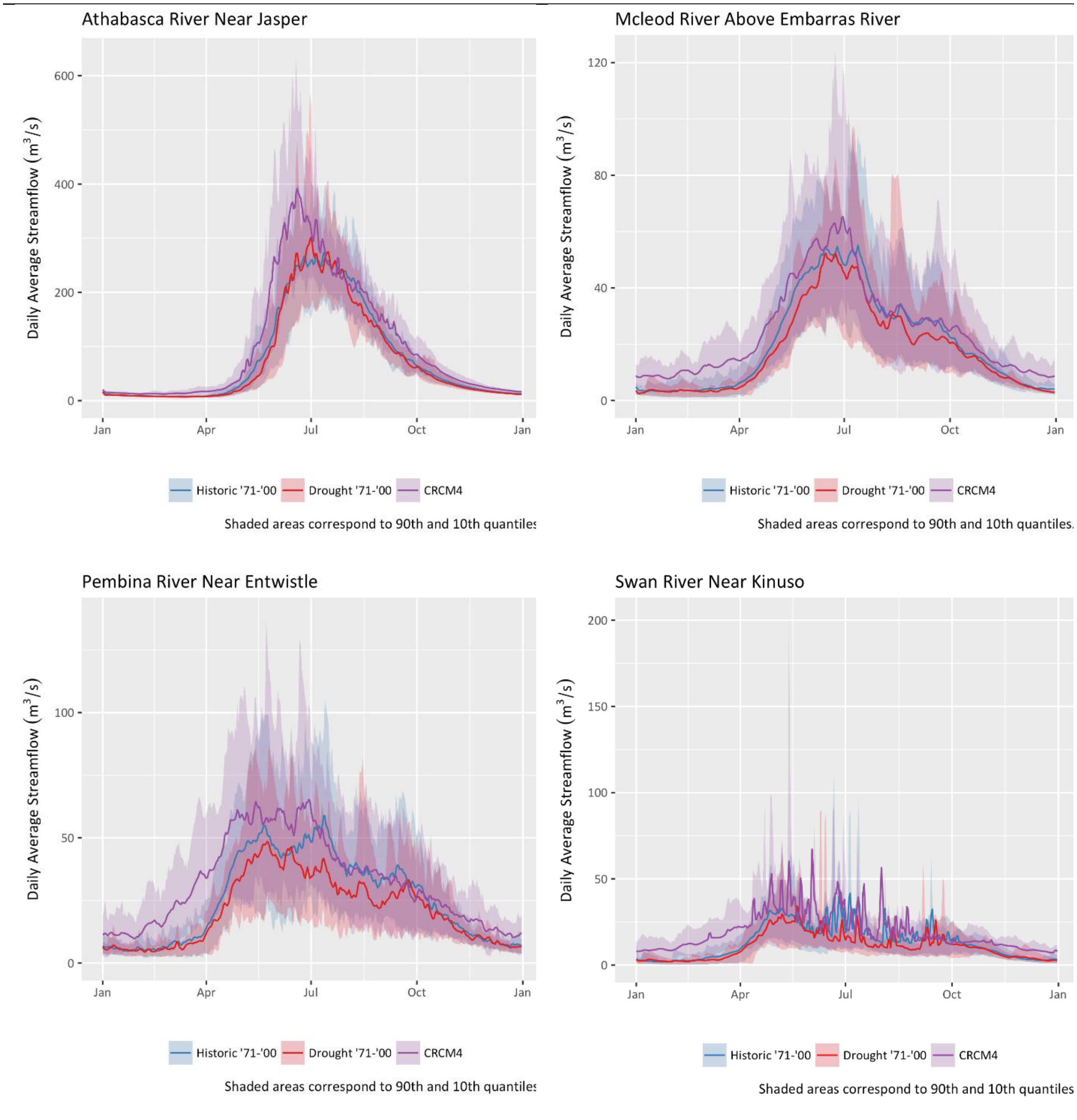
Site	Network	Latitude	Longitude	Elevation (m)	r^2		
					T	*P*	*SWE*
Sunwapta	EC, ABGov	52.54	-117.65	1,416	0.87	0.10	0.63
Columbia Icefield	EC, ABGov	52.23	-117.17	1,982	-	-	-
Edson	EC, ABGov	53.58	-116.21	900	0.98	0.76	0.78
Twin Lakes	ABGov	54.06	-114.79	655	-	-	0.78
Barrhead CS	EC	55.13	-114.19	589	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

B.3.2 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 B-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.



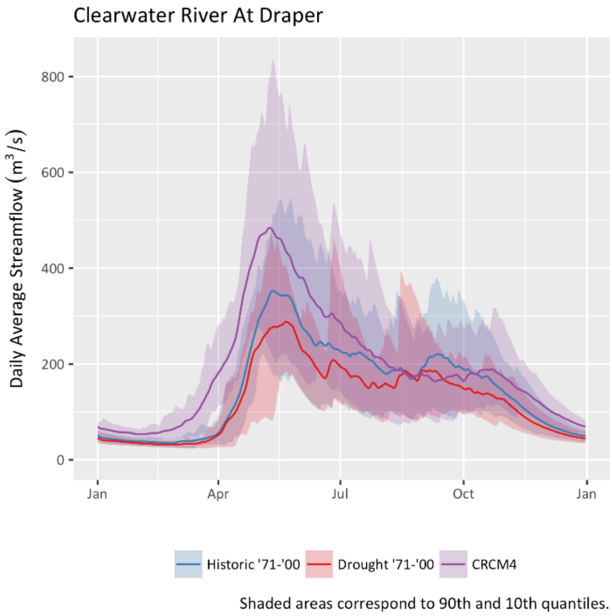


Figure B-1: Average daily hydrographs for five Athabasca River sub-basins, one from each model, under the historical 1970–2000 period, drought scenario, and CRCM4 climate change scenario.

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.

B.4 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.

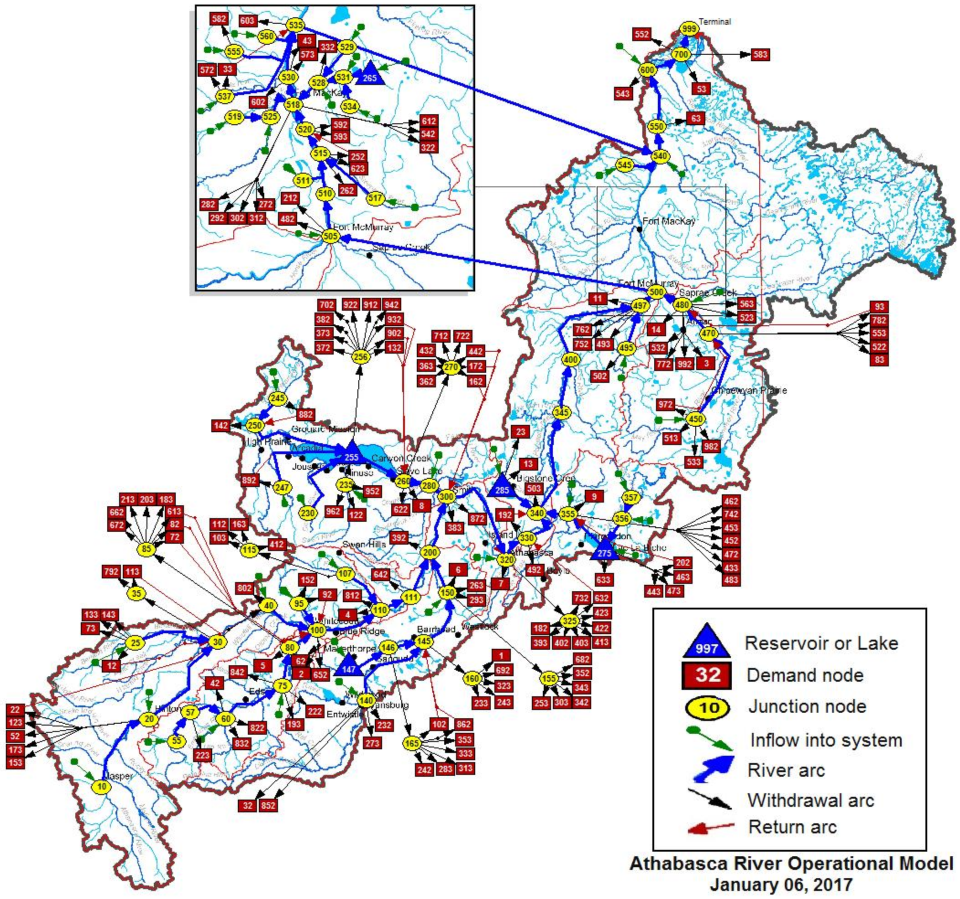


Figure B-2: The river system model schematic.

B.4.1 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 1,045 eligible licences in the basin (Table B-6). These licences were then grouped into demand nodes in the model rather than being modelled individually. Additional data on licence volume, location, owner, and type were accounted for when grouping licences into different demand nodes.

B.4.2 Grouping demands

A first pass at dividing up the licences into different demand nodes involved splitting based on volume. All licences above one 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 one 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 were counted as part of the high volume licences.

All other remaining licences (under one 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 one 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 B-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**	

B.4.3 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. When 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 junior 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.

B.4.4 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. 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.

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 (m^3/s). 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.

Allocation demand patterns

To create the full allocation demand patterns, the volume for each licence was scaled down to m^3/s and then summed by demand node number in the model to get an average annual rate of allocated withdrawal in m^3/s 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.

Return flow patterns (actual use vs. allocation)

Some licences are obliged to return a specified 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.

B.4.5 Operating rules

Minimum flows

Certain minimum flows have been incorporated into the model as simple operating rules. One of these is a minimum flow of 6 m^3/s 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 River at Fort McMurray (Figure B-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 B-3: Surface Water Quantity Management Framework cumulative oil sands withdrawal limits.

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.

B.4.6 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 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.

B.5 Land use modelling

B.5.1 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 setting precedents 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 neighbor 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.

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 neighbors 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 was 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.

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, and AAFC_30m_EOS_2014 Crop Inventory product was used in the southern half. Developed and Exposed Land categories were erased and filled with closest neighbors 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 neighbors.

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 was 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

B.6 Model parameters

Table B-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	%
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

Table B-7: Description of hydrological model parameters.

Variable	Description	Units
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 B-8: Model parameters, standard errors (SE), and composite scaled sensitivities (CSS) for all models.

Variable	Headwaters			Foothills			Parkland			Lesser Slave			Boreal		
	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

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

Variable	Headwaters			Foothills			Parkland			Lesser Slave			Boreal		
	Value	SE	CSS	Value	SE	CSS	Value	SE	CSS	Value	SE	CSS	Value	SE	CSS
Wetl_corr	-	-	-	-	-	-	-	-	-	-	-	-	0.62	0.24	9.6
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

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

Variable	Headwaters			Foothills			Parkland			Lesser Slave			Boreal		
	Value	SE	CSS	Value	SE	CSS	Value	SE	CSS	Value	SE	CSS	Value	SE	CSS
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
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

B.7 Model parameter composite scaled sensitivities

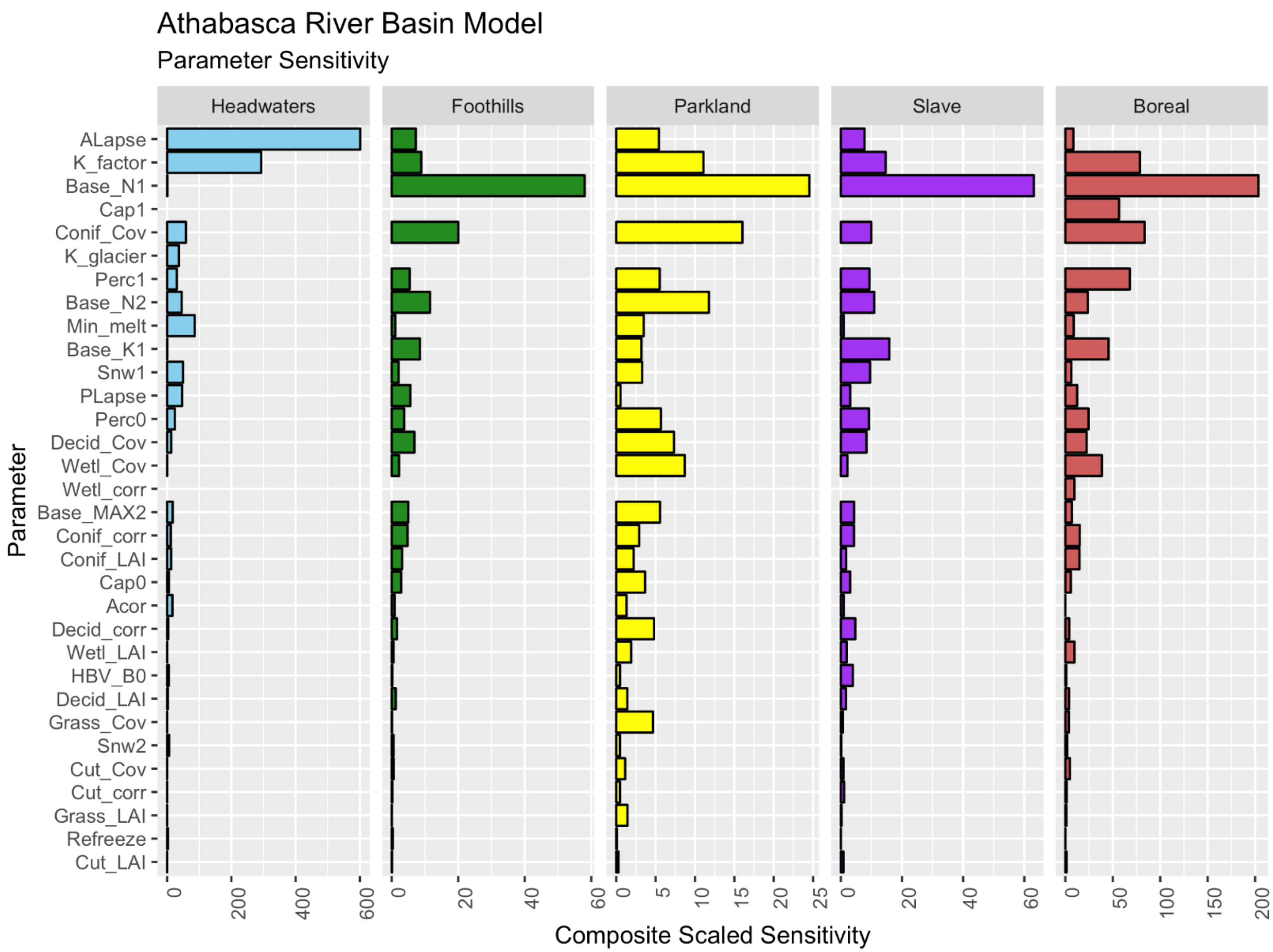


Figure B-4: Composite scaled sensitivities for all calibrated model parameters.

B.8 ALCES Online data sources

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	Alberta Merged Wetland Inventory, GVI	na
Wetlands Fen	Alberta Merged Wetland Inventory, GVI	na
Wetlands Marsh	Alberta Merged Wetland Inventory, GVI	na
Wetlands Swamp	Alberta Merged Wetland Inventory, GVI	na
Wetlands Water	Alberta Merged Wetland Inventory, GVI	na
Wetlands Treed	Alberta Merged Wetland 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 at Agriculture and Agri-Food Canada (AAFC) repeated the process of generating annual crop inventory digital maps using satellite imagery for all of Canada, in support of a national crop inventory. A Decision Tree 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 in 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

Data Source	Description	Source Link
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 was enhanced using GIS datasets provided by the Government of Alberta. The land cover product contains approximately 1 million polygons and comprises 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
AEP	The Alberta Human Footprint Monitoring Program Footprint Sub-layers 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 Alberta Energy Regulator (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

Data Source	Description	Source Link
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
CanVec Land	Land Features entities are: Island, Shoreline, Wooded Area, Saturated soil, Landform Feature (e.g., 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

Data Source	Description	Source Link
CanVec Man Made	Man-made Features entities are: Dam, Protection Structure (breakwater, dike/levee), Liquid Storage Facility (basin, swimming pool, etc.), Tank, Building, Delimiting Structure (fence, wall, etc.), Landmark Feature (cross, radar, crane, fort, etc.), Chimney, Tower, Sewage Pipeline, Conduit Bridge, Waste, Leisure Area, Residential Area, Commercial, and Institutional Area and Ritual Cultural Area (shrine, cemetery, etc.). 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 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 in Alberta for 998 to 2009, classified by the five major classes in the Canadian Wetland Classification System (CWCS): marsh, bog, fen, swamp, and open water. Thirty component wetland inventories were merged to create this wetland inventory product. These individual wetland inventories used 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 Development 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 approximately 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. 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, etc.), Waterbody (lake, watercourse, etc.), 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, etc.), Waterbody (lake, watercourse, etc.), 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

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Appendix C: Methodology and development of climate scenarios for use in the AIRM

The scientific objective for this component of 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 the project's novel methodology provided scenarios for the project Working Group to assess practical adaptive strategies for water management under changing climatic conditions.

The climate of northern Alberta is changing. It is getting much less cold, as shown in Figure C-1, which plots 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.

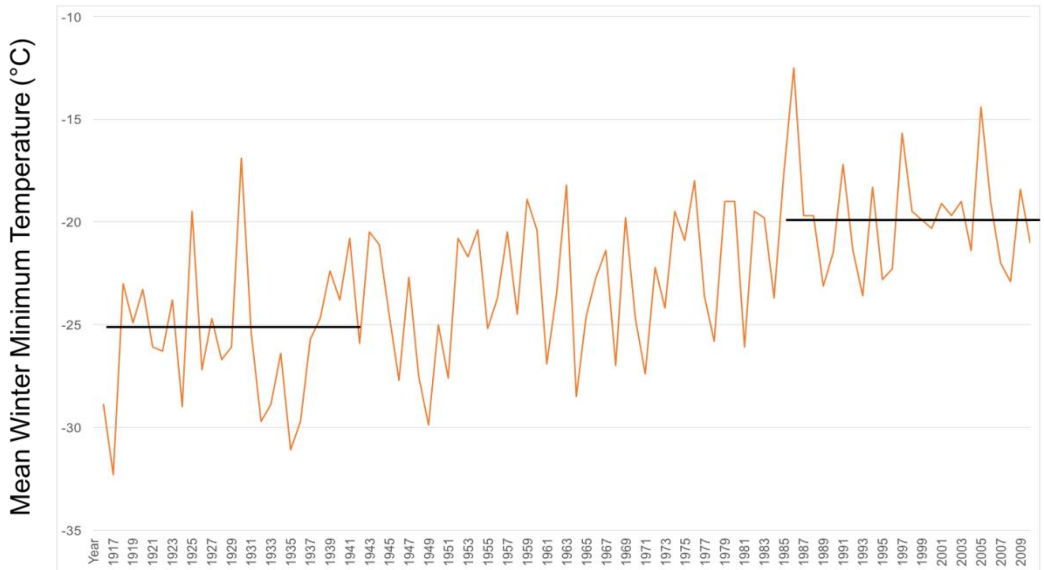

Figure C-5: Mean minimum winter temperature (°C) at Fort McMurray from 1915 to 2011.

Note: 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 C-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.

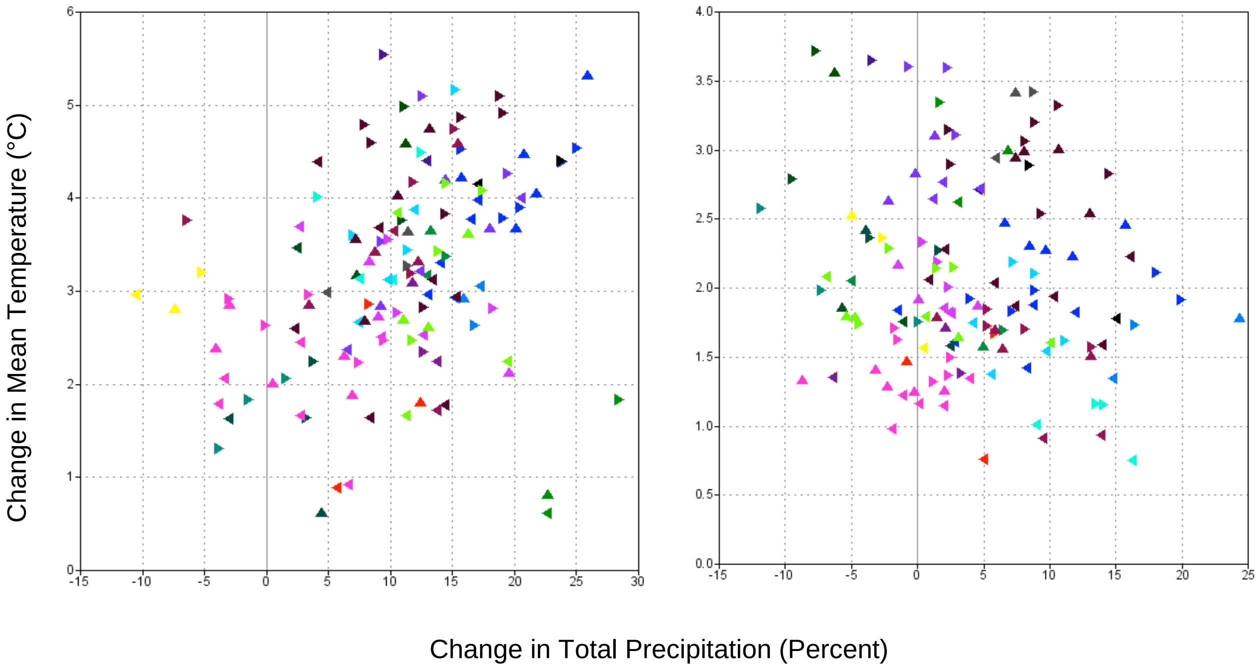

Figure C-6: Climate change projections for winter (left) and summer (right) for northern Alberta for periods 2040–69 versus 1961–90.

Source of data: Pacific Climate Impacts Consortium

Figure C-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 C-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 three or four GCM grid cells.

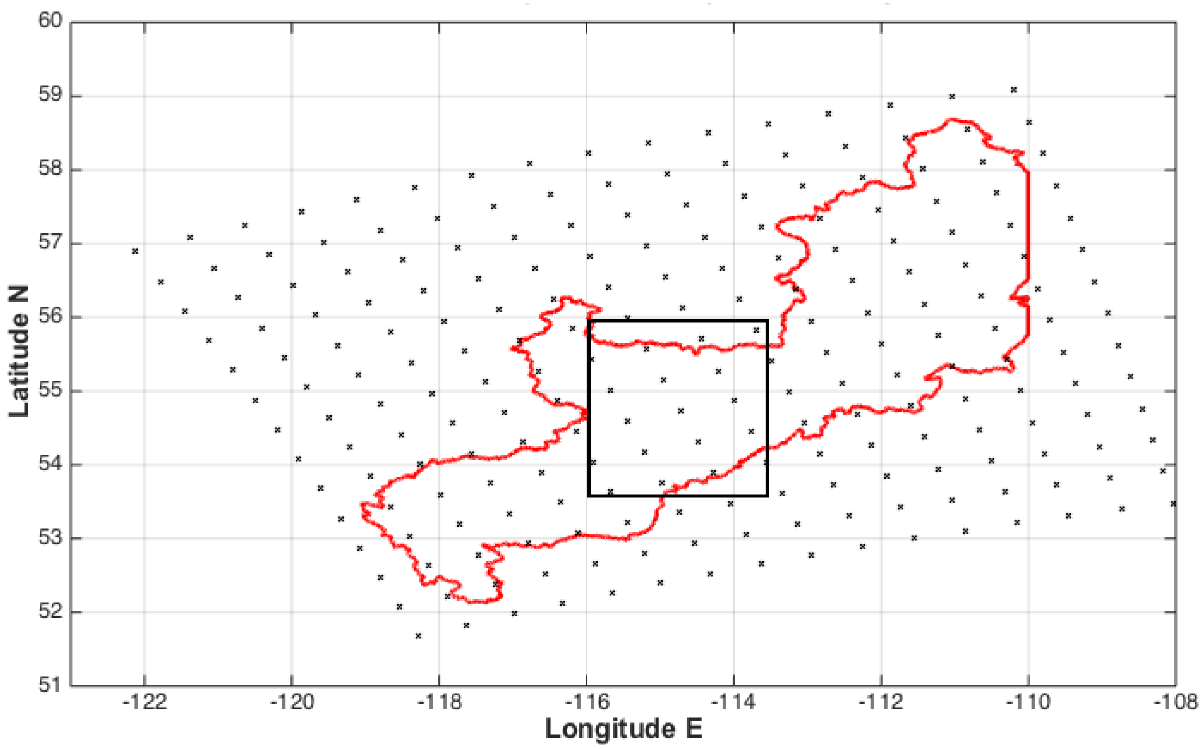

Figure C-7: The boundary of the ARB in red with the 50 km grid typical of RCMs; superimposed is a single 250 x 250 km GCM cell.

Regional climate modelling represents the dynamic 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),[18] 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 C-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 C-9: 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 C-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).

[18] narccap.ucar.edu

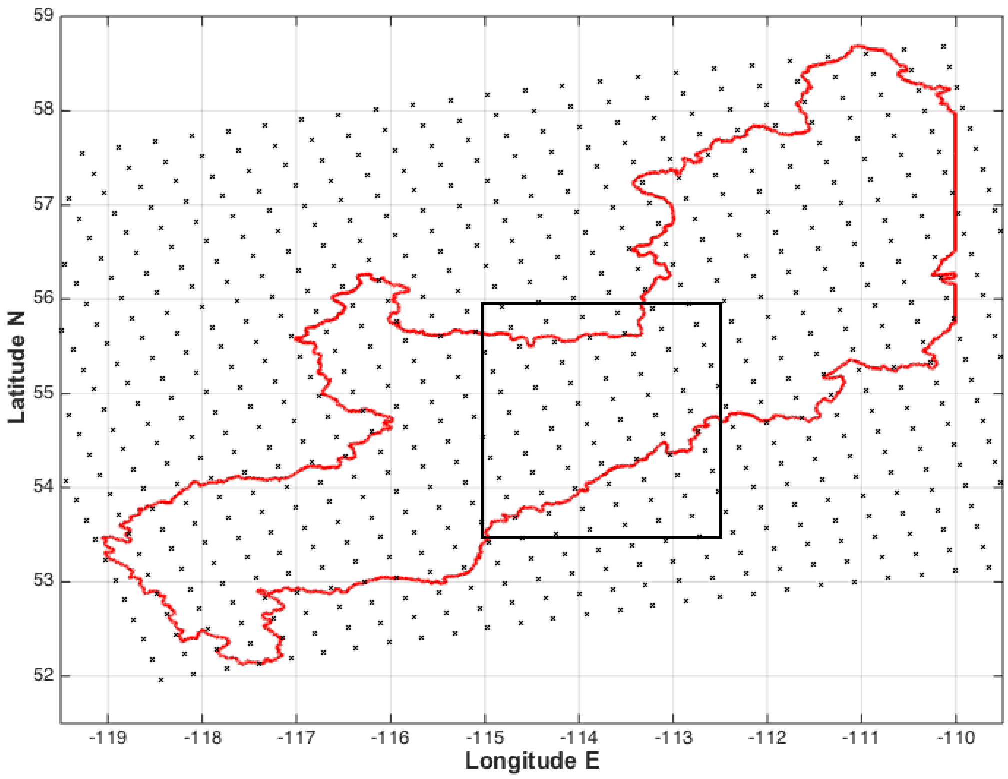

Figure C-8: The boundary of the ARB in red and the CRCM4 grid with a resolution of 25 km. Superimposed is a single 250 x 250 km GCM cell.

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 C-3 and C-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 C-5 and C-6 show output from the 10 RCM experiments in the form of two scatterplots, illustrating the projected differences in mean precipitation and temperature between the periods 1971–2000 and 2041–2070 for winter (Figure C-5) and summer (Figure C-6). Consistent with the historical trend plotted in Figure C-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 C-2, the range of projections in Figures C-5 and C-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).

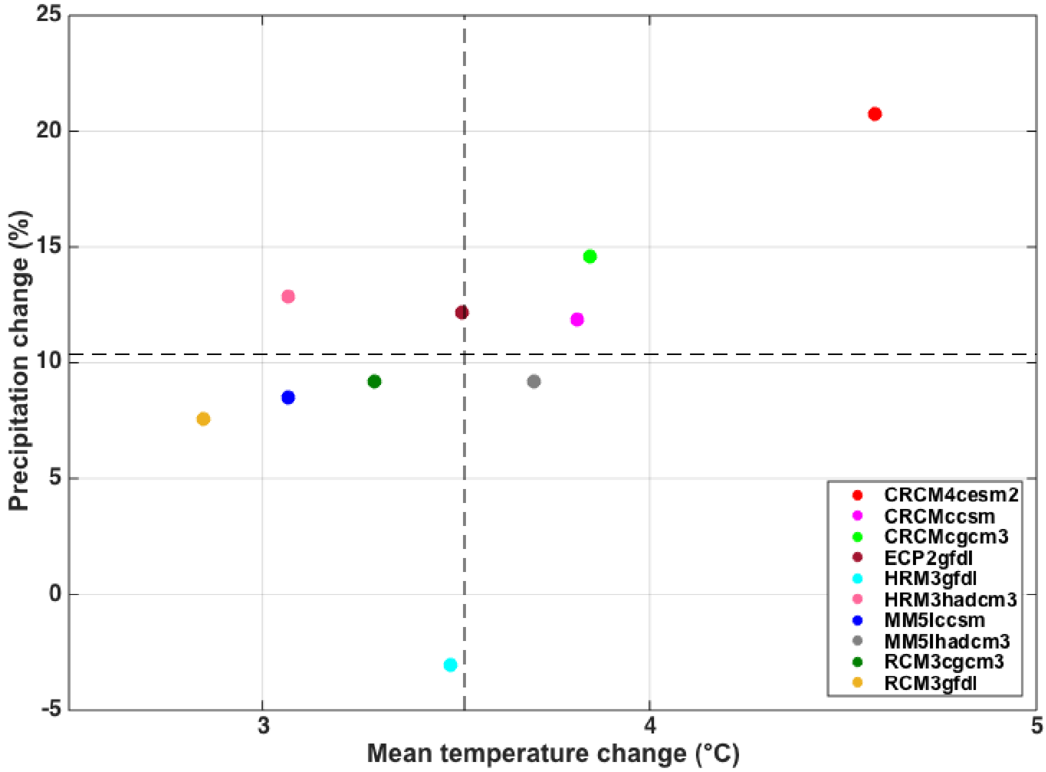

Figure C-9: A scatterplot of the 10 RCM climate change scenarios for the winter season (DJF). The changes are the difference in mean precipitation and temperature between 1971–2000 and 2041–2070.

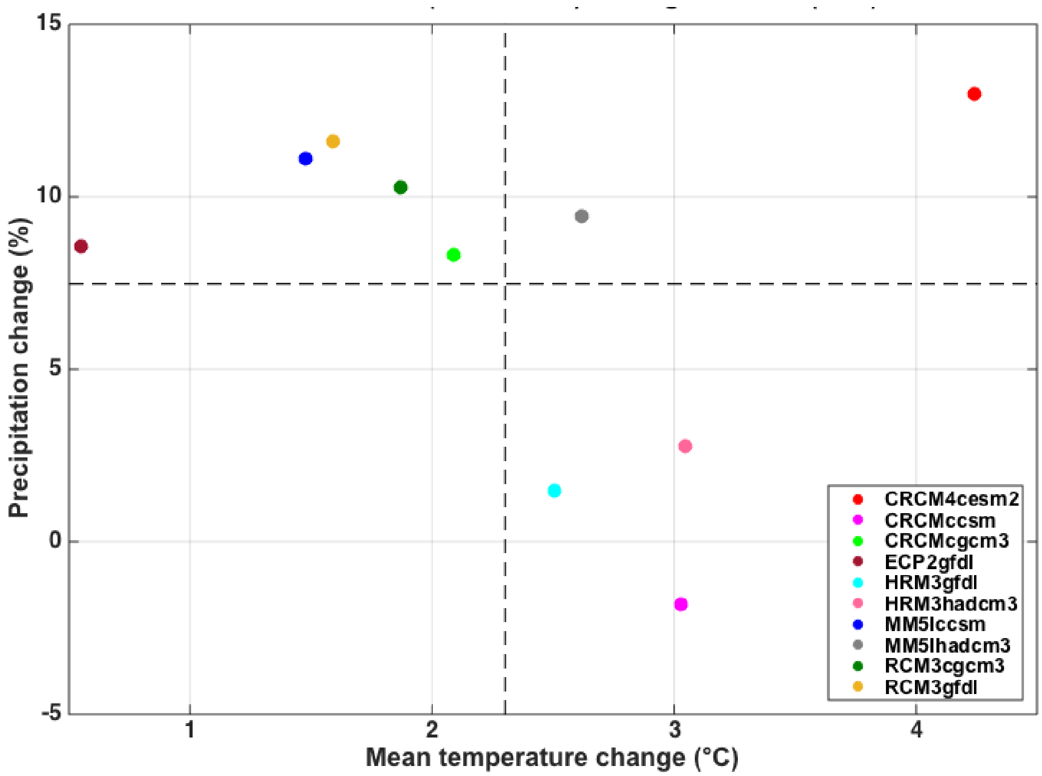

Figure C-10: A scatterplot of the 10 RCM climate change scenarios for the summer season (JJA). The changes are the difference in mean precipitation and temperature between 1971–2000 and 2041–2070.

Figures C-7 to C-10 are plots of mean monthly precipitation and temperature for the baseline and future 30-year periods. Also plotted are weather observations for the baseline period 1971–2000. These observed data were derived from Canadian Gridded Climate Data (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 C-7 indicates that the RCMs can reasonably simulate the annual temperature cycle. More models underestimate monthly temperatures than overestimate them. A comparison of Figures C-7 and C-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.

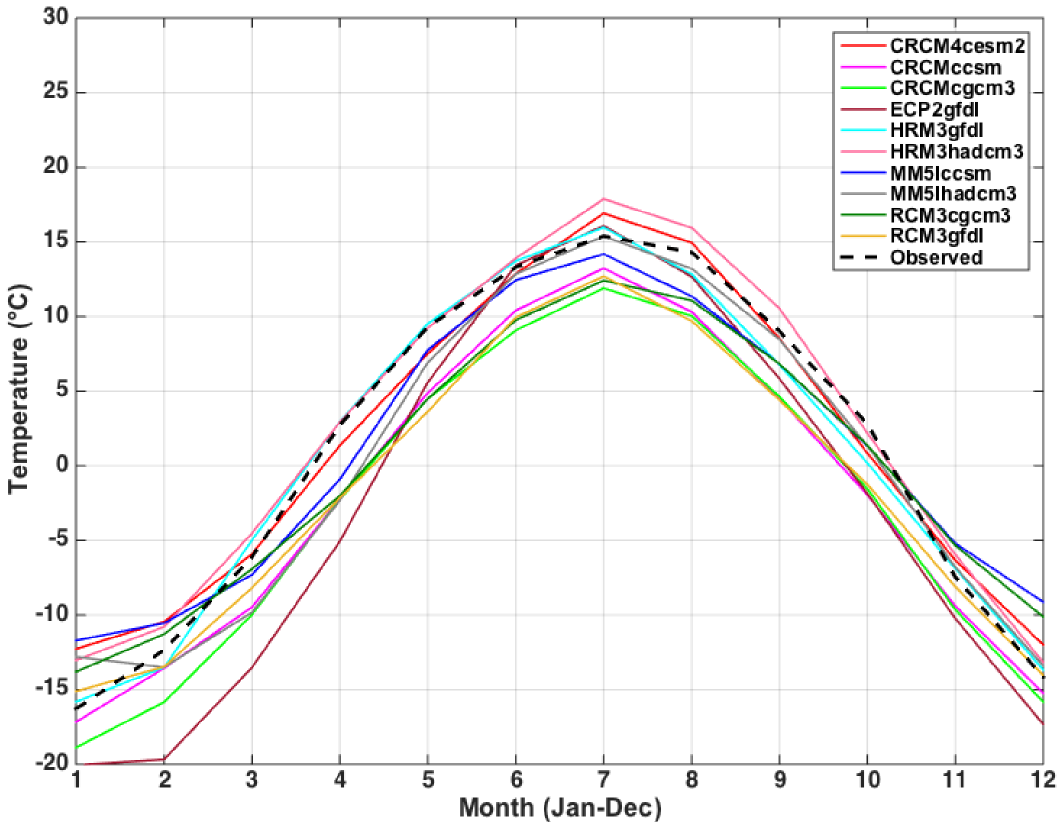

Figure C-11: Mean monthly temperature over the ARB recorded at weather stations (dashed line) and simulated by the 10 RCMs (colored lines) for the baseline period 1971–2000.

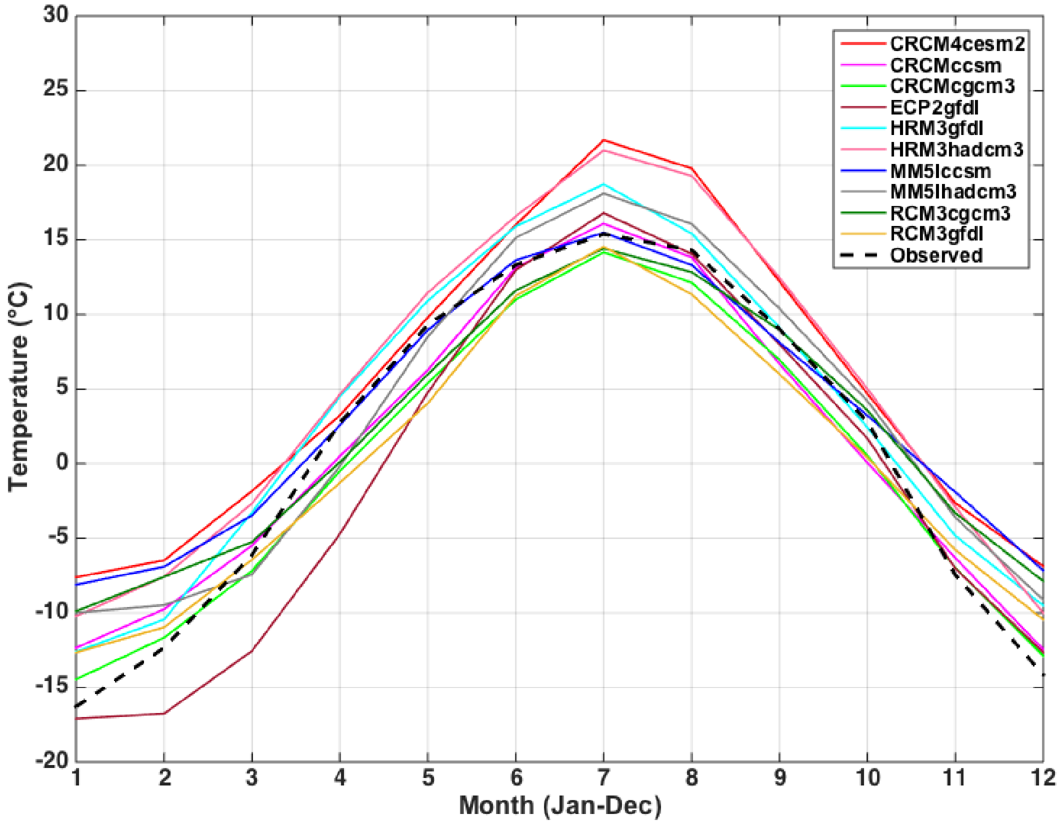

Figure C-12: Mean monthly temperature over the ARB recorded at weather stations (dashed line) and simulated by the 10 RCMs (colored lines) for the future period 2041–2070.

Figure C-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 C-9 and C-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.

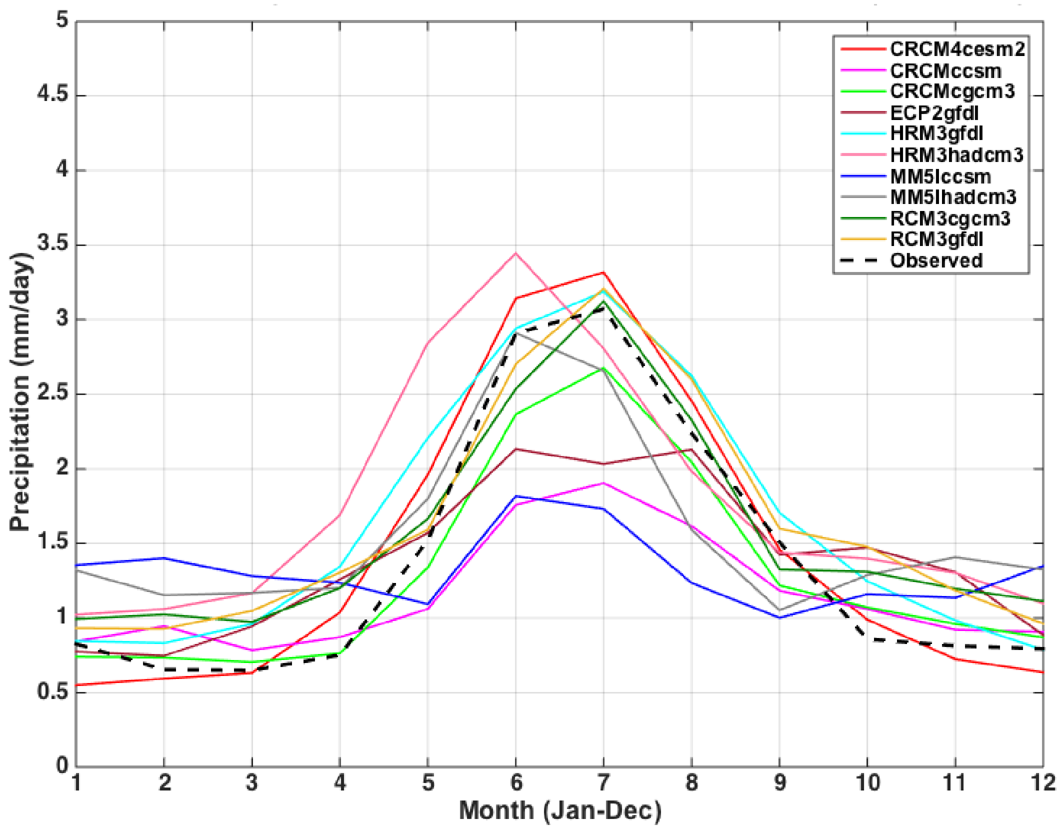

Figure C-13: Mean monthly precipitation over the ARB recorded at weather stations (dashed line) and simulated by the 10 RCMs (colored lines) for the baseline period 1971–2000.

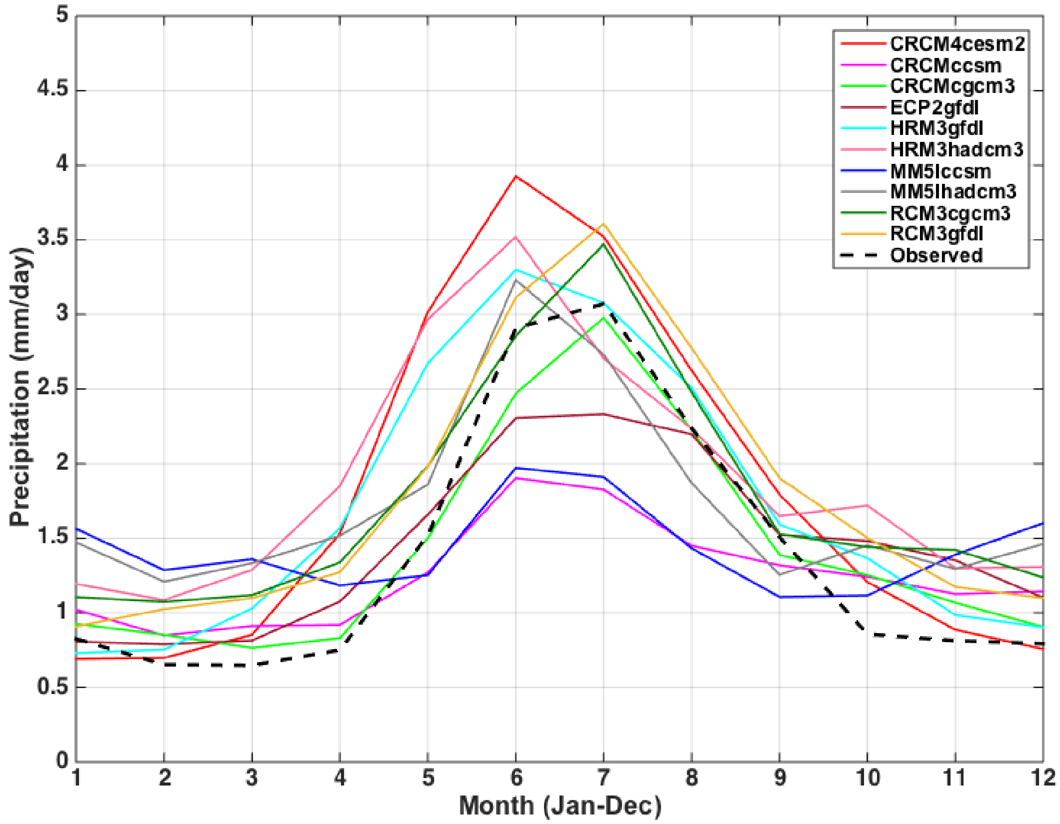

Figure C-14: Mean monthly precipitation over the ARB recorded at weather stations (dashed line) and simulated by the 10 RCMs (colored lines) for the future period 2041–2070.

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 C-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.

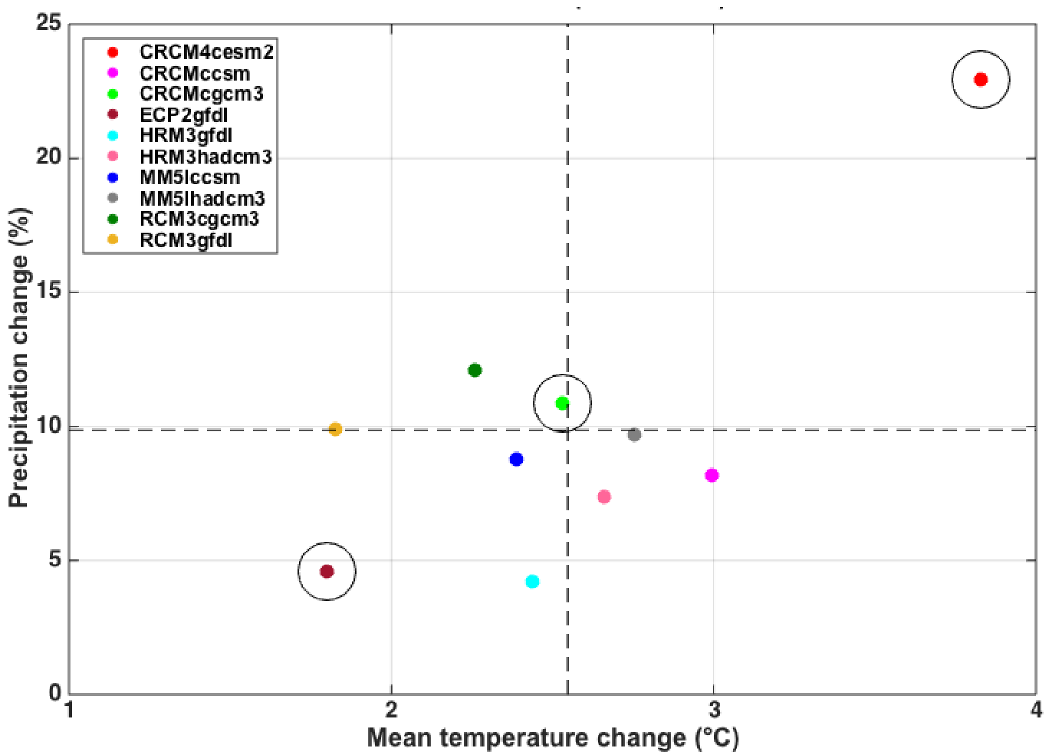

Figure C-15: A scatterplot of the 10 RCM climate change scenarios. The changes are the difference in annual precipitation and temperature between 1971–2000 and 2041–2070.

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Appendix D: Parked opportunities

These opportunities were initially identified by the Working Group but were later determined not to be feasible or necessary and were "parked" after Meeting #5. The opportunities are briefly described and the rationale for not pursuing them is documented in Table D-1.

Table D-1: "Parked" Opportunities

Group	ID	Opportunity	Description / Rationale /Details	Commentary
Supply and Demand	1	Re-naturalize or dredge Buffalo Bay	This opportunity originated in the central portion of the basin.	This opportunity was outside the scope of the project. It was noted that actions upstream to limit or reduce sediment loading would help mitigate the issue associated with this opportunity.
	2	Look at alternatives to dams for electrical generation (e.g., nuclear)	This was identified as a basin wide opportunity.	This opportunity was outside the scope of the project and does not relate directly to water management.
	3	Reuse of industrial or municipal effluent	Return flows from industry and other operations that create contaminants should be repurposed for reuse by industry. • For example, Swan Hills was considering selling such water to industry or pulp mills that send effluent to companies for hydraulic fracturing. • An example of basin wide water reuse was the purple pipes project from the Regional Municipality of Wood Buffalo to Anzac, which involved regional water supply lines for municipal needs. • A benefit of effluent reuse would be a reduction in water use intensity. • A basin-wide water reuse policy must consider the benefits, trade-offs, and overall impacts on water reuse applications and on water withdrawals and returns.	Although this remains an opportunity in some portions of the basin, it has previously been discussed at length in the lower portion of the basin and does not warrant further discussion at this time.
	4	Account for water collection at local sites in rural areas	This opportunity originated in the central portion of the basin.	This opportunity was not pursued for two reasons: there is insufficient associated data and information, and the scale and location of the issue would not be well represented in the model.
	5	Potential actions to help mitigate the drying of the Peace-Athabasca Delta (PAD)	This opportunity originated in the lower portion of the basin.	The PAD itself is not within the geographical boundaries of this project, so any existing infrastructure (e.g., weirs) in the PAD is out of scope. Instead, this project developed a Performance Measure that reflects the flows delivered from the Athabasca River to the PAD and, as upstream strategies were explored, this PM was checked to ensure flows to the PAD were not unintentionally affected.

Group	ID	Opportunity	Description / Rationale /Details	Commentary
				In addition, augmenting flows for the PAD could drive operations of upstream infrastructure, and should be added to the list of potential objectives for upstream reservoirs. It was suggested that the PM should be "% change in flow to PAD relative to naturalized."
	6	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. This was identified as a basin wide opportunity.	This opportunity was outside the scope of the project. The current water allocation system addresses the issue so it was not pursued.
	7	Decommissioning basin infrastructure that is old or no longer used (e.g., dams, culverts, diversions).	This was identified as a basin wide opportunity.	This opportunity was not pursued as there is not enough large infrastructure in the basin that isn't being used or that could be simulated in AIRM, as it was not part of the model's scope.
	8	Install weirs to raise the lake levels for ecological and traditional uses	This opportunity originated in the lower portion of the basin.	This opportunity was not pursued because there were no opportunities in specific that the group wanted to explore.
	9	Mitigate ice-jam flooding in Fort McMurray	This opportunity originated in the lower portion of the basin.	Rather than examine this opportunity, the 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. To do this, a correlation is needed between flows and ice-jam formation specific to the Fort McMurray location, but such a correlation does not exist, to the knowledge of the project team.
	10	Explore alternative methods of transportation on the river to access traditional fishing and hunting areas	This opportunity originated in the lower portion of the basin.	This is included as an option to address another opportunity (Implement an Aboriginal Base Flow or Aboriginal Extreme Flow). Minimizing disturbance to fish habitat should be a key consideration when looking at alternative transportation vessels or dredging.
	11	Explore temporal changes for withdrawals to limit stress on the aquatic system	This opportunity originated in the lower portion of the basin.	At a seasonal scale, this is already in place for new off-stream facilities in the region.
Regulatory	1	Consider how to meet the current Water Management Framework in the Lower Athabasca.	This opportunity originated in the lower portion of the basin.	The framework is already being met through the water sharing agreement between oil sands operators. There may be an opportunity for more transparency about this agreement and how it works, understanding that it uses information and data considered sensitive by the participating companies.
	2	Explore an Ecosystem Base Flow (EBF) in the lower ARB	This opportunity originated in the lower portion of the basin.	In the lower ARB, an EBF is already being implemented through the SWQMF. An additional EBF over and above the SWQMF does not need to be considered as a part of this project.

Group	ID	Opportunity	Description / Rationale /Details	Commentary
	3	Revisit policy around sand and gravel extraction in flood plains	This opportunity was identified as a basin wide opportunity.	This opportunity was outside the scope of the project.
	4	Enable transfers of old unused licences	This opportunity was identified as a basin wide opportunity.	This opportunity was not pursued because the basin is still open to new licences and, to transfer licences, a water management plan must be in place.
	5	Develop a basin wide water management plan	This opportunity was identified as a basin wide opportunity.	The aim of this project is not to create a water management plan, but its outcomes can certainly inform such a plan and be used to help create one.
	6	Explore creating a threshold for groundwater withdrawals	This opportunity was identified as a basin wide opportunity.	The effect of groundwater withdrawals on the water regime in the ARB is not well understood and the cumulative effects are unknown. Although the SWQMF has a limit for surface water withdrawals, there is no limit or threshold for groundwater, nor is there a mechanism to manage cumulative withdrawals.
	7	Share data sets	This opportunity originated in the central portion of the basin.	This opportunity is outside the scope of the project. However, this work encourages and supports the sharing of datasets and, over the course of the Initiative, issues related to data gaps and access were flagged.
Lands and Ecosystem Use	1	Advance recreational opportunities in the basin	This opportunity was identified as a basin wide opportunity.	This opportunity was outside the scope of the project.
	2	Identify alternative sources of fish for food supply.	This opportunity was identified as a basin wide opportunity.	This opportunity was outside the scope of the project.
	3	Suppress fire 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.
	4	Increase agricultural land (forest conversion)	This opportunity was discussed in the upper portion of the basin.	This opportunity was simulated as an increase in agricultural land (grassland) of approximately 30%. It was not pursued as an opportunity as it was seen more as a simulated text test for the basin.
	5	Address access management and linear disturbances	Access management to help address linear disturbances includes planning, minimizing disturbances, minimizing crossings, and mandating best-practices to have the least impact on hydrology. Examples include building access roads to optimize reclamation, or proactive designation of trails and recreational areas. Road sharing and decommissioning (e.g., revegetating redundant roads) are needed to reduce linear disturbance and its impacts on water flow, infiltration, and quality, particularly in the Swan Hills area. This opportunity was discussed in the upper portion of the basin.	This opportunity was simulated as a reclamation of 40% of the linear features in the basin. When modelled, this opportunity did not show significant hydrologic changes at a basin scale. The Working Group agreed to discuss this opportunity as a component of conservation (reclamation in areas that will be conserved).
	6	Protect specific caribou range beyond the protection provided in the LARP	Specific examples where such protection could be considered include areas west of Fort McMurray,	Protecting caribou habitat was not examined as part of this project,

Group	ID	Opportunity	Description / Rationale /Details	Commentary
			east of Athabasca River, Richardson, McClelland/Fort Hills area, and the Lake Athabasca Valley.	although conservation was discussed more generally by the Working Group.
	7	Explore fisheries compensation mechanisms other than compensation lakes in the ARB	Examples of alternative mechanisms include establishing a fish hatchery, creating a list of hanging culverts and other fish connectivity opportunities that industry could use to compensate for loss of habitat, and creating a fund with the money that is traditionally used for compensation lakes and use it to enhance fisheries or study fisheries to develop a deeper understanding.	This was deemed outside the scope of this work.
	8	Apply "Room for the River" philosophies and principles in communities in the ARB	As an example, Fort McMurray could apply these practices to reduce the risk of flood damage, especially with amplified risk from climate change. Need to ensure that municipal planning incorporates Room for the River practices.	This was deemed outside the scope of this work.
	9	Ensure adequate reforestation and buffer requirements for logging activities	Reforestation and buffer requirements reduce sedimentation, and these best management practices also offer other benefits for habitat and water quality and quantity. Better enforcement is needed, along with consideration for the timing of reforestation, recognizing that the situation differs on private land. See opportunity 5 on linear disturbances for more details.	This opportunity was out of scope for the project but was noted as an important consideration for healthy watershed practices. It is assumed that forestry companies are implementing appropriate BMPs.

Appendix E: Issues and interests that formed the basis for challenges identified by the Working Group

Table E-1 presents the issues and interests of stakeholders who participated in the ARB Initiative. The table is organized as follows:

- **Issues/Interests/Opportunities:** Different stakeholders identified specific issues, interests, and opportunities within the ARB. Each is arranged under a broad category (e.g., water quantity).
- **Description:** Each issue, interest, and opportunity is described in detail to explain how different stakeholders are affected.
- **Perspective:** This column identifies the source of the information and perspective. In some instances, multiple sources are listed to reflect various perspectives.

Table E-1: Issues and interests arising from the desktop study that could be looked at through modelling and dialogue in the ARB Initiative.

Issue/Interests/Opportunities	Perspective
Water Quantity	
Reduced water quantity due to withdrawals by industry. Current withdrawal rates could reduce flow below instream flow needs (IFN), which will lead to increased impacts on fish habitats, biodiversity and ecological integrity.	Fisheries and Oceans WPAC WWF AEP
Reduced water quantity and flow in the Athabasca River due to climate change which could limit withdrawals by water users and negatively affect ecosystem function.	COSIA AENV Academic
Changes to runoff due to landscape changes and climate change.	ENGO WPAC
Water shortages due to industrial development such as oil sands mining and hydro operations, leading to compromised ecosystem integrity.	CEMA/ENGO
Data gaps and limitations in terms of water use and flow variation prevent proper understanding of water resources in the LAR.	COSIA WPAC
Water storage • Climate change and regulatory changes could force oil sands operators to **re-evaluate water storage options**. Without adequate storage, oil sands operators may run out of water for operations. • IFN restrictions may require **oil sands operators to build water storage on-site**, to ensure sufficient process water is available. However, on-site storage may be impractical, due to issues such as cost and land area requirements.	COSIA OSDG CEMA Government P2FC

Issue/Interests/Opportunities	Perspective
• Current development of the Athabasca is centered on possible **off-stream storage** basins that would augment winter flows and create a secure water supply for growing oil sands development. • The hydrologic response of the landscape to climate change over the last 100 years has been a **decrease in natural storage for the northern half of the watershed**.	
Regulators will limit the volume of withdrawal during low flow periods to protect aquatic ecosystems. This will require oil sands operators to meet water demand **using infrastructure or technology solutions**, such as water storage.	Industry (OSDG, CAPP)
Declining water levels are **inhibiting boat transportation**	Indigenous
Concerns with **cumulative effects from decreased flows.** Decreased water levels are resulting in algae growth, higher turbidity and sedimentation as well as changes in taste and smell.	Indigenous
Environmental impacts from changing water levels due to dams.	Indigenous
Due to the cumulative effects of reduced water flow from the Peace and Athabasca, Indigenous communities want to establish an **"Aboriginal Base flow" (ABF)** to set the minimum flow required for and traditional uses.	Indigenous
Reduced water levels are resulting in sandbars and sediment being drawn up during water intake. Changes in flood patterns cause new sandbar formation and vegetation growth, which affects the timing of flooding.	Indigenous
Creeks and wetlands have dried up. Indigenous communities agreed that levels of these waterbodies have decreased considerably over the years due to less flooding.	Indigenous
The Aseniwuche Winewak Nation used to be able to **hear water flowing** in the springs, **but this is not the case anymore**.	Indigenous
Water withdrawals have a significant and negative effect. There should be **precautionary water withdrawal limits** that trigger mandatory requirements for changes in water use and management. Examples of the effect of large water withdrawals: • Indigenous communities are concerned there is a **negative impact on water-based recreation and navigational** uses of the Athabasca River. • **Water withdrawals contribute to the limitations on traditional use sites and activities** during late summer, fall, and winter. • Areas of the Athabasca River have been **physically altered due to low flows**, further affecting areas that have spiritual importance.	Indigenous ENGO
Average summer and winter low flows of the Athabasca River have declined for over 30 years as a result of climate warming and decreased snow. Runoff has also decreased by 50% in most of the basin.	Academic
Establish an Ecosystem Base Flow (EBF) in the Athabasca River. Natural flow of the Athabasca River is highly variable, therefore, an EBF will help to stabilize flows and revitalize the Peace-Athabasca Delta. EBF in the Athabasca River should be no less than 87 m^3/s, below which water withdrawals should cease.	ENGO
Change in Flood Patterns	
Forestry activity could lead to **increased volatility in water flows** (i.e., flood and drought). Development has increased the amount of **flash flooding** in Lesser Slave Lake area.	ENGO Academia

Issue/Interests/Opportunities	Perspective
	Indigenous
Lack of flooding has resulted in **increased willow growth and island formation.** Water has decreased substantially and there are many **dry lake beds**. Some lakes and rivers now consist primarily of cattails or willows.	Indigenous
Fewer ice jam formations. Ice dams are a critical component of spring flooding and help to manage the river. Lack of ice affects winter travel.	Indigenous
Priority Allocation	
Current surface water **allocations could limit ability to meet minimum surface water flows** required to maintain healthy aquatic environments.	ENGO
Industry access to water is occurring to the **detriment of ecosystem health and human health**. Government should take immediate steps to prevent harm to the Athabasca River, including updated hydrographs, suspend permitting for new mines and water licences, and **review current water allocations** to consider if they are still appropriate.	Indigenous
Indigenous rights must supersede non-Indigenous rights.	Indigenous
Climate/Land Use Change	
Decreased mean annual flow. The shortened snowfall season and increase sublimation together lead to a decline in spring snowpack, and mean annual flows are expected to decline with the runoff coefficient dropping by about 8% per °C in rise in temperature. All models predict large declines in mean annual flow by the end of the 21st century.	ENGO Academia
Climate change and anthropogenic activity have led to **changes in Peace-Athabasca Delta flow patterns**, which have **negatively affected the aquatic environment and Indigenous use**.	CEMA/ENGO
Climate change could **negatively affect the aquatic environment** (e.g., unable to meet ecological base flows).	WPAC
Degradation in ice quality and quantity. The scouring effects of ice no longer occur and fish populations are suffering due to lower water levels and inability to spawn. The ice road to Fort Chipewyan does not last as long in winter. Barges normally used in the summer cannot operate consistently due to low water levels.	Indigenous
Water Management	
Set the Athabasca River **Ecosystem Base Flow (EBF) threshold to 87 m^3/s**, which is based on the winter period 1 in 100 low-flow statistic for mean weekly flows over the period of record.	Industry P2FC
Water quantity and **flow of the Peace River must be maintained**. Maintaining water quantity at an adequate level will help adjacent wetland complexes sustain flora and fauna required for traditional uses of land.	Indigenous
We must properly **manage hydroelectricity production.** Maximizing hydroelectricity production fails to recognize the need for the Crown to balance competing values.	Indigenous
Need to manage water flow: • Generally recommended by all First Nations as a way to manage the landscape and prevent issues. **Managing flow will avoid changes in the landscape such as invasive species and sandbars.**	Indigenous Oil and Gas ENGO

Issue/Interests/Opportunities	Perspective
• Managing flows on the Athabasca River relative to **Ecosystem Base Flows (EBF)** is required. • Establish **limits on water withdrawals** to ensure water flows are adequate.	
Industry must meet water management rules in the LAR. Oil sands mining operators must meet the Water Management Rules by either **building the required storage** amount over time or through equivalent means, such as: **water sharing agreements, technological improvements in water use efficiency, curtailing production, and alternate drought response measures**.	Oil and Gas ENGO
Ecosystem Base Flows (EBF) should be included in the water management plan.	Oil and Gas Indigenous
Implement a system of **Ecosystem Management that also considers Traditional Knowledge and Use.** Indigenous communities in the Northern River Basins area recommend this approach to include all aspects of watershed management, TEK, and a commitment to engaging their community.	Indigenous
Water withdrawals must be managed in the LAR. When flows are sufficient, licences operate normally and continue to improve technology to reduce water requirements. When short-term impacts on the ecosystem are expected, a mandatory reduction in water withdrawals should occur (e.g., water storage, reduced water requirements, and enhanced recycling).	ENGO Indigenous
Flora and Fauna	
Wetland Retention. Wetlands provide a critically important habitat for several wildlife species. Oil sands mining could lead to harmful effects on nearby wetlands, including hydrogeological and geochemical changes.	Government ENGO WPAC
Oil sands mining will **change soil moisture regimes**, which will lower the surface water table. This could lead to negative environmental impacts, including reduced land capability for forestry.	Oil and Gas
Oil sands activities could result in reduced flows that adversely affect aquatic health, including; • river diversions • muskeg/overburden dewatering • Athabasca River water withdrawal • modification of surface drainage due to reclamation (increases run-off losses).	Oil and Gas
Loss of wildlife breeding and staging habitat. Large floods create water spills into perched basins in the PAD; sometimes these basins only receive water once every decade. The Delta provides some of the most significant waterfowl breeding and staging habitat in North America, is a major spawning site for fish migrating between delta lakes and rivers, provides habitat for wood bison, and supports moose, muskrat and other species. Water withdrawal under some circumstances may limit connectivity of perched basins thereby affecting the quantity and quality of available habitat in the associated floodplain and the aquatic and terrestrial ecology of the Athabasca Delta.	P2FC
Fewer birds stop over on migration due to low water levels.	Indigenous
Decrease in beaver numbers. In the Little Red River region, **beavers are declining in number due to a decrease in the amount of flowing water**.	Indigenous

Issue/Interests/Opportunities	Perspective
Fish populations are suffering: • Lower water levels are causing a decline in fish and waterfowl populations. Perception that waterfowl and fish are not safe to eat due to water pollution. • Fish are fewer in number and not good to eat. Fishing as a traditional practice is non-existent due to the scarcity of fish. • Oil sands development is negatively affecting fish population and diversity and fish is a main source of food for the Athabasca Chipewyan and Mikisew Cree First Nations.	Indigenous ENGO Government
Sturgeon Lake Elders noted that **the lack of water has resulted has resulted in a change in vegetation** and there is a scarcity of wildlife and berries.	Indigenous
Economic	
Development of a hydroelectric dam. Due to increased economic development, the potential for damming the Athabasca for hydroelectric power is being reviewed. ATCO has plans to develop hydroelectric dams at two sites on the Athabasca River and at Slave Lake, but these projects are on hold.	Government Power Industry
Impacts of dams. There are concerns surrounding forced relocation, loss of homes and personal property, decreased availability and resources for hunting, food gathering and fishing, as well as loss of trap lines.	Indigenous

Surface water quantity issues in the ARB heard and confirmed by Working Group participants

This list of surface water quantity-related issues 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 has been further developed and enhanced through dialogue with Working Group participants and informs this document. The list was updated based on discussion at Working Group meetings.

Colored text reflects discussions captured from 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, the Lower part of the basin in red. Black text represents issues that were gathered as part of the desktop study and that relate to the 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 (TDLs)? Could this be used 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 or 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 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 future, potentially drier, conditions.

- Declining water levels, which are resulting in sediment being drawn in during water intake.
- Impact of current allocations on Indigenous Rights and how that may change under future scenarios.
- Risk of water shortages to water licence holders.
- Risk of insufficient storage for water licence holders.
- Man-made impacts on the Peace Athabasca Delta (PAD). How will we know if the opportunities address man-made degradation to the PAD? (i.e., if the opportunities will counteract man-made degradation to the PAD).
- Erosion of streambanks and loss of infrastructure: At Town of Whitecourt and 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.
- 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.
- 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, dry wetlands.
  - How longer climate cycles (e.g., 60 years) could change seasonal and annual flow conditions.
  - How snowmelt, glacial, and baseflow contributions to streamflow may change.
- The lack of conversation surrounding Indigenous rights has been an ongoing issue in the basin. There is a need for the GoA to have one-on-one conversations regarding Indigenous rights with First Nations and Métis communities.
- Decreased soil moisture content may be linked to increase in occurrence or intensity of forest fires.
- Many waterbodies that were protected prior to changes to the Navigable Water Protection Act in 2012 are no longer protected and are at risk.

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

- Lack of 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 affect the basin once the policy mechanisms are specified.
- Spill tracking records system and reporting requirements along with monitoring are 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 south shore of Lesser Slave Lake and on shores of some smaller lakes in the central basin.
- Wanagame Lake with South Heart Dam has poor water quality with decreased dissolved oxygen as a result of agricultural runoff. 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 limit 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, compromised link between ARB and PAD.
- Declining fish populations 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 base flows throughout the basin. These flows need to be defined to address aquatic health, in particular, the effect on fish populations, which have been and continue to be affected (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 influence 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 and volume of flash flooding in Lesser Slave Lake area.
- Private land practices are adding to sedimentation: lack of buffers and degradation of riparian areas 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 consideration

- Phosphorus loadings from agriculture runoff: impacts in the South Heart River.
- Oil and gas development impacts (cumulative impacts of spills) on Swan River.
- Sedimentation at water intake points. It was recognized that we are not modelling sediment, and this is likely a reflection of design and 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 F: Gaps identified through work and discussions related to sustainable water management in the ARB Initiative

The following gaps were not modelled. They were identified as gaps in data, knowledge, or processes that may inform sustainable water management in the ARB.

ID	Gap	Why does this gap need to be filled?	Commentary
1	Find a technology for real-time measurement of winter flows	It is crucial to get accurate and up to date flow data on the Athabasca River during low flow periods. Currently measurements are only available monthly to approximate flows during the winter period.	This represents an opportunity in the basin to find a technology for real-time measurement of winter flows, typically under ice.
2	Enhance monitoring and data collection of snowpack data in the upper portion of the ARB	Snow water equivalent (SWE) is the primary driver of streamflow in the ARB headwaters but there are limited monthly snow surveys and very limited daily measurements. Accurate spatial distributions of snow accumulation are difficult to model due to high spatial heterogeneity in the region.	Daily SWE measurements are only available at Southesk Pass snow pillow, which is in the far southeastern corner of the basin (technically, it falls in the North Saskatchewan River basin), and Yellowhead Pass, which is west of the Miette River sub-basin, and falls outside the ARB. Sporadic monthly snow surveys are available at Marmot Basin and Sunwapta Falls. Ideally, additional snow pillows would be installed (to collect daily SWE) along further westerly reaches, specifically near the Columbia Icefield, Whirlpool River headwaters, and/or in the Snake Indian River Basin.
3	Enhance monitoring and data collection of meteorological data in the upper portion of the ARB	Precipitation and air temperature data are integral to a variety of environmental applications; however, these data are sparse in the ARB. In particular, spatial interpolation and distribution of these variables is more difficult in the headwaters, where large elevation and climatological gradients create a high degree of spatial heterogeneity.	Long climate records in the ARB headwaters region are difficult to find. In addition, sites that do have longer records (i.e. > 10 years), are heavily biased to valley-bottoms. In order to provide more accurate hydrometric simulations, knowledge of high altitude climatological conditions is important. Arguably, these data provide more value than low-elevation conditions, given that streamflow is more responsive to higher elevations. Generally, higher elevations hold a larger snowpack, experience larger and more intense precipitation events, and are where most glaciers are located.
4	Ensure the full records for collected data sets are publicly available and easily accessible	A consolidated public portal for snow, water, and climate data would allow for easier access and increased usage of collected public data. A simple-to-use public data portal would allow for practitioners, academics, industry, and stakeholders to access data easily and quickly, reducing logistical delays.	Currently most snow, water, and climate data are hosted on rivers.alberta.ca, but manual snow surveys are not, nor are climate data.
5	Enhance monitoring and data collection of streamflow for tributaries in the upper portion of the ARB	Currently, upstream of Hinton streamflow is only measured on a few tributaries. Without better observations and long-term records of streamflow from various sub-basins in the upper ARB determining the most hydrologically sensitive and largest contributing areas is difficult and relies on either modelling or sparsely available data. In addition, without a collection of long-term records from tributaries detecting temporal changes in regional hydrology become more difficult (i.e. the effect of glacial recession).	Current-day streamflow data for ARB tributaries are only available from two sites, Sunwapta River at the Columbia Icefield, which is very small, and the Miette River at Jasper, while the Athabasca River is gauged at Jasper and Hinton. In addition, streamflow records exist, but are no longer collected for the Whirlpool River, Maligne River, and Snake Indian River. Given that there are relatively significant differences in climate and land cover within the 10,000 km^2 region upstream of Hinton differences in hydrology are not readily captured in observed data. Ideally, hydrometric gauges on the discontinued sites will be re-established, or the network

			will be evaluated in order to determine what hydro-climatic systems are under-represented in the region.
6	Address how to manage tributaries where there is currently no flow data	There is a need to understand flow in tributaries where no flow data exist so that allocation of water and understanding of ecosystem needs can be made.	For large tributaries, simulated streamflow from AIRM may provide a good starting point.
7	Include water incident related reporting and monitoring (industrial incidents) in water data	Incidents, such as spills, are reported, however the information doesn't go into a publicly available database, there is valuable data that is reported that is often relevant for longer than just when the incident was reported. Building up this data set over time will improve water planning and management.	Currently these don't go into any databases. Spill tracking records system and reporting requirements along with monitoring is needed to inform cumulative effects over time.
8	Improve groundwater withdrawal reporting	There is a lack of data regarding groundwater withdrawals, these withdrawals are important to understand. This understanding is important not just from a groundwater sustainability perspective, but also because groundwater levels can impact surface water.	There needs to be a system in place for reporting and tracking groundwater.
9	Prioritize reclamation through strong reclamation modelling	If there were strong reclamation modelling it could guide where reclamation efforts are focused.	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 to complete work similar to the recent WRRP project in the Bow Basin that used ALCES to identify restoration projects of greatest value hydrologically in the Bow Basin.
10	Map areas of hydrologic sensitivity in the basin that supply water to sub-basins and are locally important to communities	Understanding where hydrologically sensitive areas are within a sub-basin, as well as how (and when) certain areas have a large effect on streamflow is an integral part of land use planning.	This is an opportunity to enhance community based monitoring, and to identify current water volumes and how the water volumes are changing in these systems. This can be quantified within the ARB by refining AIRM to investigate local areas at a higher spatial resolution.
11	Improve the understanding of the hydrological effect of watershed and local scale connectivity.	Currently our understanding of connectivity in regional hydrology is limited, and for the most part, is not incorporated in hydrological models. A better understand of this process is integral to more effective reclamation practices for features such fens, bogs, and other wetland types.	Several research programs have focused on this knowledge gap recently. Recent findings have shown promise, and are generally limited to local scale phenomena. There remains much work to be done in order to discern how these findings scale over larger spatial areas, such as an entire watershed.
12	Collect complete water use data for allocation management	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, less assumptions would be required, and their effect on the hydrology of the ARB could be better understood.	This could be done through the water use reporting system.
13	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.

14	Understand the linkage between hydrology (soil moisture) and wildfires	With a potential warming climate, it would be good to have an understanding on changes in hydrology and potential changes in risk to wildfires.	There appears to be lower soil moisture lately and there is a need to understand the linkage between this and wildfire occurrence.
15	Improve the understanding of the hydrological effect of an oil sands mine on sub-basin hydrology	Currently, estimating the effects of an oil sands mine footprint on sub-basin hydrology, or the effects of restoration, relies on assumptions for how precipitation, runoff, and groundwater flows interact with the mine site. A better understanding of the processes and engineering done on these sites will allow for improved estimates of their impacts, and could help focus and inform future reclamation.	Current practices regarding precipitation and runoff are difficult to discern, and public information is not readily available. Information on this will better ensure that the proper processes are being captured in future reclamation modelling.
16	Implement a basin wide water re-use policy	Policy surrounding water reuse must be defined and clarified if reuse is to be a water management option in the ARB.	Currently, there is no policy in place in the ARB
17	Establish a water conservation objective for the basin.	Would be good to have a WCO for tributaries and the mainstem.	Currently there is no WCO for the Athabasca River Basin.