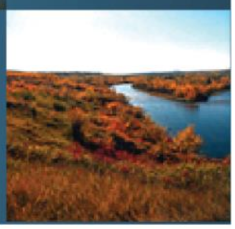


Climate Vulnerability and Sustainable Water Management in the South Saskatchewan River Basin Project

ALBERTA waterSMART
Water Management Solutions

Final Report:
Adaptation Roadmap for Sustainable Water Management in the SSRB

January 2016

Submitted by:

P. Kim Sturgess, CM, P.Eng., FCAE
CEO
WaterSMART Solutions Ltd.
#200, 3512 - 33 Street NW
Calgary, Alberta T2L 2A6

Submitted to:

Brett Purdy, PhD
Senior Director, Water Innovation Program
Alberta Innovates – Energy and Environment Solutions
1800 Phipps McKinnon Building
10020 - 101A Avenue
Edmonton, AB T5J 3G2

Suggested citation for this report:

Alberta WaterSMART. 2016. *Climate Vulnerability and Sustainable Water Management in the South Saskatchewan River Basin, Final Report.* 129 pages. Available online at http://albertawater.com/ and http://www.ai-ees.ca.

Executive Summary

Alberta faces important water challenges including a growing economy, expanding population, and the increasing impact of this growth on the environment as weather and climate patterns shift. The recent experience of both floods and droughts has made climate variability a reality for residents in the South Saskatchewan River Basin (SSRB). Growth in southern Alberta in the face of fluctuating water supply underscores the need for adaptive management of this crucial resource. The global effort to mitigate climate change must be paralleled with an equal local effort on adaptation in Alberta to reduce the risks to water resources that will come as a result of climate change. An adaptive management approach aims to develop resilient and adaptive capacity to respond to a wide range of different situations by exploring what we can do with today's infrastructure and management and then look at what else could be done now and into the future. It also aims to raise social awareness of potential flood and drought risks in support of efforts to get appropriate water management arrangements in place now.

Watershed management and climate adaptation issues are complex and cannot be appropriately addressed by any single initiative or sector, making collaboration essential. Since 2010, a series of initiatives has brought together water managers and knowledgeable water users in each of the SSRB sub-basins to explore potential adaptation approaches. Building on these prior modelling collaborations, this project integrated the sub-basin models into one comprehensive model for the entire SSRB. A number of adaptation strategies were developed for each sub-basin and where data were available strategies were modelled and assessed using the South Saskatchewan River Operational Model (SSROM). The SSROM is a comprehensive, daily, mass balance river model that enabled the collaborative working groups to compare individual strategies and evaluate the net benefits of combinations of strategies across the full basin. Strategies were sorted into three Levels that reflect degrees of adaptation:

Level 1: Strategies that could be implemented now to adapt to current flows and conditions
Level 2: Strategies that would add another level of resilience to the basin
Level 3: Strategies that would make the basin more resilient to climatic changes

Based on the modelling results, some strategies within each Level were further categorized as "most promising." Firm criteria were not established or used to identify "most promising" strategies; however, considerations of relative simplicity, cost, impact and contribution to resilience were typically used to distinguish these from other strategies within and between Levels. The detailed results are presented in section 3 of this report.

This report puts forward the Adaptation Roadmap for Sustainable Water Management in the SSRB, based on previous and current collaborative efforts. The Roadmap recognizes the adaptation strategies already being implemented as well as the three Levels of adaptation strategies.

This executive summary briefly describes the benefits and implementation opportunities for each strategy in the Roadmap.

SSRB Adaptation Roadmap

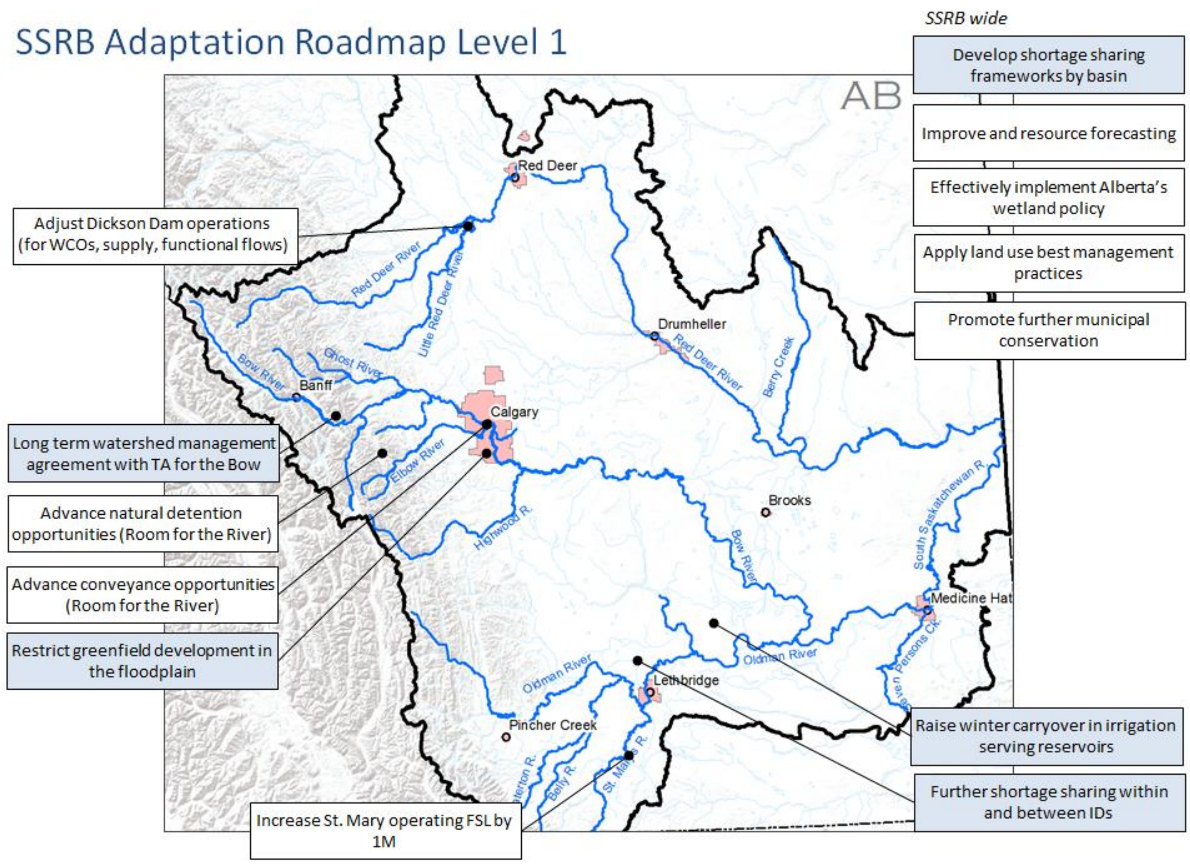
Increasing degrees of adaptive capacity →

Already In Progress	Level 1	Level 2	Level 3
• Achieve CEP Plan targets • Use water allocation assignments and transfers • Share water within IDs • Upgrade critical water management infrastructure • Release functional flows (Oldman) • Build flood defence berms where necessary • Institute Ghost Reservoir flood operations agreement • Develop large scale flood mitigation facility on the Elbow • Replace Glenmore stop logs with operable gates	• Institute a long term watershed management agreement with TransAlta for the Bow • Raise winter carryover in irrigation serving reservoirs • Further shortage sharing within and between IDs • Develop shortage sharing frameworks by sub-basin • Restrict greenfield development in the floodplain	• Redesign operations of all upstream Bow reservoirs for water supply purposes • Expand and balance Chin Reservoir (Oldman) • Build new SAWSP and Acadia Valley off-stream storage	• Build new storage low in the Bow sub-basin (~Eyremore)
	• Increase St. Mary operating FSL by 1M • Effectively implement Alberta's wetland policy • Improve and resource forecasting • Adjust Dickson Dam operations (for WCOs, supply, functional flows) • Advance conveyance opportunities (Room for the River) • Advance natural detention opportunities (Room for the River) • Apply land use best management practices • Promote further municipal conservation	• Pursue more extensive relocation and buyouts in floodplain • Build a series of new off-stream storage in the Oldman sub-basin • Build a series of new off-stream storage in the Red Deer sub-basin	• Build new off-stream storage in the WID (~Bruce Lake) • Build new on-stream storage in the Southern Tributaries (~Kimball) • Build new on-stream storage low in the Red Deer basin (~Ardley) • Reduce minimum flows through municipalities as an exceptional measure

Blue highlights the most promising strategies within a level

Acronyms used in this figure are defined on page x.

The intention is not that all Level 1 strategies would be implemented immediately or all at once; rather, Level 1 identifies strategies that should be considered before moving to Level 2. Level 2 and 3 strategies could be further explored and implemented when the water supply and demand balance in the basin warrants it.



In the map above, strategies in the blue boxes were viewed as "most promising."

Institute a long-term, flexible and comprehensive water management agreement with TransAlta to use part of the existing reservoirs in the upper Bow to meet the environmental needs of a closed basin and provide extreme flood and drought mitigation, while still creating hydropower. This requires a negotiated agreement with TransAlta, fair compensation for lost revenue, a basin-driven governance model, and robust forecasting support.

Raise winter carryover in existing irrigation-serving reservoirs, starting with Travers Reservoir in the Bow River Irrigation District, to increase water supply security for irrigators while leaving more flow in the river. This can be piloted in 2016 through a Government of Alberta (GoA) approval for Travers, and then extended to other reservoirs with appropriate study of shoreline erosion impacts and dam safety.

Implement further forecast-based shortage sharing within and between irrigation districts, when conditions and forecasts suggest a dry year, to optimize crop planting and irrigation decisions across a region. These temporary assignments and transfers of water rights or licences are enabled through the existing *Water Act* and should continue to be used by the irrigation districts in coordination with GoA, forecasters and other agencies.

Develop basin-wide shortage-sharing and reallocation frameworks for each of the SSRB sub-basins to inform and enable severe drought mitigation before emergency measures need to be triggered. Championed by GoA, the strategy and frameworks could potentially be developed in two years.

Restrict new greenfield development in the floodplains and develop strict regulations against changing the nature of brownfield developments to reduce disturbance of the floodplain and reduce flood damage. This requires policy leadership from Alberta Environment and Parks (AEP) with Alberta Municipal Affairs, as well as support and cooperation from municipalities in the floodplains.

Increase St. Mary Reservoir operating full supply level (FSL) by 1 metre to increase the usable storage capacity of an existing reservoir that is extremely well placed in the Oldman sub-basin, and which offers water supply benefits to irrigators and municipalities. This requires dam safety and shoreline studies prior to implementation, but could potentially be completed within 12 months.

Effectively implement Alberta's Wetland Policy to protect and restore the wetland functions of water retention, slowing release, and natural filtering. This depends on AEP's implementation plans, timelines, offset opportunities, and enforcement of the regulations.

Improve resourcing for and effectiveness of forecasting infrastructure, monitoring, modelling and communications systems and teams to anticipate, prepare for, and respond to extreme events across the SSRB in a consistent and coordinated manner.

Adjust Dickson Dam operations to consider downstream needs (retain the Red Deer River Water Conservation Objectives (WCOs), implement functional flows, meet some new demands) to maximize how the existing infrastructure can support the growth of the sub-basin before new infrastructure is required. These refinements could be adopted by the Dickson Dam operations team in AEP within three years.

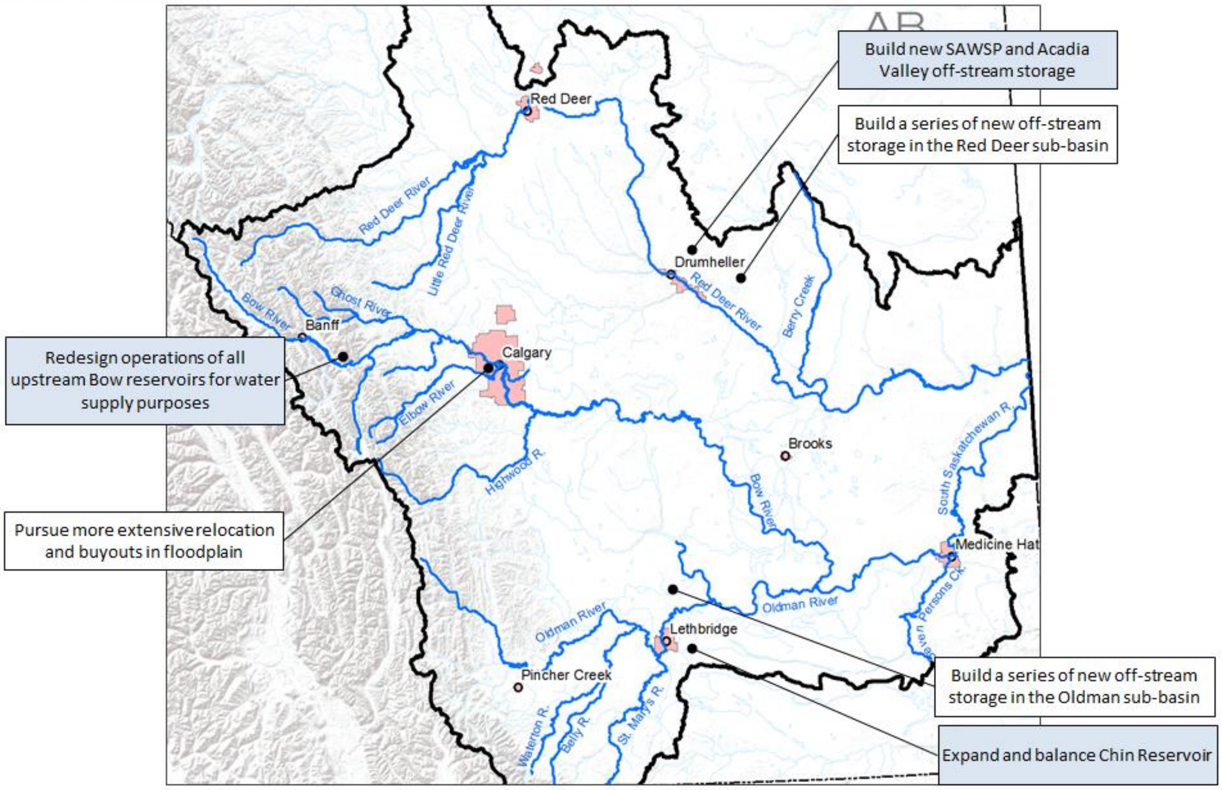
Advance Room for the River conveyance opportunities in the Bow and Red Deer sub-basins to identify and select practical projects that will alleviate constrictions on the rivers and allow greater flow to pass without flooding. This requires datasets already being compiled by AEP, AEP committing to initial high priority projects, and an approximate five-year collaborative process.

Advance Room for the River natural detention opportunities in the Bow and Red Deer sub-basins to identify and select restoration efforts that will hold high flows upstream in a flood event. This requires a commitment to AEP's Watershed Resiliency and Restoration Program and the continued support and work of Watershed Stewardship Groups.

Further apply land use best management practices to minimize impacts of land use changes on the water supply and demand balance of the region. This is currently championed through the South Saskatchewan Regional Plan Secretariat and the South Saskatchewan Regional Plan.

Promote further municipal conservation relative to today to maximize what treatment technology, stormwater management, residential use, and commercial use can contribute to the water balance in the basin, particularly in times of drought. This requires ongoing action from municipalities and industry groups as well as leadership from the Alberta Urban Municipalities Association and the Alberta Association of Municipal Districts and Counties.

SSRB Adaptation Roadmap Level 2



In the map above, strategies in the blue boxes were viewed as "most promising."

Redesign operations and expand, where beneficial, existing reservoirs in the upstream Bow for water supply, drought and/or flood mitigation, and watershed health to change priorities toward highly valued public interest outcomes while maximizing hydro revenues as an important but, in some instances, secondary objective. This requires engaging key water users in a substantial negotiation between GoA and TransAlta, followed by operational support requiring a new governance and decision-making structure supported by advanced forecasting.

Expand and fully balance Chin Reservoir in the Oldman sub-basin to optimize the usefulness of an existing reservoir for providing irrigation water and to alleviate storage demands in other upstream reservoirs, thus keeping more water closer to the headwaters and available to support ecosystems and human water uses throughout the system. This requires a significant capital investment and a shift in operational priorities and control for a major irrigation district facility.

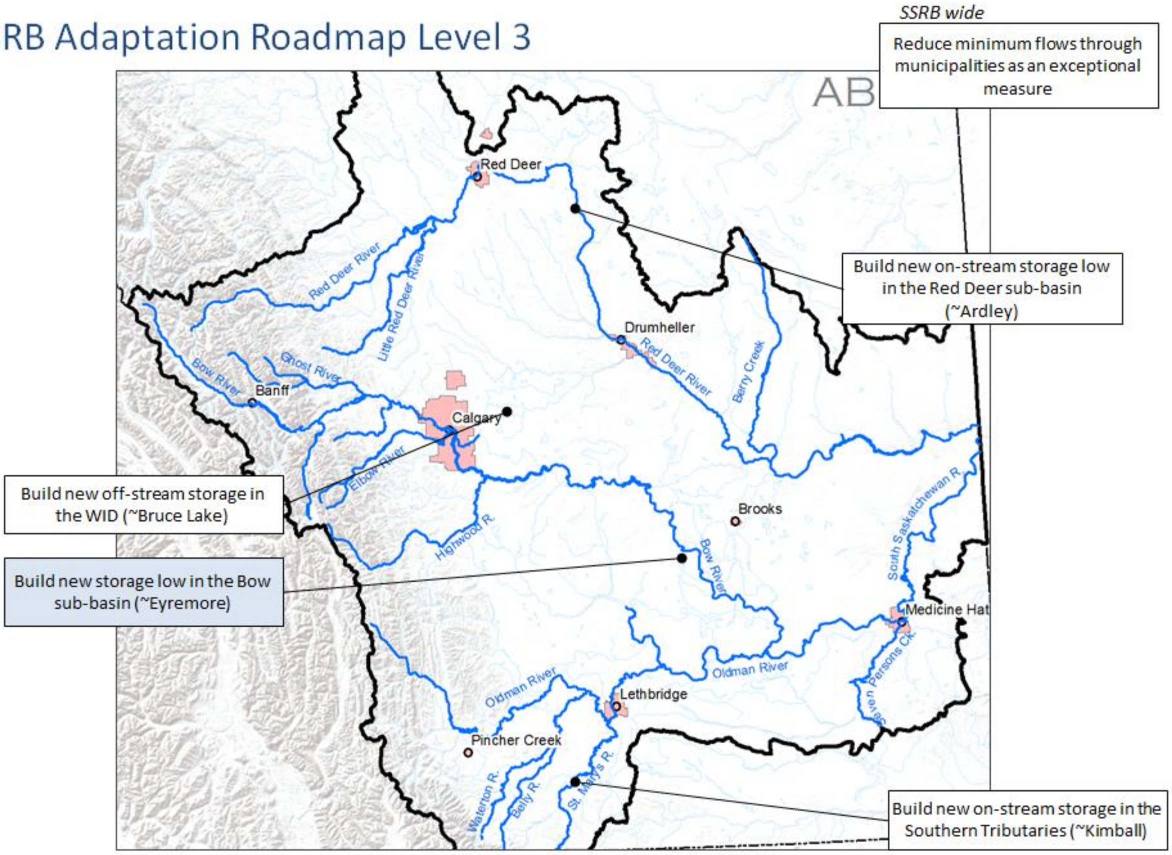
Build new off-stream storage in the Red Deer sub-basin as already proposed in the Special Areas Water Supply Project (SAWSP) and Acadia Valley Project to provide irrigation and municipal water supply to promote growth in regions currently not supported by water storage infrastructure. This project has been under consideration for at least 15 years and requires both approval and funding from GoA to proceed.

Pursue more extensive relocation and buyouts in the Bow and Elbow River floodplains to effectively and permanently mitigate flood damage and reduce the need for upstream mitigation structures. This requires strong policy leadership and funding from GoA in partnership with municipalities to successfully implement this costly shift that will have significant social impact on individuals and communities.

Build a series of new, small off-stream storage projects throughout the Oldman sub-basin as needed and where feasible to provide water supply for local demands and as a preferred solution over new on-stream infrastructure. This requires a program to enable selection and development of off-stream projects by local beneficiaries with some form of funding mechanism.

Build a series of new off-stream storage throughout the Red Deer sub-basin as needed and where feasible, in addition to the already noted SAWSP and Acadia Valley Projects, to provide water supply for further municipal, industrial and agricultural growth in the lower basin while still maintaining the environmental health of the watershed. As in the Oldman system, this requires a program to enable selection and development of off-stream projects by local beneficiaries with some form of funding mechanism. If further study demonstrates that off-stream storage sites would not be possible or effective, then a midstream facility on the Red Deer system should be moved from Level 3 to Level 2.

SSRB Adaptation Roadmap Level 3



In the map above, the strategy in the blue box was viewed as "most promising."

Build a new on-stream reservoir low in the Bow system, potentially at the previously identified Eyremore site, to supplement Oldman River flows meeting the interprovincial apportionment agreements with Saskatchewan, accommodate some of the irrigation and environmental demands currently on upstream reservoirs in the Bow system, improve minimum flow rates in the downstream Bow, and offer flood mitigation to downstream communities. This new reservoir may also have hydropower potential. This would be a large infrastructure project requiring extensive engineering and environmental study and a large capital investment.

Build new off-stream storage in the Bow sub-basin, for example the Bruce Lake project already identified and proposed by the Western Irrigation District, to improve water supply security for irrigators and multiple other users in the region east of Calgary. This would require approvals and funding support from GoA.

Build new on-stream storage high in the Southern Tributaries of the Oldman sub-basin, potentially the previously identified Kimball site, and balance this new reservoir with the other reservoirs in the Oldman sub-basin to reduce water shortages for irrigation and municipal users and improve the ability of all reservoirs to maintain environmental flows. This would be a large infrastructure project requiring extensive engineering and environmental study and a large capital investment.

Build a new reservoir midstream in the Red Deer system, potentially at the previously identified Ardley site, to support and enable significant future growth in the sub-basin by providing water supply security for future licences and to offer flood mitigation to downstream communities. This would be a large infrastructure project requiring extensive engineering and environmental study and a large capital investment.

Reduce minimum flows through municipalities and other downstream users as an exceptional measure in drought years to temporarily slow the draining of upstream reservoirs thus ensuring some level of releases for water users and aquatic health over a longer period of time. This requires an accommodation in policy, operational flexibility, and careful application informed by advanced forecasting and science-based understanding of the aquatic impacts of severe low flows.

While discussing adaptation strategies and opportunities, a number of notable aspects related to basin dynamics in the SSRB emerged or were reinforced from prior work. They have a direct or indirect effect on water use and management in the basin. These dynamics are listed here and explained further in section 3.1:

- The observed flows from the United States in the St. Mary River have been considerably higher than the volumes to which Alberta is entitled.
- Apportionment requires ~50% of annual flow by volume be passed to Saskatchewan.
- Further reducing minimum flows could negatively affect aquatic ecosystems.
- The Eastern Irrigation District and Western Irrigation District return flows to the Red Deer River contribute significantly to meeting that system's WCOs during summertime low flow periods.
- Irrigation district expansion will continue to be enabled through improved conservation, efficiency and productivity, not through increased withdrawals from the rivers. This could mean that somewhat greater flow rates may occasionally be needed from Dickson Dam to meet summer WCOs, given lower irrigation return flows from the Bow to the Red Deer.
- Building new water management infrastructure should build adaptive capacity; it should not lead to new licence allocations in closed basins.
- Connections among sub-basins mean that building new infrastructure in one sub-basin could yield benefits in another.
- Operations of TransAlta reservoirs on the Bow interact with many of the other potential adaptation strategies for this river system.
- The forecasting window in the SSRB is extremely short; investment in forecasting resources and systems are imperative for ongoing adaptation.
- The uncertain length of a drought makes it challenging to develop management responses.
- Flood mitigation and drought mitigation can be achieved in the same season, but not at the same time using the same infrastructure capacity. Flexibility and responsiveness to changing conditions are essential.

The work resulting in this report was recognized as a screening level study, after which most strategies would require more detailed study (e.g., project based cost-benefit analysis, engineering feasibility studies, environmental impact assessments, socio-economic analysis, consideration of impacts on landowners and First Nations). It was recognized that the trade-offs between the strategies were partially represented in the models and well-represented in the expertise and experience of working group participants. The best available information was compiled and provided a solid reflection of the operations of the sub-basins both today and into the future. Although the strategies and text in this report use the term “build” with reference to infrastructure, this should not be interpreted as a recommendation or advice to immediately construct that infrastructure; no construction would be started before local consultations and detailed, site-specific studies are undertaken.

Throughout the collaborative work since 2010, a short set of messages has been repeatedly reinforced:

- Activity already underway to develop and promote a market system for temporarily trading or assigning water within irrigation districts and between licensees should continue to be supported. Licence transfers and trades to optimize use of existing licences is a way to manage water shortages, but people need to understand what their options are and how to take advantage of those options.
- The Bow River has a real and immediate need for a water bank that reserves approximately 10% of the annual storage and flows within TransAlta’s reservoirs for release in accordance with downstream needs, including improving environmental flows during low flow periods while minimizing shortages to junior and senior licence holders. Establishing a mechanism for managing the water bank for flood and drought should be a high priority. This should be part of a broad watershed agreement between the GoA and TransAlta that includes the elements described in the pertinent Level 1 strategy of the Adaptation Roadmap.
- Each sub-basin needs a framework, beyond what is available today, for sharing shortages. Such frameworks should be developed soon, during “normal” conditions so that they are ready to implement by the time the next drought crisis arrives. Work is needed to determine what components such a framework should have and who needs to be part of it.
- Building on what is already being done, there are a number of practical and immediate actions that can be taken by watershed groups, irrigation districts, municipalities and others in coordination with the Province to expand the adaptive capacity of the SSRB using the infrastructure, regulations and policy in place today. These proactive efforts, for example piloting a higher winter carryover in Travers Reservoir, assessing the dam safety impact of a higher operating FSL on St. Mary Reservoir, and modelling the hydraulic impacts of Room for the River conveyance opportunities along the Bow River, are each important steps in either implementing adaptation or preparing for implementation as warranted by the conditions in the basin.

Adaptive water management will involve implementing and regularly revisiting the Roadmap as this dynamic river basin continues to change and demands grow. To build resilience and sustainability in the face of climatic and environmental change and increased growth, a layered approach will be needed, as no single solution can meet every need. The Roadmap provides a solid foundation on which to determine, refine and implement appropriate actions; adapt the plans; and invest in the science needed to better prepare the SSRB’s water management system to respond when new demands and challenges arise.

Acronyms and Abbreviations

~	Approximately
AAF	Alberta Agriculture and Forestry
AEP	Alberta Environment and Parks
AI-EES	Alberta Innovates – Energy and Environment Solutions
ALCES	A Landscape Cumulative Effects Simulator
AAMDC	Alberta Association of Municipal Districts & Counties
AUMA	Alberta Urban Municipalities Association
BMP	Best Management Practice
BRID	Bow River Irrigation District
BROM	Bow River Operational Model
cfs	cubic feet per second
dam^3	cubic decametre (1,000 cubic metres or 0.81 of an acre foot)
CEP	(Water) Conservation, Efficiency and Productivity
EID	Eastern Irrigation District
ESRD	(Alberta) Environment and Sustainable Resource Development
FSL	Full Supply Level
GoA	Government of Alberta
IDM	Irrigation Demand Model
IJC	International Joint Commission
IO	Instream Objective
m^3/s	cubic metres per second (also written as cms; 1 m^3/s = 35.3 cubic feet per second)
OASIS	Operational Analysis and Simulation of Integrated Systems
OHV	Off-highway vehicle
OSSK	Oldman and South Saskatchewan (sub-basin)
OSSROM	Oldman and South Saskatchewan River Operational Model
PM	Performance Measure
RDROM	Red Deer River Operational Model
RDRWA	Red Deer River Watershed Alliance
SAWSP	Special Areas Water Supply Project
SMRID	St Mary River Irrigation District
SSRB	South Saskatchewan River Basin
SSROM	South Saskatchewan River Operational Model
US	United States
WCO	Water Conservation Objective
WID	Western Irrigation District
WPAC	Watershed Planning and Advisory Council
WRMM	Water Resources Management Model
WSRP	Water Shortage Response Plan

Contents

List of Tables

List of Figures

1. Introduction

Alberta's environmental, social, and economic vitality depend, in large part, on how the province's natural resources are managed. An adequate, safe supply of water is vital to support manufacturing, tourism, agriculture, our resource industries, and our very lives. An expanding population, long-term economic growth, the impact of this growth on the environment, and continuing climate variability and change make it essential to adaptively manage our river basins to meet these challenges. This means making proactive and informed water management decisions in collaboration with knowledgeable water stakeholders in each basin. Such action should be based on a clear and shared understanding of how future growth and climatic change could affect water resources, the users who depend on them, and Alberta's ability to respond and adapt.

1.1 The Opportunity

With the recent experience of both floods and droughts in many parts of Alberta, climate variability has become personal, especially for residents in the South Saskatchewan River Basin (SSRB). Growth in southern Alberta in the face of fluctuating water supply has underscored the need for adaptive management of this crucial resource.

This report presents the results of collaborative efforts to develop adaptive water management strategies in the four sub-basins of the SSRB.[1] Emerging from this work is an Adaptation Roadmap for Sustainable Water Management in the SSRB, which is intended to inform water management decisions, investment, and future study; it is referred to in this report as "the Adaptation Roadmap" or simply "the Roadmap."

Each sub-basin was modelled extensively,[2] and the models were then integrated into one comprehensive mass balance model for the entire SSRB; these models are described in sections 2.3 and 2.4. The integrated model, the South Saskatchewan River Operational Model (SSROM), enables users to examine and assess strategies for adapting to climate variability as well as the impacts the strategies could have across the full basin,[3] not just in an individual watershed.

The Roadmap began with a list of the most promising individual adaptation strategies for the SSRB as identified by the working groups within each sub-basin and these were then evaluated using the SSROM. Subsequent work focused on the strategies considered most promising, defined as those that offered the most net benefits under both current and future conditions, including circumstances such as increasing growth and more severe climate conditions. Strategies were combined as appropriate and then grouped into three levels that reflect degrees of adaptation:

Level 1: Strategies that could be implemented now to adapt to current flows and conditions.
Level 2: Strategies that would add another level of resilience to the basin.
Level 3: Strategies that would make the basin more resilient to climatic changes.

[1] These are the Bow, Oldman, South Saskatchewan, and Red Deer River sub-basins.
[2] A full list of the 14 reports prepared for the sub-basins appears in Appendix A; all reports are available on the Alberta WaterPortal at http://albertawater.com/work/research-projects.
[3] In this report, when the term "basin" is used by itself, it refers to the entire SSRB.

The intention is not that all Level 1 strategies would be implemented immediately or all at once; rather, Level 1 identifies strategies that should be considered before moving to Level 2. Level 2 and 3 strategies could be further explored and implemented when the water supply and demand balance in the basin warrants it. This project was not designed to explore the technologies and activities that contribute to demand management and reduction, but many of these are included in the water conservation, efficiency and productivity plans prepared for the seven major water-using sectors,[4] which is the first listed strategy in the Adaptation Roadmap.

Numerous other demand management actions are contained in the three Levels. These actions are expected to lead to continuous improvement that will provide the resilience and adaptability needed over the long run.

Adaptive water management will involve implementing and regularly revisiting the Roadmap as this dynamic river basin continues to change and demands grow. Important outcomes from this work are first, a greater shared knowledge of the SSRB water system, its management, and the potential changes that could be in store for the region's environment and climate; and second, an available suite of tools, models, and data along with high functioning working groups to support ongoing adaptive river management.

The work described in this report was recognized as a screening level study, after which most strategies would require more detailed study (e.g., cost-benefit analysis, engineering feasibility studies, environmental impact assessments, socio-economic analysis, consideration of impacts on landowners and First Nations). It was also recognized that the trade-offs needed to properly identify and evaluate the strategies were partially represented in the models and well-represented in the expertise and experience of working group participants. The best available information was compiled and provided a solid reflection of the operations of the basin both today and into the future.

1.2 Water and the South Saskatchewan River Basin

Water is the foundation for life in the SSRB, as well as for many downstream residents and water users in neighbouring provinces. All of the major rivers in the SSRB originate in the Rocky Mountains, and protecting the headwaters has been identified as a high priority. In an area with complex geography and land uses and growing water needs, water supplies in the SSRB have historically been, and continue to be, under serious pressure and scrutiny. In much of the basin, water management has focused on drought mitigation, but the floods of 1995, 2005, and 2013 reminded everyone of the diverse hydrological conditions experienced in the region—and of the need to be resilient and adaptable in responding to a wide range of future climate events and impacts. In seeking the best solutions to sustain Alberta's prosperity and quality of life, water management issues must be top-of-mind for residents, elected officials, and other decision makers.

Alberta Environment and Parks (AEP) is responsible for regulatory decisions for developments (other than oil, gas and coal) that pertain to water management in Alberta. Several specific considerations provide a context for water management in the SSRB:

[4] These plans and their progress reports are available on the Alberta Water Council website at http://awchome.ca/Projects/CEP/tabid/209/Default.aspx

- The *Water for Life* strategy and action plan reaffirm Alberta's commitment to the *Water for Life* approach: the wise management of the province's water resources for the benefit of all Albertans.[5]
- Alberta remains committed to its existing priority system of water allocation based on licence seniority. The *Water Act* provides considerable flexibility in terms of water reallocation among licence holders for new or existing purposes. Further use of the adaptive clauses and administrative policies related to the *Water Act* may be valuable in adapting to changing conditions and demands within the sub-basins of the SSRB.
- Since 2006 when the South Saskatchewan River Basin Water Management Plan[6] was approved by the Lieutenant Governor in Council, no applications for new water allocations have been accepted in the Bow, Oldman, and South Saskatchewan sub-basins. The Red Deer is the only sub-basin in the SSRB that is still open for new applications.
- The Master Agreement on Apportionment (1969)[7] between the Governments of Alberta, Saskatchewan, Manitoba, and Canada requires that approximately 50% of the annual flow by volume of eastward-flowing provincial watercourses must be passed from Alberta to Saskatchewan. Historically, the average flow to Saskatchewan has typically been more than 75%. Fifty percent is a minimum and reflects choices and trade-offs of water use, but the river ecosystem benefits from these higher flows which are closer to the natural flows. The proportion passed on to Saskatchewan, while meeting Apportionment obligations, was much lower during low flow years such as 1988, 2000, and especially 2001 when it was 54%.
- The Boundary Waters Treaty (1909)[8] governs the sharing of international streams between Canada and the United States (US). It establishes the terms and conditions for water sharing with Montana and is relevant to the Milk and St. Mary river systems. Historically, Alberta has received more water than its entitlement allows because Montana lacks diversion and storage infrastructure to take and use its full allocation. It is not known if and when the US might take the full allotment of water to which it is entitled in the St. Mary system, which would considerably reduce the amount that is available to Alberta.

1.3 The Drivers for Adaptation

As the climate continues to change, Alberta faces important challenges with respect to balancing water supply and demand due to an expanding population, economic growth, and the increasing impact of this growth on the environment. Nowhere are these matters more pressing than in the SSRB. As potential solutions are considered, environmental, economic, and social needs must all be addressed.

Table 1 compares the four sub-basins in the SSRB by area and population.[9] Both urban and rural municipalities in the SSRB continue to grow. They require a safe, secure supply of drinking water as well as water to meet wastewater treatment and dilution needs and other municipal demands. An

---

[5] See http://www.waterforlife.alberta.ca

[6] See http://aep.alberta.ca/water/programs-and-services/river-management-frameworks/south-saskatchewan-river-basin-approved-water-management-plan/default.aspx

[7] See http://aep.alberta.ca/water/legislation-guidelines/master-agreement-on-apportionment-1969/default.aspx

[8] See http://aep.alberta.ca/water/legislation-guidelines/boundary-waters-treaty-1909/default.aspx

[9] Although there are four sub-basins, the Oldman and South Saskatchewan sub-basins were modelled and studied together as part of the OSSK project.

expanding population will create new demands for recreational opportunities, which could have implications for river flows as well as reservoir volumes and operations. Further, the clearing of land for settlement purposes and construction of buildings, storm sewer conveyance systems, and hard surfaces such as roads and parking lots tend to increase the rate at which precipitation flows off land into streams, rivers, and lakes, thus decreasing infiltration. As a result, settlements and their associated infrastructure increase both total streamflow and peak flow.

Table 1: Area and population of SSRB sub-basins

Sub Basin	Area in Alberta (km^2)	% of SSRB area	Total population	% of SSRB population
Bow	25,000	22	1,200,000	69
Oldman	23,000	20.5	210,000	12
South Saskatchewan	14,000	12.5	66,000	4
Red Deer	50,000	45	268,000	15
Total	112,000		1,744,000	

Sources: Information in this table was obtained from the websites and publications of the respective Watershed Planning and Advisory Councils for the sub-basins. Much of the population data is from 2006, and numbers are rounded.

To deal with impending shortages, many Alberta municipalities are implementing water conservation, efficiency, and productivity plans along with water reuse opportunities. However, the attractiveness of the SSRB as a place to live and work makes further population growth and the associated demands for water inevitable if current trends continue.

The natural beauty of the SSRB, its biodiversity, and its archaeological and paleontological resources support a strong and growing recreation and tourism industry. However, some plant and animal species, particularly fish, are being threatened by habitat loss and modification, over-fishing, water management infrastructure, and pressure from introduced non-native species.[10]

Agriculture is a major land use throughout the SSRB. Primary agricultural production makes the basin an attractive location for food processing and other industries, all of which need assured supplies of water. Other opportunities will also be important to regional growth and diversification, including the service industry, forestry, energy development, and the manufacture of value-added goods. Associated land use changes often lead to more linear developments, particularly roads. Roads fragment the landscape and create a larger human footprint. Other activities lead to wetland drainage and, at best, a temporary loss of the services wetlands provide, among them natural water storage, which lowers peak flows during flood events and helps alleviate drought conditions.

Forestry activities occur toward the western end of the SSRB. Generally, more water is transmitted to streams more quickly from forested areas when forests are young or non-existent, although it has been demonstrated again in recent studies that slope, aspect, and adjacent forestry status also contribute to the delivery of water to streams.

In the southern part of the SSRB, irrigation districts hold licences for most of the allocated water. The districts are improving their water use efficiency, which has enabled them to expand acreage and

[10] Fish species under threat include the Rocky Mountain sculpin, bull trout, native cutthroat trout, and lake sturgeon.

amend their licences to allow this water to be used for other purposes. However, additional storage and water management infrastructure may be desired to help meet the growing variety of water demands. The Government of Alberta (GoA) continues to investigate opportunities to increase traditional on- and off-stream storage, while other storage options using aquifers, gravel beds, wetlands, and other natural features are receiving more attention

Water management pressures have been acknowledged through the closure of three sub-basins to new water licences. Growth in southern Alberta continues but water supply remains the same or less. Compared with most river systems in Alberta, these watersheds are subject to extreme variability in weather patterns. Debate continues about the specific impacts long-term climate change will have on water supplies locally and globally. Compounding this uncertainty, tree-ring data correlated with river flow show extreme climate variability in past centuries for flows in the Bow and Oldman Rivers (Figure 1). These data suggest that future flood and drought events could be much more serious than those experienced in recent years. The same variability in river flow can also be observed in the Red Deer River. These events, combined with population and economic growth, will make it ever more important for the region to be able to adapt to and cope with new pressures and demands, whether due to droughts or floods.

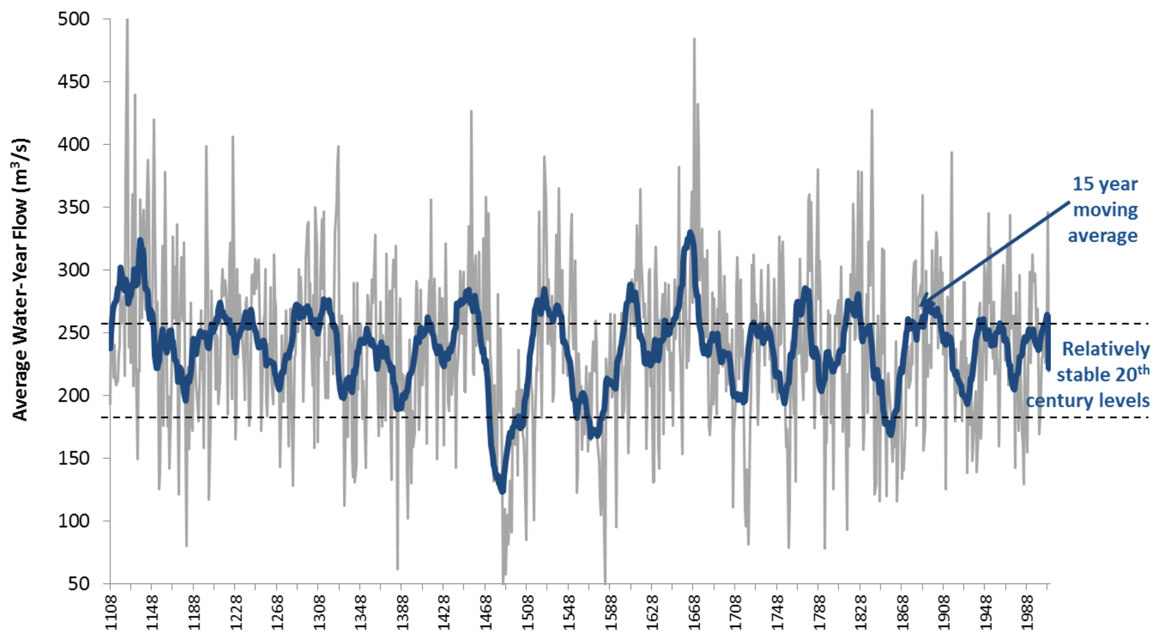


Figure 1: Reconstructed South Saskatchewan River Basin flows (Bow + Oldman) showing annual averages (grey line) and 15 year moving average (blue line)

Source: Dr. David Sauchyn, Prairie Adaptation Research Collaborative, 2015

Climate change has become a dominant global debate. Much of the recent attention has focused on emissions mitigation to address the root causes of climate change, and to lower and stabilize the levels of existing greenhouse gases. Here in Alberta, climate change will have a direct and significant impact on our water resources, as stated in the GoA's Alberta Climate Dialogue 2014: "The strong link between climate change and water has contributed to the view that if mitigation is about carbon, then adaptation is about water."[11] Alberta must put sufficient effort and resources into climate change adaptation to reduce the risks that arise as a result of climatic changes. This requires action by local and regional leaders, groups and businesses to best prepare for changes in the timing and volume of their natural water supply, both as a result of gradual change and extreme events.

Water management challenges in the SSRB present a timely opportunity to capitalize on the knowledge and experience of community and business leaders, government departments, irrigation districts, environmental organizations, and watershed groups. Watershed management and climate adaptation issues are complex and cannot be appropriately addressed by any single initiative or sector. Collaboration is essential. Alberta has a history of successfully meeting challenges through multi-sector collaboration and engagement, and the projects that have led to the Adaptation Roadmap for Sustainable Water Management in the SSRB, presented in this report, add to that legacy.

2. Project History, Process, and Methodology

2.1 Project History

Alberta WaterSMART has led several collaborative modelling projects that examined opportunities and identified a wide range of strategies to increase resilience and make the SSRB more adaptable to climate variability and change. The first major project (the Bow River Project) looked at options and strategies in the Bow River sub-basin. Building on the momentum and ideas that emerged from this multi-stakeholder initiative, another project was launched in 2013 that integrated a climate variability layer into the modelling and flow component for the Oldman-South Saskatchewan sub-basin.

Following the disastrous floods in 2013, the modelling work was applied to examining practical and resilient flood mitigation strategies in the Bow River system, including the Elbow, Sheep and Highwood tributaries. Among other things, the project clearly showed that a systemic, watershed-based approach is essential. During 2014 and 2015, river and land use models were examined and tested by water users and managers in the Red Deer sub-basin.

Table 2 lists the detailed reports produced for the sub-basins, all of which are available on the Alberta WaterPortal at http://albertawater.com/work/research-projects. In total, 14 reports were prepared that describe methodologies, flood management opportunities, and other aspects of water management in the SSRB; these are shown in Appendix A. The operational modelling assumptions and input data for the Bow, Oldman-South Saskatchewan, and Red Deer River systems are documented in the publicly available files accessible through the University of Lethbridge servers at http://www.uleth.ca/research-services/node/432/.

[11] Alberta Climate Dialogue. 2014. "Water in a Changing Climate: Citizen Panel, Summary and Synthesis," p. 8; online at http://www.albertaclimatedialogue.ca/watershed; the report is available at https://drive.google.com/a/ualberta.ca/file/d/0B0epQHfB5rvHLTB3ZWpxazVNT0lpTUstX1JhNXVqUkM0dHU4/view?pref=2&pli=1

Table 2: SSRB sub-basin final reports

Report title	Date
South Saskatchewan River Basin Adaptability to Climate Variability Report: Adaptation Strategies for Current and Future Climates in the Bow Basin; Final Report	June 2013
South Saskatchewan River Basin Adaptation to Climate Variability Project Final Report; Phase III: Oldman and South Saskatchewan (OSSK) River Basins Summary Report	April 2014
Climate Variability and Sustainable Water Management in the SSRB Project: Red Deer River Basin Modelling, Final Report	February 2015

This report refers to and draws on the earlier sub-basin work, but focuses on the integrated findings, application, and results across the entire SSRB.

2.2 The Collaborative Modelling Process

As was done for each sub-basin, this integrated project engaged a diverse group of representatives from major water-using sectors and others with an interest in how water is used and managed in the region (see Appendix B for a list of project contributors).

HydroLogics, Inc., the consultant who was involved in modelling the sub-basins, led the integration of the modelling across the SSRB, using their sophisticated simulation software called OASIS (Operational Analysis and Simulation of Integrated Systems). OASIS is flexible, transparent, and completely data-driven, and effectively simulates water facility operations. The project team and most participants had been involved in the sub-basin work and thus were familiar with the OASIS software used to develop the SSROM; the SSROM is described in section 2.4.

In addition to the many working group meetings in the earlier projects and phases, the SSRB working group participants met three times for full-day meetings—in May, June and September 2015, in Red Deer, Lethbridge, and Calgary, respectively. Live modelling sessions were part of each meeting. The first meeting was an opportunity to review the SSROM and potential performance measures, review and refine the adaptation strategies and combinations from the sub-basin work, and begin to develop a manageable set of plausible future SSRB water supply and demand scenarios against which to refine potential adaptation strategies. At the second meeting, participants focused on improving the most promising strategies for ameliorating issues resulting from high and low flow conditions. The final meeting was spent reviewing and refining the most promising strategies and actions that could be implemented now and in the future to enhance adaptation and increase resilience in the SSRB.

Throughout the project, participants worked collaboratively, providing data, advice, and insight based on their knowledge and experience. Participants actively offered ideas and comments to advance the discussion while respecting the views and opinions of others. This process was not intended to seek or achieve total consensus; rather, it was designed to explore practical water management strategies and ideas, based on the best data and knowledge in the basin. The results are presented as a solid foundation for discussion and implementation by those who use, manage, and make decisions about water in the SSRB as they anticipate and respond to future changes in water supply, water demand, and climate. The expectation is that the ideas and strategies developed through this collaboration would serve as an Adaptation Roadmap for the basin.

This project brought together some of the most knowledgeable and experienced water users and managers in Alberta, many of whom have lived and worked in the SSRB for decades. They have seen first-hand the impacts of both droughts and floods on the region's people, environment, and economy, and are very aware of the need to be prepared for a wide range of possible future flow conditions. Working openly and collaboratively, they identified a number of strategies that could benefit the basin now and could help the region adapt to more challenging future water supply and climate conditions, whether they involve too much or too little water.

2.3 Modelling the SSRB Sub-basins

Throughout this project and its predecessors, the comprehensive, daily, mass balance river models developed for the sub-basins and the SSRB have been the primary tools to support collaborative exploration and assessment of opportunities and build common understanding of the water management system. The models enable users to examine and assess strategies for adapting to changes in water supply and demand and climate variability, as well as the impacts the strategies could have across the full basin. Although operations and priority water allocations differed among the sub-basins, the core of the mass balance models was essentially the same for all of them. OASIS models preserve mass balance 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" (minimum flows, demands, reservoir storage, licensed allocations, etc.) through a weighting system; that is, higher weighted uses get water first. These weights can be modified in various alternatives to increase the priority of one use over another, but the fundamental concept is applied regardless. The models do not explicitly calculate and account for groundwater or include water quality aspects, but groundwater contribution to streamflow is inherently part of the naturalized flow data, which are used as inflows to the model. Implications for water quality as it relates to flows at points in the river can be assessed using the sub-basin model when relationships between water quality and quantity at a particular point in the system are known.

The OASIS modelling system derived from a long history of continuous improvement of water resources modelling techniques (see Appendix C). It includes a wide variety of features not found in other modelling systems, which makes it extraordinarily flexible. OASIS has been widely used to model some of the world's most complex water systems, as well as small and simple systems. It has been used widely in the US, as well as in New Zealand, Canada, and other places for evaluating alternative management plans. Many of those exercises explicitly incorporate or link to other models.

One objective of modelling the SSRB sub-basins was to propose adaptive and robust water management strategies that take into account the regional impacts of climate variability and change. This required the development of a scientifically valid set of possible future streamflow conditions that would enable testing of water management alternatives under a range of plausible future climate and hydrological scenarios (described in section 2.4). Thus, in addition to an operational model for each sub-basin river system, climate scenarios were developed to realistically advance the adaptation discussion. The innovative approaches used by the Prairie Adaptation Research Collaborative to develop these climate scenarios are described in detail in the three sub-basin reports. In all cases, both flood and drought conditions were examined and measures contemplated to mitigate their effects. The 95% of relatively normal periods were also examined for potential environmental, recreational, and other improvements using 81 years of real historical data with current and future demands built onto each year. Adaptation options were examined under various science-based climate change and variability scenarios, all of which were reviewed by senior water managers and regulators throughout multiple projects. The result was nearly 1,500 model runs (excluding flood-focused work) for the three sub-basins and the SSROM; this amounts to approximately 42,000,000 simulated days, or 115,100 simulated years.

An important early step in collaborative modelling processes is developing performance measures (PMs) to help parties scope the issues. PMs reflect the objectives and desired outcomes for the project and indicate whether one result is better or worse than an alternative. They define the functional aspects that the models need to have, and thus they inform and influence how the models are constructed. Focusing on measures that reflect basin-wide or specific concerns, participants refined and developed specific PMs based on their individual and collective water outcome needs. Although numerous PMs were developed and used to demonstrate and assess the impacts of changes made in the sub-basin models, typically a subset of key PMs was selected for regular use. Each sub-basin report lists all PMs that were processed and describes the key subsets.

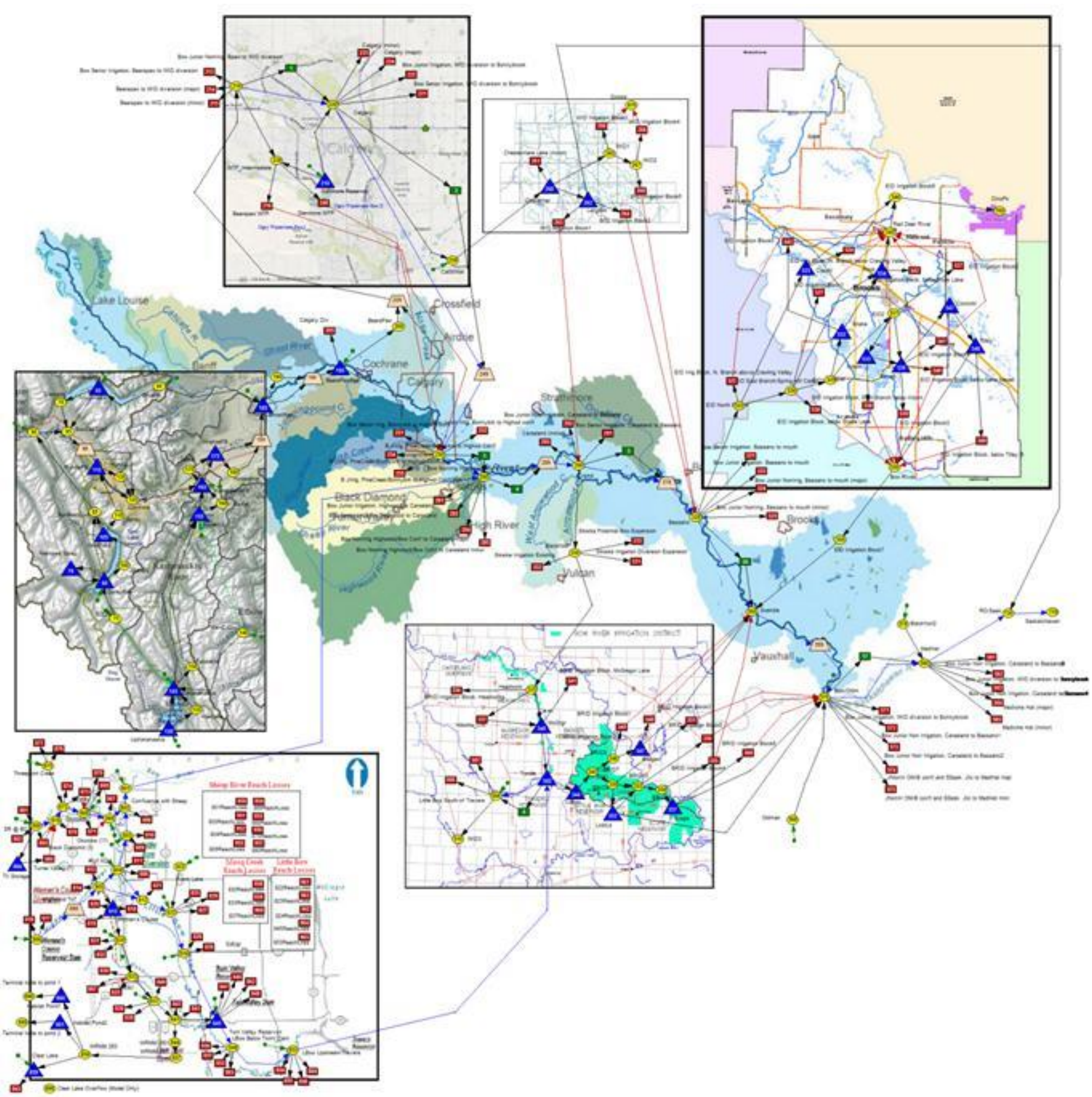
Performance measures used in the report were derived from previous work and have maintained the unit convention. The reader should be aware that both metric and imperial units are used, as the various PMs were developed for specific interpretations.

The three sub-basin models were developed with considerable input from the working group involved in each project. A brief overview of each model is provided here with more details in Appendix D and in the relevant sub-basin report. If unspecified, data were obtained from AEP and its Water Resources Management Model (WRMM) or from Alberta Agriculture and Forestry's Irrigation Demand Model (IDM). Inflows were provided weekly, but converted to daily, utilizing methodology available in the individual sub-basin reports. In some instances, hourly models of parts of the basin were developed to properly reflect flood events. Irrigation demands were provided as Irrigated Area x Depth using current crop decisions and historical precipitation data.

2.3.1 Bow River Operational Model (BROM)

The BROM is a comprehensive mass balance river model built in collaboration with Bow River licence holders and stakeholders. However, it contains substantial information beyond a simple water balance, including facility operations, power prices, informal sharing agreements, and more. This allows the model to provide results that recognize real operation projections while ensuring that mass balance remains inviolate. The BROM base case simulates current operations of facilities on, and withdrawals from, the Bow, Elbow, Highwood and Sheep Rivers from the headwaters to the confluence with the Oldman River, including major off-stream canals and storage reservoirs. Primary inputs to the BROM include naturalized flows, lake evaporation, precipitation, consumptive uses (irrigation and municipal demands), return flows (seasonal and annual), physical infrastructure data including upstream dams and reservoirs, and electricity demand and pricing systems for hydropower facilities. The BROM includes the historic flow record (1928–2009) using AEP naturalized flow data and future climate variability scenarios derived from Global Climate Models.

The best available data on the physical system (reservoir, dam, canal, and diversion structure information), inflows from the naturalized flows for 81 years of record, demand data (actual current use, allocations, irrigation demand data, return flows, municipal water use, diversion rates and limits, instream objectives and Water Conservation Objectives, or WCOs), and system operations (licence constraints, water sharing agreements, priority systems, reservoir and dam operating rules) were used in the model. Figure 2 shows the schematic for the BROM.



Legend

Reservoir node   Demand node   Instream "demand" node   Junction node

Green arrows indicate unregulated inflow.   Black arrows indicate regular flow arcs.   Red arrows indicate return flow arcs.

Figure 2: Schematic showing the area represented by the BROM

A number of PMs were developed for the BROM and six common PMs were examined for all the individual strategies modelled in this project:

1. **TransAlta System Low Storage Days**
   This PM notes the number of times that TransAlta live storage reaches critical (<5% storage remaining) and near-empty (<1% storage remaining) levels.

2. **Calgary Low Flow Days**
   This PM captures the number of days Calgary experiences extreme low flows, noting flows below 1,250 cubic feet per second (cfs) as well as flows below 900 cfs.

3. **Bassano Flow**
   This PM captures the number of low flow days below Bassano Dam. It is the same performance measure as shown in previous reports using BROM. It captures the number of days in which flow below Bassano falls into the < 400 cfs, 400–800 cfs, 801–1200 cfs, and > 1200 cfs categories. As flow that passes below Bassano has necessarily been in the river all the way to Bassano, this PM is used as a surrogate for whole river health.

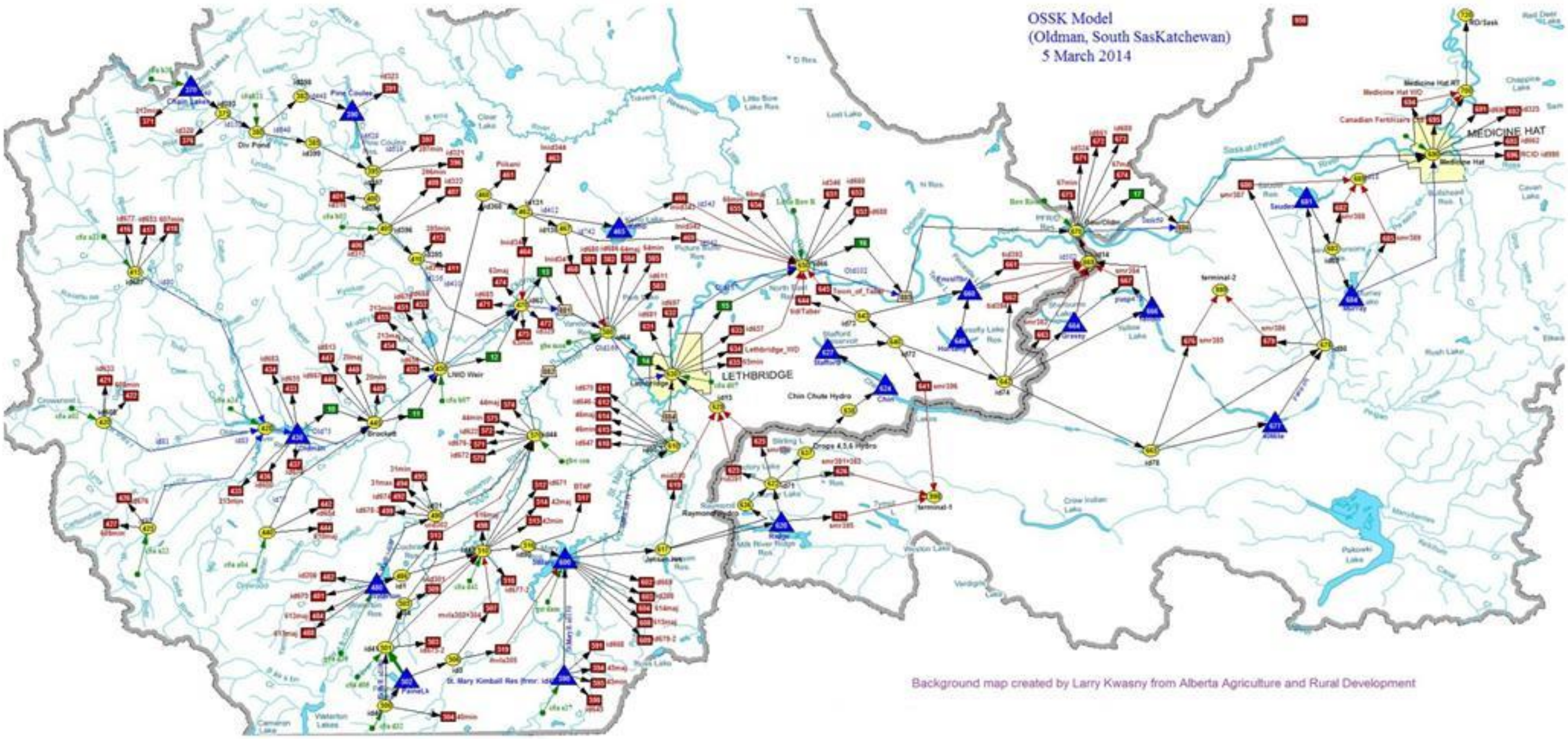
4. **Carseland Flow**
   This PM is identical to the Bassano flow PM, except that it measures flow in the river just after the Carseland diversion. In runs including Eyremore Reservoir, the flow past Bassano is no longer indicative of whole river health, as Eyremore makes releases downstream of Bassano. Carseland flow is thus used as a replacement surrogate for upstream river health in strategies that include Eyremore Reservoir.

5. **Shortage Days**
   This PM captures the number of days of shortages experienced by various groups of licence holders on the Bow River. This is a sum of all days over the entire 30-year climate variability scenario record (10,950 total days) or 81-year historical record (approximately 30,000 days).

6. **Shortage Volume**
   This PM captures the total volume (in acre-feet) of all shortages experienced by various groups of licence holders on the Bow River. This is a sum of all shorted volumes over the entire 30-year climate variability scenario record (10,950 total days) or 81-year historical record (approximately 30,000 days).

2.3.2 Oldman-South Saskatchewan River Operational Model (OSSROM)

The OSSROM includes the Oldman and South Saskatchewan (OSSK) sub-basins with all their major tributaries, including the Southern Tributaries (the Belly, Waterton and St. Mary Rivers). The primary inputs to the OSSROM are naturalized flows, lake evaporation, precipitation, consumptive uses, return flows, and physical data. The base case applies how the river is currently operated, within the context of licensed priorities and water management plans, to historical flows (1929–2009). Although there has been a progression of reservoir development in the Oldman River basin, the OSSROM does not account for this progression; rather it implies that all existing infrastructure was present in the basin for the model period since the objective is to model current and future scenarios. The model's base case assumes that the sub-basin only gets the minimum International Joint Commission (IJC) entitlement flow; if that flow is increased, it is noted in the alternative. The OSSROM schematic is shown in Figure 3.



Legend

Reservoir node Demand node Instream "demand" node Junction node

Green arrows indicate unregulated inflow. Black arrows indicate regular flow arcs. Red arrows indicate return flow arcs.

Figure 3: Schematic showing the area represented by the OSSROM

More than 20 PMs were developed for this project and eight key PMs were used to examine all the individual strategies that were modelled:

1. **Annual weekly minimum flows**
   This PM attempts to capture a sense of biological performance by examining the absolute minimum weekly flows for each year in a particular scenario at various locations. Minimum flow is measured in m^3/s.

2. **Minimum flows for fisheries**
   This PM assesses the ability to meet instream fish requirements in the Oldman River at Lethbridge. It uses Tessman Method[12] instream flow needs estimates and shows percentage of months each year with failures to meet minimum flows.

3. **Cottonwood recruitment**
   This PM estimates the likelihood of successful cottonwood recruitment and captures the quality of successful recruitment events. It shows the number of years when optimal recruitment can be expected and the number of years when partial recruitment can be expected.

4. **Fish Weighted Usable Area (WUA)**
   This set of PMs is designed to capture the effects of operations on fish habitat in selected stream reaches (the St. Mary River below St. Mary Reservoir and the Oldman River near Lethbridge) for selected indicator species. WUA is the wetted area of a stream weighted by its suitability for use by aquatic organisms or recreational activity. This PM is expressed as a proportion of total usable area.

5. **Cumulative irrigation shortage days**
   This PM examines the effects of operations schemes on irrigation districts by assessing shortage days. Shortage means that water delivered was less than water requested in any amount. Some of these shortages might be volumes too small to be significant.

6. **Total annual outflow from Oldman River as percent of natural flow (apportionment proxy)**
   This PM indicates the likelihood of violating the Apportionment Agreement by comparing natural flows at the Oldman-Bow confluence with simulated flow under various operations scenarios.

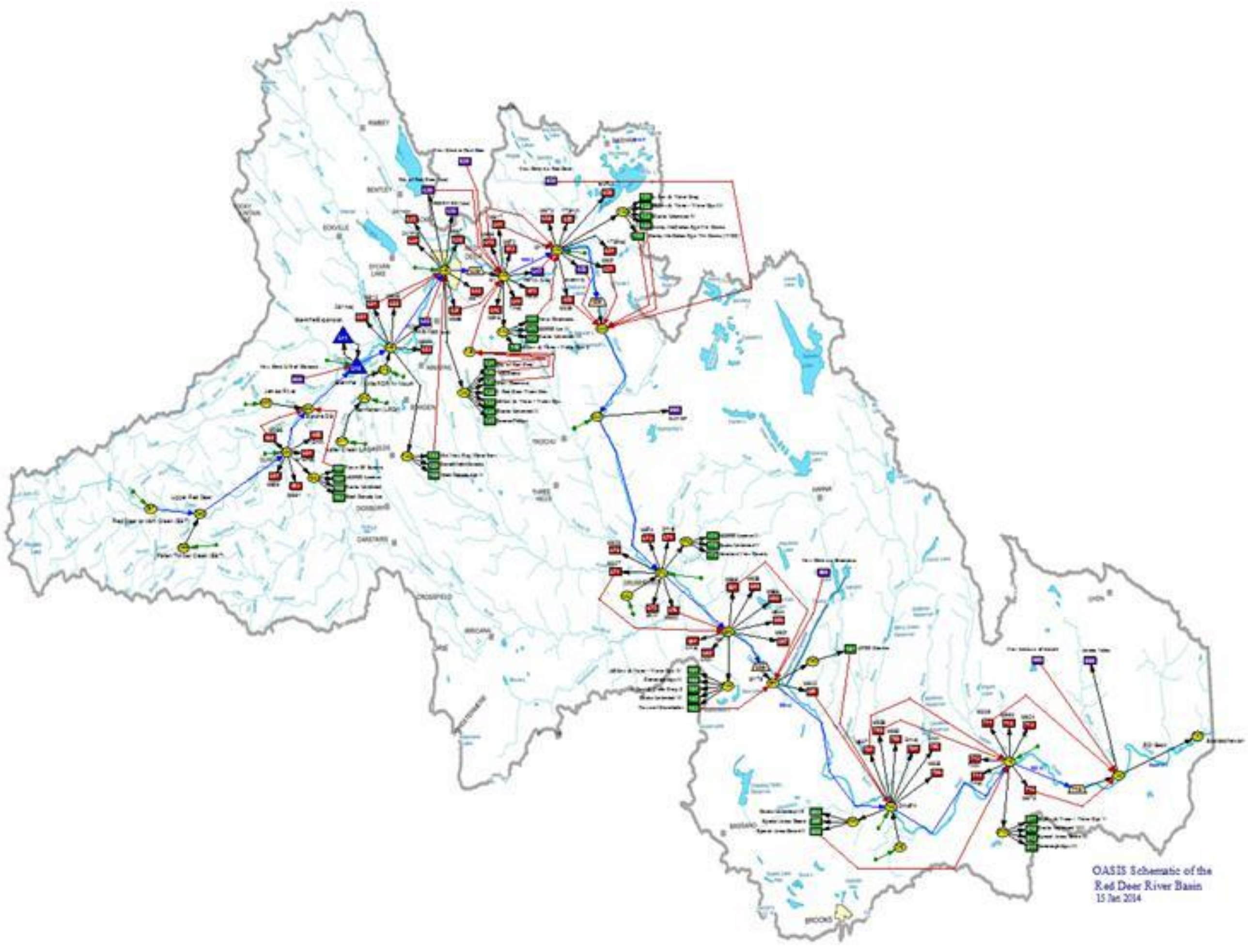
7. **Energy generation**
   This PM examines the effects of operations schemes on power generation opportunities. It is shown as total energy generated in megawatt-hours over the 81-year period for the hydro generation facilities in the OSSK sub-basins.

[12] The Tessman (1979) Instream Flow Needs (IFN) method is a commonly used streamflow method for determining the range of suitable flow conditions. It calculates the annual and monthly average flows and establishes thresholds based on 40% of the annual and monthly averages. If the average monthly flow is lower than 40% of the annual average flow, then the IFN threshold is set to the average monthly flow. Alternatively, the IFN is the greater of 40% of the average annual or 40% of the average monthly flow (Goater et al., 2007).

8. **Additional drought capacity**
   This PM refers to the number of days in a specific year by which total storage in AEP reservoirs will extend water availability and thus capacity to respond to drought conditions. It is plotted as AEP total storage in dam^3.

2.3.3 Red Deer River Operational Model (RDROM)

The RDROM was developed for the Red Deer system to run on a daily timestep. Primary inputs include naturalized flows, evaporation and precipitation, licensed allocation for the whole system or consumptive use (in some cases actual use numbers were provided by users), return flows, and physical data for diversions and reservoirs with associated operations. Since the naturalized inflow data included substantial reach losses, the decision was made to apply the same methodology that AEP chose when using the data: naturalized reach losses were adjusted to zero. The RDROM schematic is shown in Figure 4.



Legend

Reservoir node   Demand node   Instream “demand” node   Junction node

Demand node (future demand or current demand with actual use data)

Green arrows indicate unregulated inflow.   Black arrows indicate regular flow arcs.   Red arrows indicate return flow arcs.

Figure 4: Schematic showing the area represented by the RDROM

More than 20 PMs were developed for this project and six key PMs were regularly used in the RDROM:

1. **Flows at the Mouth of the Red Deer River (weekly)**
   This PM identifies periods of low flows that might be of concern for environmental, economic, and social objectives as well as noting violations of the WCO. The WCO is an important PM as it represents an agreed upon water use threshold in an approved Water Management Plan under the Alberta *Water Act*. WCO requirements at the mouth of the river are a minimum of 10 m^3/s in the summer and 16 m^3/s in the winter. Weekly (rather than daily) flows were analyzed for this PM as operations in the model were targeted towards meeting the WCO on a weekly basis.

2. **Elevation of Gleniffer Reservoir (daily/annual)**
   As Gleniffer Reservoir is the only on-stream storage in the Red Deer system, remaining storage in the reservoir is of critical importance, in particular during drought periods. Gleniffer Reservoir serves to maintain the WCO in the winter. Monitoring its storage helps to identify years where both the WCO and junior licences would be at risk.

3. **Outflow from Gleniffer Reservoir**
   Gleniffer Reservoir releases are primarily of interest in terms of the functional flow alternatives looking at environmental flows below the dam and correlating those with reservoir storage targets and operational priorities. Outflow from the reservoir is shown to establish the effect of ramping on flows immediately downstream of the reservoir.

4. **Cottonwood Recruitment**
   This PM estimates the likelihood of successful cottonwood recruitment and captures the quality of successful recruitment events. It shows the number of years when optimal recruitment can be expected and the number of years when partial recruitment can be expected.

5. **Shortages to New Demands (annual/daily)**
   Since existing demands in the system are nearly all senior to the WCO and never saw shortage in any scenario or alternative, shortages in the system were analyzed as how many occurred in demands junior to the WCO (i.e., new demands introduced in sub-basin scenarios). Although presented primarily in annual terms in the report, they were often examined on a daily basis in the working group sessions.

6. **Mid-stream Storage**
   This PM tracks the drawdown in the hypothetical mid-stream storage and operations proposed by participants to estimate the additional volume of storage needed to remedy shortages to new and current users and occasional deficits in Gleniffer Reservoir storage. It is presented where appropriate based on alternatives.

In addition to modelling the river system, the Red Deer project used the ALCES[13] model to consider land use in the sub-basin and began to explore how changing land cover impacts streamflow at the sub-basin scale. It examined five categories of land use (settlements, energy development, agriculture, forestry and fire, and wetland restoration) and how changes in these uses might influence the volume and timing of flow to the Red Deer River system over time. The ALCES model simulates spatial and temporal variance in hydrological indicators. It uses runoff coefficients to simulate water yields from different landscapes and accounts for many variables that affect hydrology (ALCES Group, 2014). ALCES was chosen for this project because it is widely applied in Alberta and it supported the project's need to explore and understand how management of changes on land affect streamflow.

2.4 The South Saskatchewan River Operational Model (SSROM)

As the respective groups worked through the modelling to explore each sub-basin and identify practical adaptation opportunities, questions frequently arose that could not be answered within the confines of the modelling for that sub-basin alone. The sub-basin models, described above, interact in critical and sometimes surprising ways. Introducing the SSROM made it possible to take a comprehensive integrated look at the entire SSRB, including the effects of operations on the Apportionment Agreement with Saskatchewan. It supported the SSRB working group as it looked for adaptation opportunities across the basin, explored combinations of sub-basin strategies to enhance the entire system without sacrifice to individual sub-basins, and consider where the best "bang for the buck" might be to guide the investment of limited adaptation effort, energy, and dollars.

The SSROM demonstrated how the SSRB sub-basins have a number of interesting interactions and opportunities, although they are often viewed as independent and unique. For example, the impacts of improving irrigation efficiency in the Bow sub-basin ripple through into the Red Deer sub-basin as the loss of return flows affects the ability to meet the system's WCOs. Extra storage in the Southern Tributaries allows the Oldman Dam to maintain extra storage, as the minimum flows and demands downstream of Lethbridge can be sourced from new storage.

The SSROM focuses on real-world operations and the opportunities that arise. It enabled stakeholders to explore combinations of sub-basin strategies and find ways to enhance the entire system without sacrifice to individual basins.

SSROM Platform, Contents, Operations, and Assumptions

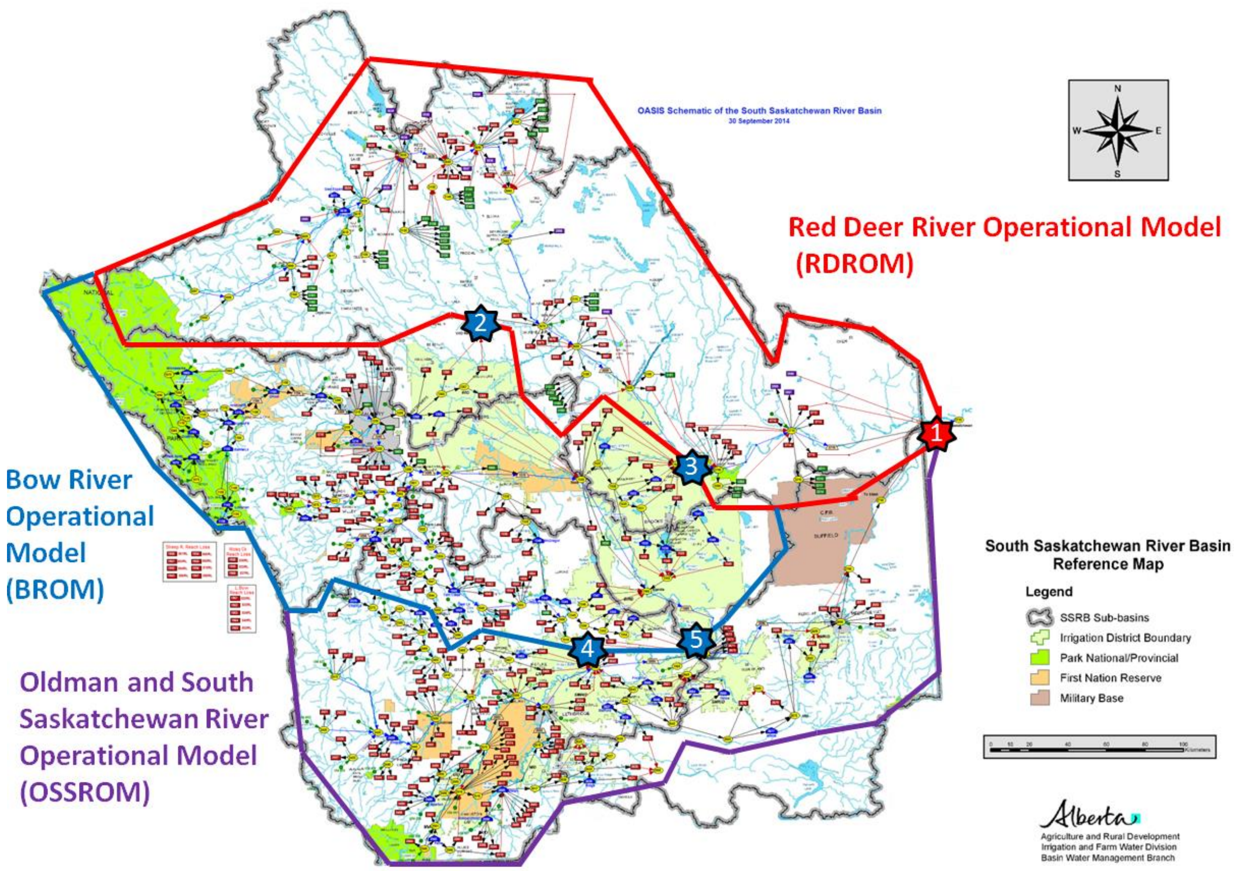
Like the sub-basin models, SSROM is built on the OASIS platform developed by HydroLogics. SSROM was built by combining the existing models described above (BROM, RDROM, and OSSROM); a complete description of operations in those systems can be found in their respective reports. Primary inputs include: naturalized flows, evaporation and precipitation, licensed allocation for the whole system or consumptive use (in some cases actual use numbers were provided by users), return flows, and physical data for diversions and reservoirs, with associated operations. Operations remained generally intact from the originating models, with one major change: previously static data sources were replaced with live model interactions.

[13] ALCES is "A Landscape Cumulative Effects Simulator."

During the project, participants raised a number of important issues to be addressed that were beyond the scope of the data gathered or the project mandate. While many of these more detailed local-scale hydraulic modelling, engineering, economic, and environmental factors, risk assessments, and systemic issues were not part of this screening level modelling, they would likely be the next steps for consideration by decision makers as these adaptation strategies are specifically evaluated for implementation. In SSROM, five major sites of basin connectivity were noted:

1. Red Deer River at the mouth
2. Western Irrigation District (WID) returns at Drumheller
3. Eastern Irrigation District (EID) returns at Dinosaur Park
4. Flow into/through the Little Bow River south of Travers Reservoir
5. The Bow/Oldman River confluence

Figure 5 shows the three sub-basins covered in the SSROM.



Legend

Reservoir node | Demand node | Instream "demand" node | Junction node

Demand node (future demand or current demand with actual use data) | Basin connection point

Green arrows indicate unregulated inflow. Black arrows indicate regular flow arcs. Red arrows indicate return flow arcs.

Figure 5: Schematic showing the area represented by the SSROM

Source: This map, originally from Alberta Agriculture and Forestry Irrigation and Farm Water Division, Basin Water Management Branch was overlain on the SSROM schematic.

Minimum flows throughout the system are maintained according to their originating model, but SSROM introduces the ability to directly measure and consider apportionment. Apportionment in the SSRB is not explicitly maintained by SSROM. It is instead evaluated separately as a PM but still merits some discussion here. The Apportionment Agreement with Saskatchewan does not dictate a strict daily minimum flow; rather it requires that approximately 50% of annual natural flow volume proceed into that province. There is a small window of exception for this 50% measure (shown below in Figure 6), as long as a daily minimum of 42.5 m^3/s (1500 cfs)[14] is maintained every day. If the flow dips below this daily threshold even once, the requirement immediately jumps back to 50%. Figure 6 shows Alberta's apportionment performance for the SSRB from 1970–2009.

[14] This number is the sum of the flows from the Oldman, Bow and Red Deer rivers at their confluence, just inside the Saskatchewan border.

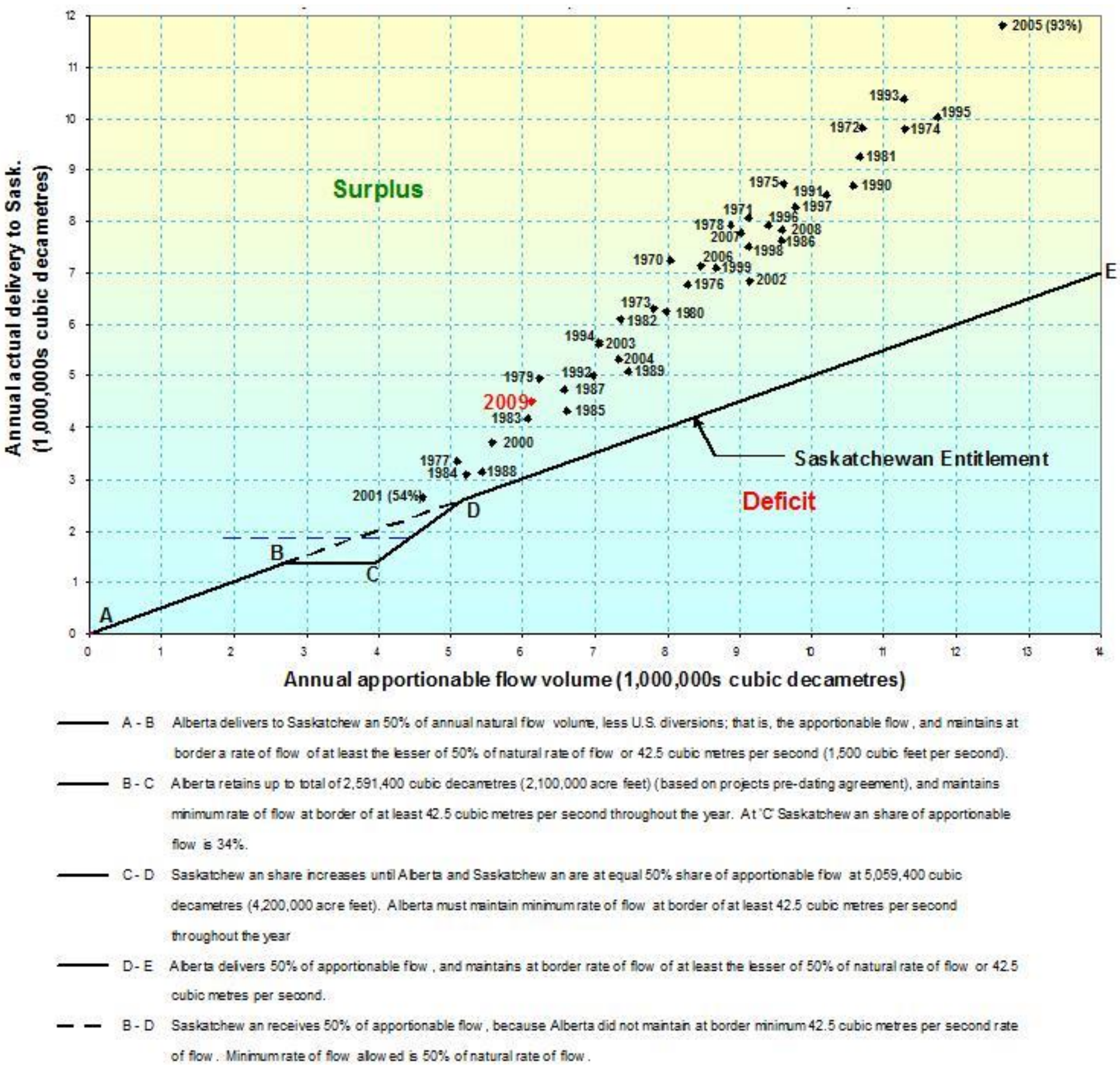


Figure 6: Alberta SSRB Apportionment Performance, 1970-2009

Note: The horizontal dashed line illustrates what happens when the minimum flows of 42.5 m^3/s on the South Saskatchewan River and 16 m^3/s on the Red Deer River are maintained as minimums regardless of natural flow.

Alberta Environment and Parks data, 1970-2001; Prairie Provinces Water Board data, 2002-2009. Source: Work done by Dave McGee, Sal Figliuzzi, and Doug Ohrn with the provincial department that is now Alberta Environment and Parks, from 2003-2012.

The Climate Variability "Frankenflow" Dataset
A set of plausible future SSRB water supply and demand scenarios was needed to further test and refine potential adaptation strategies. To do this, a "Frankenflow"[15] dataset of streamflows, demands and returns in the SSRB was created.

The logical method for the demands and return datasets was to rely on the previously completed climate variability work for each of the sub-basin models in which historical demands and returns were averaged monthly over the entire 1928–2009 record. These average monthly demands were then applied for all "future" model runs. Since they are averages, however, the demand for water is likely under-represented during dry years and over-represented during wet years since water use by irrigators and municipalities varies according to precipitation amounts. The OSSROM working group participants requested that a measure be taken to correct for this (demands increased 25% in dry years, decreased 25% in wet years), but it was not deemed necessary for other sub-basins. This correction in the Oldman and Southern Tributaries was applied in SSROM.

Daily naturalized streamflow from 1953 was used in the sub-basin models (RDROM, OSSROM, and BROM) to provide a flood scenario. This year represents the second highest peak daily streamflow for the whole SSRB. Drought years applied the lowest three years on record for the whole SSRB, which were 1977, 2001, and 1941, from lowest to highest, respectively. Normal years are represented by the median annual average streamflow over the 81-year time period +/- 5%. A 15-year time-series was derived, which follows the general trend of 1 normal year, 1 flood year, 3 normal years, 3 drought years, 3 normal years, 1 drought year, 3 normal years (Table 3). The drought years used in Frankenflow are scaled by 0.63, which is an extreme low annual flow scenario from previous work with the BROM, OSSROM, and RDROM. See Appendix E for more details on derivation of the Frankenflow time series.

Table 3: Years used in the Frankenflow time series

Year in the 15-year time series	Year(s) used
1 normal year	1946
1 flood year	1953
3 normal years	1963, 1946, 1950
3 drought years	1977, 2001, 1941
3 normal years	1950, 1963, 1946
1 drought year	1977
3 normal years	1946, 1950, 1963

Note: Drought years were scaled based on droughts used in the future climate scenario work.

The final Frankenflow time series is demonstrated at an annual scale in Figure 7 and at a daily scale in Figure 8. This time series of inflows was used to challenge and advance the development of adaptation strategies in the face of drought and flood for the whole SSRB.

[15] Called "Frankenflow" because the components were stitched together to create a realistic but artificial dataset.

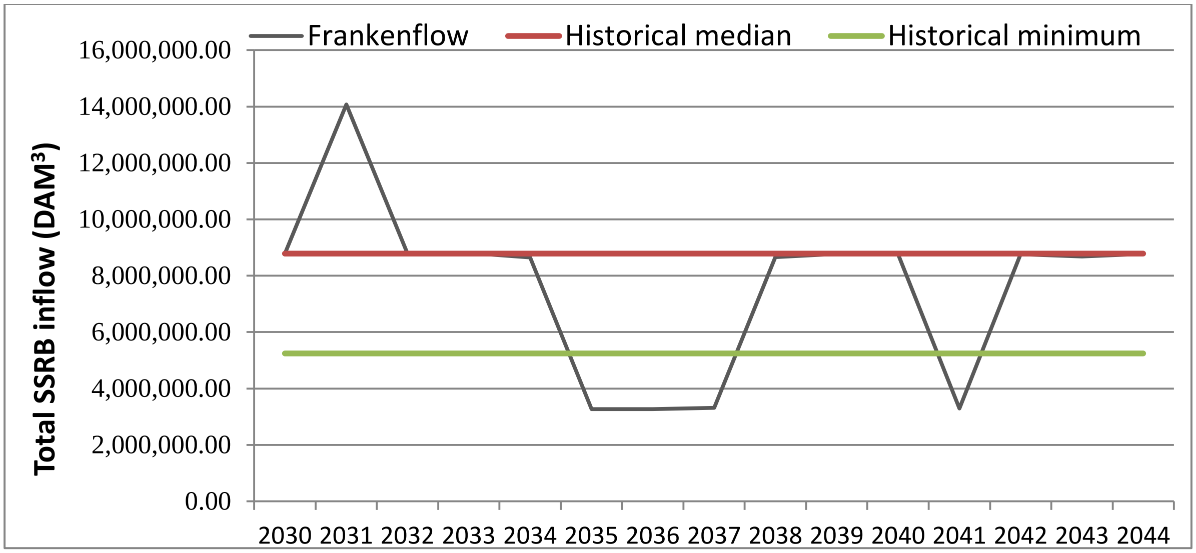


Figure 7: Frankenflow time series at an annual scale

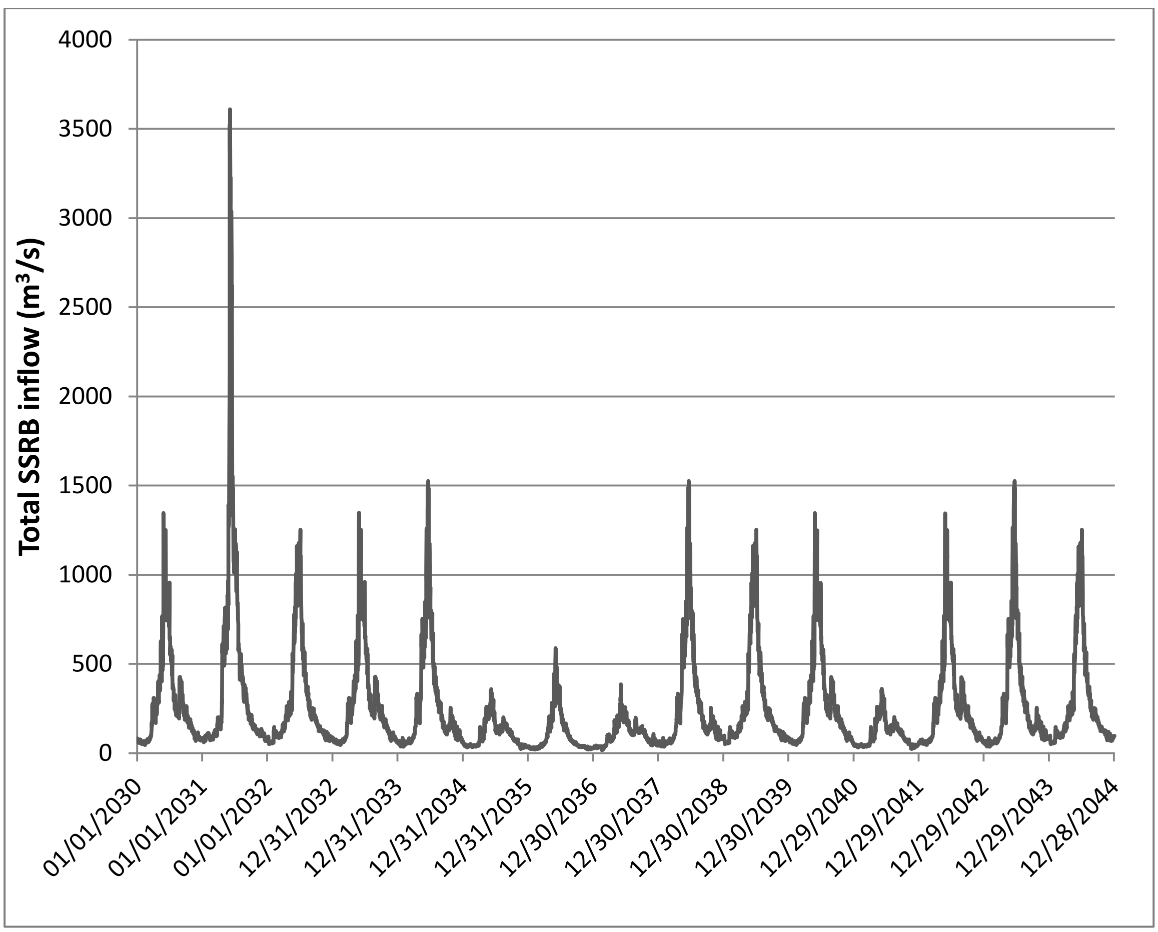


Figure 8: Frankenflow daily time series for the 15-year period from 2030–2044

Four switches were then developed that could be applied or not to the Frankenflow data scenario to reflect changes in specific conditions in the SSRB. This allowed the working group to explore how the system might be further stressed over and above the range of climate variability. The switches reflect changes in:

- Prairie wetland restoration.
    - This switch was developed using the relationship between percent change in annual flow and percent watershed existing as wetland, derived by Pomeroy et al. (2014) and was implemented in ALCES Online to derive potential flow change scenarios as a function of wetland loss.
- Major forest disturbance in the headwaters.
    - This switch was developed using forest age data from ALCES Online, where younger forests had higher runoff coefficients relative to older forests. A major forest disturbance was assumed to result in a younger forest; therefore, it had a higher runoff coefficient and higher streamflow as a result.
- Growth in water demands in each of the sub-basins. This was created using the following assumptions suggested by the working group:
    - Red Deer: licence allocation of 550,000 dam^3/year
    - Bow: 50% closer to full Calgary licence allocation than current use
    - OSSK: 50% closer to full municipal licence allocation than current use for Lethbridge, Taber, and Medicine Hat.
- Change in St. Mary inflow due to changed entitlement flows from the US (approximately 35% less inflow than current in “normal” conditions).
    - This was developed using the same methods as previous work (Alberta WaterSMART, 2014b), which was based on the 1921 IJC order.

SSROM Performance Measures

The SSROM project maintained all PMs from previous projects; the full lists are found within individual project reports and key PMs were noted in section 2.3. PMs were also developed to observe both major areas of impact in sub-basins as well as full system effects for the SSROM in four categories. Only a sub-set of the most significant of these PMs is used in this report.

Water supply PMs:

- Total SSRB-Wide Shortages by Sub-basin and Type of Demand – Municipal/Irrigation/Other (intended to capture raw economic performance in the whole system)
- Total Shortage as a Percentage of Total Demand (another way to look at direct performance)
- Average Annual Movement of Water between Sub-basins (to see the effect of any new intra-basin transfers)

Environmental PMs:

- Below Bassano/Carseland Low Flow Days (a surrogate for Bow River environmental performance)
- Percentage of Weeks where Average Weekly Flow at the Mouth is Less than the WCO Flow Threshold (intended to capture environmental performance in the Red Deer system)
- Percentage of Days where 45% of Naturalized Flows are Met or Exceeded (an ecological health indicator)

- Minimum Flow Violations (to ensure no worse performance for river needs)
- Number of Days where Total South Saskatchewan River Flow at the Border is Less than 20% of Mean Annual Discharge (an ecological health indicator)

Flood PMs:

- Maximum Flow Violations (to check against basic flood performance, recognizing that this daily PM will not identify hourly peaks)

Apportionment PMs:

- Number of Years where Apportionment is Violated (to check apportionment)
- Annual Volume of Water from the South Saskatchewan and its Sub-basins as a Percentage of Naturalized Flow (to see relative contributions to apportionment flows)
- Contribution to Total South Saskatchewan by Source Sub-basin (another way to see relative contributions by source)
- Number of Years where the Total South Saskatchewan Minimum Flow is Violated (to see how many times the minimum 42.5 m^3/s (1500 cfs) was violated even if apportionment was not for the year)
- Average Annual Volume of Water Flowing Out of each Sub-basin that is in Excess of 50% of Naturalized Flow (to determine contribution over required apportionment flow)

Performance measures used in the following sections were derived from previous work and have maintained the unit convention. The reader should be aware that both metric and imperial units are used, as the various PMs were developed for specific interpretations.

3. SSRB Adaptation Roadmap for Sustainable Water Management

A great deal of attention has been focused on water management in southern Alberta over many decades. In seeking the best solutions to sustain prosperity and quality of life in the SSRB, water management issues are a potential limiting factor, and must be top of mind for residents, elected officials, and other decision makers.

Throughout the modelling of the sub-basins, many dozens of potential adaptation strategies were proposed and tested, individually and in combination. All working groups acknowledged the often substantial value of combining strategies to maximize efficiencies and improve environmental, economic, and social benefits.

3.1 Notable Basin Dynamics

While discussing adaptation strategies and opportunities, a number of notable aspects related to basin dynamics in the SSRB emerged or were reinforced from prior work. They have a direct or indirect effect on water use and management in the basin and are briefly noted here to provide additional context for the strategies that are described later in this report.

The observed flows from the US in the St. Mary River have been considerably higher than the volumes to which Alberta is entitled.

The Boundary Waters Treaty establishes the terms and conditions under which Alberta and Montana share water. Alberta's water entitlement to the St. Mary River system was noted under this agreement and the subsequent 1921 IJC Order. Alberta has historically received more water through the St. Mary River system than it was entitled to, because Montana lacks diversion and storage infrastructure. Figure 9 compares the natural flow in the St. Mary River to Alberta's historically received flow and its entitlement flow under the IJC Order.

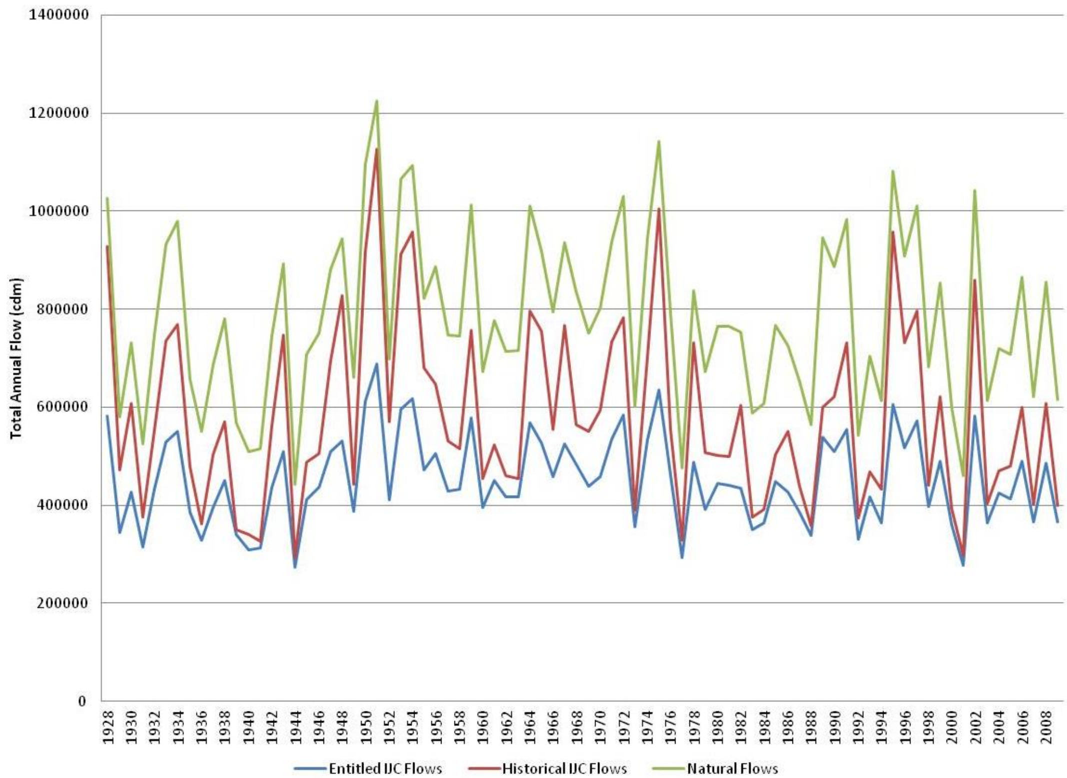


Figure 9: Total annual flow from the St. Mary River

The blue line represents the minimum entitled IJC flow, the red line represents IJC flow historically observed during the period, and the green line represents naturalized flow at the US–Canadian border if no diversions took place on the US side.

As the figure shows, in low flow years such as 2000 and 2001, Montana withdrew almost its full entitlement. Conversely, in normal and high flow years, Montana's withdrawal was proportionally lower. If Montana takes its full allotment, the volume of water coming into Alberta will be substantially reduced and water management decisions will need to take this into account. Adaptation strategies were developed using a conservative approach in which the modelling assumed the IJC flow to which Alberta is entitled was received, not the flow that has historically been received.

Apportionment requires ~50% of annual flow by volume be passed to Saskatchewan.

Under the Master Agreement on Apportionment, 50% of the annual flow by volume of eastward-flowing rivers must be passed from Alberta to Saskatchewan. Historically, the average annual flow to Saskatchewan has been more than 75%. Fifty percent is a minimum and reflects choices and trade-offs of water use, but the river ecosystem benefits from these higher, closer-to-natural flows. Each sub-basin contributes to meeting the Apportionment Agreement. Figure 10 shows the contribution from each sub-basin to meet the apportionment requirement.

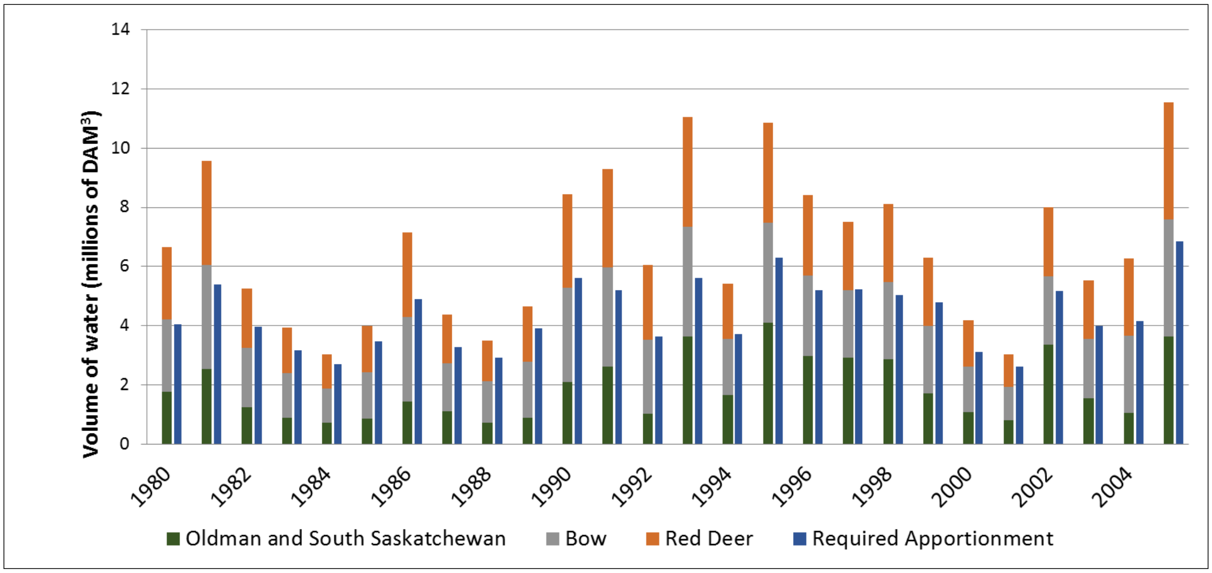


Figure 10: Contribution to total South Saskatchewan flow by source sub-basin (historical)

Further reducing minimum flows could negatively affect aquatic ecosystems.

Many river reaches in the SSRB are already stressed and strategies that contemplate further reductions to minimum flow rates during times of drought could have serious impacts on the aquatic ecosystem. For example, an established minimum flow rate of 400 cfs (11.3 m^3/s) below Bassano Dam takes into account the higher flows needed downstream from Calgary to enable the EID to take its licensed allocation of water for irrigation and municipal purposes and still meet this flow rate. The original BROM project recommended that this minimum flow be increased substantially and showed how this could be done using a relatively small water bank held in TransAlta reservoirs upstream and released to improve minimum environmental flows throughout the Bow system to and below the Bassano Dam.

During a prolonged or extreme drought period, one of the mitigation strategies was to reduce the minimum flow through Calgary for short periods of time. The current 1250 cfs (35.4 m^3/s) minimum flow through Calgary helps sustain fish habitat through the winter and helps with wastewater dilution and maintenance of minimum dissolved oxygen levels. It also helps maintain a stable ice regime so that stormwater outlets can continue to function in case of a chinook or winter run-off event, apart from direct damages that might occur due to ice jams. There is also minor benefit for one of the city's two water intakes as it is more likely to function properly with flows above the threshold. Depending on the reduced flow rate contemplated, this could have serious consequences for water quality downstream and eventually could significantly stress the aquatic ecology of the river system. On the other hand, maintaining current minimum flows in a prolonged drought could risk much lower levels once the upstream reservoirs fall below their operating levels.

Municipal minimum flows at some level are necessary to dilute even tertiary treated wastewater effluent and to protect other environmental conditions and values. Return flows from Calgary may average well over 80% year around, but during summer months this return rate often drops, largely due to irrigation of lawns, parks and recreation areas. During a dry or drought period, lower minimum flows from TransAlta at the Bearspaw Dam entering Calgary's reach of the river combined with WID withdrawals and slightly reduced return flow from the city can have negative downstream effects on the environment due to a greater concentration of nutrients. Low flows and high water temperature can affect fisheries and the ability of irrigation districts to take water for food production. This illustrates again the need for a more comprehensive and system-wide approach to managing the component parts of the SSRB as an interdependent system rather than a series of isolated and single-purpose sections of river (e.g., hydropower, recreation, human water supply, livestock water supply, recreational fishery, food production, riparian health and wildlife corridors, and quality of life). All are important, all are interrelated, and many are synergistic if the rivers were managed with this in mind.

The EID and WID return flows to the Red Deer River contribute significantly to meeting that system's WCOs.

Water taken by the EID and WID from the Bow River but returned to the Red Deer River plays a surprisingly important role in the lower Red Deer system, especially in times of low flows. This only became evident when the sub-basin models were integrated into the SSROM. The Red Deer presently has little difficulty maintaining the 10/16 m^3/s (summer/winter) minimum flow of the WCO, but when the full licence allocation scenario used in SSROM is applied, the WCO is violated in a number of weeks (Figure 11). This is primarily because most existing licences are senior to the WCO. To explore the return flow impact, the EID and WID return flows were removed completely or reduced to only 10%, resulting in WCO violations increasing by about 75%. To demonstrate the acute difficulties during these periods, Figure 12 shows flows at the Red Deer mouth during 1929–1930 of the historical run.

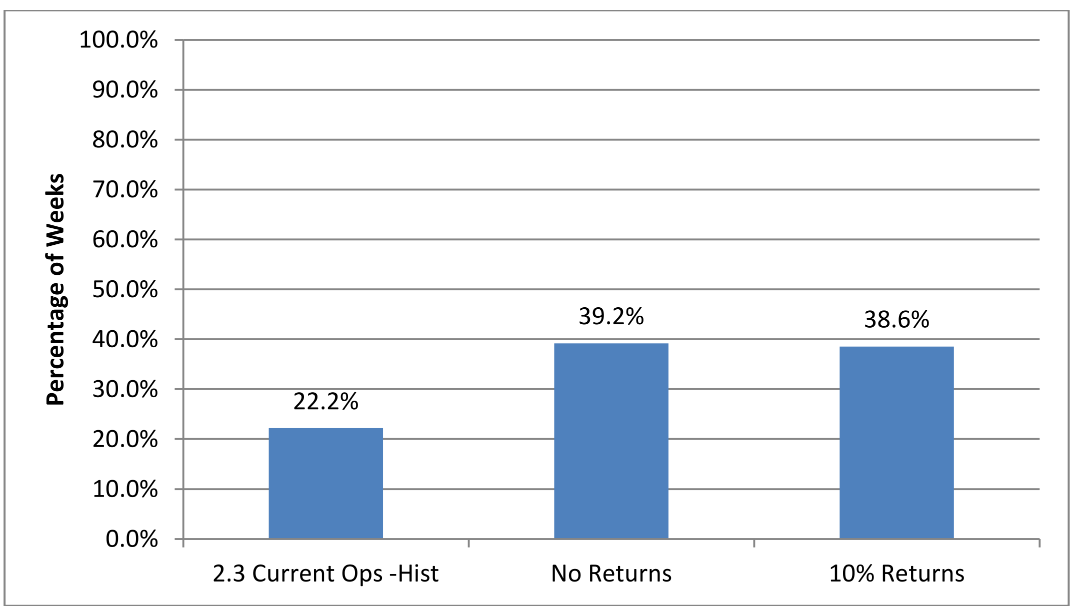


Figure 11: Percentage of weeks in the historic record where average weekly flow at the mouth is less than the WCO flow threshold in the Red Deer system

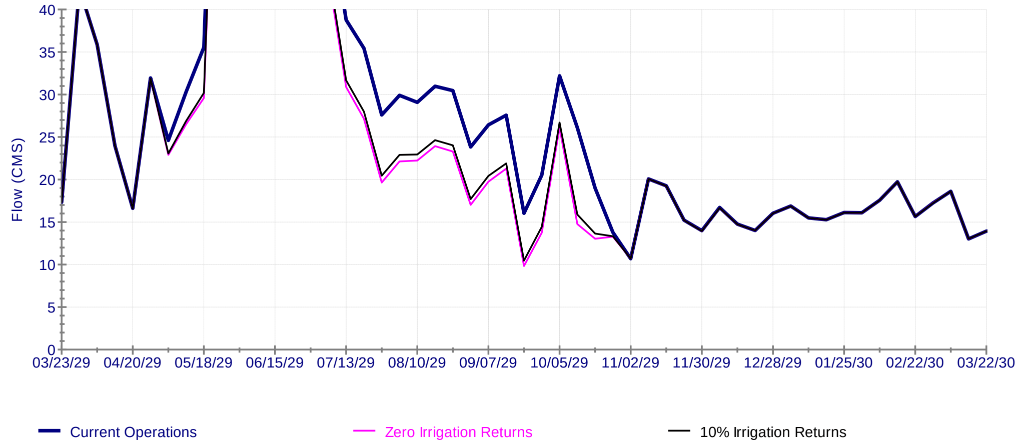


Figure 12: Flows at the Red Deer mouth, 1929–1930 of the historical run
To see the results of interest (low flows) at an appropriate scale, the upper part of the figure is cut off.

During certain times of the year, especially during relatively dry years in the Bow sub-basin (causing greater use of the available water) or the Red Deer sub-basin (reducing base flows), or both, unused water from the WID and EID taken from the Bow and normally redirected to the Red Deer would likely be reduced at exactly the time it may be most needed for environmental purposes in the Red Deer. As irrigation districts achieve continued conservation and efficiency, it is likely that these return flows will fall in the coming years. If the WCO is to remain a top priority, operators will have to be attentive to this trend.

Irrigation district expansion will continue to be enabled through improved conservation, efficiency and productivity, not through increased withdrawals from the rivers.

Irrigation is the major water use in southern Alberta and has played an important role in Alberta's agriculture sector for over a century. Irrigation districts are major water users, holding licences for 85% of the water allocated in the OSSK sub-basin and for 75% of allocations in the Bow sub-basin. They continue to make efficiency improvements, which has enabled them to expand their acreage and amend their licences to allow their allocated water to be used for other purposes. The GoA's 2014 Irrigation Strategy[16] describes five key strategies for the future of the industry: productivity, efficiency, conservation, water supply, and environmental stewardship. The irrigation sector, through the Alberta Irrigation Projects Association, has published a Water Conservation, Efficiency and Productivity (CEP) Plan, which describes the commitments made by the industry.[17] Improvements in water CEP rather than increased water withdrawals will be the basis for future irrigation district expansion.

[16] Available online at http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/irr14885/$file/2014-alta-irrig-strategy.pdf

[17] This report is available on the AIPA website at http://www.aipa.ca/wp-content/uploads/2013/11/AIPA-CEP-Final-Version-1.pdf.

Building new water management infrastructure should build adaptive capacity; it should not lead to new licence allocations in closed sub-basins.

Although opportunities for new infrastructure were considered as part of adaptation to climate variability, participants pointed out the need to maintain current allocations in closed sub-basins. Increased storage capacity could make it tempting to increase allocations, but storage does not make more water available in a watershed. Given the real risk to current licensed water users from both historic and climate variability scenarios of water supply, additional storage and other infrastructure improvements were considered as reducing risk rather than enabling additional licensing. Current licensees that are not using their full allocation should also be given incentives to refrain from using a greater percentage of their licence to the extent possible. Under the *Water Act* and regulations it may also be advisable as a risk mitigation tool to recover certain wholly unused licence allocations in accordance with the Alberta Water Council's 2009 report, *Recommendations for Improving Alberta's Water Allocation Transfer System*.[18]

Connections among sub-basins mean that building new infrastructure in one sub-basin could yield benefits in another.

Integrating work across the entire SSRB underscored the importance of looking at and understanding the connections and interactions among the sub-basins. This was particularly highlighted when considering the advantages that could accrue to one sub-basin by building new infrastructure in another sub-basin. For example, new storage capacity built in the Lower Bow to catch any flow above minimum flow and apportionment requirement could benefit the Oldman system. In addition to the modelled benefits to the Bow system, the new storage could be used to meet minimum flows and apportionment requirements rather than drawing on the existing Oldman reservoirs, potentially enabling greater resilience and mitigation of a dry period or multi-year drought in the south.

Operations of TransAlta reservoirs on the Bow interact with many of the other potential adaptation strategies for this river system.

Nearly all of the large scale, near-term flood and drought mitigation options on the mainstem of the Bow are related to how the TransAlta reservoirs are operated. Stated in its most simple and direct form, water management on the Bow River must engage and involve the operation of TransAlta's upstream reservoirs and hydro operations. Even if various proposed "dry dams" are built on the Bow and some tributaries, TransAlta operations would still have a strong bearing on if, when and how these other structures could be used. TransAlta owns and operates 11 hydro generation facilities upstream of Calgary, encompassing five reservoirs of significant size including, from the lowest site in the system to the highest, Ghost, Barrier, Upper Kananaskis Lake, Spray Lake, and Lake Minnewanka.

The TransAlta reservoir system is highly interdependent over the course of any given year, although each upstream reservoir can store and release as needed until it impinges on the

[18] Available on the Alberta Water Council's website at: http://www.awchome.ca/LinkClick.aspx?fileticket=fVWx%2b%2b%2fwG3A%3d&tabid=59

capacity of the lower system to fill or release. For example, if all the reservoirs upstream of Ghost released at full capacity, Ghost may be unable to manage all the inflows and be forced to use the emergency spillway in addition to the turbines and dam spillways. The consequences for Bearspaw Dam downstream may be catastrophic. This is a condition to be avoided by managing all the reservoirs in combination, depending on inflows and reservoir elevations (available storage), rather than as independent entities based on various physical contingencies, power prices and the complexities of ancillary services provided mostly by the Spray group of facilities.

The forecasting window in the SSRB is extremely short; investment in forecasting resources and systems are imperative for ongoing adaptation.

There are many risks and trade-offs to be considered in system-level water management. To manage flood and drought risks, a more comprehensive and multi-factor forecasting system is needed to guide water managers and regulators. This is true of all the sub-basins in the SSRB, but the most urgent need is for drought and flood management on the Bow system. Some of these factors include the obvious ones of snowpack, reservoir levels, streamflow data, and rainfall forecasts throughout the system compared with similar previous years, combined with licence allocation data and historic use patterns. Possibly the most important forecast for flood mitigation is reliable rainfall forecasts and accurate precipitation monitoring at a small grid size to allow for more advanced flow modelling and warning of coming flooding conditions. Other existing but perhaps less well-known data sources are available to inform water management decisions, such as soil moisture content in the foothills and in the agricultural areas as well as shallow groundwater levels in the upper basin. Depending on the time of year, other factors include the composition of agricultural crop acreage; crop planting plans, timing and expected water demands for irrigated crops; seasonal demands for municipal use and expected return flows; livestock numbers and type and their expected water demands; industrial water use and operational vulnerability (e.g., meat packing, thermal power, or fertilizer production); water quality data; short-, medium- and long-term precipitation forecasts and trends; and hydropower demand and pricing.

The uncertain length of a drought makes it challenging to develop management responses.

Once a drought begins, it is impossible to know how long it will last, and this makes water management very challenging. Irrigation districts, for example, will typically aim to maximize yield from the crop that is already in the ground rather than cut back in the first year of a drought to reserve more water to carry over in case a dry year occurs next year. Management options become more limited the longer a drought lasts. The recent California and Australian droughts provide clear evidence of this and illustrate the need for early action, careful stewardship of the remaining stored water, and improving the forecast system. Most of the existing infrastructure in the SSRB is sized for a one-year operational cycle—that is, one year of filling and emptying. This would accommodate a one-year drought and, in some cases, with prudent management could provide help for two years, but by the third year, the reservoirs may be empty or nearly so. Once the reservoirs are unable to continue supplying water, streamflow would be seriously depleted leading potentially to great harm to fisheries and environmental conditions generally, and to significant shortages for both rural and urban water users. Everyone would be affected.

Flood mitigation and drought mitigation can be achieved in the same season, but not at the same time using the same infrastructure capacity.

A number of the more promising adaptation strategies seek to achieve a balance between mitigating flood and mitigating drought. However, there is a natural tension between these two situations, and planning for one can increase the risk of being unprepared for the other. For example, filling a reservoir in the spring to be ready to meet downstream needs could mean that there is no room to retain water in the event of a flood. Keeping a reservoir well below full supply level (FSL) to accommodate possible flood flows could result in a shortage for downstream users later in the year if a flood does not materialize and rainfall is limited. However, a structure such as the Eyremore Dam (a Level 3 strategy) would have enough time to make pre-releases as a major rain event was happening in the headwaters, so it would offer significant flood mitigation capacity.

Under some conditions it is quite possible to have both a flood and a drought in the same year. This risk is greater if the snowmelt and flood flow come earlier in the year as is often forecast by climate change models. Accurate forecasts based on a variety of factors described previously are an essential component of adaptive basin management that balances flood and drought risks and mitigation actions.

3.2 Adaptation Roadmap for the SSRB

The Adaptation Roadmap for Sustainable Water Management in the SSRB is shown in Figure 13. It includes adaptation strategies ranging from operational changes, to natural functions to new infrastructure to policy options, which are ultimately designed to increase the SSRB's adaptive capacity to changing inflows and demands.

Through a series of projects since 2010, a large number of adaptation strategies were considered for each of the sub-basins in the SSRB. Some of these suggested strategies are already underway but more work is needed. The most promising strategies for each sub-basin emerged through collaborative modelling and discussion. All the adaptation strategies that were explored have been documented and described in the relevant sub-basin project reports. Participants in this project were asked to identify and consider strategies that could offer potential benefits between sub-basins and across the full SSRB.

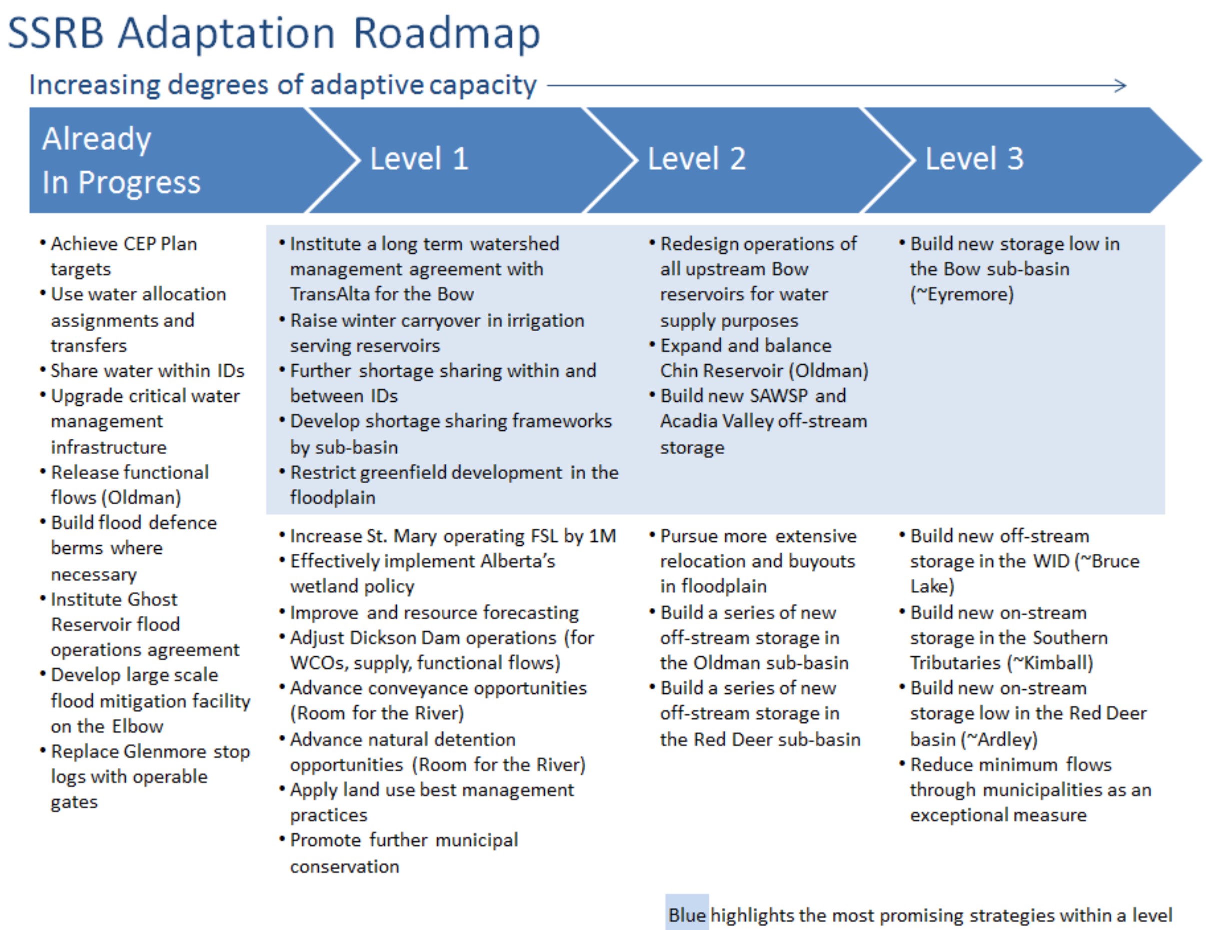


Figure 13: Schematic of the SSRB Adaptation Roadmap demonstrating all three levels of adaptation as well as what is already in progress

Strategies were then grouped into three levels that reflected "degrees of adaptation." The Levels are not meant to be read chronologically and are not related to time; rather, they reflect an increasing level of adaptive capacity with those in Level 1 viewed as the most feasible options for increasing the adaptive capacity of the SSRB. Levels 2 and 3 include additional strategies that could be pursued to build more adaptive capacity into the basin's water management systems. Based on the modelling results, some strategies within each Level were further categorized as "most promising." Firm criteria were not established or used to identify "most promising" strategies. However, through the course of discussion, typically-used considerations of relative simplicity, perceived cost, beneficial impact and contribution to resilience were used to distinguish the "most promising" strategies from the others within a Level.

Although the strategies and text in this report use the term "build" with reference to infrastructure, this should not be interpreted as a recommendation or advice to construct that infrastructure; no construction would be started before detailed studies are undertaken.

The strategies that are already underway and those in each of the three Roadmap levels are listed in Table 4, along with other sources that discuss the strategies further or provide related information; references for these sources are shown below the table. Strategies with an asterisk (*) are not currently modelled in the SSROM, typically due to limited data. Less promising strategies from the SSRB integration project and strategies from previous sub-basin work are shown in Appendix F.

Table 4: Individual adaptation strategies

Strategy	Sub-basin	Other sources
Strategies in progress but still needing work		
Achieve municipal and agricultural Conservation, Efficiency and Productivity Plan targets	Basin-wide	1, 2
Use licence assignments and transfers to optimize use of water allocations*	Basin-wide	3
Temporarily share or assign water within irrigation districts in dry seasons	Bow, OSSK	5, 10
Upgrade critical water management infrastructure to minimize damage and ensure operation in case of floods (Bassano,* Travers, Taylor Coulee Wasteway,* Bullhorn Wasteway*)	OSSK	5
Release functional flows from the Oldman and St. Mary dams	OSSK	5, 15, 16
Build flood defence berms in the Red Deer, South Saskatchewan and Bow sub-basins where necessary*	Basin-wide	6, 9
Develop a large scale flood mitigation facility on the Elbow River (SR1, MC1, tunnel)* *(The GoA announced on October 26, 2015 it would be proceeding with the off-stream reservoir at Springbank, referred to as SR1.)*	Bow	6
Replace Glenmore Dam stop logs with operable gates	Bow	6
Level 1:		
Most promising strategies		
Institute a long-term, flexible and comprehensive water management agreement for drought mitigation, flood mitigation, and watershed health with TransAlta, including: water bank for river basin management purposes, flexibly stabilizing Lower Kananaskis Lake and Kananaskis River, flood mitigation using Ghost Reservoir and other reservoirs, functional flow releases as needed for riparian and fisheries health, and adjusted fill times for Minnewanka, Spray, and Upper Kananaskis Lakes	Bow	4, 5, 9, 15, 16
Raise winter carryover in existing irrigation-serving reservoirs (start with Travers which draws water from the Bow, then investigate feasibility for the St. Mary, McGregor and other reservoirs)	Bow, OSSK	5
Implement further forecast-based shortage sharing (including agreed-upon temporary reductions in diversions and voluntary assignments of remaining licence allocations in times of drought), within and between irrigation districts	Bow, OSSK	5, 12
Develop basin-wide shortage-sharing and reallocation frameworks to inform and enable severe drought mitigation*	Basin-wide	5, 10, 13
Restrict greenfield development in the floodplains to reduce flood damage and develop strict regulations against changing the nature of brownfield developments*	Basin-wide	6, 9, 14
And		
Increase St. Mary Reservoir operating FSL by 1 metre	OSSK	5

Strategy	Sub-basin	Other sources
Effectively implement Alberta's Wetland Policy*	Basin-wide	11
Improve resourcing for and effectiveness of forecasting infrastructure, systems and teams*	Basin-wide	4, 6, 12
Adjust Dickson Dam operations to consider downstream needs (retain WCOs, functional flows, some new demands)	Red Deer	9, 15, 16
Advance Room for the River conveyance opportunities in the Bow and Red Deer sub-basins*	Bow, Red Deer	7, 8
Advance Room for the River natural detention opportunities in the Bow and Red Deer sub-basins*	Bow, Red Deer	7, 8
Further apply land use best management practices*	Basin-wide	4, 5, 9
Promote further municipal conservation relative to what is being done now	Basin-wide	4, 5, 9
Level 2: Most promising strategies		
Redesign operations and expand, where beneficial, existing reservoirs in the upstream Bow for water supply and watershed health*	Bow	4
Expand (74,000 dam^3) and fully balance Chin Reservoir (285,000 dam^3)	OSSK	5
Build new SAWSP and Acadia Valley off-stream storage (35,000 dam^3 SAWSP + 45,000 dam^3 Acadia = 80,000 dam^3 total)	Red Deer	9
And		
Pursue more extensive relocation and buyouts in the Bow and Elbow floodplains to reduce risk and reduce the need for upstream mitigation structures*	Bow	6, 14
Build series of new off-stream storage facilities*	Oldman	5
Build series of new off-stream storage facilities (~80,000 dam^3)*	Red Deer	9
Level 3: Most promising strategies		
Build new on-stream storage low in the Bow system, below Bassano Dam (~Eyremore site, ~477,000 dam^3)	Bow	4
And		
Build new off-stream storage in the Western Irrigation District (Bruce Lake, ~51,000 dam^3)	Bow	4
Build new on-stream storage in the Southern Tributaries balanced with other reservoirs (~Kimball site, ~125,800 dam^3)	OSSK	5
Build new midstream storage (~Ardley site, ~400,000 dam^3)	Red Deer	9
Reduce minimum flows through municipalities and other downstream users as an exceptional measure in drought years to slow the draining of upstream reservoirs	Basin-wide	4, 5, 9

1 Alberta Irrigation Projects Association. nd. Irrigation Sector Conservation, Efficiency, Productivity Plan 2005 – 2015.

2 Alberta Urban Municipalities Association. 2009. AUMA Water Conservation, Efficiency and Productivity Plan.

3 Alberta Water Council. 2008. Recommendations for Water Conservation, Efficiency and Productivity Sector Planning.

4 Alberta WaterSMART. 2010. Bow River Project: Final Report.

5 Alberta WaterSMART. 2014. South Saskatchewan River Basin Adaptation to Climate Variability Project: Phase III: Oldman and South Saskatchewan (OSSK) River Basins Summary Report.

6 Alberta WaterSMART. 2014. Bow Basin Flood Mitigation and Watershed Management Project.
7 Alberta WaterSMART. 2014. Room for the River Pilot in the Bow River Basin: Advice to the Government of Alberta.
8 Alberta WaterSMART. 2015. Room for the River in the Red Deer River Basin: Advice to the Government of Alberta.
9 Alberta WaterSMART. 2015. Climate Vulnerability and Sustainable Water Management in the SSRB Project: Red Deer River Basin Modelling, Final Report.
10 Government of Alberta. 2009. AENV Water Shortage Procedures for the SSRB.
11 Government of Alberta. 2013. Alberta Wetland Policy.
12 Hydrologics, Inc. 2014. Bow River Operations Support Tool (BROST), Phase I Summary Report.
13 Paterson Earth & Water Consulting. 2014. Drought Strategy for Irrigation Districts in the Oldman River Sub-Basin of Southern Alberta.
14 Pomeroy, J., R.E. Stewart, and P.H. Whitfield. 2015. The 2013 flood event in the Bow and Oldman River basins; causes, assessment, and damages. (in press)
15 Rood. S.B., G.M. Samuelson, J.H. Braatne, C.R. Gourley, F.M.R. Hughes, and J.M. Mahoney. 2005. “Managing river flows to restore floodplain forests,” in *Front. Ecol. Environ*. 3(4): 193-201.
16 Rood, S.B., S. Kaluthota, K.M. Gill, E.J. Hillman, S.G. Woodman, D.W. Pearce, and J.M. Mahoney. 2015. “A twofold strategy for riparian restoration: combining a functional flow regime and direct seeding to re-establish cottonwoods,” in *River Res. Applic.* DOI: 10.1002/rra.2919

The next section presents a comparison of the expected results of each Level of the Roadmap using common PMs to illustrate the magnitude of change obtained from the implementation of each Level. Following that, the remainder of this section provides additional description and specific benefits relevant to each of the strategies within the three Levels.

The work described in this report was recognized as a screening level study, after which most strategies would require more detailed study (e.g., cost-benefit analysis, engineering feasibility studies, environmental impact assessments, socio-economic analysis, consideration of impacts on landowners and First Nations).

3.2.1 Roadmap Results: Comparison of Levels using Performance Measures

This section compares the different adaptive levels to show the increased resilience gained from one Level to the next. Levels are compared using relevant PMs.

The number of low flow days at Bassano and Carseland is a good indicator for ecosystem health and water availability in the Bow River sub-basin. One objective of building resiliency in the SSRB is to decrease the number of low flow days throughout the river system. Resiliency can be achieved through Level 1 of the Adaptation Roadmap with the implementation of the water bank as part of a watershed agreement with TransAlta. Level 3 shows slight increases in the number of days where flow is between 400 and 800 cfs (11.3 and 22.6 m^3/s) in Frankenflow (Figure 14A). This is because the Bow River Irrigation District (BRID) has the capability to take extra water with the addition of the Eyremore reservoir.

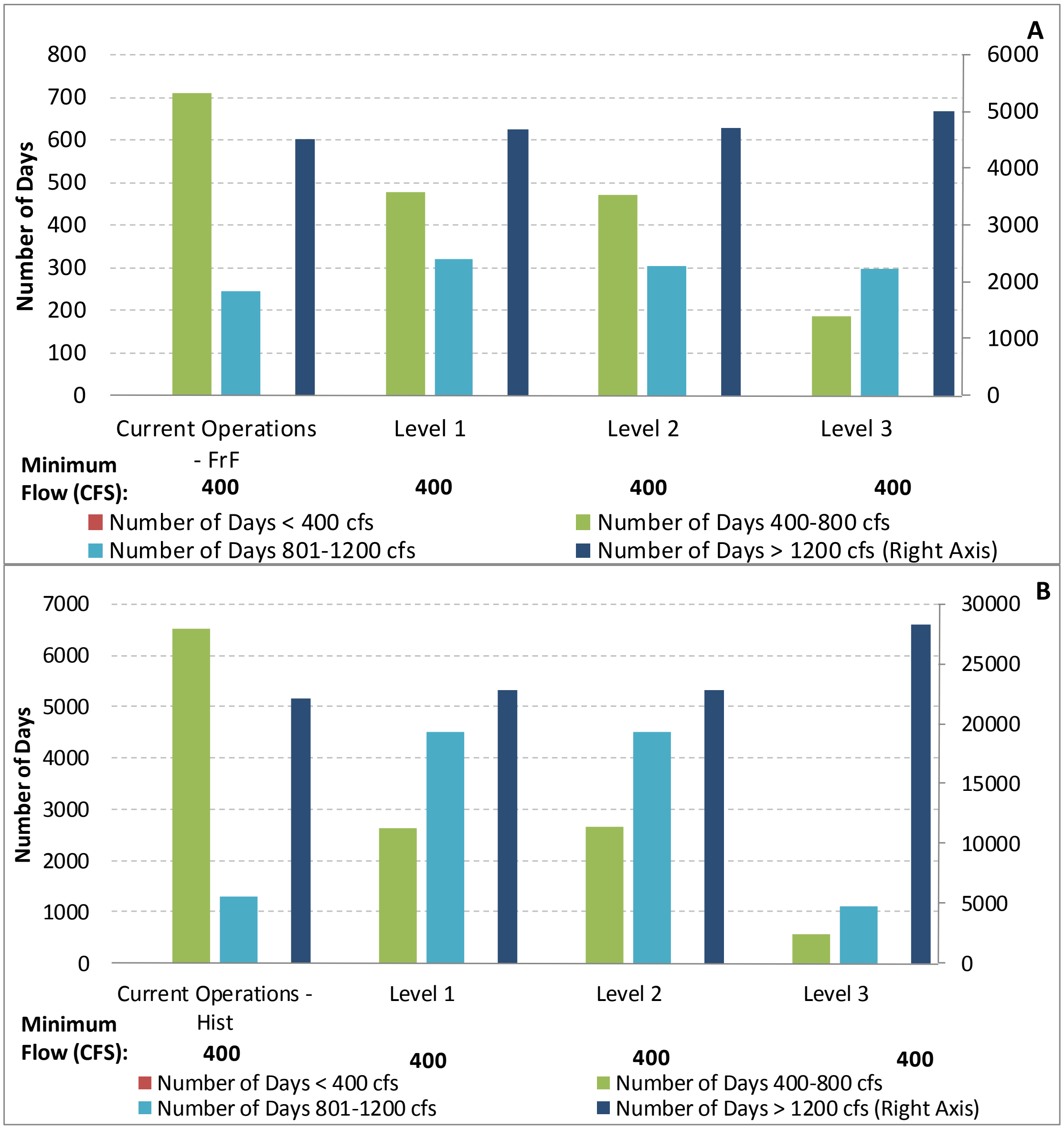


Figure 14: An inter-level comparison of the number of days in flow categories under 15-year Frankenflow (A) and 1928–2009 Historical (B) periods, where the objective is to decrease the number of days in low flow categories

Note: Values shown for current operations, Level 1, and Level 2 are for Bassano; values shown for Level 3 are for Carseland.

The percentage of weeks where average weekly flow at the mouth of the Red Deer is less than the WCO is a good indicator of the capacity of the Red Deer system to expand while meeting required flows during low flow periods (Figure 15). Operational and infrastructure changes implemented from Level 1 to Level 3 demonstrate continual improvement by decreasing the percentage of weeks that are lower than the WCO in Frankenflow (FrF) and the Historical periods. The largest change is noticeable between Levels 1 and 2, with the implementation of new off-stream storage (Figure 15). This allows for greater flexibility and increased capacity to meet demands throughout the Red Deer sub-basin.

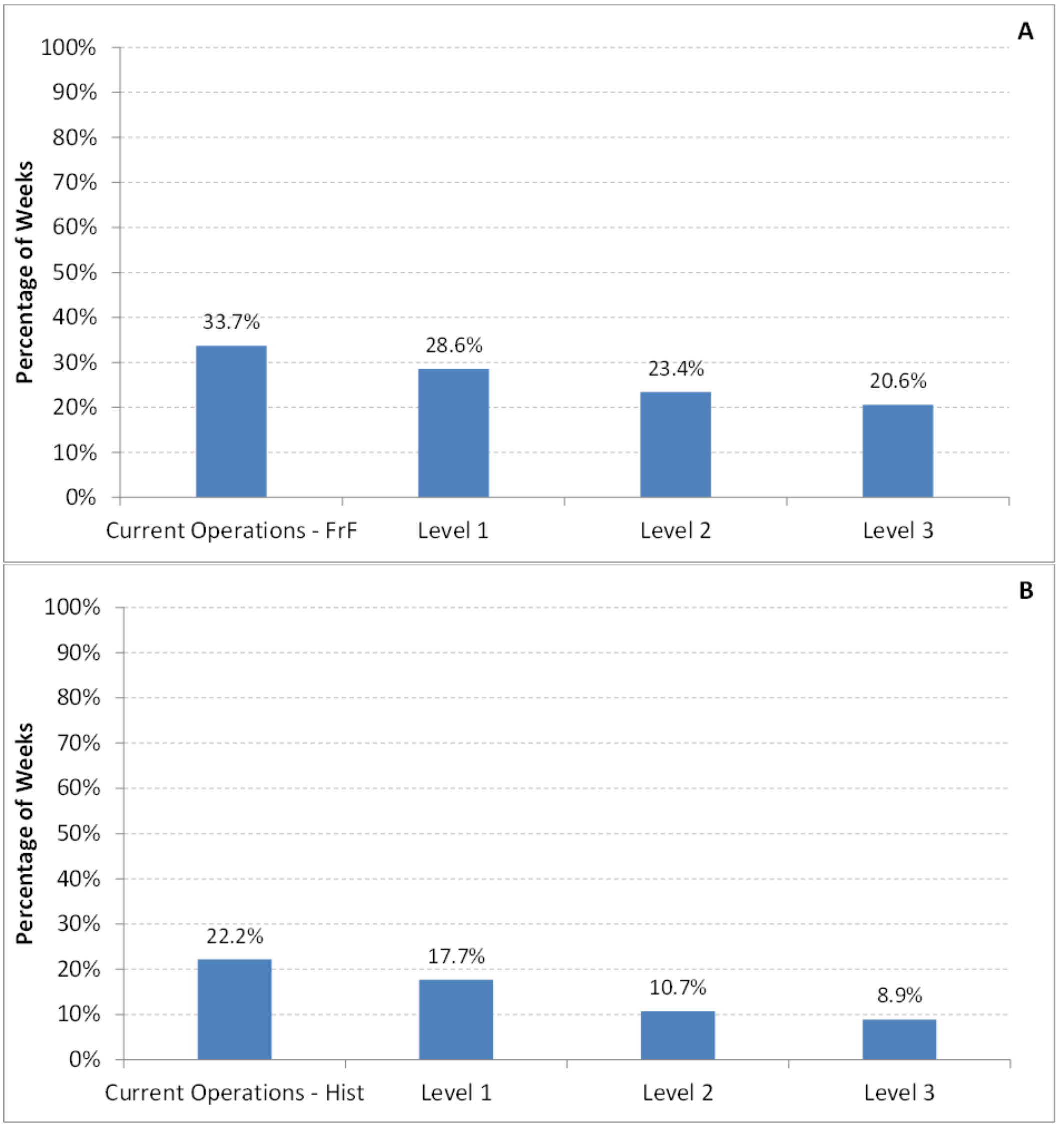


Figure 15: An inter-level comparison of the percentage of weeks where weekly average streamflow (m^3/s) is lower than the WCO (45% of natural or 16 m^3/s from November to March and 10 m^3/s from April to October) at the mouth of the Red Deer River during the 15-year Frankenflow (A) and 1928–2009 Historical (B) periods

Note: The objective is to obtain a lower percentage of weeks below the WCO.

The largest change between Levels in the number of shortages was seen in the OSSK sub-basins. This change in shortages occurred primarily in the irrigation sector (Figure 16), given that irrigation demand was reduced through forecast-based shortage sharing, resulting in less demand for the water. Shortage reductions did not occur in the Bow sub-basin; this finding is important given that environmental performance was improved by allowing more water to remain in-stream during low flow periods.

Irrigation shortages in the Red Deer system were also substantially reduced due to increased off-stream storage. In the Historical period (Figure 16B), shortages go to zero, even at full licence use and with substantial growth to 550,000 dam^3 with new demands. Only a slight reduction in shortages occurred during Frankenflow, indicating that under extreme drought situations the effects of increased storage can be exhausted.

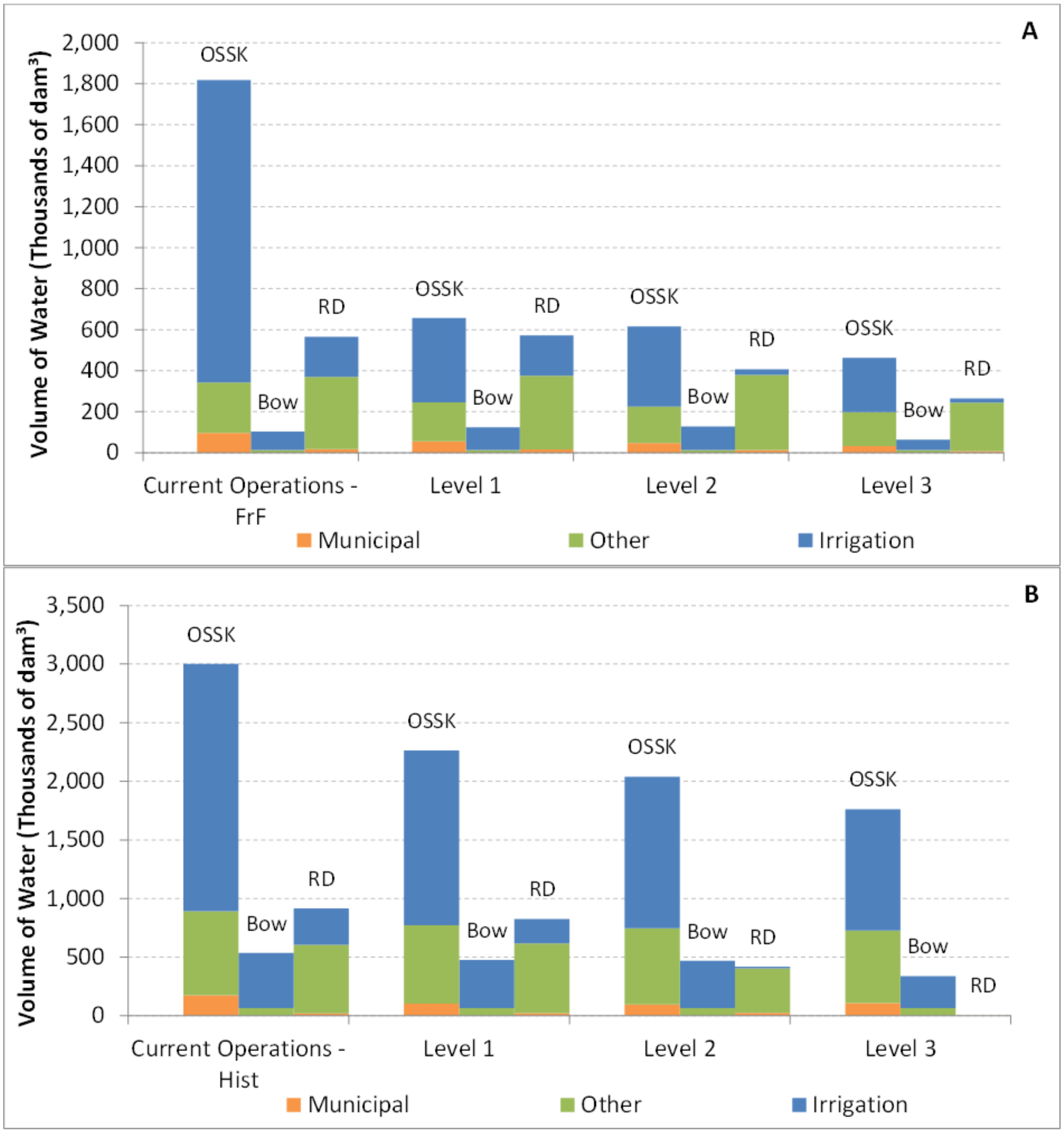


Figure 16: An inter-level comparison of the volume (dam^3) of shortages to municipal (orange), other (green), and irrigation (blue) users in all three sub-basins during the 15-year Frankenflow (A) and 1928–2009 Historical (B) periods

Note: The objective is to decrease the volume of shortages.

In addition to shortages, environmental minimum flow violations are an excellent metric for evaluating system performance. Figure 17 presents the minimum flow violations for the Red Deer, Bow, and Oldman systems and demonstrates that violations can be reduced under Level 1. Although Level 1 has a number of benefits, changing the operational scheme can have unintended consequences; for example, Level 1 operations also increase minimum flow violations in the Bow. This is only apparent in the Frankenflow simulation and when the TransAlta reservoirs are releasing extra water preceding a drought year. This extra release reduces available storage to meet minimum flow targets on the Bow near Calgary. In reality, and with good forecasting, operators may have the ability to foresee this type of situation and could take mitigation measures such as reducing releases, as was demonstrated in the 2011 drought simulation project. This increase in minimum flow violations does not occur in the historical scenario (Figure 17B).

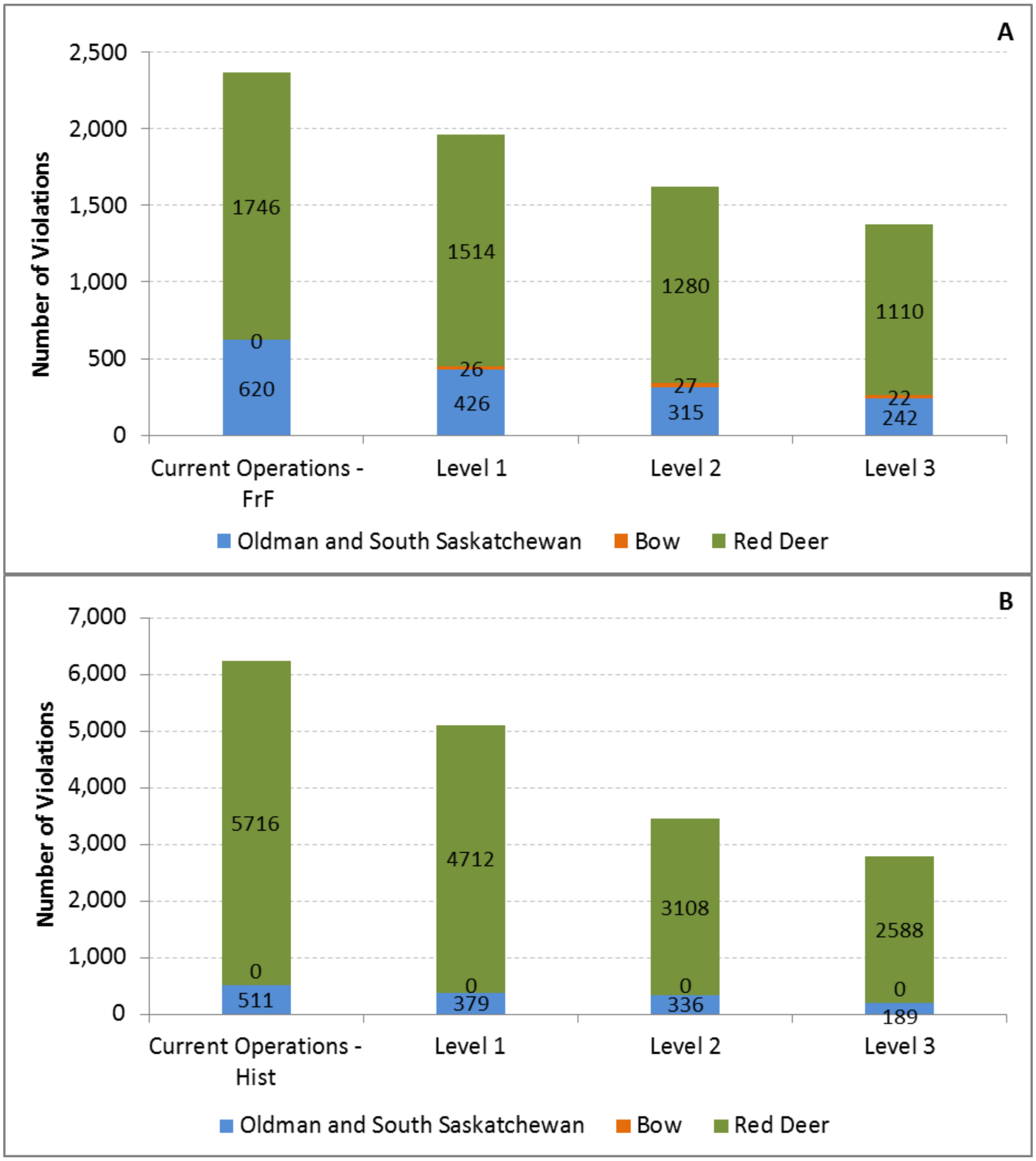


Figure 17: The number of minimum flow violations for the OSSK (dark blue), Bow (green), and Red Deer (light blue) systems, where, minimum flows are 11.5–20 m^3/s at Lethbridge (Fish Rule Curve), 30 m^3/s at Medicine Hat, 35.4 m^3/s at Calgary, 11.3 m^3/s at Bassano, and 10 or 16 m^3/s at Bindloss (WCO). Results are shown for the 15-year Frankenflow (A) and 1928–2009 Historical (B) periods

The “20% of mean discharge” PM, seen in Figure 18, is an indicator of aquatic ecosystem health in the South Saskatchewan River at the Saskatchewan border (immediately after the confluence with the Red Deer River), integrating all SSRB sub-basins. Although profoundly beneficial in other areas, implementing Level 1 of the Adaptation Roadmap increased the number of days where streamflow is lower than the 20% mean annual discharge threshold under Frankenflow and Historical scenarios. This increase was due to increased storage carryover in Travers Reservoir during the winter. With the introduction of other strategies and additional storage and releases in Level 2, the negative effect is compensated for and further improved. Level 3 introduces Eyremore and releases substantial additional water from the new storage. This increased the streamflow in the South Saskatchewan during drought periods, resulting in a complete removal of days exceeding the threshold in Level 3 under both Frankenflow (Figure 18A) and Historical periods (Figure 18B).

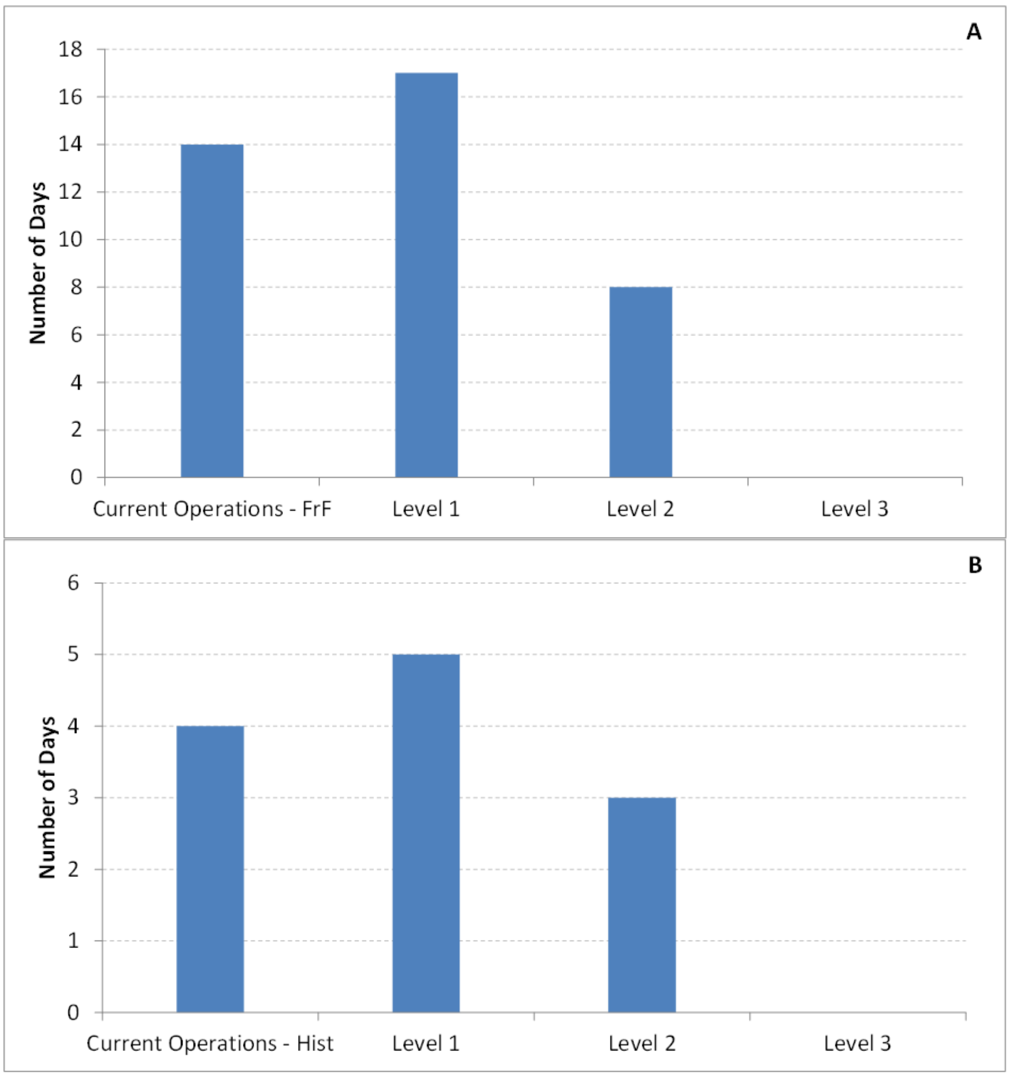


Figure 18: An inter-level comparison of the number of days where flows are below 20% of the average discharge (m^3/s) over the 15-year period in Frankenflow (A) and 1928–2009 Historical (B) periods

Note: The objective is to decrease the number of days.

3.2.2 Roadmap Strategies: Already In Progress

Water management in the SSRB is continually advancing as evidenced in the current performance of our water management operations. Many adaptive strategies have already been implemented and others are being advanced, as seen in Figure 19.

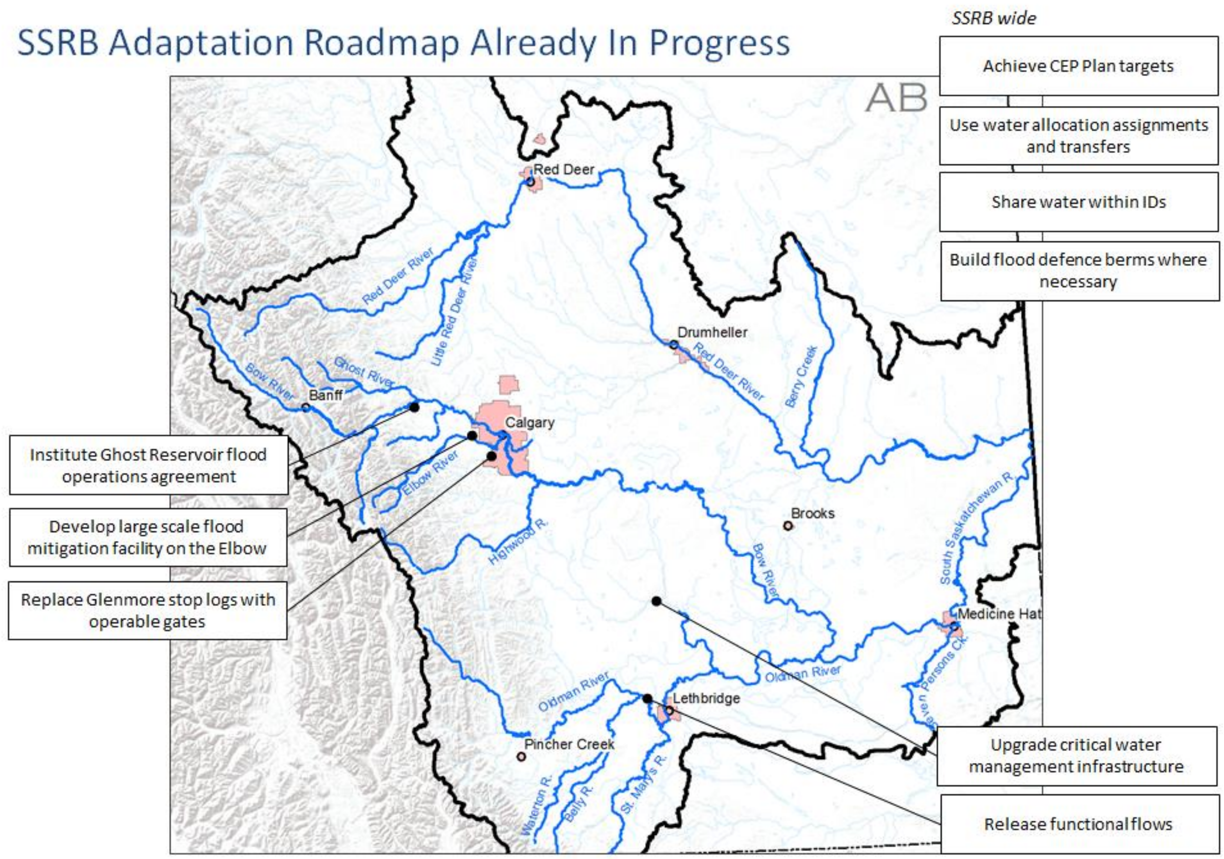


Figure 19: Map of the SSRB showing the adaptation strategies already in progress and their approximate location

At the foundation of adaptation is water conservation through careful management of agricultural, urban, and industrial water use coupled with technological advancements in water treatment, irrigation infrastructure and equipment, industrial cooling, household water applications, and other areas. Careful water use management has historically also involved the ability to optimize water allocations through licence transfers and assignments. This flexibility in the water management system enables adaptive measures to be applied during times of water scarcity, as demonstrated with decreases in irrigation demand during 2001 in the Oldman sub-basin.

In addition to water conservation, the adaptive capacity of the SSRB relies heavily on water management infrastructure, developed to manage streamflow for irrigation and municipal use and hydropower generation. Upgrading and maintaining this critical infrastructure is essential to ensure long-term operability and minimize the risk of flood and drought damage. The replacement of stop logs with operable gates that will also increase the storage capacity of Glenmore Reservoir is an example of an infrastructure-based adaptive strategy that is underway. This improvement to the Glenmore Dam has the potential to offer substantial benefit during flood periods, even beyond what was demonstrated in 2013 when Glenmore operations enabled a significant reduction in flows downstream on the Elbow River. Increasing the capacity to capture streamflow from the Elbow River further enhances the ability of operators to manage flood flows.

Reservoir operation changes are also fundamental to developing the adaptive capacity of the SSRB. Many operational changes have occurred historically, such as the implementation of functional flows for restoring and enhancing riparian cottonwood and willow recruitment in the Waterton and Oldman rivers. The 2014 and 2015 agreements between the GoA and TransAlta for operating Ghost Reservoir for flood mitigation also demonstrate applicability of operational changes for managing high streamflows. Although extreme high streamflows were not observed in 2014, the Ghost Reservoir was operated to capture potential high flows by lowering the reservoir volume prior to the typical freshet period in June. These types of reservoir operations potentially offer substantial benefit in terms of minimizing the downstream risk of damage from flooding, but they should be informed by advanced forecasting capacity. More advanced forecasting capacity requires further resourcing for infrastructure, systems, and collaborative teams in all three sub-basins.

New infrastructure has been the focal point of much discussion after the flooding in 2013, particularly in the Bow and Elbow watersheds. Large-scale flood mitigation facilities have been discussed, including a dam on a tributary in the upper Elbow, an off-stream storage reservoir on the Elbow at Springbank, and a conveyance tunnel on the Elbow at Glenmore Reservoir. On October 26, 2015, the GoA announced it would be proceeding with the off-stream storage reservoir at Springbank.[19] In addition to large-scale infrastructure, small-scale infrastructure has been constructed in numerous locations in all three sub-basins through the GoA-led Alberta Community Resilience Program (ACRP) and the Watershed Resiliency and Restoration Program (WRRP). It is expected that these types of projects will continue well into the future and will play a role in mitigating damage to infrastructure in the floodplain during high streamflow events.

Numerous strategies must be implemented strategically to develop a high level of adaptive capacity in the SSRB. The SSRB has proven resilient in the past but future climates, land use changes, human population growth, and a high range of natural streamflow variation all pose new challenges to water and watershed management. This project evaluated adaptive strategies that can be implemented to help increase the capacity of the basin to deal with these challenges. The following sections describe the results of the three presented levels of adaptation.

3.2.3 Roadmap Strategies: Level 1

The first level of adaptation relies largely on existing water management infrastructure while focusing on improving operations, establishing new frameworks, and implementing new and existing policy. Achieving the Level 1 adaptive capacity relies on a very wide range of strategies, which are shown in Figure 20. In the figure, the blue boxes represent the most promising Level 1 strategies. Strategies with an asterisk (*) in the text below are not currently modelled in the SSROM, typically due to limited data.

[19] GoA news release, October 26, 2015; http://alberta.ca/release.cfm?xID=3873971607DE6-AA9E-CE00-9521CF82FC5D4567

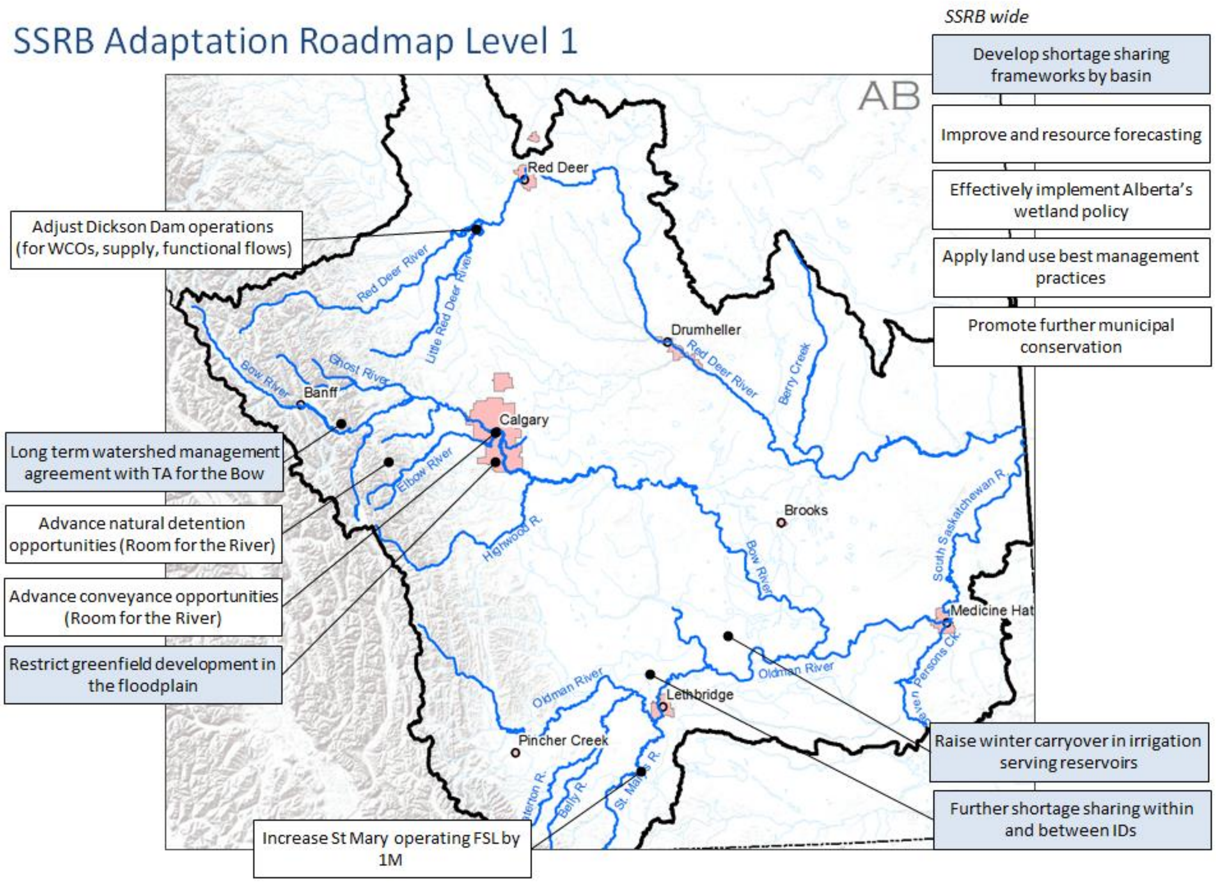


Figure 20: Map of the SSRB showing the adaptation strategies applied in Level 1 and their approximate location

This project identified the five "most promising" strategies in Level 1 through several working group meetings. These strategies are described below.

Institute a long-term, flexible and comprehensive water management agreement for drought mitigation, flood mitigation, and watershed health with TransAlta, including: water bank for river basin management purposes, flexibly stabilizing Lower Kananaskis Lake and Kananaskis River, flood mitigation using Ghost Reservoir and other reservoirs, functional flow releases as needed for riparian and fisheries health, and adjusted fill times for Minnewanka, Spray, and Upper Kananaskis Lakes

This comprehensive water management agreement would include the introduction of a water bank located in the TransAlta-operated reservoirs upstream in the Bow sub-basin governed to make releases in the interest of the whole sub-basin rather than solely for peak prices for hydropower generation. One version of the water bank strategy was modelled as being effective with 74,000 dam^3 (60,000 acre-feet) of capacity accessing about 10% of the natural inflows which it then released for downstream environmental needs, in particular low flow supplementation. Figure 21 shows an example of the water bank storage concept, where available stored water remaining extends through the summer and well into the fall. In this example, water bank releases exceed 74,000 dam^3 because inflows of up to 10% of the total flow refill the water bank storage simultaneously as water is being released.

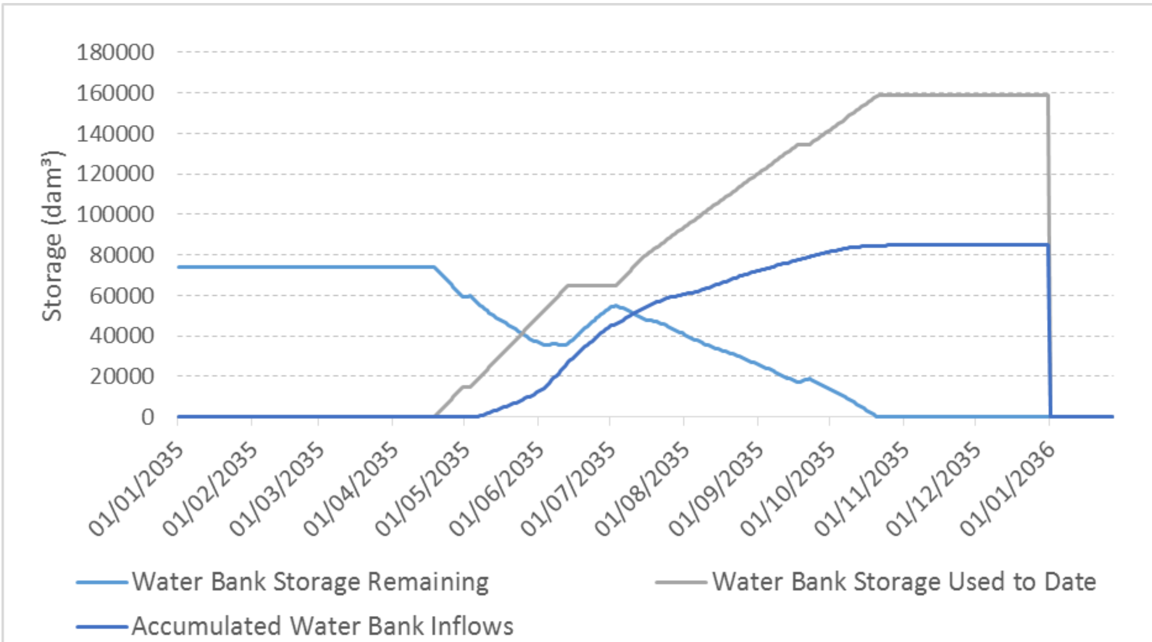


Figure 21: An example of water bank storage for the year 2035 in Frankenflow

Note: The light blue line represents the water bank storage remaining, the grey line represents water bank storage used to date for that year, and the dark blue line represents accumulated water bank inflow for that year.

Figure 22 demonstrates one of the main advantages of the water bank and the broader TransAlta Watershed Agreement, showing that the number of low flow days near Bassano can be reduced. Specifically, the shift in the number of days between 400 and 800 cfs (11.3 and 22.6 m^3/s) is notable. This change in the number of low flow days indicates that there would be environmental benefit by increasing the buffering capacity of the Bow River to tolerate changes in dissolved oxygen and water temperature.

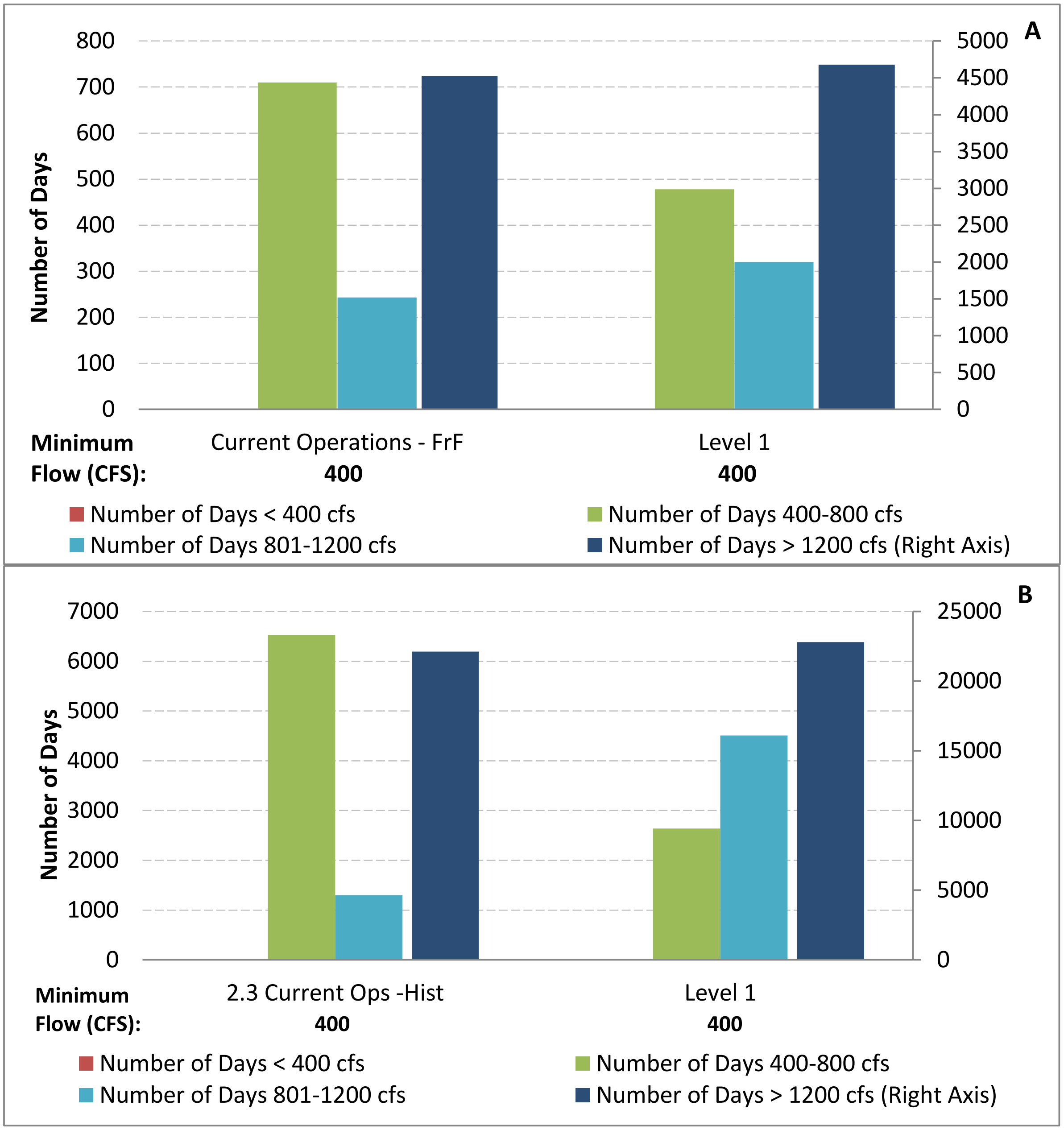


Figure 22: The number of days within flow categories at Bassano in the 15-year Frankenflow (A) and 1928–2009 Historical (B) periods

Note: It is ideal to have a lower proportion of light blue (<400 cfs) and green (400-800 cfs) bars.

The 2014 Bow Basin Flood Mitigation and Watershed Management Report (Alberta WaterSMART, 2014a) demonstrated that the Ghost Reservoir offers meaningful opportunity to reduce the magnitude of flood flows in the Bow River downstream. The new GoA–TransAlta agreement would include operating Ghost Reservoir for flood mitigation, which involves adjusting the reservoir fill curve to start refilling later in the season (Figure 23) and allowing flow from spring snowmelt and rainfall to be captured in the reservoir. This type of operation requires careful consideration of antecedent snow and soil moisture conditions and should be coordinated with forecast tools to minimize the uncertainty in the operations best suited to a particular year.

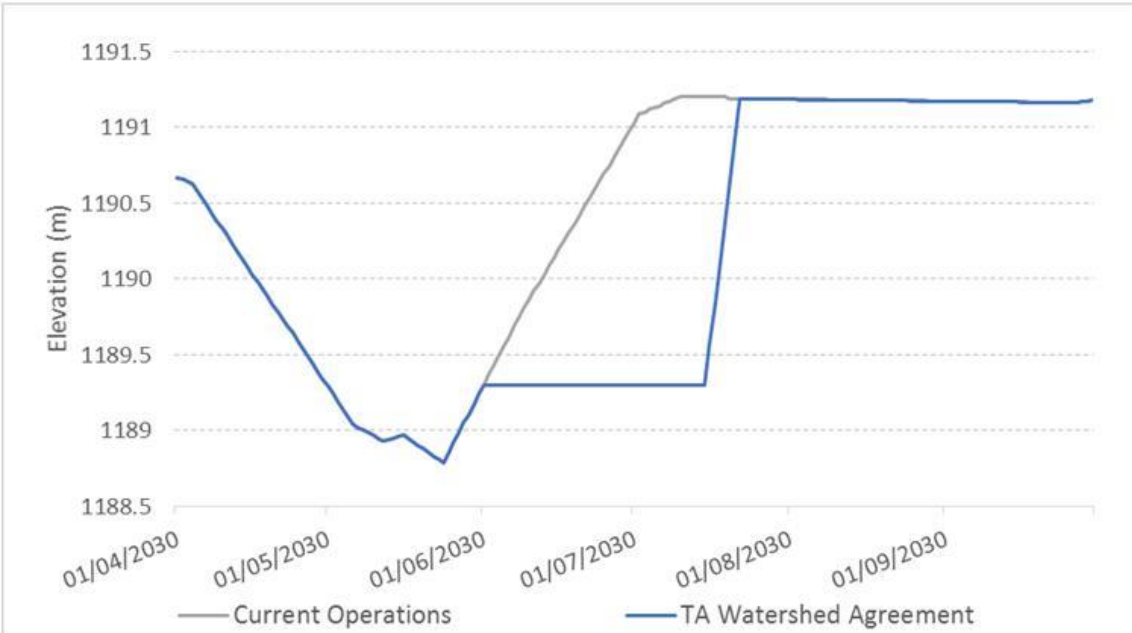


Figure 23: An example of changes in Ghost Reservoir operations to allow for the capture of more spring freshet in the year 2030 of Frankenflow

The grey line shows the model representation of current operations and the blue line represents operations applied in 2014 that could be applied again under the TransAlta Watershed Agreement.

This agreement would include stabilizing Lower Kananaskis Lake at 1663.5 metres (3.5 metres below the current 1667-metre FSL) (Figure 24). The stabilization of Lower Kananaskis Lake was simulated using the operation parameters suggested by the Fisheries and Recreation Enhancement Working Group report (2001). Although this specific suggestion was included in BROM, it was understood that best efforts and operator discretion in flexible and adaptive management was essential. Resilience to extreme conditions will require significant variation from the specifics above under flood or drought conditions.

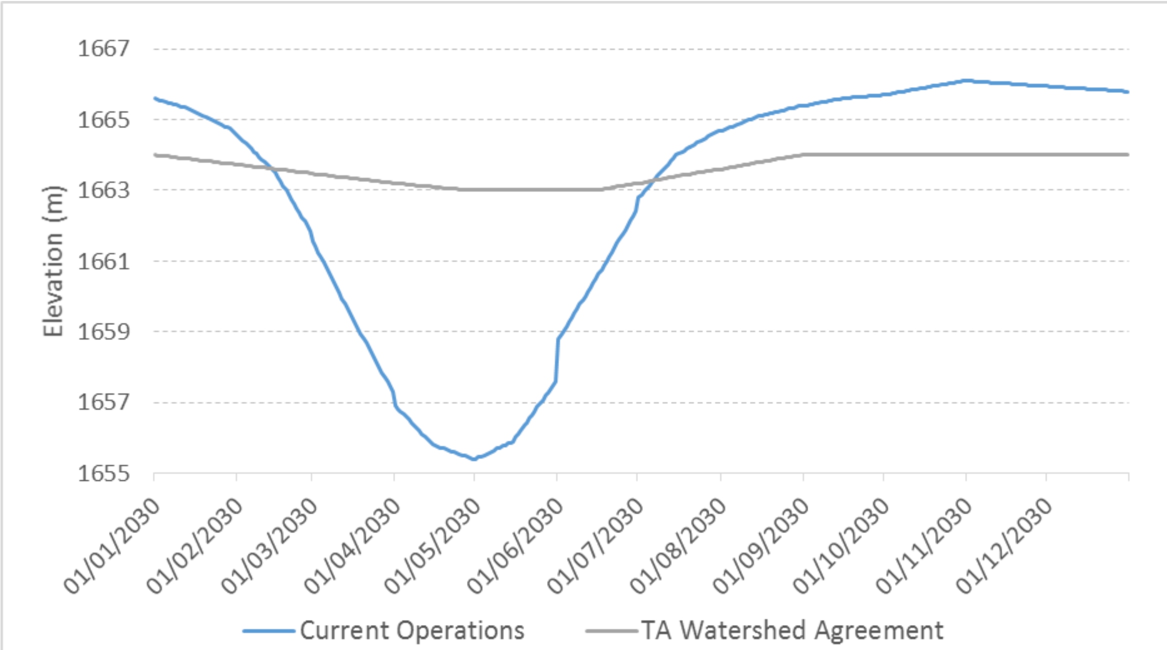


Figure 24: An example of stabilizing Lower Kananaskis Lake for the year 2030 in Frankenflow

The blue line represents the normal pattern for current operations and the grey line represents operations aiming to stabilize the lake.

In addition to stabilizing Lower Kananaskis Lake, discharge flows into the Kananaskis River from the Pocaterra power plant could be held steadier, again recognizing that these objectives would be undertaken as best efforts, enabling adaptive management to accord with the changing conditions in the region and downstream.

Adjusting the fill curves for Minnewanka, Spray, and Upper Kananaskis reservoirs would involve reservoir refill starting sooner in the year, and reaching full levels about a month earlier. This would minimize competition for flow in the high use period because the reservoirs are not trying to fill late into the summer when water is most needed downstream. Figure 25 provides an example of the Lake Minnewanka fill curves under current and new operations. The fill curves for Spray and Upper Kananaskis would resemble those for Minnewanka.

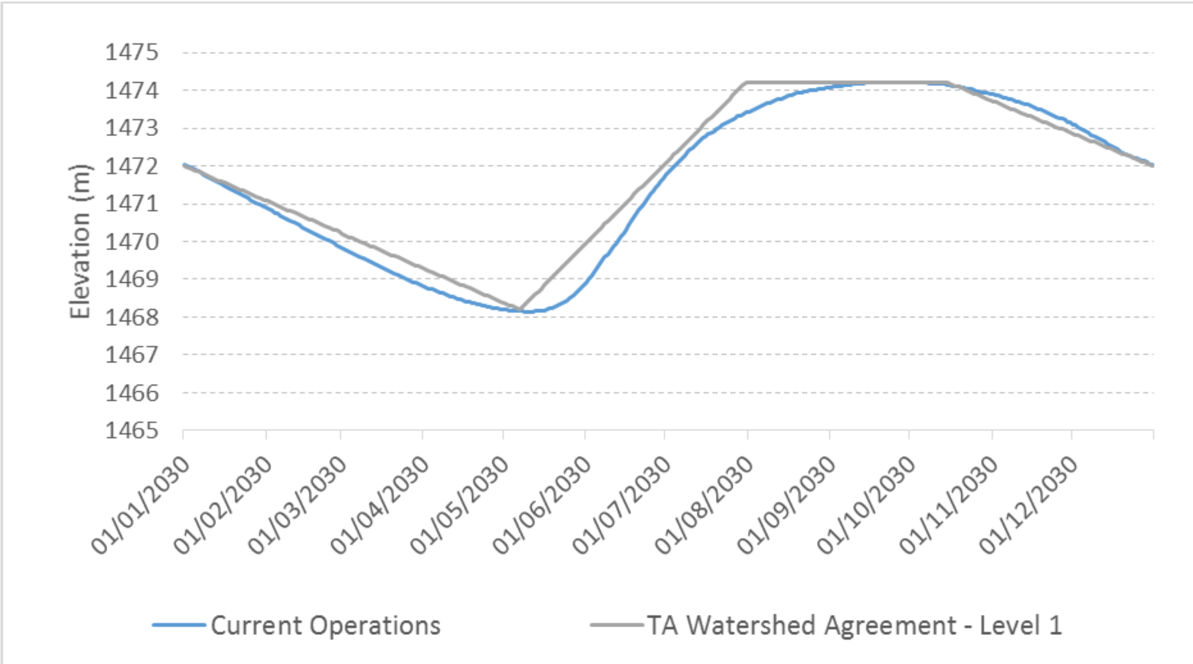


Figure 25: An example of the differences in fill between current (blue) and operations under the TransAlta Watershed Agreement (grey) for Lake Minnewanka

Implementing functional flows to benefit riparian and fisheries health is an important part of this strategy and is described under the strategy "Adjust Dickson Dam operations."

Raise winter carryover in existing irrigation-serving reservoirs; start with Travers which draws water from the Bow, then investigate feasibility for the St. Mary, McGregor and other reservoirs

This strategy would maintain higher winter water levels in irrigation reservoirs to allow higher potential to meet water demands during dry periods. This type of operation would be applied first to Travers Reservoir to determine suitability, following which similar types of operations could be investigated for the St. Mary, Oldman, Waterton, and McGregor reservoirs.

Implement further forecast-based shortage sharing (including agreed-upon temporary reductions in diversions and voluntary assignments of remaining licence allocations in times of drought), within and between irrigation districts

This strategy would apply temporary reductions and assignments in times of drought (Alberta WaterSMART, 2014b). Forecast-based shortage sharing allows water users both within and between districts to voluntarily and simultaneously reduce demand on the system. The water sharing agreement implemented for the Southern Tributaries during the drought of 2001 set a precedent for this strategy.

Forecasting is critical for this strategy to be implemented properly. Irrigation districts evaluate water availability based on winter reservoir levels and incoming early spring snowpack because these are the primary sources of water for irrigation. Water availability estimates are communicated to irrigators and can be used to set preliminary allocations. Snowpack data are not included in the model; therefore, AEP reservoir storage on June 1 is used as a surrogate to inform rationing decisions that would in reality be informed by snowpack, soil moisture, reservoir levels, and other factors not currently available to the model.

In the model, irrigators in the OSSK sub-basins would begin rationing for a given year if total AEP storage is less than 75% of the upper rule. Once this decision is made, deliveries to irrigators (districts and private) are capped at 80% of full demand for the entire year (Alberta WaterSMART, 2014b).

Shortage sharing offers substantial benefit in surviving extended droughts for the OSSK sub-basins when it is compared with current operations and Level 1 without shortage sharing, as seen in Figure 26. This figure shows that shortage sharing allows for an extension of storage well into the winter at the onset of the worst drought explored using Frankenflow. This extension of storage benefits the environment and water users by supplementing flows for a longer period. Although this strategy was modelled in the OSSK sub-basins, it could be applied effectively in the Bow and Red Deer sub-basins too.

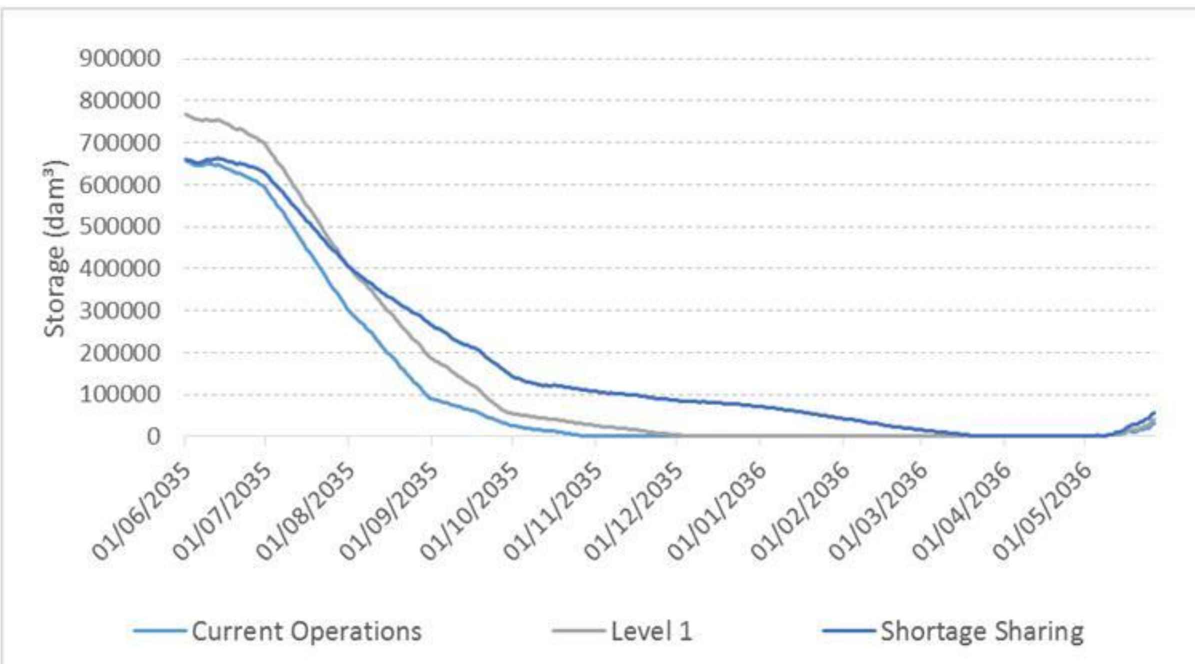


Figure 26: An example of the change in storage obtainable with Level 1 and forecast-based shortage sharing in the Oldman

The lines represent Oldman, Waterton, and St. Mary reservoir storage under current operations (light blue), Level 1 (grey), and with only forecast-based shortage sharing (dark blue).

One of the most notable changes relative to current operations is, not surprisingly, the effect of forecast-based shortage sharing on shortages in the Oldman. Figure 27 demonstrates that irrigation shortages will be substantially reduced with this type of proactive shortage-sharing agreement. Similar results may be expected if a shortage-sharing agreement were implemented in the Bow and Red Deer systems; however, most irrigation shortages seen in the model are in the Oldman, and this is the sub-basin where the most substantial benefits are likely to accrue.

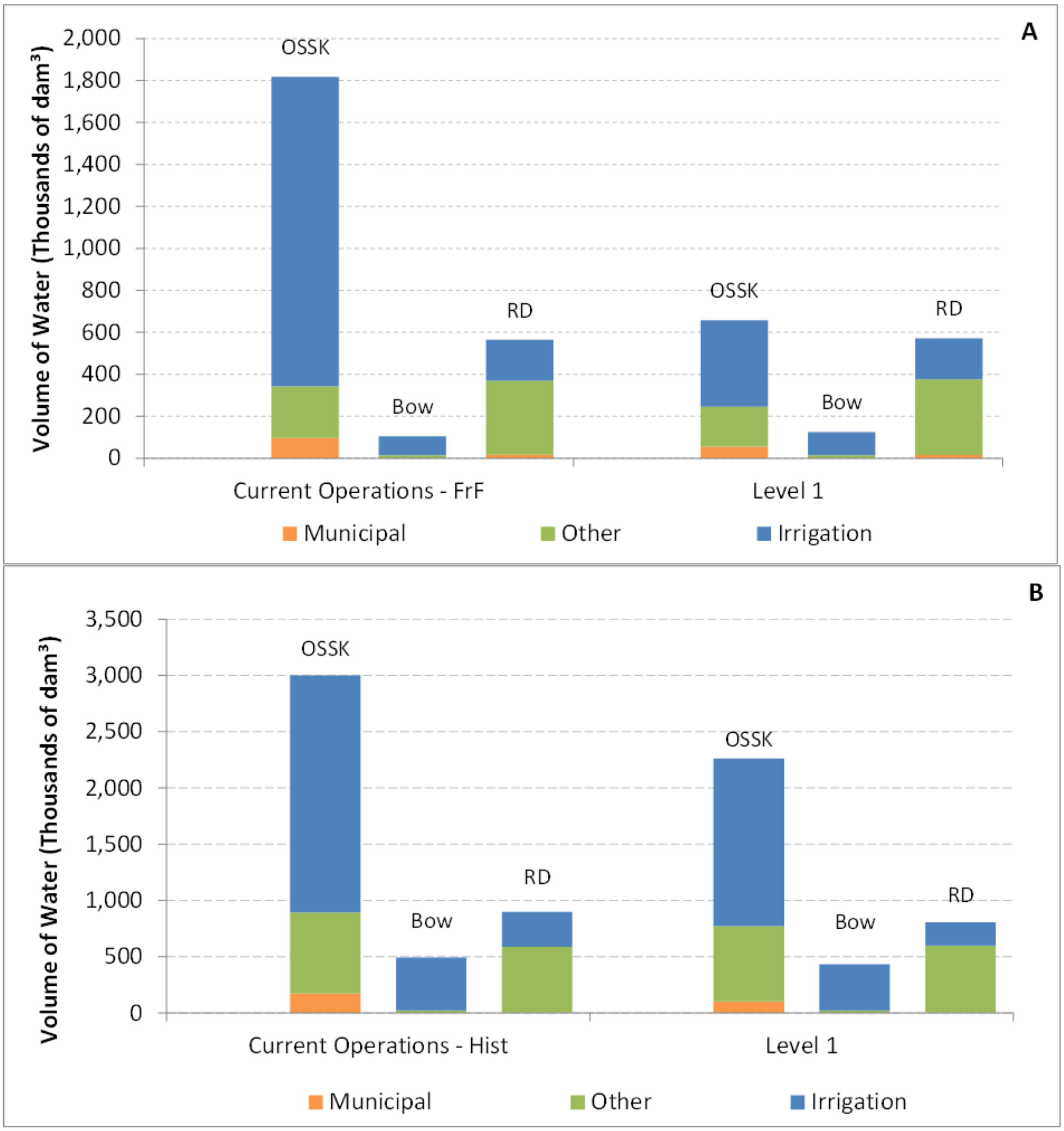


Figure 27: The volume of municipal (green), other (orange), and irrigation (blue) shortages in the OSSK, Bow, and Red Deer systems under the 15-year Frankenflow (A) and 1928–2009 Historical (B) periods

Develop basin wide shortage-sharing and reallocation frameworks to inform and enable severe drought mitigation*

This strategy was not part of the modelling work, but participants discussed that a framework is required to enable implementation of shortage-sharing agreements. This strategy is discussed in section 4 on Implementation.

Restrict new greenfield development in the floodplains to reduce flood damage and develop strict regulations against changing the nature of brownfield developments*

This strategy has been the topic of many discussions throughout the SSRB following the 2013 flood. This continues to be a preferred flood mitigation strategy, and relies on the implementation of existing and potentially new policy for development in the floodplain, but was not part of the modelling work.

OTHER LEVEL 1 STRATEGIES

Level 1 included other strategies that were considered important but had less effect on performance measures used in this work. In addition, several cannot be evaluated in the SSROM and are indicated by an asterisk (*). All of the other Level 1 strategies are described below.

Increase St. Mary Reservoir operating FSL by 1m

This strategy would increase the storage capacity of the St. Mary Reservoir, thus increasing the capacity to apply functional flows, increasing the downstream minimum flow and supporting water users during dry periods. An evaluation to determine the feasibility of these operations in terms of dam safety would be required.

Effectively implement Alberta's Wetland Policy*

As of May 31, 2015, applications in the White Area will be reviewed under the Alberta Wetland Policy. Once Green Area field assessments are complete (May 31, 2016), Green Area applications will also be assessed under the Policy.

Effective implementation of the Wetland Policy involves "minimizing the loss and degradation of wetlands, while allowing for continued growth and economic development in the province." The primary goals of the policy are to conserve, restore, protect, and manage Alberta's wetlands.

Importantly, not all Alberta wetlands are of equal value. Wetland value should be assessed based on relative abundance in the landscape, supported biodiversity, ability to improve water quality, importance to flood reduction, and human uses. These values should be used to inform wetland management. Ultimately, avoidance and minimization of wetland loss is preferred.

*Improve resourcing for and effectiveness of forecasting infrastructure, systems and teams**

This strategy was not part of the modelling but working group participants in all of the sub-basin projects identified the need for improved forecasting. This strategy is discussed in section 4 on Implementation.

Adjust Dickson Dam operations to consider downstream needs (retain WCOs, functional flows, some new demands)

The current operations of Dickson Dam are driven primarily by upstream conditions; the objective is to meet reservoir target elevations and ensure the reservoir fills by late fall. Presently, 16 m^3/s plus a buffer is released from Dickson Dam based on upstream conditions; proposed new Dickson Dam operations would calculate the buffer based on downstream conditions. This buffer is flexible and if the reservoir falls below the lowest permissible level, only the minimum 16 m^3/s (and not the buffer) is released (Alberta WaterSMART, 2015).

This type of operation is beneficial to the Red Deer system, providing additional downstream water during low flow periods (Figure 28). Previous studies suggest there is some capacity to provide water for some but not all potential new users. In addition, many downstream users are senior to the WCOs, which can result in WCO violations during low flow periods. This strategy can also be used to improve functional flows downstream of Dickson Dam on the Red Deer River.

Figure 28: A comparison of streamflow (m^3/s) in the Red Deer River at the mouth of the Red Deer during current operations (blue) and operations that aim to address downstream needs (grey)

To see the results of interest (low flows) at an appropriate scale, the upper part of the figure is cut off.

Changes in the Red Deer system as a function of Level 1 implementation are most noticeable when looking at the percentage of weeks where the average weekly flow is below the WCO threshold at the mouth of the Red Deer (Figure 29). Dickson Dam operational changes are included in Level 1, where operations are set to look downstream at demands prior to making releases. This new style of operation would attempt to release enough water to meet existing and new demands as well as maintain the WCOs. Figure 29 demonstrates that these changes are favourable and reduce the percentage of weeks where the WCO is not met at the mouth of the Red Deer.

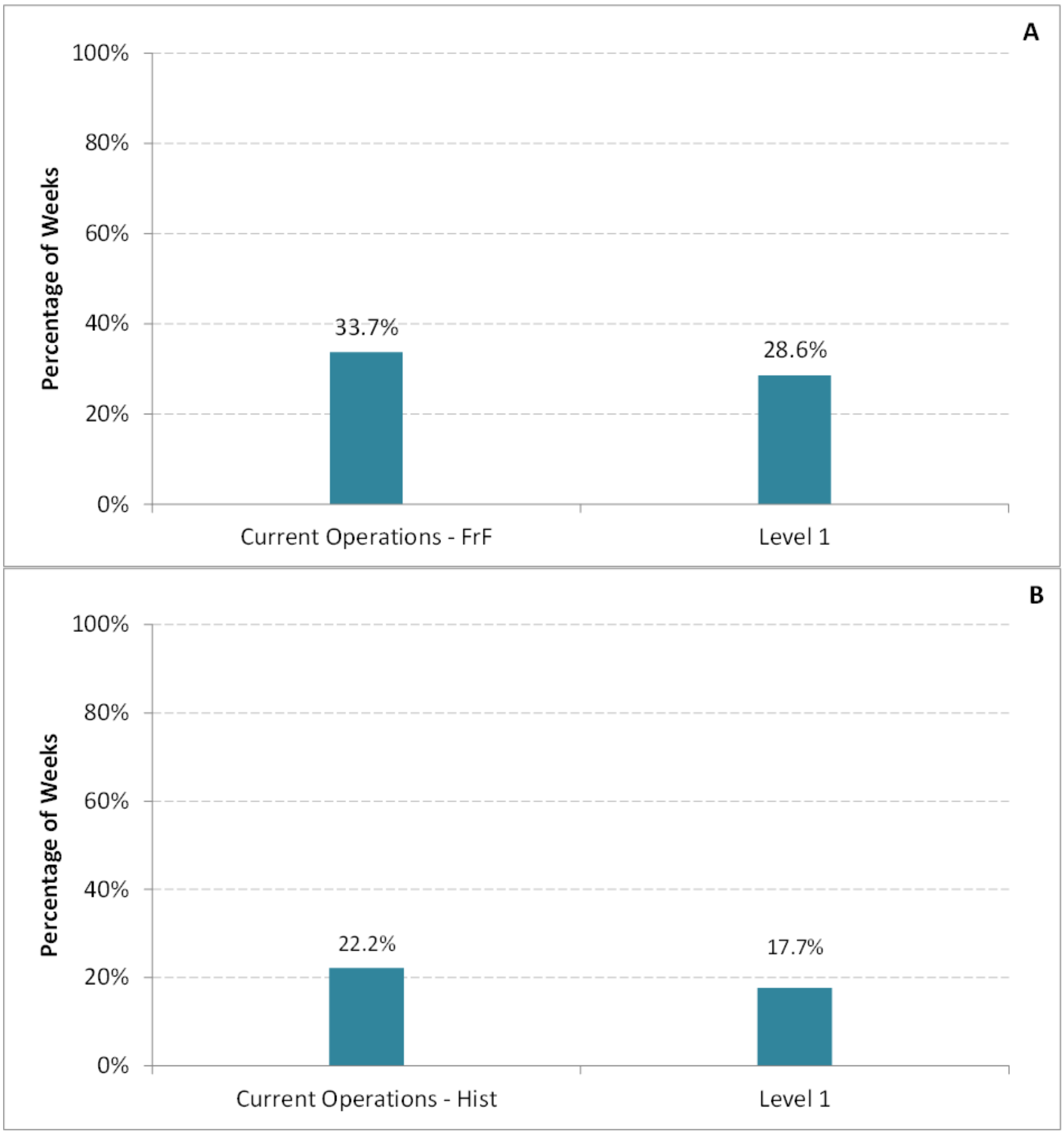


Figure 29: The percentage of weeks where weekly average streamflow is below the WCO at Bindloss for the 15-year Frankenflow (A) and 1928–2009 Historical (B) periods

One other strategy that has been partially implemented in the Oldman system and offers various environmental benefits is the release of **functional flows** using existing dams on the Red Deer and the Bow. Functional flow releases are intended to support a wide range of ecosystem goods and services by operating a reservoir to more gradually ramp down flows after a high flow event deemed suitable for cottonwood recruitment. This ramping down of flow gives a more natural snowmelt-driven hydrograph, which provides benefit to aquatic ecosystems as they are better adapted to natural flow regimes. Figure 30 illustrates an example in which the Dickson Dam is operated to ramp the flow of the Red Deer River by 4 cm/day, as measured along the banks following spring freshet. This figure also demonstrates that more water is required to conduct these types of operations, potentially resulting in lower streamflow late in the season. Therefore, these types of operations should only be done opportunistically. It should be noted that simulated reservoir operations cannot capture real-world operation dynamics due to simplified modelling assumptions. Dam operators would have to adjust operations according to real-world conditions, including pulsing, and potentially ramping at a faster rate if required.

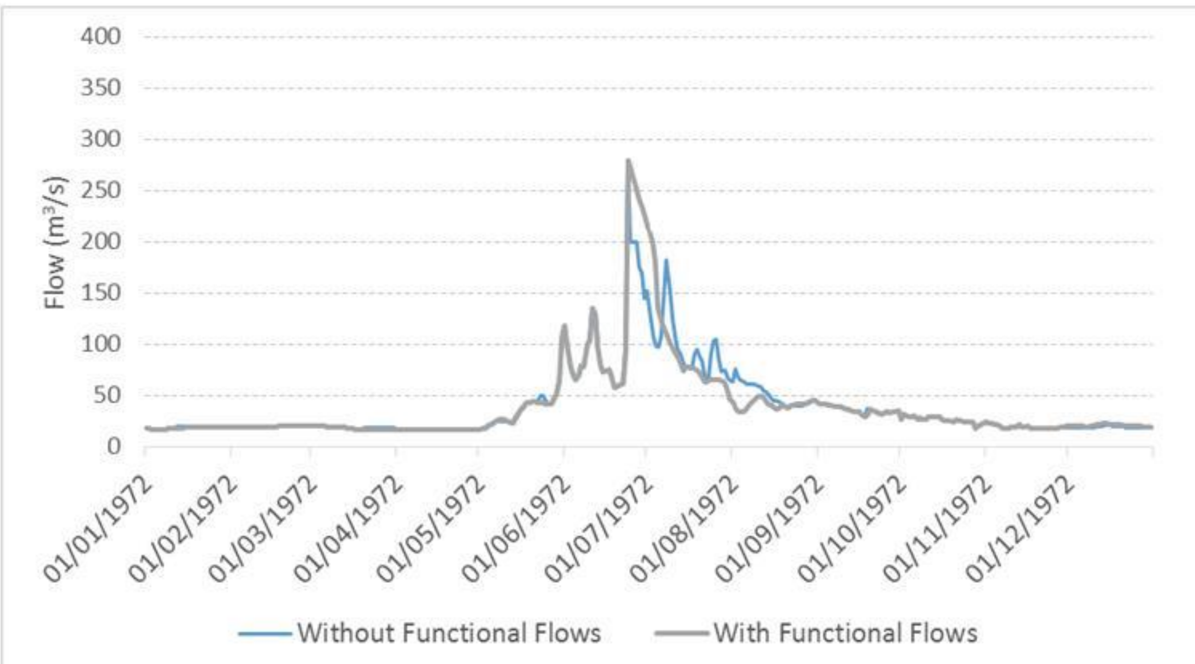


Figure 30: An example of the effect of implementing functional flows on streamflow below Dickson Dam on the Red Deer

The grey line represents streamflow below the dam with operations for functional flows, and the blue line represents streamflow below the dam without functional flows.

*Advance Room for the River conveyance opportunities in the Bow and Red Deer sub-basins**

Increasing the conveyance capacity of specific segments along the Bow and Red Deer rivers would increase the overall capacity for the system to manage flood flows. Examples of increasing conveyance include removing debris between Sundre and Dickson Dam, selective aggregate removal, and bridge redesign (increasing the span).

*Advance Room for the River natural detention opportunities in the Bow and Red Deer sub-basins**

Natural detention opportunities help lower downstream flood risk and offer benefits to the system by improving the connectivity between river channels and their floodplains. Examples of natural detention opportunities include restoring wetlands in targeted areas and reducing linear footprint in the headwaters to increase watershed storage capacity. While these natural detention opportunities will have limited impact on major flood flows, they would contribute to improved water quality and alluvial aquifer recharge as well as potentially benefitting the river during periods of low flow.

*Further apply land use best management practices**

Land use best management practices (BMPs) are an effective means of reducing the overall effect of a particular land use on water quantity and quality. Examples of BMPs that provide benefit are building bridges instead of culverts, maintaining adequate riparian buffer widths and set-backs from rivers and streams, and incorporating stormwater detention in urban developments.

Promote further municipal conservation relative to what is being done now

The effects of reducing municipal water consumption are most pronounced during low flow periods. Conservation is most effective during the summer months when urban irrigation is most common. Therefore, implementing a strategy such as 20% more conservation in the summer and 5% in the winter would likely result in the highest benefit.

The results presented here demonstrate that there is flexibility within the SSRB water management system to make beneficial changes without incurring significant economic, environmental, or social costs. This work also demonstrates that flexibility must be maintained within the water management system to mitigate potential negative consequences of new (and old) operations. Operational and decision-making changes should integrate forecasting in a meaningful way. This is particularly important given that each year is likely to present a unique situation and potential water management challenges. Benefits to the environment and water users within the range of operations presented here clearly indicate that it is possible to adaptively manage year-to-year variability and long-term change in hydrologic conditions; additional adaptive capacity may be required as future water supply and demands change.

3.2.4 Roadmap Strategies: Level 2

Level 2 strategies build on the strategies from Level 1 with six additional adaptive strategies as seen in Figure 31. In the figure, the blue boxes represent the most promising Level 2 strategies. Strategies with an asterisk (*) in the text below are not currently modelled in the SSROM, typically due to lacking or unavailable data.

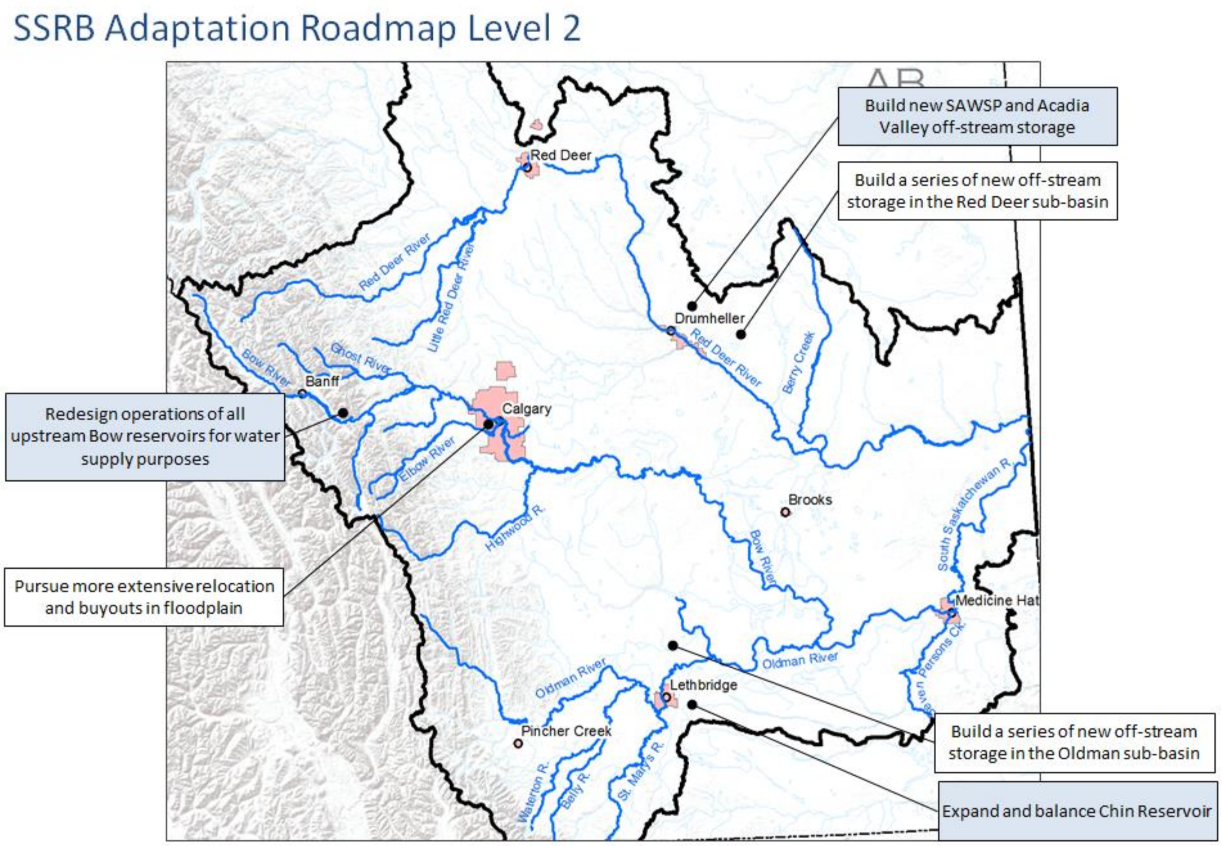


Figure 31: Map of the SSRB showing the adaptation strategies applied in Level 2 and their approximate location

Level 2 consists mainly of relatively small new infrastructure projects and infrastructure upgrades, including changes to operational regimes of some reservoirs. These strategies are described below.

*Redesign operations and expand, where beneficial, existing reservoirs in the upstream Bow for water supply and watershed health**

The 11 hydro facilities and system of reservoirs upstream of Calgary on the Bow River system were originally constructed to provide a small but stable source of electricity close to the growing demand in southern Alberta. The first run-of-river dams were built in the early 1900s, and the latest was completed in the 1950s. During the early 20th century, the hydro system provided much of the electricity needed in the region. Advancements in transmission infrastructure led to the current grid-based electrical system, making hydro generation far less important to electricity demand in the later

20th century. The Bow hydro system now supplies only a tiny percentage of the electricity used by Albertans, but provides some ancillary services that help to stabilize the transmission system.

The purpose of the Bow hydro system has gradually been moving toward a water supply system. The reservoirs are filled over the summer and fall and the stored water is released at a relatively steady pace over the winter months (see example in Figure 32). This pattern originated because electricity demand (and price) was much higher in the cold, dark winter months and therefore more water was run through the turbines during winter. Now electricity demand is balanced between winter and summer due to air conditioning, computer use, summer irrigation demand, and other year-round industrial uses. However, capture and storage during the spring snowmelt period, summer filling, and winter release of the stored Bow water has enabled Calgary and other population centres to increase water demands to their current levels. Without the reservoirs following their historic pattern of fill and release, the natural pattern of water supply could not support anything close to the modern total demand and treated effluent assimilation needs in the Bow system.

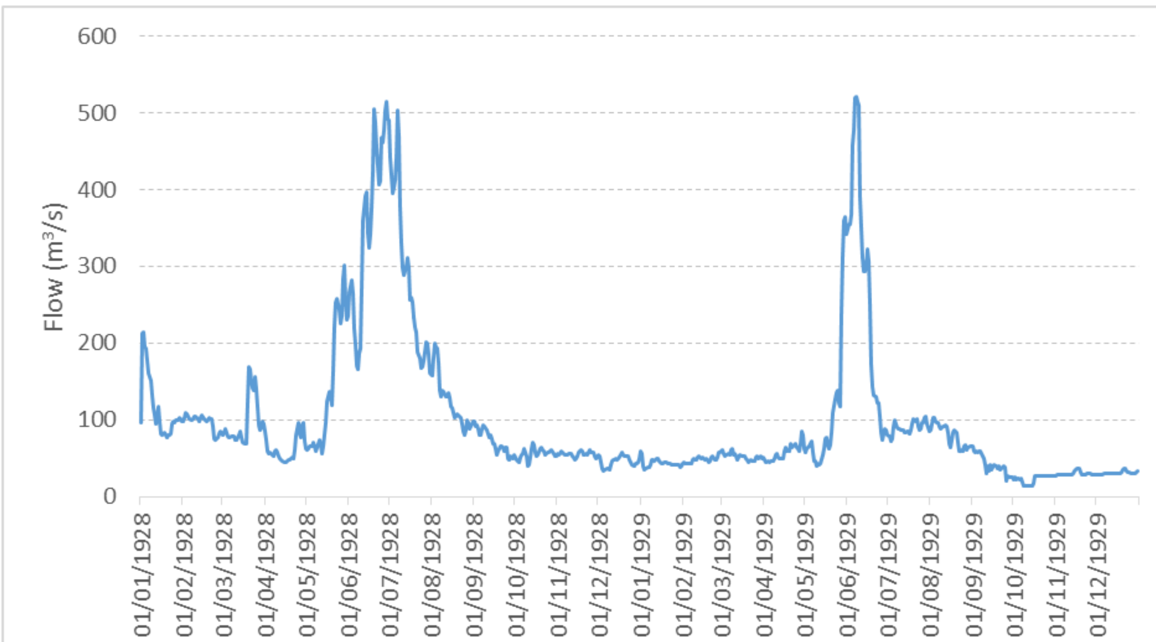


Figure 32: Daily average streamflow in the Bow River at Calgary during 1928 and 1929

The time has now come to reconsider the primary purpose of the entire upstream Bow water storage system to extend beyond its original purpose in the early 20th century: generating power during winter months. Using the water for other purposes in the public interest does not reduce the amount of electricity generated except in extreme cases, but does alter the timing of the production. Managing for these other purposes may reduce the profit from power production, but not the total amount of electricity generated. Highly valued competing purposes for this water storage and release system have now emerged. Flood and drought mitigation, environmental protection, food supply and recreational uses for the Bow water now substantially challenge the value of this water purely for peak power generation. The most recent and dramatic example is the 2013 flood, but many other examples are available.

Expand (74,000 dam^3) and fully balance Chin Reservoir (285,000 dam^3) (OSSK sub-basin)

Previous work demonstrated that expanding and balancing Chin Reservoir provides an opportunity to increase the adaptive capacity of the OSSK sub-basins. This strategy includes an expansion of approximately 74,000 dam^3 and balances the operations of the reservoir to maintain proportional storage alongside the Oldman, St. Mary, and Waterton reservoirs. This differs from current operations in that Chin Reservoir presently has higher storage priority, resulting in preferential storage in Chin. Balancing Chin with the other upstream reservoirs means that those reservoirs can maintain higher storage for longer in the season as illustrated in Figure 33. This keeps water closer to the headwaters and makes it available system-wide to support ecosystems and human uses.

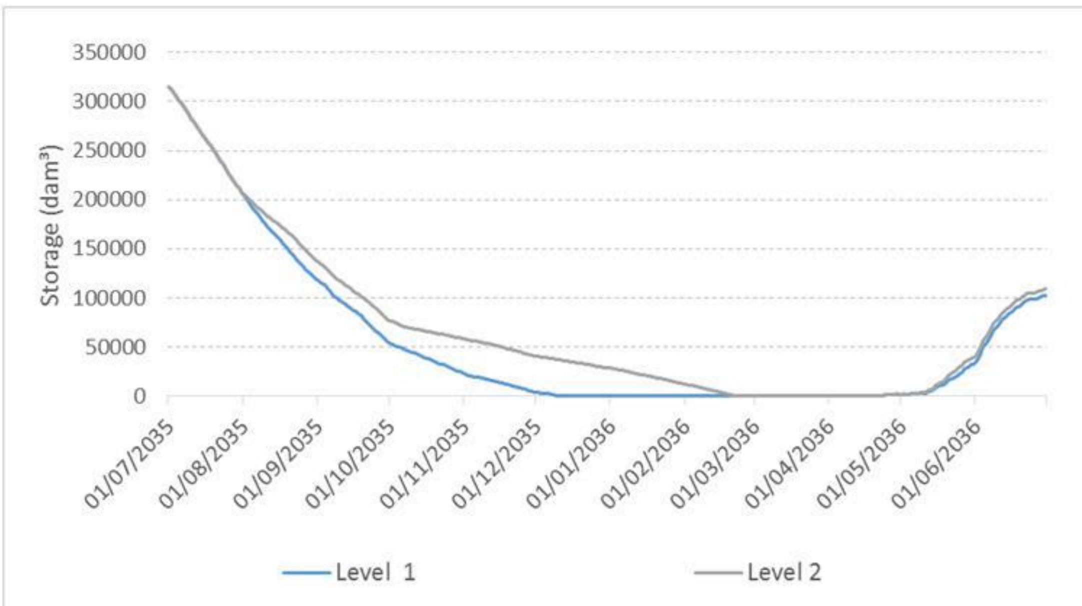


Figure 33: Comparison of Oldman Reservoir storage for Level 1 (blue) and Level 2 (grey)

This demonstrates that the available storage is extended later through the lowest flow period.

Expanding and balancing Chin Reservoir would require multiple upgrades to infrastructure as more aggressive filling would be necessary (that is, higher flows on shorter notice) (Figure 34). Initial infrastructure upgrades would include expanding and reinforcing conveyance canals to Chin Reservoir and upgrading run-of-river hydropower turbines along the canal, specifically in Drops 4, 5, and 6. An increased willingness to use spillways in that area may also be required.

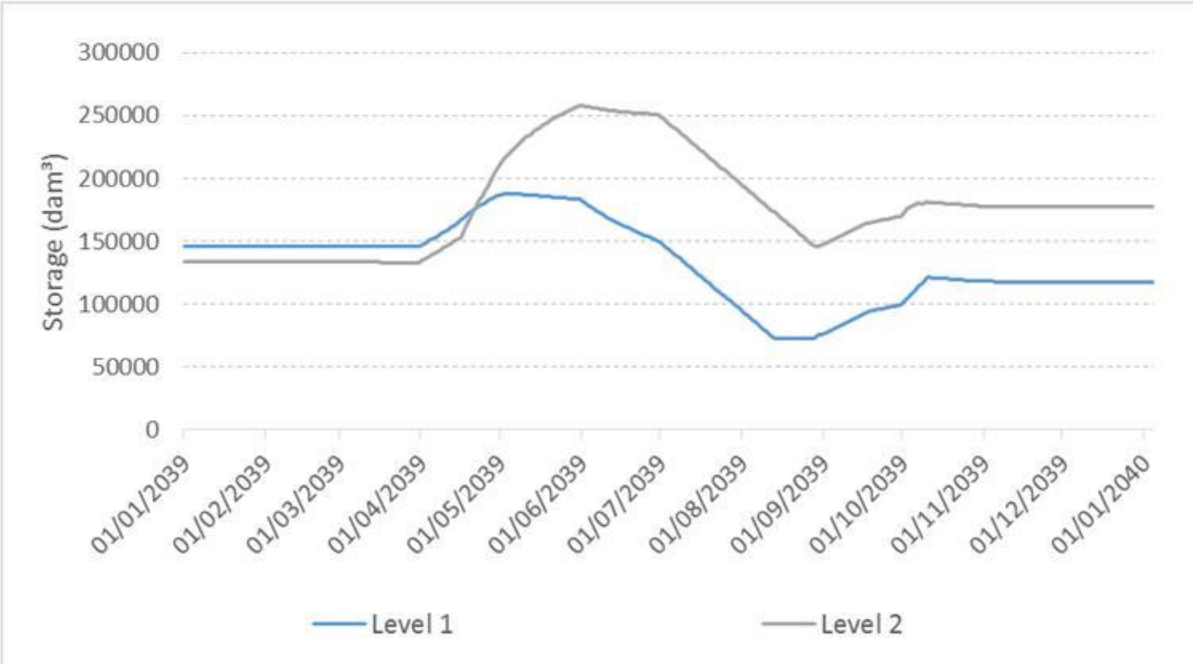


Figure 34: Chin Reservoir storage comparison in a non-drought year, demonstrating that higher fill rates and expansion result in higher late-season storage

Build new SAWSP and Acadia Valley off-stream storage (35,000 dam^3 SAWSP + 45,000 dam^3 Acadia = 80,000 dam^3 total) (Red Deer sub-basin)

The Red Deer sub-basin has limited capacity for increased water demand and growth while maintaining WCOs during low flow periods in the Red Deer River. Building new off-stream storage would expand the storage capacity of the Red Deer sub-basin by adding a total of 80,000 dam^3 (35,000 dam^3 storage for SAWSP[20] and 45,000 dam^3 storage for Acadia Valley). The location and storage capacity of the SAWSP and Acadia Valley irrigation projects was investigated in previous studies (Alberta Environment, 2008).

An additional 80,000 dam^3 of storage would likely be located in various places off stream for additional users where appropriate. Working group participants suggested that these storage options should be modelled together in Level 2, as storage increases would need to be coordinated to ensure an appropriate distribution of benefits to all water users.

Figure 35 demonstrates that the storage from SAWSP and Acadia Valley projects is used extensively during Frankenflow; the use was seen during a relatively severe drought. Figure 36 shows water use over the historical period; storage is used but is not drawn down as far during the Historical period as during Frankenflow.

[20] Special Areas Water Supply Project

Figure 35: Storage in the new SAWSP and Acadia Valley project – Frankenflow

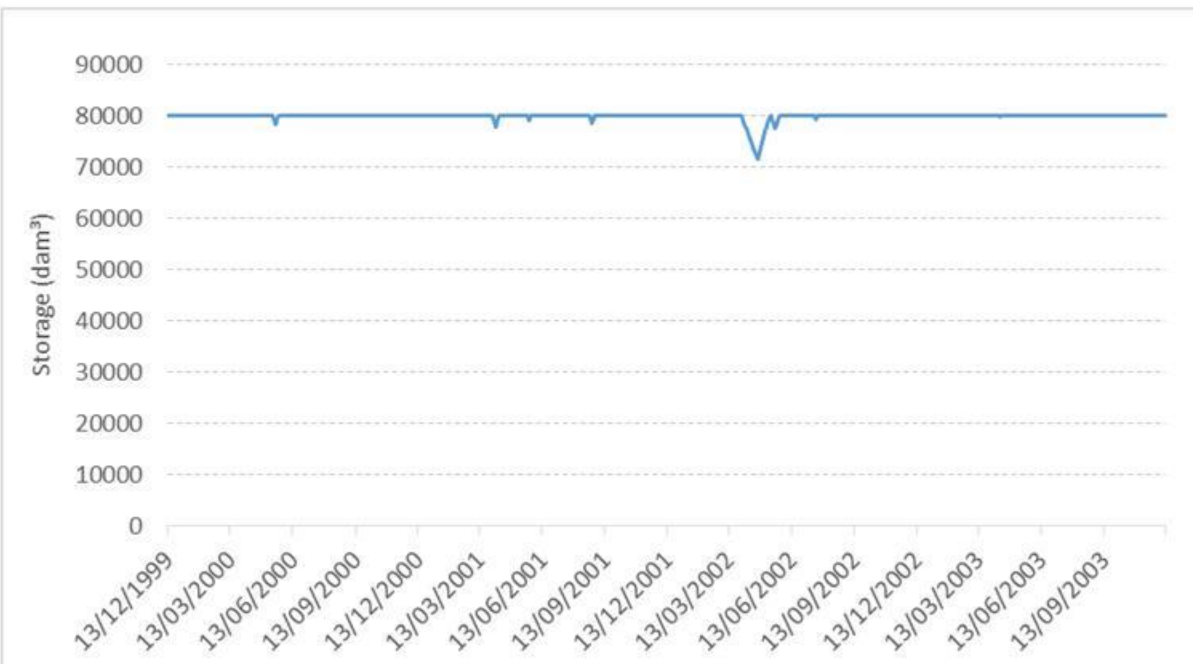


Figure 36: Storage in the SAWSP and Acadia Valley project – Historical

Figure 37 shows that shortages in the Red Deer sub-basin can be reduced by adding storage to the system. In addition, there is substantial further improvement of WCO flows, as violations to the WCOs are reduced by 5.2% (Figure 38).

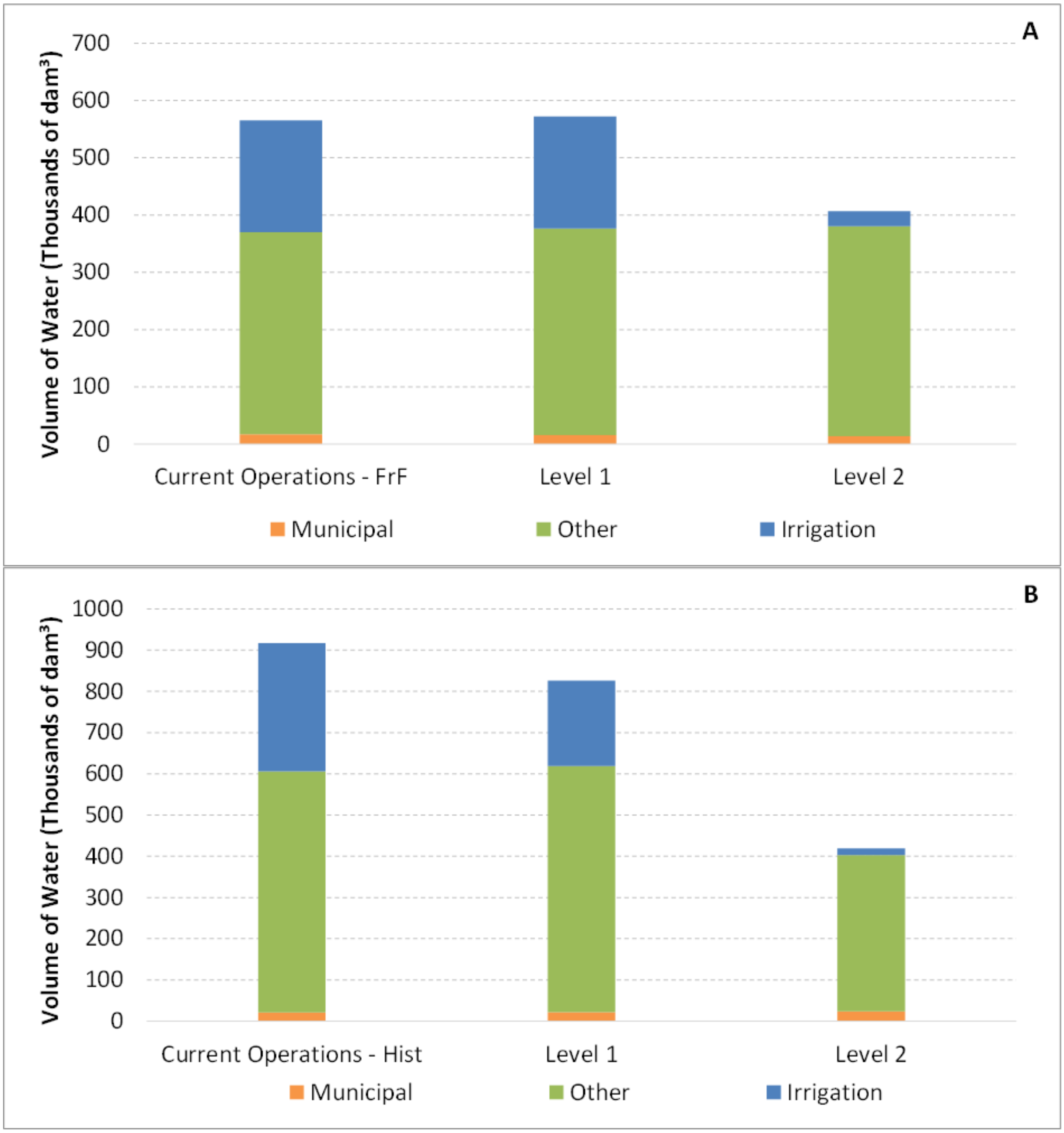


Figure 37: Total Red Deer shortages, demonstrating that Level 2 SAWSP and Acadia Valley storage almost eliminates irrigation shortages in the Red Deer under the 15-year Frankenflow (A) and 1928–2009 Historical (B) periods

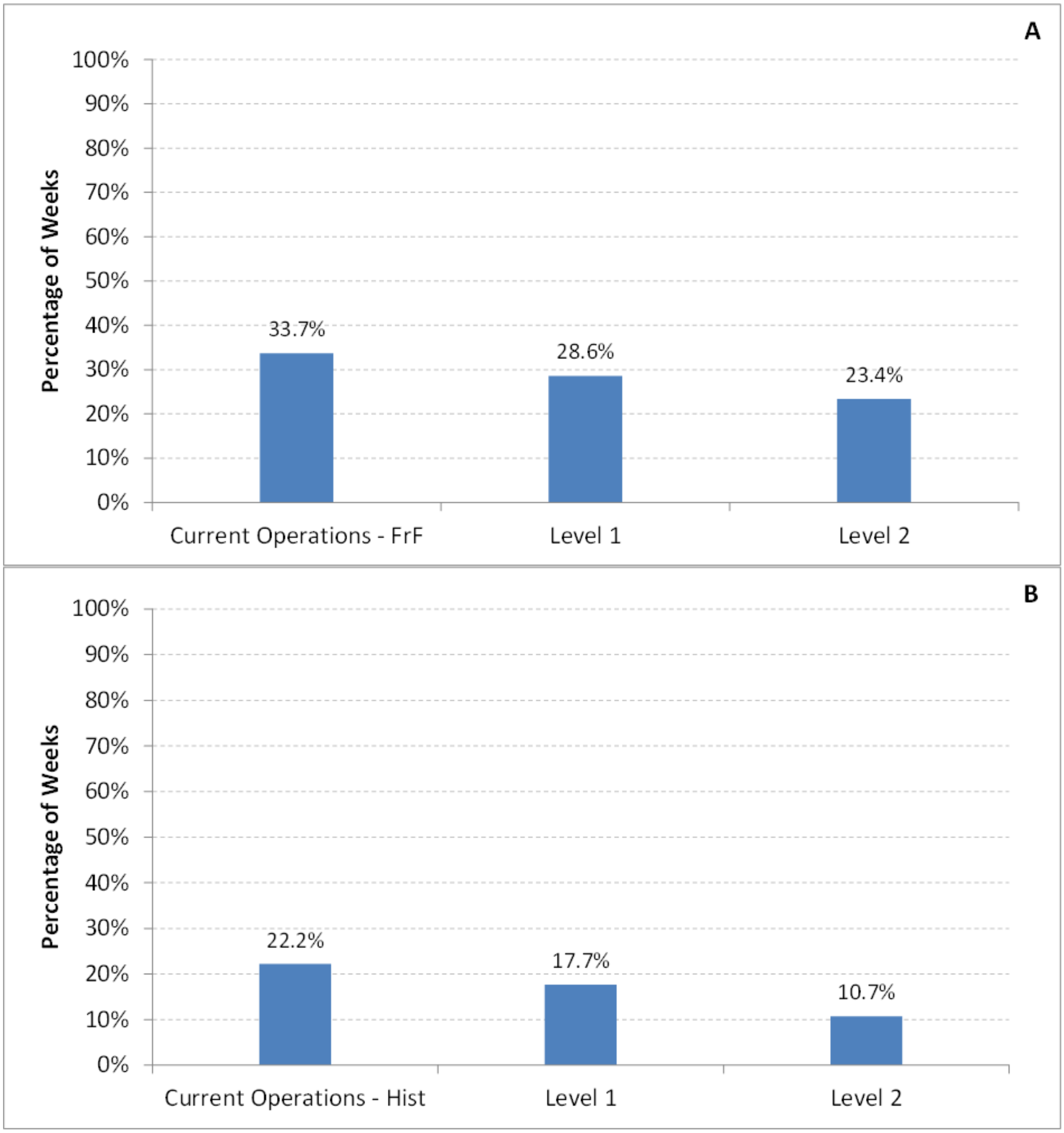


Figure 38: A comparison of the percentage of weeks where average weekly flow at the mouth of the Red Deer is less than the WCO threshold between Current, Level 1, and Level 2 under the 15-year Frankenflow (A) and 1928-2009 Historical (B) periods

Three additional strategies were determined to be appropriate for achieving Level 2.

Pursue more extensive relocation and buyouts in the Bow and Elbow River floodplains to reduce risk and reduce the need for upstream mitigation structures*

This strategy has been discussed as a way to effectively and permanently mitigate flood damage over the longer term and reduce the need for upstream mitigation. Buyouts create room in the floodplain for normal river processes, such as channel migration and over-bank flooding, without imposing risk to infrastructure. However, buyouts must be recognized as a costly endeavour with significant social and economic impact on individuals and the community.

Build a series of new off-stream storage facilities in the Oldman sub-basin*

Off-stream storage was discussed as an option for the Oldman sub-basin as a preferred alternative to building large on-stream structures. A series of smaller off-stream reservoirs could be built as needed throughout the sub-basin to meet local demands. Off-stream reservoirs can also create important lentic habitat for aquatic and terrestrial species and do not have the same environmental consequences as on-stream reservoirs.

Build a series of new off-stream storage facilities in the Red Deer sub-basin*

In addition to the SAWSP and Acadia Valley project, off-stream storage was discussed as an option for the Red Deer sub-basin rather than building large on-stream structures. This storage would supply water for municipal, industrial and agricultural growth in the lower sub-basin while still maintaining the environmental health of the watershed. Working group participants suggested that these storage options should be modelled together with the proposed SAWSP and Acadia Valley storage in Level 2, as storage increases would need to be coordinated to ensure an appropriate distribution of benefits to all water users. If further study demonstrates that off-stream storage sites would not be possible or effective, then a midstream facility on the Red Deer system should be moved from Level 3 to Level 2.

3.2.5 Roadmap Strategies: Level 3

Level 3 of the Adaptation Roadmap involves adding new on- and off-stream storage and adapting minimum flow values through municipalities during drought periods. Figure 39 shows the adaptive strategies contained in Level 3; these would be layered onto implemented strategies in Levels 1 and 2. In the figure, the blue boxes represent the most promising Level 3 strategies. Strategies with an asterisk (*) in the text below are not currently modelled in the SSROM, typically due to limited data.

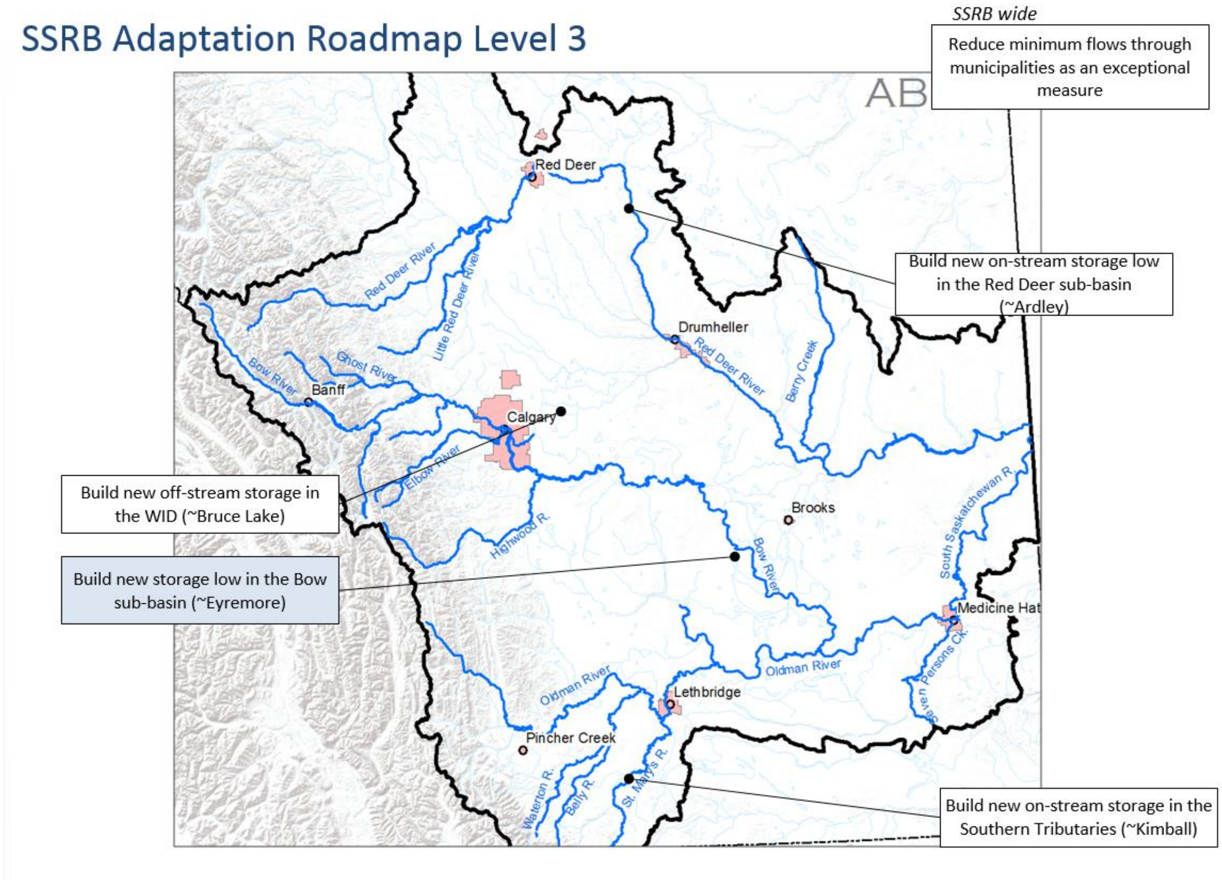


Figure 39: Map of the SSRB showing the adaptation strategies applied in Level 3 and their approximate location

The strategies in Level 3 are described below.

Build new on-stream storage low in the Bow system below Bassano Dam (Approximately (~) Eyremore site, ~477,000 dam^3)

The most promising strategy in Level 3 is building a new on-stream reservoir low in the Bow system. The location that has been discussed is the Eyremore site located below Bassano Dam, as seen in Figure 39. This work assumed that Eyremore would be a large storage facility with 954,000 dam^3 total storage and an approximate live storage capacity of 477,000 dam^3.

This large facility allows for increased flexibility of the water management system in the SSRB by supplementing downstream flow. Model runs sought to use the additional storage to supplement Oldman River flows and increase water available for use on the Bow. The additional storage could also be used to improve flows in the Bow River and the freeboard could help mitigate downstream flooding. Finally, Eyremore could be used to provide water during lower flow periods downstream and, potentially, for municipal water supply at Medicine Hat and other communities.

Oldman flow supplementation was achieved using the Eyremore Reservoir to maintain minimum flows on the South Saskatchewan. This results in less demand on the upstream reservoirs in the Oldman, allowing for additional storage to be maintained higher in the watershed, as seen in Figure 40.

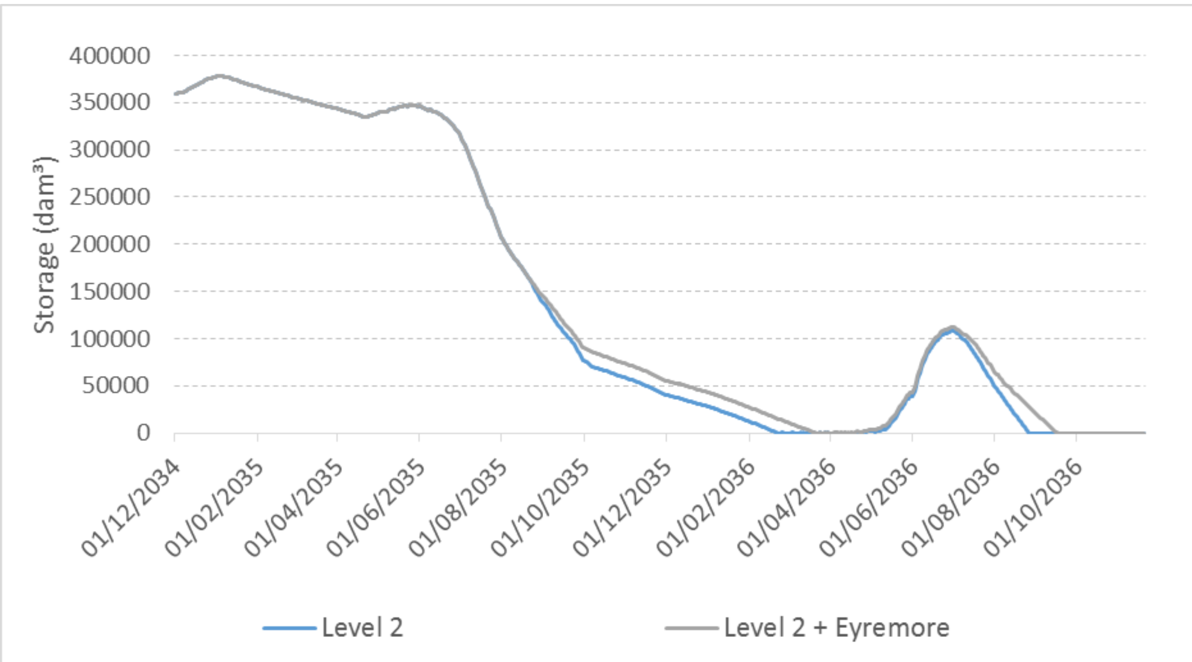


Figure 40: A comparison of storage in the Oldman Reservoir with (grey) and without (blue) Eyremore during a drought year

The additional storage increased the capacity to meet water needs in the Bow and Oldman systems. This is partly due to the EID no longer being required to pass 400 cfs ($11.3 m^3/s$) downstream, given that the new reservoir would extend to the EID diversion and could increase downstream flows more than before. This results in more water being available for other uses. In this case, the BRID uses the additional water, decreasing shortages in the Bow by 50%. A 10% reduction in shortages was found in the Oldman, again a function of increased upstream capacity to meet demands (Figure 41). When Eyremore is operated to meet environmental needs, the shortages are unchanged relative to Level 2 (Figure 42).

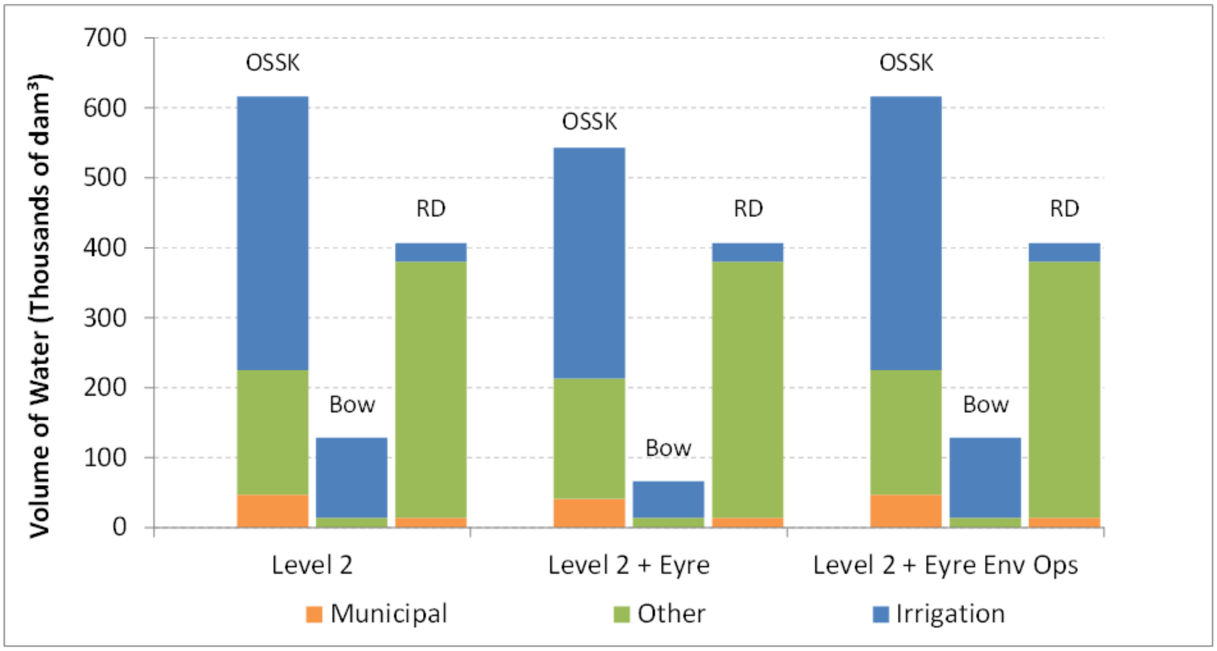


Figure 41: A comparison of municipal (orange), other (green) and irrigation (blue) shortages between Level 2, Level 2 plus Eyremore with operations to meet shortages, and Level 2 plus Eyremore with environment operations during the 15-year Frankenflow period

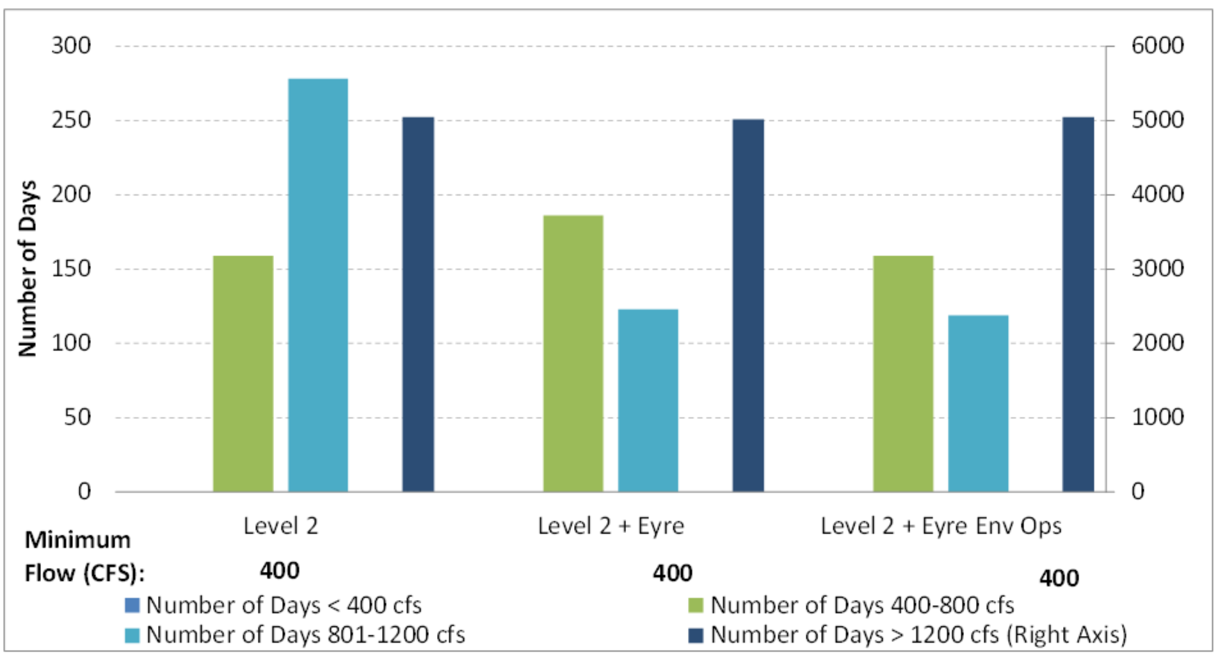


Figure 42: A comparison of low flow days between Level 2, Level 2 plus Eyremore with operations to meet shortages, and Level 2 plus Eyremore with operations for meeting downstream environmental needs during the 15-year Frankenflow period

Because Eyremore would be located downstream in the Bow sub-basin, it cannot be used directly to support upstream water needs. However, an upstream beneficial effect is possible since the flow past Bassano can be made up from Eyremore releases, allowing upstream users to take more water, conditional on environmental requirements, when required. Without a prior agreement, environmental performance could slightly decrease as the BRID may be able to take a small amount of extra water (Figure 42). Introducing Eyremore would require an evaluation of how to mitigate reduced environmental performance.

Building a new reservoir comes with potential challenges. For example, environmental effects such as potential impacts on downstream fish habitat would have to be addressed prior to any construction. That said, this reservoir could be extremely positive for downstream fish habitat if it is operated with the objective of greatly reducing the number of days with very low flow. A comprehensive investigation into the relative costs and benefits of such a large on-stream facility would be required. This dam would likely offer some hydropower potential.

Build new off-stream storage in the Western Irrigation District (~Bruce Lake, ~51,000 dam^3)

New off-stream storage in the Bow sub-basin could include Bruce Lake, which was modelled as a facility with 51,000 dam^3 live storage; the location of Bruce Lake is shown in Figure 39. This strategy offers benefit by reducing shortages in the WID. Under dry or drought conditions, Bruce Lake could enable WID to provide water to its members without diverting from an extremely low Bow River. Further analysis to evaluate the extent of system-wide benefits would be useful.

Build new on-stream storage in the Southern Tributaries of the Oldman sub-basin, balanced with other reservoirs (~Kimball site, ~125,800 dam^3)

The Kimball site, shown in Figure 39, would be a new on-stream facility on the St. Mary River with total storage of 125,800 dam^3 (Alberta Environment, 2008). This site has been examined in various studies, including the storage study done by Alberta Agriculture and Rural Development (now Alberta Agriculture and Forestry, or AAF). The location of this potential site is higher up in the watershed than many other locations and is thus better positioned to increase system flexibility by capturing and delivering water. For modelling purposes, it was assumed that the Kimball Reservoir would be responsible for meeting a new downstream WCO for the reach before the St. Mary Reservoir, while the existing instream objective (IO) would remain unchanged below the St. Mary Reservoir. This would need to be confirmed with AEP.

The effect of adding Kimball storage is to reduce shortages in the OSSK system, as shown in Figure 43. This reduction in shortages is demonstrated during both the Frankenflow and Historical time periods. Shortage reductions are most noticeable in the Historical time period, where drought periods are not as severe (Figure 43B).

Building a new reservoir does come with potential challenges, as noted for the Eyremore site. Environmental costs could outweigh environmental benefits, such as loss of riverine habitat to a reservoir and fragmentation of fish populations due to another barrier to movement.

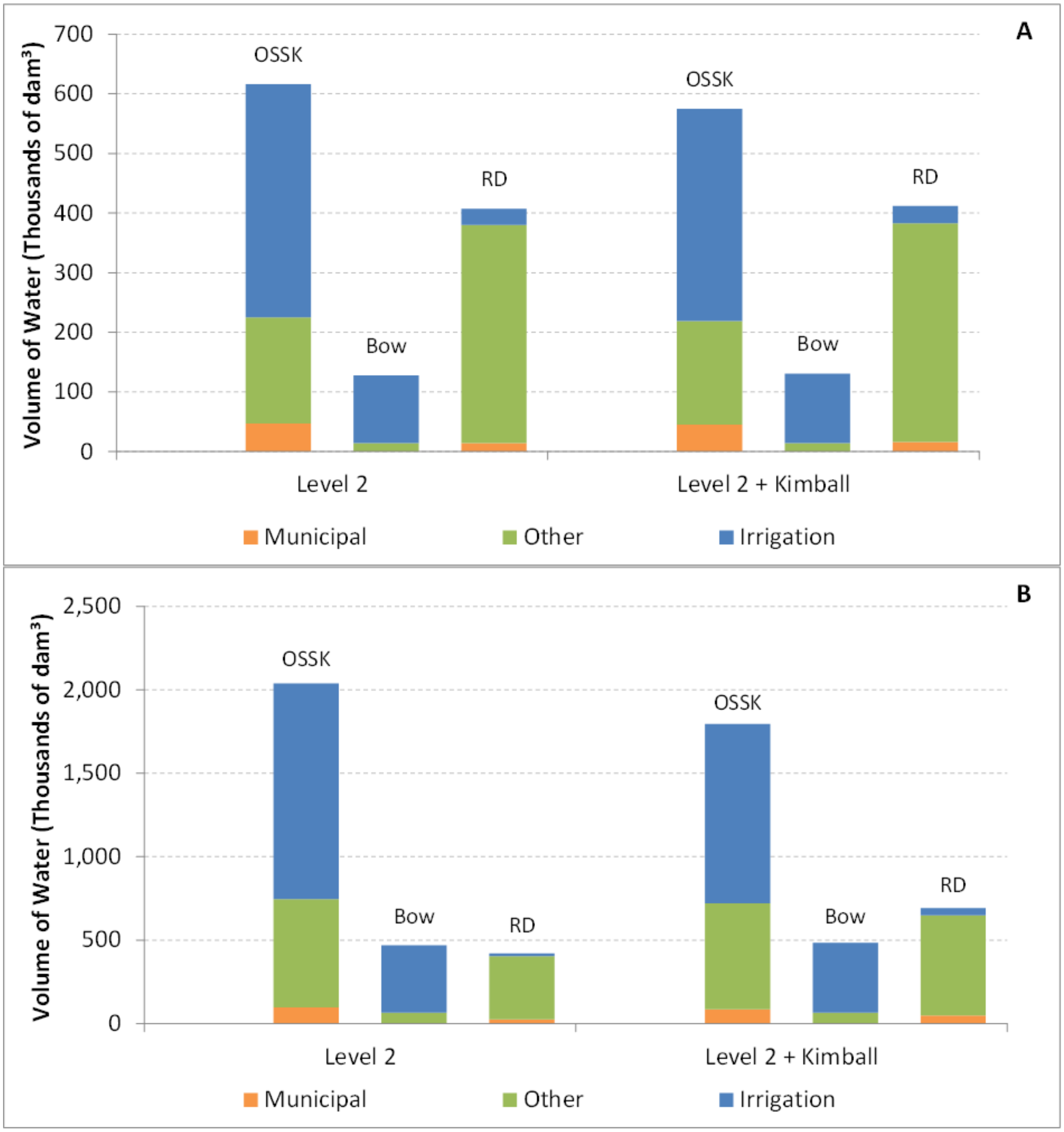


Figure 43: A comparison of municipal (orange), other (green), and irrigation (blue) shortages between Level 2 and Level 2 plus Kimball Reservoir for 15-year Frankenflow (A) and 1928–2009 Historical (B) periods

Off-stream storage was discussed as an option for the Oldman sub-basin as an alternative to building large on-stream structures. A series of smaller off-stream reservoirs could be built as needed throughout the sub-basin to meet local demands. Off-stream reservoirs can also create important lentic habitat for aquatic and terrestrial species and do not have the same environmental consequences as on-stream reservoirs.

Build new storage midstream in the Red Deer sub-basin (~Ardley site, ~400,000 dam^3)

An example often used for mid-stream storage is Ardley Reservoir, previously proposed downstream of the city of Red Deer but upstream of the Buffalo Lake diversion. The Ardley Reservoir was modelled with a maximum storage of 700,000 dam^3 (based on Alberta Environment, 2008), with 300,000 dam^3 reserved as empty storage for flood mitigation for downstream communities. This results in a 400,000 dam^3 live storage facility. This large storage facility has the potential to play a substantial role in building adaptive capacity in the Red Deer system, demonstrated by improved environmental flows downstream of the reservoir (shown previously in Figure 15) and reduced shortages (shown previously in Figure 16). It must be acknowledged, however, that there are also costs to such a large facility in terms of lotic habitat loss and fragmentation. Careful operations would also have to be implemented, particularly during the fill periods to ensure apportionment is met and downstream WCOs are maintained.

Reduce minimum flows through municipalities and other downstream users as an exceptional measure in drought years to slow the draining of upstream reservoirs

This strategy could be implemented in extreme drought periods to help slow upstream reservoir draining. The maintenance of upstream storage enables releases to be made for a longer time period to the benefit of water users and overall aquatic health. Maintaining higher minimum flow values can result in a more abrupt change in flows and potentially lower flows late in the season due to a lack of available storage for supplementation.