South Saskatchewan River Basin Adaptation to Climate Variability Project

Phase III: Oldman and South Saskatchewan (OSSK) River Basins Summary Report

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Contents

Acronyms and Abbreviations

AF	Acre-foot (1 AF = 1.233 cdm)
ARD	(Alberta) Agriculture and Rural Development
BROM	Bow River Operational Model
CAN	Computer-Aided Negotiations
cdm	Cubic decametre (1 cdm = 1,000 cubic metres, or 0.811 AF); also shown as dam^3
cms	Cubic metres per second
ESRD	(Alberta) Environment and Sustainable Resource Development
FITFIR	First-in-time, first-in-right
FRC	Fish Rule Curve
FSL	Full Supply Level
GCM	General Circulation Model
IDM	Irrigation Demand Model
IJC	International Joint Commission
IO	Instream Objective
LNID	Lethbridge Northern Irrigation District
MID	Magrath Irrigation District
MVLA	Mountain View, Leavitt, and Aetna Irrigation Districts
MW	Megawatt
OSSK	Oldman and South Saskatchewan (basins)
PARC	Prairie Adaptation Research Collaborative
PDO	Pacific Decadal Oscillation
PM	Performance Measure
RID	Raymond Irrigation District
SMRID	St. Mary Irrigation District
SSRB	South Saskatchewan River Basin. The South Saskatchewan River Basin includes the sub-basins of the Bow River, Red Deer River, and South Saskatchewan River (including the Oldman and other tributaries)
SSRP	South Saskatchewan Regional Plan
TID	Taber Irrigation District
UID	United Irrigation District
WCO	Water Conservation Objective
WRMM	Water Resources Management Model
WUA	Weighted Usable Area (a performance measure related to fish habitat)

1 Executive Summary

Alberta faces important water challenges, including an expanding population, accelerating economic growth, and the increasing impact of this growth on the environment as weather and climate patterns continue to shift. Nowhere are these matters more pressing than in southern Alberta. Water management is not a new concept to residents of the South Saskatchewan River Basin (SSRB), as much has been done to build today's water systems to ensure safe, reliable water supplies for economic, social, and environmental needs. The result is infrastructure and practice within well-defined regulatory frameworks and plans that govern water management activities throughout the province. The project described in this report brought together those who know the region's water systems best to look for opportunities to further enhance the resiliency of the Oldman and South Saskatchewan (OSSK) River Basins.

This report summarizes work done in Phase III of the SSRB Adaptation to Climate Variability Project, which focused on the OSSK River Basins. The Phase III work aimed to improve understanding of climate variability in the OSSK basins using existing data and expertise, and then to identify adaptation strategies to build the resiliency of the system. Phase III continued the collaborative modelling process used in the Bow River Basin work and Phase II of the SSRB Adaptation to Climate Variability Project. This previous work has been summarized in separate reports available on the Alberta WaterPortal at www.albertawater.com.

The long-term historic record shows that the SSRB is prone to climate far more variable than that experienced in recent memory. One goal of the SSRB Adaptation to Climate Variability Project 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 water users and managers to test water management alternatives under a range of potential future climate and hydrological scenarios. These scenarios and the historic record presented the range of hydrological regimes against which the working group could test and refine potential strategies for adaptation to both prolonged drought and severe flood using the OSSK model.

The OSSK model is a mass balance river system model that reflects the streamflows and operations of the Oldman and South Saskatchewan River systems. It is a single model that includes the Oldman and South Saskatchewan river basins with all their major tributaries. It does not explicitly calculate and account for groundwater nor include water quality aspects, but groundwater contribution to base streamflow is inherently part of the naturalized flow data, which are used as inflows to the model. As it is currently configured, the model meets as many existing and future water needs defined by stakeholders in the basin as possible. It focuses primarily on what water users actually need to do rather than strictly replicating decision making mandated by the current regulatory scheme in Alberta. That said, the operations within the model comply with the limitations established under the *Water Act.*

Six working group meetings were held in Phase III in Lethbridge. Participants actively offered ideas and comments to advance the discussion, while respecting the views and opinions of others; however, this process was not designed to seek or achieve consensus. While this report does not recommend that specific strategies be implemented, it does highlight a wide range of

opportunities that have been vetted by stakeholders. Some of these strategies could be implemented through more formalized collaboration and some would require new infrastructure. They are presented as a solid foundation for discussion and further consideration by those who use, manage, and make decisions about water in the OSSK basins.

Phase III concluded by using the OSSK model and stakeholder input to develop potential risk management strategies for helping southern Alberta adjust to climate variability and change. Performance measures were developed and used to assess and demonstrate the impact and benefits of changes made in the model, focusing on impacts to the river and aquatic ecosystem health as well as on the needs of the various water users.

Participants identified 15 individual adaptation strategies and three combinations. The strategies took a variety of approaches, including optimizing existing infrastructure, building new infrastructure, changing operations by supplementing environmental flows, reducing demand, and sharing supply. Some apply to specific geographic regions while others could be implemented across the basins. While the working group discussion tended to focus on basin-wide opportunities, local opportunities should not be lost or overlooked. Modelling results for each strategy are described and compared in this report.

An important conclusion is that there is no one simple solution for adapting to climate variability in the OSSK basins. This project confirmed that water in the OSSK region is already being managed efficiently, effectively, and, to some extent, collaboratively, which will be a big advantage in the event of future water challenges, whether caused by drought or flood. Further resiliency will come from strategies and solutions that build on what is already being done. Many of these are easier to implement than large new infrastructure projects, and can typically be done under non-crisis conditions. Nevertheless, in the face of prolonged drought, more aggressive strategies warrant due consideration.

In the next several months the Bow, OSSK and Red Deer river models will be integrated into a single model to support discussions around integrated water management across the whole SSRB. This collaborative water management opportunity identification, assessment, and analysis is fundamental to maintaining and building the resiliency of our river systems and the communities that rely on them in the face of growing demands and uncertain climate.

2 Introduction

Alberta's heritage and its social, economic, and environmental history are directly tied to its water resources. While Alberta's economy is fuelled by hydrocarbons, it runs on water, and continued prosperity depends on sound water management decisions. In the face of climate variability and change, these decisions are becoming more complex and more critical.

The province's geographical landscape encompasses the spine of the Rocky Mountains on its western border, semi-arid plains in the south, parklands in central Alberta, and boreal forest across the north. The mountain regions are the water towers for much of western Canada, while eastward and northward flowing rivers are vital to this province as well as downstream neighbours.

Both water supply and demand vary considerably throughout the province. The health of Alberta's natural resources and its economic vitality depend on an integrated understanding of natural climate variability as well as the management capacity to confront the prospects and potential impacts of changes in climate. The long-term historic record shows that the South Saskatchewan River Basin (SSRB) is prone to climate far more variable than that experienced in recent memory.[1]

Alberta faces important water challenges, including an expanding population, accelerating economic growth, and the increasing impact of this growth on the environment as the climate continues to change. Nowhere are these matters more pressing than in the southern part of the province. These challenges 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. Alberta has a history of successfully meeting challenges through multi-sector collaboration and engagement, and the South Saskatchewan River Basin Adaptation to Climate Variability project will further enhance that legacy.[2]

This report summarizes work done in the third phase of the SSRB Adaptation to Climate Variability Project, which focused on the Oldman and South Saskatchewan river basins (Figure 1). Throughout this report, these are referred to as the "OSSK basins."

[1] Axelson, J. N., D. J. Sauchyn, and J. Barichivich. 2009. "New reconstructions of streamflow variability in the South Saskatchewan River Basin from a network of tree ring chronologies, Alberta, Canada," *Water Resour. Res.*, 45, W09422, doi:10.1029/2008WR007639.

[2] See Appendix A for more information on this project.

Figure 1: The Oldman and South Saskatchewan river basins

2.1 Context for Water Management in the OSSK Basins

A great deal of attention has centred on water management in southern Alberta over many decades. Traditionally, the focus has been on managing water as a scarce commodity, 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 variability and its associated 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.

The natural attributes of the OSSK basins have long attracted settlement and development and represent a rich and diverse ecological heritage. Many of these features are important to the region's identity; participants in the OSSK basin working group acknowledged the value of these natural features and the importance of protecting them.[3] This project recognized the region's environmental uniqueness and sensitivity, and deliberately did not propose any new

[3] In the next phase of work in the SSRB, land cover and land use will be examined in an attempt to incorporate these factors into the overall modelling approach. Protecting the integrity of the headwaters of the Oldman River, the source of 90% of the river's flow, is the goal of the Headwaters Action Plan developed by the Oldman Watershed Council (http://oldmanbasin.org).

infrastructure in areas such as the Oldman River headwaters and the Castle River watershed. For streamflow modelling purposes for this project, the headwaters regions were assumed to remain more or less in their current natural state.

Nevertheless, the landscape of southern Alberta has been shaped by efforts to use water efficiently to meet the needs of people, the environment, and economic development. Several specific parameters provide a backdrop against which water is managed in the OSSK basins; they are noted here and described in more detail later:

- Alberta remains committed to its existing priority system of water allocation based on licence seniority, commonly known as first-in-time, first-in-right (FITFIR).
- Since 2006 when the South Saskatchewan River Basin water management plan was approved by the Lieutenant Governor in Council, no applications for new water allocations have been accepted in the Bow, Oldman, and South Saskatchewan River sub-basins.
- The Master Agreement on Apportionment (1969) requires that 50% of the flow by volume of eastward-flowing provincial watercourses must be passed from Alberta to Saskatchewan.
- The Boundary Waters Treaty (1909) and the 1921 Order of the International Joint Commission establish the terms and conditions for sharing water with Montana, and affect the Milk[4] and St. Mary River systems.

These parameters and other key pieces of policy and legislation provide the broader context for water management in southern Alberta and for the work undertaken as part of this project. They are briefly described here.

In 1894, before Alberta became a province, the federal government passed the *North West Irrigation Act*, which allowed allocation of water by the government for irrigation and other purposes.[5] Water was allocated based on the seniority of the licence, which meant that in times of shortage, the holder of an older licence could divert water ahead of a more junior licence-holder. This priority system (FITFIR) has been affirmed by the Government of Alberta in subsequent water legislation (the 1931 *Water Resources Act*, and the more recent *Water Act*,[6] proclaimed in 1999), and in the 2013 Water Conversations.

In 2003, the Government of Alberta published *Water for Life: Alberta's Strategy for Sustainability,* which has been the vehicle for managing Alberta's water resources since then. The Government affirmed its commitment to this approach for managing water quantity and quality when it renewed the strategy in 2008.[7] The strategy's three goals of safe, secure drinking water; healthy aquatic ecosystems; and reliable, quality water supplies for a sustainable economy are being met through knowledge and research, partnerships, and water conservation.

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[4] The Milk River system was not included in this project because the Milk is an international trans-boundary river subject to ongoing discussions by the International Joint Commission.
[5] Source: Alberta Environment and Sustainable Resource Development, http://environment.alberta.ca/02265.html
[6] Revised Statutes of Alberta 2000, Chapter W-3:
http://www.qp.alberta.ca/1266.cfm?page=w03.cfm&leg_type=Acts&isbncln=9780779733651
[7] See http://www.waterforlife.alberta.ca/

Recognizing the pressures on water in the south, the Government of Alberta approved the *Water Management Plan for the South Saskatchewan River Basin (Alberta*) in 2006.[8] This plan aimed to balance protection of the aquatic environment and water allocation of rivers in the basin. Among other things, it led the Government of Alberta to close the Bow, Oldman, and South Saskatchewan River sub-basins to new applications for water allocations.

Work on the South Saskatchewan Regional Plan (SSRP) has been underway for several years as part of the province's Land-use Framework. Nine challenges were identified in the region,[9] all of which require a strong and sustained water management effort. The 2013 draft SSRP 2014-2024[10] identified seven specific outcomes, six of which bear directly on water management.

Irrigation is the major water use in southern Alberta and has played an important role in Alberta's agriculture sector for over a century. Recently, the Government of Alberta issued a draft document, *Alberta's Irrigation – A Strategy for the Future 2013-2035*.[11] The draft Irrigation Strategy aligns with the water management and environmental stewardship outcomes in the SSRP and is expected to evolve along with the regional plan. The document 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 Plan, which describes the commitments made by the industry.[12]

In 2013, the Government of Alberta held its Water Conversations, consulting around the province to gather ideas and input in four priority areas: healthy lakes, hydraulic fracturing and water, drinking water and wastewater systems, and water management. It was intended that the outcomes from this discussion would guide regional planning under the Land-use Framework as well as the development of a provincial Integrated Resource Management System. Although it was looking for new ideas from this initiative, the Government affirmed its continuing commitment to the existing water priority licence system (FITFIR).

In early 2013, the Irrigation Council, an advisory body to Alberta Agriculture and Rural Development (ARD), initiated a study to assess potential for additional storage in the SSRB, given the importance of long-term planning for water management.[13] Possible new storage sites are being assessed for their potential to improve security of supply to existing users, protect the aquatic environment, support the needs of First Nations, and mitigate impacts of climate

[8] Available online at http://www.environment.alberta.ca/documents/SSRB_Plan_Phase2.pdf

[9] The nine challenges are: water security, expanding communities, sensitive habitats and species at risk, infrastructure needs, maintaining the agricultural land base, tourism growth, managing recreation, resource development, and sustainable forests.

[10] Online at https://landuse.alberta.ca/LandUse%20Documents/SSRP%20Draft%20SSRP%202014-2024_2013-10-10.pdf

[11] Available online at http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/irr14575/$file/2013-ab-irrigation-strategy.pdf?OpenElement

[12] This report is available on the website of the Alberta Water Council at http://www.awchome.ca/LinkClick.aspx?fileticket=Qh93ijEWpxs%3d&tabid=115.

[13] The current study drew on previous work that was documented in the following reports: *South Saskatchewan River Basin in Alberta: Water Supply Study* (2009); *Provincial Inventory of Potential Water Storage Sites and Diversion Scenarios* (September 2005); and *Assessment of Potential Water Storage Sites and Diversion Scenarios* (January 2008).

variability and change. The study team liaised with the OSSK project and some of the storage sites being examined were modelled as part of the OSSK work. The storage study is expected to be completed in mid-2014.

Most of the aforementioned initiatives were intended to address the impacts of drought. Floods in southern Alberta are not rare, with the 1995 and 2005 floods in recent memory, but no one anticipated the catastrophic events of June 2013. The Government of Alberta has estimated the total cost of the June floods at $6-billion. In economic terms, this was the worst natural disaster in Alberta history and the costliest insured natural disaster in Canadian history.[14] The Flood Recovery Task Force[15] was struck to explore and recommend options for responding to future such events. Much of its initial focus has been in the Bow River system and downstream through Medicine Hat, but the scope includes all flood-prone basins throughout the province, including the OSSK.

The geography of Alberta has also made it necessary to work with other jurisdictions. Within Canada, the Master Agreement on Apportionment (1969)[16] between the governments of Alberta, Saskatchewan, Manitoba, and Canada describes the process and conditions for sharing the waters of eastward flowing interprovincial streams. Under this agreement, 50% of the annual flow by volume must be passed from Alberta to Saskatchewan. Historically, the average flow to Saskatchewan has typically been more than 75% because Alberta lacks storage to take its full entitlement. 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. 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)[17] governs the sharing of waters of international streams between Canada and the United States, and established an International Joint Commission (IJC) to monitor compliance and resolve disputes. Of significance to Alberta, this treaty establishes the terms and conditions for water sharing with Montana, and is relevant to the Milk and St. Mary river systems. Alberta's water entitlement 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 have because Montana lacks diversion and storage infrastructure. Figure 2 compares the natural flow in the St. Mary River to Alberta's historical received flow and its entitlement flow under the IJC Order. As shown, in low-flow years such as 2000 and 2001, Montana withdrew almost its full entitlement. Conversely, in normal and especially in high-flow years, Montana's withdrawal was proportionally lower. If Montana takes its full allotment, the volume of water coming into Alberta will be reduced and water management decisions will need to take this into account. As described in Section 3, the modelling done for this project was based on Alberta's entitled IJC flow.

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[14] Source: http://www.calgaryherald.com/news/Province+boosts+cost+Alberta+floods+billion/8952392/story.html
[15] See http://www.alberta.ca/Flood-Recovery.cfm
[16] See http://environment.alberta.ca/01706.html
[17] See http://environment.alberta.ca/01359.html

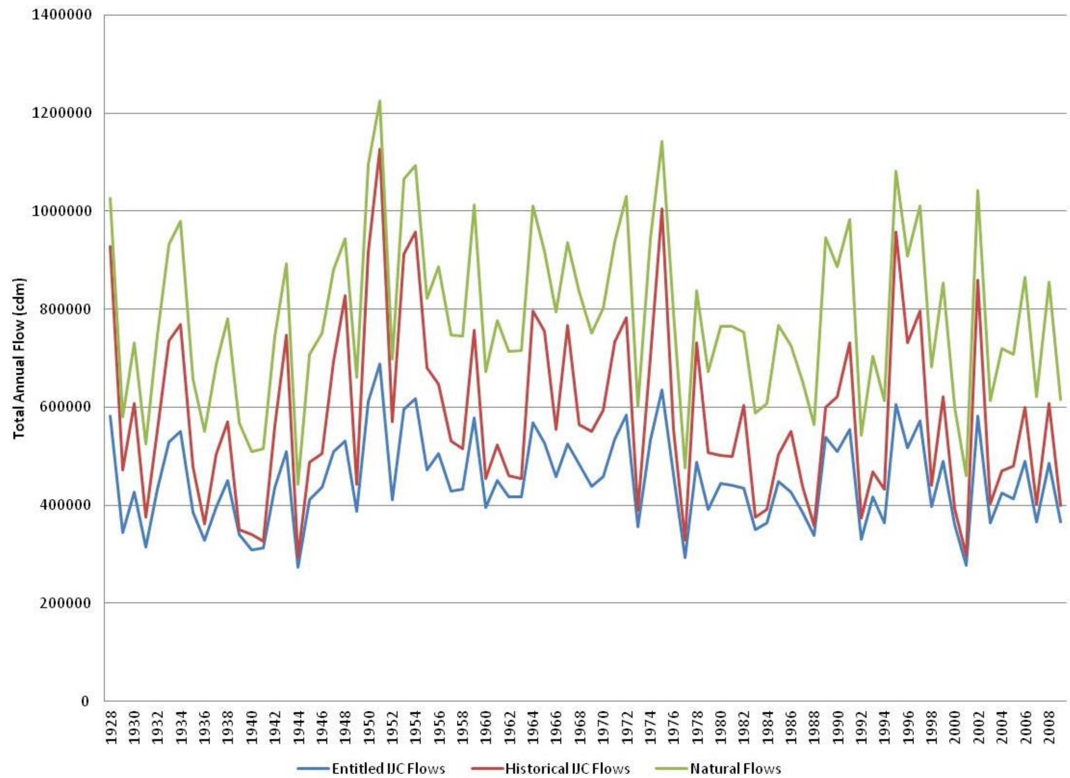

Figure 2: Total annual flow from the St. Mary River
The blue line represents the minimum entitled IJC flow, the red line represents IJC flow historically observed during the period, and the green line represents naturalized flow at the US/Canadian border.

2.2 The Need for Resilience and Adaptability

In an area that couples complex geography and land uses with diverse and growing water needs, water supplies in the OSSK basins have historically been, and continue to be, under serious pressure and scrutiny. These pressures have been acknowledged through the closure of three sub-basins to new water licences. Further, 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.

Climate variability is likely to bring more extreme and intense events than Alberta has experienced in recent recorded history. This intensification combined with continued 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 drought or floods.

Both urban and rural municipalities continue to grow in the region. They require a safe, secure supply of drinking water as well as water to meet wastewater treatment and dilution needs and other municipal demands. A growing population can also create new demands for recreational opportunities, which could have implications for river flows, reservoir volumes and operations. A number of municipalities across the province are implementing water conservation, efficiency, and productivity plans along with water reuse opportunities but the attractiveness of the OSSK basins makes further population growth and the associated demands for water inevitable if current trends continue.

Economic growth and development contribute to a high quality of life in the region. Primary agricultural production makes the region an attractive location for food processing and other industries, all of which need assured supplies of water. Other opportunities will also be important to the growth and diversification of the region, including the service industry and the manufacture of value-added goods. Irrigation districts are major water users, holding licences for 85% of the water allocated in the OSSK basins. 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. However, additional storage and water management infrastructure may be desired to help meet the growing variety of water demands. The Government of Alberta continues to investigate opportunities to increase traditional on- and offstream storage, while other storage options using aquifers, gravel beds, wetlands, and other natural features appear to be receiving more attention. Any new infrastructure and storage would require environmental impact assessments, cost-benefit analysis, socio-economic analysis, engineering feasibility studies, consideration of impacts on landowners and First Nations, and other investigations, recognizing that there are trade-offs. As well, data on the interaction between surface and groundwater volumes and flows are limited or non-existent and impacts of climate variability and change could lead to a growing reliance on groundwater in some areas.

The region's natural beauty and biodiversity support a strong and growing recreation and tourism industry, and the OSSK basins are home to a number of threatened fish and other species, including the Rocky Mountain sculpin (*Cottus bondi*), bull trout (*Salvelinus confluentus*), and lake sturgeon (*Acipenser fulvescens*).[18] Managing rivers to meet instream flow needs can be a challenge, while other species may come under pressure due to water management infrastructure and other disturbances.

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 OSSK basins for decades. They have seen first-hand the impacts of both droughts and floods on the region's people, environment, and economy, and are only too 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 potential strategies that could benefit the OSSK basins 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.

[18] According to the *Draft South Saskatchewan Regional Plan 2014-2024* (2013), the South Saskatchewan Region has more than 80% of Alberta's species at risk as listed under the federal *Species at Risk Act* and the provincial *Wildlife Act.*

3 SSRB Adaptation Project Phase III Process and Methodology

Phase III of the SSRB Adaptation Project engaged representatives of the major water users in the OSSK basins as well as others with an interest in how water is used and managed in the basins (see Appendix B for a participant list). This diverse group included water users and managers with more than 80% of the licensed water diversions on the Oldman River and over 70% of the licensed diversions on the South Saskatchewan River.

3.1 The Collaborative Modelling Process

HydroLogics, Inc. the consultant who was involved with the Bow Basin phase of this project (Phase II) again led the modelling for the OSSK basins, using the sophisticated simulation software they developed for modelling water systems throughout the US and internationally. HydroLogics' modelling software—called OASIS (Operational Analysis and Simulation of Integrated Systems)—is flexible, transparent, completely data-driven, and effectively simulates water facility operations.

The project team and some participants had been involved in Phase II of the SSRB Adaptation to Climate Variability Project. They were very familiar with the OASIS software used to develop the Bow River Operational Model (BROM), which formed the starting point for developing the OSSK model, described in more detail in Section 3.3. Operations and priority water allocations were different for the two models, but the software was the same.

HydroLogics has pioneered the use of Computer-Aided Negotiations (CAN), which enables parties with disparate goals to collaboratively develop operating policies and solutions that mutually satisfy their diverse objectives. The CAN sessions integrate computer modelling techniques and real-world data with existing water management structures.

Developing performance measures (PMs) is one of the first steps in the process 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 model needs to have, and thus they inform and influence how the model is constructed. Participants identified and developed specific PMs based on their individual and collective water outcome needs for this project.

Once PMs are in place, the model can be run and the results tested and vetted using the PMs to determine if the outcomes are reasonable and realistic, based on the deep knowledge and experience of participants. Exploring and modelling alternative operations is what most often results in model improvements and updates, and strengthens model results. When the model is refined and ready to be tested, participants then spend a number of hours working collaboratively in small groups to identify and test opportunities and potential scenarios or strategies to achieve the PMs. Based on these outcomes and the results of the PMs, collaborators can then seek agreement on the alternatives that are most beneficial to the basins and meet as many user needs as possible.

3.2 Phase III Process

Project participants met in Lethbridge six times between November 2012 and February 2014. Between working group sessions, specific individuals also volunteered to refine PMs, explore economic aspects, identify enhancements to the model, and provide data. A two-day live modelling session was held in September 2013 to examine the plausible range of climate change impacts on streamflow in the OSSK basins as developed by Dr. David Sauchyn and his team specifically for this project (Section 3.4), and to explore potential adaptation strategies in response to these impacts. This was followed by a one-day live modelling session in December 2013 and a final meeting in February 2014 to determine and refine the most promising strategies.

Throughout the project, participants worked collaboratively, providing advice and insight based on their extensive knowledge and experience. Project terms of reference were approved by the group, key components of which are included in Appendix C.

Participants actively offered ideas and comments to advance the discussion, while respecting the views and opinions of others. This process was not designed to seek or achieve consensus; rather, it was designed to explore practical adaptation strategies based on the best data and knowledge in the basin. The results are presented as a solid foundation for discussion and further analysis by those who use, manage, and make decisions about water in the OSSK basins as they consider adaptations to climate variability and change.

3.3 The OSSK Model

Like the BROM, the OSSK model is a daily mass balance model that reflects the streamflows and operations of the river systems involved (Figure 3). The OSSK model is a single, unified model that includes the full Oldman and South Saskatchewan basins with all their major tributaries (including the Southern Tributaries). This allows users to understand today’s integrated demands and operations through the entire system, simulate the balancing of the reservoirs throughout the system, and track the impacts and benefits all through the system that could accrue from changes in operational or storage strategies.

The primary inputs to the OSSK model are naturalized flows, lake evaporation, precipitation, consumptive uses, return flows, and physical data. For all canals and reservoirs in the OSSK basin, whether operated by Alberta Environment and Sustainable Resource Development (ESRD) (i.e., Oldman, Waterton, St. Mary, and Ridge) or managed by an irrigation district (i.e., Chin, Stafford, Horsefly, Yellow, Sauder, and others), physical data were provided by ESRD, Alberta Agriculture and Rural Development (ARD), and individual irrigation districts as needed. The OSSK model does 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 OSSK model when relationships between water quality and quantity at a particular point in the system are known.

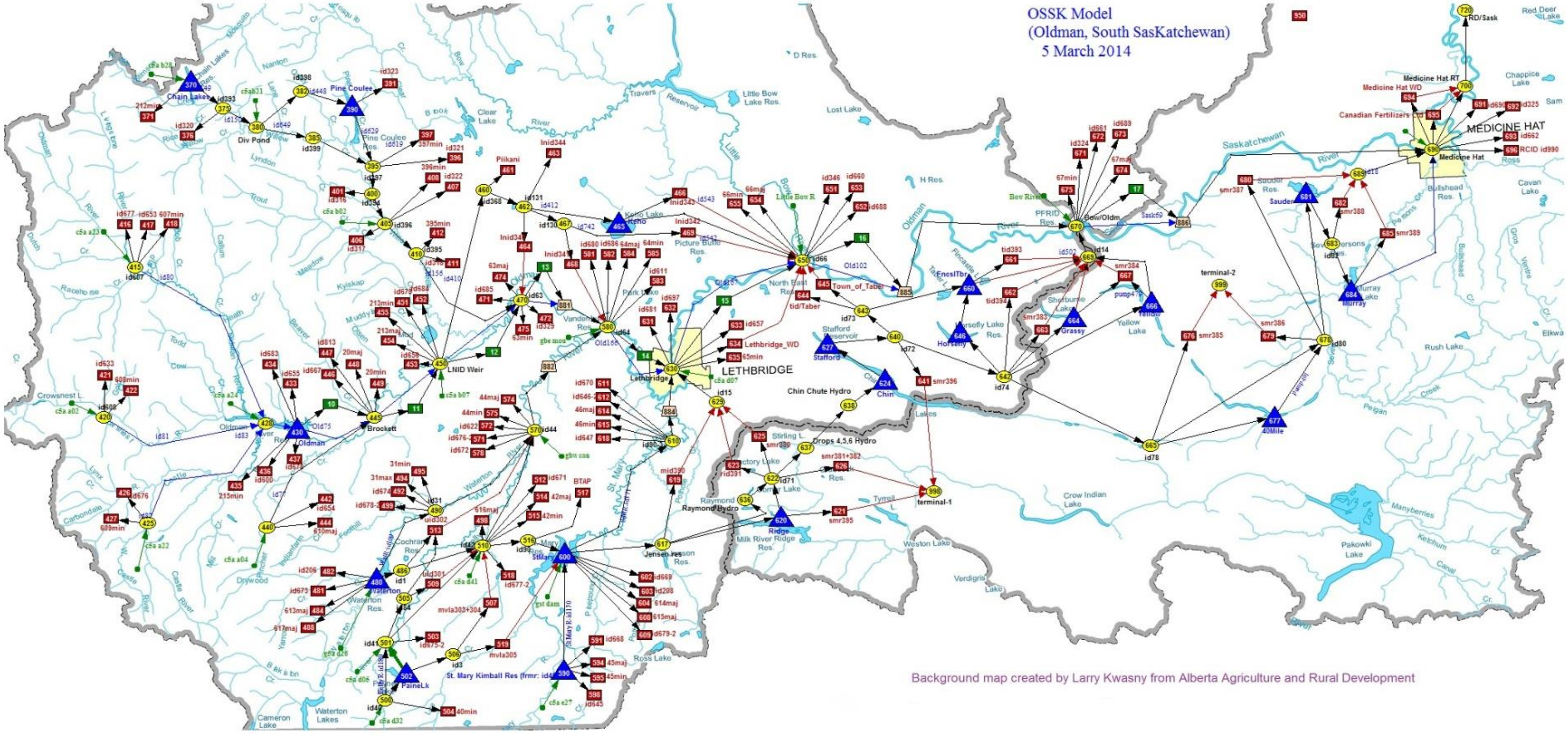

Figure 3: Schematic showing the area represented by the OSSK model

Legend (for this schematic and those that appear later in the report in section 4)

Reservoirs — Demand nodes — Instream demand nodes — Junction nodes

Green arrows indicate inflow locations.

Blue and black arrows are arcs representing how water flows between nodes.

The base case applies how the river is currently operated, within the context of licensed priorities and water management plans, to historical flows (1928-2009). It is also important to note that there has been a progression of reservoir development in the Oldman River Basin. For example, the St. Mary, Waterton, and Oldman reservoirs were completed in 1951, 1964, and 1991, respectively. The OSSK model does not account for this progression, but rather implies that all existing infrastructure was present in the basin from 1928 to 2009. In the model, IJC entitlement flows are part of the base case. The OSSK model was validated against historical records, generally matching outflows and reservoir levels for the post-Oldman Dam period. Some deviation from the historical record is to be expected, and while there is a modest overestimation of optimum crop water requirements in the ARD Irrigation Demand Model (IDM) these deviations are not seen as being out-of-scope for the modelling activities that have taken place. Additionally, 2011 crop mix, on-farm efficiency and district infrastructure are used in the IDM to calculate irrigation demands based on historical weather records (i.e., 1995 hydrology would utilize 2011 irrigation acreage in the model rather than the historical 1995 acreage that led to the historical flows and elevations). Other assumptions and key aspects of the model are described below.

Inflows and Time of Travel
Weekly inflow and lake evaporation data from ESRD's Water Resources Management Model (WRMM) were provided by ESRD for the period 1928-2001. The inflow record was extended to 2009 with the recent update of the naturalized flow dataset provided by ESRD. Weekly inflows were disaggregated to daily values by adding hydrologically-appropriate statistical variability; this approach was used successfully in earlier work with the BROM to simulate daily inflow data using weekly data sets. A daily flood inflow time series was developed for 1995 to assess flood mitigation options by using a scaling factor that represents observed peak daily flow during the 1995 flood event. This time series was scaled up to daily peak flows that were based on observations upstream of the Oldman, Waterton, and St. Mary reservoirs to approximate a flood.

In many areas of this basin, it takes water more than a day to move through a reach. Since the OSSK model uses a daily timestep, it converted Streamflow Simulation and Reservoir Regulation routing tables obtained from ESRD into time lag look-up tables in the model which were then applied to the major river reaches in the model; these reaches were Belly at the mouth, St. Mary at the mouth, Oldman downstream of the Willow Creek confluence, Oldman downstream of the Little Bow River confluence, and the Saskatchewan River downstream of the Oldman-Bow confluence. This approach is not detailed enough to inform performance measures highly sensitive to the time of travel (as noted in later sections), but is considered an appropriate way to inform basin-scale water management operations.

Water Allocations and Priorities
Individual licence priorities were modelled for 78% of the OSSK demands: the irrigation districts, Blood Tribe Agricultural Project (BTAP), the Piikani First Nation, the Cities of Lethbridge and Medicine Hat, and the Town of Taber. Most of the remaining demands (private irrigators at 13% and small municipal and industrial users at 6%) were aggregated in WRMM, the source of the data, so individual licences were modelled collectively at model nodes, not individually according to the actual legal order of licensed priorities.

In most instances, Fish Rule Curves (FRCs) and Instream Objectives (IOs) are considered to have the utmost priority, and are considered senior to all demands. For the modelling, the monthly FRCs and Habitat and Survival Flows were taken from the Oldman Operating Manual, with buffers added to these minimums to better reflect actual operations. They were not adjusted to the 80% rule (see box below). These demands are accorded special priority (called Tier 0) above all licences. It should be noted that for the South Saskatchewan River below Medicine Hat, at the direction of the working group, a flow of 28.3 cms (1000 cfs) was modelled. A higher target of 42.5 cms (1500 cfs) does exist for that reach and is a withdrawal condition for some licences.

For ease of tracking shortages in model outputs, when there is insufficient water to meet all demands, small municipal and industrial demands have first priority (called Tier 1), followed by private irrigators (Tier 2), followed by the other 78% (Tier 3), which receive water based on individual licence priority. This is different from the actual system on the river that would see the senior licence holders in Tier 3 given water first. With this approach, small municipal and industrial users and private irrigators can use Tier 3 shortages as an indication of potential shortages they may experience under different alternative management strategies, recognizing that, in terms of FITFIR, these licences have the lowest priority. Willow Creek demands, about 3% of the demand in the model, are met as long as there is sufficient flow above the minimum flow requirements in Willow Creek.

Fish Rule Curves

A Fish Rule Curve (FRC) is a variable flow recommendation based, in a specific way, on the WUA versus discharge curve and the natural available supply of water. The recommended flow varies, depending not only on the WUA curve, but also on the hydrologic conditions experienced (wet, dry, average) during the period.

The "80% fish rule curve" (defined below) is in use as the instream objective for parts of the Bow and Oldman rivers (and in the case of the latter, a water quality component is added). The FRC was determined using flow versus habitat relationships. The recommended flow varies with the seasonal hydrological conditions. Due to limitations in habitat measurement techniques at higher flows, the FRC did not address requirements in the medium to high flow range. The FRC approach does not provide for full ecosystem protection and is no longer used in Alberta for determining instream flow needs. The FRC only applies from April 1 to October 31, nominally the open water period. In the Bow River, the Tessmann method defines the instream objective during the rest of the year. In this method a flow recommendation is calculated based on a percentage of mean annual flow. In the Oldman River a minimum flow for water quality is maintained during the winter.

The 80% FRC was an arbitrary 20% reduction of the FRC flows made to permit additional water extraction from the Bow and Oldman rivers. The reduction was not based on biological criteria.

Sources:
South Saskatchewan River Basin Water Management Recommendations, in response to Phase 2 Terms of Reference, A Report to Alberta Environment prepared by: Basin Advisory Committees for the Oldman River, Red Deer River, Bow River and South Saskatchewan (sub-basin) River. July 2004

Clipperton, G. Kasey, C.Wendell Koning, Allan G.H. Locke, John M. Mahoney, Bob Quazi. *Instream Flow Needs Determinations for the South Saskatchewan River Basin, Alberta, Canada.* December 1, 2003. On-line Edition.

ESRD provided data for Tier 1 demands. Demand data were provided by node based on Scenario 18 of the WRMM, which included all existing *Water Act* licence allocations in the OSSK system with estimated build out to reflect future growth and demand. These data were reviewed and modified by the working group participants, as noted below to reflect today's demands and operations. Data for Tier 2 demands were provided by the IDM (see the box below) using current efficiencies, infrastructure, and crop mix patterns, and meeting 90% of crop demand. Both of these sources provide values that are higher than current demands during dry years. Data for the Irrigation Districts, BTAP, and Piikani in Tier 3 were also provided by the IDM using the same assumptions. Demands for the irrigation districts were then scaled back where appropriate so that the modelled average demand reflected the actual average for the last ten years, using the following multiplication factors: TID=0.85, UID=0.74, RID=0.5, MID=0.56. SMRID, LNID, and MVLA demands were not scaled as their demands reflect current conditions. Lethbridge, Medicine Hat, and Taber provided their current demand data and return flows.

All annual licence allocation limits are implemented in the model; demands withdraw the specified amount until they reach their limit, at which point no additional withdrawals are permitted for the year.

The Irrigation Demand Model

The Irrigation Demand Model was developed specifically for the study of irrigation requirements and basin supply within irrigation districts and private irrigation blocks in southern Alberta. This model comprises two modules:

- The Irrigation Requirements Module models each irrigation system in an irrigation block using detailed information on the soil, crop, irrigation equipment, and weather, to estimate on-farm daily irrigation demand.
- The Network Management Module uses irrigation infrastructure to calculate district base flow and system losses.

Summing on-farm daily irrigation demand, district base flow, and system losses provides the total irrigation requirement for an irrigation block or irrigation district.

The irrigation demand modelling done for the OSSK model is based on 2011 current irrigated acres, irrigation district infrastructure, crop mix, and on-farm irrigation system types. Files were provided from ARD and contain both irrigation demand and return flow for both irrigation districts and private irrigators. Irrigation demands generated for the OSSK model are based on the assumption that irrigators would apply sufficient water to meet 90% of the optimum crop water requirement.

St. Mary (Trans-boundary) Flows

The Boundary Waters Treaty and the 1921 IJC Order establish the volume of water to which Alberta is entitled in the St. Mary River system, which flows into Alberta from Montana. Historically, Alberta has received more water than specified in its entitlement. For the purpose of this project, three flows were examined: the natural flow, which represents all the water that would be in the river in a free-flowing state, the historical flow that has come into Canada since the agreement was put in place, and the IJC entitlement flow, which is the volume of water that Alberta is entitled to receive calculated from the historical flows based on the 1909 IJC Order (see Figure 2). Of the three, the IJC entitlement flow is the lowest, or most "conservative," and the natural flow is the highest.[19] These differences are important because the volume of water coming into the St. Mary system can affect other aspects of water management in the OSSK basins. Participants agreed that modelling for the project should use the lower entitlement flows on the basis that this would be a worst-case scenario in terms of water coming across the border. Two examples of the impact of the different flows are shown in the figures below.

Figure 4 compares the shortage days that would be experienced by all irrigation districts across the 82 years of the model. With the lower entitlement flows, the total shortages increase by 769 days, from 2904 days to 3673 days.

[19] It is possible that the entitlement could be renegotiated at some point, in which case the numbers would change.

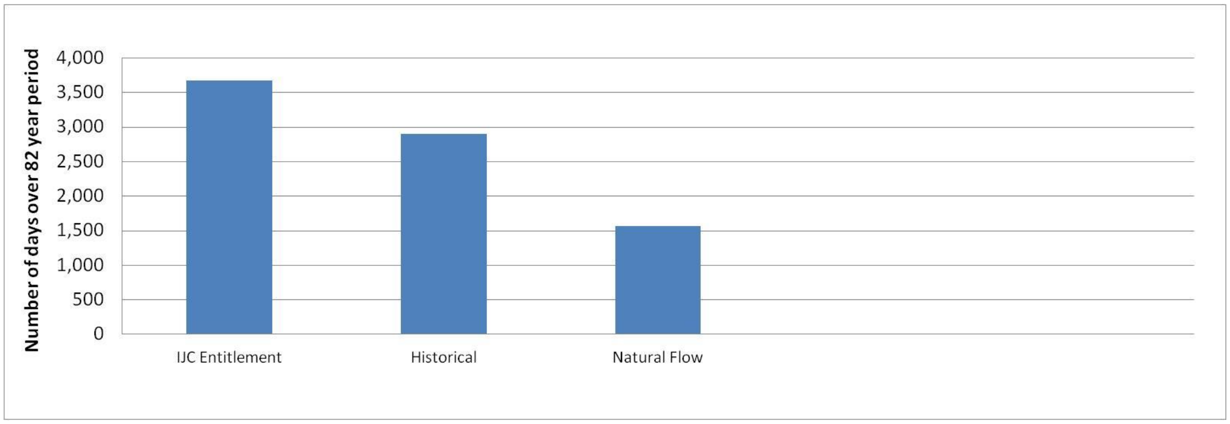

Figure 4: Total number of days in 82-year period with shortages across all irrigation districts

Figure 5 compares the number of times the minimum flow in specific reaches is below what the FRC requires, during the 82 years of record. The number increases with the lower IJC entitlement flow. Having more water in the St. Mary system relieves pressure on the Oldman through reservoir balancing. Discussed in more detail below, the Oldman system can use any additional water available in the St. Mary River to meet instream flows or downstream demands that otherwise would suffer under lower flow assumptions.

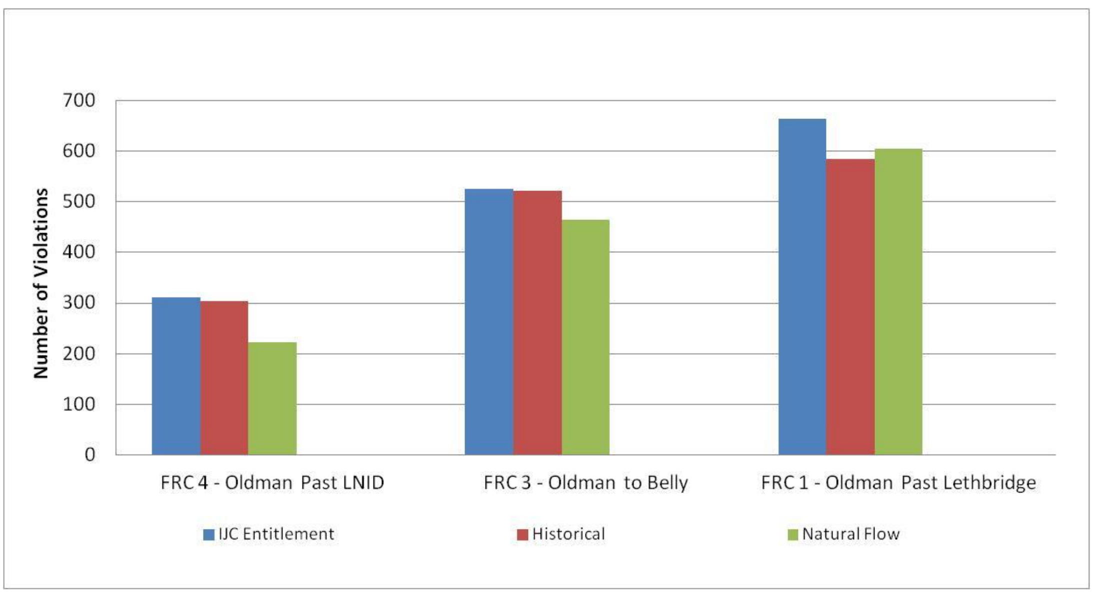

Figure 5: Number of times the minimum flow is below FRC requirements in the 82-year record

Reservoir Balancing

The Oldman, Waterton, St. Mary, and Milk River Ridge (Ridge) reservoirs, all of which are operated by ESRD, release water to meet their local requirements for withdrawals and instream flow needs. Since water needs downstream of the river confluences can be met by releases from any of these three reservoirs, water is taken from the reservoir with the highest percent full by volume. As a result, the reservoirs tend to have approximately the same percent volume of water in them, with a few exceptions. This happens in reality and is reflected in the OSSK model.

There are some exceptions to this general approach. Rather than following the same percent volume as the other reservoirs, OSSK participants suggested that the target level for St. Mary Reservoir should be 70% of the others. This helps to preserve upstream storage and maximize both the utility of storage and ability to capture inflows. Ridge, due to its unique location, has operations tied to the St. Mary Canal. Once the St. Mary Canal shuts down on or about October 10, Ridge Reservoir no longer follows Waterton patterns, and instead remains generally stable until the canal re-opens the following spring. Finally, the Oldman Reservoir frequently deviates from the pattern of the others due to the difference in local requirements and the inability to transfer water between the Oldman River and the Southern Tributaries (Waterton, Belly, and St. Mary rivers). This general approach to balancing and the exceptions to the approach are intended to equalize the time the reservoirs are at their rule curves, allowing them to more frequently make releases above the minimum requirements that reservoirs and diversions are subject to in current operations.

3.4 Development of Climate Scenarios for the OSSK Basins

One objective of the SSRB Adaptation to Climate Variability Project 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 water users and managers to test water management alternatives under a range of potential future climate and hydrological scenarios. Thus, developing climate scenarios that could be used in the OSSK model was the first step in contemplating potential climate variability and change adaptation strategies.

The innovative approach to developing the climate scenarios is described in detail in Appendix D and is summarized here. This aspect of the Phase III work was led by the Prairie Adaptation Research Collaborative (PARC), which has been developing climate scenarios for ESRD for some time. The General Circulation Models (GCMs) selected for the OSSK model were chosen for their ability to simulate Pacific Ocean temperatures, which drive the Pacific Decadal Oscillation (PDO). The PDO is one of the main factors that control precipitation and streamflow patterns in southern Alberta and reflects complex atmospheric connections.[20] Choosing GCMs that can simulate Pacific Ocean temperatures, and thus the PDO, gives a better representation of potential future climates than selecting GCMs based on output of mean changes in precipitation and temperature.

The methodology used for this project accounts for inter-annual to decadal climate variability. Streamflow change is estimated as a function of the ocean-atmosphere oscillations that drive the natural variability of the regional climate and hydrology. Given the good linear relationship between the PDO and streamflow in southern Alberta, it is possible to project changes in annual

[20] St. Jacques, J.M., D.J. Sauchyn, and Y. Zhao. 2010 Northern Rocky Mountain streamflow records: global warming trends, human impacts or natural variability? Geophysical Research Letters 37: L06407, doi:10.1029/2009GL042045.

streamflow in southern Alberta in response to climates identified in the GCMs. For this project, GCMs were selected that represented the PDO pattern of the 20th century with a correlation greater than r=0.7. Outputs from 24 GCMs were examined and 10 were judged to be satisfactory.

A statistical downscaling approach was used to convert changes in annual streamflow to daily streamflow, which were used as input to the OSSK model. To derive daily streamflow from annual averages, modellers used probabilities from a Cumulative Distribution Function (CDF). A single projected CDF of annual flow probabilities from all the climate scenarios for 2025-2054 was derived. The probabilities of a flow were used to get a historical analogue year from the gauging record.

Five scenarios were chosen for use in this project to show a spread of realistic options (Table 1). The 10th percentile of minimum flows was used to eliminate outliers of extreme low flows. All the scenarios provide annual average flows, downscaled to daily streamflow. This methodology shows the severe and extended droughts and earlier shift in the hydrograph expected as a function of climate change. However, taking annual flows to daily flows does not capture peak high flows since they must be calculated hourly; rather, it captures the high volumes in a given year.

Table 1: Selected climate scenarios

Selection Criteria	Scenario Run (GCM, Run, Emission Scenario)	Scenario Name
Single lowest minimum annual flow year (10th percentile)	CGCM3T47_3A2	1yr Min
Lowest 2yr consecutive minimum annual flow (10th percentile)	CGCM3T6_3A1B	2yr Min
Lowest 3yr consecutive minimum annual flow (10th percentile)	PCM11_B1	3yr Min
Max Average 1 year Flow	MRI_5B1	1yr Max
Median of 2yr Consecutive Median Flow-Historical Analogue	MRI_3A2	2yr Median

Each climate scenario has an independent set of hydrological conditions and all scenarios were developed using the IJC entitlement flows. Since direct statistical comparison between historical and future scenarios can be misleading, a historical analogue was chosen to serve in that role. The two-year median average scenario (2yr Median) is meant to indicate the effects of operations under a future climate scenario similar to current conditions. Even with this analogue, however, climate scenarios cannot be directly compared, as the effects of operations can be concealed by differences in hydrological conditions. In these scenarios, three show varying levels of drought (1, 2, and 3yr Min) while one represents a “wet” scenario (1yr Max). While all these scenarios were available, for the most part, collaborative modelling done by the working group focused on the historic record and the 2yr Min scenario as it emphasized drought.

In summary:

- The 2yr Median scenario (the historical analogue) has some drought periods and some wet periods, but its purpose is to assess alternatives under historic-like conditions.

- The 1yr Max scenario is generally wetter and puts almost no drought pressure on the system. The overall intent is to ensure that no alternatives have negative impacts if the actual future ends up not being dire. Flood impacts cannot be properly assessed due to methodology limitations.
- The 1yr Min scenario has a key year of interest – 2033. This drought is much worse than 2000-01. The following years (2034 and 2035) are also dry.
- The 2yr Min scenario has two consecutive dry years (2034-2035) with other low years as well. The years 2032 and 2033 are also dry.
- The 3yr Min is the worst scenario with two severe dry periods, one at the beginning of the time period and one later. The key years are 2027-2029.

These potential impacts of climate variability present risks to the environment, regional economy, and society, but they also present an opportunity to identify adaptation options and build resiliency in the SSRB to respond to future climate variability and change.

3.5 Performance Measures

Performance measures (PMs) were developed and used to assess and demonstrate the impact and benefits of changes made in the OSSK model. A short list of eight PMs was selected 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 cms.

2. **Minimum flows for fisheries**
   This PM assesses the ability to meet instream fish requirements in the Oldman River at Lethbridge. It uses Tessman 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 demanded. 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 82-year period for the hydro generation facilities in the OSSK basins.

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

The full list of OSSK performance measures (Appendix E) was processed for each strategy. Charts for specific PMs are included as appropriate in the report to illustrate a particular result, and the full set of PMs is available in the electronic OSSK model files. Some graphics in this report have dates along the horizontal axis. Unless otherwise indicated, these dates indicate years in the historical record, as shown in the model runs; for example, 08/18/41 is August 18, 1941. The span of years is indicated in the title for each of these figures.

4 Project Results and Findings

During this project, participants suggested and explored a wide range of strategies, acknowledging that more work is needed to assess socio-economic and environmental benefits and costs. Some strategies were explored as responses to flood conditions, but most are in response to drought. Any new infrastructure and storage would require environmental impact assessments, cost-benefit analysis, socio-economic analysis, engineering feasibility studies, consideration of impacts on landowners and First Nations, and other investigations, recognizing that there are trade-offs.

This report describes results and impacts for 15 individual strategies, some of which were found to provide little or no benefit. Consequently, these 15 strategies have been grouped into three categories:

- Category 1 strategies, of which there were five, were considered to have the most promise for offering adaptability and resilience in the face of more severe climate conditions, specifically drought. These strategies reflect a mix of approaches including potential new infrastructure, changes in operations and management of river systems, and collaboration in adjusting demands. They are described in Section 4.1.
- The four strategies in Category 2 were viewed as having some promise and offering moderate benefits in dealing with drought or flood conditions. These approaches mostly involved changes in operations and are described in Section 4.2.
- Finally six individual strategies, once modelled, were found to have limited promise and few benefits. These comprise Category 3. Some of these were developed in response to flood and others to drought, and they appear in Section 4.3.

The OSSK basins are complex and dynamic systems and potential adaptation strategies would likely be implemented in combinations that reflect the needs of the basins and the appropriate degree of risk management. To examine how adaptation strategies might be layered to produce cumulative and offsetting impacts, the project modelled three strategy combinations. All combinations involve a mix of additional storage as well as changes in operations, and one combination also includes demand adjustments. The combinations are described in Section 5.

All strategies and combinations were compiled and tested with the OSSK model, using the IJC entitlement flows and the climate variability scenarios. The strategies that were modelled are shown in Table 2. All modelled strategies and combinations are then briefly described, along with the modelling results and impacts, sample PMs, and associated observations. In the presentation of PMs, related strategies are compared for each PM to show the impact on that specific PM of each strategy. The most pertinent PMs are illustrated for each strategy. A number of other strategy ideas were proposed, some of which were examined briefly, but none of these was pursued for various reasons including a lack of data. These “other” strategies are listed in Appendix F along with short annotations.

Strategies in each of the first three categories are presented in geographical order from the upper basin to the lower basin. In each category there is at least one strategy that could apply across the basin and such strategies appear at the end of each list, as presented in the chart.

These strategies are presented as a starting point for discussion and further consideration by those who use, manage and make decisions about water in the OSSK basins.

Table 2: List of strategy titles

Full strategy title	Short title for PM charts
Category 1: Strategies with most promise	
Adding a Lower Belly Reservoir	Lower Belly
Minimum flow augmentation below reservoirs	Low flow augment
Adding a Kimball Reservoir	Kimball
Chin Reservoir expanded and fully balanced	Chin exp, full res bal
Forecast-based rationing	Forecast-based rationing
Category 2: Strategies with some promise	
Oldman Reservoir flood control operations	N/A
Chin Reservoir balanced	Chin balanced
Chin Reservoir expanded, and expansion balanced	Chin exp, only exp bal
Drought-modified Fish Rule Curves	N/A
Category 3: Strategies with limited promise	
1m additional storage in existing St. Mary Reservoir	N/A
Chin Reservoir expanded without balancing	Chin exp, no bal
Downstream dry dam for flood control	N/A
Simple triggered shared shortages	N/A
Lower FSL in all ESRD reservoirs by 2m when needed until July 1	N/A
Developing a storage reserve	N/A
Category 4: Combined strategies	
C1. Chin Reservoir expanded + fully balanced + St. Mary augmentation	Chin + Low Flow Aug
C2. Chin Reservoir expanded + fully balanced + Kimball Reservoir + St. Mary augmentation	Chin + Kim + Low Flow Aug
C3. Chin Reservoir expanded + fully balanced + Kimball Reservoir + St. Mary augmentation + forecast-based rationing	Chin + Kim + Aug + Frcst Rtn

4.1 Strategies with Most Promise

The strategies in this category were shown to have the most promise and provide the most benefits in conditions of climate variability, drought in particular. They represent a mix of potential approaches, including new storage, changes in operations and management of river systems, and opportunities for collaboration to adjust demands in extended drought conditions. The first four strategies are location-specific and are presented starting in the upper basin; the fifth strategy (forecast-based rationing) could be applied across the OSSK basins.

Full strategy title	**Short title for PM charts**
Category 1: Strategies with most promise	
Adding a Lower Belly Reservoir	Lower Belly
Minimum flow augmentation below reservoirs	Low flow augment
Adding a Kimball Reservoir	Kimball
Chin Reservoir expanded and fully balanced	Chin exp, full res bal
Forecast-based rationing	Forecast-based rationing

Adding a Lower Belly Reservoir

The Lower Belly Reservoir site is also known as Oldman River Site 3-1 (MPE, 2008).[21] This reservoir site is on the Belly River just before the confluence of the Belly and Oldman Rivers (node 570 in Figure 6). It would have a capacity of approximately 493,200 cdm (400,000 AF) and could capture flow from the Belly and Waterton Rivers.

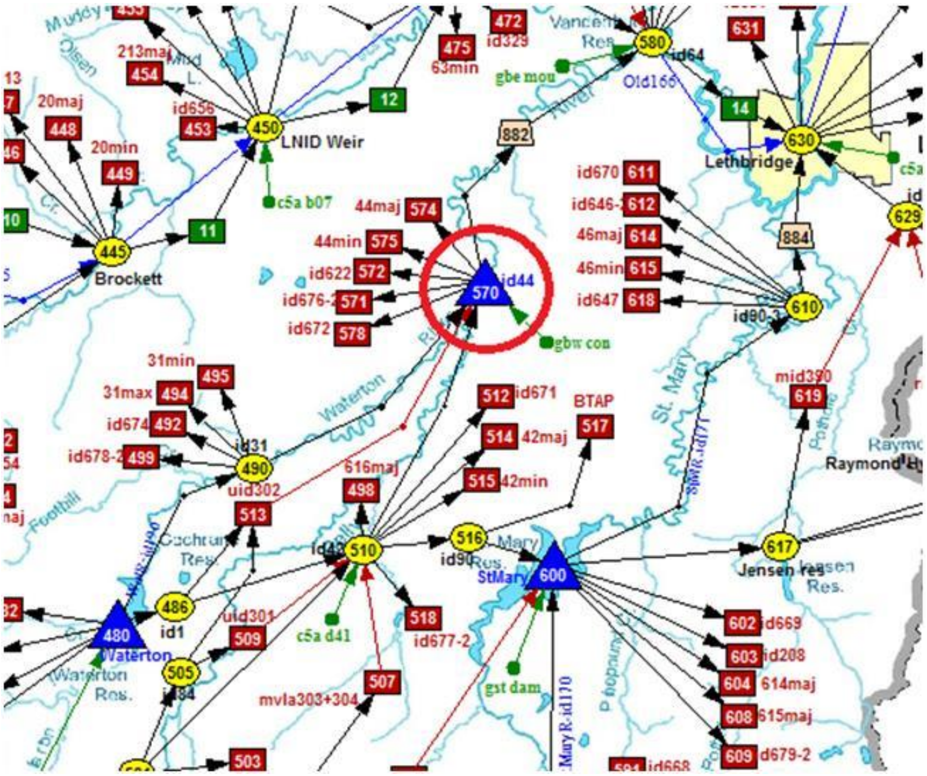

Figure 6: General location of the proposed Lower Belly Reservoir

As a new reservoir, it would normally be required to have a Water Conservation Objective (WCO), which was modelled at 45% of natural flow in the Belly River below the Reservoir or the IO, whichever is greater. Another option is to apply an Instream Objective (IO). Both approaches were modelled for the Lower Belly Reservoir, starting with the WCO, then the existing IO.

Model results and impacts

The modelling results show, not surprisingly, that this strategy with the IO in place performed better than with the WCO. Preliminary modelling results for this strategy indicated that if the Lower Belly Reservoir were included in the ESRD balancing system,[22]

[21] MPE Engineering Ltd. 2008. *Provincial Inventory of Potential Water Storage Sites and Diversion Scenarios*. Prepared for Alberta Environment. Edmonton, Alberta.

[22] The “balancing system” means that ESRD reservoirs in the OSSK basins are proportionally balanced; that is, each reservoir attempts to maintain the same percent full as the others. To do this, reservoirs with “excess storage” (storage above the percent full of the others) are preferentially drawn on to meet demands that are able to draw from multiple locations; for example, the Oldman River past Lethbridge can draw from the Oldman, St. Mary and Waterton reservoirs, while the Ridge system can draw from Ridge, St. Mary, and Waterton reservoirs.

the required WCO would cause all reservoirs to drain to meet the WCO requirement. Therefore, Lower Belly Reservoir was not added to the balancing system (rather, it was treated as the most junior storage) and the WCO was met entirely by the storage in this particular reservoir. Once this reservoir falls below an estimated 10% storage remaining, the WCO is reduced to the existing IO, both to prevent the dam from going completely dry and to disallow the WCO access to Waterton Reservoir storage. Exploration and discussion of this strategy raised the question of whether there should be a review of the basis of WCOs, given how any new storage would currently be forced to operate.

The analysis below first compares the performance of the Lower Belly Reservoir with the WCO or the IO in place against current operations. Then, the overall performance with the IO is compared with other storage strategies. Detail on the ability of the new reservoirs to fill and refill can be accessed directly in the OSSK model.

Lower Belly Reservoir with WCO and with IO vs. current operations

Figure 7 compares the number of shortage days for the Lower Belly Reservoir with WCO and with IO against current operations. With the IO in place, the number of shortage days is reduced by 716 for the 82-year record, a nearly five-fold improvement compared to performance with the WCO in place (149-day reduction). As expected, shortage days are marginally reduced across all the irrigation districts with the IO (Figure 8).

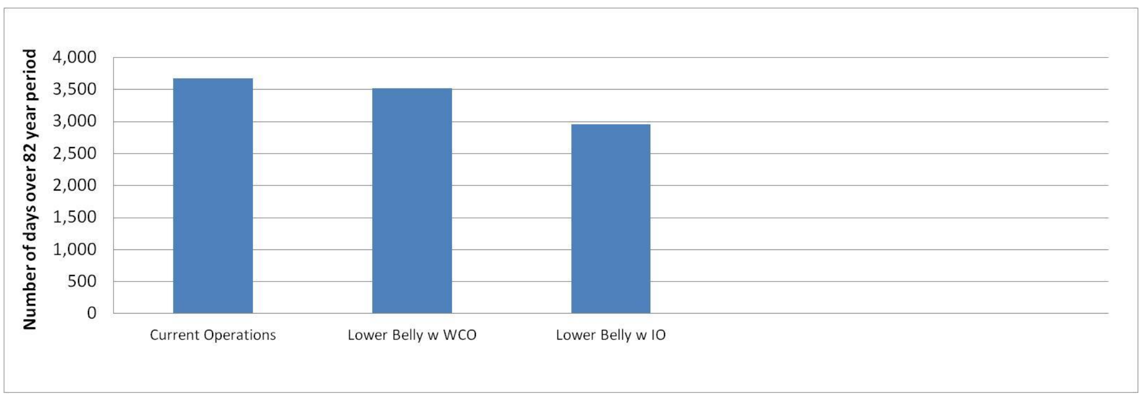

Figure 7: Total number of days in 82-year period with shortage across all irrigation districts

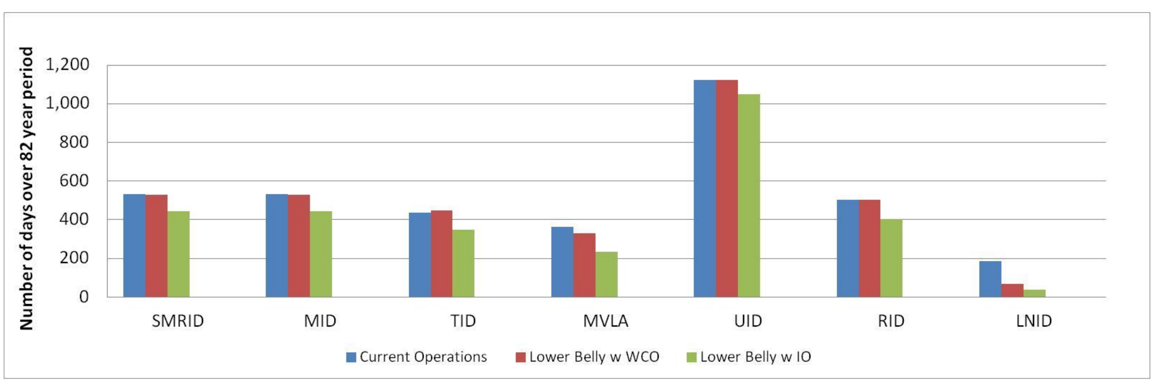

Figure 8: Total number of days in 82-year period with shortages by irrigation district

Adding the Lower Belly Reservoir, irrespective of whether the WCO or IO is applied, has a noticeable effect on minimum weekly flows of the Oldman River at Lethbridge, compared with current operations (Figure 9). This is due to the filling of such a large reservoir. Filling a 493,200 cdm (400,000 AF) reservoir would result in flow reductions to minimum flow requirements in many cases. The effect is less under the WCO, but with less capture comes less benefit.

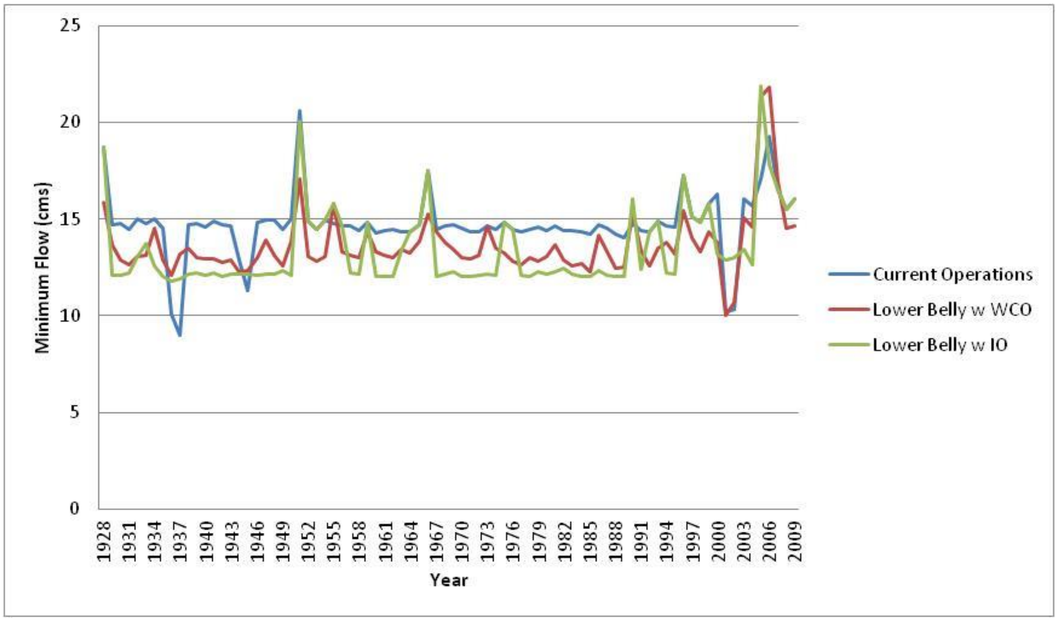

Figure 9: Minimum weekly flow, Oldman River at Lethbridge

In terms of environmental impacts, Lower Belly Reservoir with the WCO substantially reduces cottonwood recruitment success for the Oldman River near Lethbridge (Figure 10).

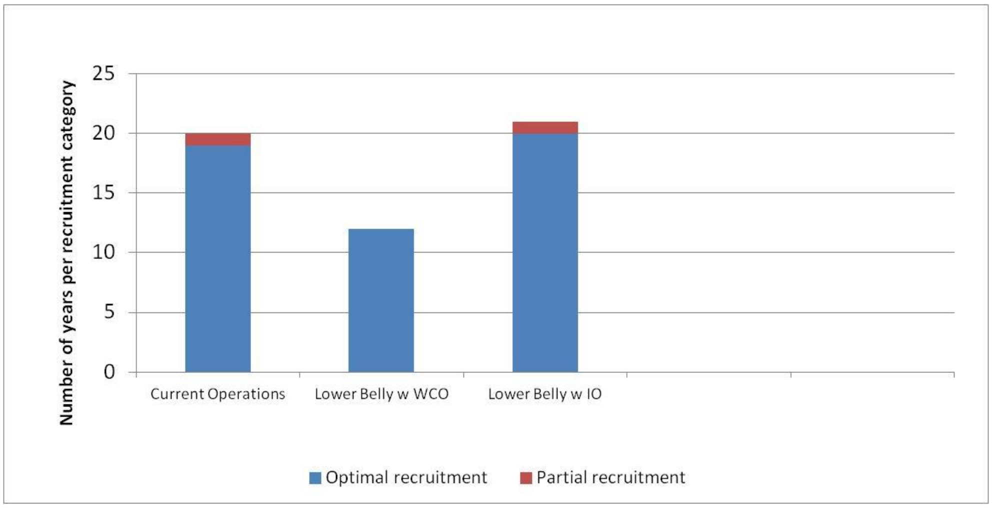

Figure 10: Years of cottonwood recruitment success for Oldman near Lethbridge during 82-year period

There may be further implications for cottonwoods in the Lower Belly River, but this was not modelled. With the base IO in place, performance is marginally improved compared with current operations. When the Lower Belly Reservoir releases WCO flows, the Oldman Reservoir anticipates those flows will assist in meeting its FRC obligations. Thus the Oldman Reservoir releases less water from its storage, negatively affecting cottonwood recruitment. In contrast, when the Lower Belly Reservoir only releases to meet the IO, the Oldman Reservoir follows more closely its current release patterns to meet the FRC obligations. With Oldman Reservoir releases similar to current operations, cottonwood performance shows only a slight change. The slight improvement in cottonwood recruitment is due to the Lower Belly Reservoir's releases allowing the Oldman Reservoir to preserve its own storage and attempt opportunistic operations more frequently.

With respect to meeting instream fish requirements in the Oldman River at Lethbridge (PM 2: Minimum flows for fisheries), both approaches improve performance during the 82 years, compared with current operations (Figure 11).

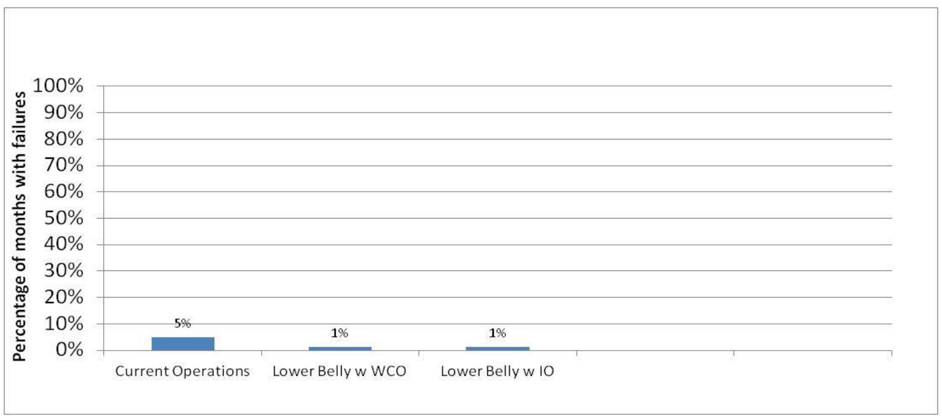

Figure 11: Percentage of months during 82-year period when instream fish requirements were not met in the Oldman River at Lethbridge

Lower Belly Reservoir with IO vs. other storage options

Performance of the Lower Belly Reservoir strategy with the IO in place was then compared against the other storage strategies regarded as having promise. Figure 12 shows that the performance of this strategy was between the other two individual storage strategies in that it reduced the number of shortage days by 719 during the 82 years vs. 879 days for Chin expanded and balanced, and 597 days for Kimball. As discussed later in the report, the combined strategies do perform better, as expected.

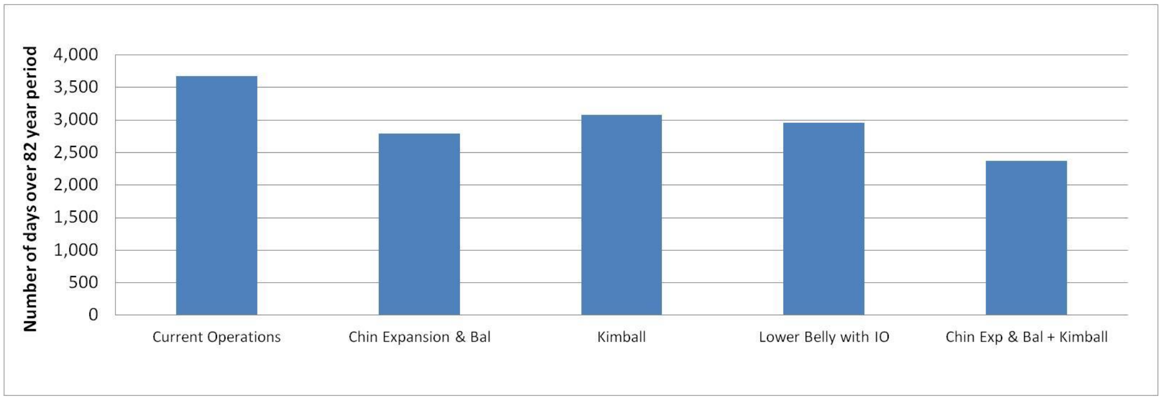

Figure 12: Total number of days in 82-year period with shortages across all irrigation districts

In terms of impact on cottonwood recruitment for the Oldman near Lethbridge, this strategy performed better than any other storage strategy including the combination and slightly better than current operations (Figure 13). Since the Lower Belly Reservoir is not part of the balancing system, its only use is to supplement water, both for consumption and environmental purposes, in the Oldman River. This pushes most of the benefit in the system to the Oldman Reservoir, which is then used more frequently for opportunistic operations. This strategy contrasts with the others, which rebalance the additional storage, and thus keep slightly more water in the Southern Tributaries area.

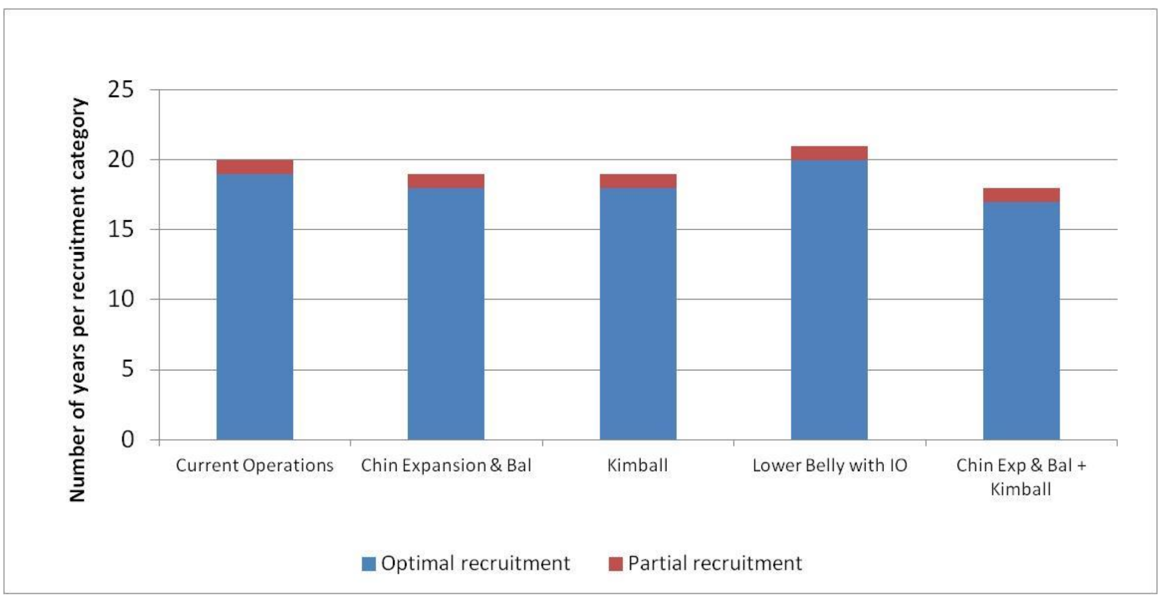

Figure 13: Years of cottonwood recruitment success for Oldman near Lethbridge during 82-year period

This strategy also outperformed all the other storage strategies and current operations when it came to meeting instream fish requirements in the Oldman River at Lethbridge (Figure 14). These requirements were met 99% of the time during the 82 years of record, vs. 95% or 96% of the time for the other storage strategies.

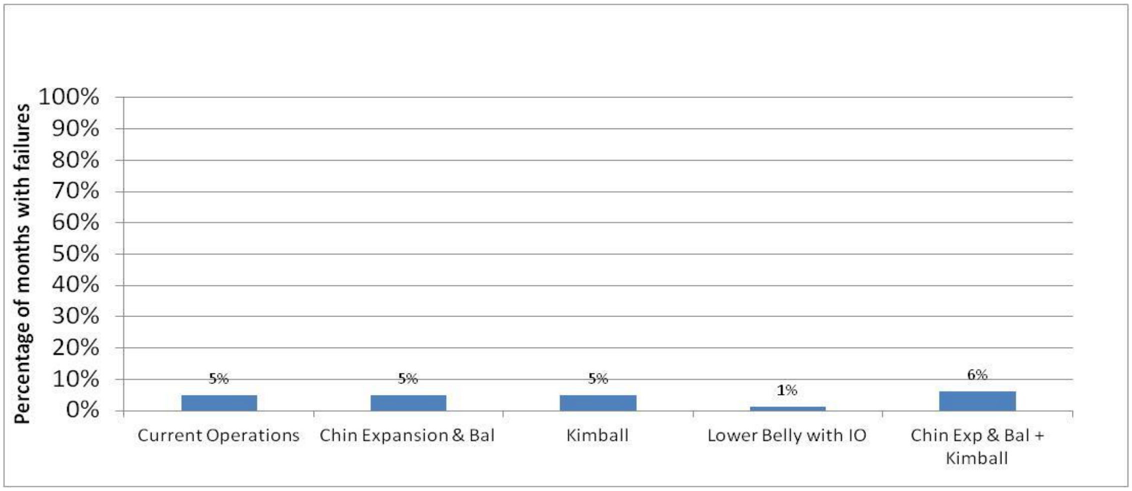

Figure 14: Percentage of months over 82-year period when instream fish requirements were not met in the Oldman River at Lethbridge

Relevant OSSK Model run name

CB6.9_LowerBelly_unbalanced-IO & CB6.9_LowerBelly_unbalanced-WCO

Minimum flow augmentation below reservoirs

This strategy is intended to augment flow below a reservoir to provide environmental benefits, particularly for fish. It would optimize low flows when reservoir volumes are high during the summer and fall to achieve ecosystem benefits. The St. Mary system was used as an example to assess this strategy (Figure 15), with the primary objective of increasing the habitat available to rainbow trout (*Oncorhynchus mykiss*) in the lower St. Mary River when water is available; other ecosystem benefits could also accrue.

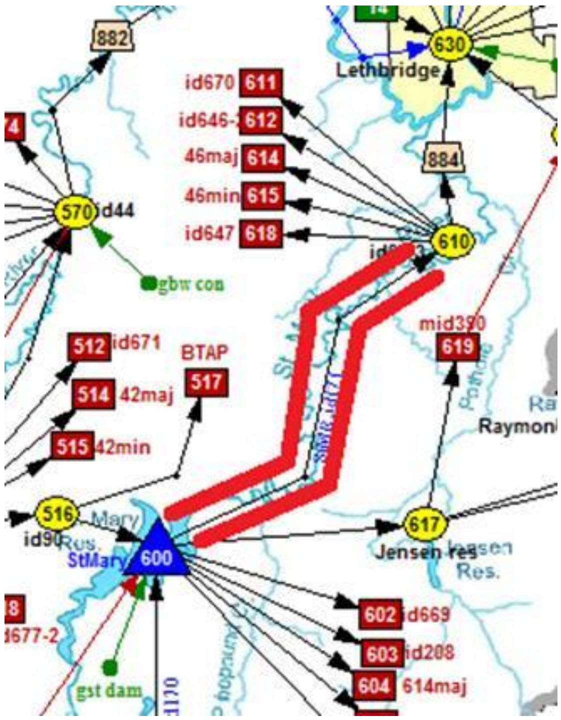

Figure 15: Location of flow augmentation on St. Mary River

For this strategy, discharge targets were based on percentile levels in the St. Mary Reservoir from May 1 to October 31:

- If the reservoir was more than 75% full (that is, more than1100 m elevation), minimum flow (which must be met) was held to 8 cms. The 8 cms value was determined through discussion with stakeholders.
- If the reservoir was 50-75% full (1090 – 1100 m elevation), the target minimum flow was 6.5 cms, which matches the optimum flow for hydro generation.
- If the reservoir level was less than 50% full (below 1090 m elevation), the minimum target flow was set to 2.75 cms, which is the minimum instream flow needed, or the minimum flow was equal to inflow if inflows are lower than the target at any point.

This strategy was also modelled in combination with others, as described in Section 5.

Model results and impacts

With this strategy, rainbow trout habitat was improved as reflected in the fish weighted usable area PM (Figure 16). Looking at the Oldman River near Lethbridge, there was no impact on mountain whitefish (*Prosopium williamsoni*) habitat nor was there improvement in cottonwood recruitment beyond current opportunistic operations (Figure 17).

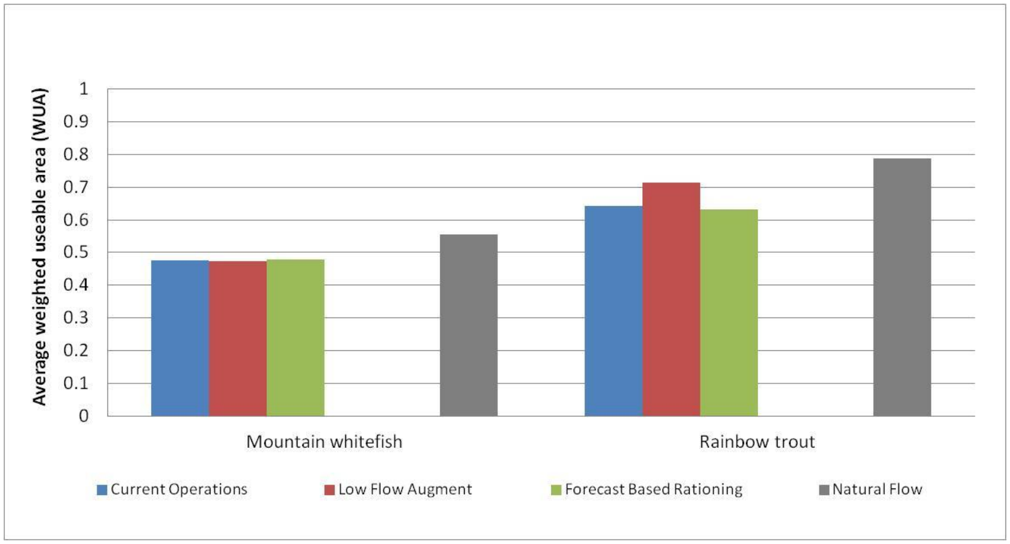

Figure 16: Average WUA of adult habitat for the 82-year period

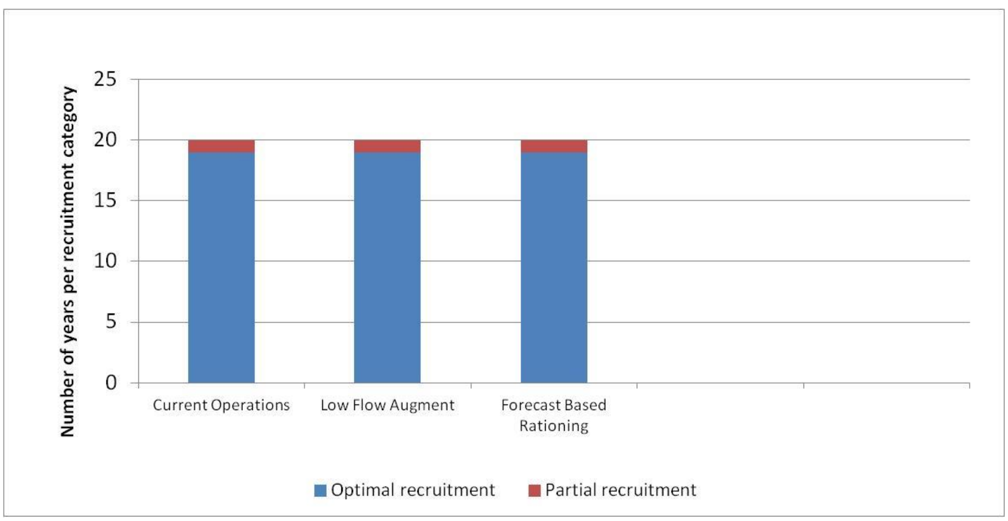

Figure 17: Years of cottonwood recruitment success for Oldman River near Lethbridge for the 82-year period

These operations demonstrate that ecosystem benefits can be obtained. However, there was an expected small increase (226 days) in irrigation shortages during the 82-year period of record when compared with current operations (Figure 18), distributed across all the irrigation districts (Figure 19).

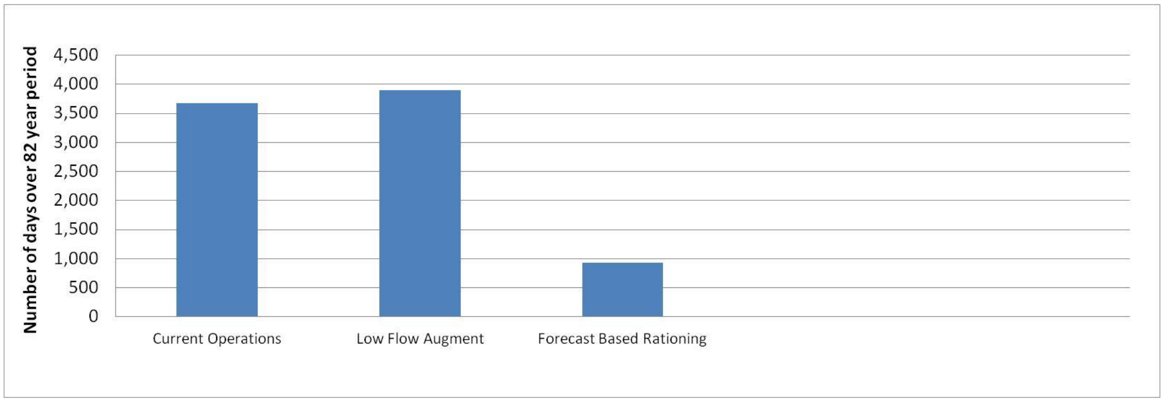

Figure 18: Total number of days in 82-year period with shortages across all irrigation districts

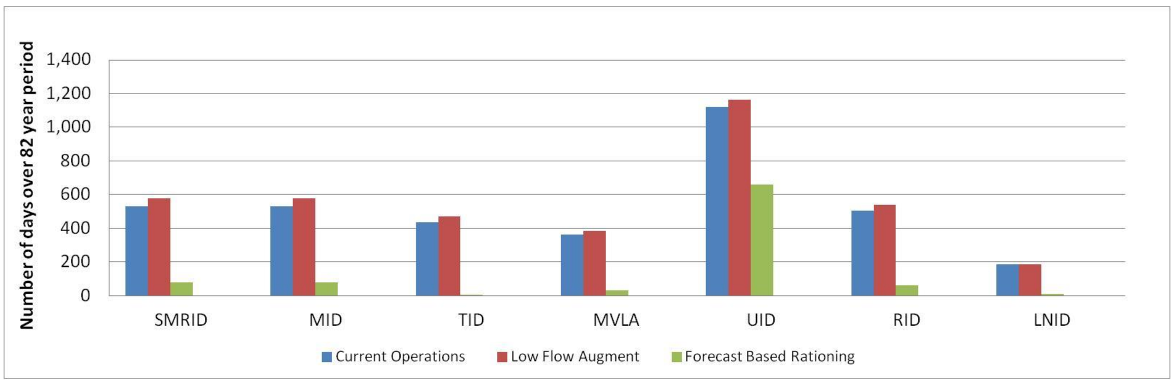

Figure 19: Total number of days in 82-year period with shortages by irrigation district

This is an example of how making relatively small changes when water is available in the system can improve the health and long-term resiliency of the watershed. Measures such as these will not address the larger climate variability issue by themselves, but are an important component of long-term adaptation strategies. It also indicates that there are several potential uses for additional storage beyond consumptive purposes.

Slower ramping down of operations from July 1 to November 1 was also examined in conjunction with more aggressive functional flows. This strategy, however, did not suggest much opportunity for environmental benefits. Reservoir drawdown is typically driven by licence demands and reservoir rule curves, so the option was not pursued in detail. It could be further explored once the Bow and Oldman models are integrated, or with the fledgling Red Deer River system model.

Relevant OSSK Model run name

CB6.9_StMary_lowflow

Adding a Kimball Reservoir

This reservoir site is also known as St. Mary-Kimball Reservoir (MPE, 2008).[23] It would provide 125,800 cdm (102,000 AF) of new storage upstream of the St. Mary Reservoir near the international border (node 590 in Figure 20) and could offset the expected effects of the US taking its full IJC entitlement at some future date. This site is also being examined in the storage study by ARD. This potential location is higher up in the system than many other suggested locations and is thus better positioned to capture and deliver water. If Kimball Reservoir were constructed, it would not be allowed to flood across the Alberta-Montana border. Further, spillways and overland flows were not considered in the St. Mary Project area (the irrigation districts that take delivery from the St. Mary River Irrigation District Main Canal), due to lack of data.

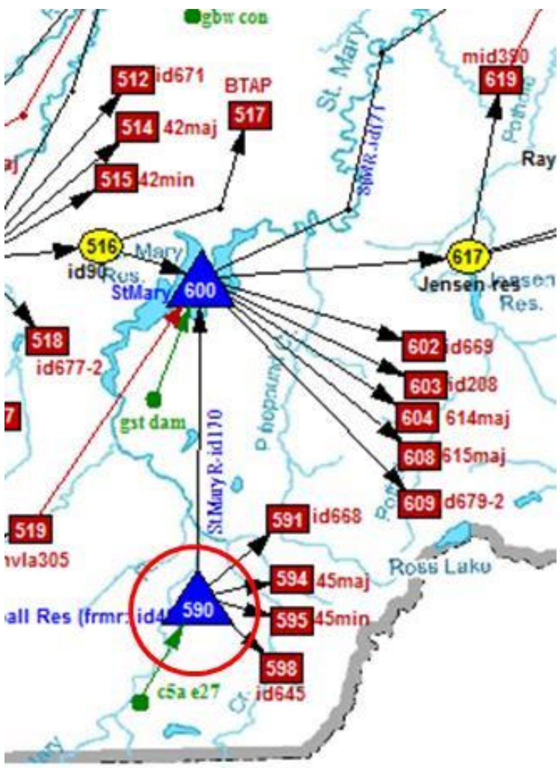

Figure 20: General location of a potential Kimball Reservoir

The Kimball Reservoir would be responsible for meeting a new downstream WCO for the reach before the St. Mary Reservoir, while the existing IO would remain unchanged below the St. Mary Reservoir. The WCO modelled for Kimball Reservoir was calculated as the greater of 45% of natural flow in the St. Mary River or the existing IO. There was discussion as to whether Kimball should be modelled as either the WCO or the IO, as was done for the Lower Belly Reservoir. Given the positive results seen from modelling the reservoir when meeting the WCO at 45% of natural flow, the group did not feel it necessary to model the reservoir meeting the lower requirement of the IO. Preliminary modelling showed that meeting only the IO netted even more positive results as the requirements on its storage

[23] MPE Engineering Ltd. 2008. *Provincial Inventory of Potential Water Storage Sites and Diversion Scenarios*. Prepared for Alberta Environment. Edmonton, Alberta.

would be lower, thus preserving the storage longer. This should be kept in mind when reviewing the charts below where Kimball Reservoir is modelled as meeting the full WCO while the Lower Belly Reservoir meets only the IO. Kimball Reservoir is also assumed to be managed as part of the ESRD reservoir balancing system.

This strategy was modelled in combination with other options, as noted in Section 5.

Model results and impacts

Figure 21 compares the various storage strategies modelled for this project. With Kimball Reservoir in place, there were nearly 600 fewer shortage days during the 82-year period of record, compared to current operations. As Figure 22 shows, these improvements were distributed fairly evenly across the irrigation districts. Figure 21 also shows that with Kimball Reservoir bound by the WCO, this strategy does not perform as well as Chin Reservoir expanded and balanced, but still has additive benefit when combined. The combination strategy shows the greatest total shortage reduction of the storage options examined.

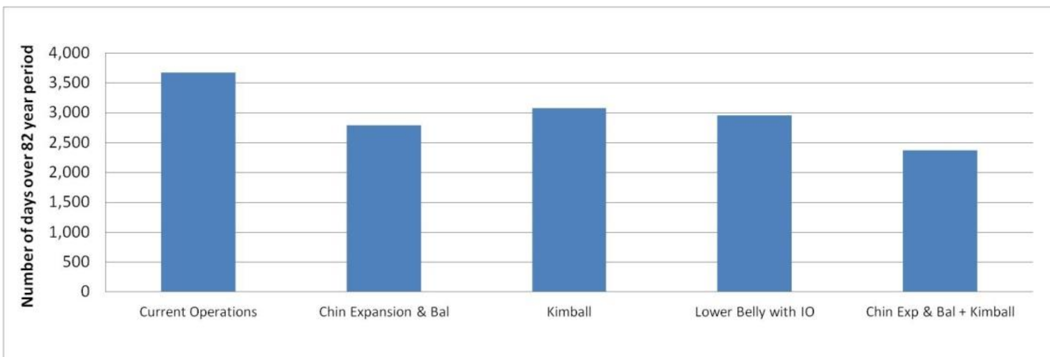

Figure 21: Total number of days in 82-year period with shortages across all irrigation districts

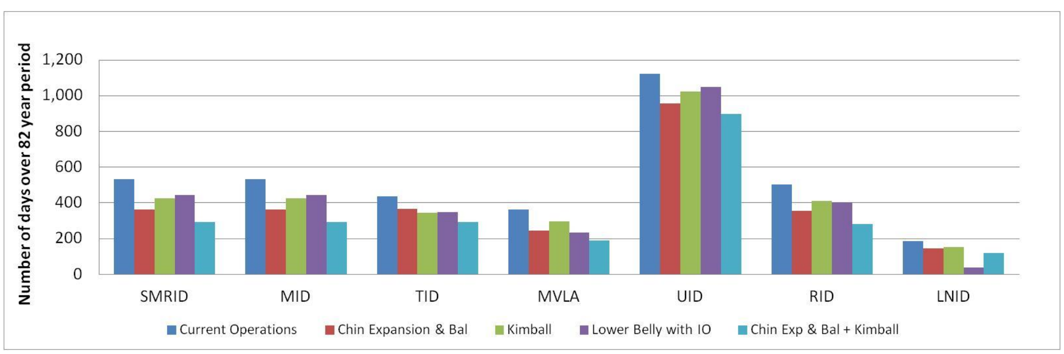

Figure 22: Total number of days in 82-year period with shortages by irrigation district

Although Kimball Reservoir with a WCO underperforms relative to the Lower Belly Reservoir with IO when considering total irrigation shortages, this does not hold true for every irrigation district. When looking at shortages to many of the individual irrigation districts in the St. Mary Project (Figure 22), Kimball Reservoir actually outperforms the Lower Belly Reservoir. This is due to the geographic location of Kimball, and the fact that it can supply water directly to those irrigators by routing it through St. Mary Reservoir. Detail on the ability of the new reservoirs to fill and refill can be accessed directly in the OSSK model.

Concerns about potential disruptions to fish habitat were noted with respect to Kimball Reservoir. Two species in particular were identified as being affected: Rocky Mountain sculpin and bull trout. The Rocky Mountain sculpin is a small benthic fish that lives in the St. Mary River above St. Mary Reservoir, among other locations. It is listed as “threatened” in Canada and does not do well in reservoirs. It is thought that the highest densities of this species occur in the St. Mary River upstream and downstream of the proposed Kimball Reservoir site.

The bull trout inhabits the St. Mary River on both sides of the international border. In the US, it is listed as a “threatened” species and is noted as a species “of special concern” in Alberta. They are known to travel back and forth between Montana and the St. Mary Reservoir, and a dam at the Kimball site would block this passage.

Given the location of this potential new reservoir, extensive discussions and consultations involving the US, Montana, Canada, and Alberta as well as the IJC would be required. This would likely make for a lengthy decision process.

In discussions about Kimball Reservoir, it was suggested that expanding St. Mary Reservoir by one metre might secure some of those benefits at less cost. Preliminary modelling indicated that only about 24,600 cdm (20,000 AF) of additional storage could be obtained in this way, which was not enough to substantially improve performance in the system. Thus this option was not pursued further. A St. Mary Reservoir expansion may be worth considering in the future, but only in combination with other alternatives.

Relevant OSSK Model run name
CB6.9-Kimball_w_WCOonNatural

Chin Reservoir expanded and fully balanced

Chin Reservoir is part of the St. Mary River Irrigation District (SMRID), shown as node 624 in Figure 23. It is an offstream storage site downstream from the SMRID headworks at the provincially-owned Ridge Reservoir. Chin Reservoir is on the St. Mary main canal system, and is located about 21 km south of the Town of Taber on Highway 36. Before entering Chin Reservoir, main canal flow serves a hydro generation facility operated by Irrigation Canal Power Cooperative Ltd. (Irrican), which has a generation capacity of 11 MW. At present, Chin Reservoir is managed by SMRID and is not part of ESRD's balancing system.[24]

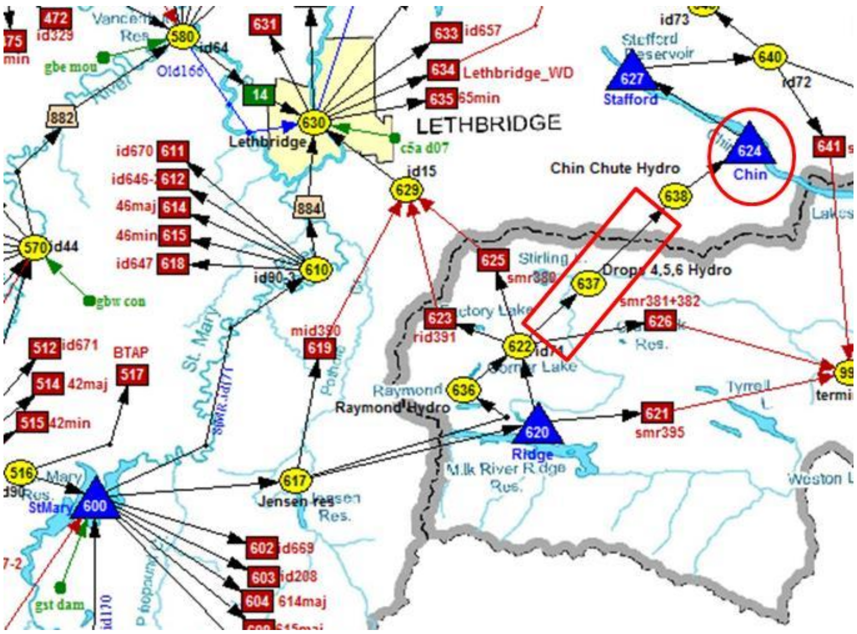

Figure 23: Location of Chin Reservoir

Under current operations, reservoir managers try to avoid sending water over the spillway, preferring to direct water through the turbines to facilitate power generation. It is not difficult for Chin Reservoir to fill at present, and it typically starts filling earlier at a lower rate to maximize the volume passing through the turbines.

For this project, several strategies were considered involving Chin Reservoir, some of which had more potential than others. It was noted that if Chin is expanded it will need new spill infrastructure to manage risk of overland flows. Two initial approaches were examined:

a) expanding Chin Reservoir storage by 74,000 cdm (60,000 AF) to reduce the risk of downstream municipal and irrigation shortages, and
b) adding Chin Reservoir at its current capacity to the balancing system.

[24] The "balancing system" means that ESRD reservoirs in the OSSK basins are proportionally balanced; that is, each reservoir attempts to maintain the same percent full as the others. To do this, reservoirs with "excess storage" (storage above the percent full of the others) are preferentially drawn on to meet demands that are able to draw from multiple locations; for example, the Oldman River past Lethbridge can draw from the Oldman, St. Mary and Waterton reservoirs, while the Ridge system can draw from Ridge, St. Mary, and Waterton reservoirs.

Based on the modelling results for these scenarios, two other approaches for this reservoir were then explored:

c) expanding Chin Reservoir by 74,000 cdm (60,000 AF) and balancing only the new storage (that is, balancing only the 74,000 cdm), and

d) expanding Chin Reservoir by 74,000 cdm (60,000 AF) and fully balancing (that is, the entire amount of existing and new storage was added to the balancing system).[25]

Strategy d) was viewed as having the most promise, b) and c) showed some promise, and a) had limited promise. As the most promising, Strategy d), described in this section, was also modelled in combination with other strategies (see Section 5). Initial model runs involving Chin Reservoir attempted to provide some optimization of power, but in the end it was decided not to consider power generation as a determining or limiting factor in operations; water will be sent when it is needed and the turbines will generate what they can.

Model results and impacts

Expanding Chin Reservoir and balancing it with ESRD-managed reservoirs showed a large decrease in shortages and an extension of the irrigable period during a drought. These benefits occur due to expansion and balancing of all storage, and to the location of Chin Reservoir, which is upstream of most of this system's demand. As such, water in this reservoir can contribute to meeting a large proportion of water needs, allowing a large number of opportunities for rebalancing existing storage. Figure 24 illustrates the number of irrigation shortage days during the 82-year period.

All strategies involving Chin Reservoir show a reduction in irrigation shortage days, but expanding and balancing the full reservoir capacity (the far right bar) was the most effective in improving this PM, compared with current operations. This strategy resulted in 879 fewer days of shortage during the 82 years (almost a 25% reduction). The chart also shows that strategies that involve fully balancing Chin Reservoir provide more benefits than simply expanding the reservoir, or expanding it and balancing only the new storage.

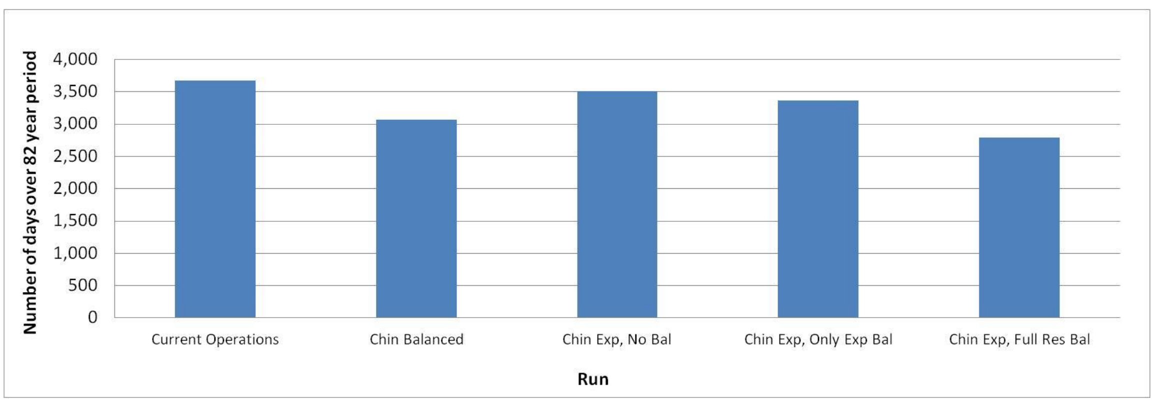

Figure 24: Total number of days in 82-year period with shortages across all irrigation districts

[25] These four strategies are listed again each time one of them is discussed in this report. The option that is being discussed is shown in bold.

Figure 25 shows that reduced shortage days for this strategy (the lighter blue bar) compared with current operations (the darker blue bar) occur across all irrigation districts.

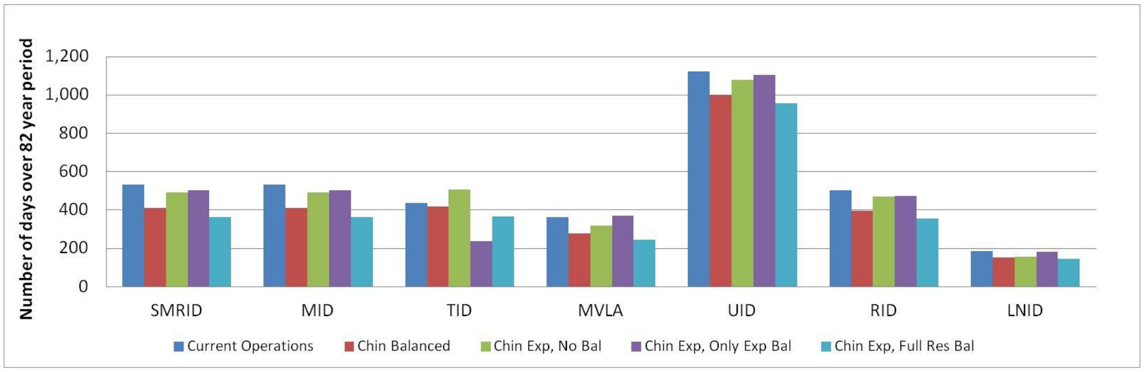

Figure 25: Total number of days in 82-year period with shortages by irrigation district

Figure 26 and Figure 27 compare this strategy with other storage strategies to show shortage days across the irrigation districts over the 82-year period.

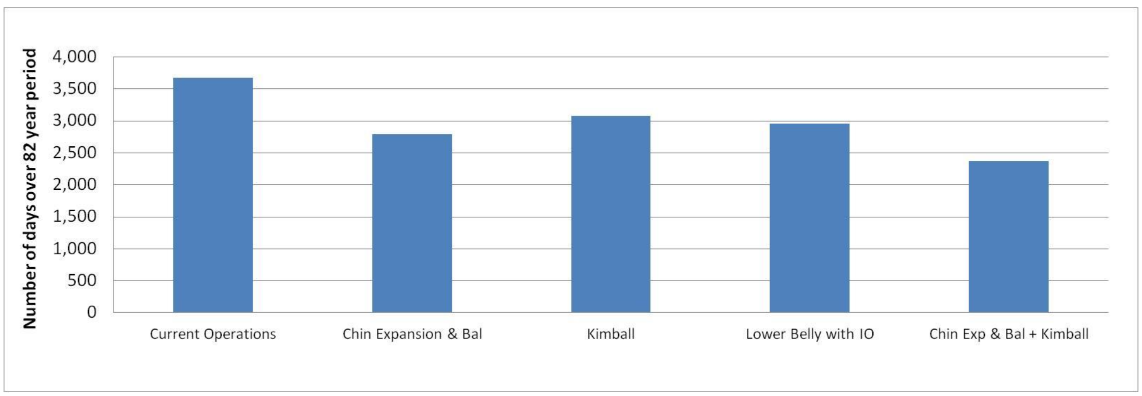

Figure 26: Total number of days in 82-year period with shortages across all irrigation districts

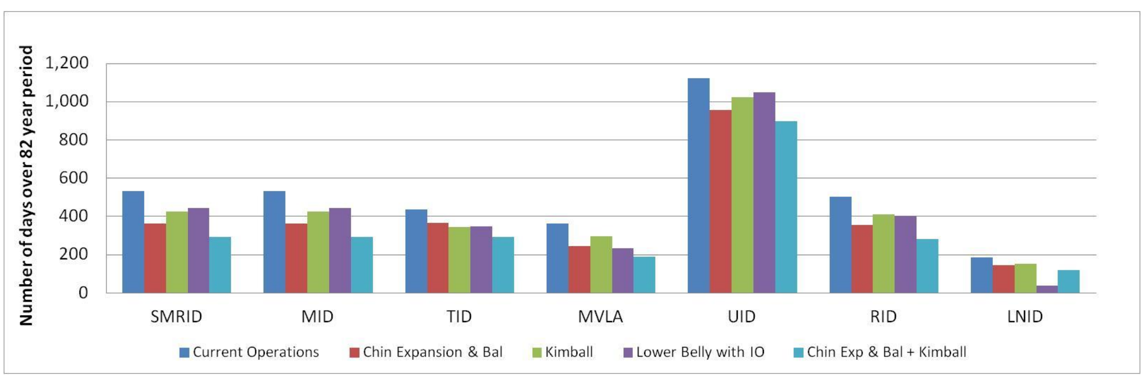

Figure 27: Total number of days in 82-year period with shortages by irrigation district

Figure 28 shows the additional drought capacity in ESRD reservoirs and Chin Reservoir that would have been available during the 1944 drought with this strategy; patterns are similar for the other periods of historical drought in the OSSK basins (1931, 1936, and 2001). The figure also includes Kimball Reservoir, discussed earlier. This plot shows that the extra storage allows for the continuation of irrigation for up to two weeks during the critical lead up to harvest. After accounting for the fact that irrigation demands are overstated and supply from the IJC flows is likely understated, this extension could become three weeks to a month.

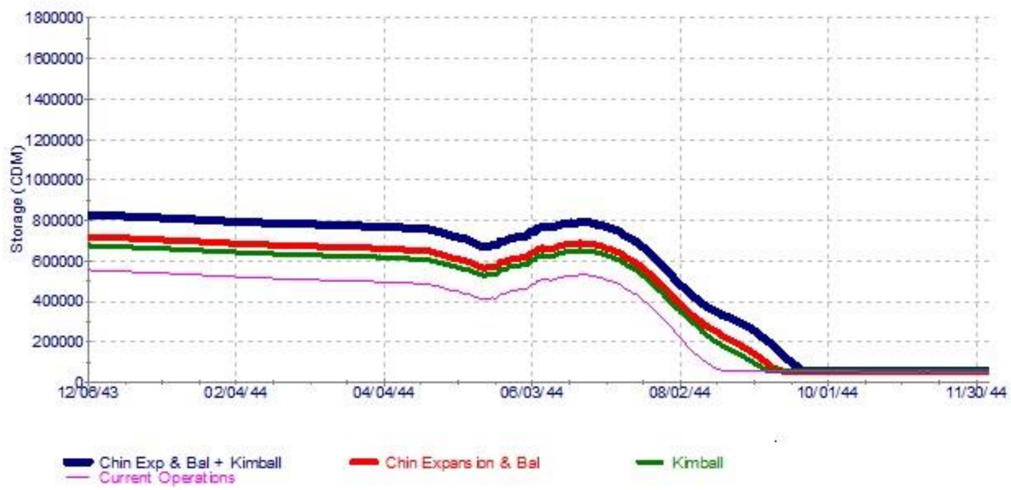

Figure 28: Storage in ESRD plus Chin Reservoir, 1944 drought (1943-1944)

Expanding and balancing Chin Reservoir enhances this PM (additional drought capacity) as much as the new storage offered by Kimball Reservoir. The OSSK working group noted that if expanding and balancing Chin Reservoir gives more or less the same benefits as new storage at Kimball, enhancing offstream expansion (that is, expanding Chin Reservoir) would be preferable.

Adding Chin Reservoir to the balancing system means that irrigation districts in the St. Mary system may assume more risk since Chin Reservoir may be kept at lower levels. However, this might be mitigated by removing current operational considerations for hydropower generation and allowing Chin Reservoir to receive water more quickly than it does today. If a Chin-based storage option is pursued, the “balancing” aspect of this strategy must also be applied to ensure that benefits accrue to the rest of the system. Without balancing, water is preferentially stored in Chin Reservoir, ahead of ESRD reservoirs, where it has fewer potential applications. This worsens total system performance because water in Chin Reservoir can only be used by irrigators in the SMRID and TID. Chin Reservoir will thus pull additional water from the system that would otherwise remain in a more versatile upstream position.

Figure 29 illustrates the impact on hydro power generation during the 82-year period of record with the various strategies involving Chin Reservoir. The impact on hydro production is negligible with the exception of additional spillage at Chin Chute. Despite disregarding the current operational modification for hydropower, the additional flow to Chin Reservoir due to its expansion seems to make up for any lost generation. Knowledgeable operations and timing of releases may be able to further enhance generative capacity during the period of record.

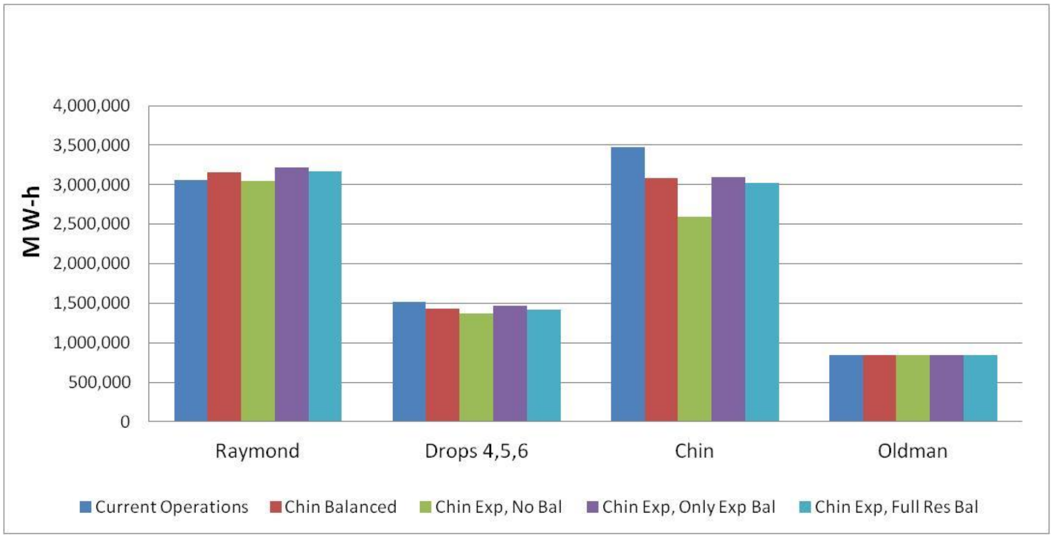

Figure 29: Total energy generation during the 82-year period

Relevant OSSK Model run names

CB6.9_ChinBalanced
CB6.9_Chin+60k-NoBalance
CB6.9_ChinBalanced+60kJust60Bal
CB6.9_ChinBalanced+60k

Forecast-based rationing

This strategy emerged as one that could be applied across the OSSK basins when severe dry conditions warranted. Although forecast-based rationing suspends FITFIR and should not substitute exploring additional storage to meet the needs of junior licence holders, the water-sharing agreement implemented for the Southern Tributaries during the drought of 2001 sets a precedent for this strategy. Currently, irrigation districts receive and evaluate water availability based on winter reservoir levels and incoming headwaters snow water reports throughout the winter and early spring. This information is communicated to irrigation water users and can be used to set preliminary allocations. Following the events of 2001, several irrigation districts routinely set these forecasted limits.

As snow pack forecasts are not available to the model, ESRD reservoir storage on June 1 is used as a surrogate to inform rationing decisions that would in reality be informed by snow pack, soil moisture, reservoir levels, and other factors not available to the model. Although in practice, many crop selection and delivery decisions are made in the first few months of the year, the model's use of June 1 storage is intended to be as close to reliable as possible, given available data, without utilizing perfect forecasting. Using storage from a period much closer to the beginning of the irrigation season is an attempt to capture the additional knowledge not included in the model. Since crop and planting decisions are external to the model as well (the OSSK model only cares about when and how much water is to be delivered on a given day), the late date in making a decision does not actually change water regimens, which are already determined by the IDM and used as input to the OSSK model.

To model this strategy, total available storage in ESRD reservoirs is measured on June 1. If total storage is less than 75% of the upper rule, irrigators would begin rationing for that year. Once this decision is made, deliveries to irrigators (districts and private) are capped at 80% of full demand for the entire year. This accounts for irrigators choosing crops and/or planning the seasonal irrigation management of those crops based on an expectation of less than full delivery.

A line is then drawn, from a full reservoir on June 1 to an empty reservoir on September 30 (Figure 30, which uses 1928 as an example from the historical record). Regardless of percent storage in the reservoirs, if the storage ever exceeds this line, rationing ceases. This reflects a conservative approach to rationing that is most likely to be taken; that is, when conditions are dire, start conservatively and increase the allocation based on an improvement in the water outlook. As the year progresses, further reduction in delivery is also possible if the conservative rationing was insufficient. If the reservoirs are less than 15% full, irrigation water deliveries are limited to 50% of full demand. If reservoirs reach 75% full, deliveries are set back to 80% of demand. Points between are interpolated.

This strategy was also modelled in combination with other options, as noted in Section 5.

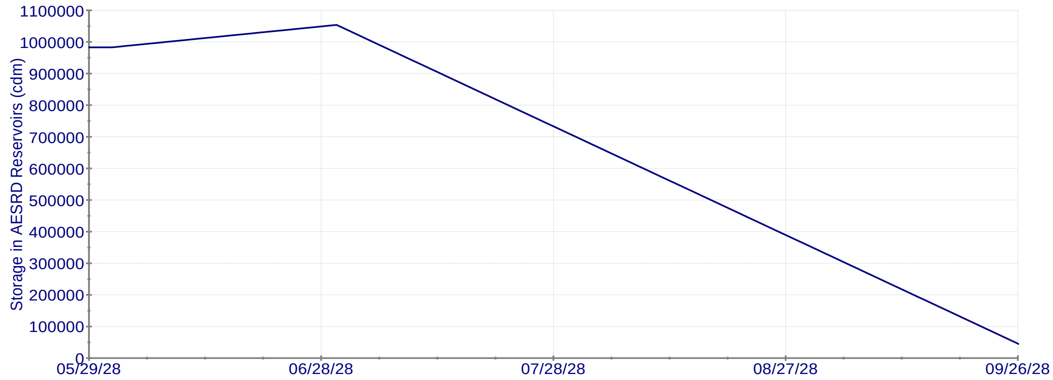

Figure 30: Total ESRD storage-rationing cutoff threshold (1928)

Model results and impacts

This strategy results in substantial extensions of storage during the four worst historical droughts, illustrated in Figure 31 through Figure 34. Further benefit would be realized from this strategy if the drought continued for multiple years. This was explored in the combination runs presented in Section 5. Almost more importantly, this strategy allows reservoirs to recover much more quickly in the years following a drought (Figure 35).

Figure 31: Storage in ESRD reservoirs, 1931 drought (1931-1932)

Figure 32: Storage in ESRD reservoirs, 1936 drought (1936-1937)

Figure 33: Storage in ESRD reservoirs, 1944 drought (1944-1945)

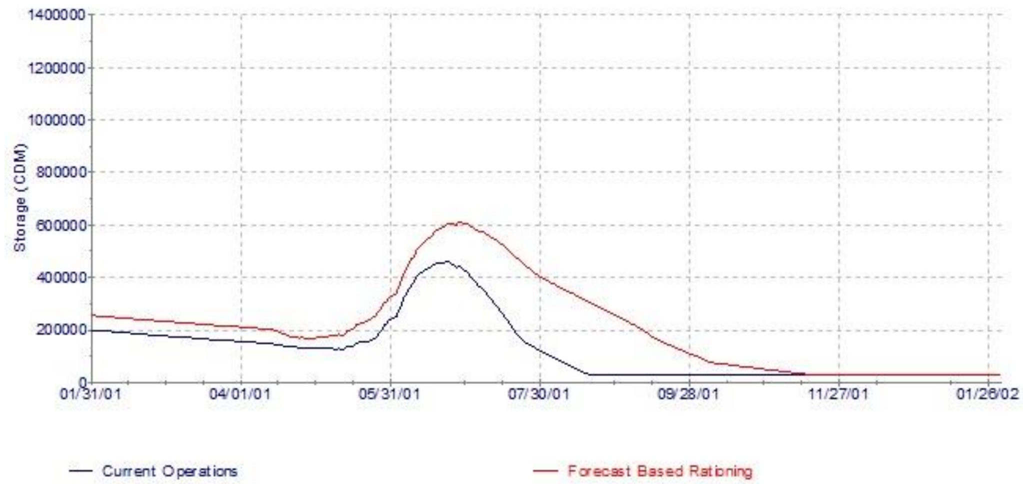

Figure 34: Storage in ESRD reservoirs, 2001 drought (2001-2002)

Figure 35 shows the recovery in total storage that would have occurred after the 1936 drought due to the implementation of a forecast-based rationing strategy compared with current operations.

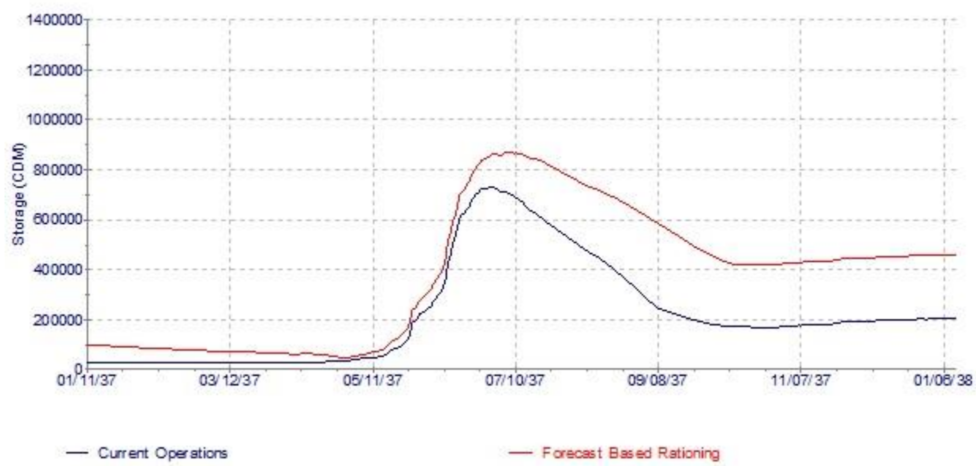

Figure 35: Storage in ESRD reservoirs after the 1936 drought (1937-1938)

A number of fairly dry years occurred after 1937 in which storage was quite uncertain. The extra recovery afforded by this strategy (and in combination with demand reductions) prevented a second premature “dry reservoir” event in 1941 (Figure 36).

Figure 36: Storage in ESRD reservoirs (1941-1942)

Forecast-based rationing also results in environmental benefits (Figure 37). Implementing this strategy means that instream fish requirements in the Oldman River would be met 100% of the time during the historical record.

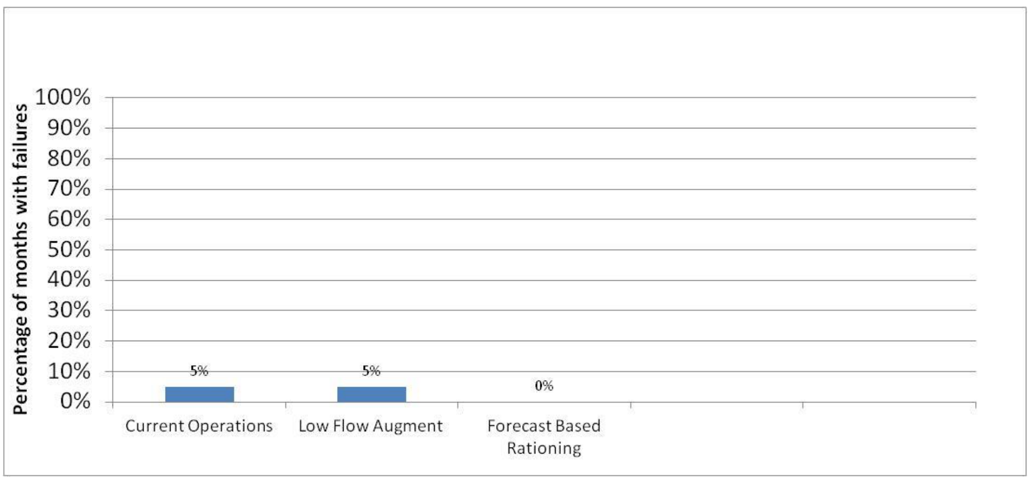

Figure 37: Percentage of months during 82-year period when instream fish requirements were not met in the Oldman River at Lethbridge

This type of strategy, similar to what was historically implemented in times of severe drought, also affects the total annual outflows from the Oldman River – a proxy indicator for apportionment. Under the Apportionment Agreement, Alberta is required to pass 50% of the flows as measured at this location to Saskatchewan. Figure 38 shows the percentage of natural flow before the Oldman-Bow confluence under this strategy (green line). In the 82-year period of record with the forecast-based rationing strategy, the number of years where the percentage of natural flow is below 50% is less frequent than current operations (the blue line, which, for the most part, sits behind the red line on the chart).

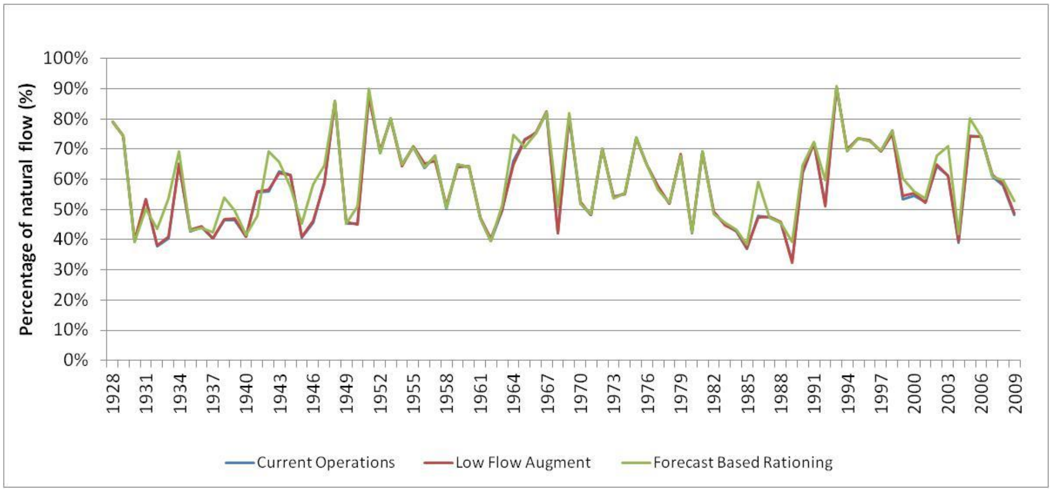

Figure 38: Percentage of natural flow before the Oldman-Bow River confluence

Relevant OSSK Model run name
CB6.9_FrcstRationing

4.2 Strategies with Some Promise

The strategies in this second category were shown by the modelling to have some promise and could provide modest benefits in conditions of climate variability. However, their benefits were fewer than those in the first category (Section 4.1). Three strategies pertain to specific geographic locations, while the fourth could be applied across the OSSK basins.

Full strategy title	**Short title for PM charts**
Category 2: Strategies with some promise	
Oldman Reservoir flood control operations	N/A
Chin Reservoir balanced	Chin balanced
Chin Reservoir expanded, and expansion balanced	Chin exp, only exp bal
Drought-modified Fish Rule Curves	N/A

Oldman Reservoir flood control operations

Several ideas were suggested for moderating flood flows in the Upper Oldman watershed, but all are constrained by the physical construction of the Oldman Reservoir, specifically that the spillway is not consistently accessible during substantial reservoir drawdowns. The spillway accessibility issue is modelled in the OSSK model.

This means that the reservoir can only pre-release so much water in advance of a flood. There is debate around whether it is advisable to pre-release an excessive amount of water and cause deliberate flooding in preparation for a natural flood that may or may not materialize. If a flood does not arrive, especially in an area that can experience water shortages later in the summer, operators tend to be cautious about releasing water too far in advance. The counterpoint is that although there may be uncertainty as to whether a flood is coming, operators often know at the time that they do not expect drought conditions, so the cost of pre-release may not be as high as one might think. If releasing water to create room in the reservoir in advance of a flood is not a desirable approach, building a dry dam downstream to capture floodwater may be a possible alternative. A dry dam was considered in this project, but was shown to have limited benefit (see Section 4.3).

In this context, two fairly aggressive approaches were taken to assess whether operations at the Oldman Reservoir (node 430 in Figure 39) could mitigate some of the impact of floods. Both approaches used perfect forecasts and allowed the reservoir to surcharge to 4 metres above its upper rule (FSL).

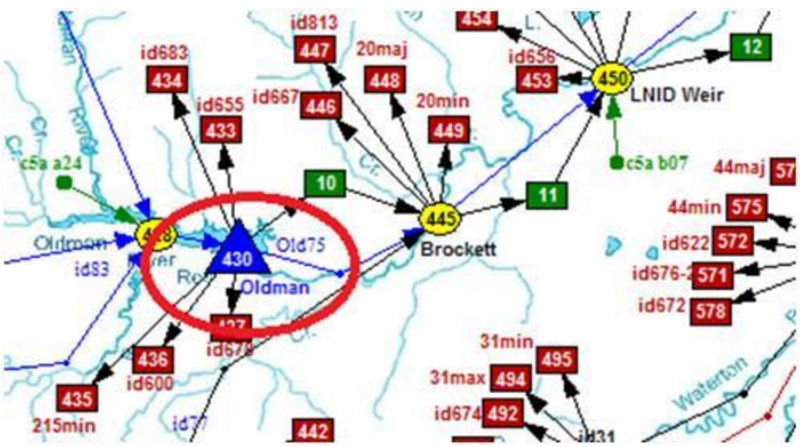

Figure 39: Location of Oldman Reservoir

The first approach was to have a minimal forecast requirement but release a substantial volume of water to make room in the reservoir. For this modelled run, for the two days before the 1995 flood hit, the Oldman Reservoir was set to pre-release 1000 cms while there is still access to the spillway. This approach has less risk for the pre-release, but creates a substantial outflow (and possible pre-flooding) to accommodate the incoming flood.

The second approach was to pre-release a smaller amount (600 cms) while there is still access to the spillway for a longer period (seven days) to lower the risk of incorrect forecasts.

As a reminder, the daily flood inflow time series was developed for 1995 to assess flood mitigation options by scaling up to daily peak flows that were based on observations upstream of the Oldman, Waterton, and St. Mary reservoirs to approximate a flood.

Model results and impacts

Figure 40 shows that in neither case were operations sufficient to mitigate the full flood. However, this strategy does show the potential for the Oldman Reservoir to at least shave some of the peak off flood flow, much as it has done due to the operations in recent flood events.

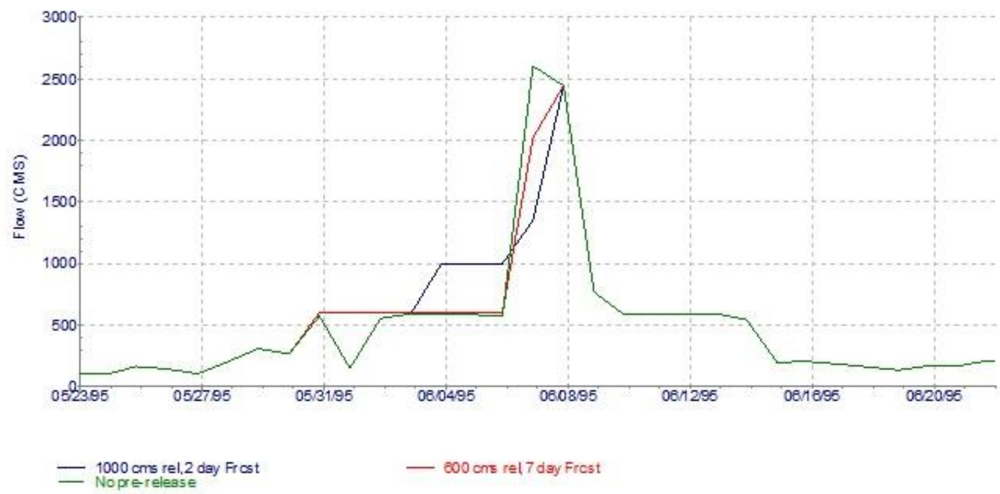

Figure 40: Outflow from Oldman Reservoir (May-June 1995)

The more substantial release (1000 cms) in the first approach performed better, dropping the maximum peak to just under 2450 cms, but this came at the cost of two days of 1000 cms pre-release. This is a flow that may well cause concern for downstream landowners and could create challenges if the predicted runoff and flows turn out to be less than expected, given that forecasts are never perfect. Nevertheless, this strategy did mitigate the first day's flood flow to about 1350 cms. The 600 cms release was less aggressive, but had fewer benefits, only mitigating the first flood day's flow to 2000 cms while also passing the full second day flow of 2450 cms.

Modelling of this strategy was insufficient to determine whether it had any effect on cottonwood recruitment, as it looked only at one year.

Figure 41 and Figure 42, respectively, show the effects of these pre-releases on elevation in the Oldman Reservoir and reservoir storage for the same period of time.

Figure 41: Oldman Reservoir elevation (May-June 1995)

Figure 42: Oldman Reservoir storage (May-June 1995)

Relevant OSSK Model run names

CurrentBase_v6.9_Flood
CB6.9_OM_Flood_1000cms_2dayForcst
CB6.9_OM_Flood_600cms_7dayForcst

Chin Reservoir balanced

Several strategies were considered that involved Chin Reservoir, some of which had more potential than others. The most promising option (d) was described in Section 4.1, where it was noted that this reservoir is owned and operated by SMRID. Although operation is communicated with ESRD, there is currently no requirement to coordinate balancing with the rest of the headworks system. Chin Reservoir options thought to have some promise (b and c) are described in this and the next strategy.

a) Expanding Chin Reservoir storage by 74,000 cdm (60,000 AF) to reduce the risk of downstream municipal and irrigation shortages,
b) Adding Chin Reservoir at its current capacity to the balancing system,
c) Expanding Chin Reservoir by 74,000 cdm (60,000 AF) and balancing only the new storage (that is, balancing only the 74,000 cdm), and
d) Expanding Chin Reservoir by 74,000 cdm (60,000 AF) and fully balancing (that is, the entire amount of existing and new storage was added to the balancing system).

Adding Chin Reservoir at its current capacity to the balancing system showed some promise when modelled, and is discussed below.

Model results and impacts

The number of irrigation shortage days during the 82-year period of record (Figure 43) shows that balancing Chin at its current capacity (the second bar in the chart) provides more benefits than simply expanding the reservoir, or expanding it and balancing only the new storage (the fourth bar). This strategy results in 610 fewer shortage days (a 17% reduction) during the 82 years compared with current operations.

This run makes it clear that, although current operations attempt to keep Chin Reservoir full as long as possible, it may be prudent to allow some preference for keeping water upstream in St. Mary Reservoir as many irrigation districts have users that cannot be served directly by Chin Reservoir. This highlights the effect of balancing in isolation and shows that incorporating operational balancing for the aggregate new and existing storage improves the value of an expansion of Chin Reservoir.

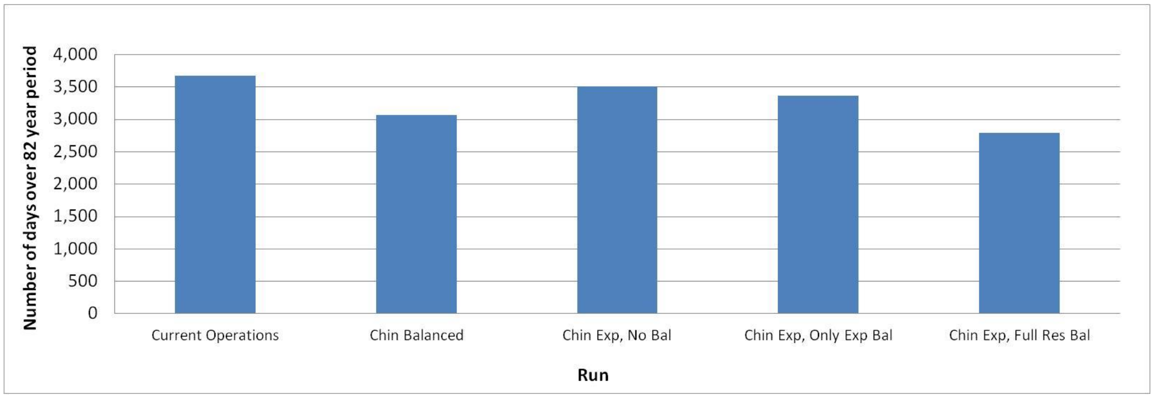

Figure 43: Total number of days in 82-year period with shortages across all irrigation districts

As shown in Figure 44, the improvements in shortage days with this strategy (the red bar) occur across all the irrigation districts.

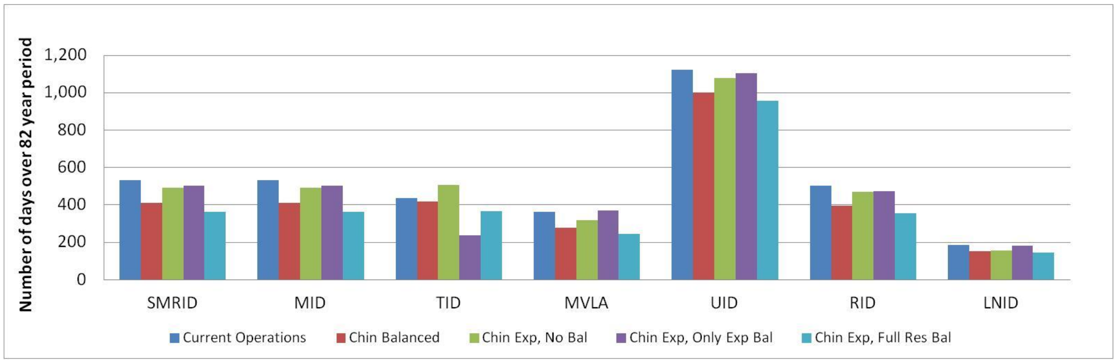

Figure 44: Total number of days in 82-year period with shortages by irrigation district

Relevant OSSK Model run name

CB6.9_ChinBalanced

Chin Reservoir expanded, and expansion balanced

Several strategies were considered that involved Chin Reservoir, some of which had more potential than others. The most promising option (d) was described in Section 4.1. Option (b) was described in the immediately preceding section, and option (c) is discussed here as also showing some promise when modelled.

a) Expanding Chin Reservoir storage by 74,000 cdm (60,000 AF) to reduce the risk of downstream municipal and irrigation shortages.
b) Adding Chin Reservoir at its current capacity to the balancing system.
c) Expanding Chin Reservoir by 74,000 cdm (60,000 AF) and balancing only the new storage (that is, balancing only the 74,000 cdm).
d) Expanding Chin Reservoir by 74,000 cdm (60,000 AF) and fully balancing (that is, the entire amount of existing and new storage was added to the balancing system).

Many irrigators felt that expanding Chin Reservoir by 74,000 cdm (60,000 AF) and balancing only the new storage was a more likely scenario than balancing the whole of this reservoir. Allowing ESRD to balance the additional storage might be considered a reasonable trade-off for expanding the reservoir.

Model results and impacts

Figure 45 shows that expanding Chin Reservoir and balancing only the new storage of 74,000 cdm (the fourth bar in the chart) offer a modest reduction in shortage days during the 82-year period of record when compared with current operations: 303 days, or a reduction of about 8%.

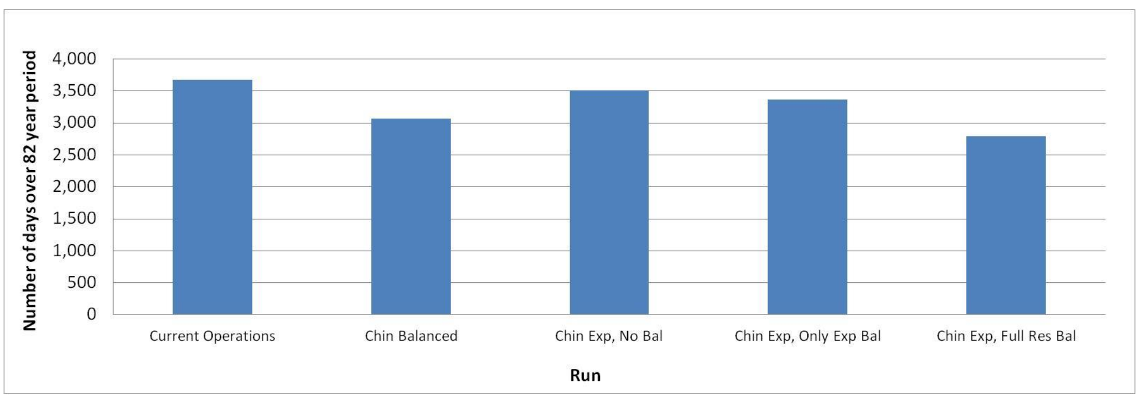

Figure 45: Total number of days in 82-year period with shortages across all irrigation districts

As shown in Figure 46, the effects of this strategy (the purple bar) vary by irrigation district; TID, for example, sees a 45% reduction in shortage days during the 82 years, while MVLA increases very slightly and others see very small reductions. SMRID, for example, has a large, fairly junior licence (1991) so it benefits only after more senior licences have benefitted.

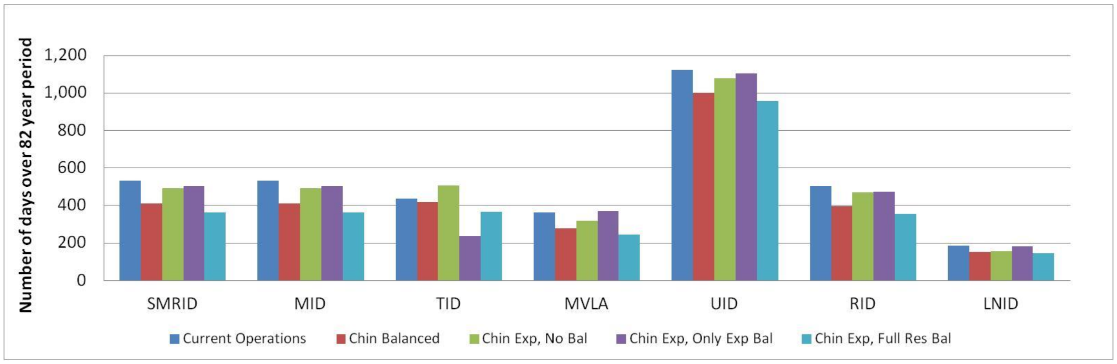

Figure 46: Total number of days in 82-year period with shortages by irrigation district

Relevant OSSK Model run name
CB6.9_ChinBalanced+60kJust60Bal

Drought-modified Fish Rule Curves

This strategy was suggested as a way to improve Fish Rule Curve (FRC) flow reliability by:

- Reducing FRC flow requirements in years where storage did not fill,
- Banking the water thus saved, and
- Releasing that water once storage is otherwise empty to continue meeting the reduced FRC requirements.

This strategy, which could be applied across the OSSK basins, would see the flows needed to meet FRCs reduced during times of drought to make the stored water last longer than it otherwise would. It was recognized that the FRCs are already written in a flexible manner to reflect flow conditions and this strategy aimed to increase that flexibility. If reservoirs are emptied to meet the full FRC, the result could have a greater impact on fisheries than a reduced flow. In drought conditions, factors such as dissolved oxygen and water temperature have a critical influence on fish. It was noted that fish have adapted to stressful conditions, and can handle "natural" low flow infrequently, but the third or fourth year of a drought would be problematic.

In years where the snowpack or soil moisture point to a potentially dry summer, some of the stored water released for instream flow support in the spring could instead be conserved in a storage bank to supplement the required instream flows in the summer. Water that is banked when flows are higher, and later released, would be used only for FRCs, which would help mitigate the effects of higher summer water temperatures and lower dissolved oxygen levels. The bank's release thresholds could be adjusted as well as how fast and how often it releases water. If reservoirs refilled, this does not become an issue as releases can return to the normal FRC obligations.

Model results and impacts

This strategy has not yet been tested in the OSSK model. Instead, to assess the potential of this approach, the model was used to calculate the volume of storage in St. Mary and Waterton reservoirs used for instream flow support from February 1 to April 30 (Table 3). This calculation was done by running the OSSK model with and without the instream flow requirements and comparing drawdown in the reservoirs. Twenty percent of this volume (as an example of the amount that could be conserved) is shown for the years with the lowest 20% of natural flow at Lethbridge from June 1 to August 31. The next two columns show the daily supplementation level of this banked storage for 60 or 20 days during the summer. More than half of these years could provide more than four cms of supplementation for 20 days under these assumptions.

Table 3: Potential benefits of drought-modified FRCs in selected years

	20% of storage used to meet FRCs from Feb 1 to April 30	Daily supplement available for 60 days in the summer		Daily supplement available for 20 days in the summer	
Year	**cdm**	**cdm/day**	**cms**	**cdm/day**	**cms**
1931	6942	116	1.34	347	4.02
1936	12902	215	2.49	645	7.47
1939	4527	75	0.87	226	2.62
1940	10042	167	1.94	502	5.81
1941	4577	76	0.88	229	2.65
1944	7504	125	1.45	375	4.34
1949	6243	104	1.20	312	3.61
1973	4040	67	0.78	202	2.34
1977	6018	100	1.16	301	3.48
1984	8821	147	1.70	441	5.10
1985	15592	260	3.01	780	9.02
1987	0	0	0.00	0	0.00
1988	11050	184	2.13	553	6.39
1992	7054	118	1.36	353	4.08
1994	0	0	0.00	0	0.00
2000	796	13	0.15	40	0.46
2001	11848	197	2.29	592	6.86

FRCs are written to vary with the climate and water supply and are a surrogate indicator for the full aquatic environment, not just fisheries health. FRC licence conditions have various policy and regulatory implications, and it is important to ensure that others (e.g., junior licence holders) are not being affected if FRCs are not met for part of the year. It could also be a challenge to ensure that when water is released for FRCs, it is not diverted for other uses.

This strategy shows some promise, but would require additional monitoring and more information to determine what the potential benefits might be in terms of meeting dissolved oxygen and water temperature criteria. Time of travel would also need to be factored in and the success of the strategy would depend on accurate forecasting.

Opportunities to adjust minimum flows in the Southern Tributaries to meet FRCs during part of the year (e.g., 10% or 20% adjustment) were also examined. However, there is so much demand already in this region that there appears to be little room for adjustments, and realistic opportunities would be limited in water short years.

Relevant OSSK Model run name

N/A

4.3 Strategies with Limited Promise

The strategies in this third category were shown to have limited promise and could not provide many benefits under conditions of climate variability, in particular drought, compared to the strategies in Sections 4.1 and 4.2. Of the six strategies in this section, the first three pertain to specific geographic locations, while the last three apply more generally across the OSSK basins.

Full strategy title	**Short title for PM charts**
Category 3: Strategies with limited promise	
1m additional storage in existing St. Mary Reservoir	N/A
Chin Reservoir expanded without balancing	Chin exp, no bal
Downstream dry dam for flood control	N/A
Simple triggered shared shortages	N/A
Lower FSL in all ESRD reservoirs by 2m when needed until July 1	N/A
Developing a storage reserve	N/A

1 metre additional storage in existing St. Mary Reservoir

Since Kimball Reservoir seemed to have substantial downstream benefit, but also required substantial cost, the question was asked whether it might be possible to gain some of that benefit with much less cost by expanding St. Mary Reservoir. It is not known if the current dam infrastructure could accommodate this expansion; as well, there could be significant land impact trade-offs, and the maximum possible increase would be only about one metre. This 1-metre increase in storage was modelled, assuming that the additional 1 metre would have the same storage-elevation relationship as the preceding 1 metre. Preliminary modelling indicated this increase would add only approximately 24,600 cdm (20,000 AF) of storage, which was not enough to substantially improve performance in the system. This strategy could be re-examined in future, but perhaps only in combination with other alternatives.

Chin Reservoir expanded without balancing

Several strategies were considered that involved Chin Reservoir, some of which had more potential than others. The most promising option (d) was described in Section 4.1 and those with some promise (b and c) were described in Section 4.2. Option a) was considered to have limited promise.

a) **Expanding Chin Reservoir storage by 74,000 cdm (60,000 AF) to reduce the risk of downstream municipal and irrigation shortages,**
b) Adding Chin Reservoir at its current capacity to the balancing system,
c) Expanding Chin Reservoir by 74,000 cdm (60,000 AF) and balancing only the new storage (that is, balancing only the 74,000 cdm), and
d) Expanding Chin Reservoir by 74,000 cdm (60,000 AF) and fully balancing (that is, the entire amount of existing and new storage was added to the balancing system).

Expanding Chin Reservoir by 74,000 cdm (60,000 AF) but not balancing any of the storage showed limited promise when modelled, and is discussed below.

Model results and impacts

The number of irrigation shortage days during the 82-year period of record (Figure 47) shows that simply expanding Chin Reservoir without adding any of the storage to the balancing system (the third bar in the chart) provides very few improvements in performance. During the 82-year historical record, this strategy results in just 158 fewer shortage days (a 4% reduction) compared with current operations.

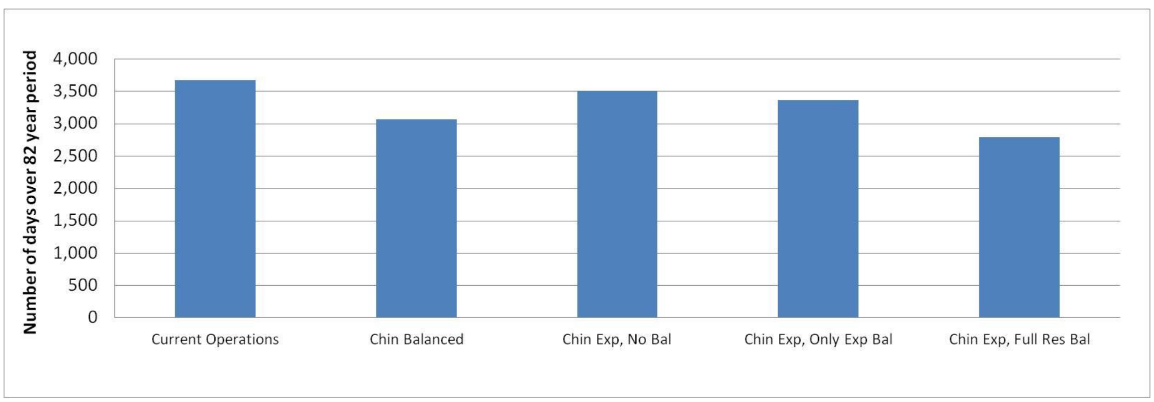

Figure 47: Total number of days in 82-year period with shortages across all irrigation districts

As shown in Figure 48, the effects of this strategy (the green bar) vary by irrigation district; TID, for example, sees a 15% increase in shortage days during the 82 years, while other districts experience very small reductions.

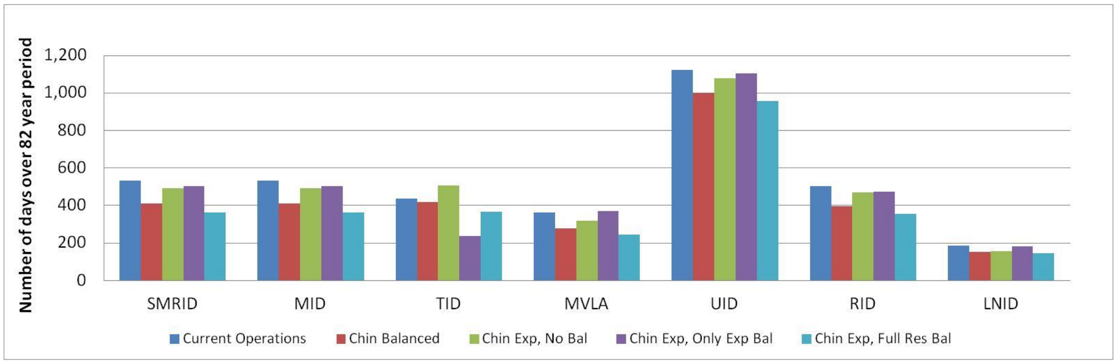

Figure 48: Total number of days in 82-year period with shortages by irrigation district

As noted earlier, strategies that involve adding Chin Reservoir to the balancing system provide more benefits to the overall system than simply expanding the reservoir.

Relevant OSSK Model run name

CB6.9_Chin+60k-NoBalance

Downstream dry dam for flood control

This strategy considered what could be done to increase flood protection for Medicine Hat. Various flood mitigation options are being actively considered, including buying out infrastructure on the Medicine Hat flood plain and/or building berms or barriers, but there is still uncertainty about appropriate mitigation targets and berm height. Some flood mitigation options for Medicine Hat are being examined by the Government of Alberta Flood Recovery Task Force. One strategy considered in this project was a dry dam in the lower basin for flood control (Figure 49, node 650). A dry dam is an onstream detention structure that temporarily detains high flows but allows normal flows to pass without hindrance and does not permanently hold water. It is built much like a full service dam and to full dam safety standards, but only stores water for short durations during and immediately following a flood event.

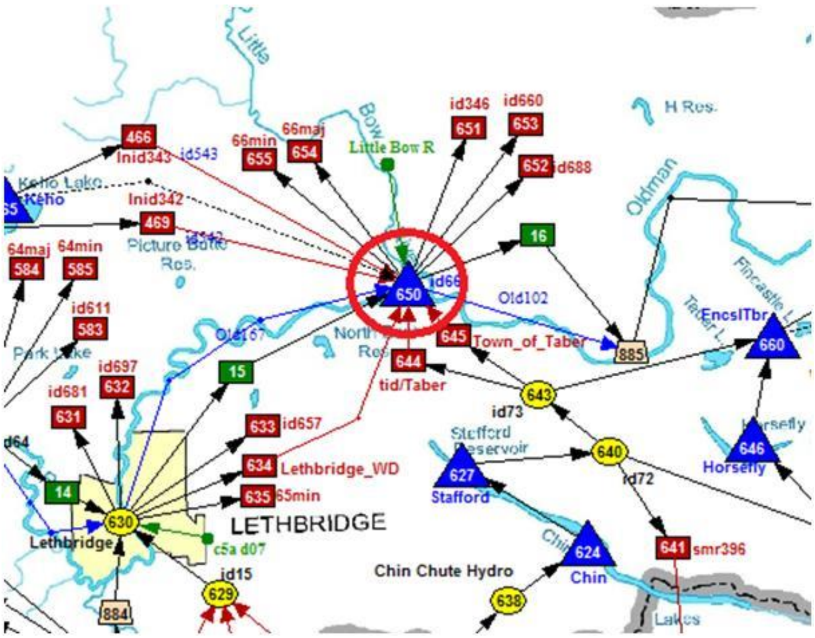

Figure 49: General location for a possible dry dam low in the basin

Model results and impacts

Preliminary work was done to examine the option of a dam that could be used for flood control and drought management, but the main intent was to consider how large such a structure might need to be. To start, stakeholders suggested a structure that could contain the flood such that flow heading to the Bow-Oldman confluence would remain under 2600 cms. Looking at the simulated record for the 1995 flood, the model suggested a large dry dam capable of storing 209,704 cdm (170,000 AF) would be required to reach this flow target (Figure 50 and Figure 51). Considering the size necessary for incomplete flood amelioration and the unlikely ability to prove the cost/benefit case for such an infrastructure investment, no additional modelling was done for this project.

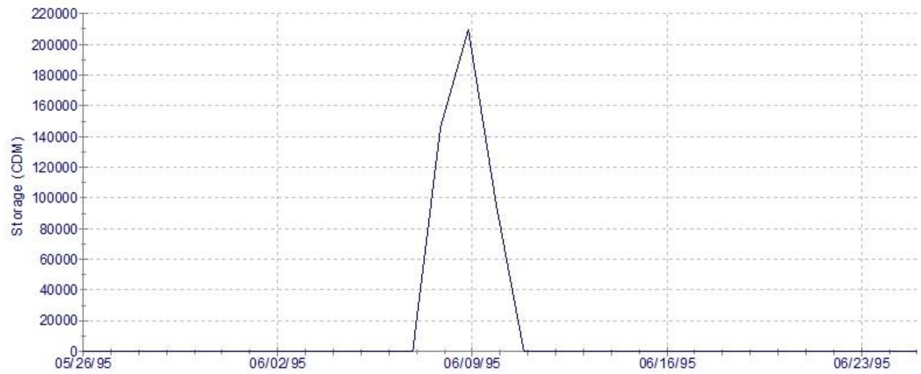

Figure 50: Storage needed in dry dam to protect Medicine Hat (1995)

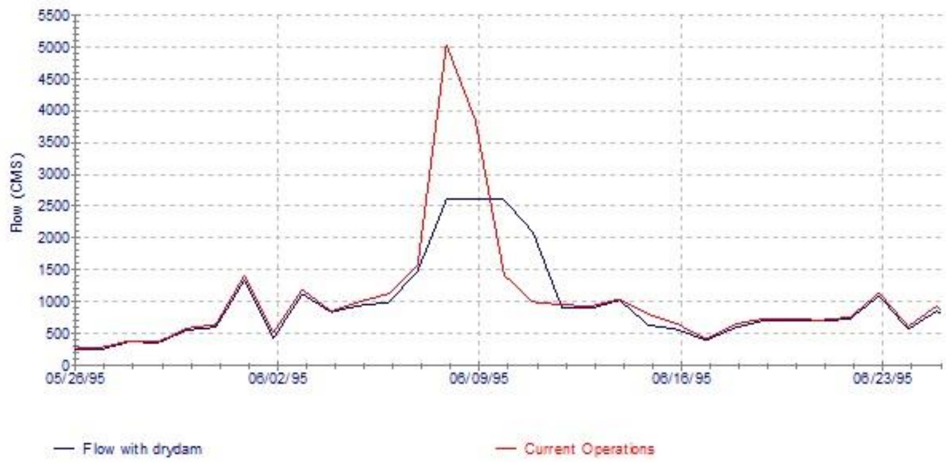

Figure 51: Flow to Oldman Mouth with dry dam in place (1995)

Many factors would influence a decision to build a dry dam, including impacts on aquatic ecosystems. Such a dam would affect access to much of the Oldman River for lake sturgeon, which is a threatened species. Some lake sturgeon are known to undertake extensive movements, thought to be related to spawning, from the South Saskatchewan River into the Oldman River. They have moved at times to sites above Lethbridge and may spawn just downstream of the Lethbridge Weir. OSSK participants were skeptical that a dry dam in this location would ever be built.

Relevant OSSK Model run name

CB6.9_OM_Flood-drydam

Simple triggered shared shortages

This strategy took a similar approach to that actually used with water users in the Southern Tributaries in 2001, but with different triggers. It arose from an early discussion with the OSSK working group that explored different approaches to sharing shortages during the climate variability CAN session. The intent was to reduce demand across all water users in the basins to prevent or delay emptying of reservoirs. Two approaches were modelled because two different groups worked on a similar strategy:

1. Reduce all demand by 25% from July to October in years when low flows are expected. In this case the model is able to look ahead to actual low flow data (“perfect forecasts”); in reality this approach would rely on forecasts.
2. Reduce all demand by 10% if reservoir is not full on July 1, until reservoir refills to rule curve. This was applied separately to the St. Mary and Oldman sub-basins.

The strategy aimed to ensure that the IO on the St. Mary River and instream flow requirements on the Oldman River were met. This discussion evolved into the development of forecast-based rationing, presented in Section 4.1.

Model results and impacts

Modelling was done using climate variable hydrology (2yr Min, Scenario CGCM3T6_3A1B, 30-year record) so that operations would be needed more frequently than under historical hydrological conditions (see Section 3.4 for a discussion of climate scenarios). Figure 52 shows the distribution of annual natural flows through Lethbridge for the climate variability historic analogue and the 2yrMin, which extends forward into the future. Flow in the median year is about 13% lower for the 2yrMin.

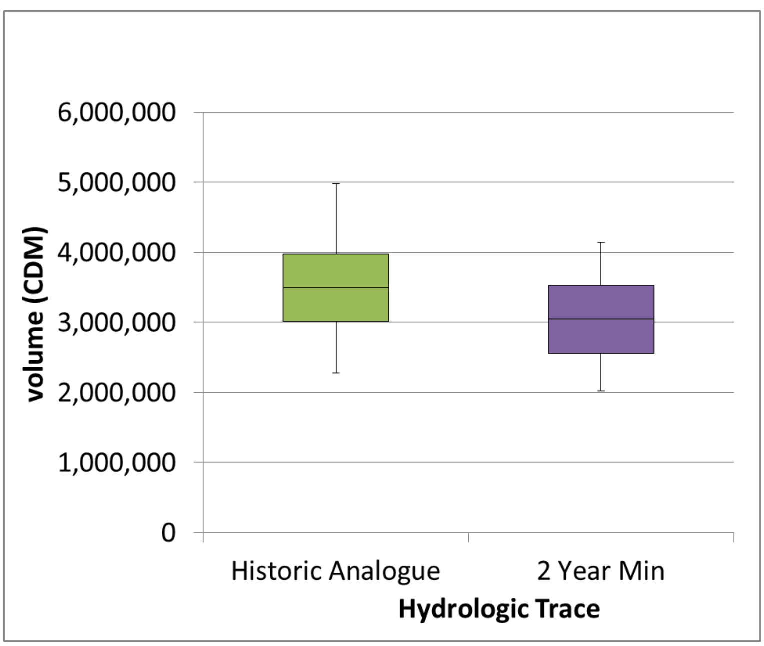

Figure 52: Yearly natural flow downstream of Lethbridge for the historical analogue and 2yr Min climate variability scenarios

Modelling results are shown in Table 4. There are three possible outcomes of implementing the shared shortage operations. First, it may be that the reservoirs (St. Mary and Waterton) would not have emptied even without the shared shortage operations. This happens in 2043, for example; these years are marked as red in the table and counted as "false positives," since the operations were put into effect unnecessarily. The second possibility is that the reservoirs empty, but they empty on the same date with or without the storage reserve operations. This happens in 2035, which is marked as orange and counted as "years without change in emptying." Finally, the shared shortage operations may help in extending the time before the reservoirs empty. This happens in 2032, for example; the years are marked as green, and the dates of the extension are given so one can judge if the additional time of storage is likely to be of benefit. If the operations are triggered in one scenario, but not the other, the year is marked with grey for the untriggered scenario.

Table 4: Extension on the number of days before Waterton and St. Mary reservoirs empty as a result of shared shortage operations

Green cells indicate True positive (the operation ran with benefit); red cells indicate False positive (operation ran without substantial benefit); orange cells indicate the reservoirs emptied with or without the operation; and grey cells were "not applicable" (indicates an untriggered scenario).

Years Shared Shortages Operations are Triggered in One or Both Approaches	Extension on reservoirs emptying	
	Approach 1: 25% redux July-Oct when low flows are expected	Approach 2: 10% redux when St Mary is not full on July 1 (until refill)
2029		
2030		
2031	prevents emptying in 2031	prevents emptying in 2031
2032	44 days (8/25 to 10/7/2032)	29 days (8/25 to 9/22/2032)
2033	reductions in prior years prevents emptying in 2033	prevents emptying in 2033
2034	51 days (7/27 to 9/16/2034)	50 days (7/27 to 9/15/2034)
2035	1 day (8/4 to 8/5/2035)	1 day (8/4 to 8/5/2035)
2036		10 days (9/11 to 9/20/2036)
2037	12 days (9/2 to 9/13/2037)	20 days (9/2 to 9/21/2037)
2038	reductions in prior years extends emptying 23 days (8/19 to 9/12/2038)	40 days (8/19 to 9/29/2038)
2039		
2043		
2044	reductions in prior years prevents emptying in 2044	prevents emptying in 2044
2048	12 days (9/8 to 9/19/2048)	5 days (9/8 to 9/12/2048)
2049	reductions in prior years prevents emptying in 2049	prevents emptying in 2049
2050		
2051		
Number of years operations triggered	**9**	15
Number of false positives (no emptying)	**3**	4
Number of years without change in emptying	1	1
Number of years emptying prevented	4	4
Number of years emptying extended > 7 days	9	9
Number of years emptying extended > 27 days	7	7
Number of years emptying extended > 28 days	7	7

In addition to the storage extensions shown in Table 4, there is a moderate benefit to instream flow with the 25% reduction for four months (Approach 1), but little to no instream flow benefit from a 10% year round reduction (Approach 2). The results show potential for extending storage, but refinements would be needed to create an effective, adaptive shortage-sharing response.

The key to benefits from sharing is the ability to forecast reservoir fill, snowpack, soil moisture, and other triggers going into the crop year. Information is needed at the beginning of the season to make decisions about crop types, seeding and other aspects. The triggers would need to be further refined to make a formal shortage-sharing strategy worthwhile. Irrigators indicated this is what they do now on an informal basis.

Tools and structure would be needed to do a shortage agreement; such agreements are hard to pre-design and have to address the problem where it is occurring. A number of players would also be involved at the basin level and communications, education and awareness are keys to overall public support. Based on experience in 2001, a template exists for one year, but a longer time period of two to three years is uncharted. It would be useful if various user groups developed water shortage plans now to be in a better position for the next drought. This overall approach was refined into another strategy – Forecast-based rationing – which did show more promise (see Section 4.1).

Relevant OSSK Model run names

CB6.9_ShrdShrt_10per_min2yr
CB6.9_ShrdShrt_25per_min2yr

Lower FSL in all ESRD reservoirs by 2 m when needed until July 1

This strategy explored potential flood mitigation benefits of keeping reservoir levels two metres below full supply level (FSL) when needed until July 1, by which time the large proportion of early summer rains will typically have passed. This option would ensure reservoir storage is available to hold large volumes of water resulting from heavy rains, if necessary. All reservoirs were to be kept at two metres below FSL until July 1. This strategy would not be implemented every year, as implementation would depend on snowpack, antecedent soil moisture, and the forecasted timing and magnitude of rain events.

Model results and impacts

Preliminary work suggested that this strategy had significant detrimental environmental effects with limited flood mitigation opportunities. It was noted that big flood events will happen, and the trade-offs of drawing down water storage in anticipation of a flood event to reduce flooding impacts downstream of the dam would need to be further evaluated before being aggressively pursued. The risk of unnecessary drawdowns in a basin that is more typically concerned about drought and water shortage than flood makes the implementation of a strategy such as this quite unlikely. No detailed modelling work was done for this strategy due to data constraints, although it did lead to the creation of a synthetic flood to mimic the actual 1995 event and led in part to the development of the synthetic flood time series. Work on this option evolved into the flood mitigation strategies for the Oldman Basin.

Relevant OSSK Model run name

N/A

Developing a storage reserve

This strategy examined the possibility of reserving some stored water in one year to support demands the following year if a drought appeared likely. The strategy differs from the triggered shared shortages described earlier in that it applies only to irrigators. It was modelled with historical flows, with Chin Reservoir expanded and the addition of Kimball Reservoir, with the following operating rule: if storage (in St. Mary, Waterton, and Kimball reservoirs) falls below *x* on or after *y*, irrigation would cease for the year, where *x* = storage reserve and *y* = cut-off date, as shown below:

With Chin Reservoir expansion only

x = 43,155 cdm (35,000 AF), *y* = September 15
x = 74,000 cdm (60,000 AF), *y* = September 15

With Chin Reservoir expansion and Kimball Reservoir added

x = 98,640 cdm (80,000 AF), *y* = September 15
x = 98,640 cdm (80,000 AF), *y* = September 1
x = 147,960 cdm (120,000 AF), *y* = September 15

Model results and impacts

Table 5 shows the results for Chin Reservoir expansion only, under two scenarios: a reserve of 43,155 cdm (35,000 AF), and a reserve of 74,000 cdm (60,000 AF), both implemented on September 15.

Table 5: Extension of the number of days before Waterton and St. Mary reservoirs empty as a result of storage reserve operations

Green cells indicate True positive (the operation ran with benefit); red cells indicate False positive (operation ran without substantial benefit), and orange cells indicate reservoirs emptied the following year with or without the operation.

Year Storage Reserve Operations are Triggered	Extension on reservoirs emptying the next year	
	Scenario 1: 35 kaf, 9/15 implementation	Scenario 2: 60 kaf, 9/15 implementation
1931	none	none
1932		
1936	none	none
1937	prevents emptying in '39	prevents emptying in '39
1939	20 days (7/23 to 8/11/40)	27 days (7/23 to 8/18/40)
1940	14 days (7/19 to 8/2/41)	20 days (7/19 to 8/8/41)
1941		
1944	prevents emptying in '45	prevents emptying in '45
1945		
2001		
Number of years with operations triggered	10	10
Number of false positives (no emptying)	4	4
Number of years without change in emptying	2	2
Number of years emptying prevented	2	2
Number of years emptying extended > 7 days	4	4
Number of years emptying extended > 21 days	2	**4**

There are three possible outcomes of implementing the storage reserve operations. First, it may be that the reservoirs (St. Mary and Waterton) would not have emptied the following year even without the storage reserve operations. This happens in 1932, 1941, 1945, and 2001; these years are marked as red in the table and counted as “false positives” since the operations were put into effect unnecessarily. The second possibility is that the reservoirs do empty the following year, but they empty on the same date with or without the storage reserve operations. This happens in 1931 and 1936; the years are marked as orange and counted as “years without change in emptying.” Finally, the storage reserve operations may help in extending the time before the reservoirs empty. This happens in 1937, 1939, 1940, and 1944; the years are marked with green, and the dates of the extension are given so one can judge if the additional time of irrigation is likely to be of benefit.

For the parameters chosen, four of the ten years show some benefit the following year. Increasing the storage reserve volume extends the time to empty by a week in two of the four years.

Results for the three scenarios that include Kimball Reservoir in addition to an expanded Chin Reservoir are shown in Table 6. The grey boxes show years in which the storage reservoir operations were not triggered for that particular scenario. There were only three years with benefits out of 10 to 12 years of triggering the operations with the chosen parameters. However, the number of false positives is reduced from eight to four under historical flows in St. Mary River at the border, as opposed to IJC entitlement flows. This result is shown in Table 7, which assumes 98,640 cdm (80,000 AF) of storage reserve and a September 15 implementation date.

Table 6: Extension on the number of days before Waterton, St. Mary, and Kimball reservoirs empty as a result of storage reserve operations

Green cells indicate True positive (the operation ran with benefit); red cells indicate False positive (operation ran without substantial benefit), and grey cells were “not applicable” (indicates an untriggered scenario).

	Extension on reservoirs emptying the following year		
Year Storage Reserve Operations are Triggered	Scenario 1: 80 kaf, 9/15 implementation	Scenario 2: 80 kaf, 9/1 implementation	Scenario 3: 120 kaf, 9/15 implementation
1931			
1932			
1936	6 days (9/9 to 9/15/37)	prevents emptying in '37*	6 days (9/9 to 9/15/37)
1937		27 days (7/29 to 8/25/40)	
1939	25 days (7/29 to 8/23/40)		32 days (7/29 to 8/30/40)
1940	20 days (7/22 to 8/10/41)	26 days (7/22 to 8/16/41)	24 days (7/22 to 8/14/41)
1941			
1944			
1945			
2001			
2003			
2007			
Number of years with operations triggered	11	**10**	12
Number of false positives (no emptying)	8	7	9
Number of years emptying prevented	0	**1**	0
Number of years emptying extended > 7 days	2	**3**	2
Number of years emptying extended > 21 days	2	**3**	2
Number of years emptying extended > 28 days	0	1	1

Table 7: Extension on the number of days before Waterton, St. Mary, and Kimball reservoirs empty as a result of storage reserve operations with IJC entitlement and historical flows at the US border

Green cells indicate True positive (the operation ran with benefit); red cells indicate False positive (operation ran without substantial benefit), and grey cells were "not applicable (indicates an untriggered scenario).

Year Storage Reserve Operations are Triggered	Extension on reservoirs emptying the next year	
	Entitlement flows at the border	Historical flows at the border
1931		
1932		
1936	6 days (9/9 to 9/15/37)	prevents emptying in '37*
1937		prevents emptying in '40**
1939	25 days (7/29 to 8/23/40)	
1940	20 days (7/22 to 8/10/41)	18 days (8/10 to 8/28/41)
1941		
1944		
1945		
2001		
2003		

* Without operations, reservoirs empty on 9/22/1937

**Without operations, reservoirs empty on 9/6/1940

In essence, out of the 82 years simulated, a benefit was seen in only a few years, assuming the strategy was perfectly implemented. Irrigators indicated that this strategy was very unlikely to be considered or supported. If the water is there and the crops need it now, irrigators would continue to use it. That said, any irrigation affected by this strategy would likely be fall irrigation since little crop irrigation occurs after September 1.

Other sharing approaches that enable decisions earlier in the year would be preferable to being required to store water later in the season. This strategy also has a number of policy implications, including crop insurance eligibility.

Relevant OSSK Model run names

CB6.9_CarryO_ChinBal+60k_35k_May29
CB6.9_CarryO_ChinBal+60k_35k_Sept15
CB6.9_CarryO_ChinBal+60k_60k_May29
CB6.9_CarryO_ChinBal+60k_60k_Sept15
CB6.9_CarryO_ChinBal+60k+Kim_80k_Sep15-IJC_Hist
CB6.9_CarryO_ChinBal+60k+Kim_80k_Sept01
CB6.9_CarryO_ChinBal+60k+Kim_80k_Sept15
CB6.9_CarryO_ChinBal+60k+Kim_120k_Sept15

4.4 Other Strategies

A number of other ideas were suggested, some of which were modelled in very limited detail. Others were not pursued at all for various reasons. This section of the report lists all of the other ideas that came forward; if they were modelled, the results and impacts are noted. Those that received some modelling attention are presented first, in alphabetical order, followed by the rest of the suggestions, also in alphabetical order.

Some of these strategies might offer valuable resiliency for local areas in the OSSK basins. While the working group discussion tended to focus on basin-wide opportunities, these local opportunities should not be lost or overlooked.

Allocate water for increased urban growth and development
Castle River (Canyon Site) Reservoir
Expand LNID acreage by 30%, reduce return flows from 18% to 5%
Expand RID acreage by 20%, reduce return flows from 15% to 5%
Expansions to Ridge
Further use of Irrigation District licence amendments
Increase canal capacity on diversion from Belly to St. Mary
Kenex site in LNID
Oldman Dam case study
Plug and play demands
Stafford spillway to Oldman River
Upper Belly Reservoir
Upper Oldman (Gap) Reservoir
West Raymond Reservoir
Dam upstream of Cardston/Lee Creek
Double municipal licence demands and double return flows
Headwaters tourism opportunities
Hydro development opportunities
Increase flow at Lethbridge
Increase on-farm efficiencies in IDs
Possible flooding of non-urban land
Regional impacts of oil and gas
Reservoir at Taylorville site (SMRID)
Restore and improve river flows on Southern Tributaries
Risk management for expansion
Several small reservoirs
Spillway on St. Mary main canal
Surcharge canals for short periods under high demand conditions
Transfer from BRID canal
Use all reservoirs for original purposes
Water reuse opportunities

Allocate water for increased urban growth and development

Three potential growth scenarios were considered for this option: full build at 1.5, two, and three times current demand for Lethbridge, Medicine Hat, and Taber. These options were briefly examined to determine the potential impact of population and economic growth in the three municipalities. The first two expansion scenarios had little impact, while the "three times current demand" scenario created a 55,500 cdm shortage for the SMRID over the full 82 year period. Even at three times current demand, water levels at Lethbridge were very similar to the present. The three expansion scenarios had no effect on cottonwood recruitment, but there were some FRC violations on the Oldman between where Lethbridge withdraws and returns water. One way to implement this strategy is by making use of Irrigation District licence amendments, described below.

Castle River (Canyon Site) Reservoir

A reservoir was suggested in the Castle River Canyon area on the Castle River, upstream of the existing Oldman Dam. This would provide on-stream storage of about 49,339 cdm (40,000 AF). Although this option was modelled, the dam is unlikely to be built, recognizing the environmental sensitivities in the headwaters region. The results and impacts are approximately the same as those for the Upper Oldman (Gap) reservoir.

Expand LNID acreage by 30%, reduce return flows from 18% to 5%

In this scenario, the LNID area was expanded by 30% (just over 20,000 ha) with the same diversion, and return flows were reduced from 18% to 5%. Over the 82 years of the model, there was one year with shortage less than 22,200 cdm (18,000 AF) and four years with less than 18,500 cdm (15,000 AF). These results indicate the LNID could expand its acreage with little negative internal impact. The few years of observed shortages indicate that a repeat of the historical hydrology would be able to support this expansion through most (but not all) years.

Expand RID by 20%, reduce return flows from 15% to 5% (RID 'pipe dream')

In this scenario, the RID area was expanded by 20% (about 3,755 ha) and return flows were reduced from 15% to 5%. This is essentially modelling the pipe dream, where a pipe from the main canal would be used to replace the current works. The current works would limit expansion to about 7%. This expansion scenario, or the pipe dream, would increase RID ability to use more allocation. Model results showed that these changes could occur with a small impact on the SMRID only.

Expansions to Ridge

This alternative was modelled, but the analysis was the same as the West Raymond site; it was too small and did not provide enough benefit so was not examined further.

Further use of Irrigation District licence amendments

At present, irrigation districts each have a relatively small amount of water in their licences that could be used for non-irrigation purposes. This water could be used in ways that break the traditional seasonality of existing irrigation district demands. For modelling purposes, these seasonal demands were assigned as year-round demand for new uses not previously in the model. The new demands were added in places that were considered to be reasonable in each irrigation district. To fully explore this option, it was assumed that the water to meet these new uses was removed from the system and there were no returns, which is not completely realistic. The additional demands were modelled as entirely dependent on local reservoir storage. The table below shows the volume of modelled licence amendments for the major irrigation districts in cubic decametres (cdm), with the volume in acre-feet in parentheses.

Irrigation District	Amended volume (cdm)	Amended volume still available (cdm)
SMRID	14,796 (12,000 AF)	7,398 (6,000 AF)
LNID	48,171 (39,068 AF)	6165 (5,000 AF)*
TID	9,864 (8,000 AF)	9,494 (7,700 AF)
RID	5,548(4,500 AF)	4,069 (3,300 AF)
MID	912 (740 AF)	912 (740 AF)
MVLA	2,096 (1,700 AF)	2,096 (1,700 AF)
UID	1,233 (1,000 AF)	1,208 (980 AF)

*5,000 AF was immediately approved for other use purposes, as some of that 39,068 AF can be used for expansion of irrigation acres as is currently the plan within the LNID. If more water for other use purposes were needed, more of the 39,068 AF could be allocated to other use purposes as needed.

Increase canal capacity on the diversion from Belly to St. Mary

This alternative (also referred to as "Improvements to Waterton-St. Mary-Ridge Canal") would change the diversion limits from the St. Mary and Belly to ensure Chin can be filled early and often. Deliveries to Chin were ramped up as Chin fell. The size of the main canal from the Belly to St. Mary would need to be increased for this alternative. This was modelled in combination with expanding Chin, but turned out to not be necessary because the Belly-St. Mary stretch was not in fact a bottleneck. Although the maximum flow is reached and maintained regularly, the actual bottleneck that affected performance was at Drops 4, 5, and 6 which were changed as part of the strategy to expand and balance Chin.

Kenex site in LNID

Another site considered for storage was Kenex, near the LNID diversion. This has obvious benefit to the LNID, but provided minimal benefit to other users. Because of its location, caution will be needed, as Kenex could interfere with the operations of the Oldman Dam if it re-fills using Oldman releases intended for other purposes. Because this dam is only able to provide water to the LNID and Piikani Nation, it was limited as a potential strategy. In the small amount of modelling that was done, it was found that if Kenex were operated aggressively (i.e., reaches full and empty in most years) it could potentially benefit downstream users and flows, though some time would be necessary to find operations to actualize this benefit. As stakeholders were more interested in investigating other options, Kenex did not receive substantial attention.

Oldman Dam case study

It was suggested that modelling be done to see what the impact would be if the Oldman Dam were removed from the system. Model results showed a large drop in storage at the end of the irrigation season. The minimum weekly flow of the Oldman River at Lethbridge was lower most of the time, and the annual minimum weekly flow drops. Without this dam, St. Mary and Waterton would try to meet the system needs. The total volume of shortages for irrigation is much greater. Other reservoirs try to meet the downstream FRC, but this is very difficult. Much more water is also being sent onto Saskatchewan as it can no longer be stored. It was noted that taking this water away is not the same as not building the dam, and that the dam was built irrigation so water was allocated accordingly. It was suggested that if the dam had not been built, the basin would probably have been closed earlier and some processors and other economic activity may not have moved in.

Plug and play demands (add a demand anywhere in the model, three were pre-modelled: corn chip factory @120,000m^3/yr; potato chip factory @300,000m^3/yr, and food processing plant at 1.8Mm^3/yr)

These options were not a high priority for stakeholders to model and explore. They will, however, be included in the model documentation and are available for future examination.

Stafford spillway to Oldman River

This spillway would be put in place on the St. Mary main canal downstream of Stafford to:

- Handle flood flows to Ridge and the main canal,
- Enable storage of more water upstream without raising the risk of overtopping, and
- Enable some flows to run through the spillway to provide more power generation.

This strategy was modelled but input data do not contain the circumstances that would merit its use (that is, no floods). This strategy is essentially flood risk prevention, but was outside the scope of this modelling exercise.

Upper Belly Reservoir

The Upper Belly Reservoir was the second storage site proposed on the Belly River at the Belly-Waterton confluence. A range of sizes was considered, with capacity between 19,100 and 55,500 cdm (15,500 to 45,000 AF). Storage at the upper end of the contemplated range could mitigate low levels on Waterton and St. Mary Reservoirs but has a marginal benefit to the Oldman Reservoir. Shortages were less to the UID and overall irrigation delivery shortages were reduced, but this could come at a disproportionate environmental cost, as this is a sensitive area. Opportunities to promote cottonwood regeneration were minimal and FRC violations increased on the Oldman mainstem, likely due to a lower contribution from the Belly River. A new set of operating tables for fish rule curves may be needed if such a dam were built. This alternative was subjected only to preliminary analysis because other reservoir sites showed much more promise. Further refinement of operations for the site could increase benefits and mitigate costs, but the maximum possible gain from this site did not seem to merit extra investigation.

Upper Oldman (Gap) Reservoir

A reservoir was suggested in the Gap area on the Upper Oldman, upstream of the existing dam. This would provide on-stream storage of about 283,600 cdm (230,000 AF). Although this option was modelled, it is unlikely to be built, recognizing the environmental sensitivities in the headwaters region. This reservoir was balanced with all other reservoirs and provided benefit for cottonwoods. It was then given priority in holding water and helped fill the Oldman Reservoir in low flow years, but with minimal benefit to flows below Lethbridge. The location of the reservoir had neither the ability to capture substantial inflows (relative to sites on the Belly and/or St. Mary), nor could it provide water to the Southern Tributaries where the vast majority of irrigation occurs. Its primary benefit was to provide extra flows for environmental purposes (reduce FRC violations and/or increase minimum flows). This option was quickly set aside by stakeholders as the environmental damage from building the dam was considered excessive relative to possible downstream environmental gains.

West Raymond Reservoir

A potential reservoir at this site would provide off-stream storage of 19,800 cdm (16,000 AF) below Ridge Reservoir. The West Raymond Reservoir would be located directly west of the existing Raymond Reservoir, approximately three miles south and west of the Town of Raymond. Water would be supplied through a minor canal or pipeline spur off the St. Mary Main Canal, 4.5 km upstream of the Raymond Hydro inlet. This reservoir had no negative impacts and was too small to have substantial positive impact, although there could be some local benefits, though reservoir balancing with other AESRD storage would need to be applied.

The following strategies were noted but were not modelled or pursued; they are shown in alphabetical order.

Dam upstream of Cardston/Lee Creek

This option was not of interest to participants.

Double municipal licence demands and double return flows, and check for the impact on waste assimilation

This strategy was not modelled because ESRD does not have a water quality model for the Oldman River.

Headwaters tourism opportunities

It was suggested that changes in flow could benefit fishing, rafting, guiding, lodging, and other recreation and tourism opportunities in the headwaters. The question was asked whether any studies are underway that might look at the significance of the tourism economy in or near the headwaters. This was not a modelling question and was noted but not explored during the project.

Hydro development opportunities

This strategy was not of interest to most stakeholders.

Increase flow at Lethbridge

Currently just downstream of the City of Lethbridge (e.g., Hwy 3 overpass) the river can be quite low in the summer, making recreational activities on the river difficult (e.g., tubing and boating) because of the need to walk to deeper water. This strategy was not modelled as flow values were never provided to which releases could be targeted. This could be done at some future time if data become available.

Increase on-farm efficiencies in irrigation districts

An example of this strategy might be to use irrigation district efficiencies to create wetlands. This option was not of interest to most stakeholders.

Possible flooding of non-urban land

It was suggested as a flood mitigation measure, that agricultural or forested land could be subject to overland flooding to protect more developed areas. This option was ruled out and not modelled. The physical geography of the region does not provide any opportunity to divert water because the valley is so incised downstream of the Oldman Dam.

Regional impacts of oil and gas

Several municipalities including the Counties of Cardston and Warner, and the Towns of Cardston, Raymond, Taber and Warner would like to know the impacts oil and gas activities are having on the water in the area. These impacts were not modelled because data were not available.

Reservoir at Taylorville site (SMRID)

This option was a proposed 52,000 cdm (42,000 AF) reservoir south and just east of St. Mary Reservoir, and east of St. Mary River. It was decided not to model this option.

Restore and improve river flows on Southern Tributaries

This option would involve changes to minimum flows on the southern tributaries over and above current flows; e.g., increase instream objective to see how much it could be increased before causing problems, such as from 10%-15%-20%. This concept led to more detailed work on the low-flow alternative for the St. Mary River, and this option was not refined further.

Risk management for expansion

Examine implications of economic growth to current users in the region. (specific example: Taber wonders if Rogers Sugar has concerns about water and they would like to know the impact of additional food processing on the water supply.) This strategy was briefly examined, but numbers were so small that they were essentially “invisible” to the model.

Several small reservoirs

Consider building reservoirs with capacity of 1,233 or 2,466 cdm (1000 or 2000 AF) along main canals in many locations. These would be less costly than larger structures to build and would enhance water availability within an irrigation district. This was floated as an idea, but not modelled.

Spillway on St. Mary main canal

This option would reduce flood risk in high runoff years, permit the main canal to collect water through drain inlets, etc. without putting SMRID structures at risk, add live storage (increase FSL at Chin and Ridge) from reduced flood risk, and allow increased power generation through all three plants. This strategy was not modelled as no overland flow data were available.

Surcharge the canals for short periods of time under high demand conditions

This was also an idea that was not modelled.

Transfer from BRID canal

Water transfer from the Bow River to the Oldman basin could be contemplated, and the BRID should be involved. This strategy could be examined when the models for the basins are integrated.

Use all reservoirs for original purposes (i.e., storing water for use)

Some reservoirs, such as Payne, are not always fully utilized because of development around them and recreational uses. The water in these reservoirs should be used before more storage is considered. This is how the reservoirs are operated in the model. Payne and other very small residential "lakes" are not modelled as reservoirs.

Water reuse opportunities

Return flows or diversions could be reduced and subsequent water reuse opportunities explored. Some strategies did look at the impacts of reducing irrigation district return flows.

5 Combining Strategies for Adaptation

Recognizing that the OSSK basins are complex and dynamic systems, it was expected that potential adaptation strategies would be implemented in combination, reflecting the needs of the basins and the appropriate degree of risk management. The project modelled three strategy combinations to demonstrate how adaptation strategies might be layered to produce cumulative and offsetting impacts. These combinations were constructed to show how:

C1: Increasing the capacity of infrastructure already in place, then improving operations could optimize the existing infrastructure,
C2: New infrastructure to expand storage capacity could be combined with existing infrastructure and operating improvements, and
C3: More storage and more aggressive operating changes could be implemented to manage through severe and prolonged drought conditions.

All of the strategies used in the combinations were also modelled individually. Strategy descriptions and model results for each individual strategy appear in Section 4.1 of this report.

Full strategy title	**Short title for PM charts**
Category 4: Combined strategies	
C1. Chin Reservoir expanded + fully balanced + St. Mary augmentation	Chin + Low Flow Aug
C2. Chin Reservoir expanded + fully balanced + Kimball Reservoir + St. Mary augmentation	Chin + Kim + Low Flow Aug
C3. Chin Reservoir expanded + fully balanced + Kimball Reservoir + St. Mary augmentation + forecast-based rationing	Chin + Kim + Aug + Frcst Rtn

C1. Chin Reservoir expanded + fully balanced + St. Mary augmentation

This strategy includes a 74,000 cdm (60,000 AF) expansion of Chin Reservoir on the existing infrastructure footprint then focuses on optimizing this storage through management changes, making it the least expensive combination. Specific operating improvements in this strategy are fully balancing the expanded Chin Reservoir and augmenting low flows below St. Mary Reservoir.

Model results and impacts

Figure 53 shows the impact of each component in this combination, as well as the cumulative effect, on irrigation shortage days. As seen previously in Section 4, the key contribution from Chin Reservoir comes from adding the full storage (existing plus new) to the balancing system. Expanding and balancing Chin Reservoir reduces the number of shortage days across the 82-year record by 879 compared with current operations. Low-flow augmentation creates 226 additional shortage days during the period of record, but that component also provides environmental benefits, as noted below. By combining these two strategies, as shown in the far right bar in Figure 53, the number of shortage days is reduced by 529 days (14%) relative to current operations.

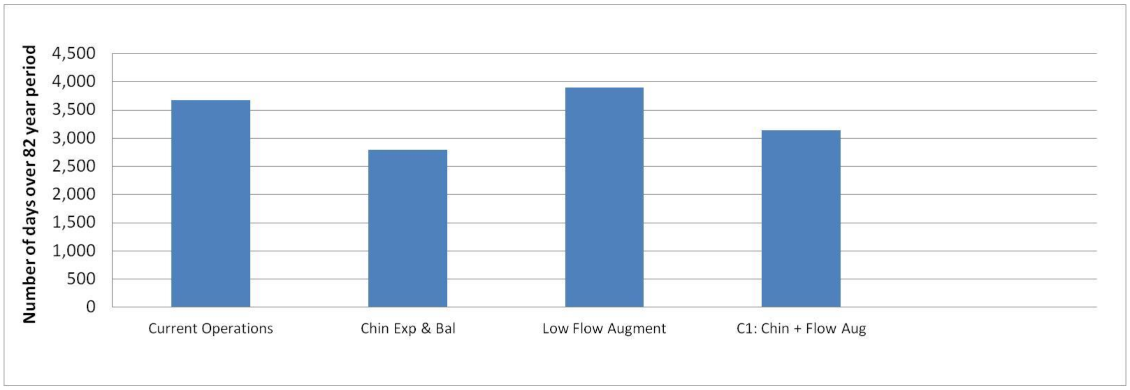

Figure 53: Total number of days in 82-year period with shortages across all irrigation districts

Figure 54 shows the distribution of shortage days across the irrigation districts. This combination (C1, the purple bar) reduces the number of shortage days during the 82-year period for all districts, but the reductions for TID and LNID are less than the others.

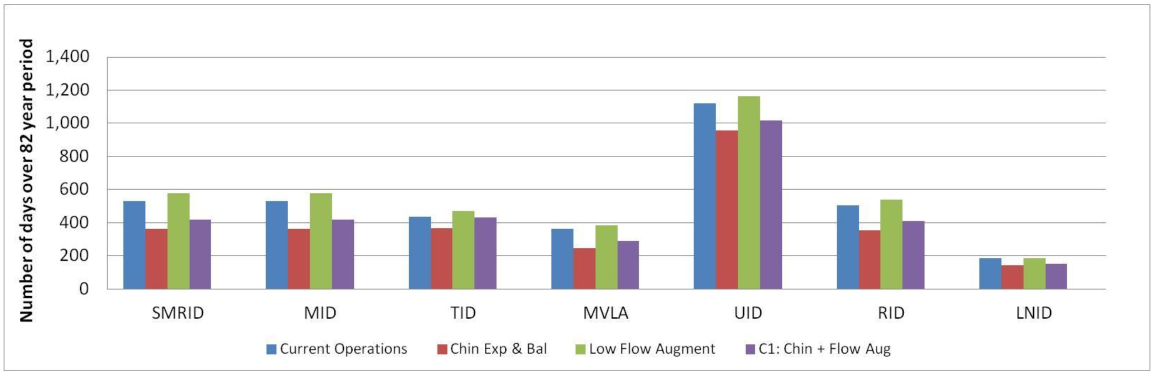

Figure 54: Total number of days in 82-year period with shortages by irrigation district

C1 has a positive environmental benefit on rainbow trout habitat in the St. Mary River, as shown in Figure 55, most of which is contributed by the low-flow augmentation component; the strategy had a very mild positive impact on cottonwood recruitment for the Oldman River near Lethbridge.

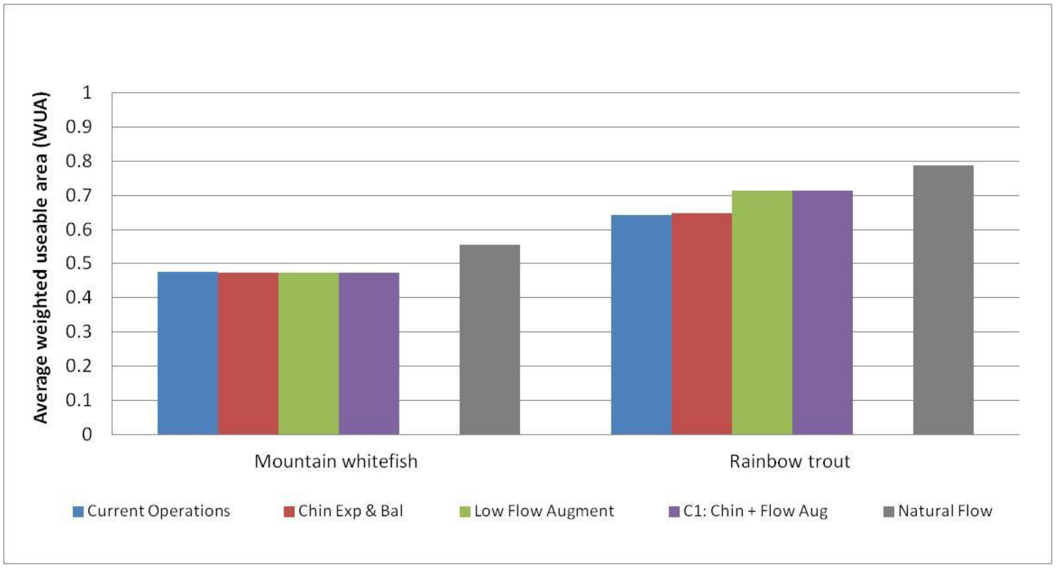

Figure 55: Average WUA of adult habitat for the 82-year period

Relevant OSSK Model run name

CB6.9_Chin&StMary

C2. Chin Reservoir expanded + fully balanced + Kimball Reservoir + St. Mary augmentation

The second combination strategy (C2) was based on both management changes and new infrastructure. In addition to expanding and balancing Chin Reservoir, C2 adds new storage with Kimball Reservoir (125,800 cdm or 102,000 AF), and then augments low flow below St. Mary Reservoir. This combination differs from C1 with the addition of Kimball.

Model results and impacts

The results show that adding Kimball Reservoir reduces shortage days less than expanding and balancing Chin Reservoir for the 82-year period (Figure 56). However, when the two were combined (the fourth bar), they reduced total shortages over the 82-year record by 1305 days. Augmenting the low flow below St. Mary Reservoir to complete the C2 combination raised the number slightly from 2368 to 2698 days, but this is still a substantial improvement over current operations with 3673 shortage days in 82 years. These results demonstrate that if a reservoir were built, the additional stored water could be used for purposes other than reducing shortages, such as augmenting low flows downstream of St. Mary Reservoir, while still maintaining substantial shortage reduction benefits.

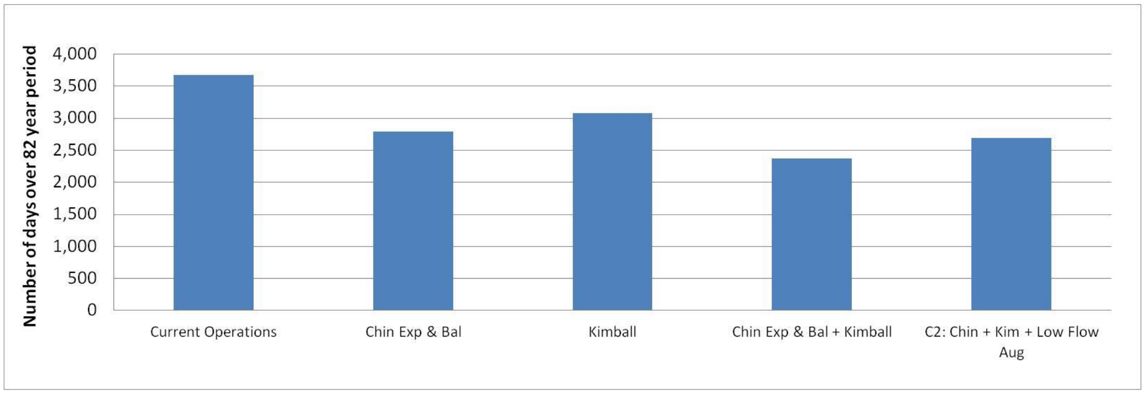

Figure 56: Total number of days in 82-year period with shortages across all irrigation districts

The reduction in shortage days compared to current operations was seen across all irrigation districts (Figure 57).

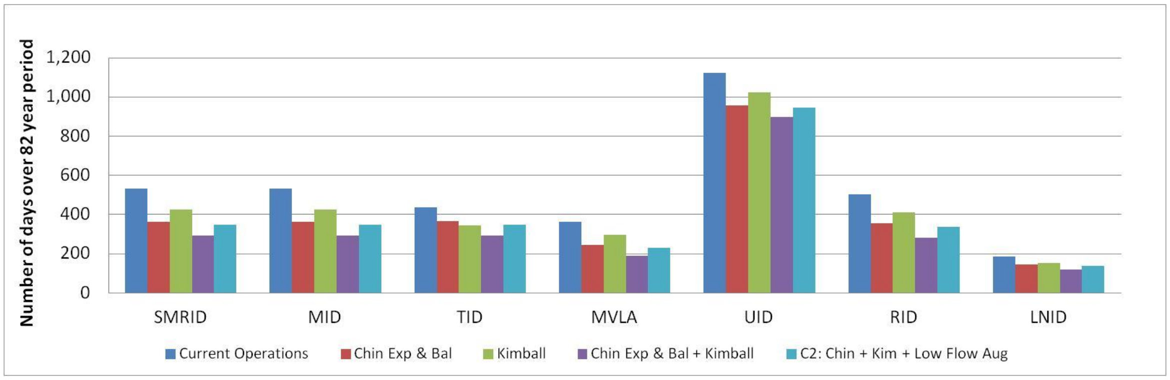

Figure 57: Total number of days in 82-year period with shortages by irrigation district

Figure 58 illustrates the improvement in rainbow trout habitat compared with current operations, resulting largely from the low-flow augmentation component of this strategy.

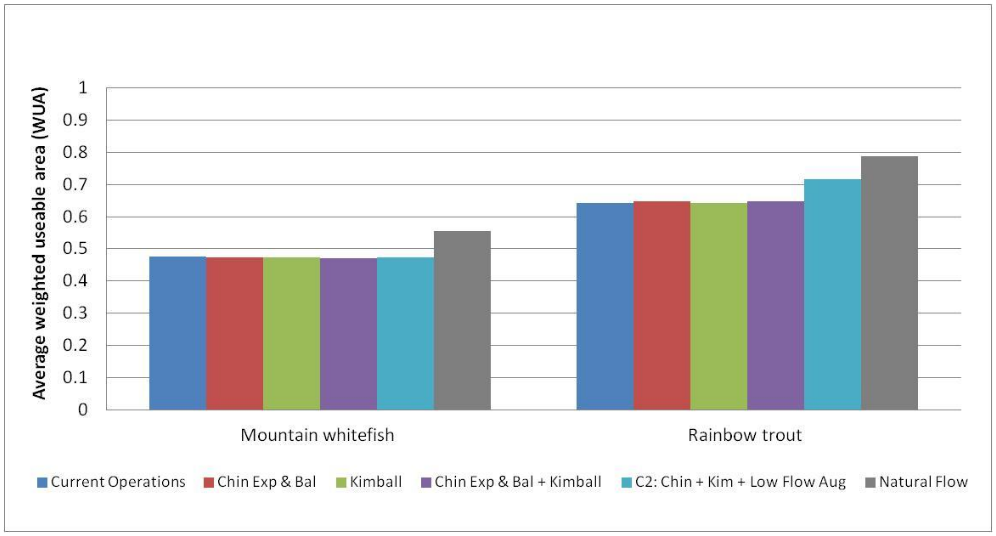

Figure 58: Average WUA of adult habitat for the 82-year period

However, this combination affected cottonwood recruitment on the Oldman River near Lethbridge, compared with current operations (Figure 59), eliminating one year of partial recruitment and one year of optimal recruitment. This was a function of slight flow reductions in the Oldman River on two occasions.

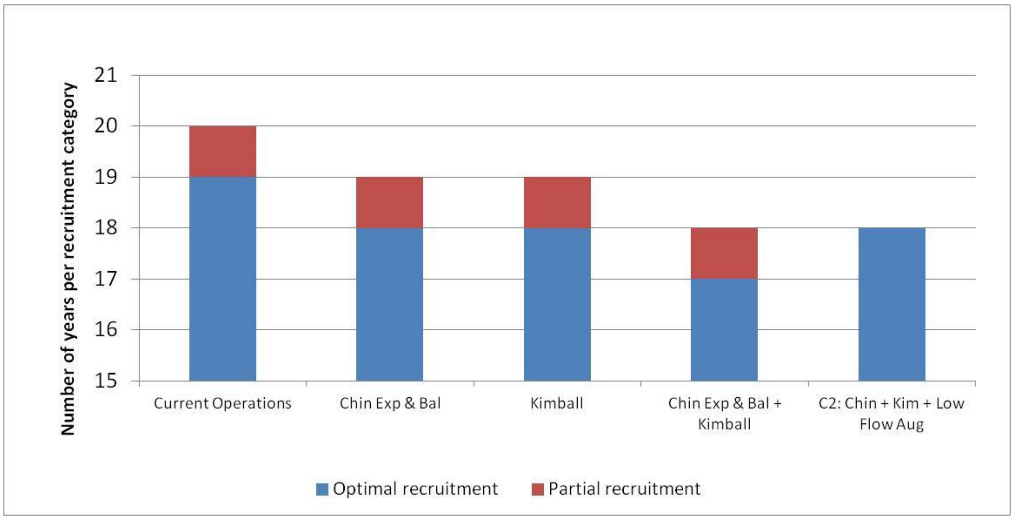

Figure 59: Years of cottonwood recruitment success for Oldman River near Lethbridge during the 82-year period

Relevant OSSK Model run name

CB6.9_Chin&Kimball&StMary

C3. Chin Reservoir expanded + fully balanced + Kimball Reservoir + St. Mary augmentation + forecast-based rationing

This strategy illustrates what could be done to respond to a severe multi-year drought. It adds all of the previously discussed storage and low-flow augmentation and then implements forecast-based rationing on the premise that storage alone is not enough to get through multi-year droughts. Although additional storage is very helpful in a single year drought, further and more aggressive reduction measures are needed to help make subsequent drought years more manageable.

Model results and impacts

The 2yr Min climate variability scenario was used to illustrate the effects of C3 as it is based on drier conditions. Figure 60 compares different storage and management options during the first year of a drought (2034). It shows that added storage by itself (the red line) is essentially the same as current operations (the green line). However, combining rationing with extra storage (the blue line) allowed for a nearly complete irrigation season, albeit with reduced volumes of water.

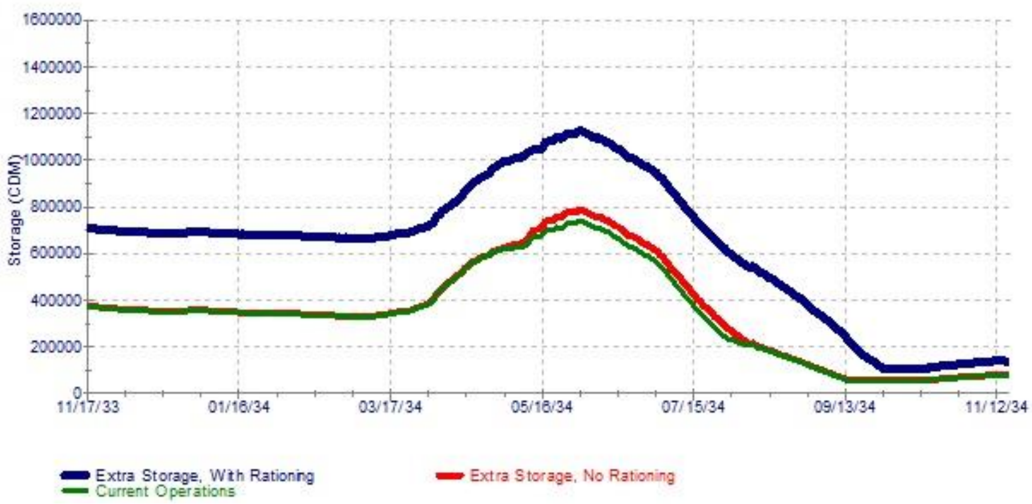

Figure 60: Storage in ESRD and Chin reservoirs (2033-2034)

Scenario: 2yr Min (CGCM3T6_3A1B), 30-year record

In the second year of a severe drought under the 2yr Min climate variability scenario, storage alone makes no difference to irrigation performance as supplies would have been exhausted in the previous year (2034). Figure 61 shows that extra storage combined with rationing enabled a longer irrigation period, again with substantially reduced volumes.

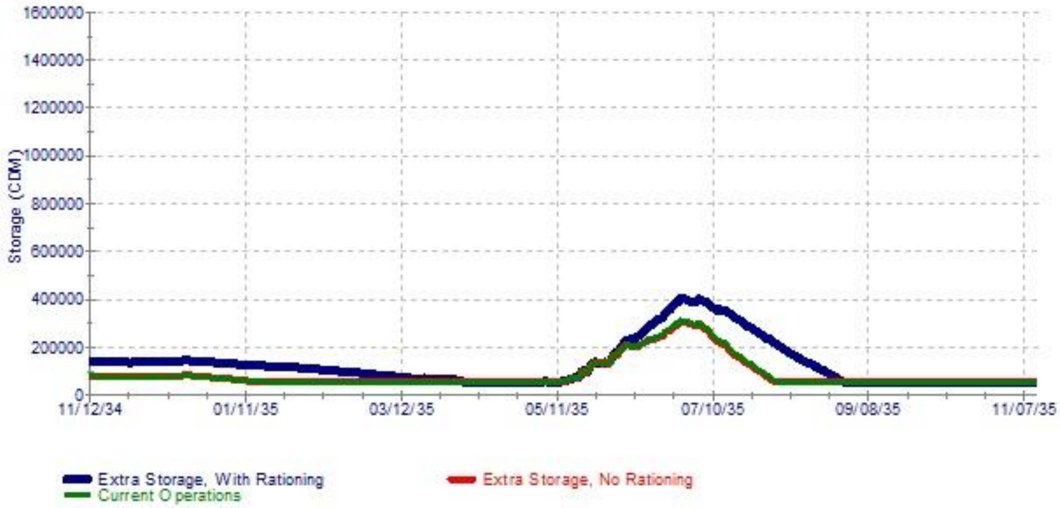

Figure 61: Storage in ESRD and Chin reservoirs in second year of severe drought (2034-2035)

Scenario: 2yr Min (CGCM3T6_3A1B), 30-year record

Returning to the historical record, Figure 62 and Figure 63 illustrate the impact that C3 would have had on the droughts in 1944-45 and 2001-02 respectively; the patterns were similar for the 1931-32 and 1936-37 droughts. The red line, which includes forecast-based rationing, shows how much the rationing component of this combination extends the irrigable season compared with current operations and the other components of C3.

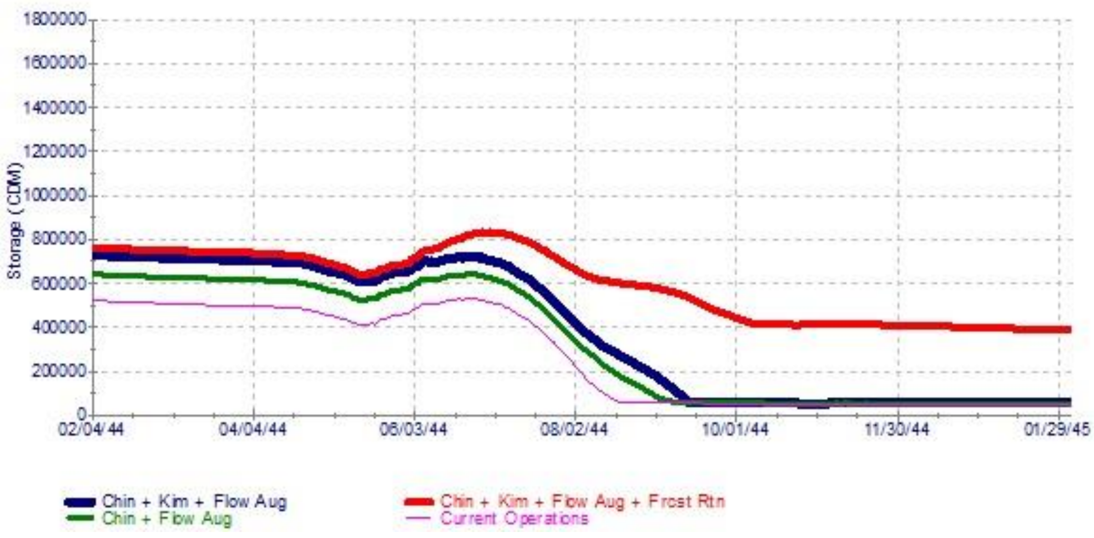

Figure 62: Storage in ESRD and Chin reservoirs (1944-1945)

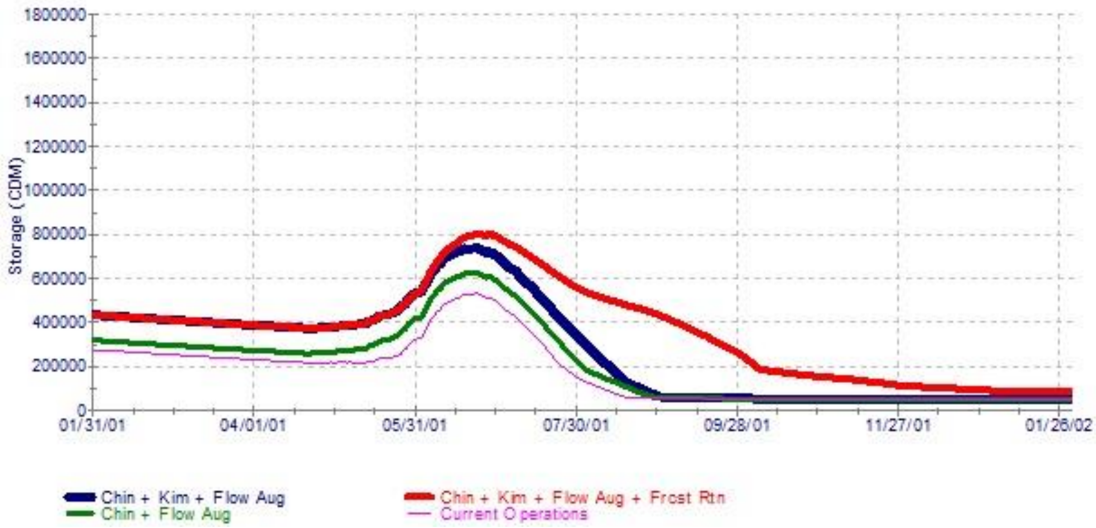

Figure 63: Storage in ESRD and Chin reservoirs (2001-2002)

Looking at PMs for this combination, Figure 64 shows the impact on shortage days for the 82-year period of record. As seen above, C2 (Chin + Kimball + low-flow augmentation) reduces shortage days by 26% compared to current operations (2698 vs. 3673 days). Adding forecast-based rationing to this combination dramatically reduces shortage days further, but it is essential to remember that this is largely because demands are much lower. As discussed in the forecast-based rationing strategy, this drought situation suspends FITFIR but shows that collaboration, as demonstrated in 2001, can add significant value to strategies that incorporate more storage to help meet the needs of junior water licence holders.

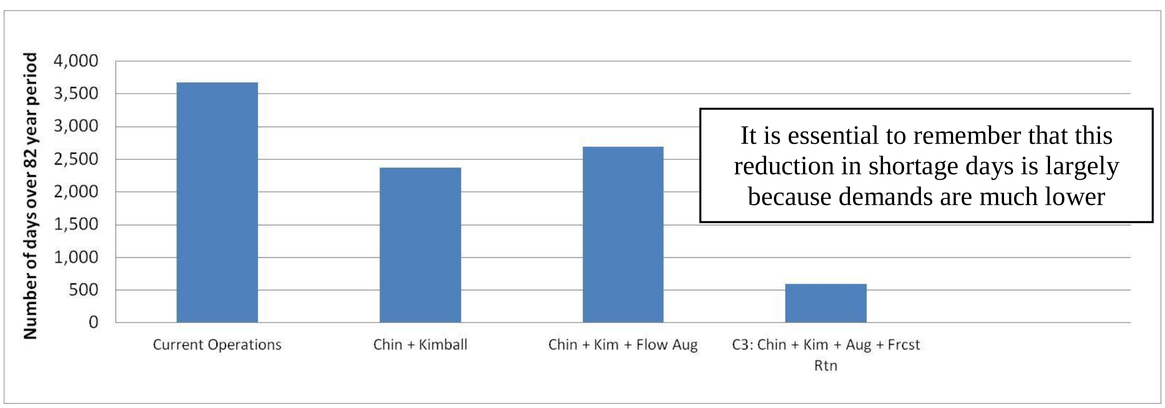

Figure 64: Total number of days in 82-year period with shortages across all irrigation districts

This strategy reduces shortages to zero during the 82-year period for nearly all irrigation districts (Figure 65), but in most cases this is due to demands being reduced intentionally rather than previously undelivered water arriving. In other words, less water is being supplied to the irrigation districts even though the figure shows a reduction in shortages. Although reduced, UID still retains some shortages as they are high in the basin and are completely unsupported by storage, and must allow a minimum flow to pass by before they are allowed to withdraw for irrigation.

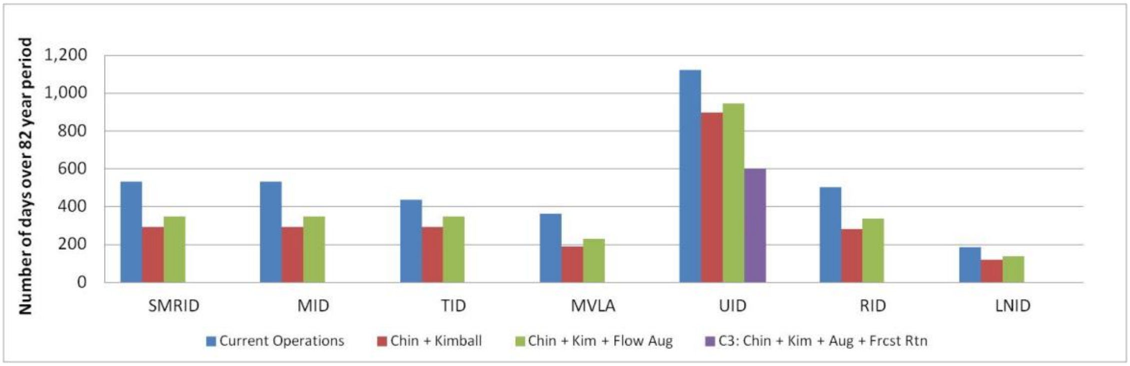

Figure 65: Total number of days in 82-year period with shortages by irrigation district

Lethbridge and Medicine Hat, as large municipalities modelled with appropriate licence priority, also saw substantial reductions in shortages as rationing reduced the burden on storage.

C3 positively affected the percentage of natural flow before the Oldman-Bow River confluence, the apportionment proxy (Figure 66). With current operations, 35% of the 82 years of record were below 50% of natural flow at the Oldman-Bow confluence, while for C3, the proportion was 29%. Combinations C1 and C2 had a negligible effect on this performance measure, each with a value of 34%.

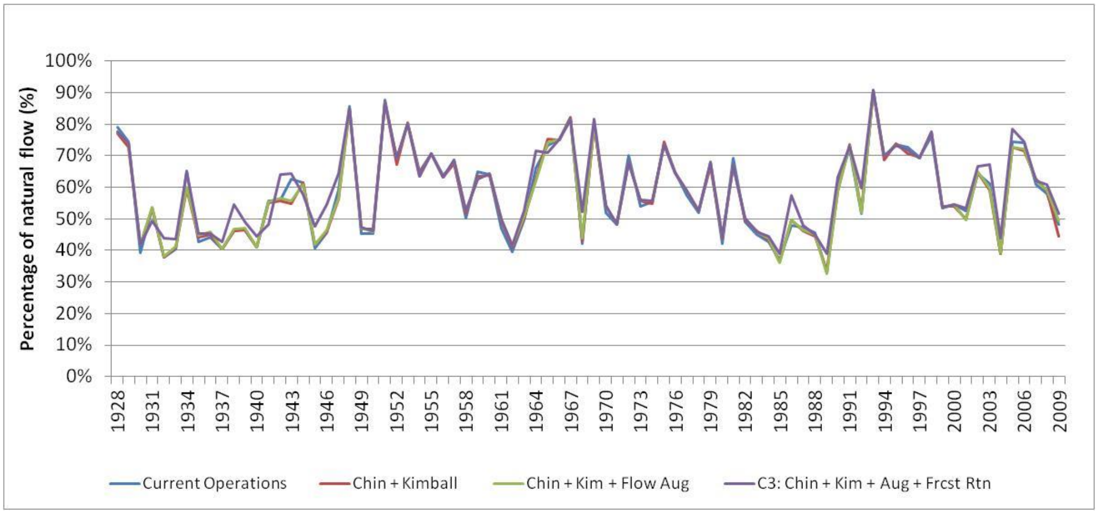

Figure 66: Percentage of natural flow before the Oldman-Bow River confluence

Relevant OSSK Model run names

CB6.9_Chin&Kimball&StMary&Ration
CB6.9_Chin&Kimball&StMary&Ration-2yrMin

5.1 Comparison of Combination Strategies

The three combination strategies can be compared for the seven plotted PMs. In most cases, the combinations improve performance compared to current operations, but it is important to remember that C3, which includes forecast-based rationing, is intended to address severe and extended droughts and that demands for water would be lower as a result of implementing this strategy.

PM 1: Annual Weekly Minimum Flows

Minimum weekly flows were generated for five locations in the OSSK basins: Oldman River at Lethbridge, Oldman River upstream of the Belly, Waterton River at mouth, Belly River at mouth, and South Saskatchewan River at Medicine Hat. As Figure 67 shows, C2 with low flow augmentation and without rationing was most affected by three specific drought years in the historical record (1936, 1944, and 2001). The charts for the four other flow locations similarly reflect flow reductions for C2 in those years.

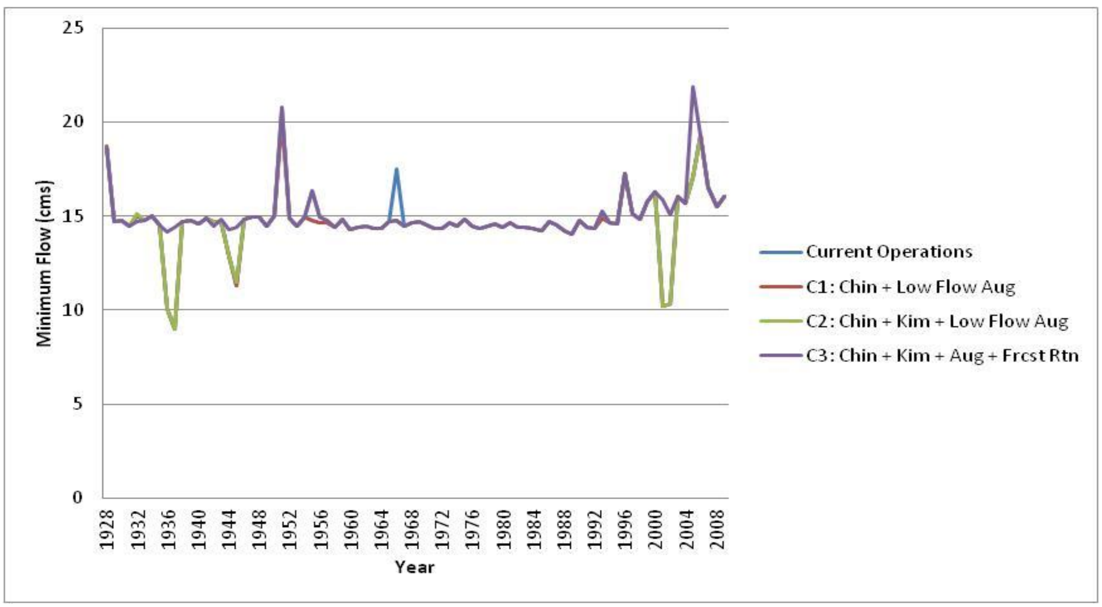

Figure 67: Minimum weekly flow - Oldman River at Lethbridge

PM 2: Minimum Flows for Fisheries

C3, and specifically the addition of forecast-based rationing, performed the best for meeting instream fish requirements in the Oldman River at Lethbridge (Figure 68).

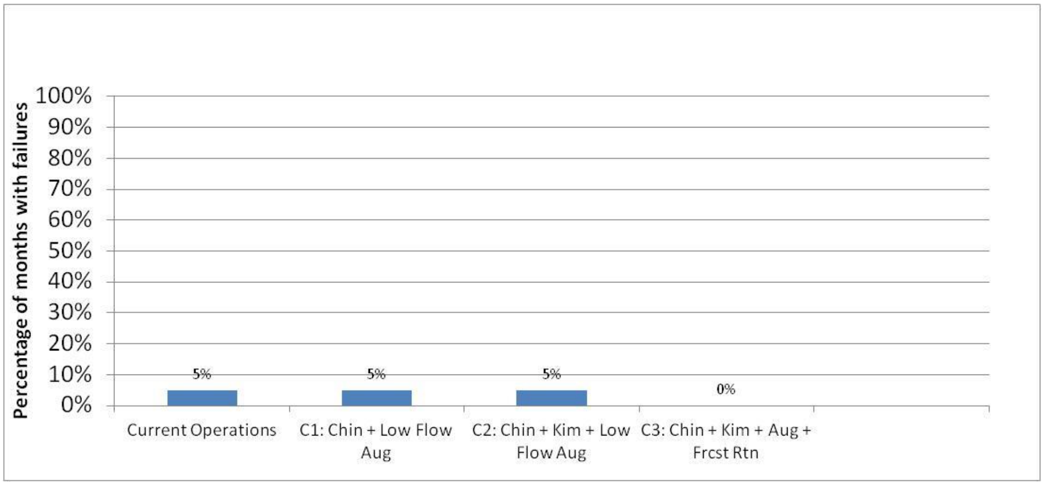

Figure 68: Percentage of months in 82-year period when instream fish requirements were not met in the Oldman River at Lethbridge

PM 3: Cottonwood Recruitment

Figure 69 compares how well the combination strategies did with respect to cottonwood recruitment for the Oldman River near Lethbridge during the 82-year record, and Figure 70 does the same for the mouth of the Waterton River. In both cases, the strategies have a relatively small impact on recruitment.

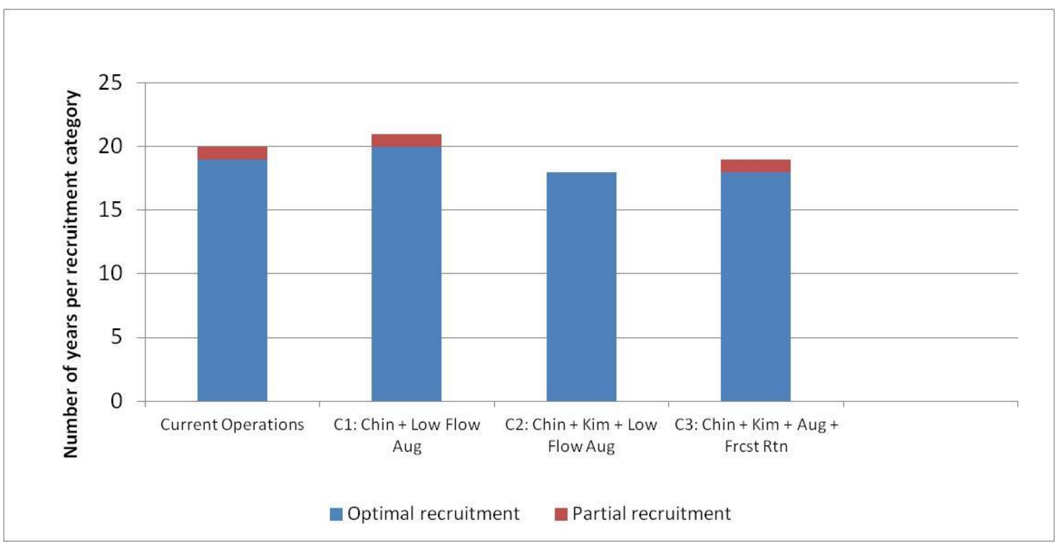

Figure 69: Years of cottonwood recruitment success for Oldman near Lethbridge in the 82-year period

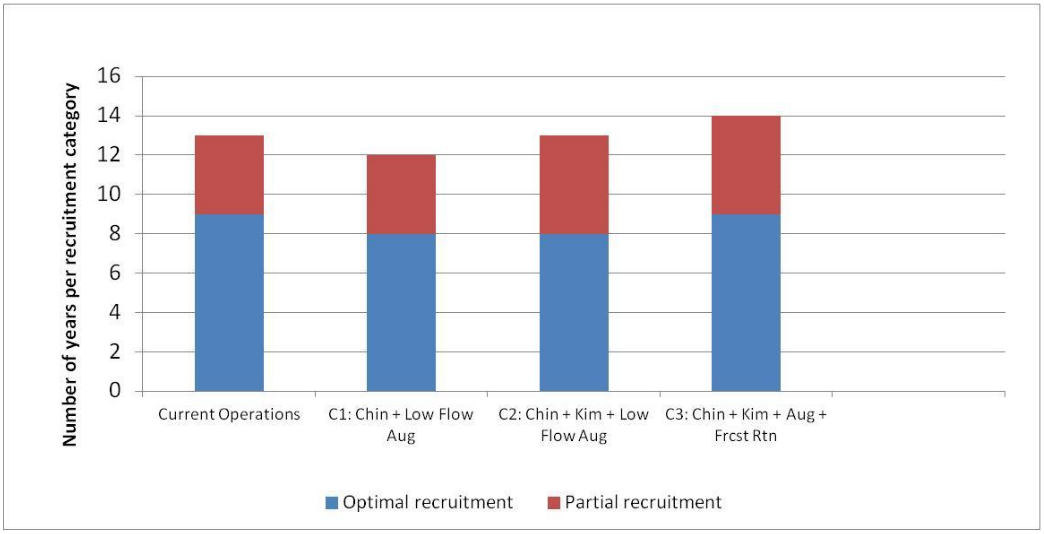

Figure 70: Years of cottonwood recruitment success for Waterton mouth in the 82-year period

PM 4: Fish Weighted Usable Area (WUA)

As Figure 71 shows, the combination strategies had no impact on downstream habitat for mountain whitefish, but the low-flow augmentation component in all three combinations improved downstream rainbow trout habitat availability.

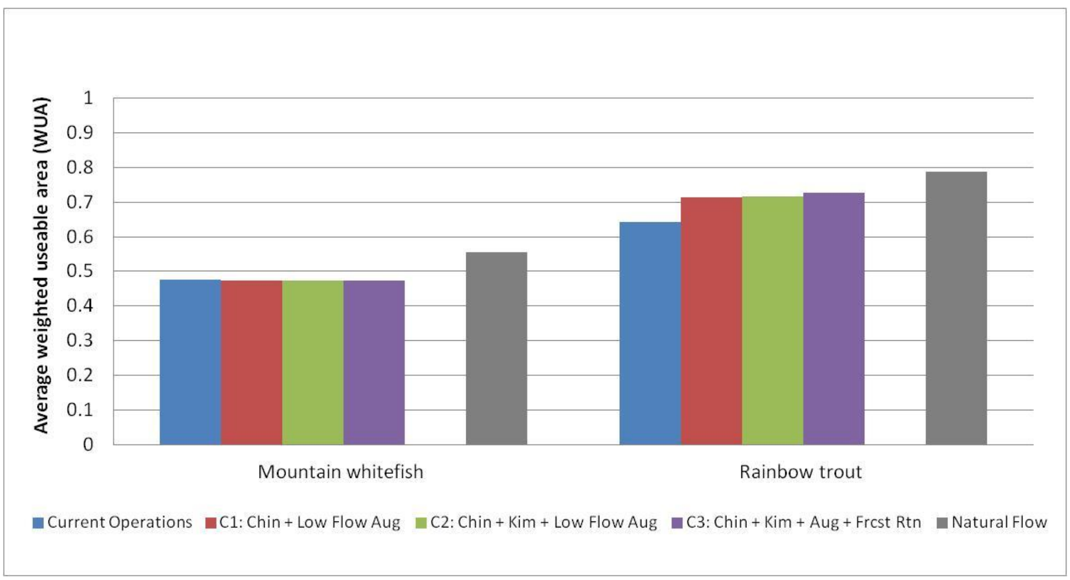

Figure 71: Average WUA for adult habitat for the 82-year period

PM 5: Cumulative Irrigation Shortage Days

Figure 72 and Figure 73 summarize the performance of the combinations in reducing irrigation shortage days, but C3 must be interpreted cautiously, as previously stated. Shortage days are dramatically reduced, but this is because demands are also reduced by instituting forecast-based rationing.

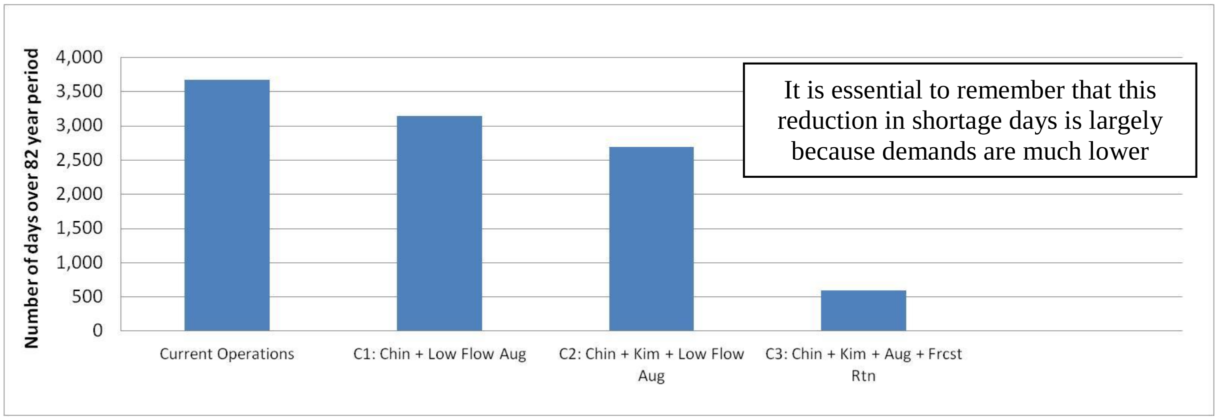

Figure 72: Total number of days in 82-year period with shortages across all irrigation districts

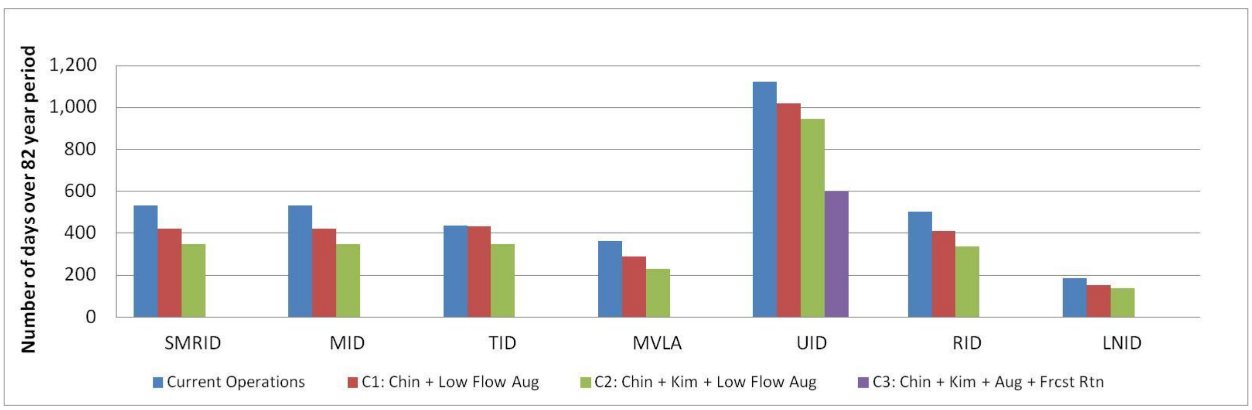

Figure 73: Total number of days in 82-year period with shortages by irrigation district

PM 6: Total Annual Outflow from Oldman River as Percent of Natural Flow (Apportionment Proxy)

There was very little difference in performance of the combination strategies for this indicator, as Figure 74 shows, although C3 did send additional flow downstream. With current operations, 35% of the 82 years of record were below 50% of natural flow at the Oldman-Bow confluence; the proportion was 34% for C1 and C2, and 29% for C3.

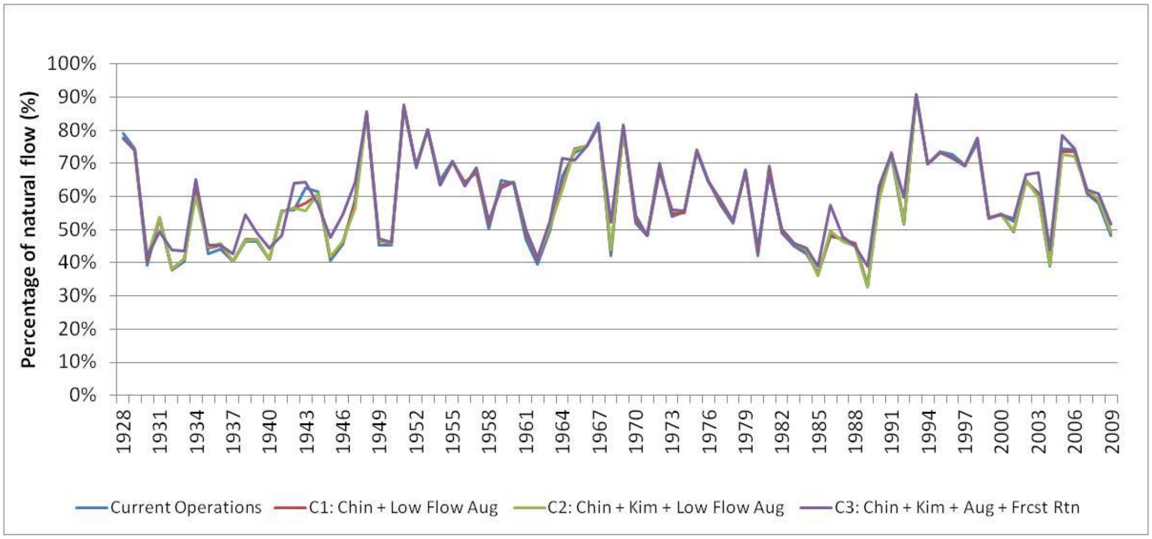

Figure 74: Percentage of natural flow before the Oldman-Bow River confluence

PM 7: Energy Generation

As Figure 75 indicates, the three combination strategies generally had similar effects on hydro power generation, causing a slight decrease during the 82 years of record. The exception was at Raymond, where C1 and C2 resulted in nearly negligible increases, while C3 caused a small decrease from current operations. Under the strategies presented, and according to conversations with stakeholders, hydro power production appears not to be a limiting factor in decision making.

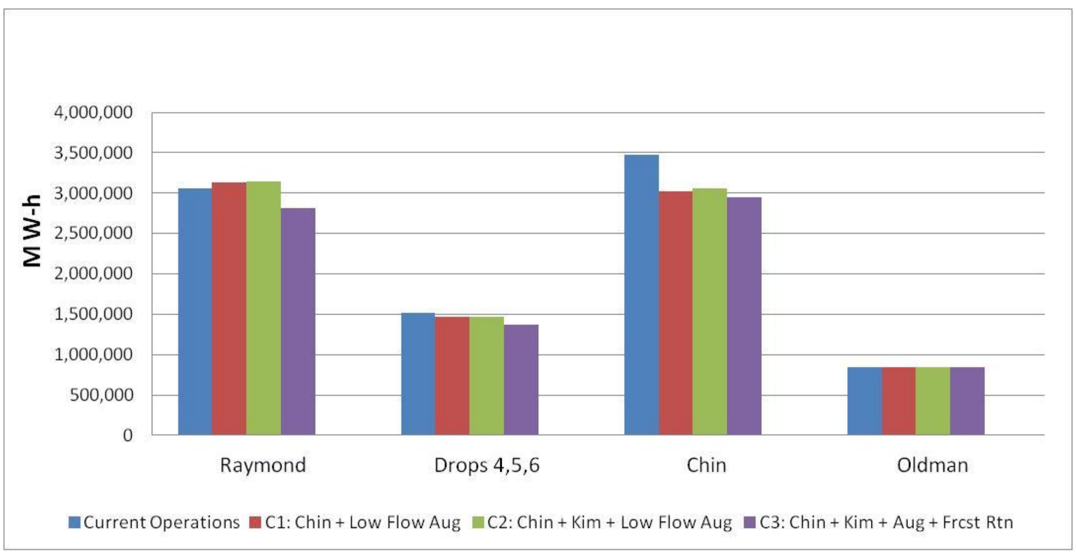

Figure 75: Total energy generation during the 82-year period

6 Next Steps

The findings from this project reflect important new ways of thinking about and planning for responses to climate variability and change in the OSSK basins. They are offered as starting points that can serve to stimulate enhancements and new approaches to water and watershed management. As data become available, additional risk management strategies can be assessed using the publicly available OSSK model.

This work recognizes and supports water management strategies that are already underway in the region, such as water conservation, efficiency and productivity plans developed under the *Water for Life* strategy and being implemented by Alberta's major water using sectors. Use of stored water for enhancing environmental health is becoming fairly common in some parts of the region thanks to the research and practice of providing functional flows for riparian health and for supporting fish populations. In the OSSK basins, irrigation and municipalities are the primary sectors involved with this work. The draft Irrigation Strategy and the draft South Saskatchewan Regional Plan are moving forward and will affect how water is used and managed in the region. The Oldman Watershed Council has also done a great deal of work in the basin and is especially engaged in headwaters protection.

Project results from climate variability scenarios and the history of drought in the region suggest it would be prudent to put in place and test procedures, agreements, and other tools that would be needed in the event of a prolonged drought. These include legal agreements, operational details, forecast-based triggers for action, and other processes for monitoring and managing a drought. The successful collaborative arrangements that emerged in the 2001 drought were generally agreed to be a good starting point but many participants suggested that had the 2000-2001 drought continued for one or more additional years the agreement would not have been practical as an effective response for the water users.

Results from this study were based on an integrated system model that enabled the use of stored water to provide benefits throughout the Oldman, Southern Tributaries and eastern St. Mary irrigated areas. It was the opportunity to balance reservoir use in an integrated manner that provided the environmental benefits as well as the municipal and irrigation supply from current and potentially increased storage reservoirs. The model results suggest that expanding offstream storage at Chin Reservoir and adding the entire storage of the expanded reservoir to the ESRD balancing system would offer a number of benefits to the basins. A business case for expanding Chin should be developed and the parameters defined and negotiated under which it could be added to the integrated reservoir balancing system.

The modelling also reinforced that management changes can create opportunities to meet environmental needs through means such as functional flows and low-flow augmentation. While dams would never be built exclusively for environmental needs, additional storage could enhance environmental health opportunities, and directing new storage in this way would help offset potential environmental damage if new structures are built for multiple objectives. These other objectives would include a modest increase in security of supply under adverse conditions of drought, potential benefits for junior licence holders by reducing the impact on irrigation districts from participating in water sharing agreements through rationing within their senior licences and, depending on the location, some possible flood mitigation for downstream infrastructure.

The OSSK region remains a desirable location for population and economic growth, both of which will place new demands on water supplies. The added value of expanded storage capacity in a few select locations should be further evaluated, in consideration of the substantial climate variability patterns seen in the historical and pre-historical past. In this study, those locations would be an expanded Chin Reservoir and an appropriately sized Kimball Reservoir in the event of a permanent reduction in supply should the US be in a position to take the full amount of water to which it is entitled in the St. Mary system.

It will be important to assess the risk tolerance for a prolonged drought and the willingness to pay to pre-empt such risks. Alberta will also need to continue to monitor the US interest in its entitlement flow under the IJC agreement and be ready to respond and protect the environmental and economic systems that depend on the current flow regime.

Given the experience in southern Alberta, most of the climate variability focus of this project was on drought. However, several major floods have occurred within living memory and the region must also be prepared for those events. Reservoirs in the OSSK basins can play only a limited role in flood mitigation, and strategies are needed to ensure that flood plain planning and development are done responsibly and that appropriate municipal flood protection measures are taken. Land and water management are closely connected and strong focused efforts are needed to better integrate them.

Project results will be shared with audiences that have an interest in the OSSK basins or in potentially designing a similar project for their region. Members of the project team are available to present this work to participant organizations and other forums as appropriate. All project participants and decision makers in the region are encouraged to seek further opportunities to examine, pursue, and test the ideas suggested in this report through their own jurisdictions, agencies, and networks.

Efforts will continue to raise awareness and share information with the public about water management and the trade-offs that sometimes need to be made in dynamic systems like the SSRB. Only by having a good basic understanding of the water management challenges and trade-offs can people be prepared to consider potentially more aggressive adaptation strategies when the need arises. The OSSK model will be freely available for use on the University of Lethbridge server for those with greater interest in exploring other objectives and alternatives for water management in the OSSK basins.

In the next several months the Red Deer, Bow, Oldman and South Saskatchewan river models will be integrated into a single model using the OASIS system. This tool will support discussions around integrated water management across the whole SSRB, not just by basin. It will be useful to consider apportionment implications under various historic and climate variability conditions as well as to integrate land use and land cover changes and how they may affect streamflow and water availability across southern Alberta.

The Bow River Operational Model is being applied to assess flood mitigation options throughout the Bow River System, including the Highwood River, Sheep River, Elbow River, and headwaters of the Bow River main stem. The purpose of that collaborative study is to evaluate the many options for future flood mitigation and to assess the combined effect on downstream infrastructure and people.

As part of the continued work in the SSRB, a land cover and land use model will be applied over the entire SSRB, including the Oldman and South Saskatchewan systems. This may provide additional insights into managing for drought and floods under the ever-changing conditions of weather and climate variability and for longer term extreme climate conditions.

Having identified some promising strategies for responding to climate variability and change in the OSSK basins, it would be prudent to undertake further study and analysis to look at these in more detail. More extensive assessment of the socio-economic and environmental costs and benefits of our findings was not part of the project mandate and is needed. This type of collaborative water management opportunity identification, assessment and analysis is fundamental to maintaining and building the resiliency of Alberta’s river systems and the communities that rely on them in the face of growing demands and uncertain climate.

Appendix A: SSRB Adaptation Project Introduction Memo

South Saskatchewan River Basin Adaptation to Climate Variability Project
May 2012

A new project being launched this spring will harness the energy and creativity of southern Albertans to explore practical options for adapting to climate variability and change. Water is fundamental to community sustainability and growth, and the way water is managed in the South Saskatchewan River Basin (SSRB) will become even more important in the face of changing weather patterns and climate.

In January 2012, the Climate Change Emissions Management Corporation awarded funding for the *SSRB Adaptation to Climate Variability Project*. The funds were provided to Alberta Innovates-Energy Environment Solutions and WaterSMART Solutions Ltd. to support the first stage of this adaptation work.

This initiative will build on and integrate existing data, tools, capacity and knowledge of water users and decision makers to improve understanding and explore how to manage for the range of potential impacts of climate variability throughout the SSRB's river systems. This understanding will support collaborative testing and development of practical and implementable adaptive responses to climate variability, from the local community scale to the provincial scale. Using existing analytical and decision-support tools, the project will engage many people and groups to build:

- a common understanding of feasible and practical mechanisms for adapting to climate variability and change, and
- increased capacity for an informed, collaborative and adaptive approach to water resource management throughout the SSRB. This will enable organizations, communities and individuals to assess their risks in near real-time and determine their most suitable responses to climate variability within the physical realities of SSRB river flows, requirements and infrastructure.

The first stage of the project is divided into four coordinated phase:

Foundational Blocks: Initial Assessment

The first phase of the work is an initial assessment of the data, tools, capabilities, processes and frameworks that already exist and could form elements of the foundational blocks to support integrated water management by water users, decision makers and other interested parties over the long term. This work will identify the core resources for the project, identify critical gaps to be addressed, and ensure existing knowledge, tools, and experiences are leveraged, while avoiding duplication of work already completed or underway.

Bow River Basin: Adaptation and Live Test Year

The second phase will re-engage Bow River Project participants and engage new participants with an interest in the Bow River Basin to: advance climate adaptation decision making related to water resources, explore climate variability scenarios, identify impacts and risks to the river system and its users, and identify adaptation options. Participants will also document the net benefits of re-managing flows in the Bow River and identify infrastructure options that could assist with adaptation strategies. All of this work will provide support for a 'virtual' river test year, or perhaps an actual test year of modified flow, to better match the three Water for Life goals

Oldman River Basin and South Saskatchewan River Modelling

In the third phase, participants will model the Oldman River Basin (Oldman River and Southern Tributaries, including the Belly, St. Mary and Waterton Rivers), and the South Saskatchewan River to the Alberta border. Users, decision makers and others in the Oldman and South Saskatchewan River (OSSK) Basins will form a river consortium and set principles to guide and inform the model-based work, incorporating an environmental and climate adaptation focus. A comprehensive river system model for the OSSK Basins will be developed. Inputs to the SSRB from the Milk River will be part of this data, but the Milk will not be explicitly modelled. Throughout the model building, participants will discuss work that has been or is being done, and possible next steps in building the capability and capacity for adaptation around river management in the SSRB.

Foundational Blocks: Development

The final phase will see development of new adaptation foundational blocks. This work will be based on the gaps identified in the initial assessment, which may include acquiring, updating, or purchasing useful data and tools for future work to develop adaptation options for integrated river management.

This project will take approximately two years to complete. It should significantly advance climate adaptation resilience in the SSRB, leave a legacy of data, information and tools, and inform similar future work throughout the rest of the SSRB. We hope, with subsequent support, to then expand the work to encourage climate adaptation throughout the entire SSRB.

Project updates and reports can be accessed through the Alberta WaterPortal at: www.albertawater.com

If you have any specific questions regarding this work, please contact AI-EES or WaterSMART Solutions Ltd.

Alberta Innovates - Energy and Environment Solutions
18th Floor, Phipps McKinnon Building | 10020 101A Avenue Edmonton, AB T5J 3G2 | P 780.638.3782 | F 780.643.1432

WaterSMART Solutions Ltd.
3608 - 33 Street N.W. Calgary, Alberta T2L 2A6 | P 403.210.5276 | F 403.210.5393

Appendix B: Project Participants

The table below lists individuals who participated in some or all of the OSSK Working Group meetings.

Organization	Representative(s)
Alberta Agriculture and Rural Development	Andrea Gonzalez Bob Riewe Jennifer Nitschelm Rod Bennett Roger Hohm Dale Miller (AMEC)
Alberta Environment and Sustainable Resource Development	Andrew Paul Brian Hills Craig Johnson Dave McGee Dennis Matis John Mahoney Terrence Lazarus Terry Clayton Werner Herrera
Alberta Innovates – Energy and Environment Solutions	Jon Sweetman
Alberta Irrigation Projects Association	Ron McMullin
City of Lethbridge	Doug Kaupp Maureen Gaehring
City of Medicine Hat	Grayson Mauch
Lethbridge Northern Irrigation District	Alan Harrold
Oldman Watershed Council	Bob Tarleck Cheryl Fujikawa Joan Tingley (ATCO Power) Kelly Scott (ATCO Power) Shannon Frank Shirley Pickering (Highwood Management Plan – Public Advisory Committee) Stefan Kienzle
Raymond Irrigation District	Gordon ZoBell
SEAWA – South East Alberta Watershed Alliance	Bob Phillips Maggie Romuld
SouthGrow	Pete Lovering
St. Mary River Irrigation District	Jan Tamminga
Taber Irrigation District	Chris Gallagher Kent Bullock
Town of Cardston	Jeff Shaw
Town Coaldale	Don Wentz
Town of Taber	Garth Bekkering
United Irrigation District	Fred Rice
University of Lethbridge	David Hill Stewart Rood
Village of Milo	Michael Monner

Organization	Representative(s)
Alberta WaterSMART	Lorne Taylor Megan Van Ham Mike Kelly Mike Nemeth Ryan MacDonald
HydroLogics Inc.	Daniel Sheer Dean Randall Megan Rivera A. Michael Sheer
Prairie Adaptation Research Collaborative	Dave Sauchyn Jeannine St. Jacques

Appendix C: Project Vision, Principles, Goals and Benefits

Vision Statement

In order to evaluate opportunities that exist to increase adaptive management capacity and integrated watershed response, the Oldman and South Saskatchewan River System (OSSK) will be modelled and managed as an integrated system, from headwaters and tributaries to the Alberta border, with due consideration given for the growth and change of the key users and purposes along its course as well as potential future impacts of climate variability. As part of the river management system, there will be open and readily available interactive, fit-for-purpose models. These models will be capable of providing information for decision-makers to assess implications of, respond to, and mitigate a wide array of user needs, water management objectives and climate variability forecasts.

Project Principles

- Causing no significant, measurable, incremental environmental harm
- Assuming the Oldman and South Saskatchewan sub-basins remains closed to new allocations
- Meeting Alberta's annual apportionment commitments to Saskatchewan
- Maintaining minimum flow requirements for municipalities
- Supporting the long term population, economic, and irrigation growth forecasts
- Meeting known First Nations' water needs
- Respecting Alberta's legal water priority system (FITFIR)
- Achieving Alberta's policy goals in Water for Life Strategy
- Aligning with South Saskatchewan Regional Plan development
- Not proposing that any one water user bear the costs of providing benefits to other users.
- Focusing on seeking solutions not historic causes
- All work and information related to the project will be made public

Project Goals

- Develop a common understanding of river flow and the respective timing and uses of water by license holders and other key water users, including essential environmental processes.
- Use available public data, verified by stakeholders throughout this technical research project.
- Use verified data sets applied to computer models to develop practical water demand and management scenarios to alter on-stream storage, flow rate timing, and water uses to determine an economically achievable river system management regime to accommodate the interests of the various water uses along each reach of its main stem and tributaries while protecting, and possibly enhancing, the aquatic ecosystem.
- Determine within reasonable ranges the costs and benefits to existing water users and/or to other users from different management scenarios.
- Evaluate regional implications for water supply and timing under historic conditions, given current and forecast future demand. Provide the capability to evaluate these conditions from forecast changes in climatological conditions.

- Based on the modeling results, assess water management alternatives and infrastructure changes to protect, and where possible enhance, the basic aquatic ecosystem while better accommodating the interests of the many water uses along each reach.
- This robust and agreed upon model can then be applied to climate variability and change scenarios using the model. If time and budget permit, the application of various climate scenarios will be begun under this round of funding. If budget or time constraints prevent that, the climate scenarios would be applied using the next round of funding.
- Communicate these scenarios and operating regimes effectively to local, regional, and provincial levels of government for their purposes.
- Prepare reports and other public communication vehicles and mechanisms (as needed).
- Conduct any additional modeling that may be needed and recommend the agreed upon adaptive management model to government. Revisions and improvements will be run on completed model as needed.

Expected Benefits

- Working collaboratively to identify and vet potential innovative solutions to the challenges facing our river basin
    - Improved management and mitigation options related to risk to high value and volume users from drought
    - Improved knowledge of risks and mitigation options, if any, from moderate flood events
    - Options to improve aquatic ecosystem protection in prioritized reaches
    - Options to improve access to senior priority water for human use
    - Improved economic development opportunities under sustainable conditions
    - Improved recreational opportunities in certain reaches
- Improved and shared data, knowledge, and management information
- A comprehensive river system model to assess possible impacts of climate variability on the river system and develop adaptation strategies.
- Preliminary adaptation strategies for the system to flexibly adapt to various climate variability scenarios
- Puts useful, credible new tools into the hands of decision-makers and advisors for the long run
- Common ground, common goals and credibility through public and community involvement from the beginning

Note: In addition to river operations and infrastructure, there is a broad set of socioeconomic, cultural and attitude issues related to water use and adapting to climate variability. The adaptation discussions and strategies developed in this project will endeavor to identify and consider as many related issues as possible, but may not have the time or scope to address them all thoroughly.

Appendix D: Developing Climate Scenarios for the OSSK Basins

A foundational concept in water resource engineering is the assumption of stationarity – that climate and hydrology fluctuate within a constant range of variability represented by instrumental records (Milly *et al*., 2008). Basing the allocation, distribution and storage of water on the analysis of instrumental records also assumes that these observations adequately represent the long-term trends and variability in climate and water variables. Reconstructions of the climate and hydrology of the past millennium reveal fluctuations at time scales (multi-decadal) that exceed the length of most instrumental records (Sauchyn *et al*., 2008, 2011). This scale of variability is important for our understanding of the stationarity of the regional climate regime, and for water resource planning and management for infrequent events, specifically extreme and sustained low water levels. There is mounting evidence of increased variability and more extreme hydroclimate in the warming atmosphere (*e.g*., Kharin *et al*., 2007; Durack *et al*., 2012). Only physically based climate models can provide credible projections of future hydroclimate.

The methodology applied to the Oldman River Basin accounts for this interannual to decadal variability. We model naturalized streamflow at the Oldman River near Lethbridge as a function of the ocean-atmosphere oscillations, *e.g*., the Pacific Decadal Oscillation (PDO) and El Niño-Southern Oscillation (SOI) (see St. Jacques *et al*., 2010, 2013) that drive the natural variability of the regional hydroclimatic regime. The generalized-least-squares (GLS) regression model is

$$\begin{aligned} Q = 550.74 - 0.22\, trend - 13.56\, PDO - 16.74\, SOI_{P1} \\ -14.61\, PDO_{P2} - 7.80\, SOI_{P2} + \varepsilon_t \end{aligned} \qquad (eqn\ 1)$$

where Q denotes mean daily flow over the water year, *trend* denotes a simple linear trend, the PDO and SOI indices are lagged: *P1* and *P2* denotes the climate index leading streamflow one year and two years respectively, and the error term ε_t follows an ARMA(2,1) residual model. The GLS model captures a large proportion of the variance in the naturalized streamflow of 1912-2009 ($R^2_{\text{innov}} = 0.60$, $R^2_{\text{reg}} = 0.50$). In this project, we drive the GLS models of annual streamflow using output from an ensemble of 50 runs generated by ten global climate models (GCMs) from the Phase 3 of the Coupled Model Intercomparison Project (CMIP3) which were chosen because they simulate the spectral and geographic characteristics of relevant teleconnection patterns (Furtado *et al*., 2011; Lapp *et al*., 2012) (Table 1). The projected PDO and SOI indices were variance scaled to correct for bias. Variance scaling was found to be among the better performing bias correction methods surveyed by Teutschbein and Seibert (2012)**.** Using data from these 50 runs from the ten GCMs and our GLS statistical model, we simulated annual flows for the Oldman River near Lethbridge over the period 1905 to 2096. Future climate is externally forced by rising greenhouse gases (GHG), according to three GHG emission scenarios: the A2 (high emissions), A1B (medium emissions), and B1 (low emissions) SRES scenarios. The simulations for all three of the SRES scenario are plotted in Figure 1, along with the gauge record and the all-model mean annual flow.

Table 1. List of the ten chosen coupled atmosphere-ocean models which archived the required fields, their details, and number of available 21st century runs per scenario.

#	IPCC4 Model ID	Country	Atmospheric resolution	Oceanic resolution	Number 21st century runs		
					B1	**A1B**	**A2**
1	**CGCM3.1(T47)**	Canada	3.7°x3.7° L31	1.84°x1.85° L29	3	3	3
2	**CGCM3.1(T63)**	Canada	2.8°x2.8° L31	1.4°x0.9° L29	1	1	0
3	**ECHAM5/MPI-OM**	Germany	1.875°x1.865° L31	1.5°x1.5° L40	2	2	1
4	**GDFL-CM2.1**	USA	2.5°x2.0° L24	1.0°x1.0° L50	1	1	1
5	**MIROC3.2(hires)**	Japan	1.125°x1.12° L56	0.28°x0.188° L47	1	1	0
6	**MIROC3.2(medres)**	Japan	2.8°x2.8° L20	(0.5-1.4°) x1.4° L43	1	1	1
7	**MRI-CGCM2.3.2**	Japan	2.8°x2.8° L31	(0.5-2.5°) x2.0° L23	5	5	5
8	**NCAR-CCSM3**	USA	1.4°x1.4° L26	(0.3-1.0°) x1.0° L40	1	0	1
9	**NCAR-PCM**	USA	2.8°x2.8° L18	(0.5-0.7°) x0.7° L32	2	2	2
10	**UKMO-HadCM3**	UK	3.75°x2.5° L15	1.25°x1.25° L20	1	1	1

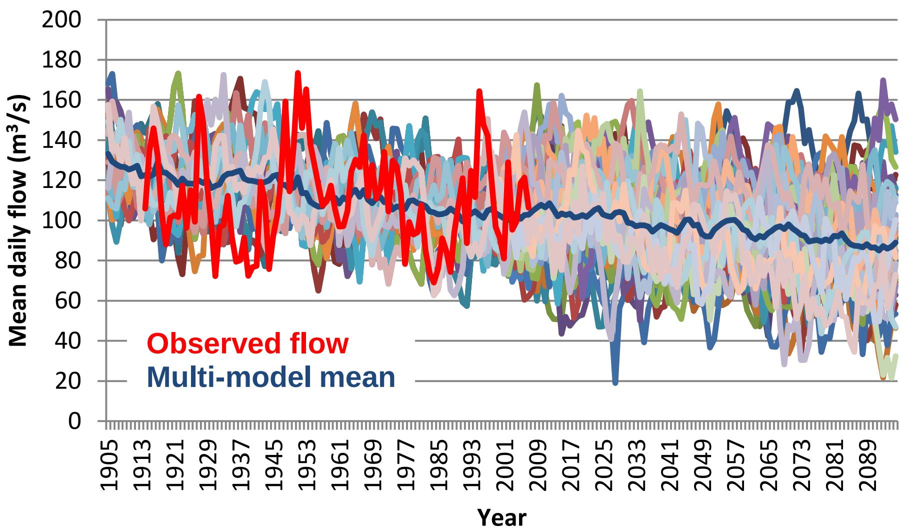

Figure 1: Simulated streamflow, for 1905-2096, for the naturalized Oldman River near Lethbridge. Each simulation corresponds to one of 50 runs of ten CMIP3 global climate models. The greenhouse gas forcing is according to the moderate A1B emission scenario. The observed gauge record (red) and all-model mean (dark blue) also are plotted. Daily mean flow smoothed by a 5-point binomial filter.

The projections are of slightly smoothed mean daily flow over the water year (October 1-September 30), using a 5-point binomial smoother. The high-frequency residual variance removed by the low-pass filter was characterized using the historical flows from 1912-2009. It followed a Gaussian distribution (μ = -0.02, σ = 16.74) which was randomly sampled in order to add back the missing high frequency variance. The outputs from the 50 simulations are re-sampled following Dettinger (2005, 2006) and St. Jacques *et al*. (2013), generating sufficient data for the construction of cumulative distribution functions (CDFs), from which the probability of exceeding critical values for hydrologic parameters can be determined. Re-sampling these complete simulated flows (*i.e.*, projected low frequency plus added randomly generated Gaussian noise) 20,000 times produced the probability distribution functions (PDFs) shown in Figure 2 and cumulative distribution functions CDFs shown in Figure 3 for the selected years 2006, 2050, and 2096. These plots clearly show a future shift to lower mean annual flows and a greater probability of extreme low flows. From here on, we concentrate our analysis on the period 2025-2054 because its relative immediacy is of concern for the stakeholders in the Oldman River watershed.

The GLS-based projection method of St. Jacques *et al.* (2013) produces projected annual mean daily flows whereas the South Saskatchewan River Basin - Adaptation to Climate Variability Project required projected daily flows. We followed the approach of Woodhouse and Lukas (2006a, 2006b) of mapping projected mean daily flows to the daily hydrographs from analogue years. Appropriate analogue years were chosen using the QPPQ transform (or quantile translation) approach (Hughes and Smakhtin, 1996). This processing of the projected and historical streamflow data to produce an ensemble of time series of projected (plausible) daily flows is illustrated in Figures 4 through 8. First, we derived the average CDF of projected flows for the 30-year period (2025-2054) (Figure 4) from the projected CDFs for the individual projected years as derived from the Dettinger resampling approach (*e.g.*, Figure 3). We also generated the empirical CDF in Figure 5 from the historical 1912-2009 mean daily flows of the naturalized Oldman River near Lethbridge.

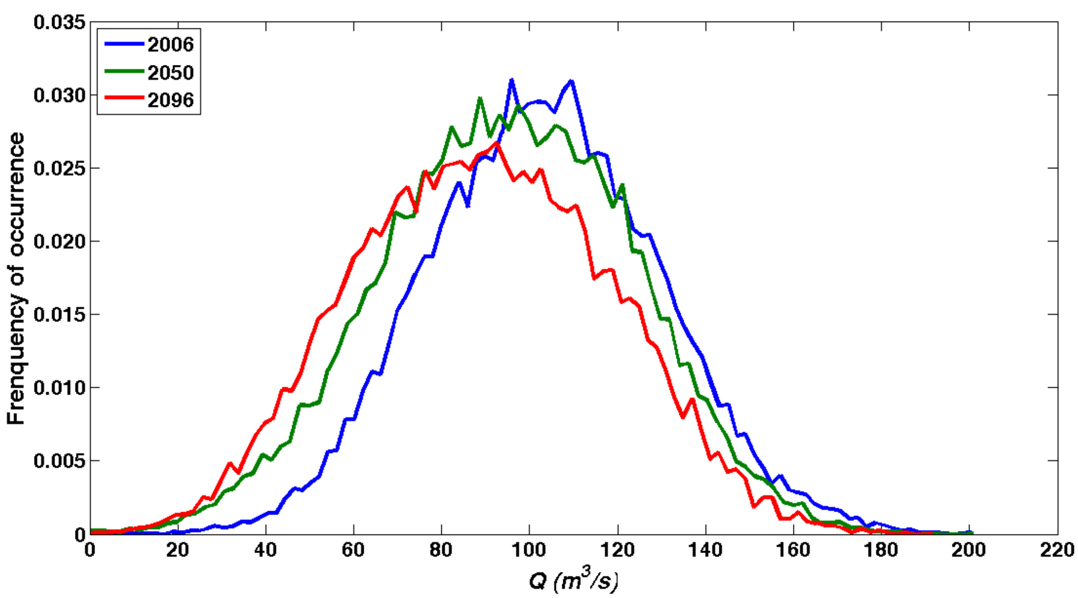

Figure 2: Probability distribution functions (PDFs) of mean daily flow for the naturalized Oldman River near Lethbridge for the selected years 2006, 2050 and 2096.

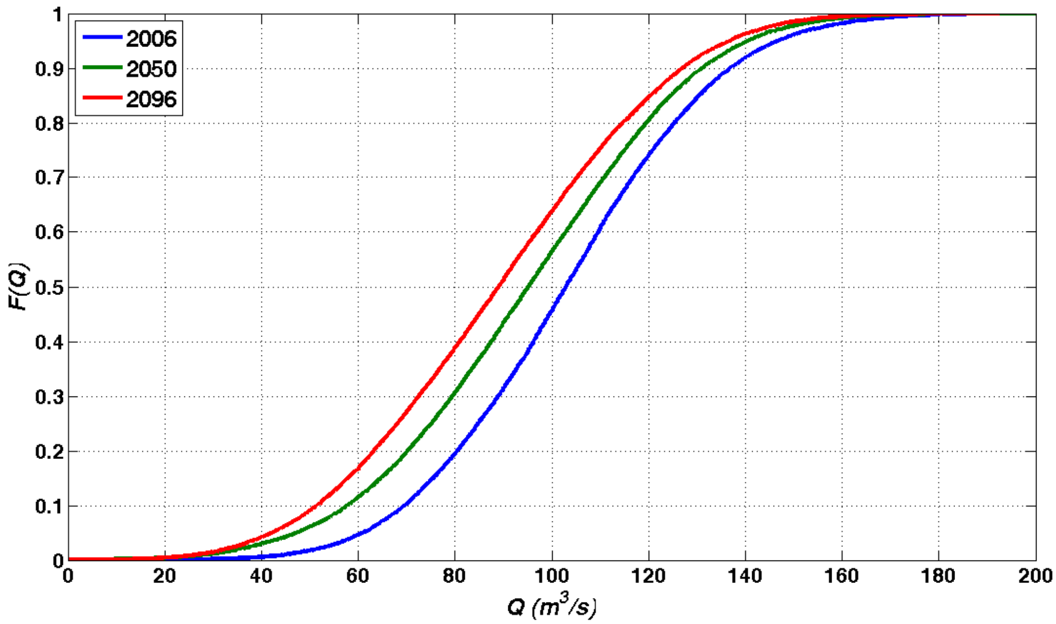

Figure 3: Empirical cumulative distribution functions (CDFs) of mean daily flow for the naturalized Oldman River near Lethbridge for the selected years 2006, 2050 and 2096.

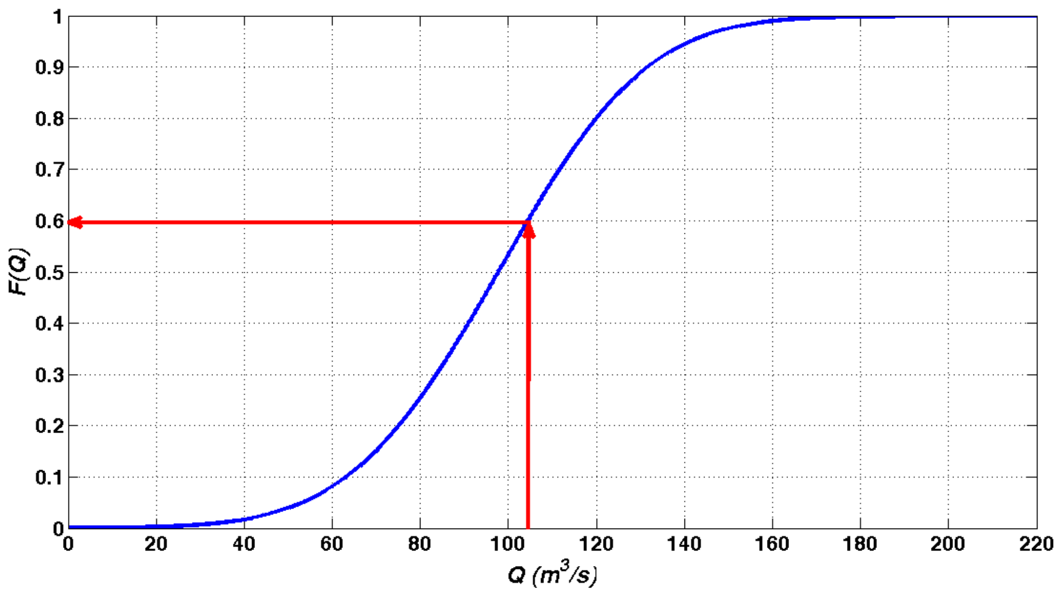

Figure 4: The CDF of projected mean daily flows of the naturalized Oldman River near Lethbridge for the period 2025-2054. The red arrows show that there is a probability of 0.60 that mean daily flow will not exceed 104.4 m^3/s.

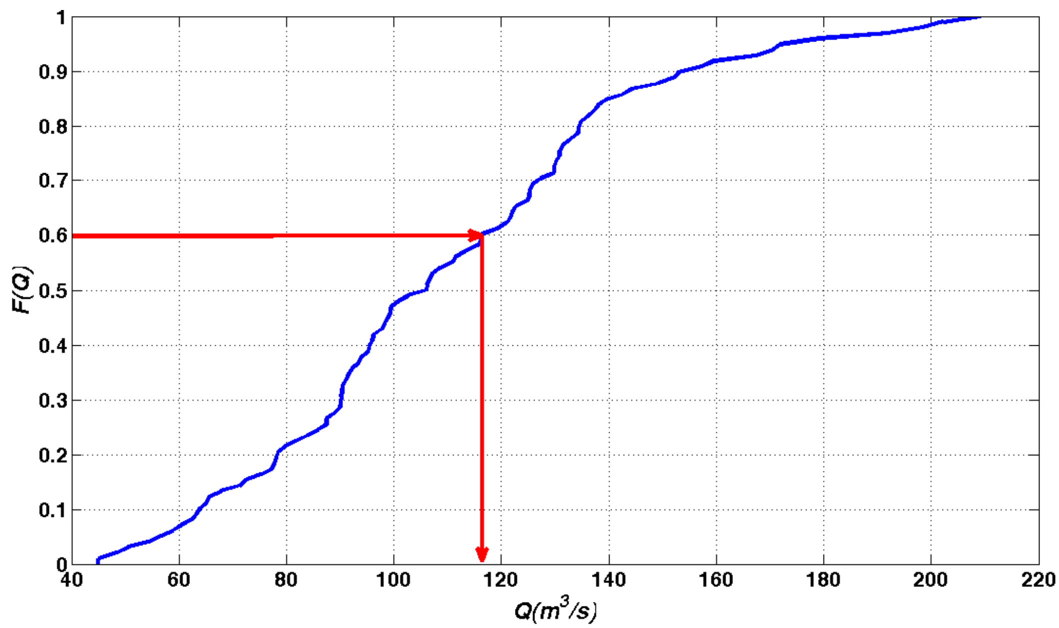

Figure 5: The empirical CDF of historical mean daily flows of the naturalized Oldman River near Lethbridge for the period 1912-2009. The red arrows show that there is a probability of 0.60 that mean daily flow does not exceed 116.4 m^3/s.

By matching flows of equal probably using a QPPQ transform, we identified a historical analogue for each run of a GCM and each future year, that is, 50 GCM runs x 30 years = 1500 model years. For example, from a run with climate data from GCM CGCM3.1(T47) run 3 (emission scenario A1B), our statistical model projected a mean annual flow of 104.4 m^3/s for the year 2026. According to the CDF for the period 2025-54, there is a probability = 0.60 that this flow will not be exceeded. The historical flow of equal probability was 116.4 m^3/s in 1913. Thus the hydrology of 1913 is the closest analogue to the hydrology projected for 2026 using climate data from GCM CGCM3.1(T47) run 3 forced by GHG emissions according to the A1B scenario (Figure 6). The daily flows for 1913 were then log-normal scaled by the projected mean and projected standard deviation to arrive at the projected daily flows for 2026 as illustrated in Figures 6-8. The strong quadratic relationship between mean and standard deviation of the historical daily flows (Figure 7) permits scaling of both parameters. The advantage of mapping to analogue years using the QPPQ transform lie in the way relatively high-flow projected years arising because of a projected negative PDO phase are mapped to corresponding high-flowing historical years arising from the negative PDO phase; and similarly mapping low-flow positive PDO phase projected years to low-flow positive PDO phase historical years. There is accumulating evidence that the annual hydrograph form varies between the two PDO phases (St. Jacques *et al.*, *in review*.).

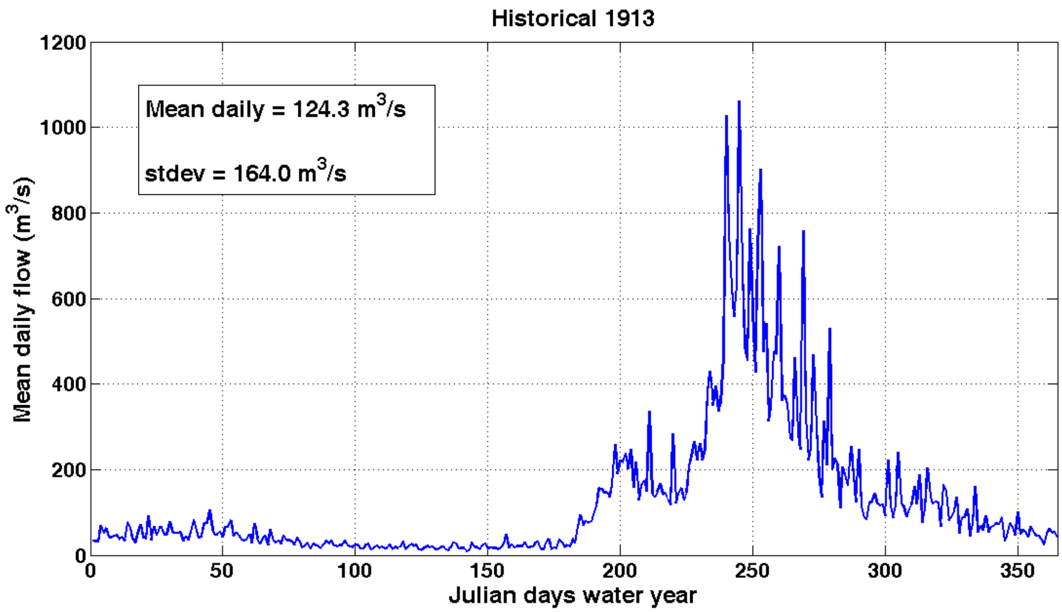

Figure 6: Historical mean daily flows for 1913 of the naturalized Oldman River near Lethbridge.

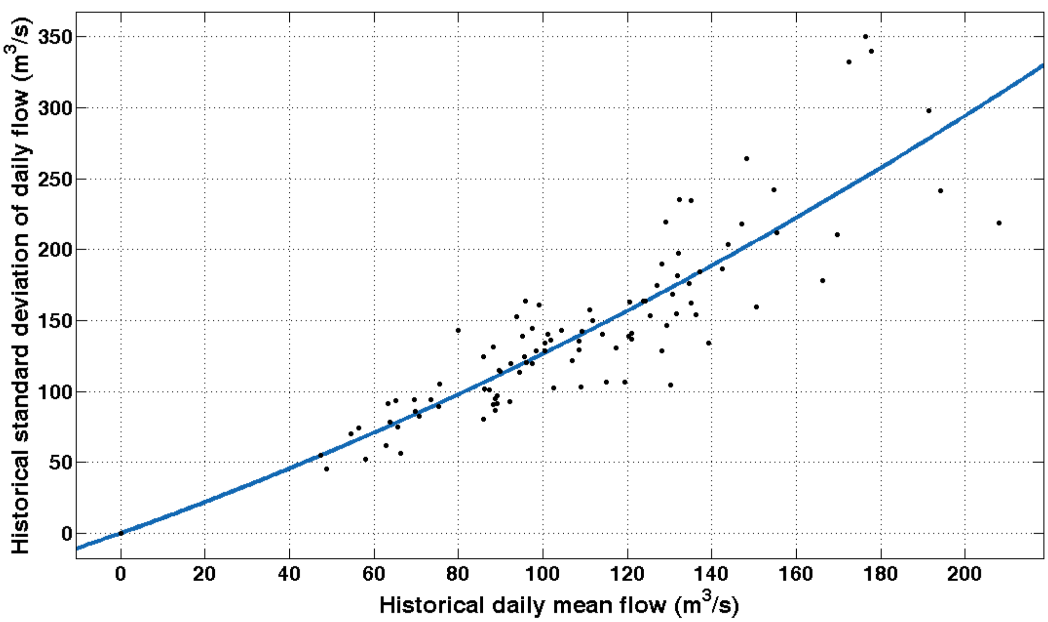

Figure 7: A scatterplot showing the strong quadratic relationship between the means and standard deviations of daily flow of the historical naturalized Oldman River near Lethbridge (1912-2009).

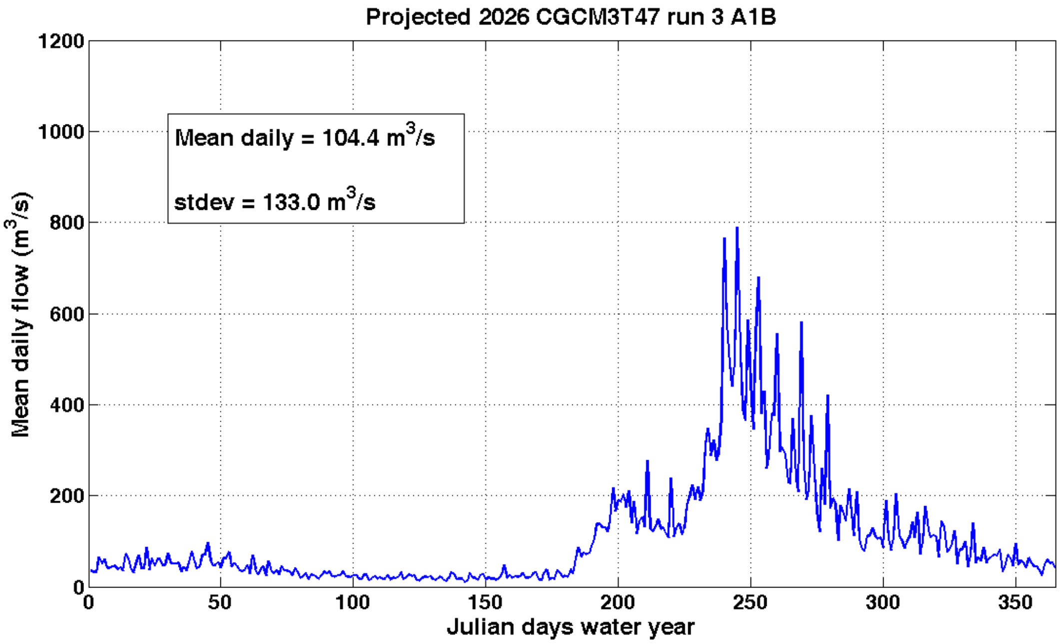

Figure 8: Projected mean daily flows for 2026 for the naturalized Oldman River near Lethbridge simulated using output from the GCM CGCM3T47 run 3, GHG emission scenario A1B. Scale same as in Figure 6.

It is projected that under global warming, spring will occur earlier in the year through-out western North America, including southern Alberta; in particular, snowmelt runoff timing will advance (Cayan *et al*., 2001; Stewart *et al*., 2005). This advance in peak flow has serious implications for reservoir and irrigation management during the growing season and particularly at the end of summer. Therefore, we included this in our model, following the approach of Stewart *et al*. (2004). A strongly significant linear relationship ($R^2 = 0.26$, $p = 5.0 \times 10^{-6}$) exists between the date of center of mass flow $CT = \Sigma\, t_i q_i / \Sigma q_i$, where t_i is the day of the water year and q_i is the daily discharge at Lethbridge, and Carway, Alberta total winter precipitation (October-May) and Carway spring temperature (April-July).

$$CT = 305.58 - 7.56\, spring\ temperature - 0.0007\, winter\ precipitation \qquad (eqn\ 2)$$

The changes in CT for 2025-2054 were projected for each GCM run by driving the regression model in eqn. 2 with the projected spring temperature and winter precipitation from the GCM grid cell that contained Carway. Because the GCMs are biased, the projected changes in CT cannot be used directly to shift the hydrograph. Using the corresponding 20th simulation run for each GCM and emissions scenario, we calculated the mean CT for 1966-1995. Then, for a given run and projected year, we calculated the projected advance to be the projected CT minus the mean CT for 1966-1995. We adjusted the projected daily hydrographs by the projected advances in spring runoff timing. The mean number of days the CT advanced was 8.6 days. For example, spring runoff is projected to advance 29 days in 2027 for the CGCM3T47 run 31 B1 emissions scenario (Figure 9). Our projected advances are comparable in magnitude to those found by Stewart *et al.* (2004) who included a few southern Alberta headwater gauges in their study.

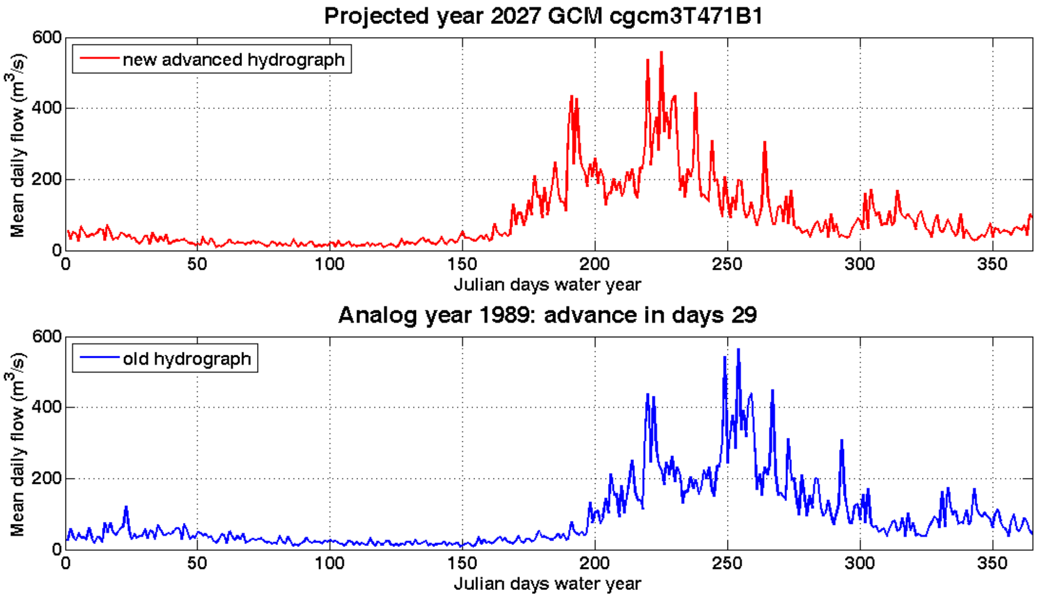

Figure 9: Projected 29 day advance in CT for 2027 for the CGCM3T47 run 1 under B1 emissions scenario.

Once projected data was in hand for each gauge, several methodologies were attempted to apply them to the Oldman and South SasKatchewan Basin Model (OSSK). The original intent was to apply each gauge's projections individually, but the misalignment of analogue years created a number of extremely high negative inflows on a daily basis. These negative inflows were well in excess of anything recorded in the historical naturalized record, so this approach had to be abandoned. Instead, to maintain consistent analogue years (and deal with time constraints) a single projected gauge was chosen to act as a "super-gauge."

We chose to use the natural flow at Lethbridge location for this purpose as it was maximally downstream whilst remaining unaffected by predictions in the Bow River. This gauge was then be disaggregated according to historical monthly patterns at each upstream location (e.g., Pincher Creek in January typically contributes 1.5% of the total natural flow at Lethbridge, so it's inflow in each January was calculated as 1.5% of the super-gauge projections for that day).

There is a major advantage to this empirical approach to deriving plausible future daily streamflows from climate model projections and a statistical model of the teleconnection between sea surface temperature anomalies (PDO and ENSO) and the hydrology of the Bow River Basin. Conventional approaches to developing scenarios of future water levels are based on the coupling of a dynamical hydrological model and "delta" scenarios of projected changes in mean climate (EBNFLO Environmental AquaResource Inc., 2010). This standard practice has the advantage of the dynamical simulation of the processes that generate runoff; but the disadvantage of requiring vast amounts of geophysical data to calibrate and validate the model, limiting the domain the model to a few decades (typically 1961-1990) in terms of range of variability and extremes. The variability that is projected, using this conventional approach, is inherited from the calibration period. Unfortunately, the highest observed variability in the Oldman River system occurred ~1930-1959 and not during the typical calibration period of

1961-1990. The scenarios that are produced generally are restricted to projections of changes in mean monthly or annual volumes or levels between past and future 30-year periods. However, watersheds and infrastructure are not managed for average conditions, but rather for extremes: flooding and especially drought. The method adopted here explicitly incorporates the climate forcing of the interannual to decadal variability of the hydrological regime over the entire instrumental record of 1912-2009. Our statistical models of streamflow at specific gauges are not calibrated to replicate a historical daily hydrograph but rather the dominant models of variability in the regional hydroclimate. By statistically linking this variability to the climate forcing, we are able to re-evaluate the teleconnection between climate and hydrology for future years using output form climate models that, in our assessment, have the capacity to simulate the internal variability of the climate system that emerges under greenhouse gas forcing. The limitation of this novel approach is that we do not attempt to model dynamically the watershed hydrology, and therefore we cannot simulate, for example, the mid-winter melting of snow over frozen ground in a warmer climate. This limitation is not problematic in these near-future projections where the objective is to determine the effect of changes in large-scale climate patterns on extreme water levels. Whereas the conventional (engineering) approach has advanced hydrology and simple climate, our novel (scientific) approach has advanced climatology and simple hydrology.

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Appendix E: Full List of OSSK Performance Measures

- Annual weekly minimum flows
- Annual daily minimum flows
- Fish survival flows
- Low flow stability from September to April
- Cottonwood recruitment
- Fish WUA
- Irrigation shortage days
- Irrigation shortage volume
- Irrigation shortage days before September 30
- Irrigation shortage volume before September 30
- Percentage of natural flow annually before the Bow-Oldman confluence
- Energy generation
- Fish Rule Curve violations
- Tier shortage days
- Tier shortage volume
- ESRD reservoir volume on August 31
- Bankfull flood exceedances
- Percentage of years when ESRD reservoirs reach Full Supply Level – 1 m by June 21
- Probability of refill by date for the Oldman, St. Mary, and Waterton reservoirs
- Total number of flood events for the Oldman at Lethbridge and S. Sask. at Medicine Hat
- Total number of daily low flow events for the Oldman at Lethbridge and S. Sask. at Medicine Hat
- Total number of weekly low flow events for the Oldman at Lethbridge and S. Sask. at Medicine Hat
- Annual average number of ESRD reservoir recreation days
- Annual average number of instream recreation days