

South Saskatchewan River Basin Adaptation to Climate Variability Project

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

April 24, 2014



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Contents

ACRONYMS AND ABBREVIATIONS.....	II
1 EXECUTIVE SUMMARY	1
2 INTRODUCTION.....	3
2.1 Context for Water Management in the OSSK Basins	4
2.2 The Need for Resilience and Adaptability	8
3 SSRB ADAPTATION PROJECT PHASE III PROCESS AND METHODOLOGY	10
3.1 The Collaborative Modelling Process	10
3.2 Phase III Process.....	11
3.3 The OSSK Model	11
3.4 Development of Climate Scenarios for the OSSK Basins	17
3.5 Performance Measures.....	19
4 PROJECT RESULTS AND FINDINGS.....	21
4.1 Strategies with Most Promise	23
Adding a Lower Belly Reservoir	24
Minimum flow augmentation below reservoirs	30
Adding a Kimball Reservoir	33
Chin Reservoir expanded and fully balanced.....	36
Forecast-based rationing	41
4.2 Strategies with Some Promise.....	47
Oldman Reservoir flood control operations	48
Chin Reservoir balanced	51
Chin Reservoir expanded, and expansion balanced	53
Drought-modified Fish Rule Curves	55
4.3 Strategies with Limited Promise	57
1 metre additional storage in existing St. Mary Reservoir	57
Chin Reservoir expanded without balancing.....	58
Downstream dry dam for flood control.....	60
Simple triggered shared shortages.....	62
Lower FSL in all ESRD reservoirs by 2 m when needed until July 1.....	65
Developing a storage reserve	66
4.4 Other Strategies	69
5 COMBINING STRATEGIES FOR ADAPTATION.....	76
C1. Chin Reservoir expanded + fully balanced + St. Mary augmentation.....	77
C2. Chin Reservoir expanded + fully balanced + Kimball Reservoir + St. Mary augmentation	79
C3. Chin Reservoir expanded + fully balanced + Kimball Reservoir + St. Mary augmentation + forecast-based rationing	81
5.1 Comparison of Combination Strategies.....	85
6 NEXT STEPS	90
APPENDIX A: SSRB ADAPTATION PROJECT INTRODUCTION MEMO	93
APPENDIX B: PROJECT PARTICIPANTS	95
APPENDIX C: PROJECT VISION, PRINCIPLES, GOALS AND BENEFITS	97
APPENDIX D: DEVELOPING CLIMATE SCENARIOS FOR THE OSSK BASINS	99
APPENDIX E: FULL LIST OF OSSK PERFORMANCE MEASURES	109

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 Milk⁴ 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.

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 2014-2024¹⁰ 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](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 Force¹⁵ 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.

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>

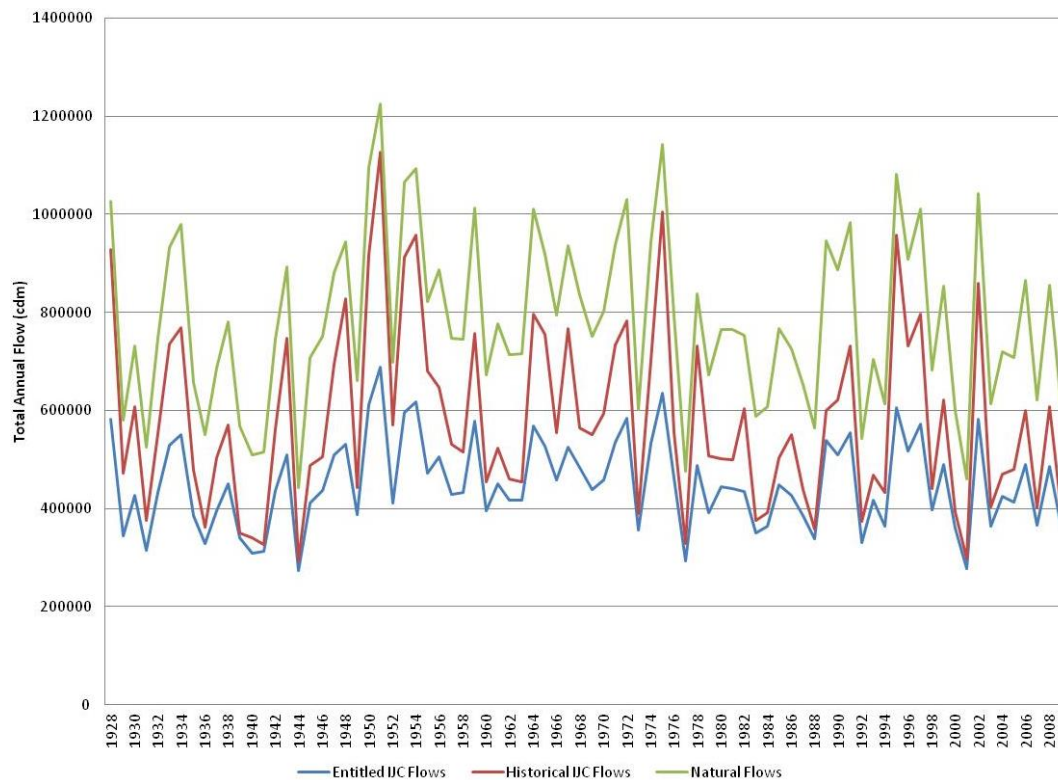


Figure 2: Total annual flow from the St. Mary River

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.

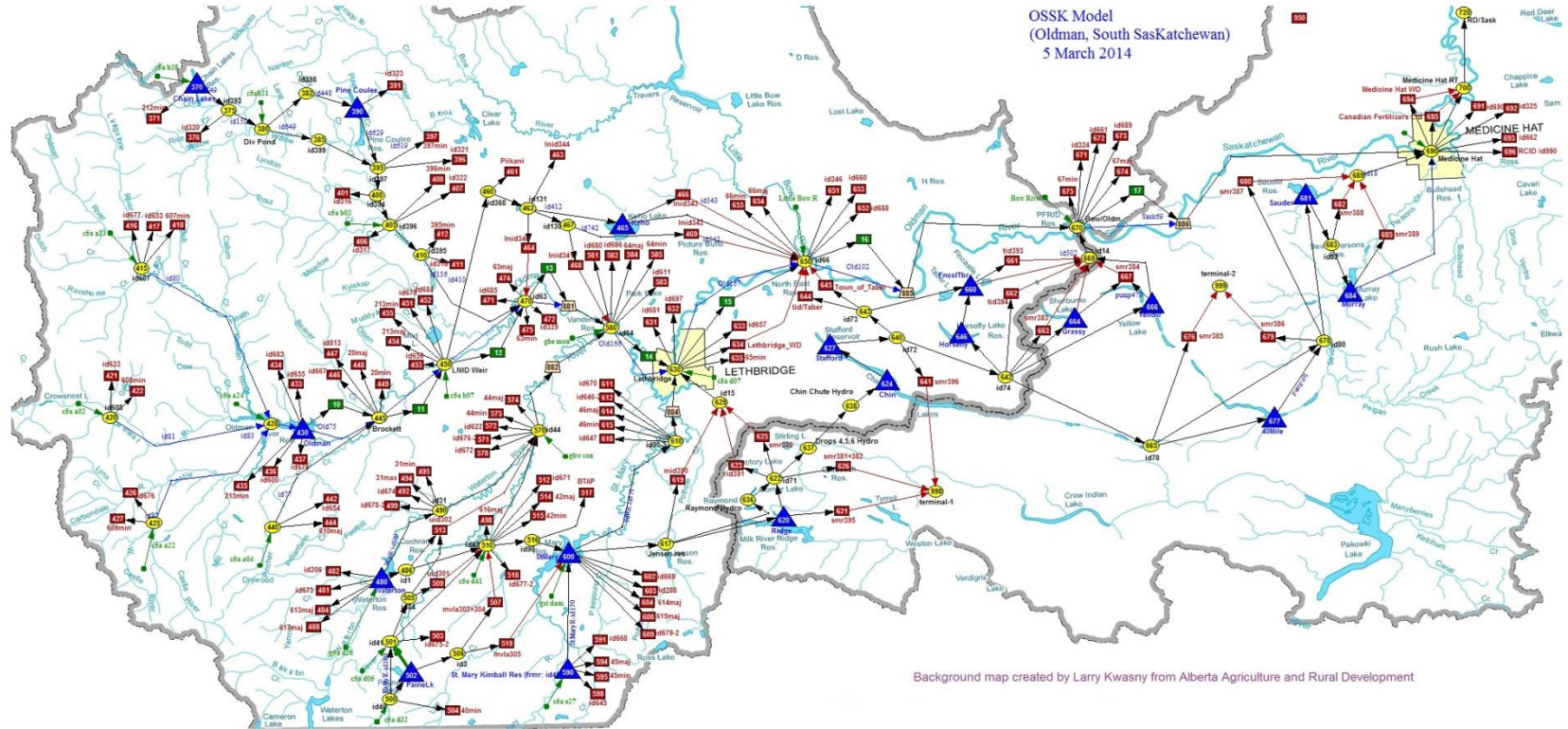
Throughout the project, participants worked collaboratively, providing advice and insight based on their extensive knowledge and experience. Project terms of reference were approved by the group, key components of which are included in Appendix C.

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.



Background map created by Larry Kwasny from Alberta Agriculture and Rural Development

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.

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.

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.

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

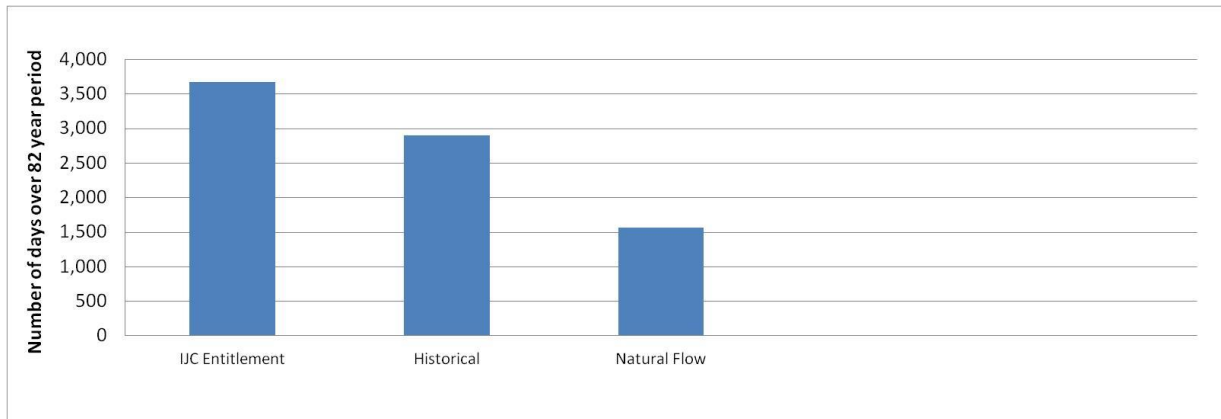


Figure 4: Total number of days in 82-year period with shortages across all irrigation districts

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.

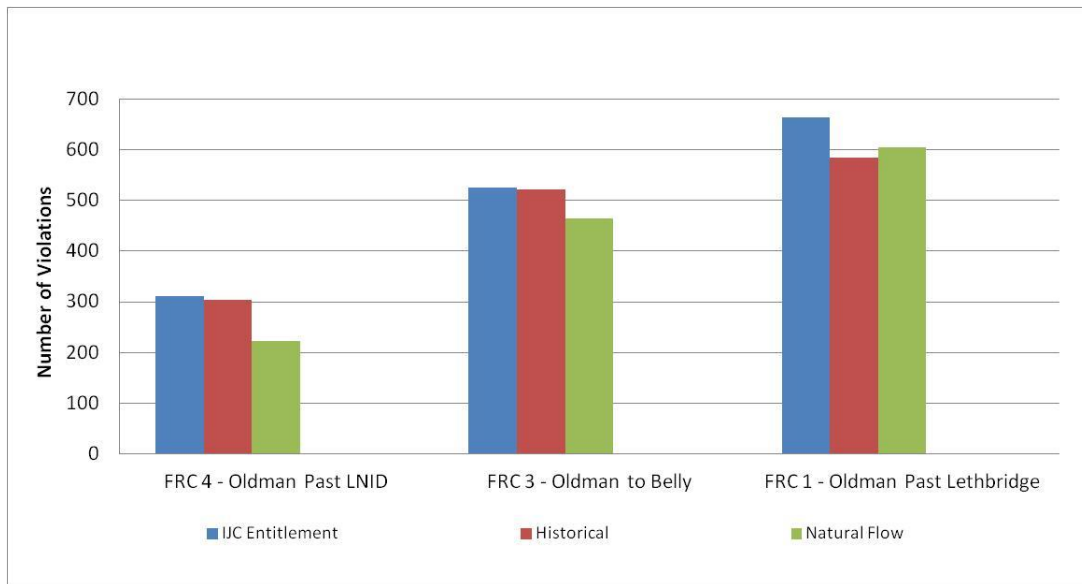


Figure 5: Number of times the minimum flow is below FRC requirements in the 82-year record

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 (10 th percentile)	CGCM3T47_3A2	1yr Min
Lowest 2yr consecutive minimum annual flow (10 th percentile)	CGCM3T6_3A1B	2yr Min
Lowest 3yr consecutive minimum annual flow (10 th 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 + Frct 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.

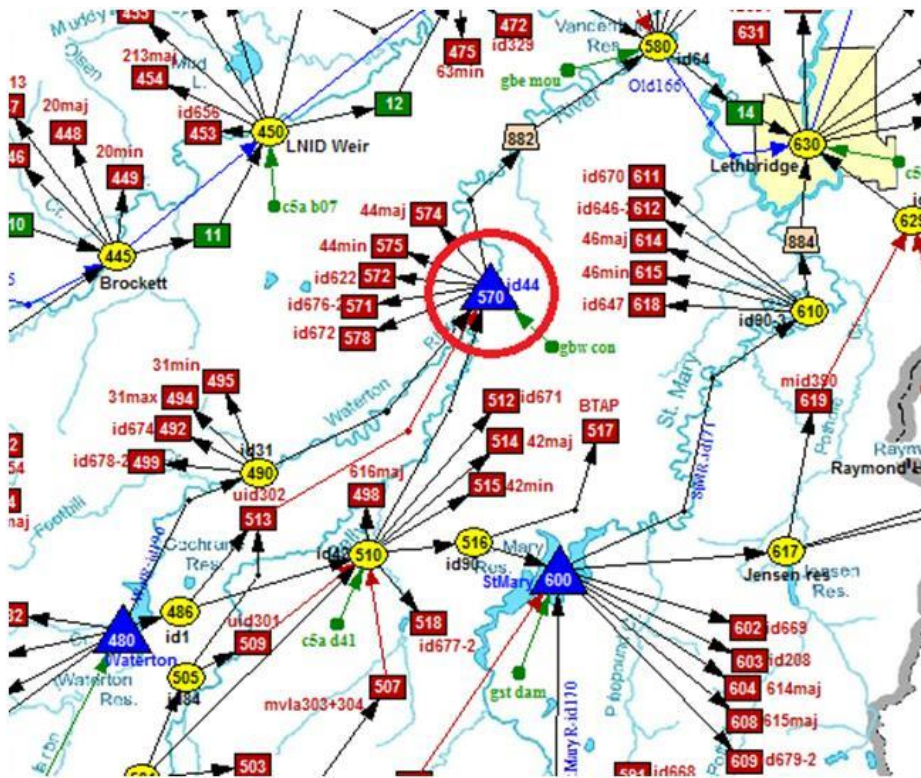


Figure 6: General location of the proposed Lower Belly Reservoir

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).

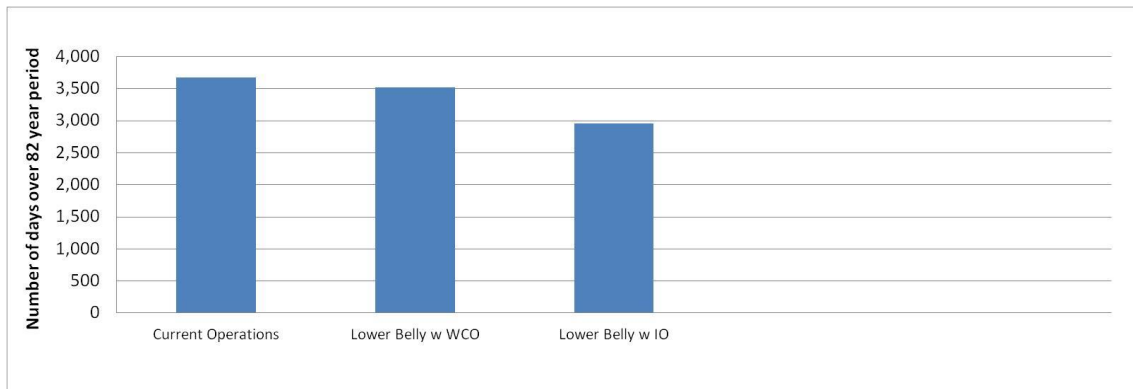


Figure 7: Total number of days in 82-year period with shortage across all irrigation districts

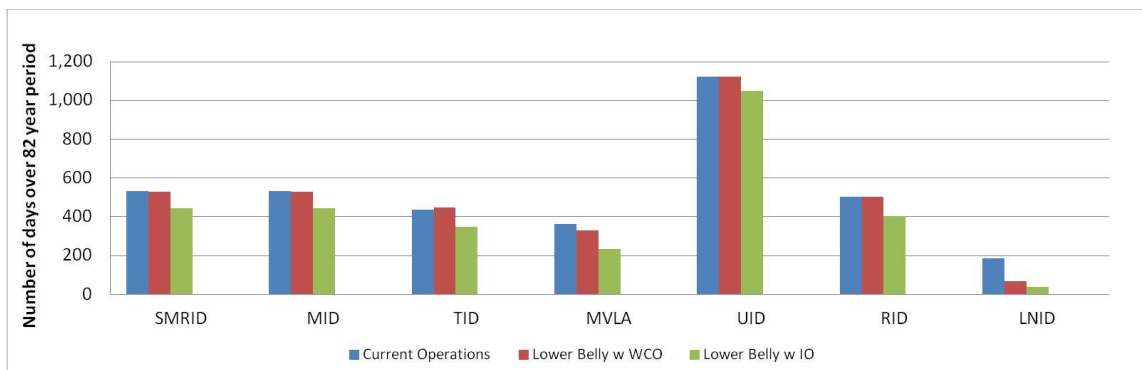


Figure 8: Total number of days in 82-year period with shortages by irrigation district

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.

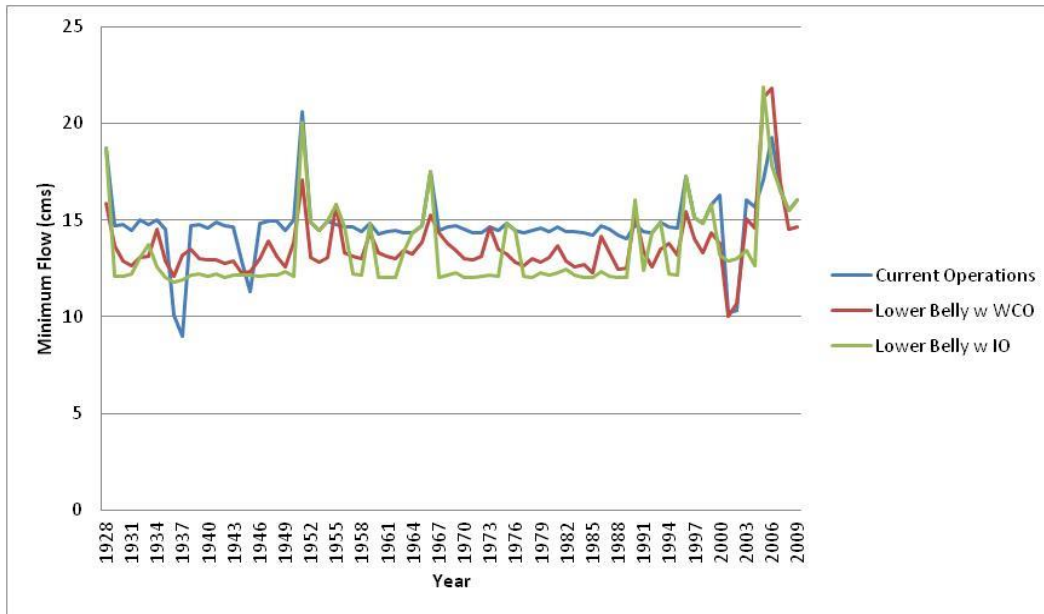


Figure 9: Minimum weekly flow, Oldman River at Lethbridge

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

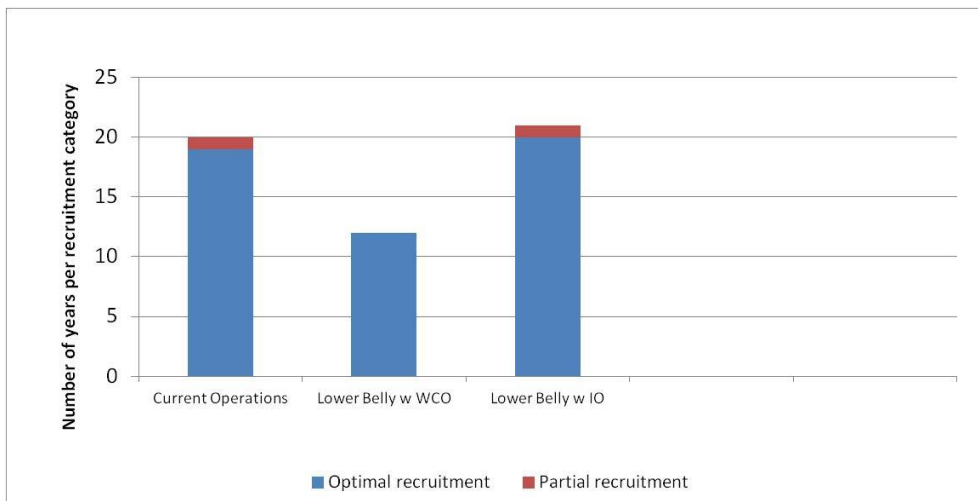


Figure 10: Years of cottonwood recruitment success for Oldman near Lethbridge during 82-year period

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).

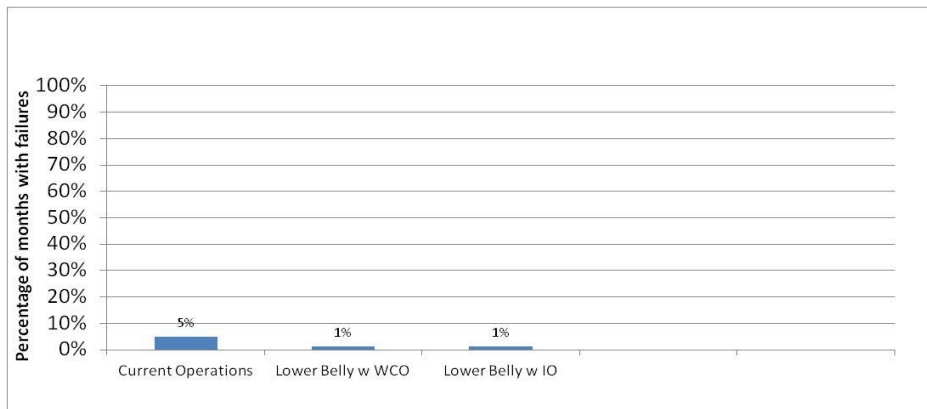


Figure 11: Percentage of months during 82-year period when instream fish requirements were not met in the Oldman River at Lethbridge

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.

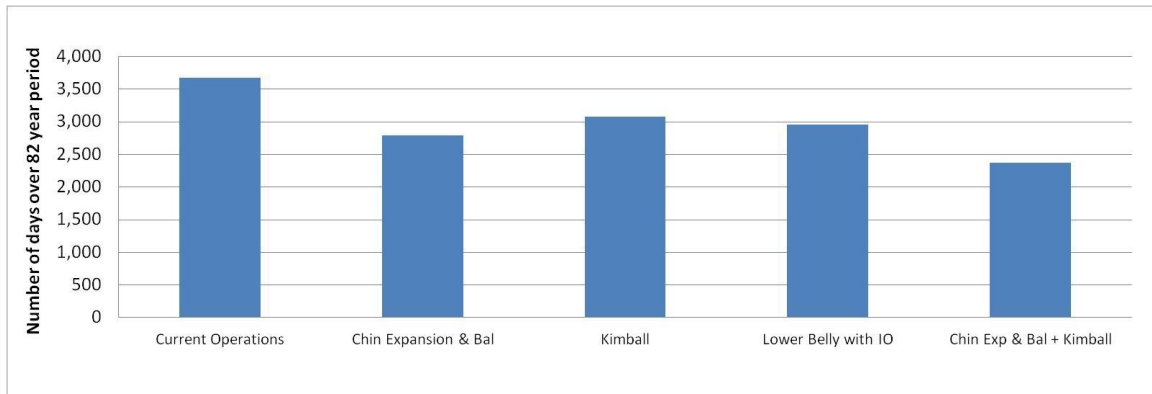


Figure 12: Total number of days in 82-year period with shortages across all irrigation districts

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.

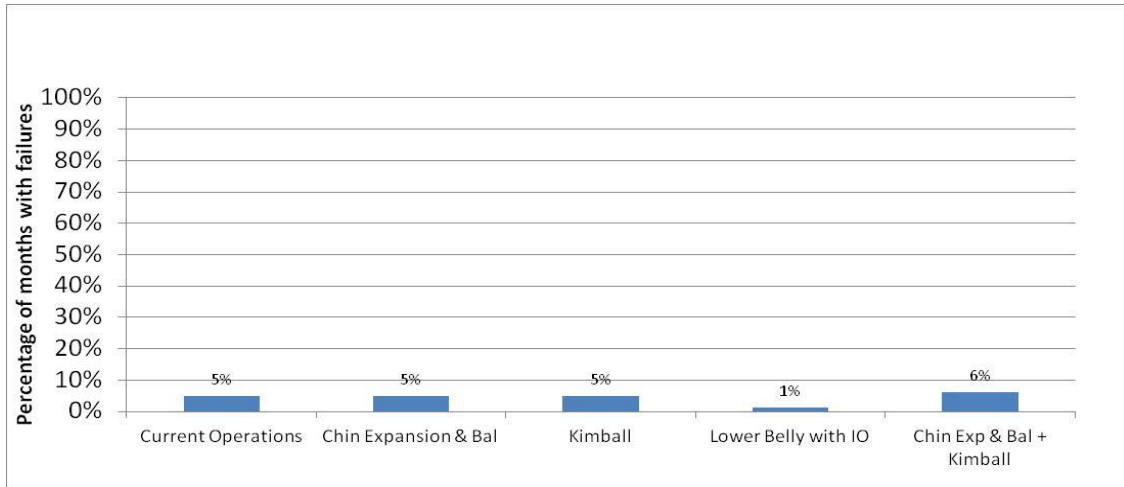


Figure 14: Percentage of months over 82-year period when instream fish requirements were not met in the Oldman River at Lethbridge

Relevant OSSF 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.

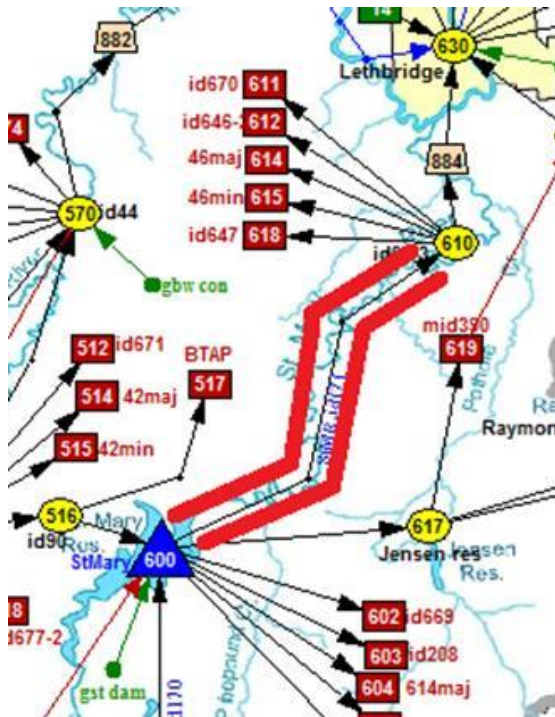


Figure 15: Location of flow augmentation on St. Mary River

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 than 1100 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).

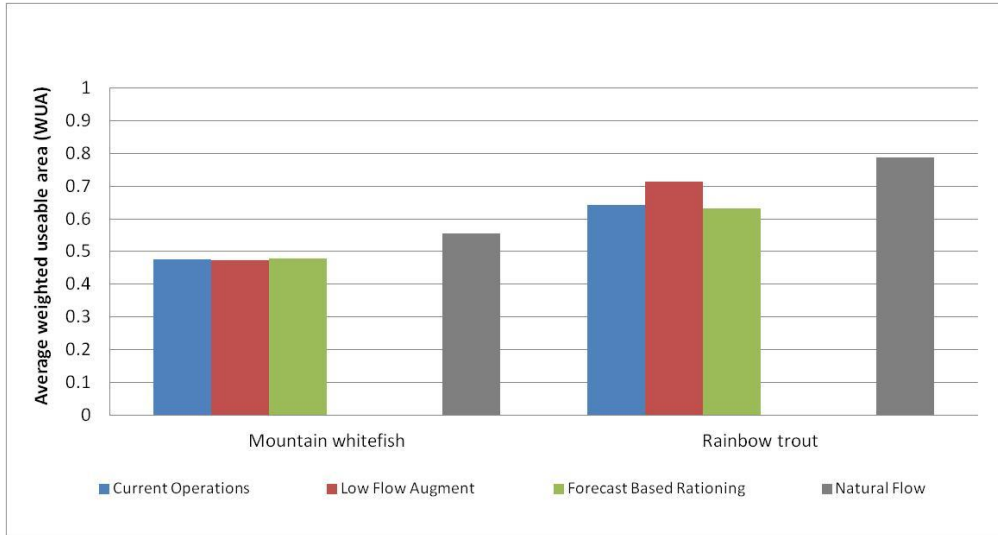


Figure 16: Average WUA of adult habitat for the 82-year period

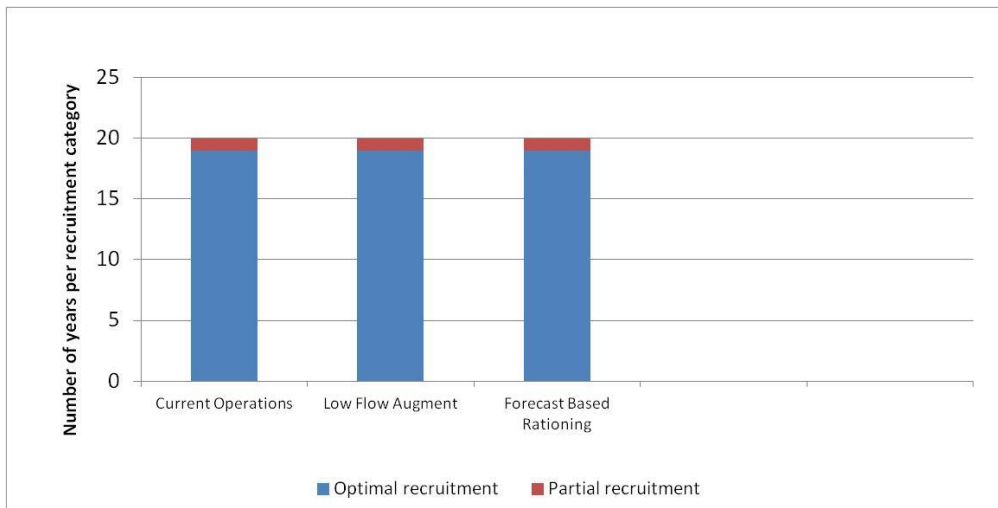


Figure 17: Years of cottonwood recruitment success for Oldman River near Lethbridge for the 82-year period

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).

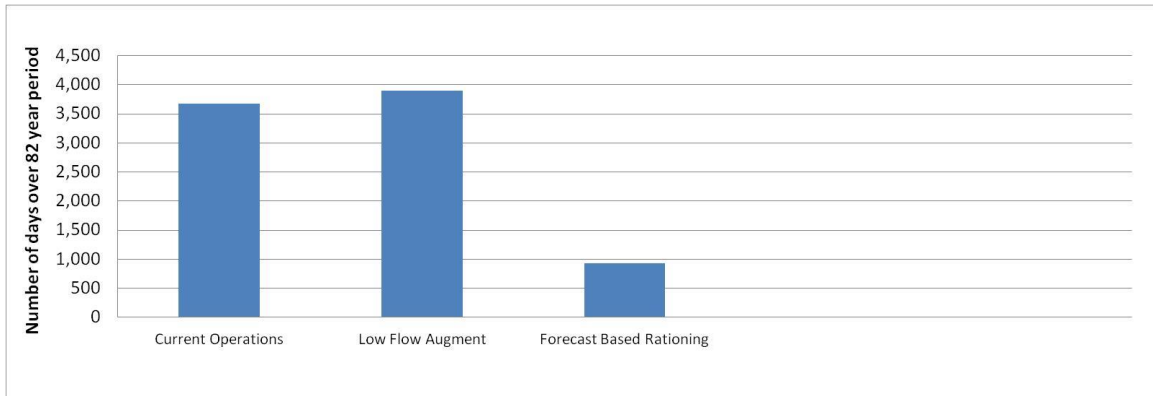


Figure 18: Total number of days in 82-year period with shortages across all irrigation districts

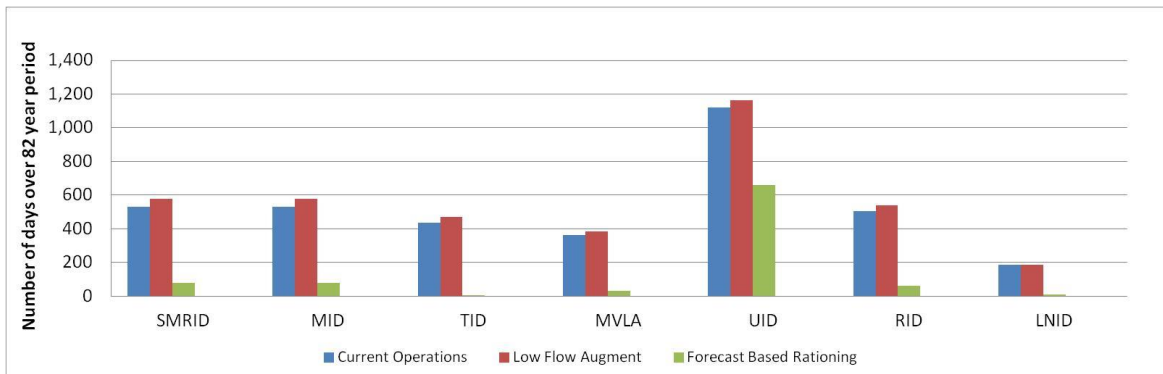


Figure 19: Total number of days in 82-year period with shortages by irrigation district

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.

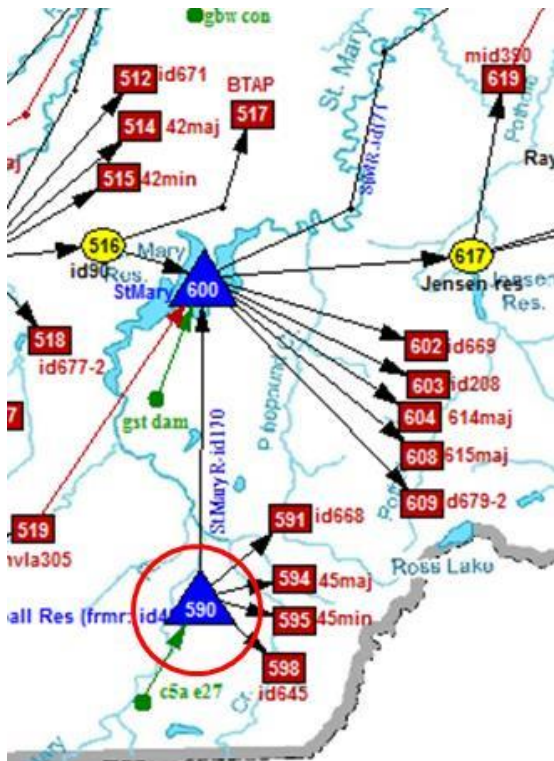


Figure 20: General location of a potential Kimball Reservoir

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.

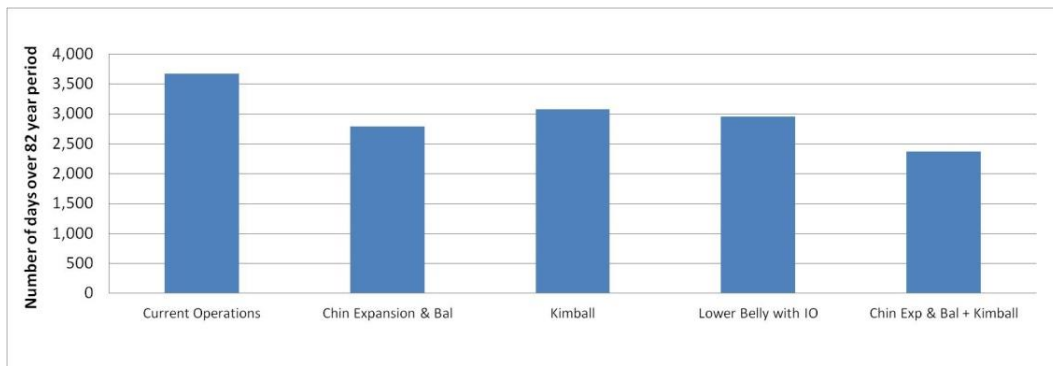


Figure 21: Total number of days in 82-year period with shortages across all irrigation districts

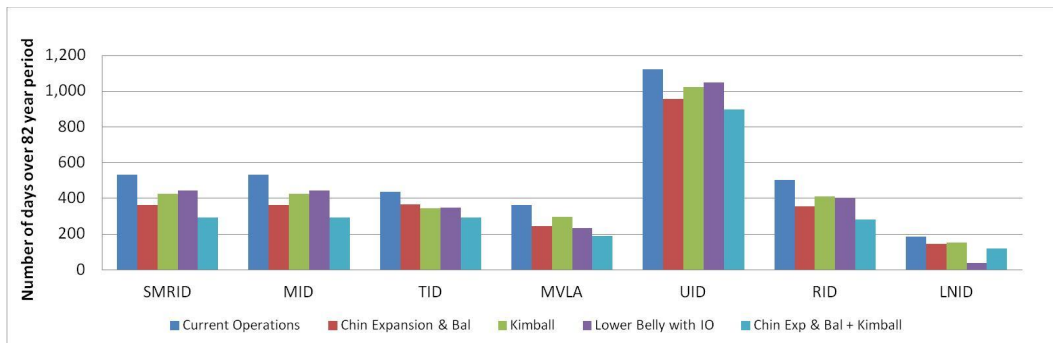


Figure 22: Total number of days in 82-year period with shortages by irrigation district

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

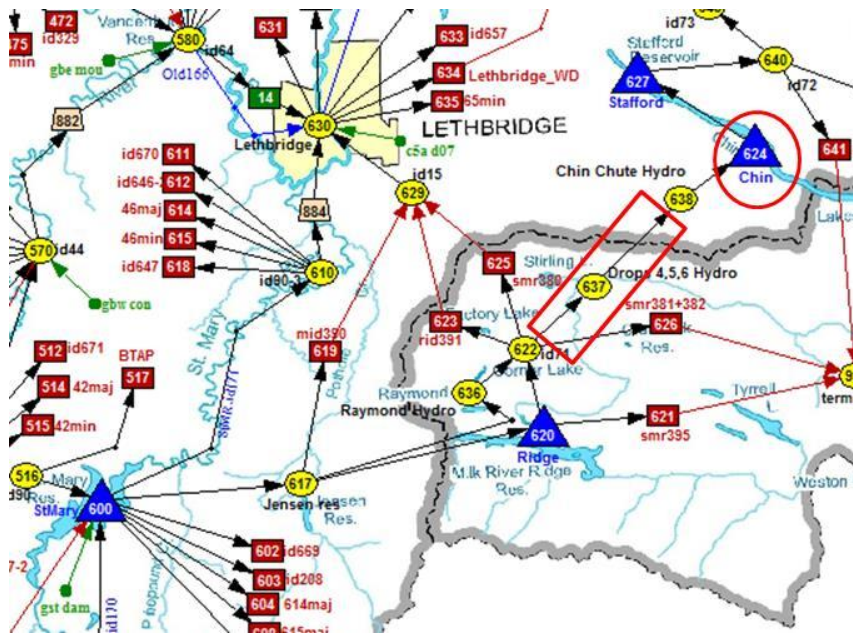


Figure 23: Location of Chin Reservoir

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:

- expanding Chin Reservoir storage by 74,000 cdm (60,000 AF) to reduce the risk of downstream municipal and irrigation shortages, and
- 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.

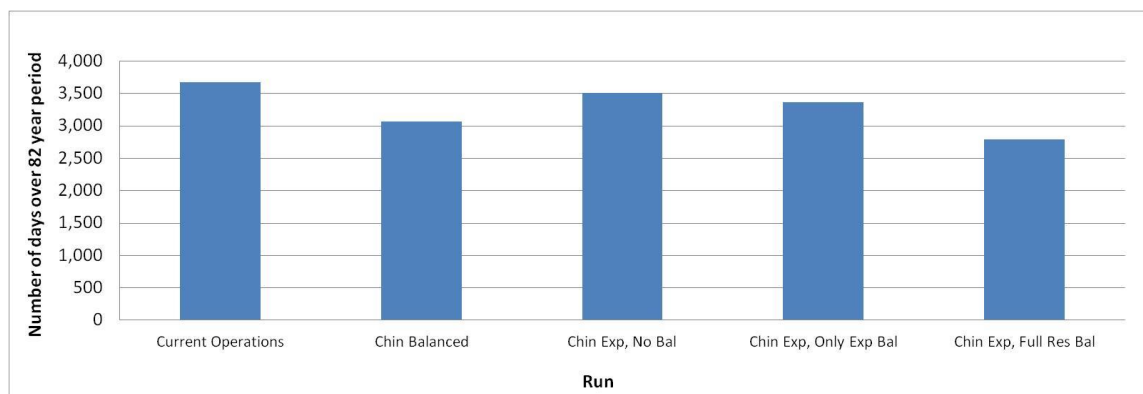


Figure 24: Total number of days in 82-year period with shortages across all irrigation districts

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.

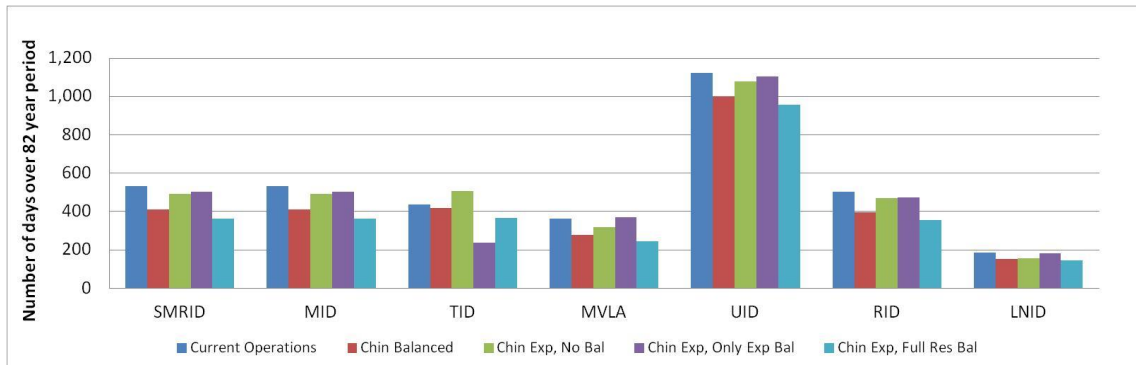


Figure 25: Total number of days in 82-year period with shortages by irrigation district

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.

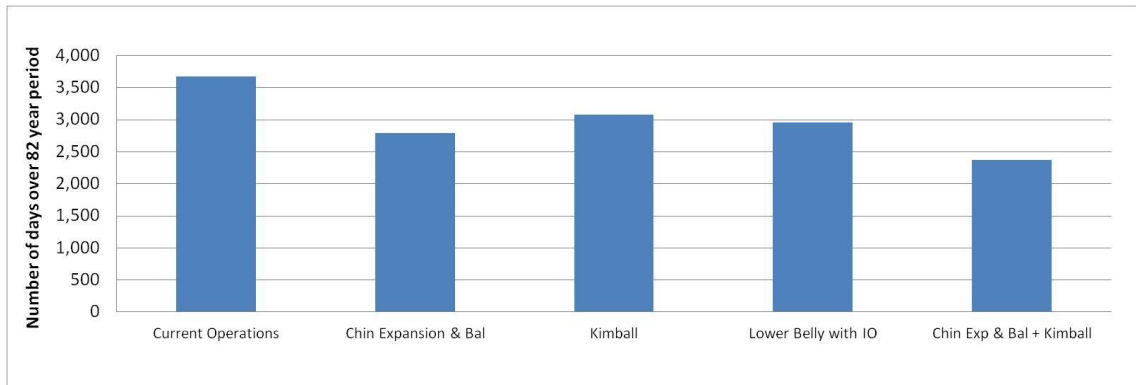


Figure 26: Total number of days in 82-year period with shortages across all irrigation districts

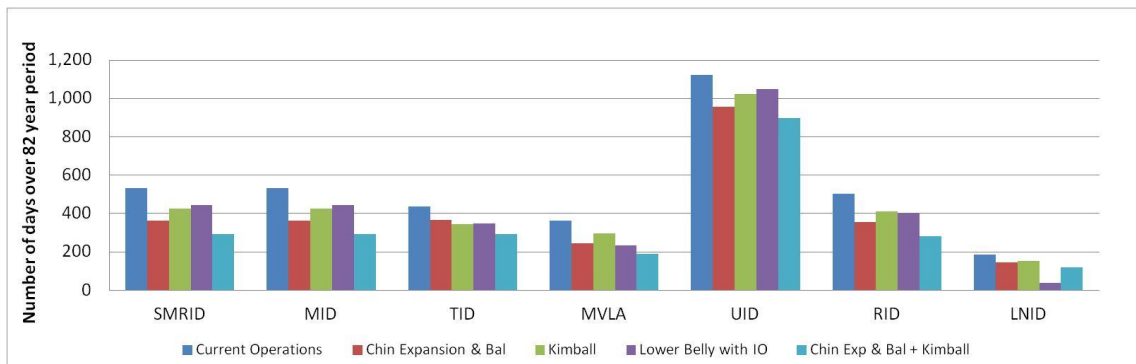


Figure 27: Total number of days in 82-year period with shortages by irrigation district

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.

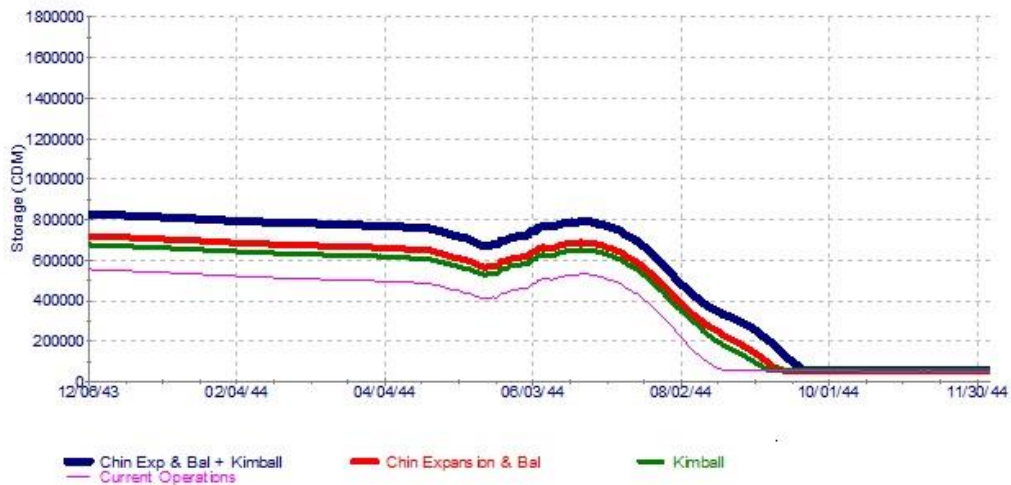


Figure 28: Storage in ESRD plus Chin Reservoir, 1944 drought (1943-1944)

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.

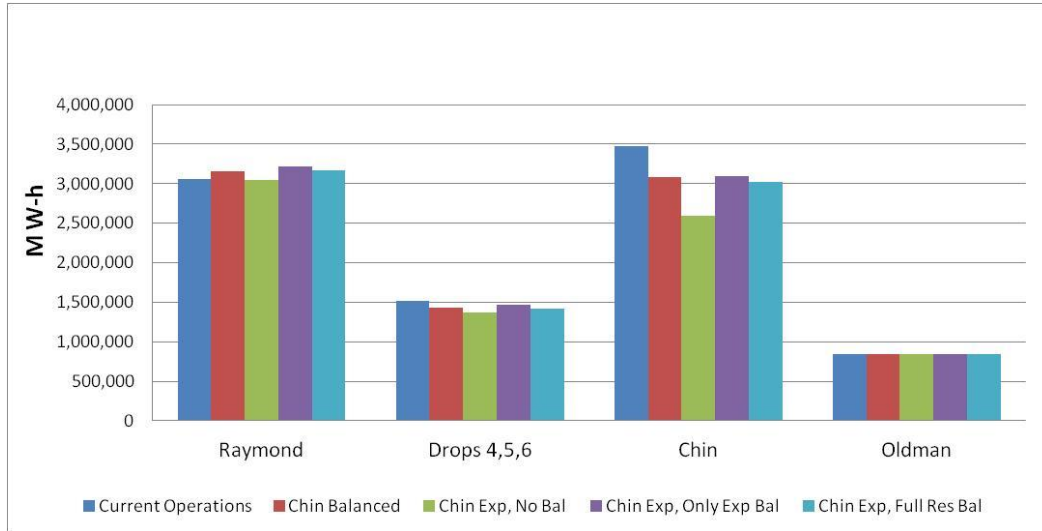


Figure 29: Total energy generation during the 82-year period

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.

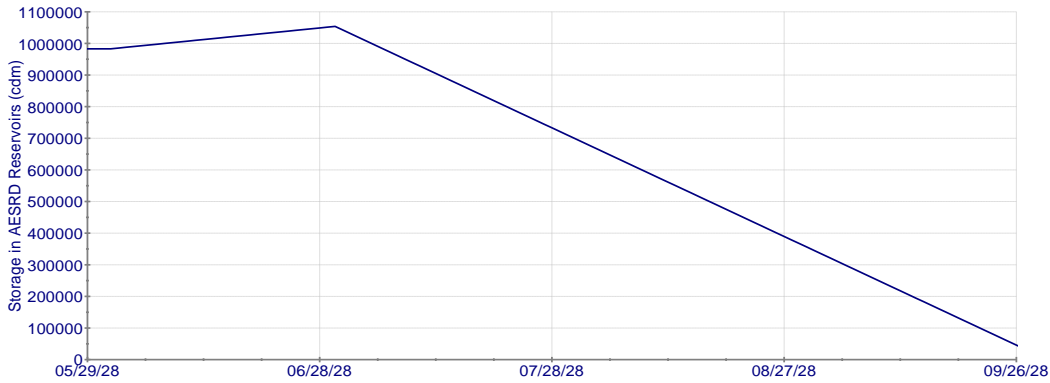


Figure 30: Total ESRD storage-rationing cutoff threshold (1928)

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.

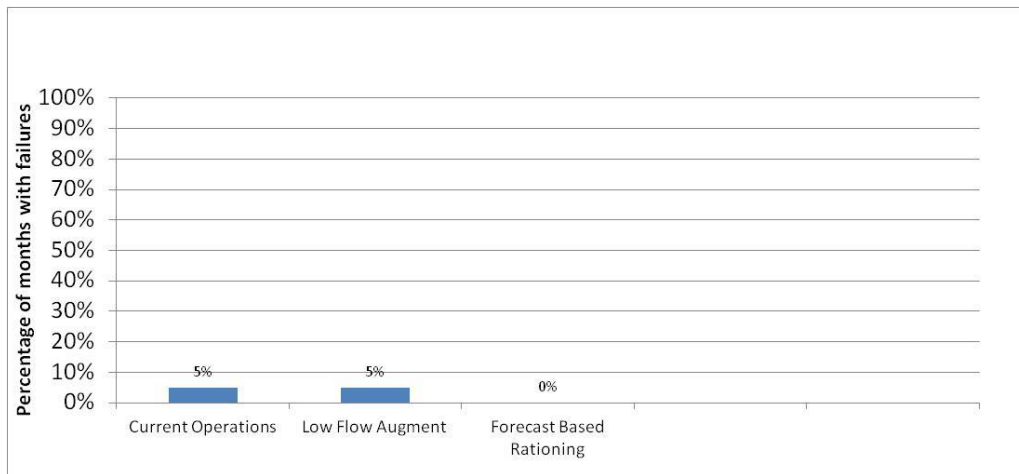


Figure 37: Percentage of months during 82-year period when instream fish requirements were not met in the Oldman River at Lethbridge

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).

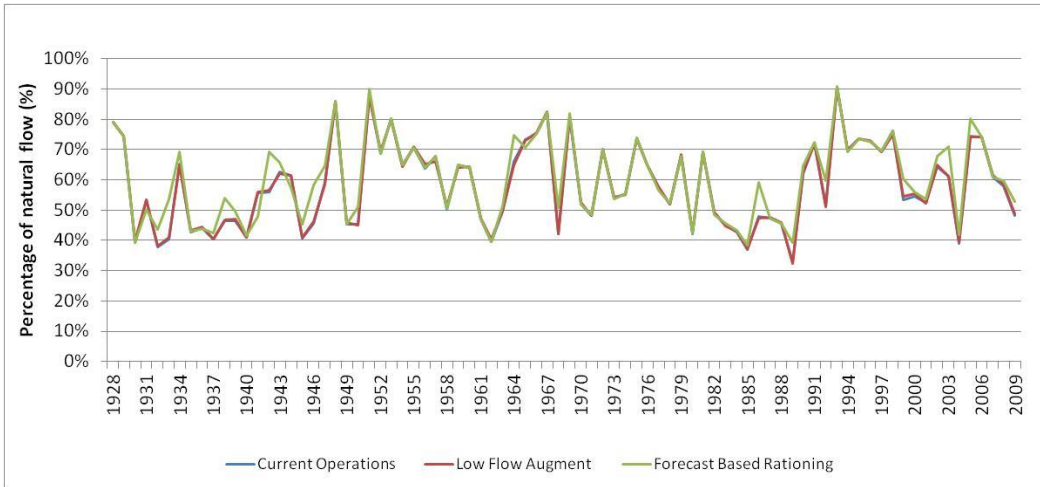


Figure 38: Percentage of natural flow before the Oldman-Bow River confluence

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).

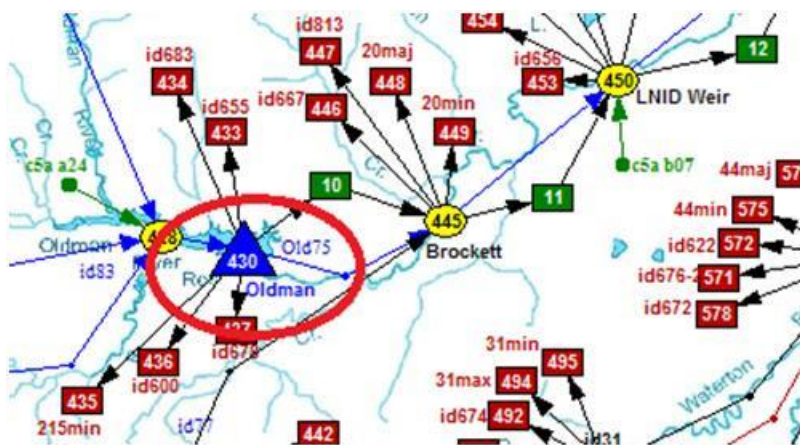


Figure 39: Location of Oldman Reservoir

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.

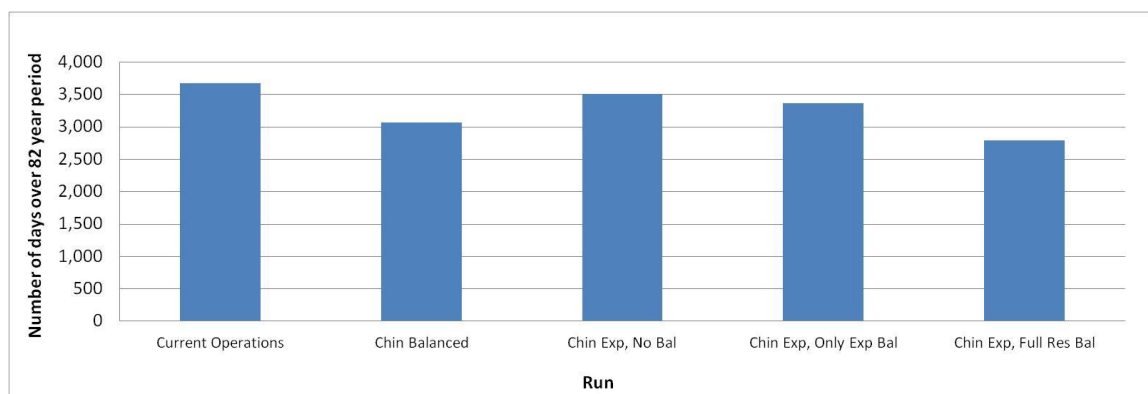


Figure 43: Total number of days in 82-year period with shortages across all irrigation districts

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

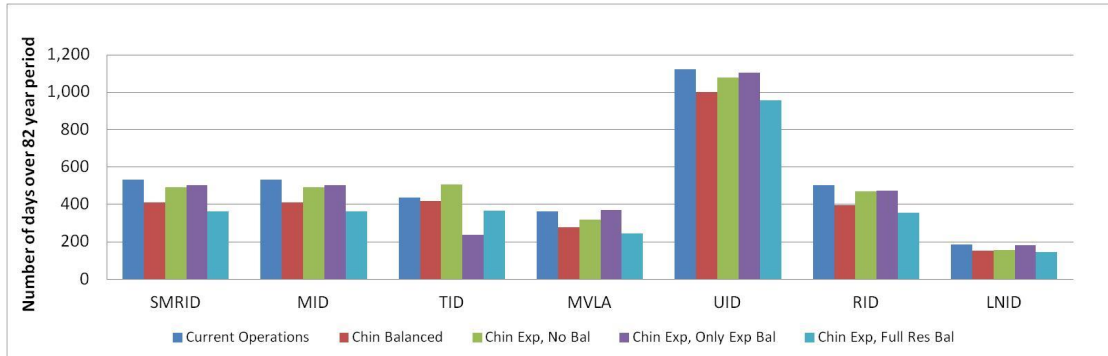


Figure 44: Total number of days in 82-year period with shortages by irrigation district

Relevant OSSK Model run name
 CB6.9_ChinBalanced