Southern Alberta Flood Recovery Task Force
Flood Mitigation Measures for the Bow River, Elbow River and Oldman River Basins
Volume 2 – General Information

Submitted to:

Southern Alberta Flood Recovery Task Force
Calgary, Alberta

Submitted by:

AMEC Environment & Infrastructure
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1.0 TERMS OF REFERENCE

Following the floods of June 2013, the Government of Alberta (GoA) also set up the Southern Alberta Flood Recovery Task Force (SAFRTF) and in October 2013, AMEC Environment and Infrastructure, a Division of AMEC Americas Limited (AMEC) were contracted to provide a flood mitigation feasibility study for the Bow, Elbow, and Oldman river basins.

This study was undertaken under contract to the SAFRTF (CON0015233) and in accordance with the agreed AMEC proposal document submitted to the SAFRTF on 16 September 2013.

This contract was carried out between October 2013 and March 2014.

2.0 REPORT FORMAT

This suite of reports consists of four volumes as follows:

- Volume 1: Summary Recommendations Report
- Volume 2: General Information
- Volume 3: Stakeholder Engagement Report
- Volume 4: Technical Analysis and Design Report

Throughout all four volumes of this report, specific recommendations are made. Where recommendations are made, the information is presented in a blue box as follows:

Recommendation #:

These recommendations are summarised in Volume 1 Summary Recommendations Report.

3.0 SCOPE

3.1 Background

In June 2013 parts of southern Alberta experienced an extreme rainfall event that tracked from south to north along the eastern slopes of the Rockies and caused widespread flood damage in communities in the South Saskatchewan River Basin (SSRB). In excess of 300 mm of rain fell in 24 hours in parts of the upper Elbow River basin with a similar amount falling in the upper Highwood and Sheep river basins. The impact of the rainfall event was compounded by a lingering snowpack which increased the rainfall equivalent by approximately 80 mm.

In the immediate aftermath of the floods, an advisory panel (AP) was set up to advise the GoA on measures to mitigate future floods. The AP were key contributors to the Alberta Flood Mitigation Symposium held in Calgary on 4 October 2013.

Consultants to the AP were Stantec Consultants Ltd (Stantec), who issued a technical report on proposed flood mitigation measures for the Elbow River, Sheep River and Highwood River basins.[1] A second brief draft report was issued with proposed flood mitigation measures for the Bow River Basin; however, it is understood that the AP were disbanded before this report could be finalized by Stantec.

3.2 Objectives

The objective of this project was to conduct a feasibility study of water management options in the Bow, Elbow and Oldman river watersheds. Assessment of the water management options focused on opportunities for flood mitigation that have secondary benefits with respect to overall

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[1] Stantec Consulting Ltd. 2013. *Flood Mitigation Measures Elbow River, Sheep River and Highwood River Basins*. October 2013.

water management objectives in the SSRB. For this reason, there is a section in this report specifically related to drought and the historical context of water management in Alberta.

3.3 Study Scope and Overview of Methodology

The scope of this study was to assess various water management opportunities, estimate the overall benefits, costs and impacts of each alternative, and determine the most feasible options for specific areas within the Bow, Elbow and Oldman river watersheds. Stakeholder and public involvement and consultation was incorporated in the assessment and decision-making process.

The assessment of flood mitigation alternatives included the following components:

- Data collection (e.g., surveys, mapping, hydrotechnical, archaeological, geotechnical, environmental, damage/recovery estimates);
- Stakeholder consultation in affected communities;
- Development and shortlisting of options;
- Evaluation of options;
- Preliminary design of options
- SAFRTF Workshop; and
- Final report.

The following sections outline the specific tasks undertaken for this study.

3.3.1 Data Collection and Review

A range of data were collected to support and evaluate proposed water management alternatives. These included:

- Other studies (flood mapping, water management, drought);
- Information on the mechanisms of the 2013 event, and past significant flood events, in the Bow, Elbow and Oldman river basins;
- Hydrometeorological data (precipitation, streamflows and water levels) and the effects of climate change on the frequency and severity of anticipated future flood and drought events;
- Flood forecasting and warning systems;
- Existing and proposed public policy relating to flood and water management in Alberta;
- Mapping and, for selected locations, LiDAR data; and
- High level environmental, geotechnical and archaeological data sufficient for conducting desktop reviews of proposed alternatives.

3.3.2 Stakeholder/Public Consultation

An understanding of what happened, why it happened, and how communities attempted to manage the 2013 event, and previous significant flood events, is fundamental to developing flood mitigation measures appropriate for each community. For example, the Town of Canmore was dealing with massive debris flows while the City of Calgary and the Town of High River were dealing with extreme high water levels. Through the stakeholder consultation process, AMEC obtained direct input from municipalities to appraise the effectiveness of existing flood protection works and their emergency response measures.

The stakeholder consultation process included public and private entities operating infrastructure pertinent to water management in Alberta. These included TransAlta Corporation (TAC), Alberta Transportation (AT), Alberta Environment and Sustainable Resource Development (ESRD), and selected irrigation districts.

The consultation process will was led by AMEC's public consultation team and supported at face to face meetings by representatives from the FRTF. The process included:

- Face-to-face meetings with communities and municipalities, including First Nations communities, directly impacted by the 2013 and previous extreme flood events;
- Telephone interviews with communities and municipalities, including First Nations, indirectly impacted by the 2013 and previous historic flood events; and
- Direct mail/email questionnaire to communities and municipalities not affected by previous flood events but with other potential water management issues.

Volume 2 describes the stakeholder engagement component of this study in detail.

3.3.3 Development of Options

Since the 2013 flood, a variety of mitigation measures have been put forward by the AP, the GoA, and the public at large. Across southern Alberta, the proposals have ranged from dredging existing river channels, to constructing flood bypasses and water storage facilities, to removing existing development from river floodplains. A number of solutions could be identified for each affected community, but not all measures may be feasible or effective. Further, those measures may not satisfy all engineering, environmental and societal requirements, or overall water management objectives within the SSRB. For example, Alberta rivers convey large volumes of sediment and river dredging might provide only temporary benefit in reducing flood levels. Hence, the maintenance requirements for this type of measure, including cost and ongoing regulatory approvals, would need to be incorporated into the decision making process.

AMEC investigated both structural and non-structural flood and water management strategies for the Bow River, Elbow River and Oldman river basins.

Potential mitigation measures are described in detail later in this report. Structural measures that were considered, depending on circumstance included:

- Wet and dry flood control reservoirs;
- Earthen levees or dykes;
- Flood walls;
- Sediment control structures;
- Bank armouring;
- Debris capture; and
- Flood bypasses.

Non-structural flood management strategies included:

- Wetlands/forestry restoration;
- Ensuring floodplain mapping is up to date and correct; and
- Accurate and timely flood warnings;
- Building code amendments to prescribe appropriate damage reduction measures into building construction practices; and
- Controlling development on floodplains through land zoning regulations.

3.3.4 Evaluation of Alternatives - Round Table Meeting

AMEC conducted a series of round table meeting with technical experts and the SAFRTF to evaluate the proposed water and flood management methods against each flood risk area.

A multi-criteria decision making (MCDM) tool was developed (**Section 4.1**) prior to the meeting and used to short list options for further appraisal.

At the round table sessions, each option was described and discussed, then ranked according to the agreed-upon requirements, objectives, and evaluation factors. Using the assigned weighting, the options will be ranked in order of preference. The highest ranked options in each of the Bow, Elbow and Oldman river basins were carried forward to conceptual design. In some cases, the conceptual design included an amalgam of mitigation measures such that the design criteria and standard of protection (1% annual exceedence probability [AEP]) were met wherever possible.

3.3.5 Preliminary Design of Alternatives

Once the preferred water and flood management options were identified, AMEC proceeded with a more detailed feasibility assessment. For structural options, this included preparing conceptual level designs.

The proposed water and flood management options were prioritised with respect to immediacy of implementation (i.e., short-term recommendations to provide immediate benefits and long-term strategies/recommendations).

4.0 WATER MANAGEMENT IN ALBERTA

4.1 Introduction

Many countries in the world face severe water shortages and poor quality water that restrict economic growth and diminish their quality of life. Alberta is fortunate to have a relatively good supply of high-quality water. However, it is recognized that Alberta's water is a finite resource that must be sustainably managed to ensure that the environment is adequately protected and the quality of life for future generations is maintained and strengthened.

Current provincial demand for this water is relatively low, with about 2% of Alberta's renewable water supply from rivers actually consumed. However, the water supply is often not accessible, or not in the right location at the right time to meet demand. In the SSRB limits for water allocations have been reached or exceeded in the Bow River, Oldman River, and South Saskatchewan River basins, prompting closure of those basins to any new water allocations. In the South Peace Region of northern Alberta, demand for water is exceeding the capacity of the Smoky River and Wapiti River systems, and access to the large volumes of water in the Peace River is very difficult and expensive to access.

Achieving the right balance between a sustainable environment and the economic and social well-being of Albertans has and will continue to be the challenge. Alberta is now managing water on a more integrated, watershed approach, taking into account the interdependence of water quality, water quantity and all other natural resources.

Before Alberta became a province, the Dominion Government of Canada (the Dominion Government) was responsible for managing water resources development under the *Northwest Irrigation Act* of 1894. Under this Act, irrigation was encouraged as a way to promote settlement. In 1915, the Dominion Government passed the *Irrigation Districts Act*, authorizing farmer-owned and operated irrigation co-operatives – the precursor to today's irrigation districts. Significant irrigation development had already taken place in the SSRB by this time.

Responsibility for managing all natural resources, including water, was transferred from the Federal Government to the GoA in 1930. Alberta subsequently passed the *Water Resources Act* in 1931. This version of the act was in effect until 1999, when it was replaced by the *Water Act,* which is currently in place*.* This act provides greater flexibility and new approaches to managing water where demand is high and water supply is limited. The *Water Act* is based on four principles:

- Crown ownership of water and suppression of individual riparian rights;
- Government control of the allocation and use of water;
- An allocation process designed to promote development; and
- A first-in-time, first-in-right priority system designed to protect existing development of water resources.

4.2 South Saskatchewan River Basin

The SSRB is home to almost 1.6 million people, and is the most developed and regulated basin in Alberta. The SSRB has a total area of 121,095 km^2, and is made up of four major basins – the Red Deer River, Bow River, Oldman River, and South Saskatchewan River (**Figure 4.1**).

The mean annual natural flow of the SSRB is made up of about 43% from the Bow River basin, 38% from the Oldman River basin, 18% from the Red Deer River basin, and < 1% from the South Saskatchewan River basin.

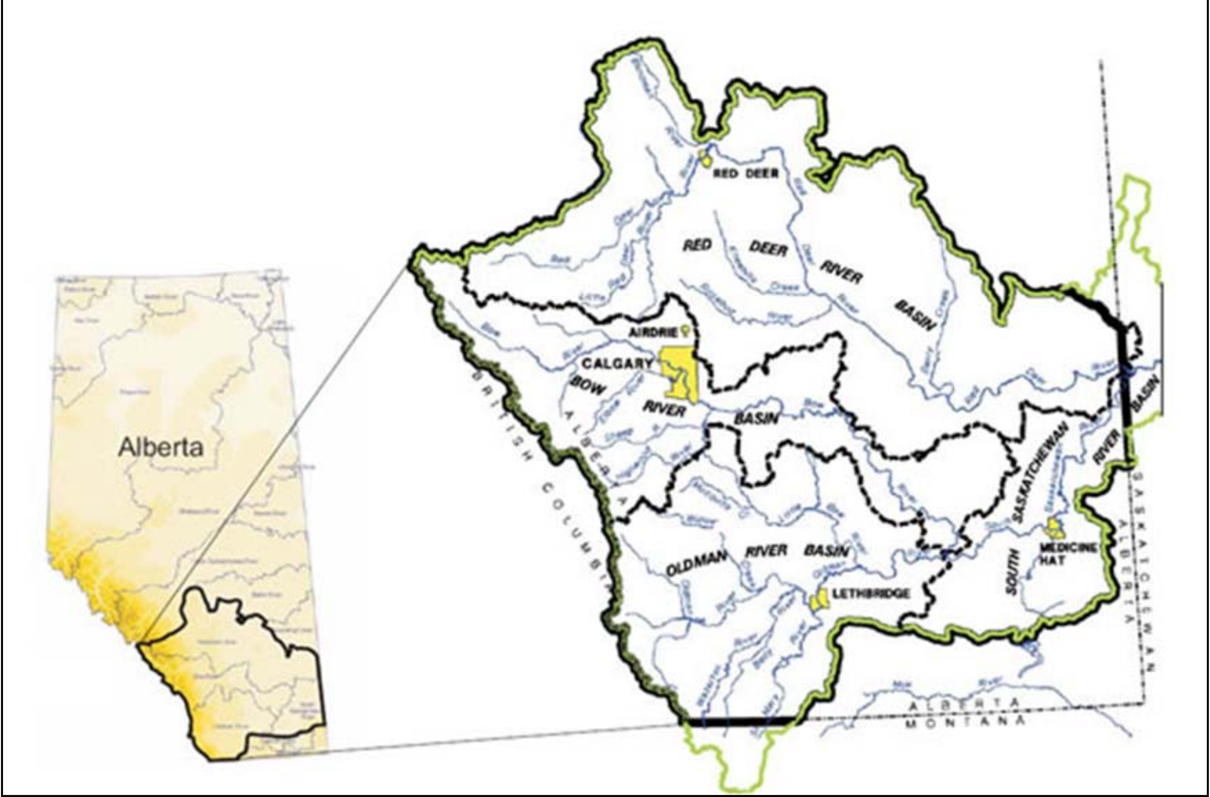
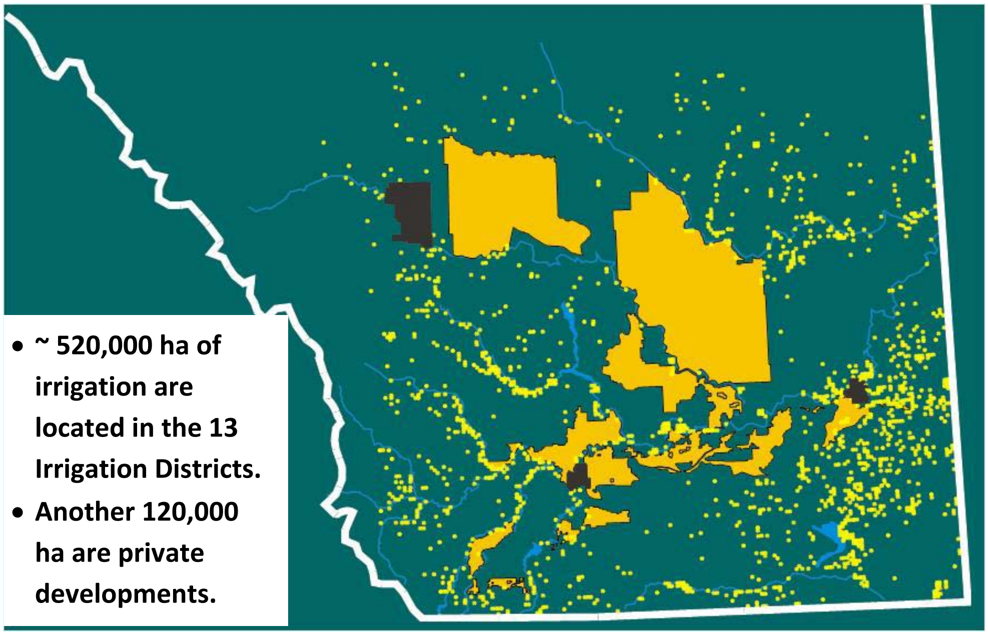


Figure 4.1: South Saskatchewan River Basin (Source: GoA, 2014)

Most who live, work, and play in the SSRB rely on water from one of the river systems, since there are few significant groundwater reserves available. The most significant use of water in the basin is for irrigation. Most of Alberta's 640,000 ha of irrigation are located in the SSRB (**Figure 4.2**).



- **~ 520,000 ha of irrigation are located in the 13 Irrigation Districts.**
- **Another 120,000 ha are private developments.**

Figure 4.2: Irrigation in the SSRB

As demand for water in the SSRB continued to grow in the 1990s, the GoA initiated an in-depth review to assess current and long-term water supply and demand throughout the basin. After a series of public consultations, the SSRB water management plan (AENV, 2007) was proclaimed in 2007.

This plan recognized that limits for water allocations have been reached or exceeded in the Bow River, Oldman River, and South Saskatchewan River basins. As a result, applications for new water allocations were no longer accepted in these river basins, which meant that any new water users were required to obtain water from existing users through the water market established under the 1999 *Water Act*. In addition, the approved plan stipulates that any water stored in new on-stream storage reservoirs would be allocated for:

- Water Conservation Objectives (WCO) – minimum river flows designed to protect the aquatic ecosystem. These were set at 45% of a river's natural (unregulated) rate of flow, or the existing in-stream objective plus 10%, whichever is greater at any point in time.
- Reduce risk to existing water licenses.
- Mitigate impacts on the aquatic environment.
- Meet water supply obligations to First Nations.

4.2.1 Water Use

In 2009 AMEC carried out a detailed study for Alberta Agriculture and Rural Development (AARD) to assess current and future water supply and demands in the SSRB (AMEC, 2009). The study focused on irrigation, since this is the largest water user in the basin.

The study found that even with increasing demands for water, Alberta continues to meet its commitments to Saskatchewan under the Prairie Provinces Master Agreement on Apportionment. From 1970 to 2006, Alberta passed, on average, about 80% of the natural flow to Saskatchewan, which is considerably higher than the 50% required under the Apportionment agreement. Surplus deliveries averaged about 2.6 million dam^3 annually, but varied from 350,000 dam^3 in 2001 (a very dry year) to almost 5.5 million dam^3 in 2005 (a “wet” year). While average values are often used when describing water supply conditions, in semi-arid climates such as the SSRB, effective long-term water management planning should be defined by dry year conditions, not average or wet years.

The Bow River and Oldman River provide nearly all the flow required to meet the apportionment agreement with Saskatchewan. Only once was the Red Deer River required to contribute slightly more than its natural share to make up the apportionment requirement, and that was before construction of the Oldman Dam and Reservoir in 1992.

The 2009 AMEC study showed that actual surface water consumed by all sectors in the SSRB was estimated to be almost 2.0 million dam^3, which is about 40% of the total volume of water (~5.0 million dam^3) allocated for use. Irrigation is the largest water-use sector in the SSRB, and accounts for about 84% of the total.

As population and development increases, the demand for water is naturally expected to increase. By 2030, water use could increase from the current 2.0 million dam^3 to about 3.0 million dam^3, if significant irrigation expansion takes place. Increased demand for non-irrigation water use would likely be small in comparison.

Demand for water may be further exacerbated by rising temperatures and resulting loss of glaciers due to climate change. Climate change predictions suggest that increased temperatures may result in a greater number of dry years, longer duration dry cycles, and subsequent reductions in natural stream-flow volumes in the SSRB. Regardless of future demands for water, meeting the apportionment flows to Saskatchewan will always take priority over meeting license commitments in Alberta.

4.2.2 Drought in Southern Alberta

The threat of water shortage and drought has been an ongoing challenge in southern Alberta, particularly for agriculture and associated food processing industries. Wherever droughts occur, the agriculture industry is always the first to feel the impacts. However, prolonged water shortages and drought ultimately affects everyone. Prolonged droughts are among Canada’s costliest natural disasters. For example, the 1999 to 2004 drought was considered one of the worst on the Canadian prairies in over a hundred years. Wheaton et al. (2005) indicate that the 2001/2002 drought resulted in about $5.8 billion loss to agricultural production on the prairies. The widespread drought in the United States in 2012 is estimated to cost about $30 billion.

To add to these concerns, tree ring research (Sauchyn et al. 2001) suggest that the 20th century was somewhat wetter than earlier centuries. Given the frequency of flood events in southern

Alberta during the past 15 years, the beginning of the 21st century is also shaping up to be relatively wet.

Predicting droughts are difficult, in spite of advances in science and weather monitoring technologies and modeling. Because agriculture is usually the first industry to feel the impacts of a drought, ongoing monitoring of precipitation and weather patterns is a high priority for dry land and irrigation producers, and irrigation districts responsible for supplying water to most of Alberta's irrigation area. The ESRD operates a network of snow monitoring stations and are able to provide almost real-time information on mountain snowpack levels and estimates of runoff water volumes. This information is important since most of the water to fill the approximately 50 on-stream and off-stream reservoirs that supply irrigation water comes from the mountains during the relatively short spring runoff period (**Figure 4.3**). A lower than normal snowpack provides an indication that summer water supply may be reduced. Since a significant amount of the snowpack generally develops during late winter and spring, there is often not a lot of time to react to low snowpack levels.

Figure 4.3: Mountain Snowpack is a Critical Water Source for the SSRB

If reservoir levels are at normal operating levels during the winter, most irrigation districts have sufficient water to meet expected water user demands, even if snowpack levels are below normal. However, high summer temperatures combined with low precipitation can draw heavily on water stored in the reservoirs, leaving irrigation districts vulnerable to a second winter of low snowpack levels.

This was the situation in 2001 that faced irrigation districts and all water users that rely on water from the Southern Tributary Rivers (St. Mary River, Belly River and Waterton River) in the Oldman River basin. Precipitation during the summer of 2000 was very low, temperatures were high, and irrigation demand was subsequently very high. As a result, reservoir levels in this region were very low entering the winter season. Snowpack levels during the winter of 2000 and spring of 2001 were well below normal, meaning that reservoirs would not be filled during the 2001 spring melt period. **Figure 4.4** shows Chin Reservoir, a key off-stream water supply to the St. Mary River Irrigation District, during the summer of 2001(left) and the same reservoir during a more normal year (right).

Figure 4.4: Chin Reservoir During the Summer of 2001 and During a More Normal Year

Martz et al. (2007) assessed the impact of climate change on surface water supply in the SSRB. Their study indicated that temperatures could increase between 1.5°C and 2.8°C in this region by 2050, which would increase evaporation and evapotranspiration levels. This would lead to potential changes in annual flow of the rivers, with potentially significant declines in flow during the summer season. This is important as the large majority of water demand occurs during this season.

The study showed that in-stream flows could decrease by an average of 8.4% across all basins (**Figure 4.5**), ranging from:

- -13% in the Red Deer River basin;
- -10% in the Bow Riverbasin;
- -8.5% in the shared (Alberta/Saskatchewan) South Saskatchewan River basin; and
- -4% in the Oldman River basin.

This could reduce water availability by approximately 546,000 dam^3 between 1996 and 2046.

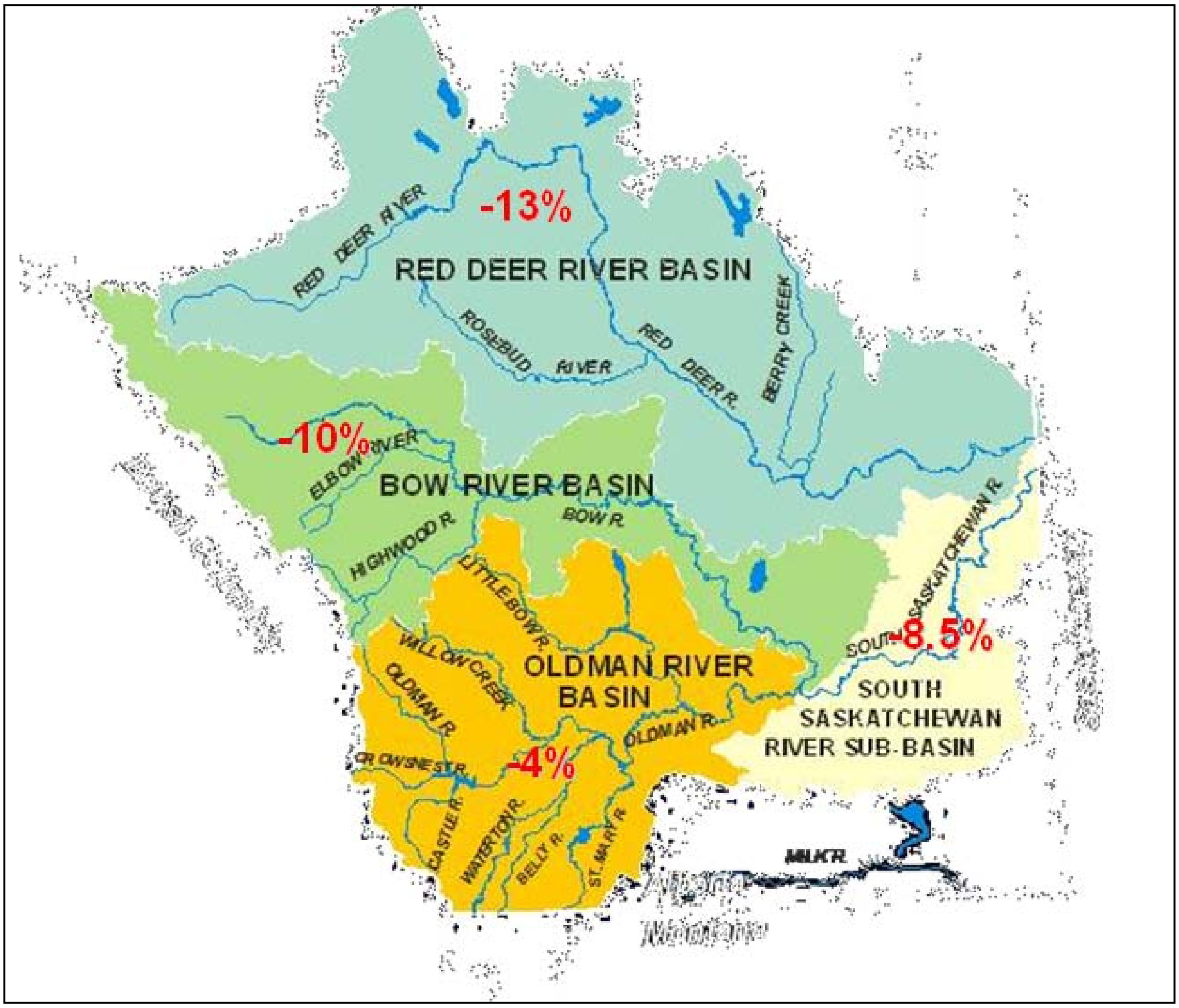


Figure 4.5: Projected Flow Reductions in the SSRB with Climate Change

There is also the potential for more mountain runoff taking place during the winter months. This would further reduce overall storage potential as current reservoir management would generally not store winter runoff. For on-stream reservoirs at normal winter operating water levels, winter runoff would simply be allowed to flow through the reservoir. Off-stream reservoirs would not benefit either as diversion canals are not operated during the cold winter months.

The demand for water by irrigated crops is expected to increase with projected temperature increases under a changing climate. Preliminary work carried out by AARD indicates that forages (alfalfa) and root crops (potatoes, sugar beets) will see the highest increases in water demand (**Figure 4.6**).

Harm (2010) assessed potential water demand increases for alfalfa under changing temperature increases. For a 2°C temperature increase, alfalfa's water demand could increase by 28%. A 4°C increase could see the water requirement increase by 63%. On the positive side, the overall yield of alfalfa would be expected to increase significantly as well.

Figure 4.6: Alfalfa and Potatoes Are Expected to See Significant Increased Water Demand with Climate Change Temperature Increases

4.2.3 Drought Mitigation

Southern Alberta is likely to experience one or more multi-year droughts in the future. Based on experiences in the United States and other parts of the world, the potential impacts of a multi-year drought on the economy could be very significant. There is currently no strategic plan in place to prepare for a multi-year drought, proactively plan for this eventuality, and implement a management plan when it occurs.

Southern Alberta has insufficient water storage capacity to weather successfully a multi-year drought. Total storage capacity (on-stream and off-stream reservoirs) within the SSRB could sustain water demand for less than 2 hot, dry years, such as was experienced in 2000 and 2001. This time-frame may even be optimistic since no one can predict whether a single hot, dry summer will be followed by good winter precipitation, or if it signals the beginning of a drought. It is also not known how long the drought will last.

If it is assumed that the hot, dry summer will be followed by good winter precipitation, there is unlikely to be any curtailment of water diversions to meet water demand, which will deplete reservoir levels more than would have taken place if planners knew of an impending drought. It is only after the following winter season that the drought scenario begins to manifest itself, and by then reservoir levels may already be low.

Effectively managing a multi-year drought requires a strategy that optimizes the management and operation of existing reservoirs to increase water supply before and during drought years. In addition, construction of new on-stream and off-stream reservoirs at key locations in the SSRB should be considered to increase storage capacity.

To address this issue, a study was carried out in the Bow River basin to assess *Adaptation Strategies for Current and Future Climates in the Bow Basin* (Alberta Innovates – Energy and Environment Solutions; and WaterSMART Solutions Ltd. 2013). The project assessed a large number of options that could be applied in the basin to meet existing and future water demands under projected climate change scenarios and recommended a suite of practices that could be implemented.

The study generated 50 annual flow projections for the 2025 to 2054 period. From these flows, three annual low-flow scenarios were chosen to reflect dry conditions in the basin. The low flows showed significant impacts on water supply in the basin, including much lower storage levels (and at times, no storage) for TAC reservoirs and Calgary's Glenmore Reservoir, reduced flows through Calgary, adverse impacts for downstream aquatic health, and water shortages for the Western, Bow River, and EIDs. There were also shortages to non-municipal users throughout the Highwood River basin.

The study recommended implementation of a suite of options that would help mitigate the drought conditions envisaged for the basin. This combination included the following:

1. **Water bank + stabilization of Lower Kananaskis Lake + discharge flow management into Kananaskis River + increase capacity of Langdon Reservoir**.
    - Establish a "water bank" of about 72,000 dam^3 that would be used to supplement flows during high demand and low flows. The "water bank" water could be stored by TAC within their reservoir network.
    - Stabilize Lower Kananaskis Lake at 1,663.5 m, which is 3.5 m below the current full supply level. This is a major change from the current 13.5 m fluctuation of the lake that can occur each year.
    - Maintain a steadier flow range into the Kananaskis River from the Pocaterra Power Plant.
    - Double the capacity of Langdon Reservoir in the WID from 8,100 to 16,200 dam^3.
2. **Reduce seasonal consumptive demand in Calgary.** This strategy suggested that Calgary reduce consumptive demand by 30% during the summer period from April 1 to September 30.
3. **Increase winter water storage in Travers Reservoir.** This reservoir is owned and operated by ESRD and supplies water to the Bow River Irrigation District. It is recommended that winter storage levels could be increased by about 1 m without any infrastructure changes, which would reduce the required volume of water to be diverted from the Bow River in the spring. In dry periods, this would also help TAC fill its reservoirs.
4. **Adjust fill times for TAC Reservoirs**. The study indicated that Minnewanka, Spray and upper Kananaskis reservoirs would be filled earlier in the season – by approximately July 31 – and held full until the end of October. This would allow more natural flow in the river during the normally low flow July and August period.
5. **Construct a new on-stream reservoir downstream of Bassano**. This proposed reservoir would be located on the Bow River about 10.5 km north of secondary highway 539. The reservoir would have a storage capacity of about 300,000 dam^3 and would supplement water flow in the Bow River below Bassano. It could also be used to help mitigate downstream flood impacts, enhance flow requirements through Medicine Hat, and help meet water apportionment requirements to Saskatchewan.

With a robust and modern flood forecasting system, mitigation measures for drought can also be used for flood control, which will be an important consideration for the future. The adaptation analysis undertaken for the Bow River should also be carried out for the Oldman River and Red Deer River basins to assess potential strategies that could be implemented to more effectively manage a multi-year drought, and that can also potentially mitigate the impacts of flooding.

High priority for drought mitigation should be given to the Oldman River basin because of the significant demand for water for both irrigation development and other water users. There is less immediate concern about the Red Deer River basin because of Glennifer Reservoir and the relatively small volumes (less than 15% of annual natural flow) of water diverted from the Red Deer River.

4.3 Oldman River Basin

4.3.1 Water Supply

The Oldman River headwaters are made up of three rivers: the Oldman River, the Castle River, and the Crowsnest River, which merge at the Oldman Dam and Reservoir, located near Pincher Creek. Further downstream the Oldman River is joined by the Belly River and St. Mary River. The St. Mary River enters the Oldman River just upstream of Lethbridge. The St. Mary River, Belly River and Waterton River (a major tributary of the Belly River) are collectively referred to as the Southern Tributaries.

The eastern slopes of the Rocky Mountains (**Figure 4.7**) are the main source of water for the Oldman River and its tributaries (Crowsnest River and Castle River, Willow Creek and Pincher Creeks). The headwaters of the Belly River, Waterton River and St. Mary River originate in Montana.

Figure 4.7: Mountain Water Source

The Oldman River joins with the Bow River north of the town of Grassy Lake to become the South Saskatchewan River, which flows through Medicine Hat and on to Saskatchewan (**Figure 4.8**).

Figure 4.8: Confluence of Oldman River and Bow River

Water supply has always been a concern in the Oldman River basin. Three major on-stream water storage reservoirs (the Oldman Reservoir, St. Mary Reservoir and Waterton Reservoir) are located within the Oldman River basin (**Figure 4.9**). The smaller Twin Valley Reservoir is located on the Little Bow River downstream of High River. These reservoirs have a combined storage capacity of a little over 1.0 million dam^3.

Figure 4.9: Waterton Dam and Reservoir

More than 25 off-stream reservoirs located within the basin store another 430,000 dam^3 of water (**Figure 4.10**). Many of these off-stream reservoirs are owned and operated by one of the nine irrigation districts located in the sub-basin, and are important irrigation water sources during the summer growing season. They are also important recreational destinations for many residents throughout Southern Alberta.

Figure 4.10: Chin Reservoir South of Taber

The on-stream and off-stream water storage reservoirs are important to capture runoff water from the mountains during the relatively short snowmelt period in May and June. This stored water is used by a wide variety of users throughout the basin during much of the summer season when the natural flow in the rivers is often very low. Prior to the Oldman Dam and Reservoir, water flow past the city of Lethbridge was often so low in July, August and September that the city sometimes had difficulty accessing water for the residents. With the completion of the Oldman Dam and Reservoir in 1992, summer and winter flows were increased to meet agreed upon levels past Lethbridge and Medicine Hat. The Oldman Dam and Reservoir is also important to ensure that apportionment flows to Saskatchewan are met.

4.3.2 Droughts and Floods

Droughts and floods severely impact people’s lives and can cost billions of dollars in damage to the economy. Floods are the result of too much water in the short-term (**Figure 4.11**). They are very quick to start, often provide little warning of their approach, and are often of short duration; but their impacts can be felt for years.

Figure 4.11: Impact of Flood Waters

Droughts are often difficult to comprehend because they are slow to develop (**Figure 4.12)**. Where floods are short-lived, droughts can persist for years, as is the current situation in California and other parts of the world.

Figure 4.12: Dry and Drifting Soil as a Result of Drought

In the Oldman River basin the threat of water shortage and drought continue to be dominant long-term concerns facing water users in the basin, particularly those directly or indirectly related to the agriculture sector. Climate change studies project a warmer, drier climate for southern Alberta which is expected to result in more frequent and longer-term droughts.

4.3.2.1 Floods

Climate change studies also predict the occurrence of more severe weather events, including floods. Whether or not climate change is the cause, southern Alberta has experienced numerous floods over the past two decades caused by high rainfall combined with spring snowmelt. These floods caused significant damage to public and private infrastructure in various communities. While the 2013 flood has been one of the most devastating on record, recent floods in 1995, 2002, 2005, 2010, and 2011 also caused significant damage.

Most of the flood damage has been the result of rivers and streams overflowing and inundating infrastructure located in the floodplain and flood fringe areas. High rainfall associated with the flooded rivers often resulted in storm and sewer systems being overwhelmed, causing damage to basements in homes and businesses.

In 2010 and 2011, severe flooding across southern Alberta was the direct result of overland flooding caused by excess rainfall and snowmelt, combined with runoff from the Milk River Ridge in south-western Alberta and the Cypress Hills of south-eastern Alberta. These flood events caused significant damage throughout this part of the province to infrastructure (highways, roads, irrigation canals, storage reservoirs, farm buildings and homes; **Figure 4.13**). Thousands of hectares of agricultural land were flooded and many livestock were threatened.

Figure 4.13: 2010 Flooding of Municipal Road

The area south of the Oldman River and South Saskatchewan River from the Waterton Reservoir to east of Medicine Hat was particularly hard hit by these back-to-back flood events because of a lack of drainage infrastructure to remove and quickly spill excess water back to the rivers.

This region is somewhat unique in that a significant part of the area has been developed for irrigation. About 4,000 km of canals distribute water from the Oldman River system to irrigation producers and other water users in the region. In the past, all of these canals were surface (**Figure 4.14**). While unintended, these canals often served as temporary drainage channels that collected surplus water from fields during rainstorm and flood events.

Figure 4.14: Surface Distribution Canal

Over the past several decades, irrigation districts have replaced many of these surface canals with underground pipelines (**Figure 4.15**). At present almost 50% of the 4,000 km distribution system consist of underground pipelines. These pipelines are much more efficient to transport water, reduce water losses through seepage and deep percolation, are less expensive to operate than surface canals, and allow valuable irrigation lands to be brought back into production. However, removal of almost half of the surface canals has reduced the capacity of the distribution system to absorb some of the flood flows.

Figure 4.15: Underground pipeline installation

Irrigation canals do not make good drainage channels because they are designed to be larger at the beginning of the canal system, and become progressively smaller as the canal continues downstream and irrigation water is diverted for farms and industry (**Figure 4.16**). Drains are designed exactly opposite – small at the beginning and gradually getting larger as more runoff water enters the drain downstream.

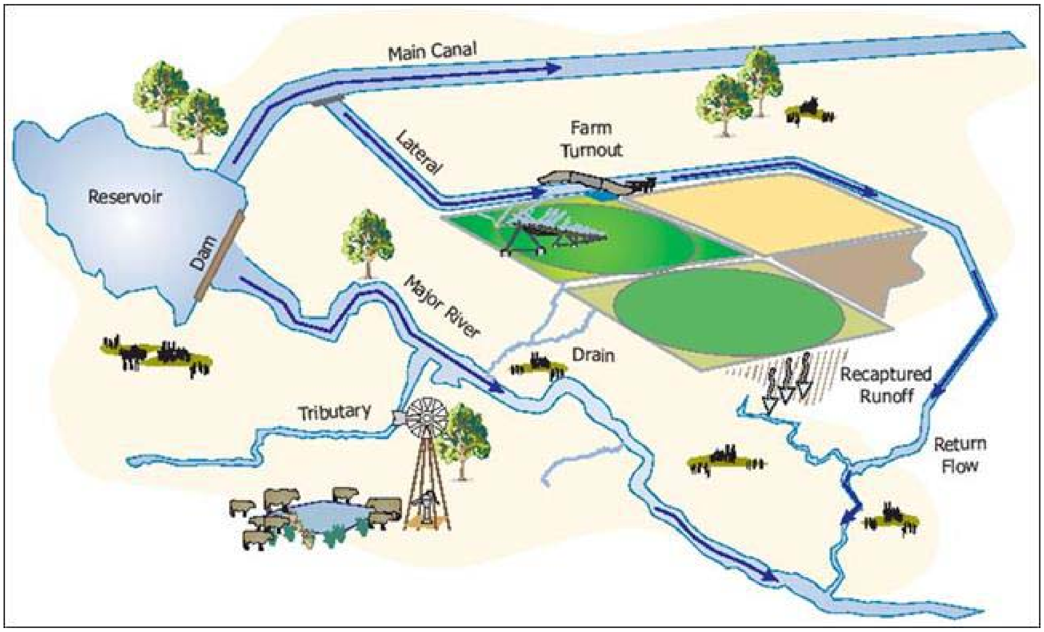


Figure 4.16: Schematic of Irrigation Distribution System

In both 2010 and 2011, irrigation canals and off-stream reservoirs could not handle the excess flood waters, and serious overland flooding resulted in many downstream areas. This was a particular issue with the St. Mary River District (SMRID) main canal which runs from the Milk River Ridge Reservoir (near Cardston) to south of Medicine Hat. To prevent the Milk River Ridge Reservoir from overtopping, excess water was diverted into this canal. For a short time the SMRID was able to accommodate this water and store the excess water in one of several downstream reservoirs. However, these reservoirs quickly reached, and sometimes exceeded their design capacity. This resulted in one reservoir near Medicine Hat being in danger of breaching, which caused serious concerns for the safety of downstream residents in and around Medicine Hat.

Three Irrigation Districts share responsibility for the operation of the SMRID main canal system, and have proposed that one or more emergency spillways be constructed at key locations along the 200 km canal to allow excess water to be diverted into the Oldman River. This would allow the main canal to act as both an irrigation and drainage channel during flood events.

4.3.2.2 Flood and Drought Mitigation

It is unlikely that a single action can prepare the Oldman River basin for a flood, or a multi-year drought. A successful strategy will require implementation of a number of integrated actions that need to be in place well before these events occur.

Effectively managing a drought or a flood requires a strategy that optimizes the management of water – whether there is too little or too much. Short-term storage of excess water during a flood, or long-term storage of water for a drought may be able to use essentially the same storage infrastructure. This would optimize the effectiveness of the infrastructure, and save significant costs compared with construction of single-purpose infrastructure for floods and droughts separately.

During the 1995 flood, existing storage reservoirs in the Oldman River basin were credited with saving the two bridges crossing the Oldman River at Lethbridge, and reducing the impact of the flood waters on downstream communities. During the 2013 flood, the Twin Valley reservoir downstream of High River was credited with reducing the impact of Little Bow River flood flows on the downstream Travers Dam (Richard Phillips - personal communication).

Increasing the storage capacity of existing reservoirs would not only increase water supply for drought conditions, but could further reduce downstream flood impacts, particularly if monitoring and communication systems were optimized to allow timely drawdown of storage reservoirs in advance of a flood. It is recognized that existing reservoirs alone are not sufficient to achieve optimum drought or flood protection in the Oldman River Sub-basin. Construction of new on-stream and off-stream reservoirs at key locations in the sub-basin should be considered to for both drought and flood protection.

Additional information on water management in Alberta can be found in **Appendix A**.

5.0 MULTI CRITERIA DECISION MAKING

5.1 Introduction to Multi Criteria Decision Making

Selecting the best strategy from a number of potential alternatives in flood mitigation planning is a complex decision making process. This process is made even more challenging when mitigation measures need to be prioritised or allocated across a large river basin or basins.

Decision making for flood risk management may include conflicting quantitative and qualitative criteria and multiple decision-makers. The decision-making process can benefit from the use of multi-criteria decision making (MCDM) tools and techniques. They can be used to facilitate the decision-making process by making the process more explicit, rational, efficient and transparent.

MCDM is a concept. It is based on a developing a set of criterion upon which the analyst team wish to make decisions and can include a system of weighting various criterion to assign an “importance” factor to the decision. For example, the client may instruct that a scheme should not exceed 1 year in construction duration. So timeliness would be an important criterion with high weighting.

The main steps in MCDM can be summarised as follows:

1. Identify/agree the problems that need to be solved
2. Establish an assessment team
3. Identify potential solutions to the problem
4. Establish the criterion upon which the solutions should be judged
5. Establish the scoring system and weighting (if necessary) of the criterion
6. Undertake scoring of schemes against criteria
7. Undertake sensitivity analysis on weighting and criteria
8. Analyse results
9. Make recommendations based on findings

Several variations to the approach presented above are possible and the complexity of the analysis should be commensurate with the size and importance of the problem being solved. Problems often don’t need to be identified but, rather, present themselves; sometimes unexpectedly as is often the case for a flood. The MCDM methods allow a large number of decisions to be made to prioritise flood mitigation measures in advance of undertaking costly detailed feasibility or design work.

The approach taken by AMEC in cooperation with the Flood Recovery Task Force is presented in the following paragraphs.

5.2 MCDM for Flood Mitigation

AMEC used Microsoft Excel 2007 to compile an MCDM decision model in a format that:

- Facilitated consideration of changes to key assessment assumptions;
- Incorporated and provided ready access to significant assumptions, data, and calculations;
- Summarized the scoring results in a series of custom reports; and
- Can be regularly reviewed and updated as key assumptions are modified or refined.

The workbook incorporated the options, areas, criteria, and weighting schemes used in the assessment. Area-specific worksheets contain the scoring results for each structural and non-structural flood mitigation option for a single area. The scoring results for each area are compiled in several reports as follows:

- Summary of total scores for each area and option;
- Summary of total scores and rankings for each area and option; and
- Summary of total scores for each area, option and weighting scheme.

To facilitate ease of use, macros were incorporated in the workbook decision making tool. To assist with navigation through the workbook, a control panel (i.e., dashboard) was developed. The dashboard acts as a table of contents, describing the information available within the workbook. Clickable buttons on the dashboard provide immediate navigation to the associated worksheets in the workbook. The user can return to the dashboard at any time by clicking on the button labelled “Home” found at the top of each worksheet.

5.3 Elements of the Comparative Analysis

The variables in the comparative analysis included the following:

- Seven structural and six non-structural flood mitigation options;
- Twenty-one areas across three river basins;
- Three mandatory conditions criteria;
- Thirteen desired outcome criteria;
- Four weighting schemes; and
- One scoring system.

5.3.1 Options and Areas

The model was developed to enable rapid evaluation of the structural and non-structural flood mitigation options shown in **Table 5.1** for the areas located within the Bow River, the Elbow River and the Oldman River basins identified in **Table 5.2**. The evaluation was based on the evaluation teams (consisting of 13 engineers and scientists) considerable experience in aspects of the evaluation criteria and the river basins under analysis.

Table 5.1
Flood Mitigation Options

Category	Mitigation Option
Structural	Wet Dam
	Dry Dam
	Levee/Dyke
	By-Pass Channel
	Erosion Protection
	Improve Conveyance
	Sediment/Debris Control
Non-Structural	Managed Retreat
	Warning /Forecasting/Management
	Land Zoning (Restricted Development)
	Buy-Outs
	Flood Proofing
	Building Code Changes

Table 5.2
Geographic Extent

Basin	Area
Bow River	Canmore
	Exshaw
	Kananaskis Country
	First Nations (Stoney/Nakoda)
	Cochrane
	Priddis
	City of Calgary
	First Nations (Siksika)
Elbow River	Bragg Creek
	First Nations (Tsuu Tina)
	Upstream of Glenmore Dam
	Downstream of Glenmore Dam
Oldman River Basin	Pincher Creek
	Crowsnest Pass
	Cardston
	First Nations (Piikani)
	First Nations (Kainai)
	Lethbridge
	Fort MacLeod

5.3.2 Criteria

5.3.2.1 Mandatory Conditions

The initial test in the comparative analysis involved filtering the options to ensure compliance with the following mandatory conditions:

- Flood control infrastructure can be designed and built in a suitable location;
- Non-structural options can be implemented; and
- Existing trans-boundary legal commitments (i.e., downstream volumes to other users) must be met.

Options were rejected if the mandatory conditions could not be met. The options that could meet the mandatory conditions were further assessed by scoring the desired outcome criteria.

5.3.2.2 Desired Outcomes

The criteria included in the decision matrix were designed to describe the desired outcomes of flood mitigation. These criteria, described in **Table 5.3**, ensured that a wide range of issues were taken into account when comparing the options. A process of participation and discussion amongst members of the AMEC project team and the FRTF was used to design the decision matrix, with a goal of identifying appropriate criteria that would address key aspects of the flood mitigation options.

Table 5.3
Decision Matrix

Desired Outcome Criteria	Importance Weighting				Scoring System
	AMEC	Sensitivity Analyses			
		Equal	Exclude Cost	Exclude Environment	
1. Improve existing shelter, sustenance and security for individuals within the basin (compared to current situation), and not increase flood impacts to other users/basins both upstream and downstream.	9	6.38	9	9	1 = negative outcome 4 = positive outcome
2. Increase property protection for residents, business, and First Nations (business includes agriculture and irrigation, as well as provincial and municipal infrastructure).	8	6.38	8	8	1 = negative outcome 4 = positive outcome
3. Protection of designated natural areas (traditional use, recreation, historical resources).	5	6.38	5	5	1 = low benefit 4 = high benefit
4. Ensure access to life-line services (fire, police, hospital, water & wastewater etc.) for all residents within the basin.	8	6.38	8	8	1 = low benefit 4 = high benefit
5. Provide adequate protection for at least the 1% annual exceedance probability event.	8	6.38	8	8	1 = low benefit 4 = high benefit

Desired Outcome Criteria	Importance Weighting				Scoring System
	AMEC	Sensitivity Analyses			
		Equal	Exclude Cost	Exclude Environment	
6. Provide adequate protection for the largest historical flood of record.	4	6.38	4	4	1 = low benefit 4 = high benefit
7. Be designed and operated to meet multi-purpose objectives (e.g., manage water resources for both floods and droughts).	4	6.38	4	4	1 = low benefit 4 = high benefit
8. Development and construction costs.	6	6.38	0	6	1 = high cost 4 = low cost
9. Operating and maintenance costs.	7	6.38	0	7	1 = high cost 4 = low cost
10. Ensure species (fish, wildlife, vegetation, etc.) are not adversely impacted.	7	6.38	7	0	1 = negative outcome 4 = positive outcome
11. Must not increase potential for flood-related loss of life (compared to existing situation).	10	6.38	10	10	1 = high risk 4 = low risk
12. Protection is implemented in the near term.	3	6.38	3	3	1 = 10+ years 2 = 5-10 years 3 = 2-5 years 4 = <2 years
13. Meets existing federal and provincial policies and regulations.	4	6.38	4	4	1 = meets few/none 2 = meets some 3 = meets most 4 = meets all

5.3.2.3 Numerical Weighting

The weighting process involved assigning numeric values to the judgments made by the AMEC project team. The criteria were assigned two numerical values - one value based on importance, as perceived by AMEC, and the other value or score based on the likelihood of occurrence and/or impact. A process of participation and discussion amongst members of the AMEC project team was used to assign importance weighting to each criterion included in the decision matrix. The resulting weight of the attribute reflects the relative importance with a greater value representing a higher degree of importance.

The likelihood scheme incorporated a scale of 1 to 4, with four representing the most desirable choice or outcome, and 1 representing the least desirable choice or outcome (e.g., for the criterion of “Development and Construction Costs”, a likelihood of 4 represents a low cost while 1 represents a high cost).

The resulting score for each criterion was the product of the numerical value for importance (i.e., the weighting), and the numerical value for likelihood. A total score for each flood mitigation option was calculated by summing the individual scores for each criterion.
The preferred flood mitigation option for any area was the one with the highest score. This calculation is:

Score = Weight x Likelihood

Overall Score for each Mitigation Option = Sum of all Scores

The scores were totaled to obtain an aggregate weighted score for each option. It is important to recognize that the scores are significant due to their relative values only, not due to their absolute values (i.e., the mitigation option with the highest score is perceived to be the most desirable option; the score does not yield any additional information other than this preference relative to the other options). Furthermore, the scores are relevant within the same river basins and areas only; individual scores cannot be compared against different basins to obtain a meaningful result.

5.3.3 Sensitivity Analysis

A sensitivity analysis was conducted by changing the weights applied to the criteria as follows:

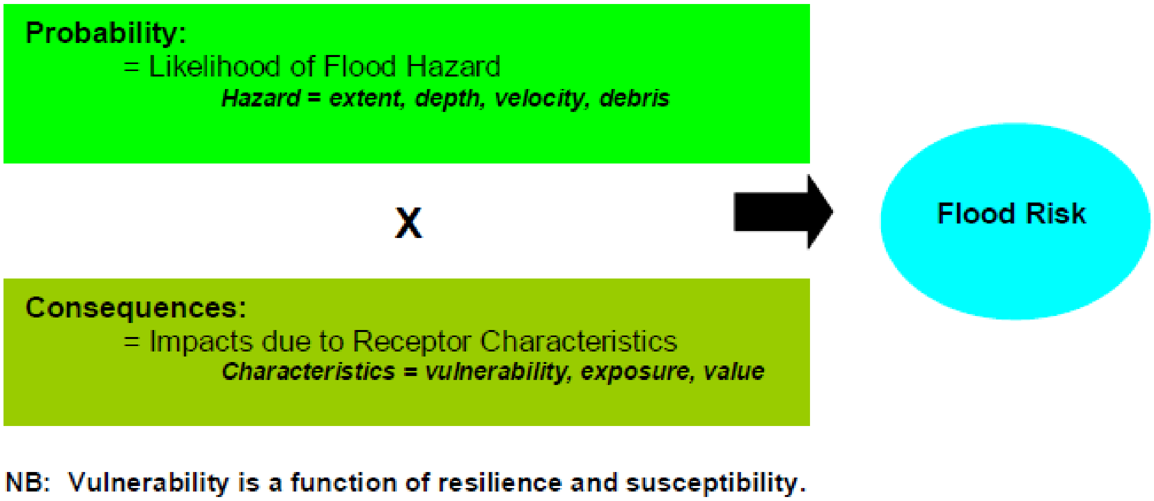
- applying equal weighting to all criteria;
- excluding environmental criteria; and
- excluding cost criteria.

The resulting weights for each analysis are shown in **Table 5.3**. The results of the sensitivity analysis were used to determine if any of the model inputs caused significant uncertainty in the outcome.

6.0 MITIGATION OPTIONS

6.1 The Concept of Flood Risk

For a risk to arise there must be a hazard; something that could potentially lead to damage (**Figure 6.1**). Flood risk can be defined as the probability of negative consequences due to floods and depends on the exposure of elements at risk to a flood hazard.



(Source: SEPA, 2012)

Figure 6.1: Probability, Consequence and Flood Risk

It is important to understand why flood risk management professionals are moving away from referring to return period of flooding and towards referring to the probability of a flood event of a given magnitude occurring in a given year. Referring to a “1:100-year flood” can easily lead individuals to believe that after this flood has occurred, they are safe for another 99 years. It also becomes awkward when referring to several floods over a short period.

By referring to a 1% AEP it is easier to understand that, setting aside longer-term oscillations in regional climate, the likelihood of an event of a given magnitude occurring becomes a matter of probability or chance.

A river is considered primarily as a conduit for the transport of water to the oceans and seas. It is also an efficient means for causing erosion and the transport of eroded material from the river basin to the estuary. Though floods can be very destructive to both the manmade and natural environment it is important to understand that flooding is a natural phenomenon and that some natural processes rely on periodic flooding for the health of the environment. High river flows can help disperse point source pollution, recharge groundwater levels and allow wetlands to flourish. In some extreme cases, such as where the entire basin is within an urban setting, the prevention of all flooding in a basin should never be the aspiration of the flood management professional.

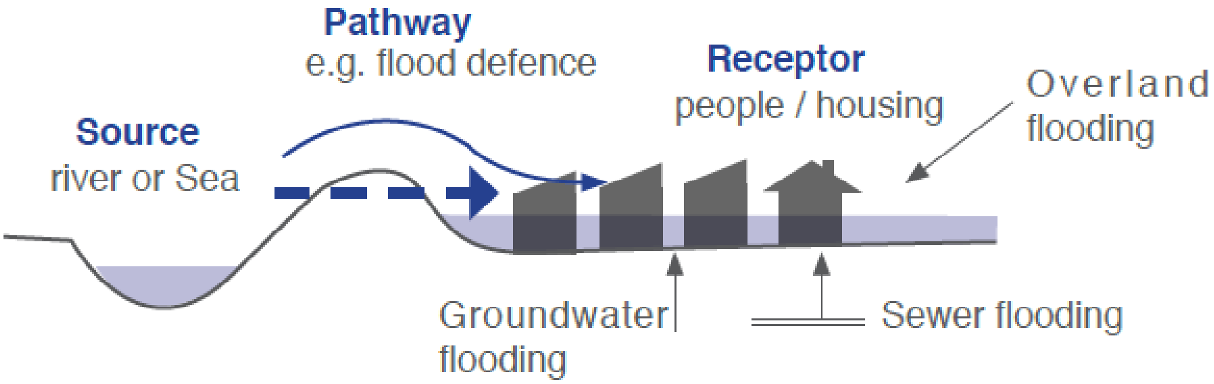
There must be a justifiable socio-economic reason for flood mitigation to make sense; not just from an economic (benefit cost) point of view, but also to avoid unintended consequences of structural mitigation measures.

In order to mitigate against flood risk, it is necessary to first understand the nature of the risk, using a “source pathway receptor” approach.

6.1.1 The Source-Pathway-Receptor Concept

The management and reduction of flood risk requires a thorough understanding of the sources of flood water (e.g., high intense or prolonged rainfall, snowpack leading to runoff and increased flow in rivers and stormwater systems), the people and assets affected by flooding (known as the receptors) and the pathways by which the flood water reaches those receptors (e.g., river channels, drains, storm-sewers and overland flow). The source-pathway-receptor (S-P-R) concept has become widely used to assess the management of environmental risks and inform stakeholders. This is illustrated on **Figure 6.2**.

Though it seems obvious to the engineer, mitigation measures can be effective by modifying the source (for example, by constructing a dam upstream of the flood risk area), the pathway (for example, by constructing a levee), or the receptor (for example, by moving assets at risk out of the floodplain).



(Source: Office of Public Works (Ireland) 2009)

Figure 6.2: Illustration of the Source Pathway Receptor Concept

Effective flood risk management requires identification and assessment of all three components of the S-P-R system and appropriate targeting of the mitigation measure. For example, a given location might be at risk of fluvial flooding from high river levels; however, the properties at risk are constructed on an historic alluvial bed which is highly permeable to groundwater movement. The successful mitigation measure would seek to alter both pathways (i.e., overtopping of river banks or levees and groundwater seepage through the levee). By identifying all pathways of flooding, the mitigation project has a higher likelihood of success.

Another example is where flood risk might be increasing in a locality not because the climate is changing or because the frequency of extreme rainfall is increasing, but because development is being permitted within the floodway or flood fringe. In this case development policy should be reviewed.

This study has sought to understand the nature of flood risk in an area by identifying the sources of flooding (generally fluvial flooding from rivers), the pathway that the floodwater takes to cause damage (or the flood mechanism) and, wherever possible, the specific infrastructure at risk. Where available, the ESRD flood mapping studies were used to quantify and assess flood risk at a community level. In some cases, the improvements recommended are related to improvements to the flood mapping itself (with the intention of reducing the proliferation of development within the floodway or flood fringe areas).

In other cases, historical and anecdotal information was used from the media, internet research, other reports and the consultation process to identify possible schemes. The mitigation measures proposed in Volume 4 include measures that reduce flood risk in a strategic and effective way.

6.2 Design Standard of Protection

In agreement with the FRTF, the normal convention of using a 1% AEP flood as the design standard was used in the design of flood mitigation measures. Where possible, the “flood of record” was assessed against the design to determine if the worst known event would have been prevented by a particular measure. The question of design standard can be an emotive one. There are a number of issues at play which the designer needs to take into consideration and sometimes the balance between economic viability, aesthetics and risk means that the worst event on record would still have caused damage even if the defences had been in place.

6.2.1 Residual Flood Risk

Flood mitigation measures cannot guarantee that flooding will never occur in the protected area. In fact, the introduction of some structural mitigation measures merely changes the pathway to flooding or nature of the risk. For example, the construction of a flood control dam or levees may reduce fluvial flooding but a new risk of breach is introduced and must be taken into consideration in the design process. Risks are often highest during the construction of the mitigation measure, as a flood may occur before the structural integrity of the defence is assured by completion. A breach in a half finished flood defence presents a very serious hazard to those who are meant to be protected.

In view of this residual risk, it is recommended that the GoA undertake to communicate to the public that flood risk can only be reduced, not eliminated.

Recommendation 2.1: The Government should seek to make beneficiaries of flood mitigation schemes aware of the nature and extent of residual flood risk after a scheme is complete.

6.3 Alberta’s Seven Elements of Mitigation

This stage aims to identify a number of measures and options that have the potential to mitigate flooding in the study area. Information comes from the identification of flood risk areas in

conjunction with research, site visits and hydraulic and hydrologic modelling. Where possible, options have been identified with multiple benefits such as drought mitigation.
Feedback from community workshops was used to support and inform the decision making process with regards to selecting and assessing suitable options. Our approach to flood mitigation was underpinned by the Government of Alberta's (GoA's) seven key elements to mitigation, they are:

1. Overall watershed management;
2. Flood modelling prediction and warning systems;
3. Flood risk management policies;
4. Water management and mitigation infrastructure;
5. Erosion Control;
6. Local mitigation initiatives by municipalities; and
7. Individual mitigation measures for homes.

To maintain continuity within the report and to reflect the GoA's seven elements of mitigation, we have aligned the structural and non-structural options to reflect the flooding mechanisms within the study area. The identification of flood mitigation measures has taken place at both local and river basin scales.

The flood mitigation options assessment considers options that:

- Work with natural processes wherever possible;
- Change the probability of flooding;
- Modify receptors (homes and businesses) to reduce the consequences;
- Are adaptable to future changes in flood risk;
- Require actions to be taken to deliver the predicted benefits (for example, opening a gate to operate a weir or flow diversion structure); and
- Can deliver opportunities and wider benefits through working partnerships, where possible.

A risk-based approach to flood management requires a mix of actions to manage both the likelihood and the consequences of flooding. The removal of existing properties from flood risk areas, directing new development away from flood risk areas or the construction of flood defences all reduce the likelihood of flooding. Actions to provide timely flood warnings, or to make individual properties more resilient to flooding, reduce the consequences of flooding.

Table 6.1 outlines the potential mitigation measures that were considered for flood risk areas within the Bow River, Elbow River and Oldman River basins.

Table 6.1
Potential Mitigation Options

Options/Method	Description
Structural Flood Mitigation Options	
Dry dams/flood storage reservoirs	Typically large-scale flood storage areas that attenuate (reduce) the discharge from a basin.
Wet dam/flood storage reservoir	Basins that have a permanent pool of water. They provide temporary storage for additional storm runoff above the permanent water level. Wet ponds may also provide amenity and wildlife benefits.
Bypass or flood relief channels	Managing flood exceedance through the urban environment to improve conveyance and routing to watercourse.
Erosion control/protection	In-stream erosion control measures to reinforce susceptible riverbanks (e.g., riprap/boulder revetments, riverbank bio-engineering, vegetated geogrids, use of geotextiles).
Sediment and debris control	Managing debris that poses a risk to people and property.
Individual household protection/flood resilience	Improved resilience and resistance measures to existing development. Community-scale temporary or demountable flood defences.
Flood dyke/levee	Flood dike/levee refers to an embankment, wall or fill, that is constructed, assembled or installed to prevent the flooding of land.
Non Structural Flood Mitigation Measures	
Improvements to flood forecasting and warning systems	Improvements to the province’s deterministic (or probabilistic) flood forecasting capability and improvements to the methodologies used to disseminate those forecasts to emergency responders and the public Where the onset of flooding is gradual (say >3 hours) homeowners and business owners could register to receive an SMS flood warning message prior to a flood; thereby allowing time to move valuables and people to higher ground.
Buy-outs/removal of existing properties from the floodway	This is normally a reactive measure that is in response to a flood event where an application for disaster relief has been made. Where appropriate the GoA purchases property located within the floodway and the property is demolished.
Managed retreat	This is a proactive measure whereby the Government purchases property located within the floodway or flood fringe as the properties come up for sale or when leases expire. This is generally a long term strategic move.
Building code changes	Updates to municipal building codes, where required. Ensure new development within the flood hazard area is designed and built to be resilient to flooding.
Planning Policy/Land Zoning	Use land zoning and planning policies to direct development away from areas of flood risk. Using a risk based approach, it is still possible to allow certain types of development within flood risk areas while discouraging or preventing developments that are not flood resilient. The process can be underpinned by requiring a site specific flood risk assessment (FRA) for developments that are proposed within the flood fringe or those that are greater than say 1 ha in development area. The FRA would seek to demonstrate that the proposals are safe from flooding and do not increase the risk of flooding elsewhere.

7.0 PROJECTED EFFECTS OF CLIMATE CHANGE ON FLOODS

7.1 Introduction

7.1.1 Background

Over the last four decades, climate scientists have developed a theoretical framework and observational evidence to indicate that the average temperature of the earth is increasing and that part of this increase can be attributed to emissions of greenhouse gases generated by human activities (IPCC, 2007a). Modern climate simulation models, referred to as Global Climate Models (GCM;, technically referred to as general circulation models), have been used to develop quantitative projections of future changes in temperature, precipitation and other climate variables based on estimates of future emissions of greenhouse gases. These models show a consensus that global average temperature will increase, though the amount of projected temperature increase varies with latitude and is not evenly distributed seasonally. Because increases in global average temperature will increase evaporation, global average precipitation will also increase although there is a high degree of uncertainty regarding the amount of that increase and its spatial and temporal distribution. In some areas of the globe, precipitation will decrease.

Theory, and analysis of GCM outputs, indicates that warmer temperatures will change the characteristics of precipitation extremes (Kharin *et al*., 2007) and the pattern of snow accumulation and snowmelt (Kundzewicz *et al.*, 2007; Christensen, *et al*., 2007). This scientific information, along with recent flood events, have motivated infrastructure planners at various levels of government to undertake efforts to quantify the impact of projected climate change on estimates of frequency and intensity of precipitation and runoff. These estimates are used to support hazard assessment and adaptation. This report provides a general quantitative assessment of the impact of projected changes in climate on the frequency and intensity of severe runoff in the Bow River Basin (climate impact assessment).

Estimates of future climate conditions are referred to as *projections*. Projections present estimates of the statistics of future conditions in the atmosphere and the oceans rather than predictions or forecasts of conditions at a particular time and at specific locations. Climate projections are the basis for much of the information and analysis provided by the Intergovernmental Panel on Climate Change (IPCC) in its assessment reports. The *IPCC Fourth Assessment Report: Climate Change 2007* (IPCC, 2007b) contains estimates of future climate based on projections of future climate made by GCMs at more than 20 research institutions worldwide and archived as part of the Coupled Model Inter-comparison Project, (CMIP) Phase 3 (PCMDI, 2013). The fifth assessment report (AR5) is currently in development. The first part of that report, which describes the physical science of climate change, has been issued (IPCC, 2013). It is based on model runs archived as part of the CIMP Phase 5. There is no fourth phase to CMIP; phase numbering was advanced from three to five to be consistent with the numbering of the assessment reports.

The projections from CMIP Phases 3 and 5 have been archived as part of the World Climate Research Programme through the efforts of the Bureau of Reclamation, Lawrence Livermore

National Laboratory and Santa Clara College (WRCP, 2009; Bureau of Reclamation, 2013). The archive contains 112 projections from the CMIP Phase 3 experiment and 234 projections from the CMIP Phase 5 experiment.

7.1.2 Uncertainty in Climate Projections

Uncertainty reflects imperfection in our state of knowledge, as distinguished from variability, which is the effect of random processes. In theory and in practice, such a distinction is not clear cut (e.g., the variability in atmospheric processes leads to considerable uncertainty about tomorrow's weather). Nevertheless, it is important to respect the distinction, because while variability can be addressed in quantitative ways, uncertainty must be addressed, at least in part, by subjective judgment (Vick, 2002).

All measurements contain uncertainty, and estimates of future conditions, such as climate projections, are more uncertain than measurements. Each element of a climate impact assessment contains its own degree of uncertainty. These individual uncertainties do not add up in a straightforward way, but they do interact and each added element does increase the overall uncertainty of the final estimate of impact.

As a practical matter, a portion of the uncertainty about future climate manifests in disagreement between individual projections of future climate conditions and impacts. In North America, the available projections from GCMs show that temperature is highly likely to increase. However, projections of future precipitation are more uncertain (e.g., in some parts of North America model projections disagree on both the sign [direction] and magnitude of changes in precipitation). The sources of this uncertainty include the data and structure of the GCMs, the methods used to relate GCM projections to points or small areas on the earth's surface (downscaling), and the projections of future greenhouse gas emissions. Barsugli, *et al*. (2009) identified the following sources of uncertainty in projections of future climate conditions:

- **Climate Drivers** - The anthropogenic component of climate drivers is greenhouse gas emissions which are formally quantified in emission scenarios. These scenarios in turn depend on projections of future socio-economic, demographic and technical factors.
- **Climate Sensitivity** - This is represented by the climate models themselves. The imperfections in climate models arise from coarse resolution, limitations in simulation of feedback mechanisms (e.g. cloudiness), limited knowledge of initial conditions and a number of other factors.
- **Downscaling** - This is required because of the coarse resolution of climate models and the local nature of climate impact assessments. All downscaling techniques introduce uncertainty.

In addition, there is uncertainty in the models used to assess impact. In just the water resources sector, these can include hydrologic models (both physically-oriented and statistical models), hydraulic models and operations models.

Wilby and Harris (2006) found that the greatest uncertainty in climate impact assessments arose from the climate models themselves, followed, in order, by the downscaling method, the hydrology model structure, hydrology model parameters (i.e., the calibration of the model), and finally by the uncertainty in future emissions scenarios.

Uncertainty in climate drivers and climate sensitivity can be represented by using an *ensemble* (a large number) of climate projections. (Harding *et al.*, 2012) Fortunately, reasonably large ensembles of climate projections are available and can be obtained with a relatively low effort. However, the readily available projections of climate conditions are derived using one downscaling technique, so the uncertainty inherent in downscaling is not represented in the projection ensemble. This uncertainty may be considerable.

The additional uncertainty arising from impact models is not ordinarily evaluated in impact studies, as using multiple hydrologic models, each with multiple calibrations along with multiple hydraulic or operations models, is simply too costly for most agencies. However, it is important to recognize that decision-makers have routinely relied on the results of impact models as the basis for planning and operational decisions, and thus have implicitly accepted the uncertainties in those models.

The results presented herein represent one estimate of the range of future conditions. That range is informed by the range of future projections of monthly average climate conditions across the ensemble consisting of a large sample from the readily available model runs. Collectively, that ensemble reflects the range of emissions scenarios and the different degrees of climate sensitivity among the GCMs and the different assumptions about greenhouse gas emissions used to force those model runs. However, it is exceedingly important to recognize that an ensemble of projections, such as the one used in this study, may not capture the full range of uncertainty. That is, there is some unknown and unknowable probability that the actual future conditions are not contained in the range of projections in any given ensemble.

Accordingly, the results of this work should be used with full consideration of the uncertainties inherent in climate projections, in combination with all relevant sources of information, including recent experience, and with careful professional judgment.

7.1.3 Snow Accumulation and Melt

Collectively, GCMs project increases in annual precipitation over much of North America except for the American southwest and Mexico. In the northern region of North America, including Canada, precipitation is projected to increase in autumn and winter, and models show a greater consensus on winter increases in the more northerly portions of North America. However, as a result of projected increases in temperature, which shortens the season over which snow can accumulate, the ensemble mean of simulations used for the IPCC fourth assessment report projects a general decrease in snow depth in these regions (Kundzewicz *et al.*, 2007; Christensen *et al*., 2007). Exceptions can be found in the extreme northerly, very cold regions of Canada (e.g., near the Arctic Ocean and in the northernmost Northwest Territories), which may experience an overall increase in snow depth (Christensen *et al*., 2007).

Christensen, *et al*., 2007 state that these changes favor an increased risk of winter flooding. The net effect of projected climate conditions over much of Canada is to reduce the amount of water stored as snow and to shift spring runoff earlier in the season. The IPCC 2012 analysis of the impact of climate change on extreme events (IPCC 2012) expresses “high confidence” that there have been historical trends toward earlier occurrence of spring peak flows in snowmelt and glacier fed rivers, and characterizes as “very likely” a projected shift toward earlier spring peak flows. Neither Christensen *et al*. (2007) nor the IPCC (2012) project whether the volume of spring flows will increase.

7.1.4 Heavy Precipitation

Evidence from climate modeling studies indicate that it is likely that the frequency of heavy precipitation or the proportion of total rainfall that comes in the form of heavy precipitation will increase over many areas of the globe (IPCC, 2012). Modeling studies give high confidence that it is likely that the number of days with heavy precipitation and the depth of heavy precipitation will both increase throughout much of Canada. An annual maximum daily rainfall depth that at the present time will occur with a 5% AEP is likely to occur with a 7% to 20% AEP by the end of the 21st century in many regions (IPCC, 2012). There is medium confidence, based on physical reasoning, that projected changes in heavy precipitation will tend to increase rain-generated local flooding (IPCC, 2012), though the effect of seasonal shifts of precipitation may cause mitigating changes in antecedent soil conditions (e.g., lower soil moisture in summer during convective storms).

These projected trends are supported by some evidence of historical trends in heavy precipitation at a global scale. There are statistically significant trends in the frequency of heavy precipitation events in some regions, but as is true with all measures of precipitation, there are large variations across regions. It is likely, however, that more of the regions with statistically significant trends are experiencing increases than decreases in heavy precipitation. According to the IPCC(2012), there is only medium confidence regarding increases in historical heavy precipitation in eastern Canada, and no trend elsewhere in the country. The IPCC (2012) report states, “…there is limited to medium evidence available to assess climate-driven observed changes in the magnitude and frequency of floods at regional scale. Furthermore, there is low agreement in this evidence, and thus overall low confidence at the global scale regarding even the sign of these changes.”

The analyses upon which the IPCC statements are based do not distinguish between rainfall and snowfall (e.g., Kharin *et al*., 2007).

7.2 Projected Future Climatic changes for Upper Bow River Basin

7.2.1 Precipitation and Temperature

Figure 7.1 and **Figure 7.2** show projected future precipitation and temperature for a grid cell straddling the Continental Divide near Banff and Yoho National parks. This location is representative of the snowshed for the Bow River. The grid cell is identified as 97974 in the North American Land Data Assimilation (NLDAS; Mitchell *et al.*, 2004) grid and is approximately

8.7 km × 13.9 km in size. The simulated monthly average precipitation and monthly average temperature on which **Figure 7.1** and **Figure 7.2** are based were obtained from the Bias Corrected and Downscaled WCRP CMIP3 Climate Projections website (WCRP, 2009; Bureau of Reclamation, 2013). Those datasets were produced using the statistical bias-correction and spatial disaggregation (BCSD) method described in Wood *et al*., (2002, 2004).

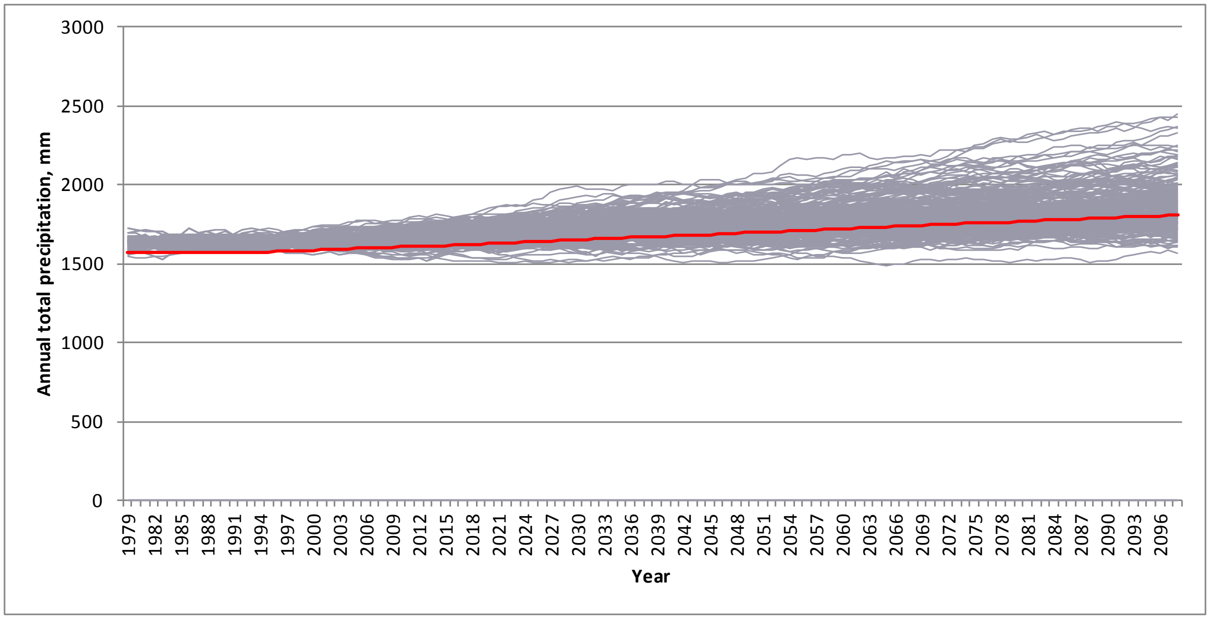


Figure 7.1: Projected 30-year Trailing Average Annual Total Precipitation, mm, for LDAS Grid Cell 97974

*This chart includes 254 projections sampled from the CMIP Phases 3 and 5 ensembles. Fine gray lines represent individual projections and the red line represents the ensemble mean.

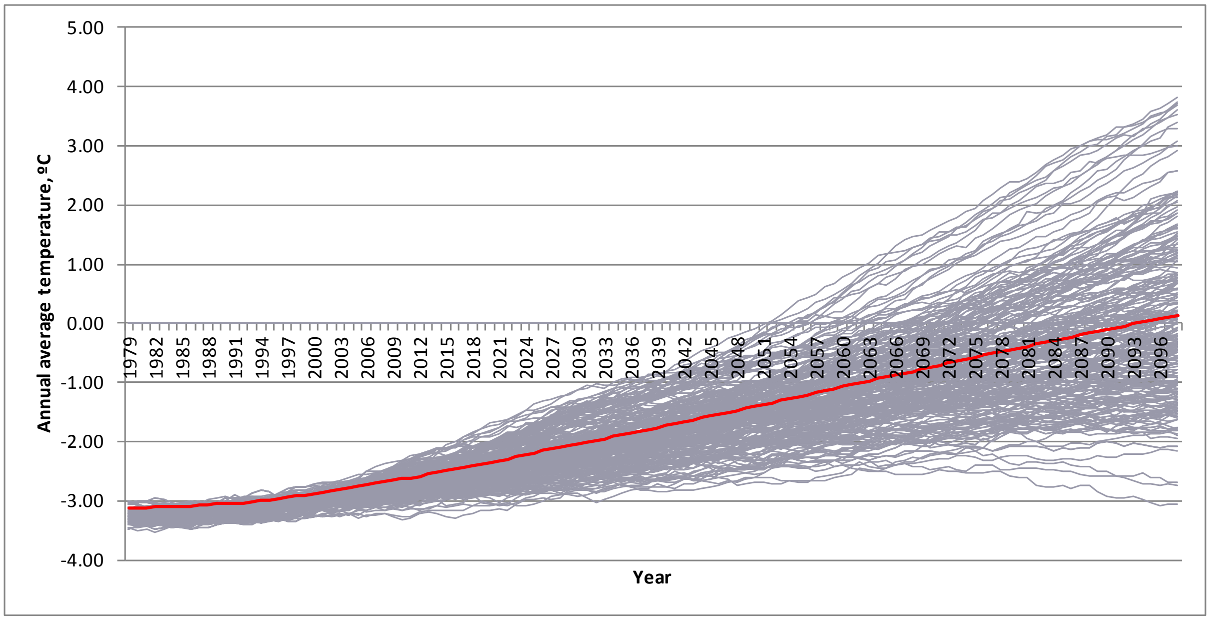


Figure 7.2: Projected 30-year Trailing Average Annual Average Temperature, ° Celsius, for LDAS Grid Cell 97974

*This chart includes 254 projections sampled from the CMIP Phases 3 and 5 ensembles. Fine gray lines represent individual projections and the red line represents the ensemble mean.

Figure 7.1 shows that none of the GCM runs in the sampled ensemble show a significant decrease in precipitation, but there is substantial disagreement across model runs about how much of an increase might occur. The ensemble mean shows about a 15% increase in precipitation by the end of the century. **Figure 7.2** shows that virtually all model runs show substantial increases in temperature. The few projections that show a decline in temperature after about 2050 are from a scenario in the CMIP Phase 5 dataset described as “peak and decline” that envisions concerted, global action to decrease output of greenhouse gases. The ensemble mean shows about a 3º Celsius increase in annual average temperature by the end of the century.

7.2.2 Snow Accumulation and Snowmelt

Projected trends of increasing winter precipitation and increasing temperature complicate the picture of future snowmelt-driven events or the effects of snowmelt contributions to “rain-on-snow” events. On the one hand, increased winter precipitation leads to an increase in the amount of water stored in the snowpack, but this is offset by the effect of increased temperature that shortens the period over which snow can accumulate and likely also reduces the areal extent of snowpack at a given time due to elevation changes in the snow line.

There is no scientific basis to conclude that the probability of snowmelt-driven floods should change, but there is scientific evidence that snowmelt-driven events are very likely to occur earlier in the spring (e.g., Christensen *et al*., 2007).

AMEC conducted hydrologic modeling for LDAS grid cell 97974 (**Figure 7.1** and **Figure 7.2**) using a physical process-based hydrology model, the variable infiltration capacity (VIC) macro-scale hydrology model. The VIC model is a distributed (gridded) macro-scale (regional-scale) physical hydrology model with several applications to climate change studies and successful application to numerous basins around the world (Wood *et al.*, 1992; Liang *et al.*, 1994; Liang *et al.*, 1996; Lohmann *et al*., 1998a; Lohmann *et al*., 1998b, Christensen *et al.* 2004; Christensen and Lettenmaier, 2007). The VIC model has three main components:

1. A component to model land-surface (e.g., evapotranspiration);
2. A sub-surface modeling component (e.g., infiltration and baseflow); and
3. A routing model that simulates transport to points on a flow network.

Distinguishing characteristics of the VIC model include the representation of the following (Nijssen *et al.*, 2001; Wood *et al*., 1992):

- Sub-grid variability in land surface vegetation classes;
- Sub-grid variability in the soil moisture storage capacity;
- Modeling of baseflow as a nonlinear recession;
- Spatial sub-grid variability in precipitation;
- Energy balance modeling of snow dynamics; and
- Modeling of evapotranspiration based on energy transfer and aerodynamic resistance.

The VIC model operates on each grid cell independently. The scale of the grid cells may be varied depending on the application, but in this work the model used a 1/8° spatial resolution, based on the LDAS grid. The VIC model was run on a daily time step. The VIC model uses a separate set of vegetation and soil parameters for each grid cell. The soil and vegetation parameters used in this work were developed during the NOAA/NASA North American Land Data Assimilation System (NLDAS) project (Mitchell *et al*., 2004).

The model forcings were developed using an application of the “delta” or “change fields” approach (Hamlet and Lettenmaier, 1999; Miller *et al*., 2003). A daily meteorological climatology that includes precipitation, maximum temperature, minimum temperature and wind speed for the period from 1949 through 1999, developed as described in Maurer *et al.* (2002), formed the historical climatology and forcing dataset used in this study. Like the downscaled projections, the historical data are aligned spatially to match the LDAS grid. The historical forcings were perturbed by projected changes in temperature and precipitation (wind was not perturbed) to represent projected future conditions in 2050. The change fields were calculated on a monthly basis for each climate projection by comparing simulated average conditions over the period 1950-1999 to simulated average conditions over the period 2035-2064. Change for precipitation was represented by factors; change for temperature was represented by offsets.

The VIC hydrologic model was run once for the baseline historical conditions (forced with the daily climatology) and once for each projection forced with the respective perturbed climatology.

The outputs of the hydrology simulation for the projected future case were compared with the baseline historical case to determine the change in future conditions. For this analysis, changes were calculated for 1 May snow water equivalent (SWE; depth), 1 May total soil moisture depth and 1 April through 30 July total runoff depth. Change factors were calculated for each variable for each of 82 projections sampled from the CMIP Phase 3 (AR4) and CMIP Phase 5 (AR5) ensembles. The quantiles of the empirical cumulative distribution function (ECDF) of the resulting change factors are shown in **Table 7.1**.

Table 7.1
Quantiles of the ECDF of Projected Changes in Annual Hydrologic Conditions

Percentile	Runoff	SWE	Soil Moisture
5%	8%	-12%	-1%
10%	9%	-9%	1%
25%	13%	-4%	3%
50%	18%	3%	9%
75%	27%	9%	16%
90%	36%	15%	22%
95%	40%	16%	24%

Note: Percentile is the non-exceedance value across 82 climate projections sampled from the CMIP3 and CMIP5 ensembles. Changes are in percent relative to average values for the historical period. Positive values mean increases, negative values mean decreases. Runoff is annual April to July runoff. SWE is 1st May, and soil moisture is 1st May soil moisture.

7.2.3 Heavy Rainfall Events

Guidance for adjusting the intensity and return period of heavy precipitation can be found in the published literature. Kharin *et al*. (2007) looked at annual maximum daily precipitation (rainfall or snowfall) from GCM outputs averaged over the North American continent. Alain Mailhot and his colleagues at the Institut National de la Recherche Scientifique in Quebec (Mailhot *et al*., 2012) looked at annual maximum rainfall projected by regional climate models (RCMs) for four durations over fourteen regions in Canada.

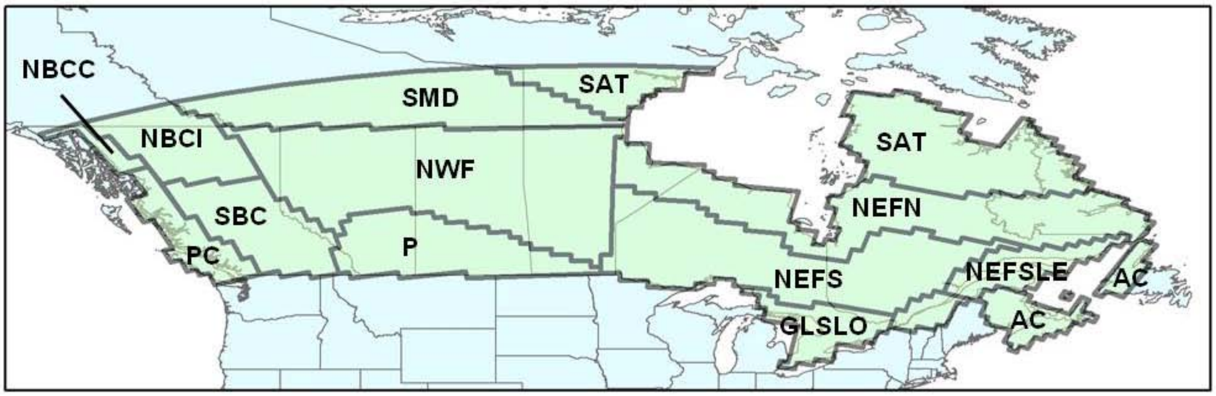
Kharin *et al.* (2007) estimated projected changes in heavy precipitation depth and annual probability for North America for 2046 to 2065, and for 2081 to 2100. The projected changes are shown in **Table 7.2**.

Table 7.2.
Estimated Projected Changes in Heavy Precipitation Depth and Frequency

Period	Change in Depth (%)	Projected AEP for Current 5% AEP Event
2046 to2065	+3% to +16%	13% to 7%
2081 to 2100	+5% to +23%	20% to 8%

Source: Kharin *et al*., 2007

Mailhot *et al.* (2012) reported aggregate values for changes in heavy precipitation depth for fourteen regions, listed and illustrated in **Figure 7.3**. Mailhot *et al.* (2012) reported that the greatest increases in heavy precipitation for all durations and return periods were in Ontario and the prairies. Some areas in British Columbia and in the Northwest Territories are projected to experience a decrease in heavy precipitation.



North British Columbia - Coast (NBCC)	Southern Arctic Tundra (SAT)
Pacific Coast (PC)	Northeastern forest - South (NEFN)
North British Columbia - Inland (NBCI)	Northeastern forest - North (NEFS)
South British Columbia (SBC)	Northeastern forest - St Lawrence Estuary (NEFSLE)
South Mackenzie District (SMD)	Great Lakes St-Lawrence - Ontario (GLSLO)
Northwestern Forest (NWF)	Great Lakes St-Lawrence - Quebec (GLSLQ)
Prairies (P)	Atlantic Canada (AC)

Source: Mailhot, *et al*., 2012

Figure 7.3: Canadian Climatic Regions

For each of the 14 regions shown in **Figure 7.3**, Mailhot *et al.* (2012) developed estimates of projected mean changes in precipitation depth for the period 2041 to 2070 for storm durations of 6, 12, 24 and 120 hours and for annual probabilities of 50%, 20%, 10% and 5% (return periods of 2, 5, 10 and 20 years). Mailhot *et al.* (2012) also provide error estimates, in the form of the standard deviations of results across the region, which incorporate both spatial variability (due to atmospheric dynamics and topography) and disagreement among the models used to project future conditions. **Table 7.3** shows the projected changes for the prairies region.

Table 7.3
Projected Changes Mean and Standard Deviation of Annual Maximum Precipitation

Annual Exceedence Probability (AEP)				
Storm Duration	**50%**	**20%**	**10%**	**5%**
	Change in mean precipitation, %			
6 hours	19	20	21	22
12 hours	18	18	18	18
24 hours	18	17	16	16
72 hours	16	15	14	14
120 hours	16	15	15	14
	Change in mean standard deviation, %			
6 hours	4	4	5	5
12 hours	3	3	4	4
24 hours	3	3	3	3
72 hours	3	3	3	3
120 hours	3	3	3	3

Changes are relative to historical values. Positive values mean increases.
Source: Mailhot *et al*., 2012

An important caveat regarding the results of Mailhot *et al.* (2012) is that, for practical reasons and resource limitations, the analysis used an ensemble of four model simulations. Each model simulation involved a RCM and a GCM. The larger scale GCM results are used to set the boundary conditions for the RCM run that operates at a finer spatial resolution. Grid cell scale for a GCM is typically about 200 km or more; grid cell resolution for the RCMs used in the Mailhot *et al.* (2012) study was 50 km. RCMs must take conditions at the edges of their domains from GCMs, so they inherit some of the uncertainty exhibited in the GCM ensemble. To put the size of the Mailhot ensemble in context, the IPCC fourth assessment report (discussed above) relied on an ensemble of 112 runs of 16 different GCMs. Each RCM and GCM have their own characteristics, and each run of an RCM or a GCM will vary from other runs that are initialized differently. Accordingly, the error estimates made by Mailhot *et al.* (2012) understate the true value of model-to-model disagreement that would be apparent from analysis of the full GCM ensemble and using the full set of RCMs (a total of several hundred runs).

7.3 Qualitative Assessment of Expected Changes in Flood Volumes

Recent severe flooding in the Bow River watershed has been the result of precipitation from multi-day storms with low annual probabilities falling on snow. In these low probability events, approximately 70% of the resulting runoff originates directly from rainfall, with the remaining approximately 30% originating from snowmelt. These storms have occurred in late spring, while snowmelt is occurring and while streamflows are elevated by normal seasonal snowmelt.

Projected changes in extreme precipitation by Mailhot *et al.* (2012) are somewhat sensitive to storm duration, but are not significantly sensitive to annual probability. Storm durations of interest range from 24 through 120 hours, and across that range Mailhot projects increases in precipitation depth of about 15%. If rainfall constitutes approximately 70% of storm event streamflow, then the effect on streamflow of these projected changes in precipitation will be about 11%.

AMEC's hydrology modeling shows a median change in 1st May SWE of about 3%. This translates to an increase in streamflow of about 1%, assuming a contribution from snowpack of approximately 30%. At the 90th percentile non-exceedance, the contribution of snow pack to streamflow would be approximately 5%.

Thus, depending on the range of conservatism adopted for planning purposes, the storm event volumes can be expected to increase from about 12% to about 16%. Storm event volumes are only a surrogate for peak flows, but because only very specialized and rarely used models can directly simulate storm events, there is not sufficient scientific basis to quantify the impact of future climate on peak flows in a context that also illustrates the uncertainty in such projections.

Projected changes in normal seasonal runoff and soil moisture, from hydrology modeling, both point towards increased storm event volumes. The median April to July runoff is projected to increase by about 18%, and the 90th percentile of the estimated projected increase is 36%. While seasonal runoff will probably be a small component of flows in a severe flood, they will still contribute to incremental increases in damage. Soil moisture is also projected to increase; increased soil moisture at the outset of a storm will increase the peak flow and storm event volume. It is difficult to quantify the effect of antecedent soil moisture without conducting storm-event hydrology modeling, but virtually all projections show an increase of 1st May soil moisture, which supports the expectation that storm event volumes and peak flows will increase.

There is not sufficient scientific evidence available in the literature to provide projections for the change in the seasonality of heavy precipitation. Should future heavy precipitation come later in the year, watersheds may be less responsive to precipitation, because snowpack, runoff and soil moisture may be lower than has been the case with recent storms. However, a trend toward earlier occurrence of heavy precipitation might increase the responsiveness of watersheds.

8.0 OVERVIEW OF HISTORICAL FLOODING

8.1 Introduction

Flooding in the Bow and Oldman river basins is a common occurrence along watercourses. While flooding along small streams affects those living or working in local areas, the major floods that occur along the largest streams can affect millions of people, and severely disrupt business, and agriculture. Causes of flooding and a review of the frequency and severity of flooding in the Bow River and Oldman River basins will be discussed in this chapter.

8.2 Causes of Flooding

Flooding can result from three primary causes:

- Rainfall;
- Rainfall during snowmelt (commonly referred to as "rain-on-snow"); and
- Ice jams.

Other impediments to flow such as debris jams, culvert blockages, etc. can result in local flooding on smaller streams.

Rainfall can occur as a result of convective summer rainstorms affecting relatively small areas over short durations or from larger frontal storms that affect one or more river basins at the same time. The former might only have an appreciable effect on small local streams, while the latter affects one or more major watercourses. As the large frontal storms have the greatest effect, this flood-producing mechanism will be discussed more fully below.

Severe storms affecting river basins in southern Alberta have the same general characteristics. Cold low pressure systems deepen appreciably as they pass onto the prairies east of the Rocky Mountains. The anti-clockwise flow of air around the centre of the low draws warm moist air up from the south and from as far away as the Gulf of Mexico. This air moves westward around the northern side of the low towards the Rocky Mountains. The rising topography within the foothills and the Rocky Mountains immediately to the west forces the westward-moving moist air to rise rapidly. The rising air mass cools as it rises and as the air cannot contain as much moisture when it cools, significant precipitation can occur. As reported in Alberta Environment (1983), Nemanishen 1978 discussed the probability of such storms occurring in southern Alberta.

> *"A study of Former cold-low Flood events along the eastern slopes of the Rocky Mountains indicates that there is a high incidence of these storms. There is about thirty percent probability that in any given year, a severe rainfall event will occur somewhere along the eastern slopes from Montana to central Alberta. The probability of a specific Alberta River basin (such as the Oldman, Bow, Red Deer, etc.) experiencing destructive flooding in any given year is about five percent."*

Flooding from glacier melt affects only local areas in the Rocky Mountains, and does not have an appreciable effect on streamflows further downstream.

8.3 Historical Flood Events

Information on regarding the frequency and magnitude of historical flooding is contained within written reports and streamflow (hydrometric) data gathered by provincial and federal agencies.

The primary federal agency responsible for gathering and publishing hydrometric data is the Water Survey of Canada (WSC), which operates within Environment Canada. In addition to the data WSC gathers as a part of a federal-provincial cost sharing agreement, the WSC obtains data from provincial partners and non-governmental partners, including TAC, and irrigation districts.

Table 8.1 indicates the years during which major flood events occurred on southern Alberta streams based on flow records for selected WSC hydrometric stations. From this table it can be seen that major flood events have occurred in 1908, 1915, 1923, 1929, 1932, 1942, 1948, 1953, 1964, 1975, 1990, 1995, 2005, and 2013 along various streams in southern Alberta. This information suggests that flooding is relatively frequent, over two dozen events have occurred in 100 years. This corroborates the conclusion reached by Nemanishen (1978) discussed above.

Table 8.1
Select Historical Floods in Southern Alberta

	St. Mary River	Lee Creek	Belly		Waterton		Pincher Creek	Crowsnest River	Oldman				South Saskatchewan River	Elbow					Bow		Red Deer	North Saskatchewan River	
	Lethbridge	Cardston	Mountain View	Glenwood and Standoff	Waterton Park	Glenwood and Standoff	Pincher Creek	Frank	Wadron's Corner	Cowley	Fort Macleod	Lethbridge	Medicine Hat	Elbow Falls	Bragg Creek	Sarcee Br	above Glenmore Dam	below Glenmore Dam	Banff	Calgary	Red Deer	Rocky Mountain House	Edmonton
1908					680													159					
1915	162		38.8	76.5	60.6			34.8		123		626	2400					239	236	796	1590	3680	4640
1916	254		77.3	93.2	206	297		47.6		170		1220	2200					146	309	767	705	1060	1670
1923	101	22	63.1	69.7	155	309				626		2360	3710					331	377	714	985	1260	2380
1929	109	15.5	39.6	60.9	115	161				419		1110	3060					382	215	1150	968	850	1080
1932	139	6.82	51									852	2710					311	279	1160	1040		1870
1937	196	57.2	118			360						1130	1290		64.8		53.2	54.9	148	257	149		892
1942	165	44.2	71.1			447						2340	2080		155		127	128	166	303	527		1200
1948	362	130	88.1		171	317						2830	2550		183		127	154	292	558	682		1850
1951	136	110	69.1	223	121	294		44.7	125		125		1680		82.7		137	152	243		377		1100
1952	67.4	12.4	27	51	72.2	108		25.7	51		51		1070		59.7		79	80.4	155	408	1070		3540
1953	408	96.8	120	273	200	382		65.7	337		337	2890	4080		118		132	124	260	513	612		1270
1954	175	20.3	68.5	69.7	150	202		58.9	127		127		1090		39.4		48.1	59.7	286	388	1210	1060	3030
1963	86.1	8.33	47.9	16.2	128	160		28.6	198		198	861	1550		141		124	99.1	183	317	174	648	1050
1964	447	151	303	292	643	467		47.6	131		131	1980	1830		89.5		62.9	70.2	246	351	382	776	1350
1965	122	22.5	69.1	67.1	155	266		59.7	155		155	923	1520		127		104	99.7	289	456	731	1050	2590
1967	185	34.8	62.9	75.3	133	205		47	242		242	1060	2170		185		199	146	275	382	504	617	1000
1970	147	27.4	85.2	124	176	270		19.7	91.5		91.5	722	1360	52.1	92		97.1	105	155	331	841	1120	1520
1972	131	17.7	73.6	63.7	167	209		59.7	217		217	867	1350	38.8	49.8		41.9	41.1	311	402	648	1470	2970
1975	702	146	331	267	467	660		48.7	286		286	2440	2860	39.4	49.3		49	43.3	144	224	210		419
1995	522	166	184	340	449	902	79.9	92.8	539		539	4100	4200	93.1	190			144	263	452	410	587	1010
2002	196	114	89.9	220	180	300	62.8	50.1	180		180	1590	1800		70.2	80.4		84.1	226	339	105	220	360
2005	370	74.9	70.6	91.3	115	245	66.4	47.3	362		362	2190	3490		231	268		251	167	602	1180	2150	2270
2008	65	51.8	102	110	207	188	32.5	50.7	168		168	760	1560		125	183		160	163	287	511	620	972
2010	860	164	77.2	171	118	287	58.2	26.1				1810	2020		43.3	49.1		51.2	138	185	161	313	837
2013																				1700			

Legend	
🟥	1 - Highest
🟧	2nd highest
🟨	3rd Highest
🟩	4th Highest
🟩	5th Highest

In addition to the systematic record for the WSC hydrometric stations, there are records of other historical flooding occurring prior to the start of recorded water levels and stream flows. **Table 8.2** lists some historical data for the Oldman River at Lethbridge and for the Bow River at Calgary.

At the time of writing this report, only the flow estimates made by AENV, 1983 are available. The stage data is currently being researched. AENV, 1983 state that data for Table 8.2 were estimated by extrapolating the rating curve at the gauging station site and are thus expected to be very uncertain.

Table 8.2
Historical Floods Prior to the Start of Streamflow Gauging

Year	Annual Maximum Instantaneous Discharge (m^3/s)	
	Oldman River at Lethbridge[1]	Bow River at Calgary[2]
1879	No estimate	2,270
1897	No estimate	2,270
1899	No estimate	n/a
1902	No estimate; greater than flood of 1908	1,560
1908	3,960	(part of systematic record)

Notes:
1. Beckstead and Garner, 1978.
2. AENV, 1983

n/a - no reference to this flood being significant in the Bow River basin.

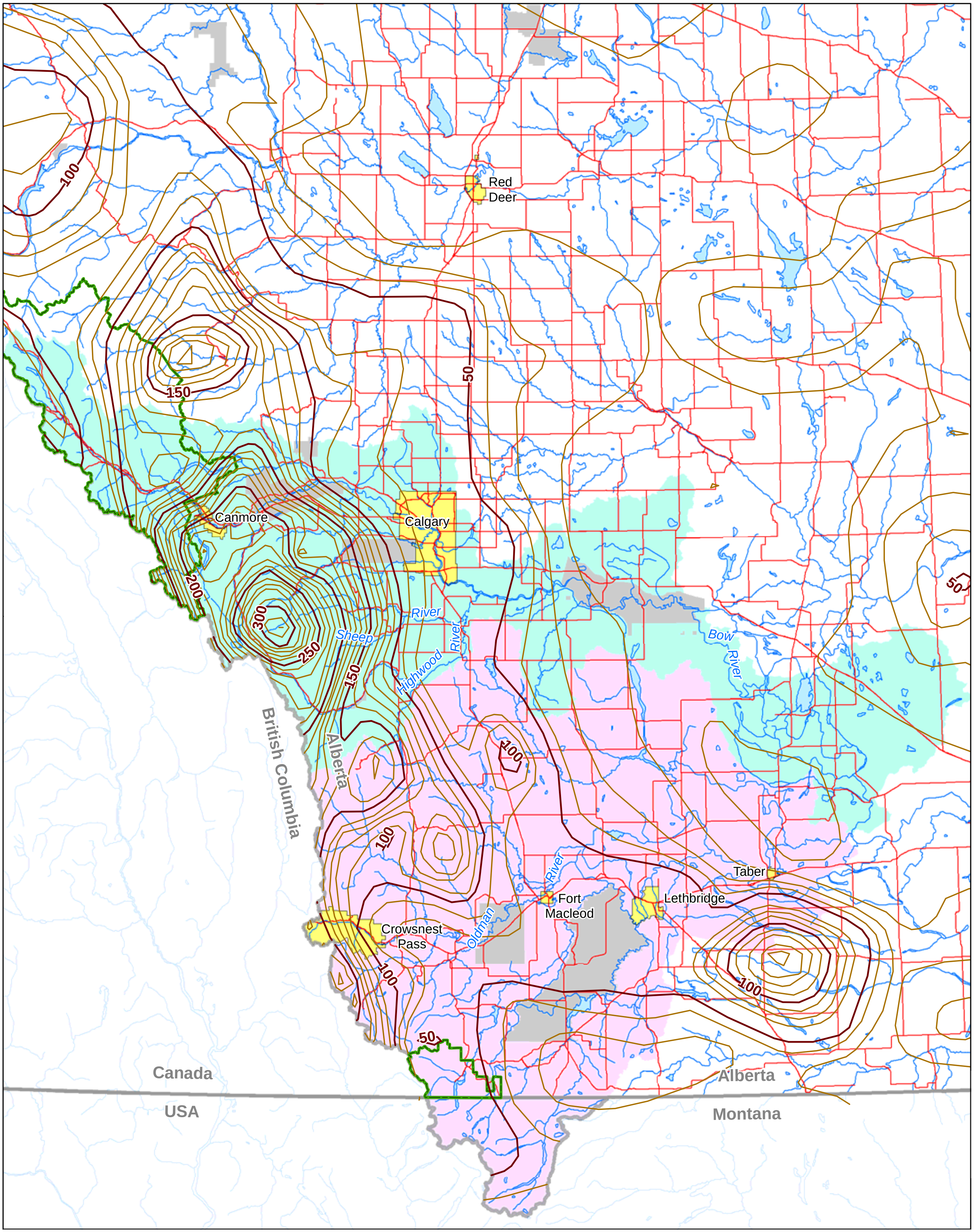
8.4 The 2013 Flood Event

The June 2013 flood event was an extreme flood event that affected primarily the Bow, Elbow, Sheep, Highwood and South Saskatchewan river basins. Portions of the Red Deer and North Saskatchewan river basins were also affected, but to a much lesser extent.

8.4.1 Rainfall

8.4.1.1 Rainfall Depths

Figure 8.1 illustrates the rainfall isohyets based on information obtained from ESRD. The data for 19 to 22 June 2013 indicate accumulated precipitation of over 200 mm across portions of the Bow, Elbow, Sheep and Highwood river basins. There were local areas within the upper Elbow River and Sheep River basins where the rainfall reached over 310 mm. The accumulated precipitation in the Bow River and Elbow river basins amounted to 1 090 000 dam^3 and 247 000 dam^3, respectively. These translate to basin average precipitation depths of 138 and 203 mm for the Bow River and Elbow river basins, repectively.



Sources: GeoBase®, Spatial Data Warehouse Ltd.

Legend

🟦 Bow River Drainage Basin
🟪 Old Man River Drainage Basin
🟨 Urban Municipality
🟩 National Park
▨ Indian Reserve
🟦 Lake
— River
— Highway

Isohyet Interval = 10mm

PDF: Fig8.1 2013 Isohyets 14-03-14			
DATE: March 2014	PROJECT: CW2174		
PROJECTION/DATUM: 10TM/NAD83	ANALYST: NH		

Alberta Flood Recovery Task Force
Flood Mitigation Study

10 0 10 20
Kilometres
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Rainfall Isohyets for the 19 June to 22 June 2013 Storm Over the Bow River and Oldman River Basins

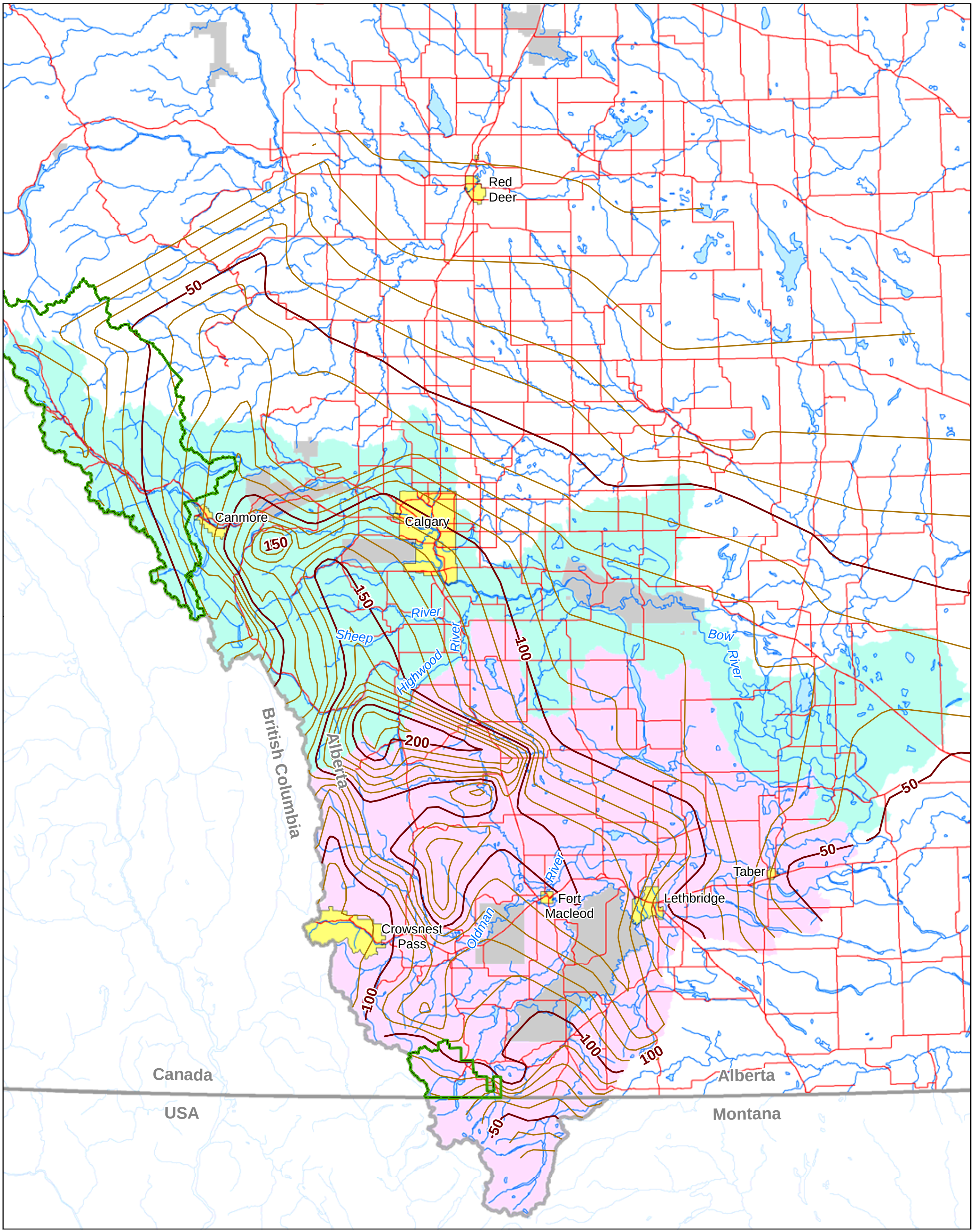
Figure 8.1

S:\Gis\Projects\CW2174_Flood_Mitigation\ArcGIS\Report March 2014\Fig8.1 2013 Isohyets.mxd

Figure 8.1 illustrates the rainfall isohyets, which indicates areas of high precipitation near the Spray River valley south of Banff. A more significant zone of high rainfall is evident short distance to the southeast in the headwaters of the Elbow River and Sheep River. The rainfall depths decrease sharply to the northwest into the upper Bow River Basin.

Figure 8.2 and **Figure 8.3** illustrate the storm isohyets for the 1995 flood and the 2005 flood, respectively. Comparing the isohyets for 2013 (**Figure 8.1**) to those for the events in 2005 (**Figure 8.2**) and 1995 (**Figure 8.3**), it is evident that rainfall depths were much lower for 2005 and lower yet for 1995 within the Bow River Basin. This conclusion is corroborated by computed average rainfall depths of 65 mm for 2005 (approximately half of that for 2013) and 44 mm for 1995 (one-third of that for 2013).

In the Oldman River Basin, the 2013 average basin precipitation upstream of Lethbridge was less severe, amounting to about two-thirds of the precipitation that resulted in the 2005 and 1995 floods. This percentage is a basin-wide value that does not account for areas of intense precipitation in smaller catchments, such as the Crowsnest River, where very high flood discharges occurred.



Sources: GeoBase®, Spatial Data Warehouse Ltd.

Legend

🟩	Bow River Drainage Basin	🟨	Urban Municipality	🟦	Lake
🟪	Old Man River Drainage Basin	☐	National Park	—	River
		▨	Indian Reserve	—	Highway

Isohyet Interval = 10mm

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amec

PDF: Fig8.2 2005 Isohyets 14-03-14

DATE: March 2014

PROJECT: CW2174

PROJECTION/DATUM: 10TM/NAD83

ANALYST: NH

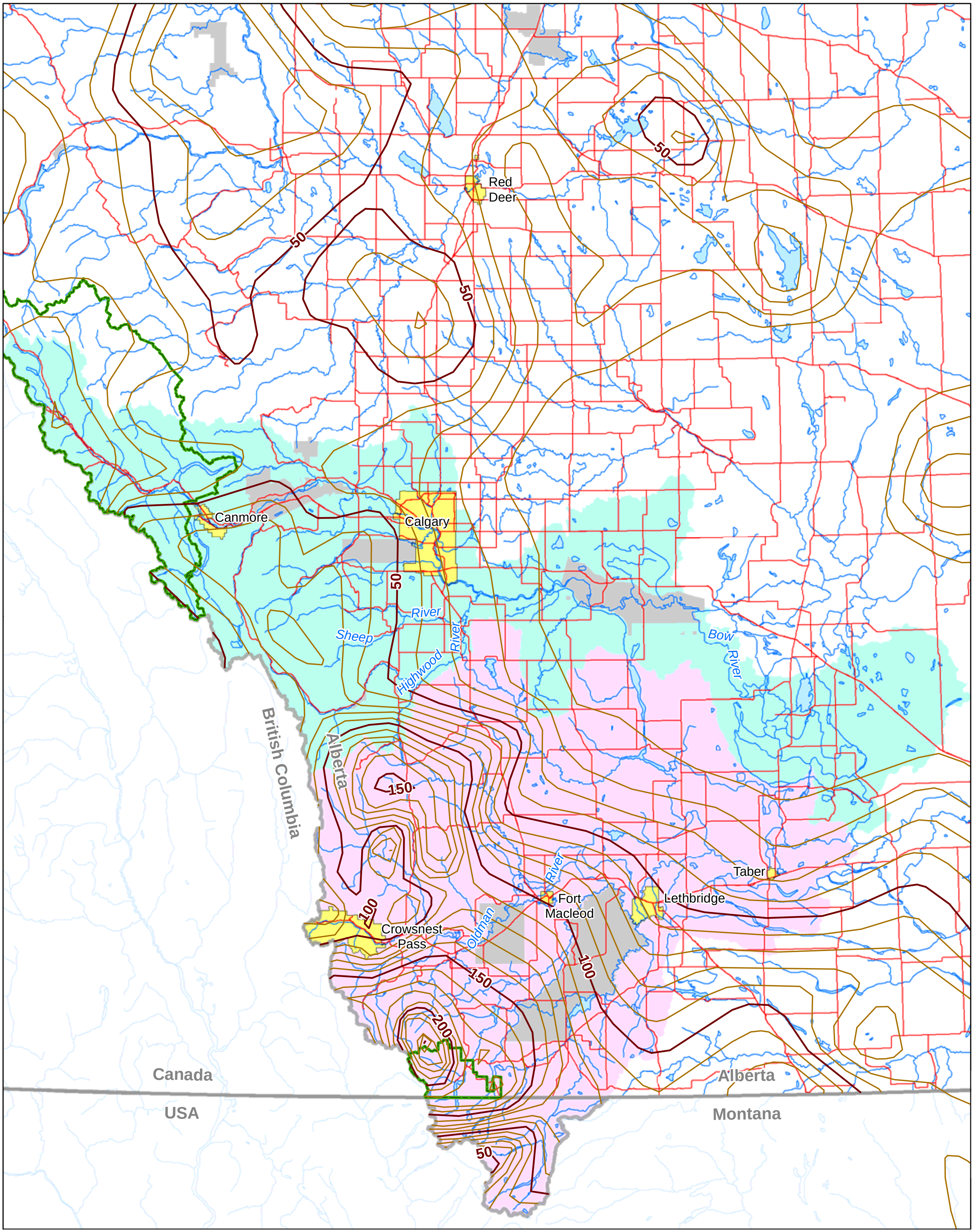
Alberta Flood Recovery Task Force

Flood Mitigation Study

10 0 10 20
Kilometres
1:2,100,000
N

Rainfall Isohyets for the 06 June to 09 June 2005 Storm Over the Bow River and Oldman River Basins

Figure 8.2



Sources: GeoBase®, Spatial Data Warehouse Ltd.

Legend

- 🟩 Bow River Drainage Basin
- 🟪 Old Man River Drainage Basin
- 🟨 Urban Municipality
- ☐ National Park
- ⬛ Indian Reserve
- 🟦 Lake
- — River
- — Highway

Isohyet Interval = 10mm

amec

PDF: Fig8.3 1995 Isohyets 14-03-14
DATE: March 2014
PROJECT: CW2174
PROJECTION/DATUM: 10TM/NAD83
ANALYST: NH

Alberta Flood Recovery Task Force
Flood Mitigation Study

10 0 10 20
Kilometres
1:2,100,000
N

Rainfall Isohyets for the 05 June to 07 June 1995 Storm Over the Bow River and Oldman River Basins

Figure 8.3

S:\Gis\Projects\CW2174_Flood_Mitigation\ArcGIS\Report March 2014\Fig8.3 1995 Isohyets.mxd

The rainfall from the event accumulated at rates of up to 17.2 mm per hour on 19th June 2013 at Spray Reservoir meteorological site. **Figure 8.4** illustrates the rainfall accumulations at selected meteorological stations in the Bow River basin. The slope of the lines in **Figure 8.4** is indicative of rainfall rates. The greatest rainfall rates appear to have occurred late on 19 June and early on 20 June. **Figure 8.4** also indicates temporal changes in rainfall over some sub-basins. There appears to have been a second rainfall event, albeit at a lesser rate, between mid-day on 20 June to late on 21 June.

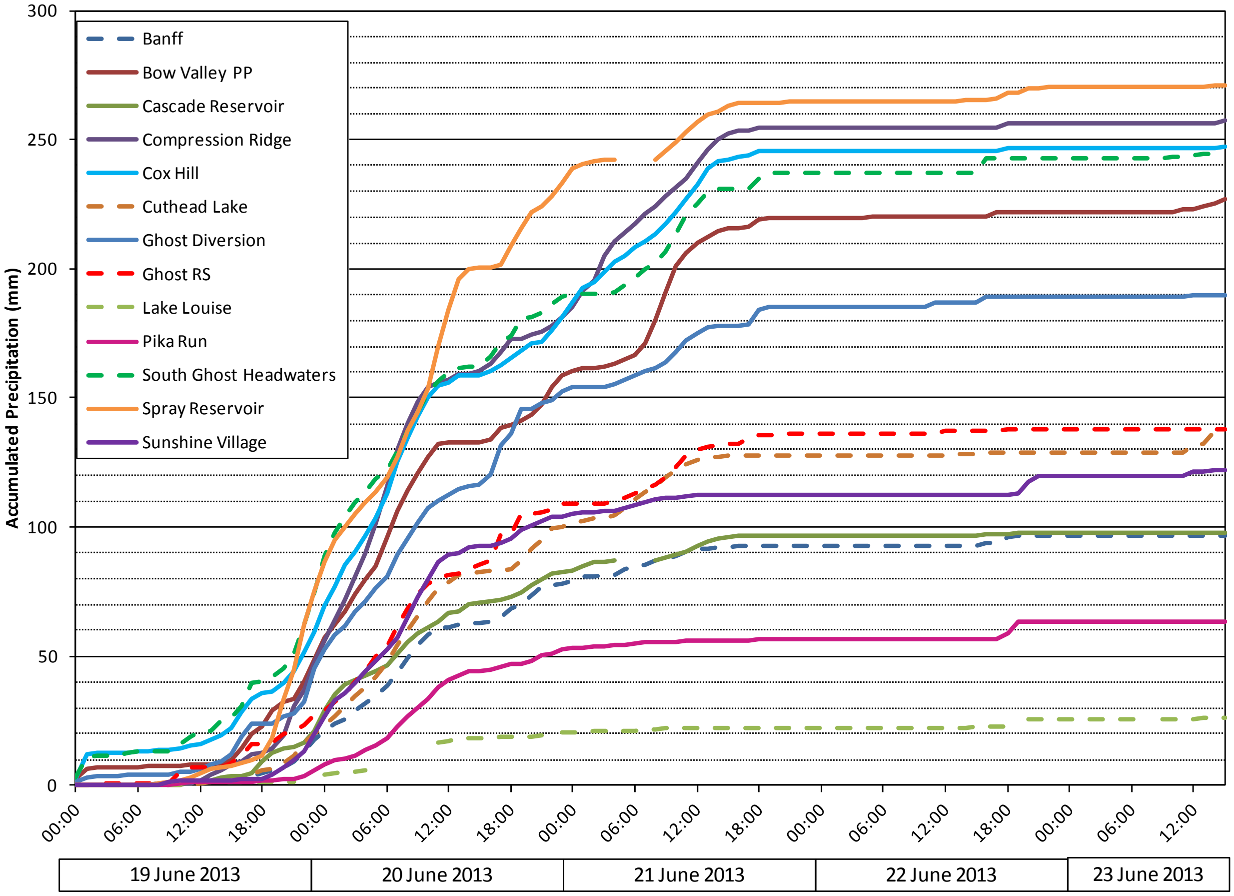


Figure 8.4 Rainfall Accumulation in the Bow River River Basin During the 19th to 23rd June Storm Event

The flood of 2013 resulted from extreme high rainfall over the upper Elbow River basin during a period when snowmelt was still ongoing. **Figure 8.1** illustrates the rainfall isohyets, which indicates areas of high precipitation in the headwaters of the Elbow River adjacent to the Sheep River Basin. The sizeable zone of over 200 mm rainfall depth in the upper Elbow River Basin. Overall, the Elbow River basin upstream of Calgary received an average of 203 mm of rainfall.

Comparing the isohyets for 2013 (**Figure 8.1**) to those for the events in 2005 (**Figure 8.2**) and 1995 (**Figure 8.3**), it is evident that rainfall depths were much lower for 2005 and lower yet for

1995 within the Elbow River Basin. This conclusion is corroborated by computed average rainfall depths of 123 mm for 2005 (60% of that for 2013) and 67 mm for 1995 (one-third of that for 2013).

Not surprisingly, the greatest rainfall occurred in the foothills and mountain areas, while little rainfall occurred on Prairies. Data provided by the University of Calgary (Marshall, 2013) has been plotted to illustrate this effect. The data represent a series of rainfall gauges along an approximately west-east transect running from Town of Banff area and along the Elbow river valley west of Calgary to the Strathmore area east of Calgary. **Figure 8.5** illustrates the west to east rainfall gradient. It is illustrative to note how the trend in accumulated rainfall depth closely parallels the ground elevation at the gauges.

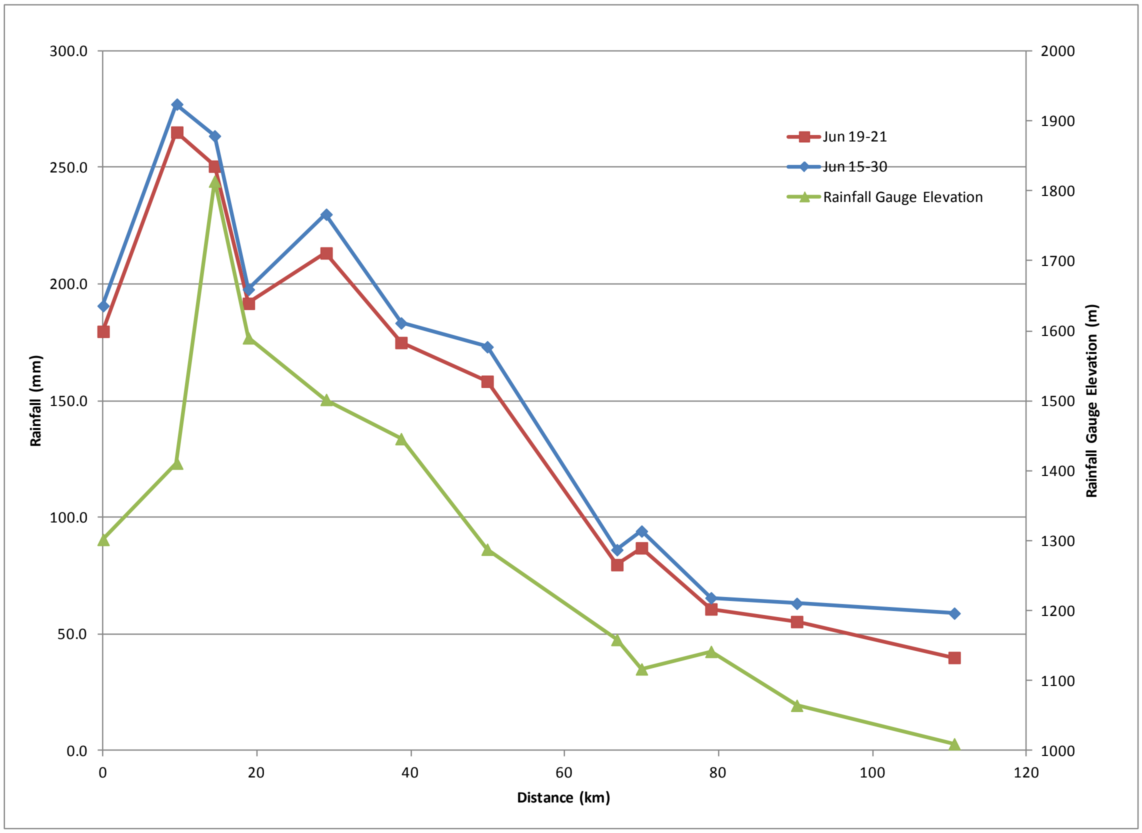


Figure 8.5: June 2013 Rainfall, University of Calgary Foothills Climate Array

8.4.1.2 Rainfall Rates

Long-term short-duration and daily rainfall data in the upper Bow River basin are available for the meteorological station at Kananaskis (MSC Station 3053600). **Figure 8.6** indicates that for the 1-day, 2-day and 3-day duration, the June 2013 rainfall exceeded the 1% exceedence probability magnitude, and might have approached the magnitude for the 0.5% event for the 3-day duration. Rainfall data obtained at the nearby Cox Hill and Bow Valley Provincial Park meteorological stations was compared to the intensity-duration-frequency (IDF) curve for the

Kananaskis meteorological station. **Figure 8.6** indicates that for durations less than 24-hours the 2013 rainfall was less than the 1% exceedence probability magnitude. Further, for comparison purposes, the rainfall recorded at the Spray River gauge far exceeded the rainfall for the other two sites and might have had a very low exceedence probability based on the Kananaskis IDF curve.

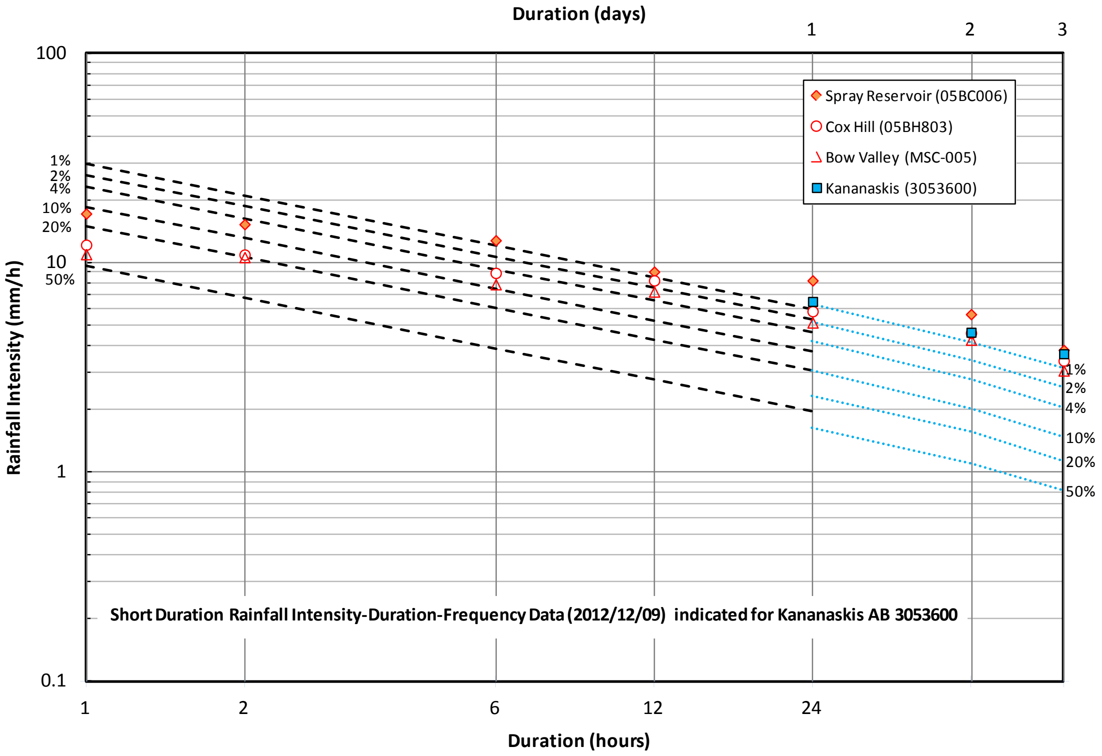


Figure 8.6: Kananaskis IDF and 2013 Rainfall at Adjacent Stations

8.4.2 Snowmelt

Snowpack existed in the mountain areas of the catchments of interest at the onset of the June 2013 event. Temperature and the thremal effect of rainfall falling on the snowpack contributed to accellerated and agmented runoff. Data provided by ESRD indicates that between 29 and 131 mm of snow water equivalent was lost to the snowpack during the event. This water contributed to runoff. **Figure 8.7** illustrates the snowpack lost from selected snowpack measurement sites. All of these sties are above 2,000 m elevation. Their locations are illustrated on Figure 2.3 in Volume 4.

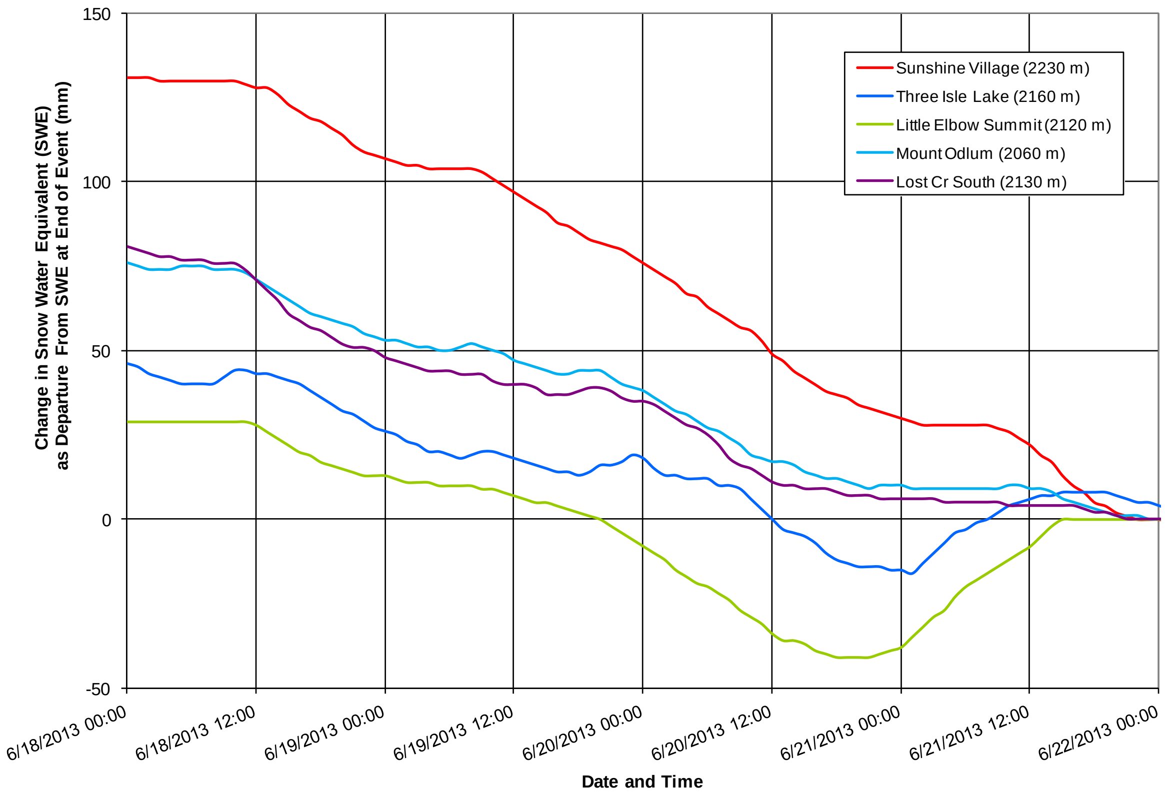


Figure 8.7: Snowpack Depletion During June 2013 Rainfall Event

Thus the total contribution of snowmelt and rainfall was in the range of 350 to 400 mm at some locations. This “rain on snow” event resulted in extreme runoff and significant high discharges along streams in the Bow River and Elbow River basins.

8.4.3 Discharges

8.4.3.1 Bow River at Banff

The flow at Banff reached a record high peak discharge of 401 m^3/s at 17:00 on 21 June 2013, based on preliminary data received from WSC. The previous historical high discharge was 399 m^3/s on 14 June 1923. **Figure 8.8** illustrates the 1923 and 2013 flood hydrographs.

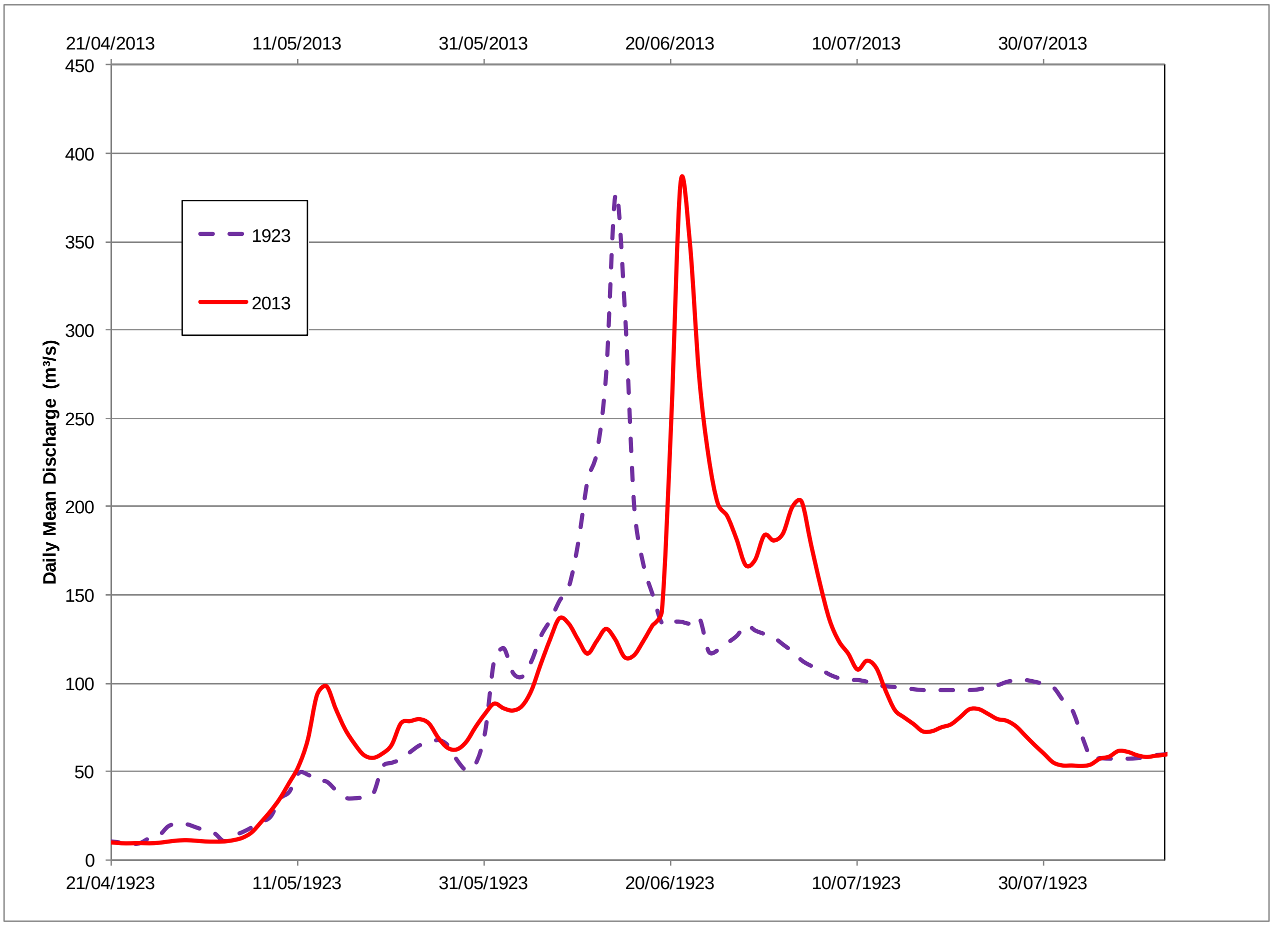


Figure 8.8: Comparative Flood Discharge Hydrographs for 1923 and 2013, Bow River at Banff

The 2013 peak discharge at Banff is estimated to have an annual exceedence probability of less than 0.5%, based on a frequency analysis provided by Northwest Hydraulic Consultants (2013).

8.4.3.2 Bow River Between Banff and Calgary

TAC (2013) provided the preliminary information presented in **Table 8.3** for flow releases from their upstream facilities up to end of day on 21 June 2013.

Table 8.3
Flow Releases from TAC Upstream Facilities

Facility	Maximum Inflow	Maximum Release
	(m^3/s)	(m^3/s)
Lake Minnewanka	314	27
Spray Lake	255	18
Upper Kananaskis Lake[1]	99	0
Lower Kananaskis Lake[1]	117	0
Barrier Lake[2]	360	

Notes:

1. AMEC understands that maximum releases occurred following 21st June 2013.
2. At Barrier Dam, the spillway operation passed the inflow.

Hydrometric information is not readily available for many of the tributary streams entering the Bow River because many stream gauging stations were not operable at the time of peak flow. However, an indirect assessment of the peak discharge reached along the Ghost River was provided by TAC (Golder, 2013a and 2013b). The estimated peak discharge for the Ghost River at Benchlands (downstream of the mouth of Waiparous Creek and upstream of the discontinued WSC gauge 05BG001) was 670 m^3/s. The estimated exceedence frequency of this June 2013 peak discharge is 0.56% to 0.67%.

TAC indicates that the spill from Barrier Dam on the Kananaskis River could have reached 360 m^3/s and that the peak flow in Jumpingpound Creek likely exceeded 130 m^3/s (the gauge was out of service prior to the peak).

8.4.3.3 Bow River at Calgary

The flow in the Bow River at Calgary (upstream of the Elbow River confluence) reached a record high peak discharge of 1,780 m^3/s at 02:45 on 21st June 2013, based on preliminary data received from WSC. The previous historical maximum recorded discharge was 1,520 m^3/s on 3rd June 1932. **Figure 8.9** illustrates the 1932 and 2013 flood hydrographs.

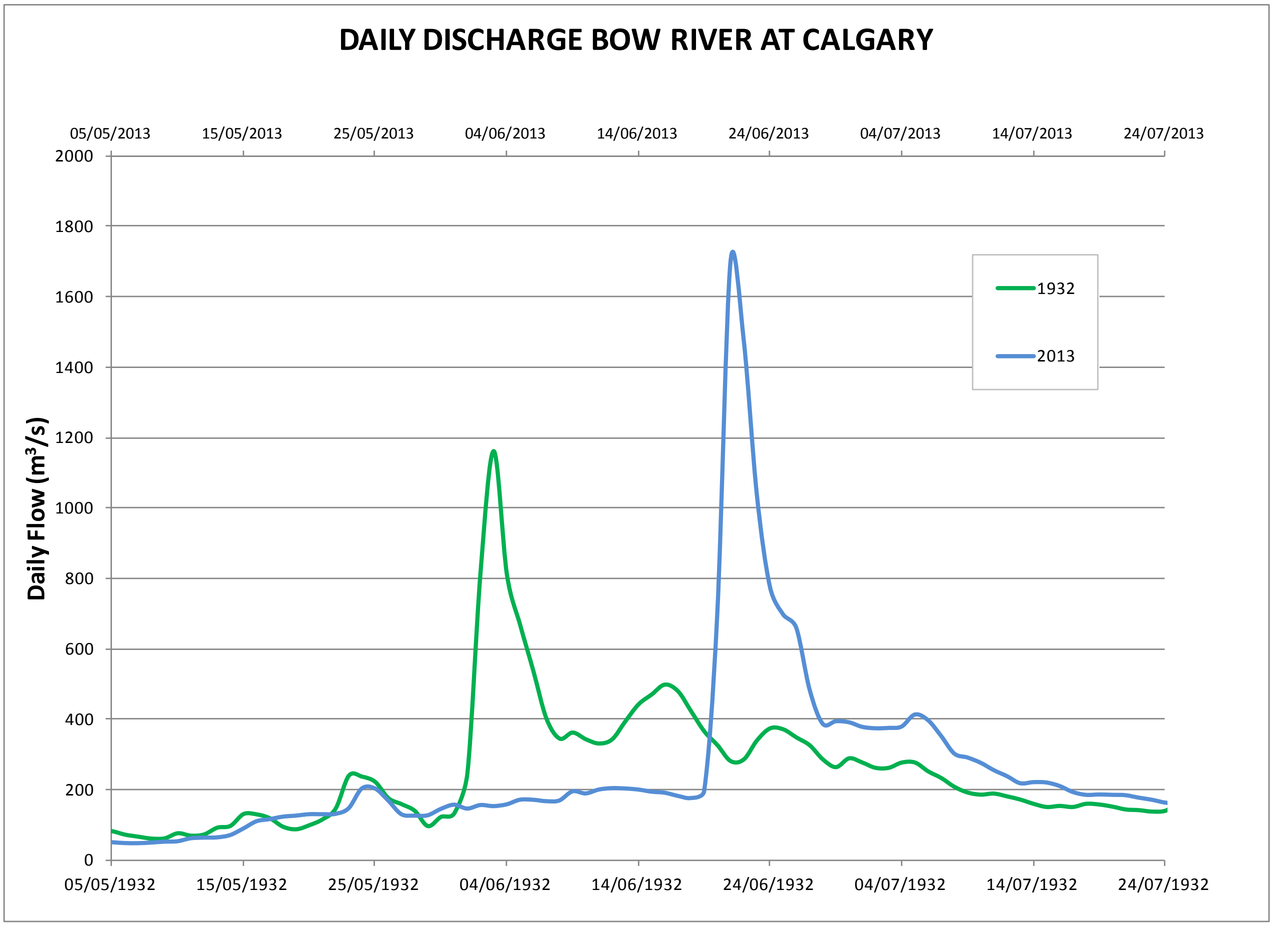


Figure 8.9: Comparative Flood Discharge Hydrographs for 1932 and 2013, Bow River at Calgary

The 2013 peak discharge for the Bow River at Calgary is estimated to have an annual exceedence probability of less than 1%, based on a frequency analysis provided in Golder Associates (Golder) 2010.

8.4.3.4 Bow River Downstream of Calgary

June 2013 rainfall within the Nose Creek basin appears to be in the range of 50 to 70 mm. There has been no indication that flooding was a problem along Nose Creek. Based on an interview with the Town of Airdrie, there was no flooding along Nose Creek during the 2013 storm.

The Elbow River enters the Bow River downstream of the WSC station 05BH004. Flooding occurred along the Elbow River, which is discussed more fully in **Section 8.4.3.5** in this volume.

As Fish Creek has its headwaters in the foothills southwest of Calgary, high rainfalls resulted in high streamflows in Fish Creek. No estimate of discharge for the Fish Creek at Priddis WSC hydrometric station is currently available. AMEC understands that there was erosion damage and overbank flooding at and around Priddis. Further downstream, several pedestrian bridges were washed out in Fish Creek Provincial Park.

The Highwood River enters the Bow River downstream of Calgary. The characteristics of the Highwood River flood hydrology and damages are addressed by AECOM under a separate contract.

Downstream of the mouth of the Highwood River, very high discharges and water levels were experienced during the 2013 flood. At Carseland Weir, where the discharge likely exceeded 3,540 m^3/s (WSC gauge 05BM002 was not operable), a fuse plug in the diversion embankment washed out.

Further downstream at the Bassano Dam, the peak discharge is estimated to have reached between 3,900 and 4,200 m^3/s, based information provided by the Eastern Irrigation District (EID). ESRD commented that when the discharges are high, the river tends to flood the river valley and the station rating curve indicates an unrealistic low discharge value (approximately 3,340 m^3/s) for the measured 2013 peak water level compared to the EID spillway discharge estimates.

Near the confluence with the Oldman River, WSC has estimated the peak discharge on the Bow River to have been 3,490 m^3/s on 23 June 2013 (station 05BN012).

8.4.3.5 Elbow River Basin

Limited estimates of discharge are available for the Elbow River basin. At Bragg Creek, discharges have been simulated by hydrological modeling. **Figure 8.10** illustrates simulated flood discharges by ESRD using their SSARR model and by AMEC using the HEC-HMS model. The near real time (NRT) discharge was derived from the stage-versus-discharge rating curve used by ESRD. In addition, WSC also conducted an indirect discharge determination from surveyed high water mark information, which resulted in a peak discharge value of 1,220 m^3/s. This value is subject to review/revision. Observed water levels came from recorded water levels at the WSC hydrometric station on the Elbow River at Bragg Creek (05BJ004). This plot suggests that the NRT observed discharge might be low, given that it was derived from an extrapolation using the existing rating curve for the gauge.

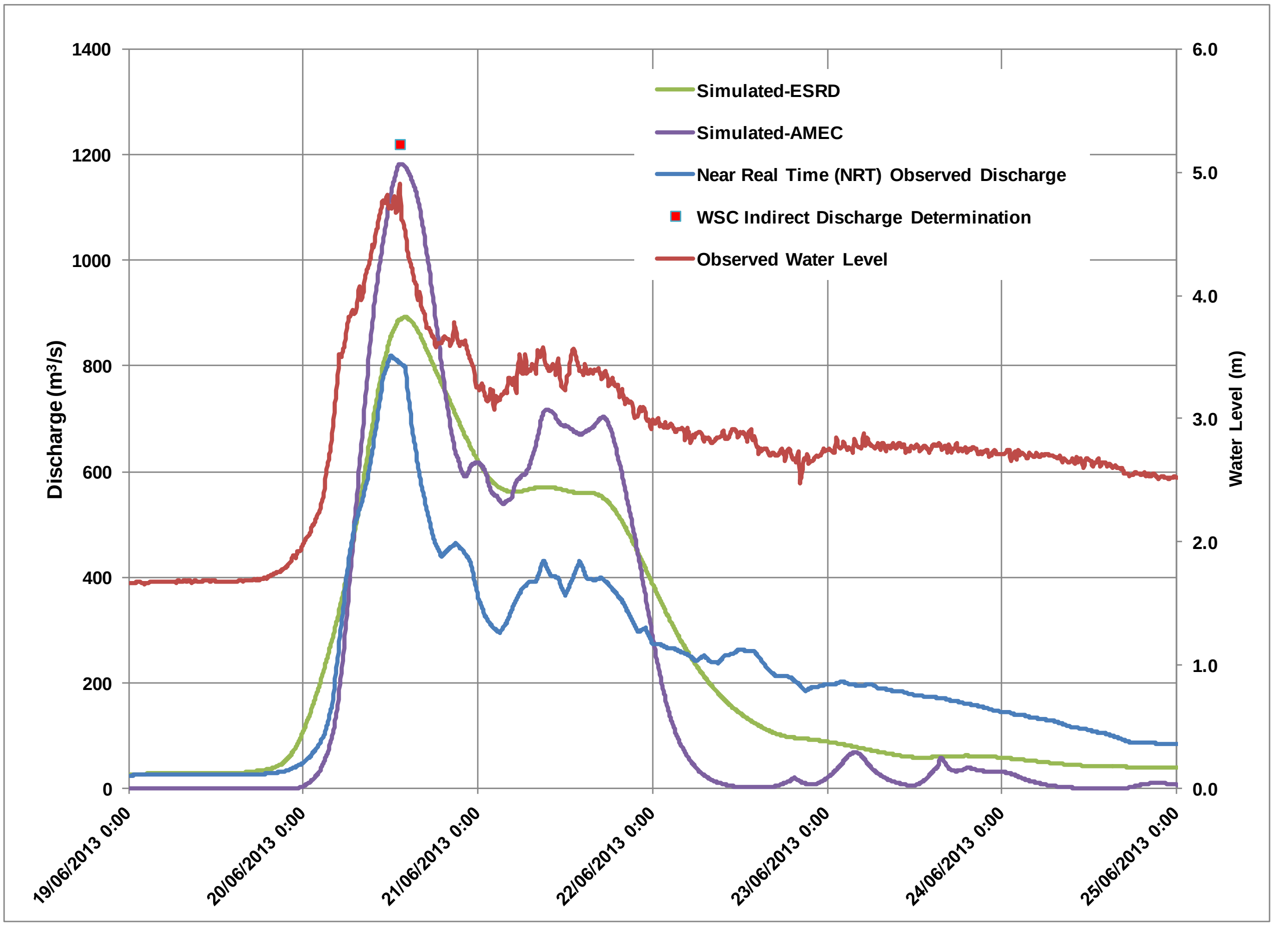


Figure 8.10: Simulated and Observed Discharges and Observed Water Levels at Bragg Creek during the June 2013 Flood

Figure 8.11 illustrates historic water levels at Bragg Creek[2]. The recorded maximum mean daily water level and maximum instantaneous water level for 2013 are also provided for comparison. Clearly, the water levels reached in 2013 far exceed previous recorded water levels.

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[2] In 1983, the hydrometric station was moved upstream to its present location. A surveyed elevation change between the old gauge datum and the present gauge datum is not available. To estimate this elevation change, the difference between the median stage for the old dataset (29 years) and the median for the data at the present location (30 years) was computed. This difference of 5.163 m was used to produce estimates of the annual maximum stage at the present location for the period when the gauge was at the old location downstream.

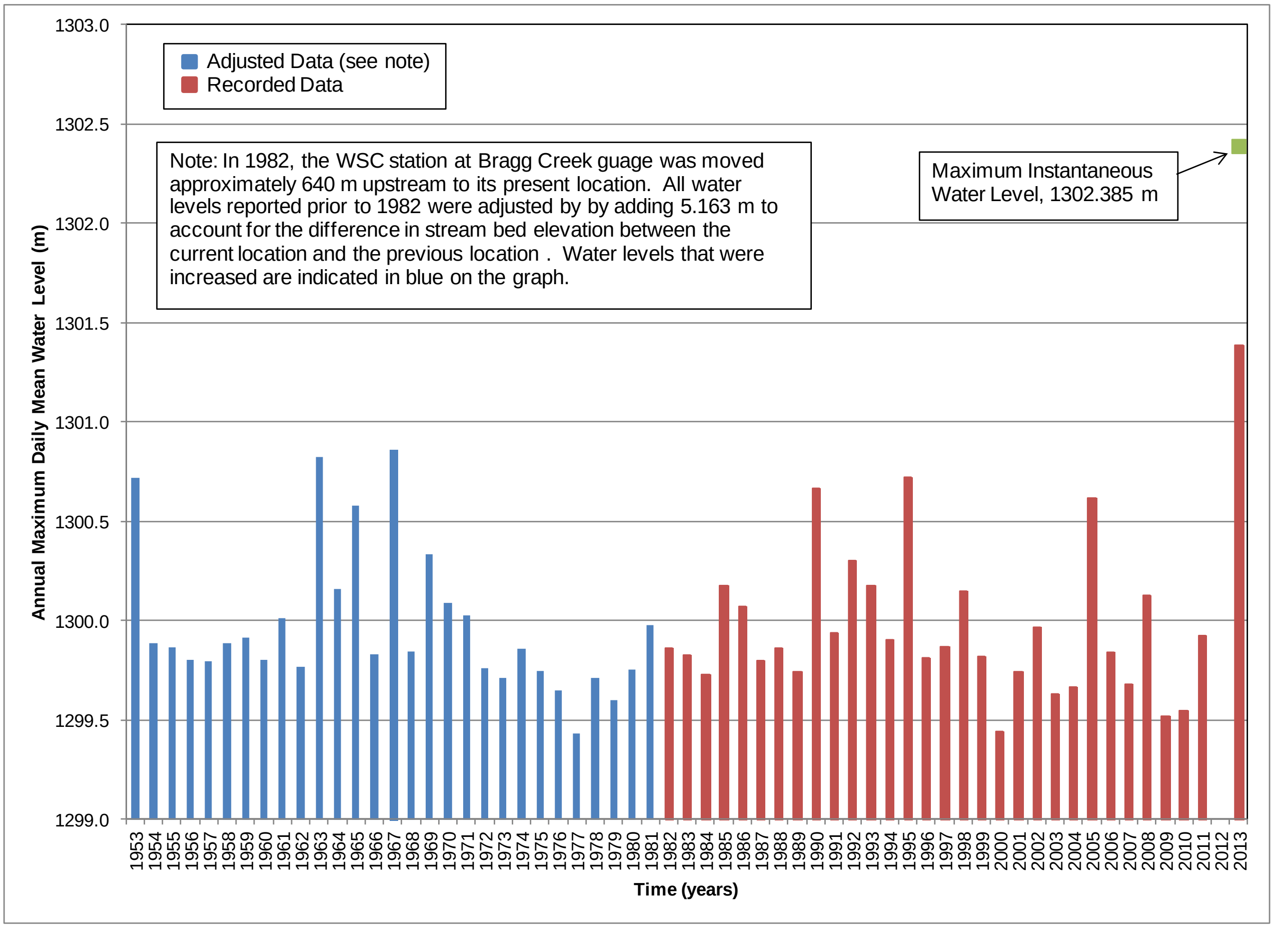

Figure 8.11: Historic Water Levels Recorded at WSC Station 05BJ004, Elbow River at Bragg Creek

A frequency analysis was conducted using the annual maximum mean daily water levels to 2011 from **Figure 8.11**. The results are plotted in **Figure 8.12**. In addition, the computed peak water levels for a range of flood frequencies from UMA Engineering (1992) for Section 15 corresponding to the present location of WSC hydrometric station 05BJ004 have also been plotted. From this, the following estimates of the exceedence probability of the 2013 flood water levels at Bragg creek can be made:

- 0.2% for the maximum daily mean water level; and
- 1% for the maximum instantaneous water level.

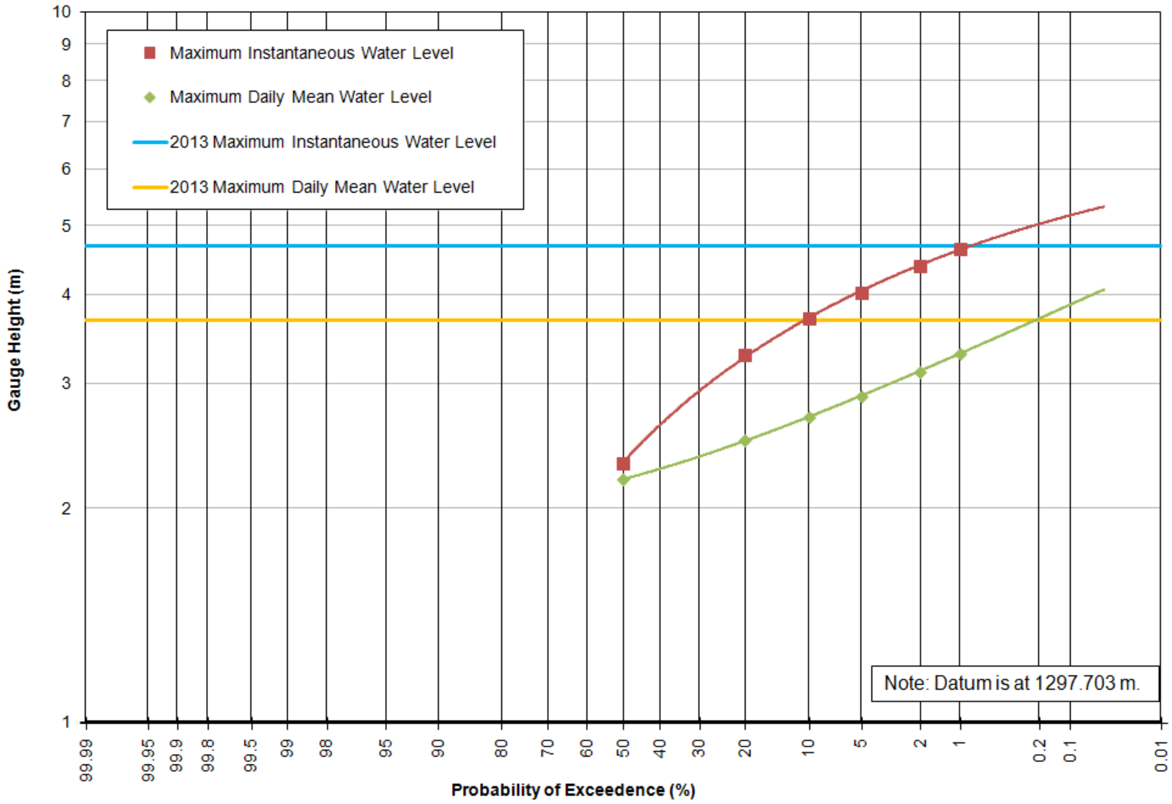

Figure 8.12 Frequency Curves of Water levels at WSC Hydrometric Station 05BJ004, Elbow River at Bragg Creek

Historic flood discharges for the Elbow River at Bragg Creek are illustrated on **Figure 8.13**. Discharge estimates for 2013 previously illustrated on **Figure 8.10** (simulation values of 894 and 1,180 m^3/s, and the WSC indirect discharge determination value of 1,220 m^3/s) are provided for comparison. The discharge frequencies provided on **Figure 8.13** from UMA (1992) clearly indicate that the flood discharge at Bragg Creek was in excess of the 1% exceedence probability value.

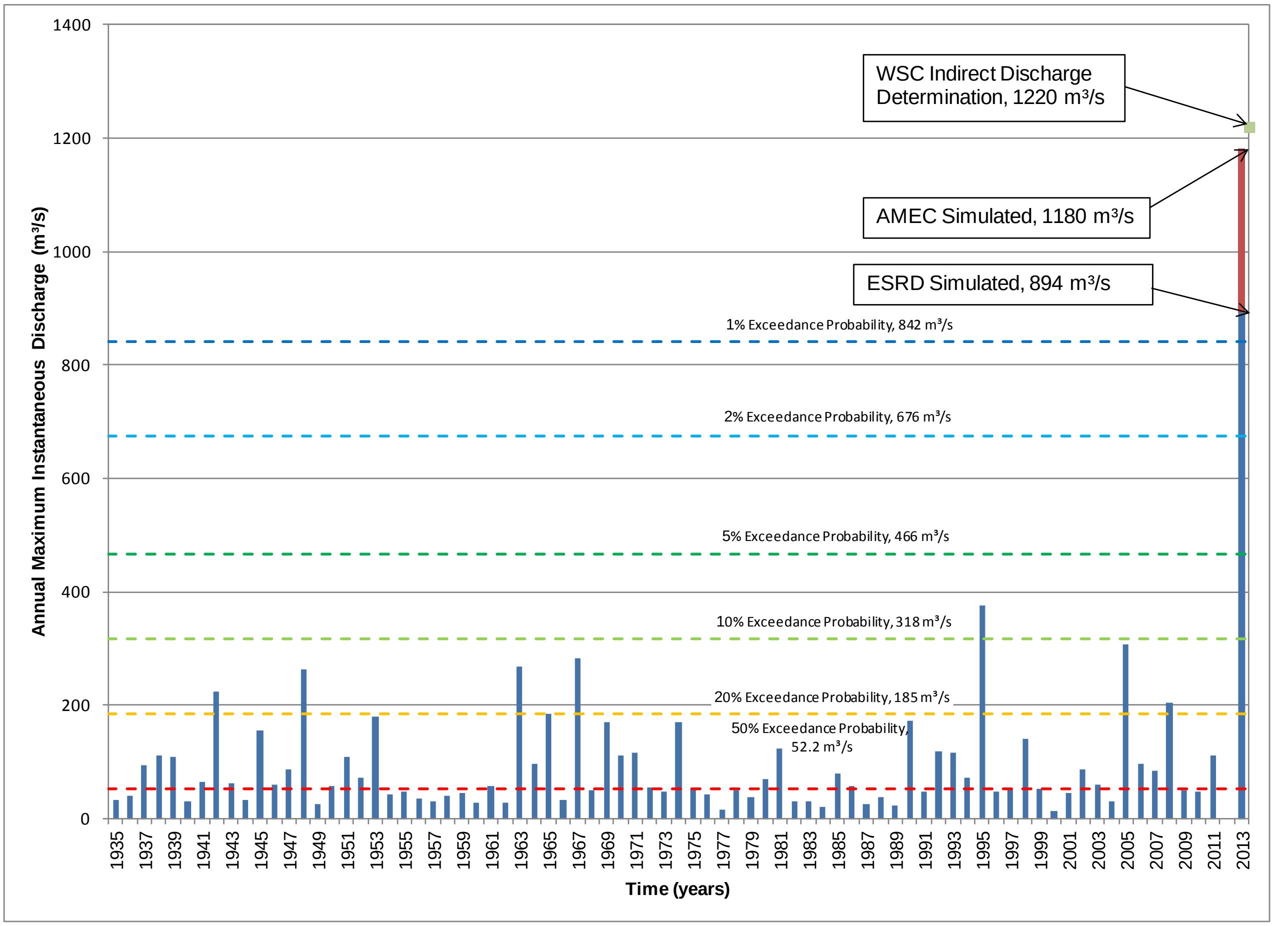

Figure 8.13: Historic Discharges for Elbow River at Bragg Creek

Estimates of discharges for Elbow River downstream of Bragg Creek are available at the location of WSC hydrometric station 05BJ010, Elbow River at Sarcee Bridge, located immediately upstream of Glenmore Reservoir. These discharge estimates were derived by WSC from surveyed high water mark information and from back-calculating inflows to Glenmore Reservoir based on measured reservoir water levels and outflows. **Figure 8.14** illustrates the estimated discharge hydrograph and peak discharge estimate upstream of Glenmore Reservoir.

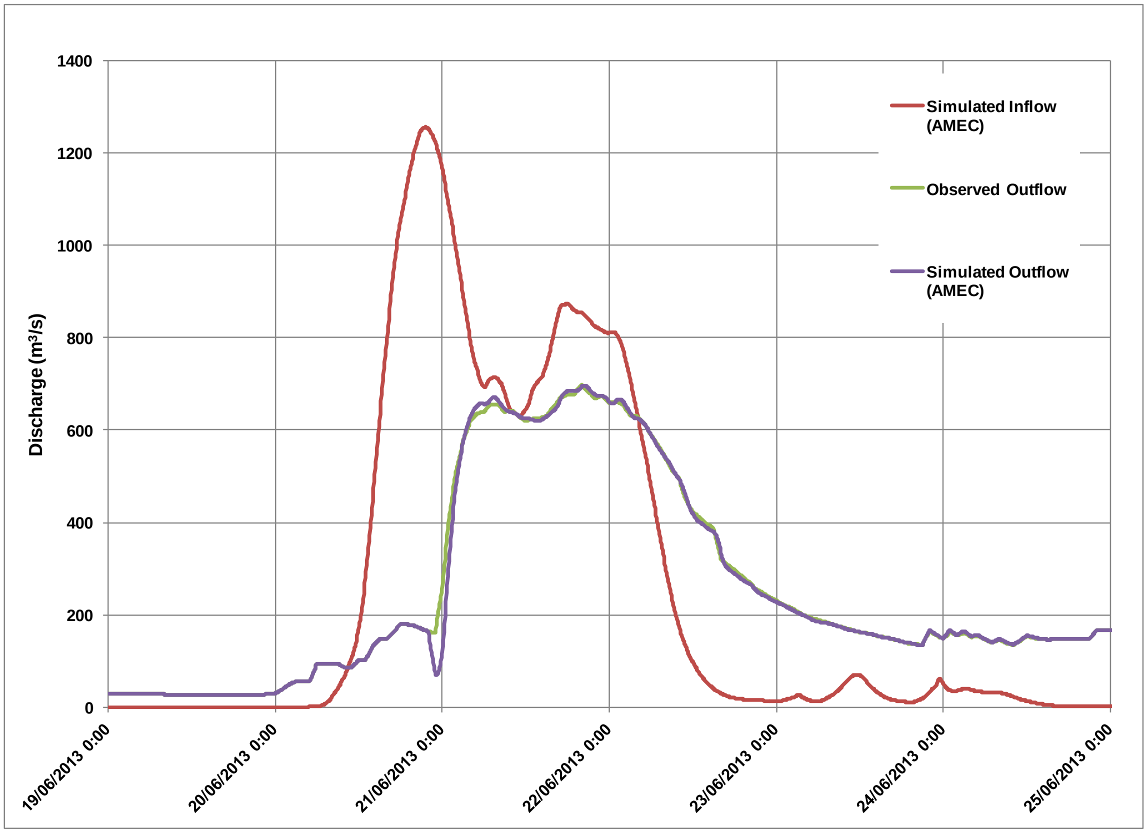

Figure 8.14: June 2013 Flood Discharges for Elbow River at Glenmore Reservoir

The simulated peak inflow of 1,260 m^3/s is slightly greater than that simulated for the Elbow River at Bragg Creek, and likely has an exceedence probability between 0.2% and 0.5%, based on flood frequency analyses conducted by AMEC for this project.

The discharge downstream of Glenmore Dam peaked at approximately 700 m^3/s. This discharge corresponds to the 1% exceedence probability event (Golder, 2010).

9.0 REGULATORY PROCESS

The activities associated with construction of flood mitigation measures such as dyking or dams on the Elbow River will require a number of permits, licenses, authorizations and approvals from a variety of regulatory bodies. The main regulatory agencies and major approvals that will likely be required for project construction based on current and existing information are summarized in **Table 9.1,** and discussed further below.

Table 9.1
Regulatory Overview

Regulator	Legislation	Requirements/Process	Estimated Length of Time for Process[1]
Provincial			
ESRD	*Environmental Protection and Enhancement Act* (EPEA) Environmental Assessment Mandatory and Exempted Activities Regulation 111/93	Under EPEA an environmental impact assessment (EIA) is required for a dam greater than 15 m in height, as specified in the mandatory and exempted activities regulation.	0.5 – 1 year to deem an application complete before the NRCB process begins
Natural Resources Conservation Board (NRCB)	*Natural Resources Conservation Board Act*	The NRCB review process is triggered when a water management project requires an EIA.	1 to 3 years to review and make a determination on a project
ESRD	*Alberta Water Act*	Authorization/approval	Variable
	Alberta Water Act	Licence	Variable
	Public Lands Act	Dispositions following the Environmental Field Report (EFR) process	5-8 months
Alberta Culture (AC)	*Historical Resources Act*	Application for clearance	Depends on requirements; for historic resources impact assessment, expect 4 to 6 months from initial application for clearance.
Other			
Stakeholders		Third Party Agreements	Variable
Federal			
Fisheries and Oceans Canada (DFO)		Authorization pursuant to the *Fisheries Act* (habitat and fish passage)	90 days post-filing, providing submission is complete.
Transport Canada		Application under the *Navigable Waters Protection Act* (NWPA)	-[1]
Miscellaneous Federal Acts		*Migratory Birds Convention Act* (MBCA)	n/a[2]
		Species at Risk Act (SARA)	n/a

Notes:
1. NWPA, which comes in to force April 2014, does not list Elbow River and therefore would not apply after that time.
2. Not available at this time

9.1 Major Alberta Environmental Review Requirements

9.1.1 Alberta *Environmental Protection and Enhancement Act*

Both of these options for flood mitigation would result in the construction of flow regulation structures that trigger Alberta Regulation 111/93 EPEA Environmental Assessment (Mandatory and Exempted Activities) Regulation that requires an EIA be completed for a dam greater than 15 m in height. The EIA process (preparation and review), combined with the NRCB process discussed below, could take between 2 to 5 years for these types of projects. Some projects have taken longer. Prior to submitting a project application, the preparation of an EIA requires a solid understanding of the existing environment, which typically requires four seasons of field work (i.e., 1 year) to gather baseline data. An additional 6 to 12 months would be required to analyze the data and complete the impact assessment, including writing the report. Once the project application and supporting EIA have been submitted for review, ESRD would make a determination of completeness. This review process includes the issuance of supplemental information requests (SIRs). Depending on the number of SIRs and the number of rounds of SIRs, this process could take 6 to 12 months. ESRD then deems the EIA complete and the NRCB review process (below) proceeds.

9.1.2 Natural Resources Conservation Board

The NRCB process is triggered when a water management project requires an EIA. After ESRD deems an EIA complete it is passed to the NRCB for review. The NRCB then completes the review and hearing process. At the completion of the process, the NRCB sends its determination to cabinet, which reviews the report and issues its final approval decision.
The whole NRCB review period could take 1.5 to 3 years, depending on the level of public interest in the project.

9.2 Additional Requirements

If the cabinet decision decides the project can proceed, additional permits and authorizations are then required. These are briefly discussed below.

9.2.1 Alberta Water Act

Approval under the Alberta *Water Act* would be required for activities that could affect surface and subsurface water management including construction in, under or adjacent to water bodies. Pre-development and post-development aquatic environmental assessments would be necessary as part of the application for approval.

Reporting required to be included in a *Water Act* application would included detailed design drawings, hydrotechnical analyses (including reservoir stage/area, discharge rating, hydrographs and water levels upstream and downstream of the project area). It is also likely that a dam breach analysis would be required.

A *Water Act* licence would also be required for all water diversions (withdrawal or storage) of surface water.

The timeframe for approvals can take upwards of a month and depends on the complexity of the scheme and whether there are any objections by anyone who is directly affected by the scheme.

9.2.2 Federal *Fisheries Act*

As of 25 November 2013, amendments to the *Fisheries Act* proposed in Bill C-38 are now in force. Proponents are responsible for avoiding and mitigating the serious harm to fish that could result from their projects. When proponents are unable to completely avoid or mitigate serious harm to fish such that some residual serious harm to fish remains, they must seek an authorization under paragraph 35(2)(b) of the *Fisheries Act* to carry on a work, undertaking or activity.

The construction of a dam or an off-stream diversion could cause serious harm to fish even after the application of avoidance and mitigation measures. This would then require development of a plan to undertake offsetting measures to counterbalance the unavoidable residual serious harm to fish. Offsetting plans are negotiated on a case-by-case basis and may require consultation with Aboriginal groups, as well as other stakeholders (e.g., the province on crown lands). At least four seasons (i.e., 1 year) of baseline data collection is typically required.

The dam or off-stream storage projects could cause lasting changes to habitat. To evaluate the potential residual serious harm to fish and to identify the appropriate measures for avoidance, mitigation and offsetting, a plan would be required to obtain an authorization. New DFO policies will measure the success of offset objectives by quantifying the changes in productive capacity. Significant post-construction monitoring would likely be required to determine this change.

The offsetting plan is to be included as part of the proponent’s application for authorization under paragraph 35(2)(b) of the *Fisheries Act*. A letter of credit issued by a recognized Canadian financial institution must be included with the offsetting plan. The letter ensures that if conditions of the authorization are not completed, DFO can access funds to implement all remaining elements of the plan. The amount of the letter of credit should be sufficient to complete the offsetting plan and monitoring program.

While the total time line is estimated to be two years, one year is for baseline data collection, which would like be done as part of the data collection for the EIA. The second year is for working with DFO to reach agreement on the mitigation and offsetting plan. This work would likely be done concurrently with the EIA preparation and NRCB review. The final offsetting plan and letter of credit could reasonably be expected to be complete within six months of project approval by cabinet.

9.2.3 Federal *Navigation Protection Act*

It is anticipated that the amendments to the *Navigable Waters Protection Act* (NWPA) will come into force in April 2014, under a new legislative name entitled the *Navigation Protection Act* (NPA).

If either of these options were scheduled to commence prior to April 2014, work must adhere to the provisions under the NWPA and an approval will be required. However, these options are more likely to commence after the April 2014, in which case the NWPA would no longer be applicable. Under the NPA only watercourses identified on the *List of Scheduled Waters* require an approval; the Elbow River is not included on the list. However, the right to navigate is still protected under common law and should be considered by both options as there is documented canoeing use of the Elbow River.

9.2.4 Others

These projects are likely to require land use dispositions (from ESRD) as well as clearance under the *Historical Resources Act* by AC prior to any clearing or construction activities. Typically these processes occur after the project has received approval and may take from 2 to 9 months. They occur in parallel.

9.3 Canadian *Environmental Assessment Act*

Some projects would require a federal environmental review, as noted in **Table 9.2**. At this point it is unclear if either of the options would trigger a federal review process. As the design for each option progresses, the reservoir surface area and the volume of water to be diverted will be determined.

Table 9.2
Federal Environmental Review

Regulator	Legislation	Requirements/Process	Estimated Length of Time for Process[†]
Canadian Environmental Assessment Agency (the Agency)	Canadian *Environmental Assessment Act*, 2012 Regulations Designating Physical Activities SOR/2012-147	Environmental assessment (EA) is triggered when a new dam would result in a reservoir with a surface area that would exceed the annual mean surface area of a water body by 1,500 ha or more. An EA is triggered when a new diversion structure moves 10,000,000 m^3/year or more of water from a natural water body into another natural water body.	1 to 3 years (coordinated with NRCB process)
[†] not including surveys or studies to support applications			

As well as the projects listed in the *Regulations Designating Physical Activities*, if a project receives federal funding, then an environmental review is also required. It is unknown at this time if either of these options would receive federal funding. If required, the environmental review would be carried out by the Canadian Environmental Assessment Agency. It would most likely be coordinated with the NRCB review (described above). Joint federal/provincial reviews have been held several times for water management projects in Alberta, and the NRCB and the Agency have established a good working relationship. The inclusion of a joint review process should not increase the NRCB review time for a project.

9.4 Regulatory Timelines

Overall, the regulatory process for either of these options could take between 2.5 and 6 years, as shown in **Table 9.3**.

Table 9.3
Potential Regulatory Timeline

Preparation of EIA	Environmental Review	Post-approval Permits and Authorizations	Total
18 to 24 months	18 to 36 months	3 to 9 months	29 to 69 months

10.0 CLOSURE

This report has been prepared for the exclusive use of the Southern Alberta Flood Recovery Task Force. This report is based on, and limited by, the interpretation of data, circumstances, and conditions available at the time of completion of the work as referenced throughout the report. It has been prepared in accordance with generally accepted engineering practices. No other warranty, express or implied, is made.

Yours truly,

AMEC Environment & Infrastructure

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Vice President
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Permit to Practice No. P-4546

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Appendix A

Water Management in Alberta: Additional Information

Alberta's Water for Life Strategy

In 2003, Alberta developed the Water for Life Strategy that redefined how water was to be managed in the future. This strategy was assessed and renewed in 2008, and continues to set the direction for water management in Alberta.

A key principle of this strategy is the continuing recognition of the limits to the available water supply, and the need to manage water resources within the capability of each of Alberta's seven major watersheds in Alberta (**Figure A.1**). Inter-basin transfer is discouraged, and is only allowed through special legislation. To date, this has only been granted to potable water supplies for communities and rural development.

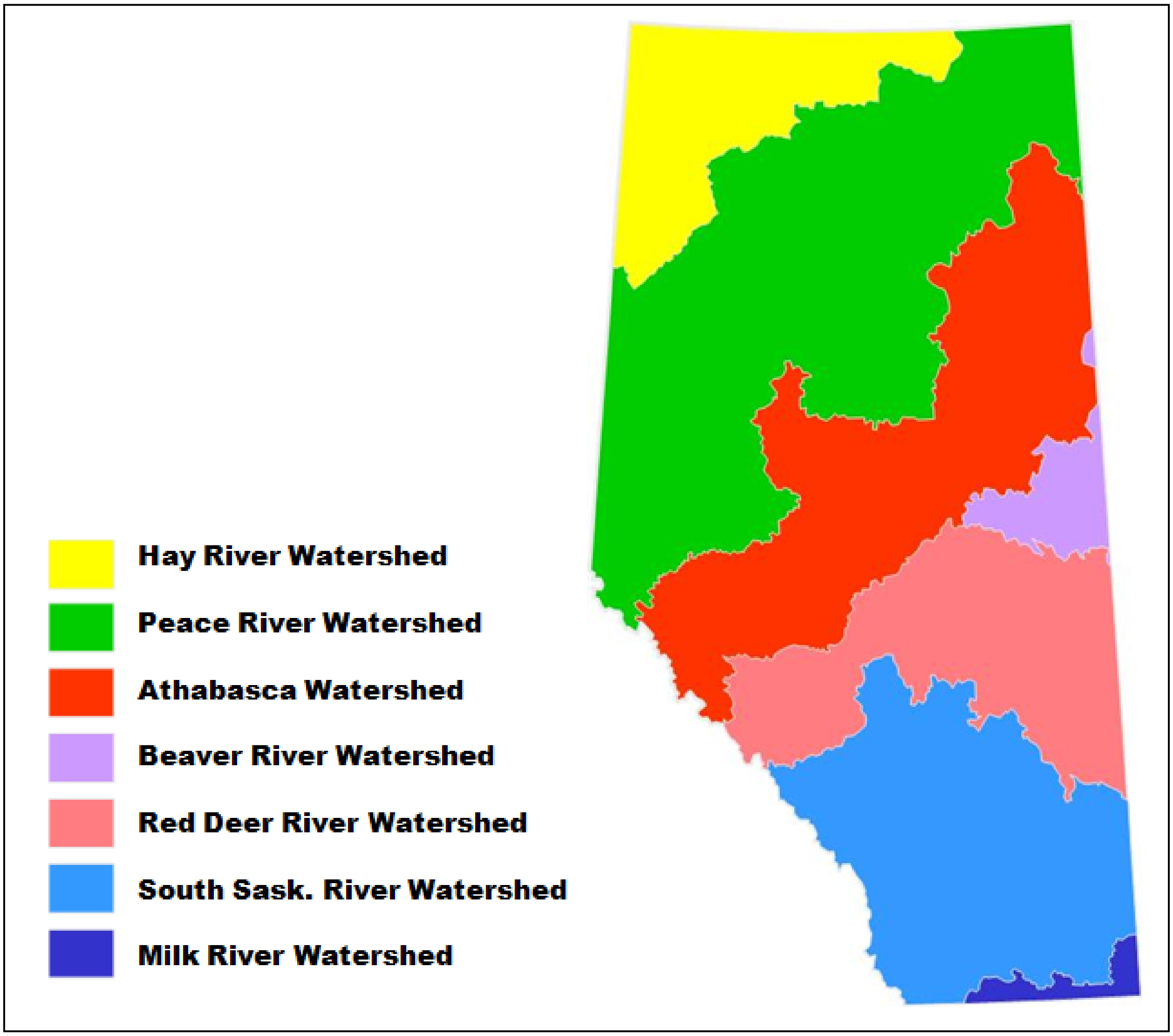


Figure A.1: Alberta's Watersheds

The strategy also recognized that limited water must be used more effectively and efficiently. A key outcome for the strategy was to "ensure that overall efficiency and productivity of water use in Alberta improves by 30% from 2005 levels by 2015."

To this end, the major water users in Alberta have developed strategies that address this outcome. These include:

- Chemical producers;
- Forestry;
- Irrigation;
- Upstream oil and gas;
- Downstream petroleum products;
- Power generation; and
- Urban municipalities.

The renewed *Water for Life Strategy* also recognizes the need to better integrate land and water resources, and promoted the development of the Regional Land-use Planning Framework, which is currently being implemented in seven regions of Alberta. These include:

- South Saskatchewan Region;
- Red Deer Region;
- North Saskatchewan Region;
- Upper Athabasca Region;
- Lower Athabasca Region;
- Upper Peace Region; and
- Lower Peace Region.

A land use plan has been completed in the Lower Athabasca region, and a draft plan developed for the South Saskatchewan Region is currently under public review.

Water Management Options

Increasing demand, coupled with expected reductions in river flows, create ongoing concerns about future water availability. The 2009 AMEC study examined water management options that could increase water supply opportunities to help meet expected increases in demand. The following options were discussed.

Modifying the Operation of Existing On-stream Storage Reservoirs

All provincially owned reservoirs in the SSRB are managed to meet multi-use needs in the basin. Uses include:

- meeting interprovincial flow requirements;
- irrigation;

- urban and municipal use;
- environment;
- stock watering; and
- power generation.

The Oldman River Dam and Reservoir (**Figure A.2**) was the last major on-stream reservoir constructed in Alberta. While these reservoirs were not designed for flood control, they have succeeded in reducing peak flood flows that helped ease flood impacts. This was particularly evident during the 1995 flood that saw the Oldman River threaten the two main bridges crossing that river in Lethbridge. Management of the Oldman Dam and Reservoir by ESRD was credited with saving those bridges by reducing the peak level of the Oldman River at Lethbridge by about 1 m.

Figure A.2: Oldman Dam and Reservoir

Successful management of these reservoirs to meet the competing needs in the SSRB is complex and demanding, but possible management options have been identified that could potentially optimize future demand for water. In the Bow River basin increased demand for water during the summer months could be met by enhancing summer flow from one or more existing TAC reservoirs. Currently, water is generally released from the reservoirs during the winter months to meet increased demand for hydro-electric power generation. Changing these operations would require a change in operational management by TAC, which could reduce higher electricity revenues that are generated by releasing water during the winter, rather than the summer. The benefits of enhancing water supply during the summer would have to be weighed against the revenue generated by water release during the winter months.

Enhancements to existing off-stream reservoirs have been evaluated by the irrigation districts to determine the potential to increase storage. While potential exists, the benefits appear to be relatively small under current water management scenarios. There may be long-term benefits of increasing storage capacity to provide water during drought conditions. However, these benefits have not been thoroughly assessed.

Development of New Storage Reservoirs

Climate change studies suggest that the SSRB will see a warmer climate with more potential for multi-year droughts. On-stream and off-stream reservoir capacity within the SSRB is not sufficient to weather a multi-year drought event. There is sufficient surplus water flow in the SSRB rivers to support additional storage of more than 1.0 million dam^3 (AMEC, 2009). Essentially all of the additional water for storage would result from mountain runoff, and on-stream storage is considered to be more effective than off-stream storage in capturing mountain snowmelt events. On-stream storage reservoirs have the ability to capture the water whenever runoff occurs and off-stream reservoirs do not. Climate change research suggests that mountain runoff in the future may occur during winter and early-spring seasons because of climate warming. With current technologies, off-stream diversion canals that transport water to the off-stream reservoirs cannot safely operate during the winter months.
AMEC currently has a study underway for AARD identifying and assessing potential locations for on-stream storage reservoirs in the Bow River and Oldman River basins. Preliminary information from this study suggests that while good sites exist, their potential may be limited because of the current GoA policy that requires all new on-stream storage reservoirs release sufficient water to meet the 45% water conservation objective (WCO) requirements in the river.

About 50 off-stream reservoirs currently exist in the SSRB, with most located within the 13 irrigation districts. Good locations for new off-stream reservoirs are scarce. In the Bow River, the proposed Bruce Lake Reservoir (northeast of Calgary) would potentially store about 50,000 dam^3 of water from the Bow River during the spring high flow period. This reservoir would benefit the Western Irrigation District (WID) and area municipalities, while reducing water diversion requirements from the Bow River during the summer season.

Improving Urban Water Use Efficiency – City of Calgary

Calgary is the largest city in the South Saskatchewan River basin with over 1 million residents and more than 20,000 industries, commercial operations, and institutions (**Figure A.3**). In 2006, Calgary supplied over 165,000 dam^3 of water to meet customer needs (City of Calgary Water Efficiency Plan, 2007).

Figure A.3: Downtown Calgary skyline

Calgary recognizes that demand for water will continue to grow with rapid population increases combined with significant economic growth. There is also recognition that Calgary's future demands will compete with a variety of users in the basin on the finite and possibly shrinking water supply. Calgary has made the commitment to reduce water consumption by 30% over the next 30 years through a variety of strategies including:

- Repairing leaks and replacing old water distribution systems before they leak. The number of water main breaks has decreased by about 50% over the past 10 years.
- Replacing old and inefficient water fixtures in city facilities.
- Installation of water meters in homes. By 2014, all Calgary homes are expected to have their water metered.
- Providing incentives to promote homeowners to replace inefficient fixtures (toilets, faucets, washing machines, etc.) with more efficient ones (e.g., switching to low flush toilets can save up to 70% of water use).
- Promoting the re-use of potable water whenever possible.

These measures are projected to reduce per capita water use from about 500 litres/day in 2004 to about 350 litres/day by 3032. It is recognized that other cities and towns in the SSRB are implementing similar programs as Calgary to conserve water and improve water use efficiencies.

Improving Irrigation Efficiency

Irrigation is by far the largest water user in the SSRB. The irrigation districts and producers recognize the need to become increasingly efficient and productive in the use of limited water supplies. Almost 8,000 km of canals and pipelines, worth an estimated $3.5 billion, distribute water to the 550,000 ha of irrigated land within the 13 irrigation districts (**Figure A.4**). This distribution system also supplies water to about 50 towns and municipalities, numerous industries, recreation facilities, and more than 35,000 ha of wetland habitat.

Figure A.4: Surface Water Supply Canal

Of the approximately 8,000 km of distribution canals, about 47% are now in buried pipelines (**Figure A.5**). This has reduced water losses due to seepage and evaporation, returned valuable irrigation land back to productivity, and incented irrigation producers to invest in more efficient on-farm irrigation systems.

Figure A.5: Buried Pipeline Installation

In 2008, the replacement value of all on-farm irrigation systems in the 13 irrigation districts was $1.14 billion. Improvements in irrigation technologies have resulted in significant increases in on-farm irrigation efficiency - from about 35% in 1965 to almost 75% in 2010. This is considerably higher than the average world irrigation efficiency of about 43%. These efficiency gains began with the introduction of sprinkler irrigation to Alberta in the late 1950s, and continued with rapid advances in sprinkler irrigation technology to the present day (**Figure A.6**).

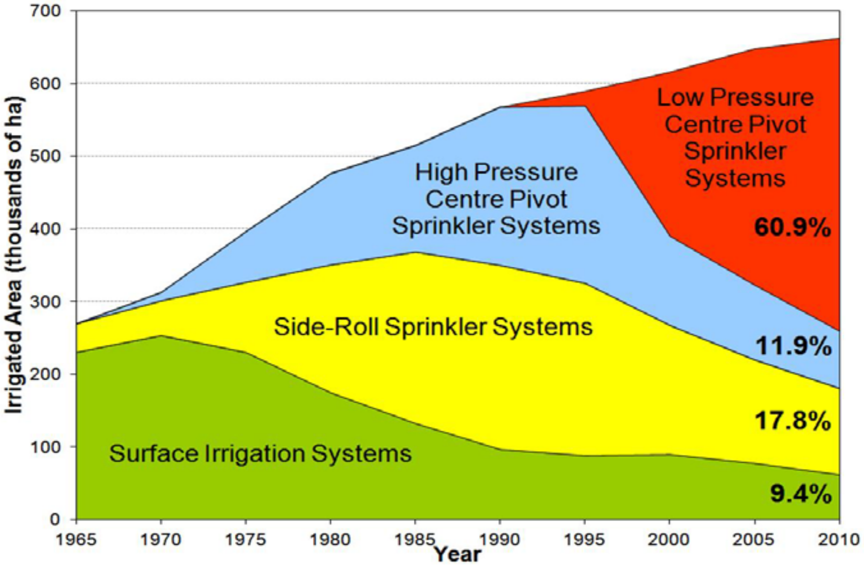


Figure A.6: Changes in On-farm Irrigation Systems – 1965 to 2010).

Between 1999 and 2008, irrigation producers invested $275 to $325 million in improvements to on-farm irrigation infrastructure, with most investments going to purchase the most efficient low pressure, drop-tube pivot systems (**Figure A.7**). The improvements to canal distribution infrastructure combined with increased on-farm water use efficiencies resulted in water savings of about 200,000 dam^3 each year (AARD, 2013).

Figure A.7: Drop-tube Low-pressure Irrigation Pivot

AARD projects that on-farm irrigation efficiency could increase to at least 85% by 2025 as new precision sprinkler irrigation technologies (**Figure A.8**) are adopted by producers (AARD, 2013).

Figure A.8: Low Energy Precision Application Sprinkler Technology

Efficiency gains, combined with improved crop management technologies, are expected to result in continued reduction in water use and increased yields (**Figure A.9**).

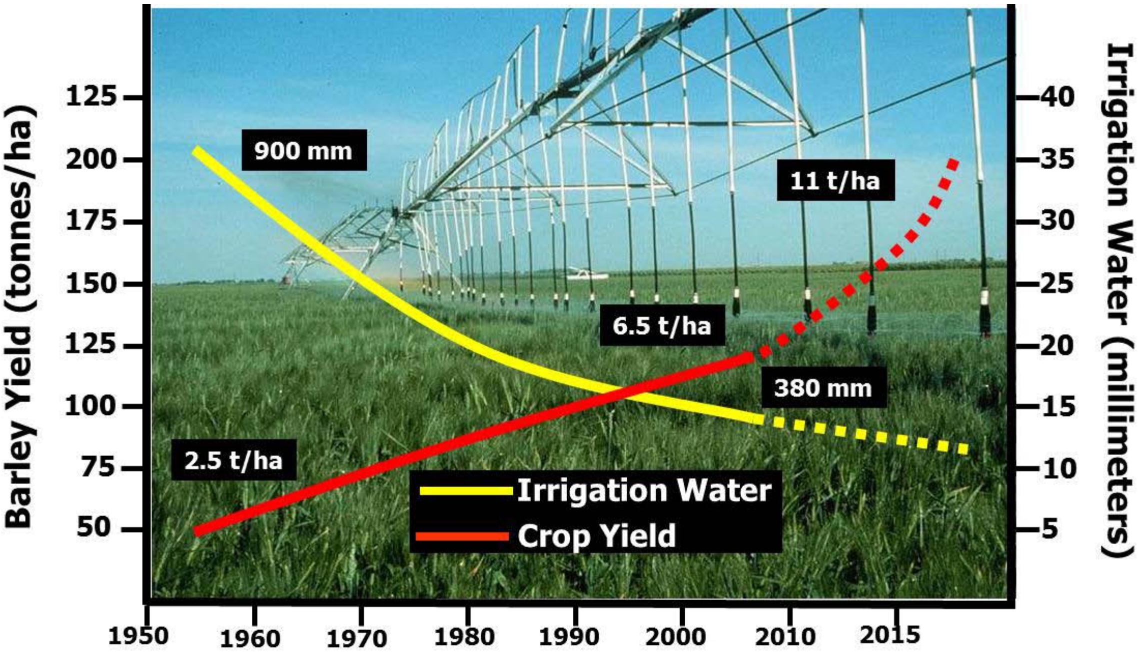


Figure A.9: Water Use and Yield Projections for Irrigated Barley in Southern Alberta

Irrigation Expansion and Consolidation

The water saved as a result of improved irrigation efficiencies within the irrigation districts has allowed the districts to consider expansion of their irrigated land base. Under the *Irrigation*

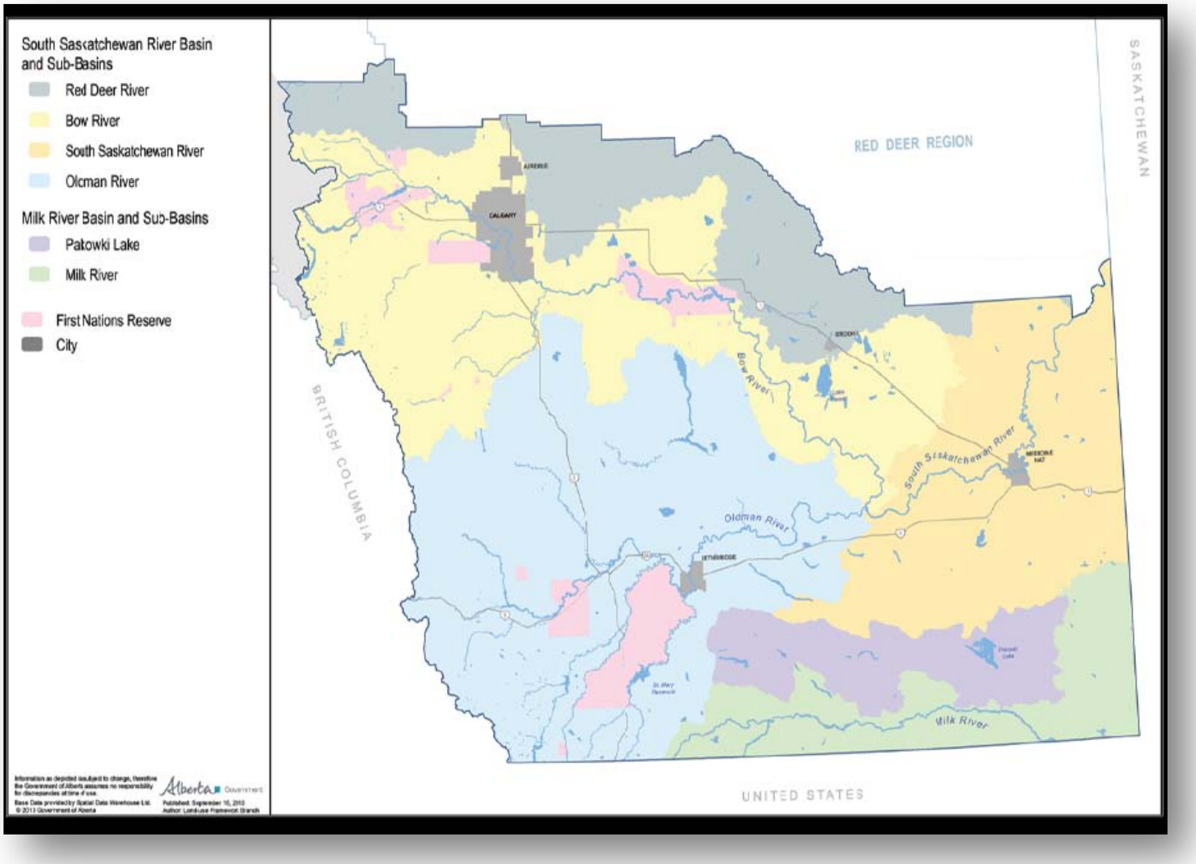
Districts Act, irrigation districts must receive approval from their water users through a plebiscite before expansion can proceed. Through the plebiscite process, the 13 irrigation districts received approval from their water users to expand the irrigation area by about 70,000 ha. The irrigation districts have chosen to proceed cautiously with expansion plans to allow for ongoing assessment of water supply and demands over time.

Given the uncertainties related to climate change, this cautious approach is warranted. Irrigation districts will need to assess fully their long-term water management strategy if temperatures continue to increase, and projected reductions in river flows take place because of climate change. Water conserved through increased efficiencies and water management may be required to sustain existing irrigation acres in the future.

South Saskatchewan Regional Draft Plan - Advancing Water Management

In December 2008, the GoA implemented the Land Use Framework which provides a blueprint for planning Alberta’s economic, environmental, and social goals. Seven planning regions were established within the framework that align with municipal boundaries and somewhat align with the province’s seven major watersheds. The South Saskatchewan Regional Plan (SSRP) is the second plan to be initiated.

This region is about 84,000 km^2 and is bounded on the west by the Rocky Mountains, Saskatchewan on the east, Montana to the south, and the Municipal Districts of Bighorn and Rocky View, and Wheatland, Newell and Cypress counties to the north (**Figure A.10**). This



region encompasses the Bow River, Oldman River, and South Saskatchewan River basins, plus the Milk River Basin. The Milk River is the only river in Alberta that eventually flows to the Gulf of Mexico.

Figure A.10: Map of South Saskatchewan Regional Planning area

This region comprises only 12.6% of Alberta's total land area, but about 45% of Alberta's population are located here, including the City of Calgary. This region could see its population increase by 2 million people in the next 50 years.

Water management in the South Saskatchewan Region is and will continue to be a significant concern in the future. Water supplies are limited in this region, and may be a constraint to economic growth as water demand continues to increase. Currently the sub-basins within this region are closed to new water allocations because of concerns with over-allocation. Droughts are not uncommon in this region, and climate change may bring more intense and longer lasting droughts in the future.

The SSRP was initiated in 2009. An appointed regional advisory council (RAC) was charged with assessing issues within the SSRP and providing advice to the GoA on key policy issues related to economic, environmental and social issues. The RAC recommended that water supply should be a key focus of the SSRP. Based on the work of the RAC and public consultations, a draft plan was developed and released in the fall of 2013 for further public consultation and input. A number of water-related recommendations are contained within the current draft SSRP report.

- The GoA supports the existing water management system, including the "First in Time, First in Right" principle contained in the *Water Act*. Trans-boundary agreements with Saskatchewan and the United States will continue to be honoured as defined by the Master Agreement on Apportionment and the Boundary Waters Treaty.
- It is recognized that matching water supply with increasing water demand will be a key challenge for the region into the future. The Approved Water Management Plan enacted in 2007 for the SSRB will continue to provide direction for water management in the South Saskatchewan Region.
- The SSRB water management plan's closure of the Bow River, Oldman River, and South Saskatchewan River basins to new water allocations require that future water demands will need to be met through improved water use efficiencies. Efficiency gains are being promoted to attain the Water for Life Strategy's target of 30% improvement in water use efficiency and productivity by 2015. All major water-using sectors in the SSRP are committed to this target, and have submitted water conservation, efficiency and productivity plans to the Alberta Water Council.
- The draft SSRP recognizes the importance of investing in key infrastructure that will continue to provide future economic, environmental and social benefits. On-stream and off-stream water storage reservoirs are considered an important management tool that can contribute to the Water for Life Strategy goals of improved conservation, productivity and efficiency.

- Climate change may reduce the amount of available water in the future, and result in more severe weather events. Adaptation for drought management and flood mitigation are essential for regional development and depth. Mitigating the impacts of flooding is important to reduce risks to public safety and infrastructure, while saving tax dollars for flood recovery. Existing and future storage infrastructure may help dampen flood severity, and provide additional water supplies to meet future demands.
- Wetlands are recognized for the contributions they make to human and ecosystem health, and have been linked with reducing the impacts of flooding. Implementation of the Alberta Wetland Policy will consider past and current pressures on these areas.
- The introduction of aquatic invasive species to the SSRP water system is an emerging and important concern. The impacts of zebra and quagga mussels, and Eurasian water-milfoil on water ecosystems and infrastructure are well documented in the Great Lakes and many locations throughout the United States. Introduction of these invasive species into Alberta's water systems could seriously reduce operational efficiencies and cost water users millions of dollars. The current focus is on preventing the establishment of these noxious aquatic invasive species.

Final public comments are being received by the GoA until 28th February 2014. The final SSRP report will then be compiled and submitted to cabinet for approval and implementation.

Drought

Drought is among the most devastating of natural hazards, and can have damaging long-term effects on the quality of life and even survivability of affected peoples, to say nothing of the loss of important livestock and economic development in a region (**Figure A.11**).

All arid and semi-arid regions of the world are susceptible to reduced precipitation, which leads to water shortages and drought. In 2011 and 2012 serious droughts affected the Horn of Africa and the Sahel region and impacted millions of people and their livelihoods.

Photo – Courtesy of Time Magazine

Figure A.11: Drought in Africa

In 2012, about 55% of the continental United States was in a moderate to severe drought, affecting about 80% of agricultural land. This drought had serious impacts on crop and livestock sectors, with an estimated cost of about $30 billion. In January 2014, Governor Jerry Brown of California declared a state of drought emergency for that state after experiencing the driest year on record in 2013 (**Figure A.12**). Approximately 9% of the state is in an exceptional drought situation – the worst drought category on the state's drought monitoring system. Almost 70% of the state is in an extreme drought. Snowpack in the Sierra Nevada Mountains was only about 12% of normal in January 2014. California's $44.7 billion agriculture sector is only getting a fraction of the water it requires, and high value crops such as grapes and orchards, which require water each year, will be particularly susceptible.

Figure A.12: Images of Drought in California

Drought Mitigation

To properly plan for a future drought, particularly a multi-year event, governments, communities, and industries need to cooperate in the development of proactive drought strategies to ensure that plans, trigger mechanisms, decisions, and necessary actions are in place before a drought occurs. Much of this planning must revolve around access to water. Determining how much water is absolutely required during a drought, setting priorities for access to water, and effectively managing the available water are critically important issues that need to be resolved well before a drought occurs.

The majority of the SSRB water supply comes from mountain snowmelt during a relatively short period in May and June each year. For the rest of the year, particularly during the warm summer months, natural flow in the rivers is quite low, and must be supplemented with water from the more than 50 on-stream and off-stream reservoirs located throughout the SSRB.

Current on-stream and off-stream storage capacity in the SSRB totals almost 3 million dam^3. This includes the four on-stream reservoirs - Oldman, Waterton, St. Mary and Glennifer reservoirs – and approximately 50 off-stream reservoirs located throughout the Bow River and Oldman River basins. This does not include the TAC reservoirs located on the Bow River basin. These reservoirs generally store water during the spring/summer season, which is then released during the winter season when power demands are the highest.

During a dry, hot summer in the SSRB, these on-stream and off-stream reservoirs are more than capable of meeting all water supply needs in the basin. However, water supply in many of the reservoirs may be reduced significantly by the end of the summer season. With normal winter precipitation and resultant snowpack, the reservoirs are fully recharged in time to again meet the summer demands. However, if the winter following a dry, hot summer has low precipitation and resultant low snowpack levels, there may be areas in the region where full demand is not met.

Real-time monitoring of precipitation and snowpack levels in the mountain watersheds, and real-time monitoring of key streams and rivers flowing from these mountain watersheds are critical requirements for successful drought planning. Converting the precipitation and snowpack information into water supply forecasts is also important to allow water users and decision makers pro-actively develop appropriate plans and policies regarding water allocation and management.

The 13 irrigation districts, located mainly in the Bow River and Oldman River basins, are the largest water users in the SSRB, and are often the first to feel the impacts of water shortage. During the summer of 2000, which was very hot and dry, the irrigation districts diverted 2.3 million dam^3 of water to meet the needs of irrigation producers, municipalities, industries, livestock, and wildlife habitat. As a result, on-stream and off-stream storage reservoirs in the Southern Tributary river basin were at about 26% of capacity going into the 2000/2001 winter season. This is much lower than normal. Low winter precipitation in 2000/2001 meant that water supply for the 2001 summer season could only supply about 50% of the total water demand.

The “First in Time, First in Right” principle contained in the GoA *Water Act* allows senior water license holders to divert their share of water before more junior license holders. In the SSRB, the irrigation districts hold the oldest and largest share of the senior water licences. In an unprecedented action, the irrigation districts proposed a water sharing arrangement that would result in all water users affected by water shortage sharing the available water equally in 2001, regardless of the water license priority. A total of 200 participants, responsible for more than 300 water licenses, agreed to participate in the water sharing arrangement. This included 7 irrigation districts, 13 towns, 3 municipal districts, numerous livestock feeding operations, 13 commercial and food processing industries, golf courses, and the Kanai First Nation – Canada’s largest reserve.

Many irrigated crop producers who grow high value crops such as potatoes, sugar beets, vegetables, and seed canola, recognized early in 2001 that their share of water would not be sufficient to achieve the desired crop production and quality required by food processors and clients. As a result, they entered into private agreements to purchase temporary water rights for the 2001 season in order to supplement their existing share. They often purchased their temporary water rights from grain farmers who agreed to sell part or all of their water right for that year. The grain farmer could then decide not to grow a crop that year, or take a chance on growing a relatively low water requirement crop such as barley or wheat under dryland conditions – and hope for timely rains during the growing season. All water right transfers had to be approved by the irrigation district or ESRD.

The water supply restrictions in 2001 meant that all water users had to make significant management changes to ensure that the limited water available to them was used effectively and efficiently. Irrigation districts monitored water diversions very closely to ensure that users diverted only their assigned share of water. This placed considerable stress on staff tasked with water supply monitoring and enforcement.

The following winter season was again very dry and snowpack levels very low – similar to snowpack levels leading up to the 2001 summer season. Discussions again took place with the affected water users to determine if a similar water sharing agreement might take place during the 2002 summer season. Irrigation producers growing high value crops again purchased water rights early in the spring to ensure sufficient water would be available. Fortunately, significant late spring and summer rains arrived, which temporarily ended the drought concerns for this region.

This water sharing agreement among the users was an excellent example of cooperation during a crisis. The group was recognized for their cooperative leadership by the Irrigation Association in the United States, and were presented with the association’s Annual National Energy and Water Conservation Award.

While management of the 2001 drought was considered a huge success, it is recognized that this was an ad hoc solution to a very short drought situation. Climate change science appears to be clear – this region will likely experience sustained, multi-year droughts in the future. The question remains - how will water users in this region prepare for and manage a multi-year drought of a similar magnitude as the 2001 occurrence?

In the United States, assessment of long-term drought impacts and potential mitigation strategies have been carried out on one of the most important river systems – the Colorado. This is a highly managed river system that originates in Wyoming and Colorado, and with its tributaries, flows through a total of seven states (Wyoming, Colorado, Utah, Nevada, Arizona, New Mexico and California. The Colorado also flows through northern Mexico on its way to the Gulf of California (**Figure A.13**). The average annual flow of the Colorado River is almost 20 million dam^3, which is more than double the average annual flow of the SSRB rivers. The flow of the Colorado River is generally fully utilized, and water only reaches the Gulf of California during wet, high flow years (Young, 1995). This is in sharp contrast to the SSRB river systems, where at least 50% of the annual natural flow must go to Saskatchewan.

In 1995, a study was carried out to assess the impacts of a sustained (38-year) drought on water users throughout the Colorado River Basin (Harding et. al, 1995). The study indicated that the Colorado River system supplied water to approximately 25 million people within the seven states. Irrigation in the basin totalled 1.3 million ha, including about 200,000 ha in northern Mexico. Total consumptive use in 1995 exceeded 12 million dam^3, with an additional 1.8 million dam^3 provided to Mexico under a 1944 treaty.

Figure A.13: Colorado River Basin

The system of reservoirs on the Colorado River system has the capacity to store approximately 72 million dam^3, or nearly 4 years of the river's natural flow. This compares with total storage in the SSRB of about 3.0 million dam^3 (not including TAC reservoirs), which is less than half of the average annual flow of the SSRB rivers.

The study showed that a sustained drought in the Colorado River Basin, even with 4 years of water storage capacity, would cause serious damage throughout the basin. It would be particularly serious for water users in the headwaters states of Wyoming, Colorado, and Utah. This is because the rights of these water users are junior to downstream users (Booker, 1995). The study suggests that damages could be reduced by reallocating water from low to high value uses, and reservoir storage management to reduce evaporation losses.

By 2012, the Colorado River and its tributaries were supplying water to nearly 40 million people and about 2.2 million ha of irrigated land (USBR, 2012). The *Colorado River Basin Water Supply and Demand Study* (USBR, 2012) study was carried out to assess future water supply challenges relative to expected increases in demand in the basin. The study did show that, in spite of experiencing the worst 11-year drought in the last century, the system was able to meet all demands in the lower part of the basin, and experienced only periodic shortages in the upper basin.

An assessment of future water supply and demand scenarios indicates that by 2060, as a result of increased demand and climate change, an average supply-demand imbalance of approximately 4.2 million dam^3 could occur unless significant changes are implemented. Work is ongoing to assess and develop long-term solutions to help mitigate this imbalance.

There is no single action that can prepare the region for a multi-year drought. A successful strategy will require implementation of a number of integrated actions that will need to be in place well before the drought occurs. Assessment of water supply and demand for both average years and drought scenario years is important to determine the ability to effectively manage a multi-year drought, and identify what actions need to be taken.

Background

The Oldman River basin is located in the southwest part of the province, and covers about 23,000 km^2 in Alberta and 2,100 km^2 in Montana (**Figure A.14**). It is bordered on the west by the Rocky Mountains and extends east through foothill rangelands, dryland and irrigated agricultural lands, and Prairie grasslands to the confluence of the Bow and Oldman Rivers. Waterton National Park, a UNESCO World Heritage Site, is located in the extreme southwest corner of the basin and forms the International Peace Park with Glacier National Park in Montana.

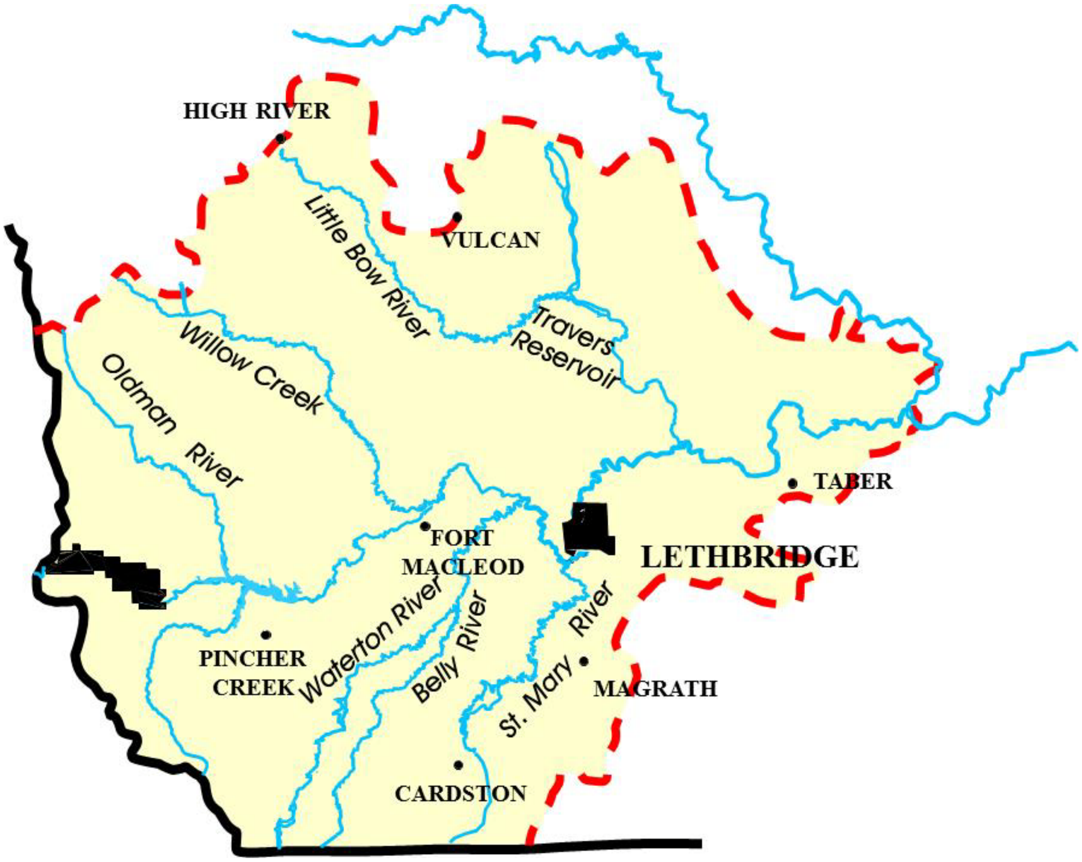


Figure A.14: Map of Oldman River Basin

First Nations peoples have occupied the Oldman River basin for many generations. The Blackfoot name "Napi" means Old Man, and is the basis of the name of the sub-basin and main river. Today, two First Nations have land in the sub-basin. The Piikani Reserve occupies about 430 km^2 between Pincher Creek and Fort MacLeod, and the Kainai Reserve occupies 1,400 km^2 southeast of Lethbridge.

European ettlement began in the late 1800s, and included ranching and later irrigation and dryland farming. Lethbridge is the main urban centre in the Oldman River basin, with a population of about 90,000. This basin has a semi-arid climate, with much of it located in what is known as the Palliser Triangle (**Figure A.15**). When John Palliser visited this area in 1857, he reported that it was too dry to ever consider settling.

Figure A.15: Palliser Triangle

Settlement did occur at the start of the 20th century with ranching, and later dry land farming (**Figure A.16**). The soil was fertile and the prairie grassland was ploughed and planted to wheat and other grain crops.

Figure A.16: Breaking the Sod

Palliser was correct that the area was relatively dry, and lack of precipitation was a challenge for the early farmers. There were devastating failures during the 1930s because of drier than normal conditions combined with poor soil management practices for this region. Many farms were abandoned during those difficult years, and their remnants are still visible today (**Figure A.17**).

Figure A.17: Abandoned Farmstead

Some pioneers who settled in the Oldman River basin recognized the challenges of growing dry land crops, and began to develop irrigation agriculture around Cardston and Magrath. The first irrigation development in the area was initiated in the late 1800s, using gravity surface irrigation methods (**Figure A.18**).

Figure A.18: Early Flood Irrigation

The pioneer spirit of the early settlers prevailed. Today, about 60% of the sub-basin is used for agricultural production, including about 40% of Alberta's 640,000 ha of irrigation. This is considered to be one of the most intensive agricultural regions in Canada because of the large area of irrigated crop land and high densities of livestock feeding operations (Saffran, 2005) (**Figure A.19**).

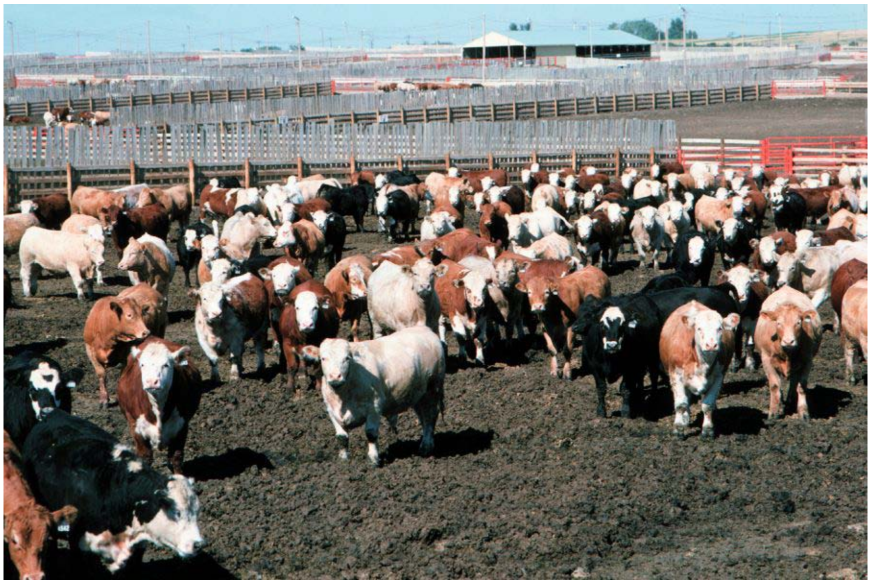


Figure A.19: Cattle Feedlot

Other land use activities in the watershed outside of urbanized areas include forestry, mining, oil and gas extraction, and recreation. As visitors travel through the basin today, they should appreciate that prior to settlement this region was devoid of trees, except for those that grew in the river valleys. All other trees they see were planted and maintained by the pioneers and subsequent generations of settlers.

The Oldman River basin currently has a total population of about 220,000 people. Almost half live in Lethbridge, the largest city in the basin. The remainder live in rural areas and smaller towns including High River, Taber, Pincher Creek, High River, Nanton, Vulcan, Claresholm, Magrath, and Cardston.

St. Mary River and Milk River – International Water Sharing

The St. Mary River, a key tributary of the Oldman River, originates in the eastern slopes of the Rocky Mountains in Montana. This river is an important source of water for both Alberta and Montana, and along with the Milk River, has been the subject of ongoing negotiations and discussion since the early 1900s.

The St. Mary River joins the Oldman River near Lethbridge, and ultimately discharges into Hudson Bay. Unlike the St. Mary River, the Milk River originates in the foothills of Montana. It initially flows northeast into Alberta, then along the Alberta/Montana border for approximately 160 km where it re-enters Montana near the Saskatchewan border (**Figure A.20**). The Milk River is the only river in Alberta that discharges into the Missouri River just downstream of Fort Peck Reservoir, and ultimately joins the Mississippi River, which discharges into the Gulf of Mexico.

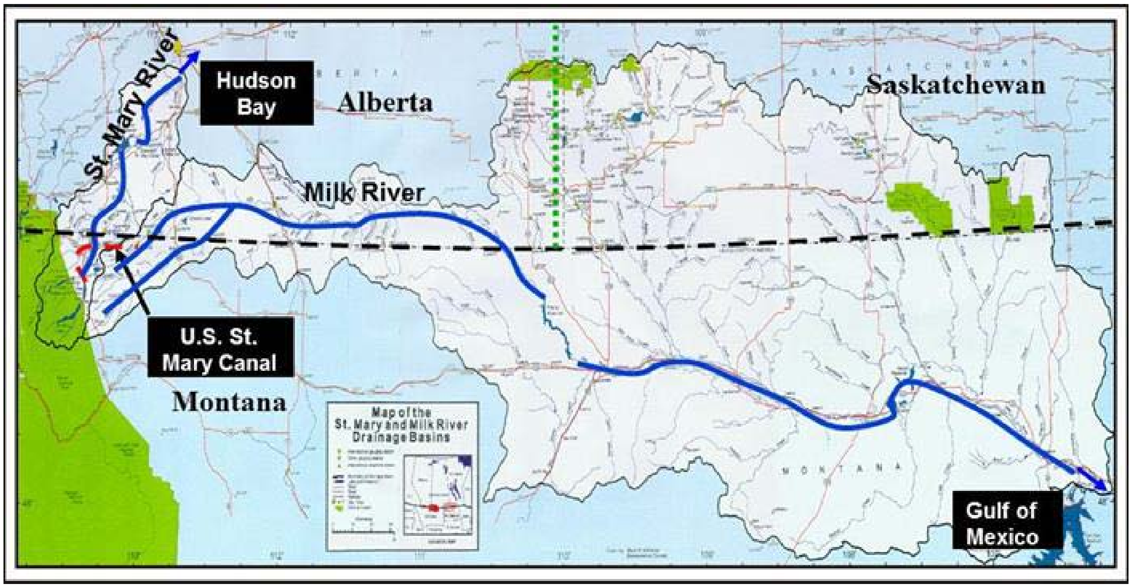


Figure A.20: St. Mary River and Milk River Systems

Both rivers were sourced for irrigation development in the late 1800s. Because the Milk River does not originate in the mountains, it does not benefit from sustained summer flows from melting snow like mountain-fed rivers. As a result, the natural flow of the Milk River during the summer months can be very low. To supplement flows in the Milk River, the United States began construction of a canal in the 1890s that would divert water from the St. Mary River into the Milk River to irrigate lands within the Milk River basin downstream of where the Milk River re-enters Montana. This canal was completed in 1917 and continues to provide water to irrigate approximately 55,000 ha of land and numerous communities in Montana. The canal is typically operated during the months of April through October. The volume of water that it conveys makes up a significant portion of the Milk River flow. This subsidized volume is often 10 to 20 times the natural flow of the Milk River.

In 1899, the Alberta Irrigation Company began the development of a canal that would divert water from the St. Mary River to irrigate about 200,000 ha of land in the Oldman River sub-basin. By 1900, 185 km of the diversion canal was completed from just north of the Alberta/Montana border to present day Magrath, Alberta.

Both Canada and the United States disagreed on the sharing of the St. Mary and Milk Rivers. To resolve this, the International Joint Commission (IJC) was set up by Canada and the United States to help resolve all trans-boundary water issues between the two countries. This resulted in the 1909 Boundary Waters Treaty and later the Order of 1921, which provided a specific sharing agreement for sharing of the St. Mary River and Milk River.

The 1921 Order provided Alberta with 75% of the St. Mary River flow during the irrigation season when the natural flow of the river is 18.9 m^3/second or less. Any portion of the natural flow in excess of 18.9 m^3/second, and all of the natural flow outside of the irrigation season, is to be shared equally between the two countries. This agreement affects the volume of water that is available for use in the Oldman River sub-basin.

Montana is entitled to the same flow arrangements for the Milk River. However, Montana feels it should receive a larger share of the St. Mary River water, and continues to challenge the 1921 Order to the IJC. Alberta believes the 1921 Order accurately reflects the original agreement. Discussions are ongoing between Alberta and Montana to see if a compromise settlement is possible.

Water Use

In the Oldman River basin, 2.2 million dam^3 of water is allocated for various uses, and 1.1 million dam^3 is actually used on average. This is 51% of the total allocation, and 34% of the median natural flow of the river (AMEC, 2009). Irrigation is the dominant water use in the Oldman River basin, accounting for about 88% of the total volume of water allocated. Nine of Alberta's thirteen irrigation districts are sourced from water in the Oldman River basin. Combined with private irrigation schemes, which divert water directly from rivers, streams, and reservoirs, 285,000 ha of land is irrigated in the basin. Much of that irrigation is carried out with efficient, low pressure sprinkler irrigation systems (**Figure A.21**). Municipal use accounts for about 3% of allocation, commercial and livestock use about 1% each, and other uses about 7%. Industry and petroleum use is barely measurable.

Figure A.21: Irrigation of Potatoes with State-of-the-art Pivot System

Cereals, forages, oil seeds and specialty crops are grown under irrigation in the Oldman River Sub-basin. A major livestock feeding industry is associated with the irrigated land, with beef accounting for the majority of fed livestock. An estimated 1.6 million head of cattle were fed in Alberta in 2012 (AARD, 2012), with the majority of them finished in feedlots located in this basin.

Beef processing plants located in High River and Brooks are major Alberta employers, which are present because of the cattle feeding industry.

Approximately 53,000 ha of specialty crops are grown in the Oldman River basin. These include crops such as potatoes, sugar beets, onions, fresh corn and other fresh vegetables, seed canola, dry beans, and sunflowers. Irrigation of these crops has spurred the development of major food processing industries in the Oldman River basin and other regions in Southern Alberta (**Figure A.22**). The Oldman River basin is home to a number of world-class canola seed processing companies, making this region a world leader in canola seed production and processing.

Figure A.22: Potato Processing Plant East of Lethbridge