Bow Basin Flood Mitigation and Watershed Management Project

March 31, 2014

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Disclaimer

Further, the list of individuals and the organization they represented, which appears in Appendix A, reflects those who participated in some or all of the working group meetings for this project. Their inclusion on this list does not suggest advocacy for any particular strategy discussed, but rather provides a sense to the reader of the range of perspectives involved in the working group discussions.

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Abbreviations, Acronyms, and Definitions

(A)ESRD	(Alberta) Environment and Sustainable Resource Development
BRBC	Bow River Basin Council
BRID	Bow River Irrigation District
BROM	Bow River Operational Model
CBRH	Carseland-Bow River Headworks
cdm	cubic decametre (1 cdm = 1,000 cubic metres)
cms	cubic metres per second
DUC	Ducks Unlimited Canada
EID	Eastern Irrigation District
GIS	Geographic Information System(s)
GoA	Government of Alberta
NHN	National Hydrography Network
SSRB	South Saskatchewan River Basin. The South Saskatchewan River Basin includes the sub-basins of the Bow River, Red Deer River, and South Saskatchewan River (including the Oldman and other tributaries)
SSRP	South Saskatchewan Regional Plan
SWCRR	South West Calgary Ring Road
WRMM	Water Resources Management Model
Flood fringe*	The portion of the flood hazard area outside the floodway. Water in the flood fringe is generally shallower and flows more slowly than in the floodway. New development in the flood fringe may be permitted in some communities and should be flood-proofed.
Flood plain	The active river valley that can be occupied by streamflow. Typically relatively flat areas of varying width constructed by alluvial processes and over bank deposition from previous flood events. Hydrologically, a flood occurs when streamflow exceeds channel capacity, and water enters the flood plain.
Floodway*	The portion of the flood hazard area where flows are deepest, fastest and most destructive. The floodway typically includes the main channel of a stream and a portion of the adjacent overbank area. The floodway is required to convey the design flood. New development is discouraged in the floodway and may not be permitted in some communities.

* Definitions from Government of Alberta.

1 Executive Summary

Severe flood and drought conditions have occurred in Alberta throughout living memory, history and prehistory. Although droughts have been more common, floods are not rare. The events in June 2013 caused loss of life and devastated homes, businesses, property, infrastructure, and landscapes. Following emergency responses by various authorities and volunteer agencies, the Government of Alberta established the Flood Recovery Task Force to explore and recommend options for responding to future such events. This project was designed to identify, examine and assess the intended and unintended consequences and trade-offs of potential flood mitigation options for the Bow River Basin from a "headwaters to confluence" river system perspective, and to make flood mitigation and resiliency recommendations to the Task Force.

The enormous scale, scope, and impact of the 2013 flood were such that many of the mitigation alternatives proposed so far are similarly large and impactful. Most of the options presented in this report have significant costs and carry environmental, social, or economic consequences. No one option is able to meet all needs. The choice of levels of protection in each affected area is a matter of social policy to be decided by elected officials. Once targets are set, the necessary suite of flood mitigation options can be identified and implemented to achieve the target, given the broad range of potential future flood events. Chapter 8 of this report describes three hypothetical target flow rates set by the participants as potential starting points for mitigation. The targets were applied to specific locations on four river systems, the Highwood, Sheep and Elbow tributaries, and the Bow main stem. These targets were set as starting points and may need to be revised as the costs and impacts of mitigation are better understood.

Choices among where to invest in mitigation options, where to redirect flood flows, where to reinforce banks, where to put in new infrastructure, and where to accept impacts on homes, businesses, fisheries, ecosystems, park lands, roads, bridges, and other factors are complex, difficult, and highly charged with uncertainties of many kinds. Nonetheless choices will be made among many diverse trade-offs, as repeating an estimated $6-billion in damages is presently deemed unacceptable.

A wide variety of experienced water managers, experts, and decision makers from across the Basin actively participated in this collaborative project, freely sharing their knowledge, expertise and perspectives. The purpose was to identify and examine as many alternative flood mitigation concepts as reasonably possible, to raise the many negative and positive factors to be considered for each, to model and compare the effectiveness of each option and combinations of options, and to report our findings and conclusions to the Provincial Flood Recovery Task Force.

This project clearly showed that a systemic, watershed-based approach is essential. Mitigation options implemented in one part of the complex and interrelated Bow River and tributary system can have major, even catastrophic, consequences in other parts of the system. Mitigation activities in the upstream reaches will have a cumulative effect on downstream communities and infrastructure. Diverting flow away from one community may transfer an unacceptable risk to another. All mitigation options will affect the watershed; they must function to build the natural resiliency of the watershed and allow for sound water management under flood, drought, and normal conditions. These interconnections have been known for decades and modelled for years by many of the participants in this project.

It is understandable and natural for flood impacts to be mitigated locally or regionally, but management of a basin-wide system is the responsibility of the Province. A prudent approach requires comparative assessments of every option, and an evaluation of the effects of options in combination prior to committing significant resources to something that could prove counterproductive and perhaps more damaging than doing nothing in some cases. This project is intended to inform a small part of the larger systemic approach as described in the Government of Alberta’s publication, *Respecting Our Rivers: Alberta’s Approach to Flood Mitigation*.

Specific mitigation options examined in this project were compiled from various sources, and many were modelled individually and in combination for the Bow, Elbow, Highwood, and Sheep river systems. A number of the flood mitigation concepts showed promise on their own while others were generally not supported. The group’s identification and assessment of these mitigation targets and the infrastructure and other mechanisms to reach them in no way implies endorsement of these options. The objective was to provide the factual data needed for decision makers to be fully informed of what is possible, not necessarily what is advisable.

Participants identified mitigation options that could be combined to achieve a range of mitigation targets. Recognizing the quickly approaching flood season, two combinations were developed to identify achievable mitigation options for spring 2014 and 2015.

The most promising near-term options for flood mitigation throughout the Bow River Basin that were identified through this project are:

1. Operate TransAlta facilities for flood control when needed. This should be implemented immediately for relatively low cost and maintained over the long term to achieve overall water management improvements as described in the Bow River Project results.
2. Construct a channel for the Highwood River through the Town of High River capable of handling 1300 cms or more. If needed, construct a channel north around High River to mitigate flood impacts on the town without increasing flood flows down the Little Bow system south of the town.
3. Operate Glenmore Reservoir in the same manner as in 2013. It was acknowledged that Glenmore Reservoir was operated optimally for flood peak attenuation during the 2013 flood event.
4. Apply existing wetland, riparian, and land management policies and plans to stop further loss and achieve a level of wetland and riparian restoration throughout the headwaters, foothills, and prairie reaches of the Bow System. This includes implementing the new Wetland Policy, making all wetland impacts subject to the mitigation process, implementing watershed and land management plans, and enforcing existing legislation.
5. Reinforce existing downstream infrastructure as soon as possible with spillways conforming to full safety standards, given potentially higher future flows; in particular, Bassano Dam and Travers Dam.
6. Improve resourcing for forecasting systems and better integration of communications to the first responders and the public if and as severe flood risk potential increases and becomes imminent.

Options to achieve medium and longer term flood flow targets

A system-wide approach to watershed management with a focus on flood mitigation options will remain an ongoing challenge for the next several years. To determine what the options might be, hypothetical flood flow targets were set by the participants using estimates from many official and unofficial sources. Alternatives to meet each of the targets were tested in the model. Both infrastructure and natural functions were included in the dozens of model runs conducted by the participants during interactive modelling sessions. The table below shows the hourly peak flow mitigation targets and locations. These targets were set in categories with increasingly rigorous objectives. The targets are for medium- or long-term mitigation purposes, can be mixed and matched as needed across categories, and assume the short-term actions will be taken immediately.

Many of these targets are already being revised upward by local actions such as the channelling of the Highwood River through High River, buyouts of homes in the floodway in High River and Calgary, protective actions for the water treatment plant in Okotoks, planned berming in Medicine Hat, and many other local and regional flood damage-reduction activities.

Bow Basin mitigation targets

Location	**Hourly Mitigation Target 1 (cms)**	**Hourly Mitigation Target 2 (cms)**	**Hourly Mitigation Target 3 (cms)**	**1:100 Event (cms)**
Bow River upstream of the confluence with the Elbow	~1050	~825	~540	1970
Elbow River downstream of Glenmore Reservoir	~450	~300	~180	758
Highwood River at High River	~1500	~1300	~1100	750
Sheep River at Okotoks	~850	~750	~650	954

Recognizing that the entire system has to be taken into account in any substantial mitigation infrastructure, Tables 7 and 9 in the text provide some preliminary downstream flow rates where major infrastructure may be in jeopardy.

By applying many of the mitigation options presented in Tables 3, 4, and 5, almost all of the targets in the table above could be achieved. However, there were clearly diminishing returns as one progresses to increasingly aggressive hourly mitigation targets. For example, on the Bow and Elbow rivers, achieving Target 1 reduced the flooded area in Calgary by 11 km^2, from approximately 40 kms^2 to 29 km^2. This area includes the stream channel, so the area of flood reduction consists almost entirely of areas that are outside the river banks. Target 2 reduced the approximate area flooded by an additional 3 km^2 and Target 3 by a further 1 km^2. See the GIS representations in Figures 62, 65, and 68.

Achieving the more aggressive mitigation target scenarios would require a considerable array of expensive and environmentally impactful new infrastructure. For many participants this raised the issue of too much control. Flood flows up to the point of serious safety threats or severe negative economic consequences are necessary as are healthy functioning river ecosystems. Further discussion centred on how much ordinary citizens are willing to pay in terms of pure financial costs as well as environmental and recreational costs to protect a relatively small number of homes, businesses, and infrastructure. The all-in costs including environmental and social issues versus the benefits of flood protection against relatively low probability flooding would have to be carefully considered by decision makers before proceeding down the path to some of the more aggressive mitigation targets.

In some cases, such as the Highwood River at High River, little in addition to the channelization infrastructure that is underway and planned may be needed at this location, recognizing upstream communities may still face flood mitigation challenges. The Elbow River presents the greatest challenge with a net reduction from inflow to Glenmore Reservoir of approximately 1200 cms to meet the most stringent target of 180 cms in the modelled 2013 event. In this event, Glenmore was able to reduce the peak flow downstream to 700 cms but had the peak runoff continued for several more hours it would have had to release the full inflow. This is where social policy decisions are likely to be the most difficult.

Next steps in flood mitigation decision making, including implementation of the short term options described above, should include:

1. Social policy decisions on what flow rate and elevation level we want to target mitigation to in each basin.
2. Comparative cost-benefit analyses of what it would take to achieve the desired mitigation targets, including consideration of these measures in terms of their ecological, social, recreational, downstream, and upstream impacts.
3. Analysis of the level and location of risk associated with these mitigation measures including upstream and downstream consequences, transfer of risk, and the cost of mitigating the negative impacts of the mitigation.
4. Setting aside some percentage of the costs of the infrastructure being engineered and built, proposed to be approximately 5-10% of the total, which would be used exclusively to retain and improve healthy functioning ecosystems and to establish and operate a collaborative governance function to administer and support watershed management.
5. Broad and full communication of the flood mitigation information, analyses and decisions to all communities and residents in the Bow River Basin.

A flexible, adaptive, and resilient approach to flood mitigation is needed since the next flood will no doubt have different characteristics than previous flood events. Planning to fight and win the last battle is rarely a successful strategy particularly with infinitely variable climate and weather patterns. Protecting against such a severe and massive flood will require some potentially severe and massive trade-offs among a variety of mitigation options, none of which are pleasant to contemplate nor beneficial to everyone. This report has laid out some of the options available to us, on the assumption that we as a society must not allow a recurrence of the human and economic damages suffered in the flood of 2013.

2 Introduction

Albertans value and respect the role that water plays in their day-to-day lives. Access to water is fundamental to human settlements and is the basis for economic activity and quality of life throughout Alberta. In the South Saskatchewan River Basin (SSRB), severe flood and drought conditions have occurred throughout living memory, history, and prehistory. Although droughts have been more common, floods are not rare. With the 1995 and 2005 flood events still in recent memory, the June 2013 floods were devastating, affecting families, homes, businesses, property, infrastructure, and landscapes.

Following emergency responses by various authorities and volunteer agencies, the Government of Alberta (GoA) established the Flood Recovery Task Force[1] to explore and recommend options for responding to future such events. The Task Force's scope includes all flood-prone basins in the province, but much of the initial attention has been on the Bow River system. Figure 1 shows the area covered by the Bow River Basin.[2]

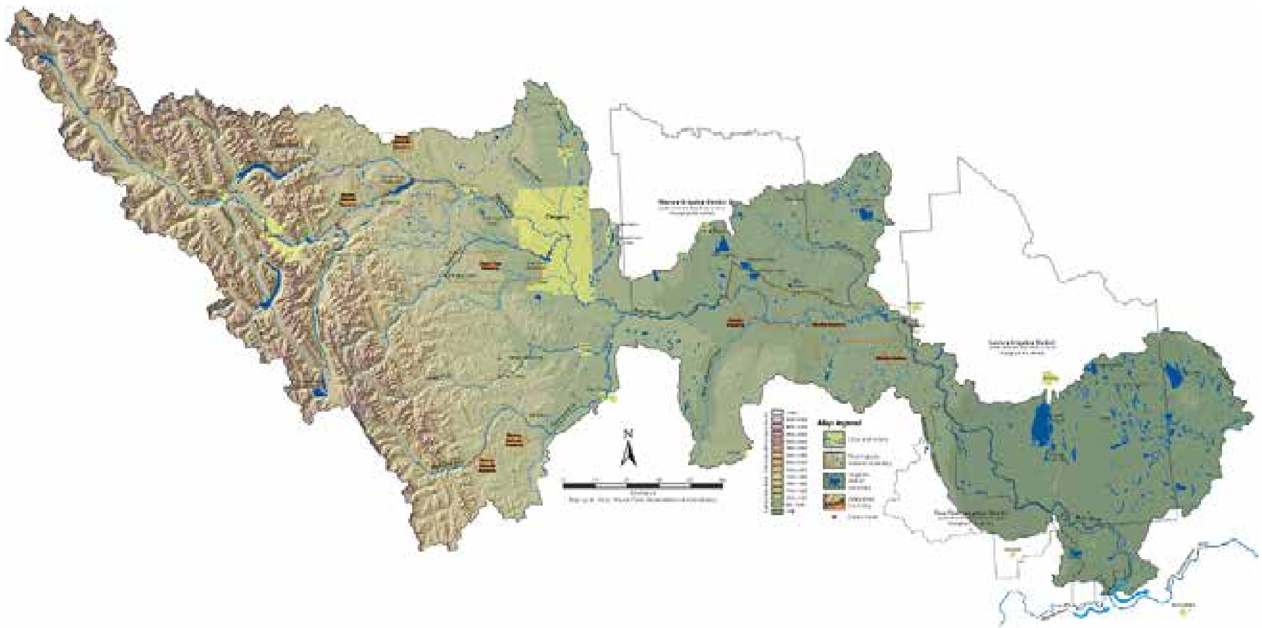

Figure 1: The Bow River Basin

The Bow River Basin is a highly responsive hydrological system with a disproportionate amount of mountain catchment characterized by steep slopes, high terrain, and late snowmelt. Precipitation is concentrated in May, June, and July and shifts quickly between catchment areas with limited warning. The historic record shows the basin to be prone to large flood events as well as periods of drought and periods of relatively "normal" conditions, as illustrated for the Bow River (Figure 2) and for the Elbow River below Glenmore Reservoir (Figure 3).

[1] See http://www.alberta.ca/Flood-Recovery.cfm
[2] The map in Figure 1 is provided courtesy of the Bow River Basin Council (www.brbc.ab.ca).

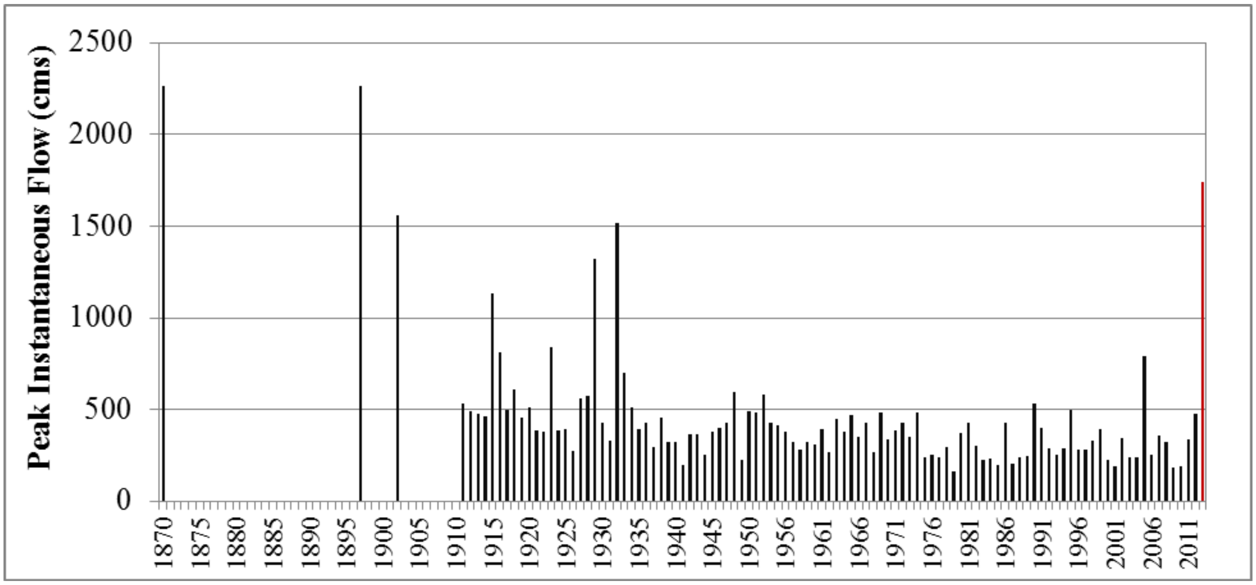

Figure 2: Peak instantaneous flow for the Bow River (1870 to 2013). The red bar indicates preliminary estimates of peak instantaneous flow in 2013.

Data sources: Water Survey Canada Archived Hydrometric Data and the City of Calgary

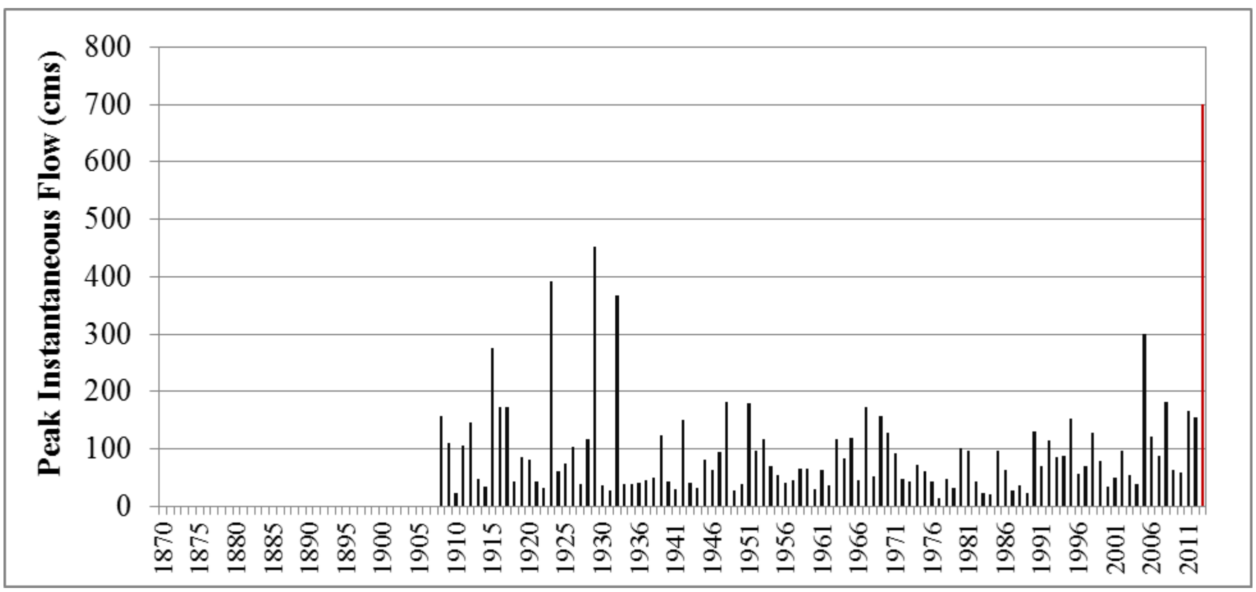

Figure 3: Peak instantaneous flow for the Elbow River below Glenmore Reservoir (1870 to 2013). The red bar indicates preliminary estimates of peak instantaneous flow in 2013.

Data sources: Water Survey Canada Archived Hydrometric Data and the City of Calgary

Both droughts and floods test water management infrastructure and operations as well as human ingenuity and creativity. Existing approaches are proving inadequate to mitigate the risks and damages from these socially and economically stressful events. With the magnitude and impact of the 2013 floods, recent focus has naturally been on flood mitigation. But given Alberta's long experience with drought and the reality of increasing climate variability and change, it is vital that we manage the province's water resources and watersheds with flexibility and adaptability to ensure resilience and sound watershed management, no matter what future conditions might be. Comprehensive water management frameworks are already in place in the Bow Basin or are being developed; examples of these are the 2006 *Water Management Plan for the South Saskatchewan River Basin (Alberta)*[3] and the 2008 *Water Management Plan for the Watersheds of the Upper Highwood and Upper Little Bow Rivers* (including the Sheep River).[4]

This project was designed to recognize and capitalize on the extensive body of work done to date on river management in the SSRB to identify, explore, and assess potential flood mitigation options in the Bow Basin. It applied proven methods, analytical tools, data, and information that support the development of adaptation strategies and opportunities in response to climatic and hydrologic conditions throughout southern Alberta. The experience, knowledge, and expertise of a wide range of stakeholders from throughout the Basin were essential to the success and credibility of the work.

[3] Available online at http://www.environment.alberta.ca/documents/SSRB_Plan_Phase2.pdf
[4] Available online at http://environment.gov.ab.ca/info/library/7977.pdf.

3 Project Objectives and Scope

This project was undertaken to:

- Enhance understanding of the immediate causes and consequences of the 2013 flooding in the Bow River system, including the Elbow, Sheep, and Highwood tributaries, by filling gaps related to data, interpretation, quantification, and application of flood flow levels. When the origins, locations, and rates of flood flow are understood, it becomes possible to determine more effective means to mitigate and reduce damages from future floods.
- Develop a consistent mechanism to evaluate the effectiveness of alternative flood mitigation strategies, relocation, infrastructure, and other ideas to reduce flood damage. The approach taken with this project was to combine data assembly, reviews, testing, and application of the Bow River Operational Model (BROM) with a flood inundation visualization tool to assess the relative effects of mitigation techniques, both individually and in combination.
- Facilitate the collaborative identification and development of practical and resilient adaptation strategies by individuals and organizations with extensive experience and knowledge related to the Bow River system.
- Enable the collaborative testing of new and adaptive operating strategies, infrastructure, and natural systems using the comprehensive and interactive mass balance streamflow model (BROM) of the entire Bow River Basin.
- Identify the intended and unintended consequences of potential flood mitigation options, including trade-offs, from a "headwaters to confluence" watershed perspective.
- Put forward flood mitigation and resiliency recommendations to the Government of Alberta's Flood Recovery Task Force.

The project focused on the Bow River Basin including the Bow, Elbow, Highwood, and Sheep rivers. While the flood mitigation options were specific to this Basin, they aligned with the objectives and frameworks established by the province-wide Flood Recovery Task Force. The project did not examine the economic and social impacts of flood flows, nor did it undertake detailed engineering or feasibility analysis, but it does offer informed opinion on advisability. Participants noted the potential value of local mitigation options but the overall project looked more broadly at flood mitigation options from a basin-wide perspective.

As participants moved through this work, they identified uncertainties and unknowns that should be recognized:

- The role and significance of groundwater in flooding remains uncertain. Groundwater and green water[5] are both forms of natural storage and contribute greatly to streamflow. The complexity of these issues needs to be communicated to and understood by decision makers.

[5] Green water is the precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation. Eventually, this part of precipitation evaporates or transpires through plants. Green water can be made productive for crop growth (although not all green water can be taken up by crops, because there will always be evaporation from the soil and because not all periods of the year or areas are suitable for crop growth). Source: Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M. and Mekonnen, M.M. (2011) *The water footprint assessment manual: Setting the global standard*, Earthscan, London, UK.

- Flood flow levels are still in a draft stage and are being debated. What level are we mitigating to? This is a social policy question that needs to be addressed.
- River hydraulics in many areas of the Bow Basin continue to be poorly understood, for example, around High River where tributaries, ground water and bank interactions add to the complexity of the river dynamic.
- Models are useful tools, but they do have limits. They cannot reflect all aspects of water movement through systems and across the landscape in real time, nor can they capture the temporary barriers and emergency response measures put in place during a particular event. It is very difficult for large-scale watershed models like the BROM to capture changes in local barriers and fortifications that affect streamflow. The model cannot take into account any channel morphology or bathymetry effects occurring as a result of the 2013 flood, which occurred after the modelling data set was collected.
- The BROM is a large-scale screening level model that does not explicitly account for streamflow routing and changes in the speed of flow. Participants raised a number of important issues to be addressed, many of which are not part of this modelling process, but rather are for consideration by decision makers who must take into account the screening of more detailed local-scale hydraulic modelling, engineering, economic, and environmental factors, risk assessments, and systemic issues.
- Return frequencies (e.g., 1 in 100) are a statistical estimate. More relevant to humans is actual water levels, and Winnipeg provides an example. All programming and mitigation structures in Winnipeg are established by water level, not flow rate return period. Primary datum is the James Avenue Pumping Station. Datum 0 is the normal winter ice level. That becomes the reference point for everything in the city, including mitigation. In Winnipeg the Primary Dikes are built to a standard of 26.5 feet above datum (river gradients are taken into account).

4 Methodology

4.1 A Collaborative Approach

The collaborative nature of this project was designed to identify and use the most accurate and comprehensive data and facts and, thereby, build understanding, confidence, and trust among participants. It provided an opportunity for government agencies at the provincial, regional, and local levels to work closely with most of the major stakeholders in the Bow River Basin in a neutral setting. The starting point was a common set of objectives and agreed-upon data that could be applied and tested using transparent and proven modelling tools. Among others, one outcome was an integrated suite of analytical tools, specific to the Bow Basin, that are open, accessible, and usable by anyone.

A wide variety of experienced water managers, experts, and decision makers from across the Basin actively participated in the project, freely sharing their knowledge, expertise, and perspectives. The work was co-funded by Alberta Innovates – Energy and Environment Solutions and by the Government of Alberta Flood Recovery Task Force. Tremendous in-kind support was provided by project participants. Representatives of the Task Force attended project meetings and indicated a strong interest in receiving the results. The Bow River Basin Council (BRBC) partnered with the project by opening up four forums to obtain broader input on potential flood mitigation options and by ensuring the outcomes align with watershed management plans.

Participants gathered for three full-day meetings in November 2013, and in January and February 2014, spending time at two of these meetings in live modelling sessions to examine potential flood mitigation options and combinations of options.

4.2 Project Tools and Technologies

The project applied proven methods, analytical tools, data, and information to support the assessment of flood mitigation options. Specific components included OASIS modelling technology, XA Solver technology, and Geographic Information System (GIS). The OASIS and XA Solver patents are held by HydroLogics Inc. and Sunset Software, respectively. These technologies were made available via HydroLogics Inc. Upon completion of this initiative, the tools and access to them and the supporting data and knowledge will continue to be publicly accessible without additional licensing. Tools and data were combined and applied collaboratively by project participants to identify, quantify, and test specific practical solutions to mitigate future flood risk and damage. Project tools and technologies were designed to look at many possible flood scenarios, not just those observed in 2013.

4.2.1 The Bow River Operational Model (BROM)

An interactive mass balance water model – the BROM – was developed and refined through the 2010 Bow River Project and the 2013 SSRB Adaptation to Climate Variability Project,[6] and has been tested for accuracy and credibility by senior water managers from governments, irrigation districts, and other water interests over the past several years. The BROM has been used in

[6] Reports from these projects are available by searching on the Alberta WaterPortal at http://www.albertawater.com/.

previous projects to a) evaluate and recommend changes to existing infrastructure and operations on the Bow River system to improve environmental, social, and economic conditions under current climate patterns, and b) assess strategies to manage and mitigate conditions that may arise due to future climate variability and change. Data used in the BROM were obtained from Alberta Environment and Sustainable Resource Development's (ESRD) Water Resources Management Model (WRMM), Alberta Agriculture and Rural Development, the Irrigation Demand Model, Water Survey Canada, TransAlta, and various municipalities in the Bow Basin, including the City of Calgary.

The BROM can address multiple objectives and evaluate many performance measures besides flood flows, including water shortages, power, and environmental indices. It is a daily time step model for the available historic flow record (1928-2009), and was converted to an hourly time step model for this project for the 2005 and 2013 floods.

This modification allowed flood peaks to be captured as well as hourly operations that were or could be implemented during flood situations. Hourly streamflow data were not available for all naturalized flow locations represented in BROM; therefore, peak flows were iteratively calibrated to known upstream and downstream locations for the 2005 and 2013 flood events. The calibration involved scaling existing daily inflows by observed hourly flows at nearby stations in 2005. Synthetic hydrographs were derived for 2013 at locations without observations. The synthetic hydrographs were based on hourly preliminary Water Survey Canada data from nearby stations, then scaled appropriately based on preliminary peak flow estimates.

Hourly streamflow simulations compared well with observations in 2005 and preliminary observations in 2013 at the Water Survey Canada station 05BH004 (Figure 4). While the flow levels and rates in specific locations may not match the actual event precisely, the simulated flows were considered to be a good representation of the events and useful for understanding the direction and magnitude of flood mitigation options. Participants worked with the model to test and validate various flow levels for mitigation purposes during live modelling sessions.

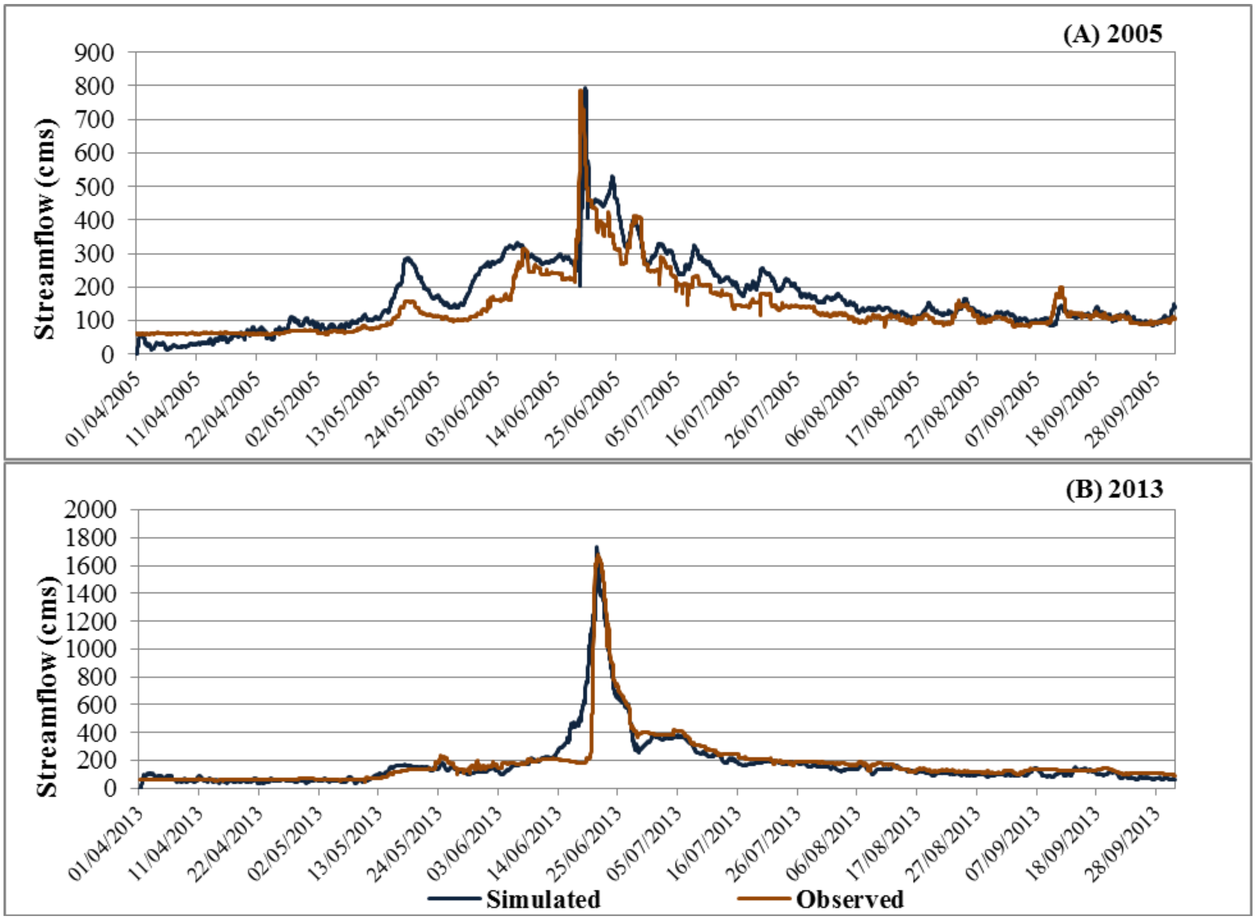

Figure 4: Comparison of observed and simulated hourly streamflow in the Bow River upstream of the confluence with the Elbow River in (A) 2005 and (B) 2013

The BROM is a mass-balance hydrology model and not a hydrodynamic model, flood inundation model, or precipitation runoff model. As such, it cannot be used directly to model flood flows resulting from changes to upland land cover, flood plain connectivity, channelization, or precipitation patterns. However, these effects can be modelled in BROM if estimates of their impact on storage and travel time are known.

Figure 5 illustrates the breadth and complexity of the area modelled in the BROM for this project.

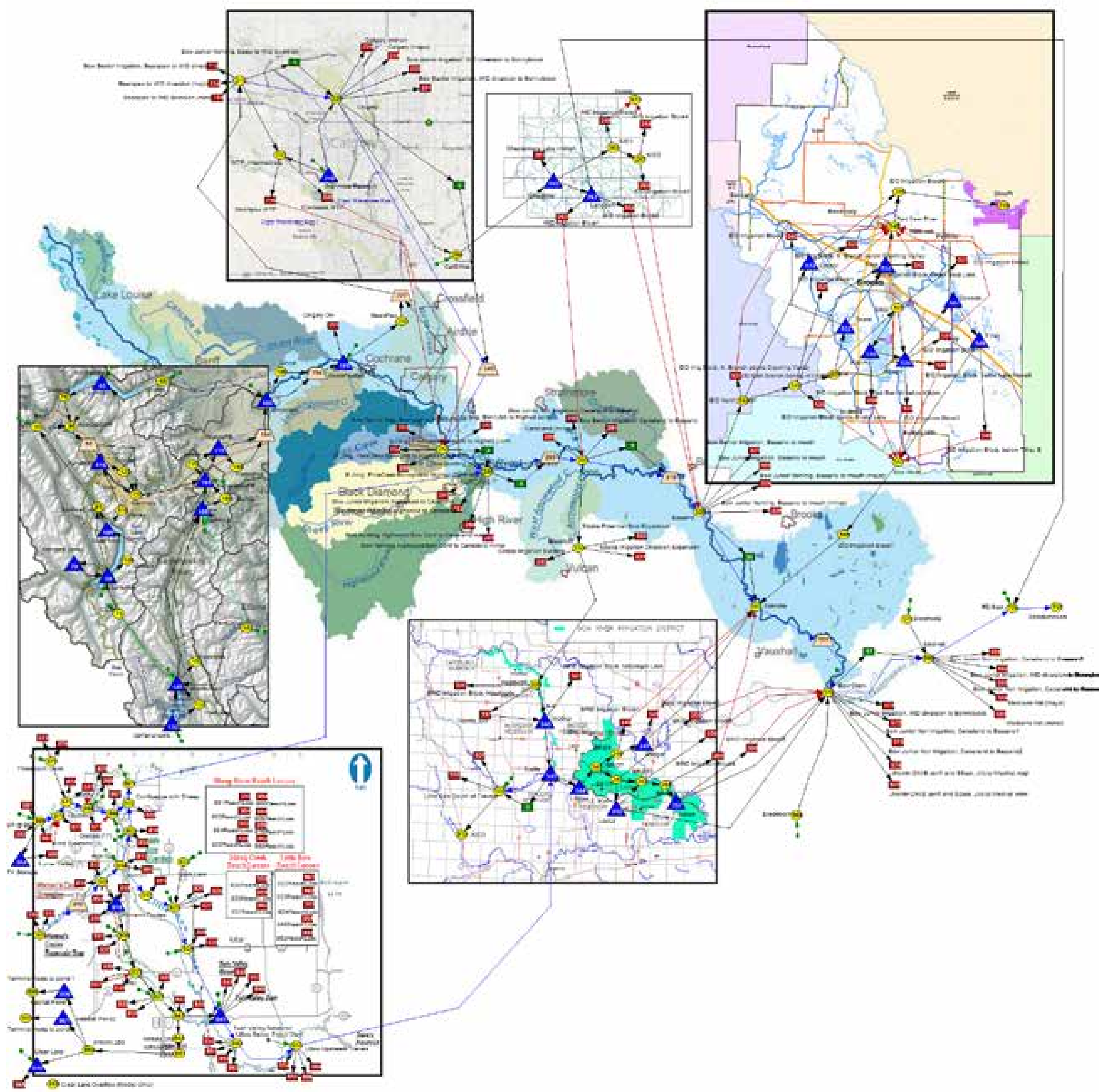

Figure 5: Schematic showing the area modelled in the BROM

4.2.2 Flood Visualization Engine

A new flood visualization engine covering the City of Calgary was developed by GranDuke Geomatics Ltd. for this project to make the flood flow performance measures meaningful and understandable.The goals were to:

- See where flood flows would spill over river banks
- Estimate how much spillover would occur
- Approximate where water would go
- See how the flooding relates to existing floodway mapping
- Assess relative differences in flooding as a result of mitigation options.

Flood extent estimates were based on the 2005 and 2013 flood events that were simulated using BROM.

The visualization tool is very data intensive and uses data from both ESRD and the City of Calgary. Two key data sets were required for this modelling and were provided by the City of Calgary:

- transects with associated rating curves exported from a hydraulic model (HEC-RAS), and
- raster digital surface models showing "bare earth" elevations.

Six hundred and fifty transects along the Bow and Elbow rivers were acquired as ESRI Shapefiles. Rating curve (stage vs. discharge) data generated using HEC-RAS were provided for each transect. The data were delivered as a MS Excel™ file that included a linear interpolator to compute water surface elevation for each transect at a given discharge.

Two additional datasets were also acquired to facilitate the modelling process:

- side-channel flow proportions as a function of streamflow, and
- stream main channel and island hydrography GIS data.

Golder Associates Ltd. (2012)[7] provided key information regarding streamflow partitioning between main and secondary channels. GIS features representing the Bow and Elbow rivers were acquired from the National Hydrography Network (NHN) via GEOBASE (www.geobase.ca).

Flood inundation maps were developed by interpolating water surface elevations between the 650 cross sections. The difference between the water surface elevation and "bare earth" elevations was generated through overlay analysis in a GIS. Areas of inundation were deemed valid if a) the inundated area was spatially connected to the river mainstem, or b) the inundated area was within 250 metres of the spatially connected flood extent. The extents of flood inundation were then compared and verified using previously published flood maps and airborne imagery acquired during the June 2013 flood.

The 1:100 flood values from the City of Calgary that were used in the flood visualization tool are based on the following reference: Golder Associates Ltd. 2010. *Hydrology Study, Bow and Elbow River Updated Hydraulic Model Project, Revision A.* Prepared for Alberta Environment. Report No. 09-1326-1040.

Following the verification of preliminary results, several model improvements were identified and implemented. The modifications were implemented to address a) depth of water discrepancies between the Bow and Elbow rivers that were forecast following mitigation strategies, and b) extreme events where flooding was observed well beyond transect extents near a sharp meander along the Elbow River. Following the model modifications, three comparison datasets were used to assess model accuracy:

[7] Golder Associates Ltd. 2012. *Hydraulic Modelling and Inundation Mapping, Bow and Elbow River Updated Hydraulic Model Project.* Report Number 09-1326-1026.7000. Prepared for The City of Calgary and Alberta Environment and Water.

1. Simulated results for the 1:100 year event were compared to the Flood Hazard Mapping datasets published by GoA.
2. Simulated results for the 1:100 year event were compared to the flood mapping conducted by the City of Calgary.
3. Aerial imagery flown shortly after the 2013 flood were accessed through a GIS image service hosted by the GoA, and airborne imagery was provided by the City of Calgary. These datasets were used to check for obvious discrepancies.

The flood visualization tool was delivered as a web application powered by GranDuke servers and accessible through any browser that supports the Google Earth plug-in. Google Earth provides free access to relatively up-to-date imagery as well as three-dimensional buildings, neighbourhood labels, and labelled roads. Figure 6 shows an example of a flood inundation extent. The visualization engine also includes a graphing component that enables users to compare inundation extents.

The flood visualization graphic component includes the river channels in its statistics, so a calculation of total area flooded will include not only the over-bank flooding, but also the normal river channels. Thus when mitigation options are modelled and the area flooded is shown to be reduced, nearly all of that calculated reduction will consist of locations not normally under water. For example, the base case shows about 40 km^2 in total was covered by water, but this includes the stream channels. If a mitigation strategy reduces the flooded area by 10 km^2, the stream channels are still covered in water, so virtually all of the reduction in flooded area comprises normally dry land.

Figure 6: An example of the flood visualization engine. The pale blue polygon is an example of a flood inundation extent shown in the tool.

4.3 Assessing Potential Flood Mitigation Options: What Are We Mitigating To?

As potential flood mitigation options were identified and the data required were made available, each option was modelled using the BROM and presented to participants at the working sessions. Participants examined and refined these options and their potential mitigation impacts, and had opportunities to suggest new approaches or combinations. These general approaches, the more specific mitigation options, and the results of the modelled runs are described in the following sections.

The performance measures used for assessing flood mitigation results are flow values compared against the 2005 and 2013 hourly base case runs at four locations. Flow comparisons are made at: 1) the Bow River upstream of the Elbow Confluence; 2) the Elbow River downstream of the Glenmore Reservoir; 3) the Sheep River at the Town of Okotoks; and 4) the Highwood River at the Town of High River.

Table 1 presents the suite of mitigation targets discussed and used in this project for key locations in the Bow Basin. Numbers in the column labelled "initial mitigation targets" were identified initially and, as participants worked with them and as municipalities and others gathered more information, the targets were revised to be more realistic and achievable (the column labelled "revised mitigation targets").

Table 1: Potential Bow Basin mitigation targets

Location	Initial Mitigation Target (cms)	Revised Mitigation Target (cms)
Bow River upstream of the confluence with Elbow	~825	~1050
Elbow River downstream of Glenmore Reservoir	~180	~450
Highwood River at High River	~180	~1500
Sheep at Okotoks	~750	~750

Mitigation targets were developed from discussions with municipal officials, water managers, project participants, and from results of the flood flow visualizations. Mitigation targets are required for decision making on mitigation infrastructure, pre-flood planning, estimations of cost for mitigation options, and cost of previous and forecast flood inundation. They are intended to be flexible in the sense that reaching slightly higher or lower flow rate targets with one or another mitigation option should be part of the costs and benefits evaluation. For example, if raising the Ghost Reservoir dam and dike system by 3 metres as modelled impinges on the railway or First Nations reserve, but 2.5 metres would not, then a model run with a 2.5 metre raise as opposed to 3 metres could be provided, or any other level; the peak flow reduction could then be approximated, which may become the new mitigation target for practical purposes.

Both the initial and revised targets, and others, are shown in the modelling results in Section 7. They continue to evolve and ultimately the GoA will decide what the targets should be. This is a fundamental social policy decision that will be influenced by many factors. To inform this important discussion and decision, three different flow target scenarios were developed as mitigation options were combined, and this work is described in Section 8.

5 Flood Mitigation Approaches

Seven broad flood mitigation approaches were identified in this project and discussed by participants. These approaches align with many of the principles and key elements identified in *Respecting Our Rivers*, the pamphlet published by the GoA that described the Province's approach to flood mitigation.[8]

The approaches are summarized in Table 2; further commentary and feedback received from participants during meetings and at the BRBC forums is noted below the table for each approach. This commentary is presented in two categories: comments pertaining to the operations and approach, and comments on potential impacts on the river system or watershed.

Table 2: Flood mitigation approaches

Approach	Brief description
Relocation	Reduce risk to people and property by removing infrastructure from the flood plain and restricting future development
Dry dams	Build detention facilities that temporarily detain high flows but allow normal flows to pass without hindrance and do not permanently retain water
Diversions[9]	Divert high flows around high risk areas; diversion channels could include new overland routes; existing overland routes, and subsurface tunnels
Wetland storage	Use natural storage function of wetlands to temporarily detain high flows
Natural river functions	Restore natural river functions to slow and detain high river flows; this includes wetlands, healthy riparian areas, bio-engineered bank protection, re-widening the floodway, natural channel design, meander belts, active flood plains
Change existing operations	Draw down spring reservoir levels and/or raise full supply level capacities of existing reservoirs to capture high flows
Land management	Implement best land management practices in upstream areas (headwaters) to slow the water from reaching infrastructure; this includes wetland restoration, timber harvesting, wildfire management, timber disease and pest management, off highway vehicle trail management, reducing fragmentation and linear disturbances

[8] This document is available online at https://pabappsuat.alberta.ca/albertacode/images/respecting-our-rivers.pdf.
[9] This report uses the common definition of diversion as "altered stream flow" rather than a diversion of water for a licensed offstream use.

Relocation

This approach reduces risk to people and property by removing infrastructure from the flood plain and restricting future development. Potential relocation sites include floodways and flood fringes throughout the Bow Basin.

Operational comments:

- Relocation after the 2013 flood event includes floodway buyouts and future development restrictions. The best approach is not to develop in a susceptible flood plain, and to enforce development restrictions. Relocation is the only way to be certain of avoiding infrastructure flooding.
- Moving infrastructure and homes where appropriate and functional is a more effective and may be a less costly solution than flood mitigation structures that simply address the symptoms and spread the risk to others. Mitigation approaches are trade-offs in an attempt to protect people so they can continue to live and work in active flood plains, and the costs are borne by all Canadians as well as by the affected aquatic communities.
- The assumption is that it is often cheaper to mitigate than to move existing development. "Givens" may be, for example, that downtown Calgary and large infrastructure such as dams will not be moved.
- Flood plains are mobile and flood maps should be kept up to date to improve cost-effectiveness of potential relocations. If mitigation funds are repeatedly requested, costs should be borne by those who want to develop and live in these areas.
- It can be challenging to make individual relocation choices in the context of a basin's decisions on mitigation options.

Impact on river system or watershed:

- Relocation enables restoration of natural river functions, such as more space for rivers to run, additional buffering, more green space, and improved water quality.
- If Albertans truly want their rivers to look as natural as possible in the future, and to provide good habitat for fish and wildlife, the best way to achieve this is to prohibit further development within the entire floodway and, where feasible, the whole flood plain. If this is done, and those who now have houses located in the flood plain are provided with assistance to relocate, then the amount of money that would need to be spent on erosion control and the Disaster Recovery Program would be greatly reduced in the future, although short-term costs may be quite high.

Dry dams

Dry dams, or detention facilities (barrier with culvert or concrete reinforced opening, whether gated or not), would be built to temporarily detain high flows but allow normal flows to pass without hindrance; such structures do not permanently retain water. Representatives of the Flood Recovery Task Force and the Expert Panel on Flood Mitigation visited the operators and facilities of Miami Conservancy District dry dams in Dayton, Ohio in January 2014. This interaction was valuable in pointing out the differences between dry and wet dams in terms of their construction, operations and maintenance, financing, the mitigation the structures can offer, and the impact they have on the river system.

In preliminary assessments, potential sites for dry dams were identified in all four river systems in the Bow Basin:

- Bow: Waiparous Creek, Ghost River, West of Bearspaw Reservoir
- Elbow: Quirk Creek, Canyon Creek, McLean Creek
- Highwood: West of Eden Valley, Ings Creek
- Sheep: Macabee Creek, Three Point Creek

Operational comments:

- Dry dams must be built to full dam safety standards, including a spillway, as the consequences of failure could be extreme.
- Ongoing operation and maintenance costs as well as initial costs are significant.
- Dry dams would need to be managed for public safety at all times.
- Dry dams would require extensive and ongoing debris and silt management.
- Sizing the outlet design will be critical to prevent significant inundation for extended periods during normal high runoff. Gates may be required, which could enable better overall management of dry dam operations, but entail additional maintenance and cost.
- Water velocity could be substantial at the outlet, and energy dissipation would require a concrete stilling basin or other such energy dissipation measure. An arch-pipe culvert would likely require a concrete floor to mitigate scour and undermining. An impressive vortex is likely to form, which would have potential to draw floating debris down. There are likely a few ways this could be minimized, but it will be a challenge and there may be no way to guarantee that debris will not be a problem.
- These openings may be too big rather than too small unless they have gates. Bigger is better for fisheries and for allowing natural flooding and debris movement up to a highly unusual flow rate. The smaller size would be subject to tremendous pressure with a large magnitude flood; many large culverts were crushed and dislocated from their bedding material in the 2013 flood, which would be very harmful to an earth fill dam.
- Post-flood event releases need to be understood and information shared appropriately, as these releases would create temporary high flows through the river system.
- Structures should be built and operated to help mitigate future droughts as well as floods, thus making them no longer dry dams, which raises a number of other issues to be addressed.
- Dry dams require a clear governance and decision-making process in all aspects of structure management.
- The further upstream that structures are placed, the greater the chance that a flood will miss the structure.
- There is potential to create a false sense of security downstream; for example, a dry dam could be built with the intent of protecting downstream residents, but if a flood occurs outside the dam’s catchment area, downstream residents who thought they were protected by the structure could still be in jeopardy.
- Land ownership could be an important issue and potential barrier in siting new infrastructure.
- Dry dams have been used elsewhere but typically in streams that go dry and have much lower gradients.

- Compared to the Elbow River system, the dry dams of the Miami Conservancy District in Ohio are in a radically different ecosystem and climate and have a much different elevation drop in their rivers, as well as differing riparian ecology and species. To expect the same results of a dry dam in each system may be misleading. The highest rainfall event in the Miami River occurred in 1925 at 121 mm in one day. Over three days, 170 mm was recorded in Bragg Creek in 2013. Considering the length and drop of each river, the average drop of the Miami River is 0.64 m/km, whereas the average drop of the Elbow River is 8.83 m/km. The run off coefficient in the Alberta East Slopes would be much higher than in the Eastern Corn Belt Plains Ecoregion, with a dramatic difference in soils and slope. Additionally the saturation rates would play a significant role in timing of flows. This presumably led to issues in Ohio with siltation and some woody debris entering the system, but in our East Slopes we would face a very different issue of introducing shallow-rooted large woody debris and large boulders with significant gradient and bed load movement. This will make flows, timing, and debris very different, as well as the associated ongoing maintenance costs. The aquatic community in the Miami River is also different, with slow moving waters and poor-swimming fish species. As long as there is active flood plain for the fish to escape the flows, they likely are not often washed downstream. Another significant difference is seen in the case of the Taylorsville Dam (built in 1914), on the Miami River located 10 miles north of Dayton, Ohio. A view on Google Earth shows that the community has taken a major step away from the active river channel. There has been little or no development in the active flood plain through Dayton proper. Instead there is functional flood plain and active forests upstream of the dry dam and, in the flood plain, only parks and golf courses with minimal infrastructure.
- When considering the financing for building and operating such a structure, it was noted that in Ohio the facilities are paid for by homeowners who benefit from the dam through a special levy on property tax.

Impact on system or watershed:

- Dry dams would likely impede fish passage and destroy spawning sites.
- Potential locations are in valued ecosystems and wildlife corridors as well as popular recreation areas. The overall landscape and use of the area would be changed, including substantial loss of vegetation, creating more potential for erosion.
- Habitat for both flora and fauna would be lost, potentially affecting some species at risk.
- The implication of limiting, un-gated culverts is that entire flood peaks would be cut off, which means loss of the beneficial flood pulses that are important for rivers, riparian areas, and flood-dependent species such as willow, poplar, and cottonwoods.
- The temporarily flooded area behind a dry dam prevents opportunity for new development and infrastructure. Such flooding could also be stressful for trees that do not tolerate periodic sustained submergence.
- Dry dams would be most useful if they were built lower on the main stem rather than high in a tributary to offer a greater catchment area for the structure.
- Dry dam failure could lead to cascading failures of downstream dams in the system. Should such a failure occur, it would carry a greatly increased risk of loss of life.

Diversions and channelization

This approach involves diversion of high flows around or through high risk areas via constructed channels. Diversion channels could include new overland routes, existing overland routes, and subsurface tunnels. A number of potential diversion sites in the Bow Basin have been identified and are at varying levels of consideration and study. The list of potential diversion options includes:

- Calgary conduit under 58th Avenue
- Calgary open channel or conduit diversion along 14th Street to Fish Creek
- Calgary open channel diversion along South West Calgary Ring Road (SWCRR) to Fish Creek
- Elbow River open channel diversions through Priddis Creek and/or old irrigation channels
- High River enhanced channelization of the Highwood River through the town
- High River overland diversion north of the Town of High River
- Highwood open channel diversion to the Little Bow River.

Operational comments:

- Challenges from overland and underground diversions include diffusion of high velocity outflow, debris, backwater risk, possibility of increased erosion and sedimentation, and relocated flood risk.
- Debris and sediment management and the difficulty of access to maintain the system in an extreme event must be considered.
- Diversion management would require clear governance and decision-making process.
- If diversion channels are cost-effective, they are potentially a good solution.
- If there is a diversion channel and offstream storage, storage is limited by the capacity of the channel.

Impact on system or watershed:

- Water quality could be a concern at the outflow of an underground diversion or open channel due to potential leaching of contaminated areas that are not normally flooded.
- A diversion channel would restrict access to slower water flow by fish and wildlife. In the 2013 event, fish moved into sheltered (low flow depth and velocity) inundated areas for protection and may not have this opportunity with an above-ground diversion, and certainly not with a tunnel.
- Diversions could negatively affect recharge of alluvial aquifers.
- Diversions may increase the need for flood mitigation in areas downstream and may create ethical and legal issues if risks are transferred from one area to another.
- Potential increase and/or acceleration of time to peak flow in downstream areas may require additional safety measures at downstream infrastructure including bridges, highways, and communities. Furthermore, impacts on downstream dams (Bassano, Twin Valley, Travers) would need to be clearly understood and the appropriate upgrades made.

Wetland storage

The natural storage function of wetlands could be used to temporarily detain or slow high flows. Specific sites with high potential in the Bow Basin include Jumpingpound Creek and Ghost River, with others to be identified. Wetland conservation and restoration would likely play a more important role in communities lower in the watershed than in headwaters areas, underscoring the value of wetlands when the watershed is considered as a whole. Project participants stressed repeatedly the value of wetlands in mitigating floods, as well as providing many other benefits to the ecosystem and watershed. In addition to looking at wetland detention on specific sites, there was strong support for efforts to re-establish wetland and riparian areas more broadly in the basin.

Operational comments:

- The success of this approach would depend on availability of storage capacity in a flood event, influenced by wetland type, its saturation going into a high-flow event, and its location relative to streams and rivers.
- Many wetland areas have been lost and are unlikely to be recovered, so the potential value of this approach is much reduced from what it once was, and this degradation has already reduced watershed resiliency. Remaining wetlands should be protected from development, harmful logging practices, destructive recreational activity, and other improper land uses, especially in the headwaters.
- A significant area of wetland would be required to detain large flow volumes such as those experienced in 2013. Potential mitigation value is likely higher in less extreme flood events and for overall watershed diversity and health.
- Wetland restoration done in partnership with landowners is an opportunity during implementation of the new provincial Wetland Policy. A current and appropriate wetland inventory is a key first step.
- Infrastructure may be required to divert flow to wetland areas. This type of infrastructure has been successful in many urban environments.
- Wetlands offer a range of mitigation functions throughout the basin including resisting and slowing flows in the steep slope headwaters, absorbing and detaining flows in the Prairie pothole region, and maintaining the effectiveness of other control structures and mitigation measures throughout the basin by moderating inflows.
- Much of the science, knowledge, and policy already exist for the effective conservation and restoration of wetlands; the next step is recognizing and pursuing wetland opportunities.

Impact on system or watershed:

- Wetlands are an integral component of a healthy functioning watershed, increasing the resilience needed to achieve many watershed objectives in addition to flood mitigation. Among these are removal of phosphorus, nitrogen, sediment, and heavy metals – additional benefits that are not necessarily provided by other mitigation options. Maintaining wetland integrity fits well with overall watershed management.

- A recent report by Ducks Unlimited Canada (DUC)[10] describes the flood mitigation role that wetlands can play, and shows that investing in wetland restoration and conservation is a cost-effective means of helping to mitigate flooding.
- The text box summarizes the important role that wetlands can play in mitigating floods and maintaining a healthy watershed. As an example, the constructed wetlands at Fish Creek appear to have made a meaningful difference in retention and flow of water through that area in the 2013 flood.

> "Wetlands are known to be an effective flood control measure. The ability of wetlands to act as storage basins on the landscape, allows for increased water storage, slowing the release of water from extreme rainfall events into surrounding streams and rivers, thereby decreasing flood heights and volumes (Ramsar 2011). Areas that are rich in wetlands, particularly in headwater regions, have shown to be less at risk for flooding, whereas regions that have seen large amounts of wetland loss have been shown to experience a greater degree of flooding (Ramsar 2011). Flood attenuation is only one of many ecosystem services that wetlands provide, and these rich ecosystems, also provide a variety of critical ecosystem services, i.e. drought prevention, biodiversity, habitat, increase water quality (nutrient and pollutant filtering), groundwater recharge, carbon sequestration, etc., that are valuable and support other societal objectives (GoA 2011)."
>
> Source: Ducks Unlimited Canada. 2014. *Wetland Conservation and Restoration as Flood Mitigation Tools in the Bow River Basin*, p. 3.

- A follow-up report coming soon from DUC will identify opportunities for short-term actions and high potential locations for conservation and restoration.

Natural river functions

With this approach, natural river functions would be restored as a means to slow and detain high flows. Natural river functions include healthy riparian areas, bio-engineered bank protection, restoring the natural flood plain, natural channel design, and others. High potential sites for such restoration are the Elbow River upstream of and through Calgary, upstream and downstream Highwood River sites, and conservation sites in the Town of High River.

Operational comments:

- All the damage in 2013 was to infrastructure; natural areas either depend on or are resilient to flood events. Healthy functioning ecosystems depend on the natural cycle of flooding and the disruption and benefits that floods bring. Thus, the only damage caused by floods is going to be to people and their property. Many areas of deeply rooted trees and intact riparian vegetation and understory throughout the Bow River system held up very well during the 2013 flood, showing little if any erosion. The protected Inglewood Park region is one example of this. As well as showing the resiliency of the riparian zone, it is an example of where the river has the ability to fully spread the flows across the river bed and dissipate energy.
- In the past, we have allowed intensive development and infrastructure investments in some flood plains. Thus it should not be surprising that damage to these developments from the 2013 floods resulted in the most expensive disaster in Canadian history.

[10] Ducks Unlimited Canada. 2014. *Wetland Conservation and Restoration as Flood Mitigation Tools in the Bow River Basin*. Available by searching on the WaterPortal at http://www.albertawater.com/.

- Part of this approach should include taking an integrated look at geomorphology and channel migration zones, and not allowing development where fill is used to build up banks. That sort of development can put people at risk when channels migrate.
- Meander belts and alluvial flood plains and aquifers should be identified and respected.
- In some places, erosion due to improper recreational access along a river bank can compromise natural integrity.
- It is important to allow the stream room to move throughout its flood plain.
- Voluntary rehabilitation and/or conservation by landowners could be encouraged in support of this approach. Organizations such as Cows and Fish, Watershed Stewardship Groups, land trusts, and some rural municipalities are already working with landowners to undertake such initiatives and these efforts are encouraged.

Impact on system or watershed:

- Provided that erosion is not accelerated as a result of human activities (e.g., removal of riparian vegetation, overgrazing, off-highway vehicles), natural processes create some of the best fish habitat in rivers and streams. Armouring river banks to prevent erosion adversely affects not only fish and wildlife habitat, but also the aesthetics, the function of the river, and the transfer of energy.
- We need to consider what we want our rivers to look like in the future. Perhaps it is time that question was asked of all Albertans, since the bed and shore of rivers belongs to them. Otherwise, the decision as to what our rivers look like in the future will be made by the adjacent landowners, who have built houses, golf courses, etc., in the flood plain or on top of erodible river banks.
- If Albertans truly want their rivers to look as natural as possible in the future, and to provide good habitat for fish and wildlife, the best way to achieve this is to prohibit further development within the entire floodway and, where feasible, the whole flood plain. If this is done, and those who now have houses located in the flood plain are provided with assistance to relocate, the amount of money that would need to be spent on erosion control and the Disaster Recovery Program would be greatly reduced in the future, although short-term costs may be quite high.
- ESRD's *Stepping Back from the Water* report[11] highlighted the role riparian areas play in reducing peak flows and downstream flooding. Plants resist the flow and dissipate the energy, allowing increased time for infiltration into the soil and for sediment to settle out. The report's beneficial management practices guidelines are a starting point for the easiest and least expensive form of natural mitigation, which is to stop land use practices that degrade the natural function of riparian areas.
- Since "erosion control" through developed areas typically means bank armouring, the statement on page 5 of the GoA's pamphlet *Respecting Our Rivers*, is something that some people would not agree with: "Investing in erosion control today..." ensures that water "...flows within natural channels in the future..." Armoured banks are not what many would call "natural channels" and will require ongoing investment for maintenance.

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[11] Government of Alberta. 2012. *Stepping Back from the Water: A Beneficial Management Practices Guide for New Development near Water Bodies in Alberta's Settled Region*. Available online at http://environment.alberta.ca/04100.html

- The relative contribution of individual natural river function measures to mitigate large floods may be small but locally significant. However, the cumulative impact could be valuable and can achieve many watershed objectives through the river's entire flow regime (e.g., droughts and floods).

Change existing reservoir operations

Existing operations could be changed to draw down spring reservoir levels and/or increase capacity of full supply levels of existing reservoirs to attenuate high flows. Potential sites for this approach include all the existing reservoirs, in particular the Ghost, Barrier, and Glenmore reservoirs.

Operational comments:

- Changing reservoir operations requires clear governance and a decision-making process.
- Sediment should be actively monitored to avoid storage loss, whether the reservoir is used for its designed purpose or for flood mitigation.
- Managing for floods, including releasing water in advance of a possible flood, needs to be carefully monitored and balanced with managing for drought. Reservoirs can be made to serve multiple purposes but only with a sound basis for forecasting inflows as well as outflows.
- Operations for flood mitigation should be designed to minimize the risk to fill reservoirs in mid to late July when river flow typically drops. The flood mitigation operations must be balanced with other water management considerations since water storage often provides essential services later in the year.
- Changing reservoir operations in isolation can result in considerable peak flow reduction, but works best with other options in combination. A key factor is linking many data sources to improve forecasting to understand the probability of refilling and spur a continuum of action as a particular storm risk increases.
- The best approach is to optimize what is already in place before building new mitigation infrastructure; this is also one of the mitigation options that can be implemented most quickly and flexibly.

Impact on system or watershed:

- Pre-releases would need to remain below specified flood thresholds to mitigate damage from a flood that may or may not occur.
- As with any structures, operational errors can lead to cascading system failures.
- Drawing down or raising water levels may have temporary and only periodic negative recreational, environmental, and aesthetic impacts (e.g., on property owners, boaters, nesting birds, shoreline erosion).
- Temporary and occasional local flooding could become a risk for infrastructure along the reservoir shoreline.
- If lowered reservoirs are unable to refill due to extremely dry conditions after the flood, and thus cannot supplement low flows through the winter, these reduced winter flows could affect environmental conditions and ice dam flooding.

Land management

Implementing best land management practices in upland areas could slow the water and potentially prevent it from reaching infrastructure. Practices affected include wetland restoration, timber harvesting, timber disease and pest management, off highway vehicle management, urbanization (i.e., reducing impervious surfaces), and reducing fragmentation and linear disturbances. Priority areas where land management may be effective are found throughout the Bow watershed including headwater and upland areas, for example the Ghost-Waiparous watershed and the Elbow headwaters.

Operational comments:

- Protecting the headwaters involves difficult political trade-offs, but has been done and other jurisdictions provide good examples.
- The Eastern Slopes have been affected by intensive linear disturbances, timber harvesting, other resource development, urbanization, and recreational activity. Best management practices should be applied where possible to mitigate the impacts of these disturbances on sediment loading and runoff generation.
- A systems approach to protecting ecosystems and watersheds is needed. However, in mountainous areas such as Banff National Park where development restrictions are in place, floods still occur with heavy rains, suggesting land management is part of overall watershed health but will play a limited role in mitigating large flood events.
- Much would be learned from studying the overall impacts of the 2013 flood in Banff National Park. While the Park did suffer infrastructure damage and emergency conditions, the proportional damage was probably lower than in Canmore or Calgary. If so, there might be two complementary hypotheses for the effect: a) infrastructure, or at least newer infrastructure, tends to be built with greater consideration to working within the natural ecosystem; and, b) pristine watersheds, while not eliminating floods, resulted in flows being attenuated by the upland landscape and flood plain storage.
- The current draft of the South Saskatchewan Regional Plan (SSRP) is designed to address many land management concerns and opportunities. Additional timber harvesting and managed off-highway vehicle access to some areas and not others can be used to mitigate and manage rapid runoff in the headwaters.

Impact on system or watershed:

- While the relative contribution of individual land management measures to flood mitigation may be locally significant but small, especially in very high-flow flood events, the cumulative impact could be sizeable and may achieve many other watershed objectives in addition to flood mitigation.
- Improved land management achieves many watershed objectives during the periods of time when rivers are not in flood condition, in addition to flood mitigation.

6 Flood Mitigation Options for the Bow Basin

Specific mitigation options for each river system were compiled from various sources, including suggestions from project participants and work done previously for the Flood Recovery Task Force. These options were modelled by the project team prior to live meetings, and were reviewed and refined, individually and in combination, during two of the project meetings. The full list of individual mitigation options is shown in the tables below, by river system; the underlined options were modelled, but data were not available to model those not underlined. In some cases, options were identified but not explored by the participants and therefore are not discussed further in this report. Each modelled option is briefly described in Section 7 along with a summary of the modelling results.

6.1 Bow River System

Project participants discussed at length potential mitigation targets for each river system and options that might achieve them. For the Bow River main stem at Calgary, the mitigation target discussion ranged from approximately 800 cms to approximately 1150 cms. It was noted that different targets may be needed upstream (e.g., for Banff, Canmore, and Cochrane). The first and most logical place to look for mitigation is at existing infrastructure: TransAlta facilities. The group considered a broad range of mitigation options, as reflected in Table 3; among these were:

- Flood control operations on TransAlta reservoirs when needed
- Expanding existing infrastructure owned by TransAlta (raising reservoirs and diversion)
- Construction of new dry dams (at Ghost, Waiparous, Bearspaw, and Barrier).

These discussions reinforced the need for the best possible streamflow and snowpack data, soil moisture content, and meteorological forecasts to inform operational decisions. As well, flexibility in the system is critical so that reservoir levels can be flexibly and adaptively adjusted as approaching storms are monitored.

Table 3: Flood mitigation options: Bow River

Concept Category	Short Term (Quick Wins by 2014)	Medium Term (2-5 years - by 2018)	Long Term (> 5 years)
Natural Mitigation	· Initiate bio-engineered bank protection where appropriate	· Wetland detention on Jumping Pound Creek · Wetland detention on Ghost River · Wetland detention capacity of the whole Bow Basin · Enforce Ghost-Waiparous Access Management plan and others · Acknowledge and avoid the river's meander belts · Change location of Johnson's Island dike to allow natural flooding	· Full wetland and riparian system assessment and re-establishment program · Mitigation through land management and use practices that reduce runoff throughout the Bow Basin
Operational Mitigation	· Operate Ghost for flood control · Operate all tributary control structures for flood control · Monitor ice dam formation and manage as needed	· Assess value of dredging Ghost reservoir · Auxiliary spillway at Johnson's Island to avoid dike surge	
New Infrastructure Mitigation	· Armour river banks in key spots · Divert high water into suitable low lying areas	· Expand capacity of Ghost Reservoir · Low level outlet in Ghost to expand capacity · Rebuild/expand Ghost diversion · Expand Barrier Reservoir · Municipal storm water projects (on- and off-steam storage into tributaries) · Debris protection to keep Carseland-Bow River Headworks canal intake open	· Dry dam west of Bearspaw Dam (BR1) · Dry dam on Ghost River (BG1) · Full service dam on Ghost River · Dry dam on Waiparous Creek (BW1) · Dry dam between Lower Kananaskis Lake and Barrier · Full service dam downstream of Bassano Dam ("Eyremore Reservoir")

6.2 Elbow River System

Discussion on mitigation targets for the Elbow began with 180 cms, then evolved to approximately 450 cms, recognizing the need for local protection and relocation. The City of Calgary noted that this flow of 450 cms would require approximately 5,500 residences to be evacuated. Looking to existing infrastructure as a way to meet the targets, Glenmore Reservoir operations was a first step. The group looked at a broad range of mitigation options, as reflected in Table 4, including:

- Flood control operations on Glenmore Reservoir (current and expanded)
- Various diversions: overland or tunnel, upstream and in Calgary
- Potential dry dams (Quirk Creek above Elbow Falls; Canyon Creek, and McLean Creek)
- Sum of small solutions including wetlands and land management.

Table 4: Flood mitigation options: Elbow River

Concept Category	Short Term (Quick Wins by 2014)	Medium Term (2-5 years - by 2018)	Long Term (> 5 years)
Natural Mitigation	· Initiate bio-engineered bank protection where appropriate	· Increase the capacity of the Elbow River through Calgary · Natural channel design through developed areas · Engineered wetlands in Fish Creek · Wetland detention capacity of the whole Bow Basin	· Mitigation through land management and use practices that reduce runoff throughout the Bow Basin
Operational Mitigation	· Operate Glenmore for flood control · Dredging in reservoir and/or river reaches	· Low impact development to manage storm water	
New Infrastructure Mitigation	· Armour river banks in key spots · Divert high flow into suitable low-lying areas	· Diversion from Glenmore to Bow River under 58th Ave. · Priddis Creek area diversion upstream of Bragg Creek to Fish Creek, with detention · Glenmore to Fish Creek diversion (SWCRR or other path), with detention · Multiple historically identified detention sites · Dikes protecting downtown Calgary infrastructure	· Dry dam at Quirk Creek (EQ1) · Dry dam on Canyon Creek (EC1) · Detention on Prairie Creek · Multiple small detentions instead of one · Expand capacity of Glenmore reservoir

6.3 Highwood and Sheep River Systems

Discussion on mitigation targets for the Highwood-Sheep system started at 180 cms through High River, and evolved to approximately 1500 cms, recognizing the berming planned for the town. It was recognized that this option in the town of High River may not fully reflect the concerns of upstream and downstream rural homeowners. At present, the Sheep and Highwood rivers have few existing control structures, so opportunities for mitigation using existing structures are limited. The next promising option was to look at diversions around municipal and other infrastructure. Two high potential diversions were considered: a new north diversion and/or augmenting natural flow south into the Little Bow system. Both would be significant investments and it is uncertain at this time which, if either, of these might proceed. Other options, including dry dams, were also explored (Table 5), but dry dams continued to receive very little support. It was noted repeatedly that full cost-benefit analysis is needed before any major infrastructure investments proceed.

It was also noted that the Highwood Water Management Plan Phase 1 included a WRMM Modelling Review of Additional Storage. This study found that there were no useful full service storage sites available in the Highwood system because of the unreliability of water supply in that area to fill them.

Table 5: Flood mitigation options: Highwood and Sheep Rivers

Concept Category	**Short Term** (Quick Wins by 2014)	**Medium Term** (2-5 years - by 2018)	**Long Term** (> 5 years)
Natural Mitigation	· Initiate bio-engineered bank protection where appropriate	· Re-naturalize the flood plain · Reconnect dried oxbow lakes · Riparian and wetland inventory assessment (expand on previous 2000-2002 health assessments) · Wetland detention capacity of the whole Bow Basin	· Wetland and riparian restoration program · Mitigation through land management and use practices that reduce runoff throughout the Bow Basin
Operational Mitigation	· Temporary diversion into natural depressions		
New Infrastructure Mitigation	· Armour river banks in key spots · Channelization of the Highwood through High River combined with existing natural diversion south into the Little Bow · Divert high water into suitable low-lying areas	· Diversion of Highwood North around High River with Bassano reinforcement · Diversion of Highwood south into Little Bow system with Travers build and expanded capacity at Twin Valley Reservoir	· Dry Dam west of Eden Valley Reserve (H52) · Dry dam upstream of Longview (H2) · Full service dam upstream of Longview · Dry dam upstream of Turner Valley (S2) · Detention at Three Point Creek confluence · Detention above Three Point Creek

6.4 Combinations

Flood mitigation solutions for the Bow Basin will almost certainly be a combination of options – operational changes, infrastructure, and natural measures; several combinations were modelled and explored, and these are presented in Table 6. Modelling results for these combinations are described in Section 8. All combinations should be evaluated for their full system effects, especially the potential for downstream flooding or damage created by passing the flow faster and more efficiently into downstream municipal developments or infrastructure that may not have been affected otherwise.

Table 6: Potential combinations of flood mitigation options

River System	Potential Combination
Bow	· Operate TransAlta facilities (Ghost, Barrier, Minnewanka, Spray, Kananaskis Lakes) for floods · Operate and expand TransAlta facilities (Ghost and Barrier) · Dry dam upstream of Bearspaw, Operating TransAlta facilities (Ghost, Barrier, Minnewanka, Spray, Kananaskis Lakes) · Three dry dams: west of Bearspaw (BR1), on Ghost River (BG1), and on Waiparous Creek (BW1) + Operating TransAlta facilities (Ghost, Barrier, Minnewanka, Spray, Kananaskis Lakes) for floods · BR1, BG1, and BW1 dry dams + Operate and expand TransAlta facilities
Elbow	· Aggressive Glenmore operations and Quirk Creek (EQ1) dry dam · Glenmore operations + Priddis region diversions · Glenmore operations, Priddis region diversions, wetlands, land management · Calgary bypass + Quirk Creek (EQ1) dry dam · Calgary bypass + Glenmore operations (smaller tunnel?)
Highwood/Sheep	· North diversion around High River and augmented south diversion into Little Bow · Two dry dams: west of Eden Valley Reserve (H52) and upstream of Longview (H2) + North diversion · Sheep River dry dam (S2) and Threepoint Creek dry dam on switches
Whole Bow Basin	· 'Quick Win' – Operate TransAlta and Glenmore for floods · 'Optimize the current system' – Wetlands + land management + Glenmore operations + TransAlta operations + augmenting the south diversion · 'Infrastructure' – All dry dams and diversions · 'Flow target' – whatever it takes to get to target flows at Calgary, High River, Okotoks, Bassano Dam, Medicine Hat, etc. · 'Local benefit/downstream impact' or 'need to manage as a basin' – e.g., Calgary tunnel + north diversion = impact to Bassano or diversion to Little Bow = impacts to Travers.

6.5 Other Options

Some of the options discussed could not be modelled in the BROM because sufficient data do not exist or because the options were outside the scope of a mass balance model. Examples include fully quantifying land management and wetland effects, and local mitigation like flow rate changes due to barriers and berming.

7 Modelling Results

This chapter presents the modelling results for the underlined mitigation options shown in Tables 3, 4, and 5 in Section 6. The results for each option are organized by river system, starting with the Bow, then the Elbow, and finally the Highwood-Sheep. Operational and infrastructure results are presented first for each river system, and results for the natural mitigation options appear at the end, since they apply generally to all systems. To guide readers in interpreting the charts, the following information is provided:

- Dates shown in the charts that accompany each option are formatted by day/month; for example, 17/6 is the 17th of June.
- Two mitigation targets are shown in each chart. The red line is the target that was initially proposed and the green line is the target that evolved as the work on this project progressed.
- The dashed black line represents the GoA 1:100 event.

7.1 Bow River System

Operate Ghost Reservoir for flood control

This option involved lowering the upper storage level rule curve for Ghost Reservoir by about 5 metres in advance of an expected flood. A probabilistic forecast-based system would be used to determine if and when the reservoir is lowered and by how much; in other words, it would be triggered by a forecast event and not held low every year. Additional storage of about 31,000 cdm would enable the reservoir to attenuate high flows on the Bow main stem and leverage its position as having the greatest catchment area in the basin (other than Bearspaw which has a larger catchment area but currently far less storage capacity). Figure 7 shows the location of Ghost Reservoir (node 185) relative to other infrastructure on the Bow River system upstream of Calgary.

It is important to recognize that the TransAlta operations during the 2013 event certainly helped to reduce the flood peak seen through Calgary and the rest of the downstream Bow River Basin. That impact is already reflected in the simulated flood shown as the Base Case in BROM and in the charts below. The participants worked to identify what further mitigation might be achieved with the existing reservoirs, over and above what was accomplished in 2013.

This run lowered the Ghost Reservoir upper storage level rule by ~ 5 m down to 1186 m from 17/6 – 21/6 (with a three day lowering/filling period). The run added a flow target downstream of Ghost that will force the reservoir to store water (up to 1191.78 m) when flood waters are peaking (that is, greater than 1050 cms).

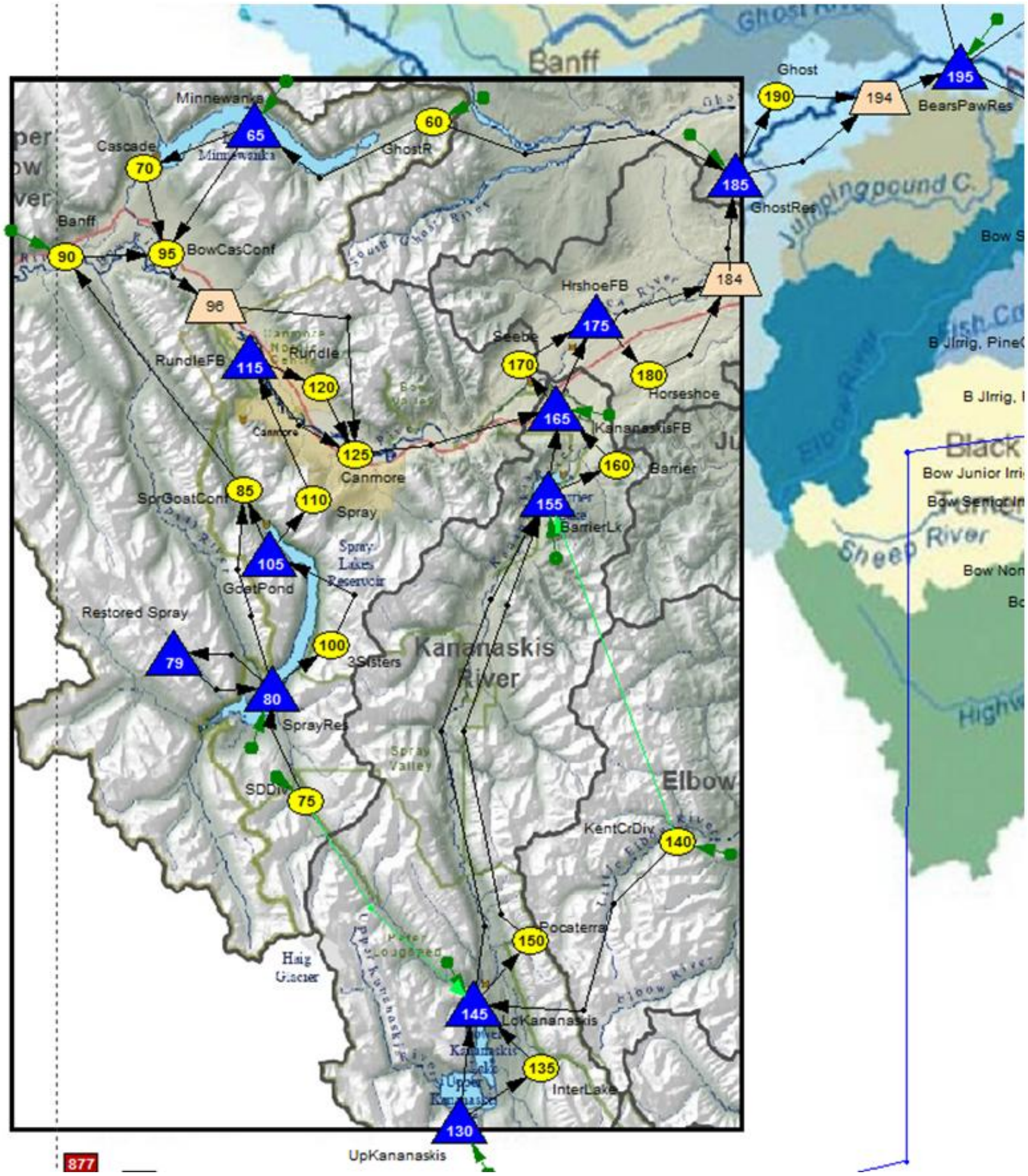

Figure 7: The Upper Bow region with general locations of existing structures

Operation of Ghost Reservoir for flood control reduced flows in the Bow River upstream of the Elbow confluence by 34 cms in the 2005 modelled scenario, and by 550 cms in the 2013 modelled scenario (Figure 8). The reason flood flows were not reduced by a significant amount in the 2005 flood relative to the 2013 flood was the much higher flow objective set as a flood flow target. The 2005 flood barely exceeded this flow target, but the 2013 flood exceeded it by nearly 70%.

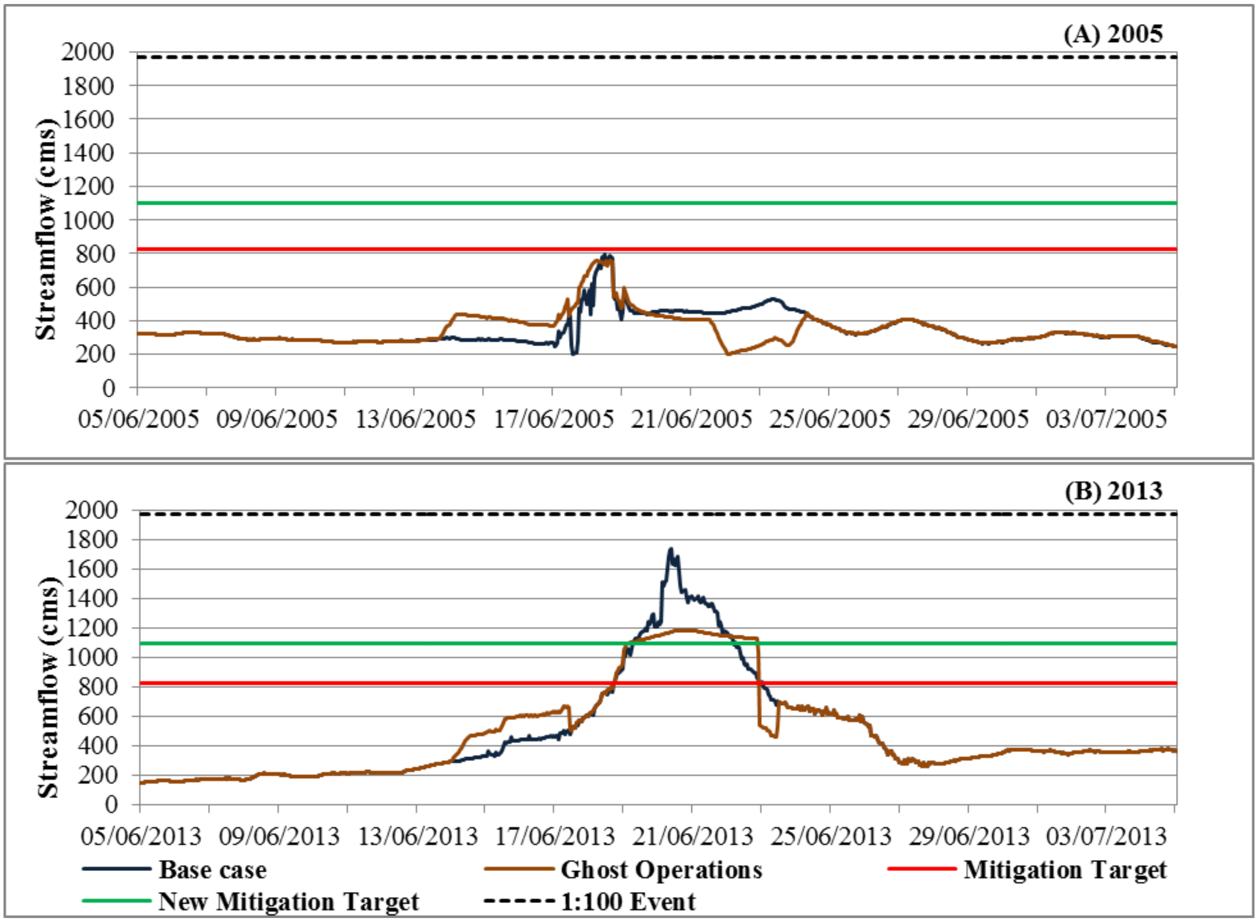

Figure 8: Comparison of streamflow in the Bow River upstream of the Bow-Elbow confluence between base case and operating Ghost Reservoir for flood control in (A) 2005 and (B) 2013

In discussing this mitigation option, participants noted that recreational and aesthetic concerns could arise for users of Ghost Reservoir if water is pre-released, and the release rate would need to consider the risk of proactively-induced damage. As a flood event develops, outflow must match or exceed inflow to keep the freeboard space in the reservoir to be able to attenuate the peak flow during the coming big event. Pre-releases need to take into account the need to refill after the middle of July when flow normally starts to drop rapidly. Once the reservoir is full, outflow must again match inflow to mitigate overtopping the dam. Overall operations for flood mitigation would include filling some of the larger upstream reservoirs to full supply level (FSL) if necessary, based on improved and reliable forecasts so as not to contribute to the peak flood flows. This additional storage may offset a dry period starting immediately after the flood. As well, an integrated systemic approach would ensure irrigation district reservoirs are able to fill as the upstream flood tapers off but they still have strong flow downstream.

The question arises whether operations designed to mitigate smaller floods can mitigate larger floods. Further work should be done to determine if targets should be set for upstream (e.g., Cochrane and Canmore) in light of effects in Calgary. The initial target of 825 cms would result in manageable damage to Calgary and would rely on measures implemented within the city such as temporary and permanent barriers. Finally, this option would likely have an impact on power generation for the reservoir operator, TransAlta. Although the Bow hydro system provides a minimal portion of daily or annual electricity to the grid, impact on power generation and potential compensation would need to be considered. These matters can be resolved, and although this option by itself does not achieve the lower range of the mitigation targets, it does reduce peak flows substantially and could be implemented quickly and cost-effectively with appropriate agreements with TransAlta. This option, like others involving releases ahead of possible flood events, relies on the best possible forecasts of preceding conditions and the location and duration of heavy precipitation as individual storms approach.

Operate all tributary control structures for flood control

This mitigation option expands on the previous option by also lowering Barrier Reservoir by about three metres prior to a forecasted flood event, and allowing it to fill up to FSL to attenuate flood peaks. Furthermore, Minnewanka and Spray reservoirs, and the Kananaskis Lakes were operated to hold back flood inflows, as they were during previous flood events, 2013 in particular. Ghost Reservoir is operated in the same manner as in the previous run – "Operate Ghost Reservoir for flood control."

Operation of all upstream tributary control structures for flood control reduced flows in the Bow River upstream of the Elbow confluence by 10 cms in the 2005 modelled scenario, and by 590 cms in the 2013 modelled scenario (Figure 9).

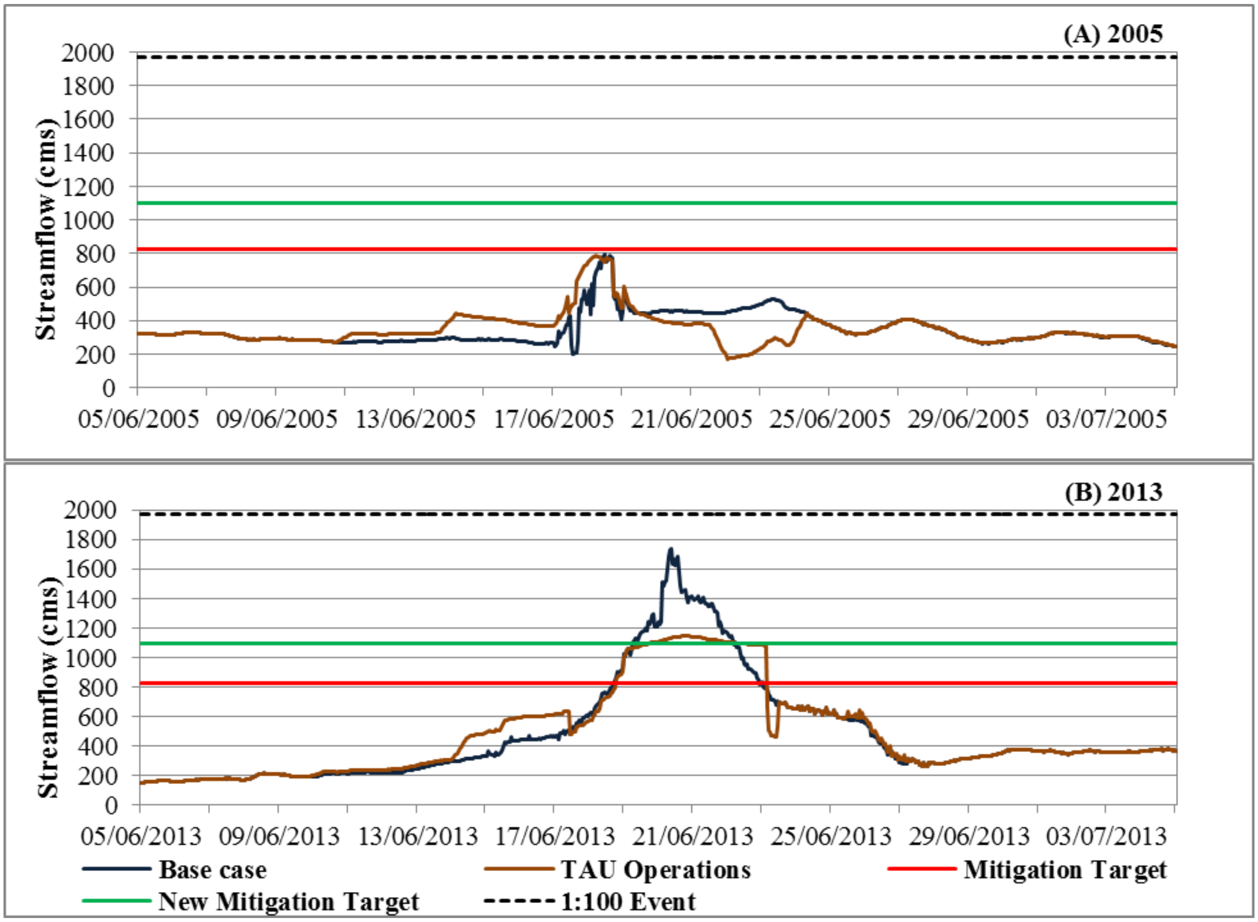

Figure 9: Comparison of streamflow in the Bow River upstream of the Bow-Elbow confluence between base case and operating all tributary control structures for flood control in (A) 2005 and (B) 2013

This option is an operational extension of operating Ghost Reservoir for flood mitigation. To use Ghost Reservoir and reduce risk of inadequate storage for offsetting low flows later in the year, allowing the large upstream reservoirs of Minnewanka, Spray, and Upper and Lower Kananaskis to fill, depending on conditions and forecasts, is logical and potentially necessary to enable

Ghost Reservoir to release no more than a set flow rate to mitigate a major flood. Ghost is the receiver of all the flow from all the upstream reservoirs and natural flow in the main stem, as well as the Waiparous and Ghost rivers that flow directly into Ghost Reservoir. Although this combination achieves an additional 40 cms reduction from the peak flow, it provides some risk protection in the event of a dry period following a rapid flood event.

Rebuild a larger Ghost Diversion into Lake Minnewanka

This model run assumed the diversion from Ghost River into Lake Minnewanka, which was destroyed in 2013, would be rebuilt to convey a flow of up to 100 cms. It was assumed that the diversion (Figure 10) would only be used when Ghost River flows were greater than 200 cms.

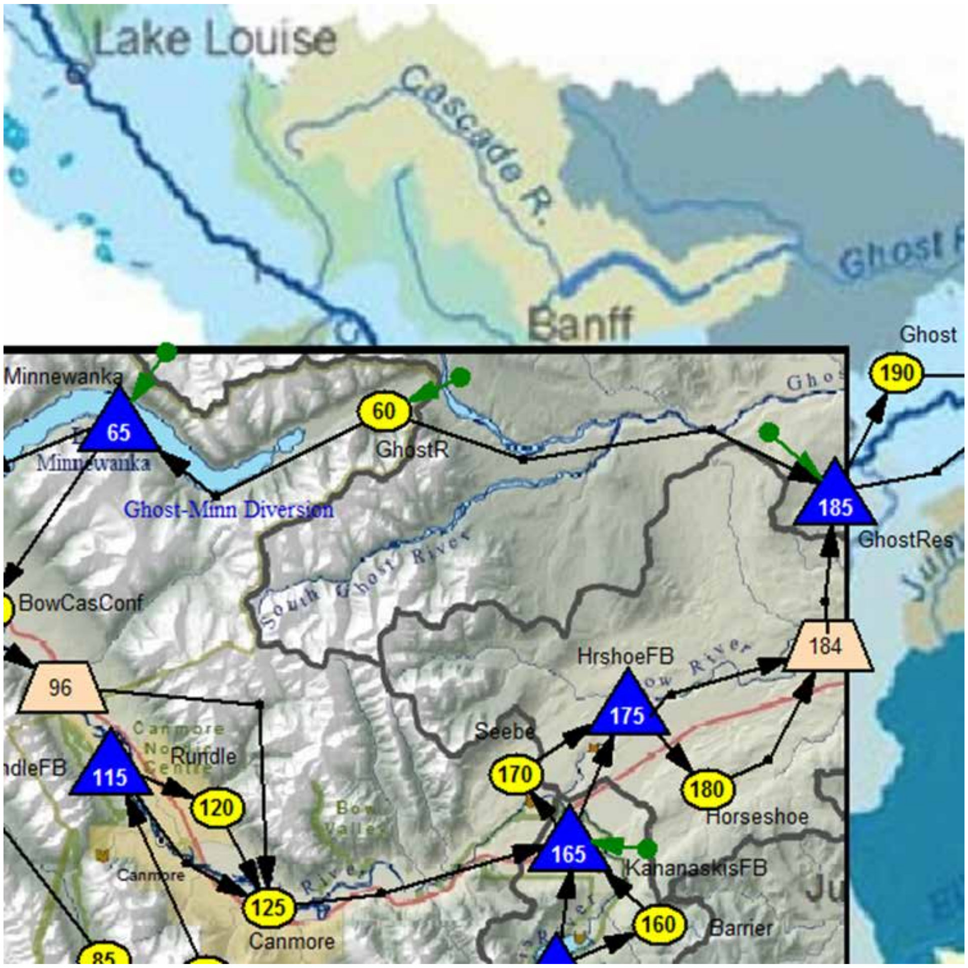

Figure 10: General location of the Ghost Diversion, represented by the arrow from node 60 to 65

The diversion was not used in the 2005 run because the diversion was only used when flows were greater than 200 cms, which was higher than the Ghost River estimated hourly peak flow in 2005. However, there was a reduction of 100 cms from the simulated peak flow in 2013 in the Bow River upstream of the Elbow confluence (Figure 11). It is estimated that the 2013 inflow to Minnewanka after the diversion was destroyed was zero, but that a slightly downstream berm caused flows into Minnewanka between 10 and 50 cms. This would reduce the net benefit by approximately that amount, but only if Minnewanka was full at that time and had to spill whatever inflows it received.

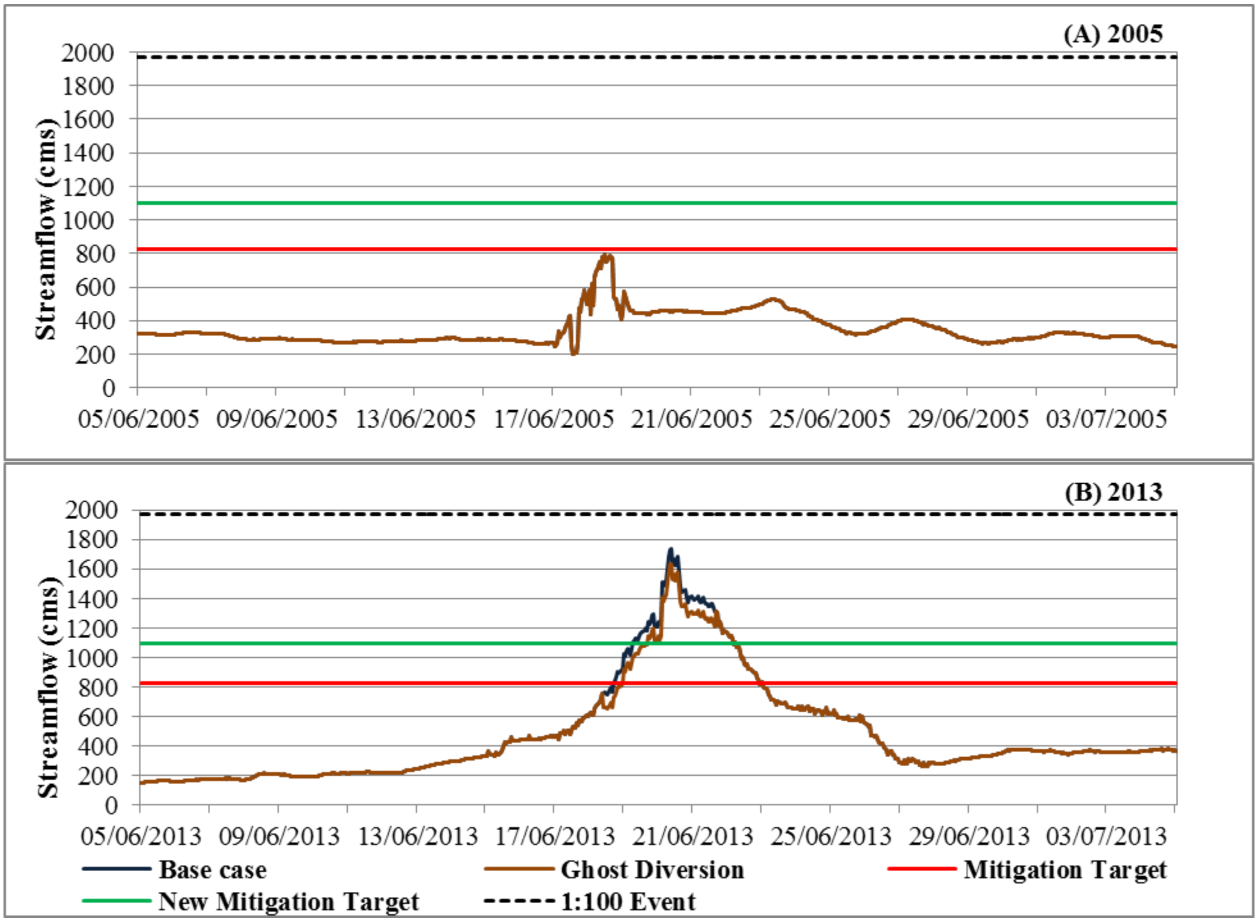

Figure 11: Comparison of streamflow in the Bow River upstream of the Bow-Elbow confluence between base case and operating all tributary control structures for flood control in (A) 2005 and (B) 2013

The TransAlta-owned and operated diversion was blown out in 2013 and would need to be rebuilt with increased capacity to handle higher flows. Depending on conditions at Minnewanka, the reservoir may need to be lowered slightly to contain the extra inflow long enough to not increase net flow through Canmore during the peak flow period.

It is very likely that TransAlta will rebuild the Ghost diversion in some form. There may be opportunity for cost sharing given that the new diversion may offer a basin-wide flood mitigation service. Permitting on the rebuild could begin soon, underscoring the need for discussion on this option to begin quickly. Since the reservoir itself is within Banff National Park, federal-provincial negotiations may be needed to modify operations on the reservoir during the infrequent but nearly certain to occur 1:50 to 1:100 year return flood.

Expand the capacity of Ghost Reservoir

This option would raise the dam and dike system of Ghost Reservoir by 3 m but would keep the existing FSL so that the additional storage is only used for emergency purposes. This model run lowered the Ghost Reservoir upper storage level rule by about 5 m, down to 1186 m from 17/6 – 21/6 (with a three day lowering/filling period). The run added a flow target downstream of the reservoir that will force it to store water 3 m higher than current FSL, to 1194.78 m when flood waters are peaking (more than 875 cms), creating additional storage of about 52,000 cdm to attenuate high flows on the Bow main stem.

Expanding Ghost Reservoir and operating it for flood control reduced flows in the Bow River upstream of the Elbow confluence by 34 cms in the 2005 modelled scenario, and by 725 cms in the 2013 modelled scenario (Figure 12).

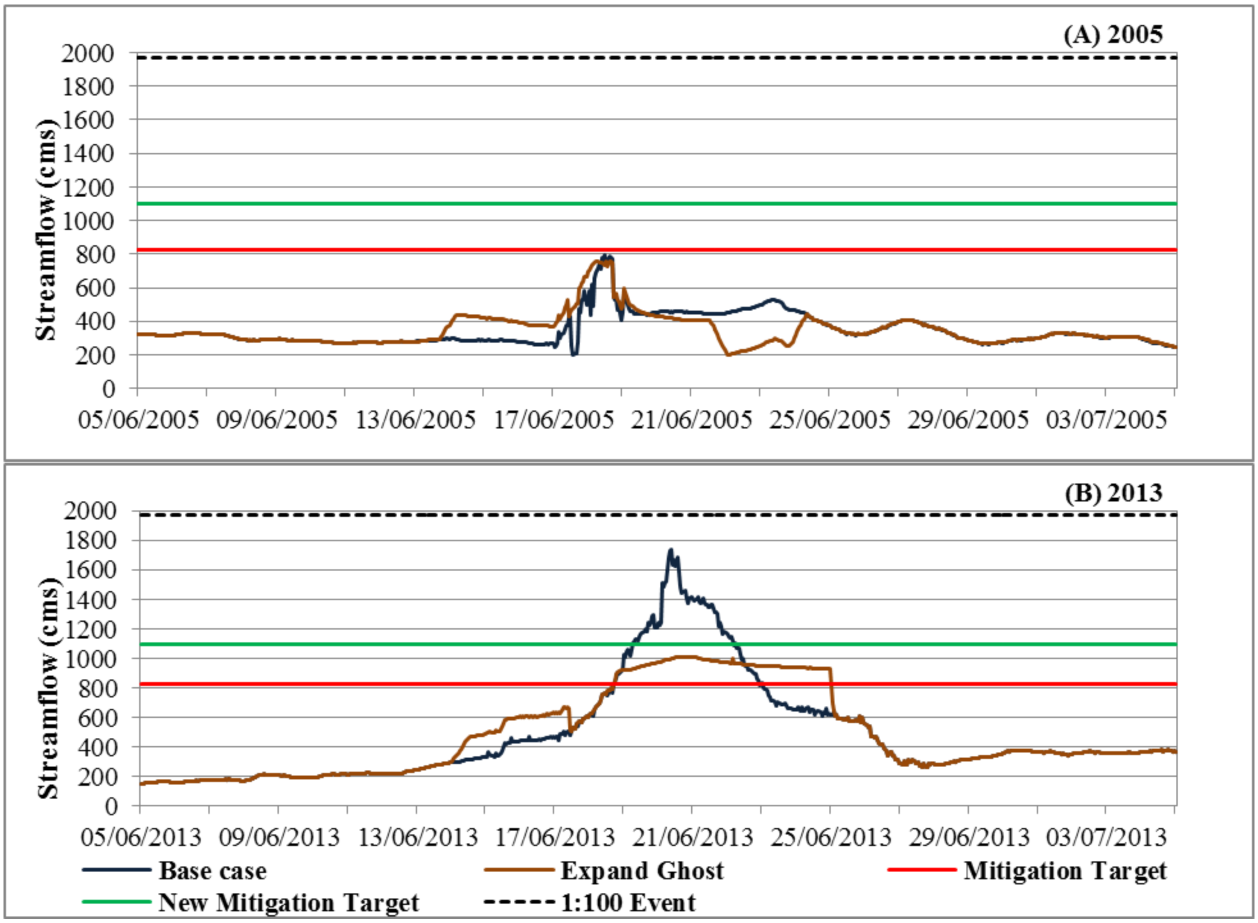

Figure 12: Comparison of streamflow in the Bow River upstream of the Bow-Elbow confluence between base case and expanding Ghost Reservoir for flood control in (A) 2005 and (B) 2013

This option would pose occasional temporary local flooding risk along the reservoir shoreline, which may affect a summer village, railway, and possibly First Nations land. A survey of the region would quickly determine the extent of this flooding and if and to what extent any actual impacts would be felt at 3 m or whether more or less storage volume would be available.

Expand Barrier Reservoir

This run lowered the Barrier Reservoir upper storage level rule by about 3 m prior to the flood (with a three day lowering/filling period). The run added a flow target downstream of Barrier that will force the reservoir to store water 3 m higher than current FSL, to 1378.56 m when flood waters are peaking (more than 205 cms).This option would be triggered by a forecast event so the reservoir would not be held low every year.

Expanding Barrier Reservoir and operating for flood control reduced peak flows in the Bow River upstream of the Elbow confluence by 106 cms in the 2013 modelled scenario, while extending the duration of the high flows. In Calgary it did not affect peak flows in the 2005 modelled scenario (Figure 13).

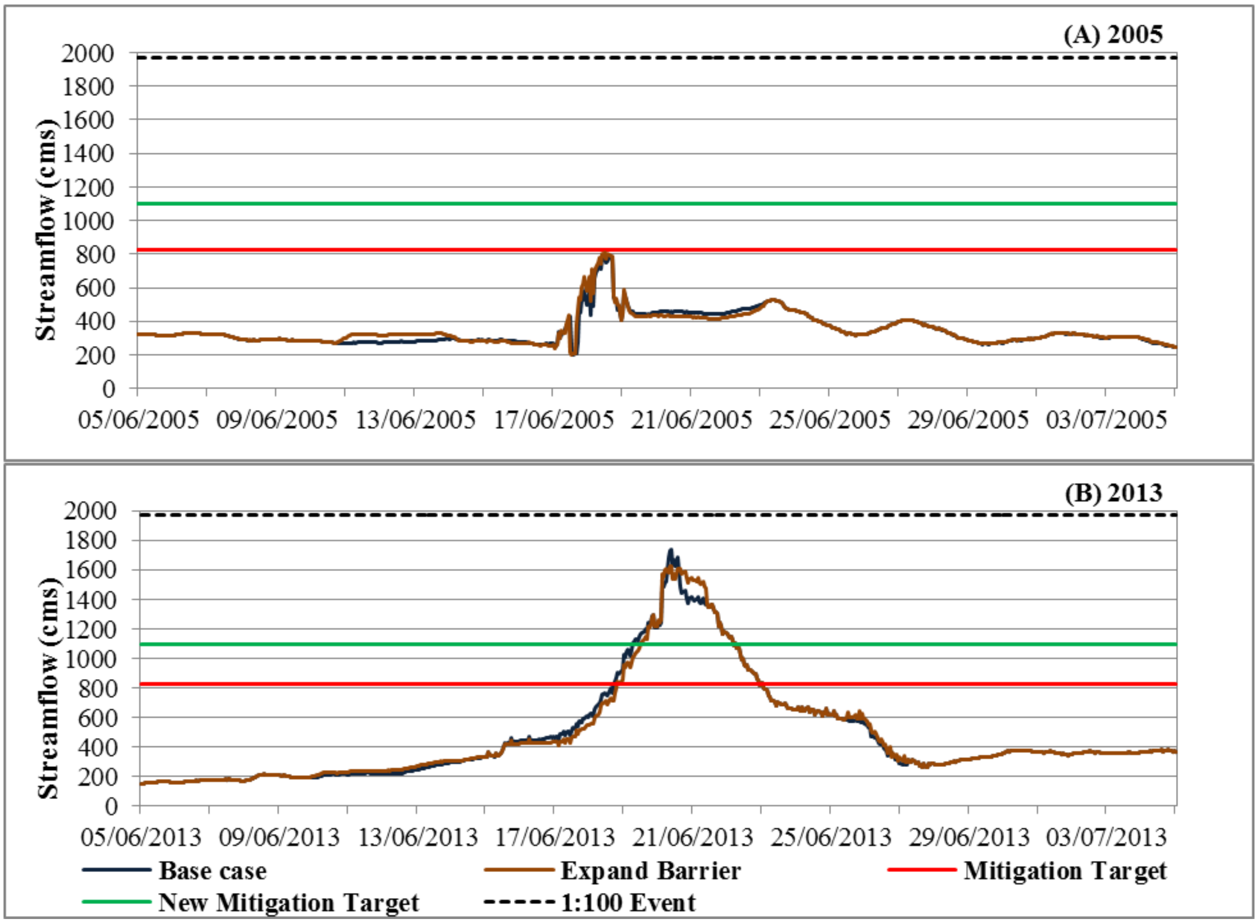

Figure 13: Comparison of streamflow in the Bow River upstream of the Bow-Elbow confluence between base case and expanding Barrier Lake for flood control in (A) 2005 and (B) 2013

Like all the options, raising the Barrier structure is problematic due to the benchland geomorphology. The existing dam fills up the first valley already and raising it would extend that flooding into the next larger area on an occasional and temporary basis. It could add a substantial volume of storage but the cost should be evaluated relative to other alternatives for the Bow system. The Kananaskis system, to which Barrier belongs, may not receive the same amount of rainfall as seen in 2013 in future floods, but there are data that could assess the risk-reward potential.

Debris protection to keep Carseland-Bow River Headworks canal intake open

This option simulates the deflection of debris away from the Carseland-Bow River Headworks (CBRH) canal intake by installing rock spurs, thus allowing diversions from the Bow River to continue during high flows. The diversion would be maximized at 51 cms when Bow River flows at Carseland exceed 1000 cms. In practice, the Bow River Irrigation District (BRID) demands and reservoir storage levels would also need to be considered before allowing the maximum diversion.

The rationale for this option is that during floods the intake to the canal that supplies water to the BRID plugs with debris, making it impossible to divert any water until the river recedes and the debris can be cleared away. If debris could be deflected away from the canal intake, up to 51 cms could continue to be diverted. Depending on conditions further downstream in McGregor and Travers reservoirs, as well as in the BRID's internal system, it may not be possible to always divert this full amount, but it would usually be possible to do it for the duration of a typical flood.

Allowing CBRH diversions to continue at the maximum during high flows reduced flows in the Bow River at Bassano Dam by 51 cms in the 2005 modelled scenario and in the 2013 modelled scenario (Figure 14). This is a small change that could be done quickly and contribute to successful flood mitigation efforts until a larger spillway is constructed at Bassano.

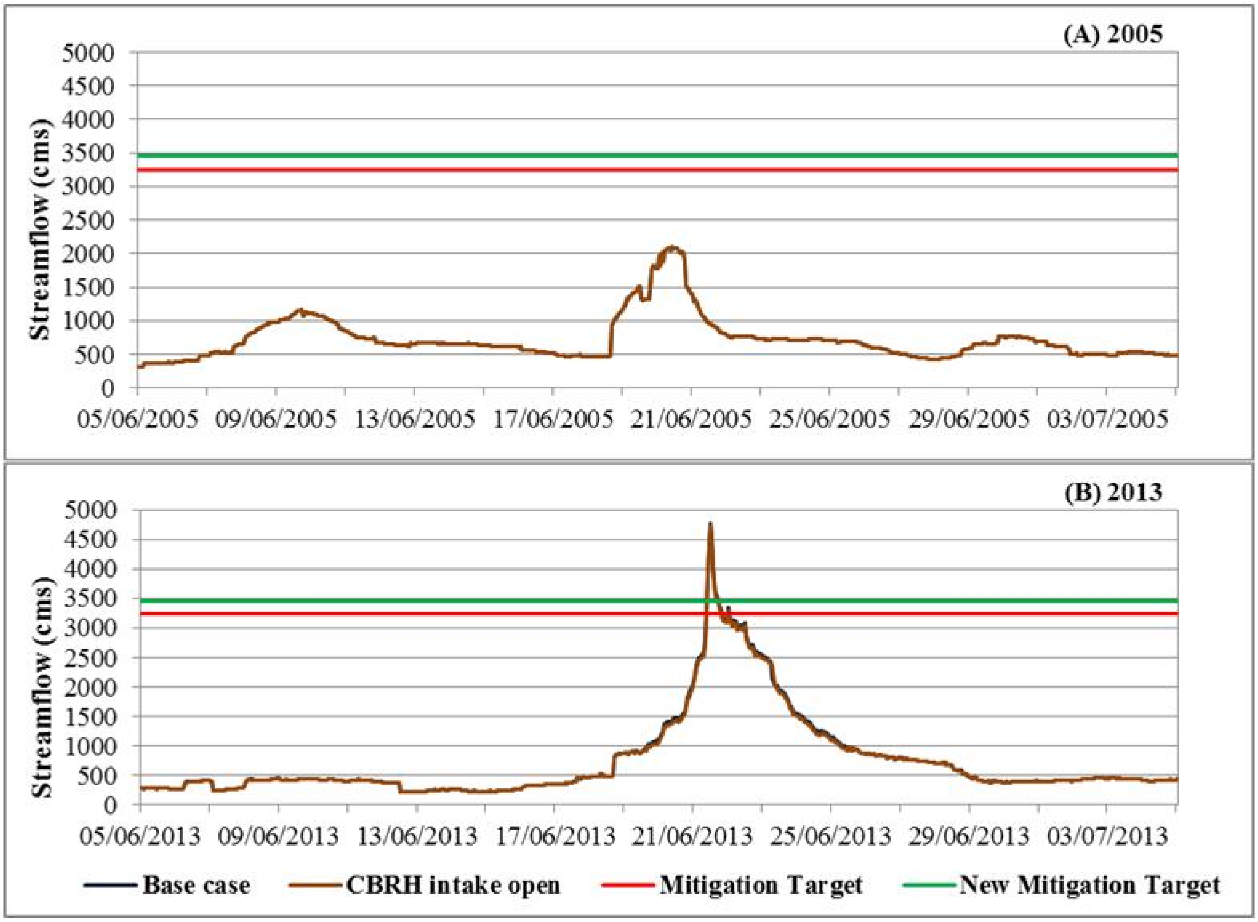

Figure 14: Comparison of streamflow in the Bow River at Bassano between base case and keeping the CBRH intake open through debris control in (A) 2005 and (B) 2013. Note: the lines are over-plotted.

The extreme turbidity of flood water makes it undesirable to take this water into the canal, but on the other hand the current situation is also hard on the canal, because the rapid drop in the canal water level when the intake becomes clogged causes slope failures. It would be up to ESRD, who owns the canal, to decide if this were acceptable relative to other risks of damage downstream.

The best way to divert debris away from the intake would probably be to construct one or two rock spurs just upstream of the intake, to direct the debris toward the middle of the channel, where it would be carried over the weir. This may also be beneficial to the fishery, under a wide range of flow conditions; one fisheries biologist has suggested that many of the small fish that are entrained in the canal are probably newly hatched fry drifting with the flow. Such fish might be diverted away from the canal intake by spurs. The cost of one or two spurs should be relatively small, so even though the benefit will be limited, this may be cost-effective. This could be modelled in the BROM by eliminating the current restriction on the Carseland diversion at high flows. The biggest potential benefit would likely be seen at Bassano Dam and Medicine Hat, so the model of the entire SSRB would be required to demonstrate the latter benefit; the full model will not be available until the fall of 2014.

Change location of Johnson's Island dike

One specific suggestion arose that illustrates the need to explore alternative solutions. This was the option related to changing the location of Johnson's Island dike to allow a more natural flood flow.

At the Carseland diversion, there is a concrete weir across the south channel of the river, a large dike across Johnson's Island, and a fuse plug (a section of dike made primarily of gravel, designed to wash out rapidly once it is overtopped) across the north channel (Figure 15).

Figure 15: Aerial photograph of Carseland diversion showing dike across Johnson's Island

The fuse plug had a crest elevation a bit lower than the top of the dike so that a large flood would wash out the fuse plug to allow flow in the north channel without damaging the dike. This is what happened in 2013, and once the fuse plug was gone, all of the flow was going down the north channel, with no water over the weir. It was extremely challenging to block the north channel with a cofferdam, restoring flow over the weir and into the canal after the flood. A new fuse plug is now being built behind the cofferdam, which will essentially restore the pre-flood condition.

The only apparent value in the large dike across the island is that it prevents flood damage to the north abutment of the weir by preventing flow adjacent to it, which is critical. It might be better to remove this dike and instead build a dike that would wrap around the end of the weir to protect the abutment, as well as blocking the north channel with a berm that would be more solid than the fuse plug. This would allow the river to flow over the island during floods, as it would have prior to development, rather than building up to an extreme depth and then washing out the fuse plug. This is an example of where a more natural solution may be better.

Assess value of dredging Ghost Reservoir

Also related to the operation of TransAlta reservoirs for flood control was the question of whether lost storage capacity could be regained by dredging the reservoirs to remove the sediment and aggregate that have accumulated over many years. Dredging was put forward as perhaps a more cost-effective means of gaining storage in the headwaters when compared to raising existing structures or building new structures.

Ghost Reservoir was presented as a specific example where this opportunity should be investigated. While this was not discussed in detail, TransAlta did indicate its position that dredging Ghost Reservoir would regain little capacity in the live storage. The City of Calgary recently shared the results of a study it commissioned to determine if dredging Glenmore Reservoir would significantly improve downstream flood mitigation. Its conclusion was that dredging would have negligible flood mitigation benefits.

Dry dam west of Bearspaw Dam (BR1)

This option is a 25.4 m high dry dam with a capacity of 48,500 cdm on the Bow River upstream of the existing Bearspaw Dam (blue triangle 196 in Figure 16). It is quite far downstream in the Bow system and thus could potentially mitigate high rainfall events in various headwater catchments. The dry dam would be used to attenuate flows greater than 1225 cms in the Bow River.

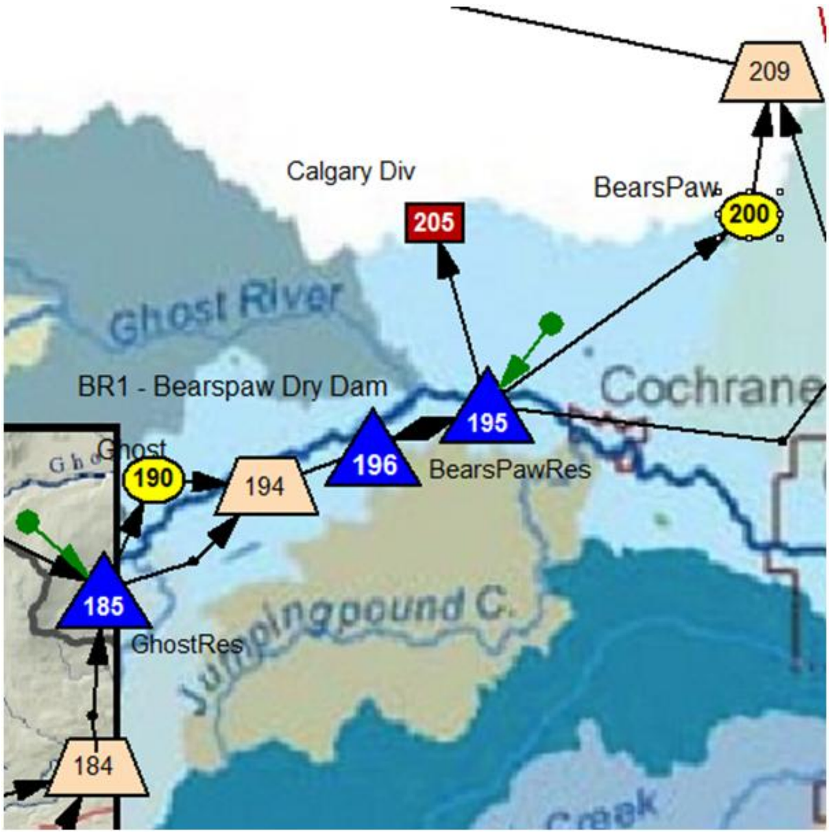

Figure 16: General location for possible Bearspaw dry dam (node 196) ***(not to scale and not intended to suggest specific sites)***

Use of the dry dam BR1 reduced flows in the Bow River upstream of the Elbow confluence by 510 cms in the 2013 modelled scenario, and did not affect peak flows in the 2005 modelled scenario (Figure 17). However, it is very unlikely that new infrastructure of this magnitude would be built before optimizing the mitigation potential of existing infrastructure, in particular the Ghost Reservoir just upstream of this identified dry dam site. The mitigation value and impact on flow through Calgary of this option would be reduced if Ghost Reservoir were first operated for flood control.

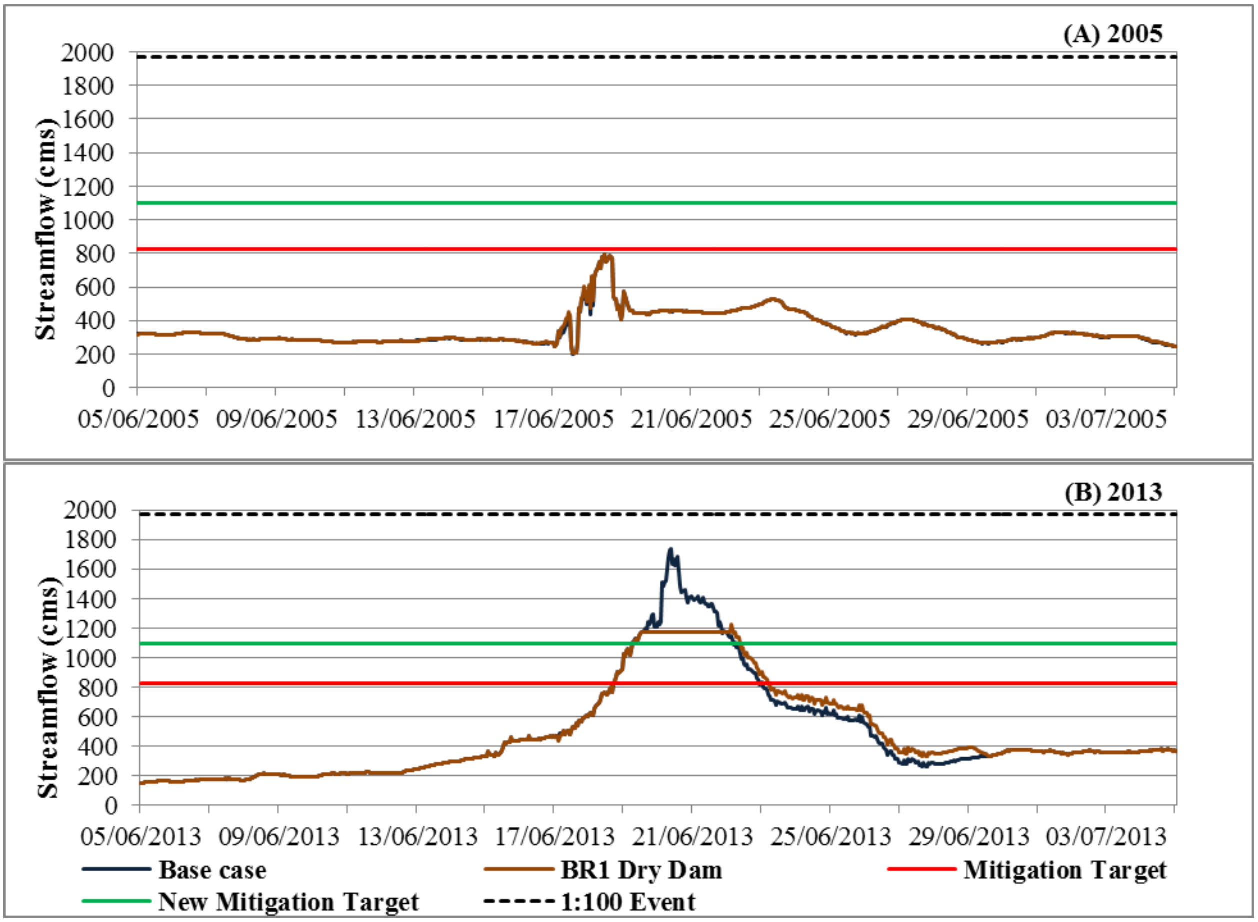

Figure 17: Comparison of streamflow in the Bow River upstream of the Bow-Elbow confluence between base case and a dry dam west of Bearspaw Dam (BR1) for flood control in (A) 2005 and (B) 2013

This option is located in or near Glenbow Provincial Park and if it proceeded, it would affect wildlife and recreational corridors, riparian areas, and the CPR rail line. There is a lot of development pressure in this area, both upstream in Cochrane and downstream on the western edge of Calgary which could also pose a conflict.

As with any dry dam, there are issues related to public safety, debris management, and ecological impacts. Participants stressed the need to fully understand post-flood event releases, especially if multiple dry dams are releasing water at the same time. Again the participants emphasized that new infrastructure of this magnitude should not be built before optimizing the mitigation potential of existing infrastructure.

Dry dam on Ghost River (BG1)

This option is a 39.6 m high dry dam with capacity of 62,800 cdm, located on the Ghost River upstream of the Benchlands and Waiparous communities (blue triangle 182 in Figure 18). The intended function is to attenuate flows greater than 205 cms in the Ghost River. The Ghost River has a relatively small catchment area and in the upper reaches, the river disappears under a huge boulder field, so a dry dam could be circumvented by underground streaming depending on its depth, its location, and its construction method.

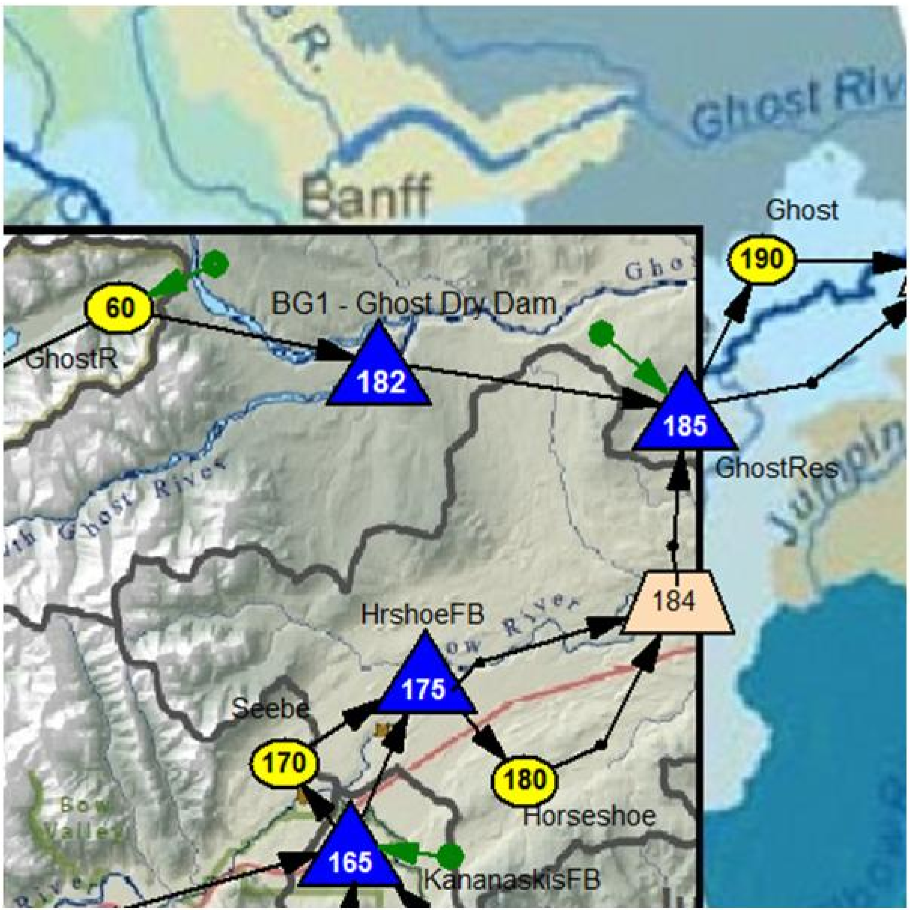

Figure 18: General location for possible Ghost River dry dam (node 182) ***(not to scale and not intended to suggest specific sites)***

Use of the dry dam BG1 reduced flows in the Bow River upstream of the Elbow confluence by 375 cms in the 2013 modelled scenario, and did not affect peak flows in the 2005 modelled scenario (Figure 19).

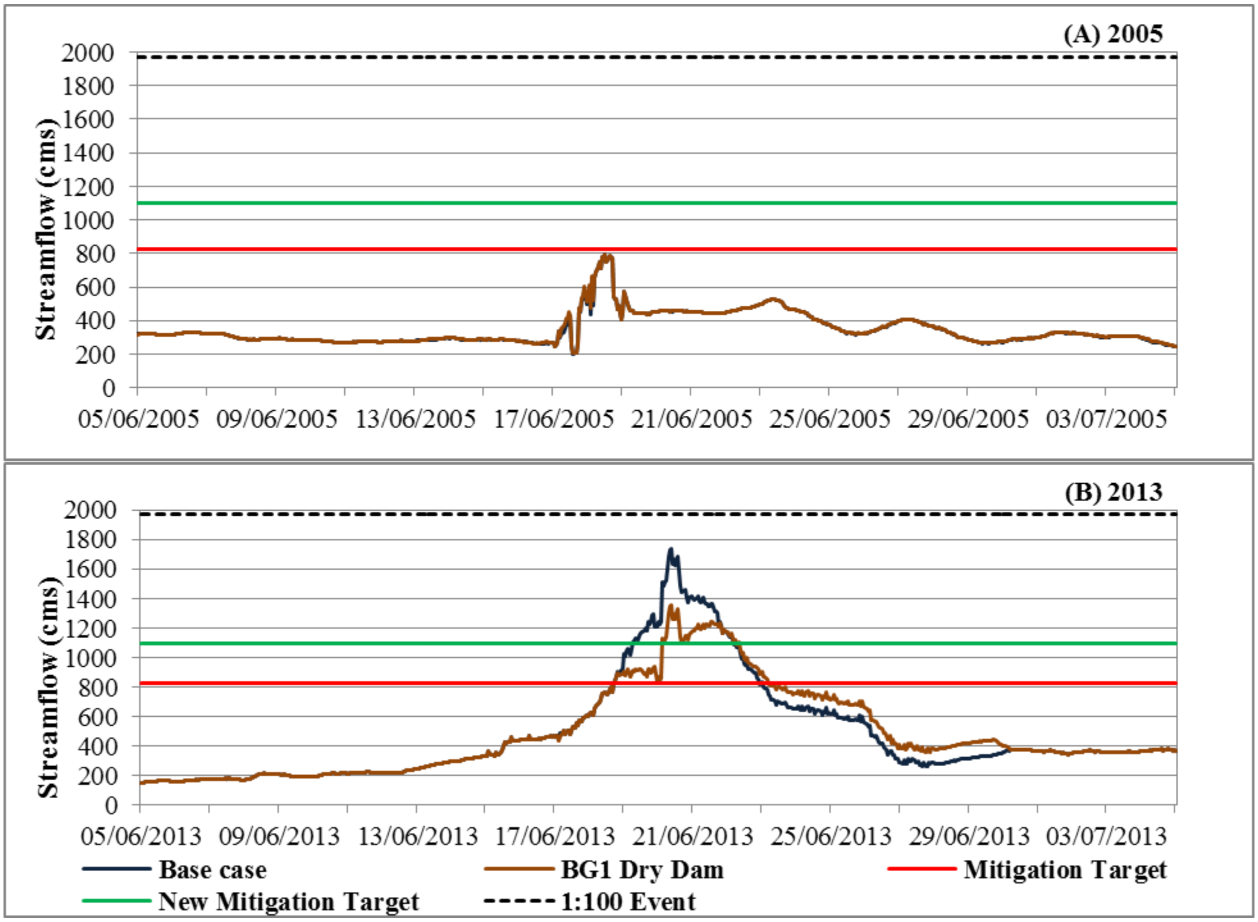

Figure 19: Comparison of streamflow in the Bow River upstream of the Bow-Elbow confluence between base case and a dry dam on the Ghost River (BG1) for flood control in (A) 2005 and (B) 2013

In the 2013 event, rains fell heavily in this area, which increases the appeal of this option for capturing water. However, in other events, rain may fall in different parts of the catchment, reducing the flood mitigation value of infrastructure in this location. Placing such options lower in the system increases the catchment area. If dry dams are to be built and used intermittently, public safety for campers and hikers could become an issue if the dams fill quickly. Other issues relate to debris management and ecological impacts, all of which should be carefully considered in a cost-benefit analysis.

Dry dam on Waiparous Creek (BW1)

This option is a 38,000 cdm, 40 m high dry dam on Waiparous Creek upstream of the Hamlet of Waiparous (blue triangle 183 in Figure 20). It would be used to attenuate flows greater than 40 cms in Waiparous Creek.

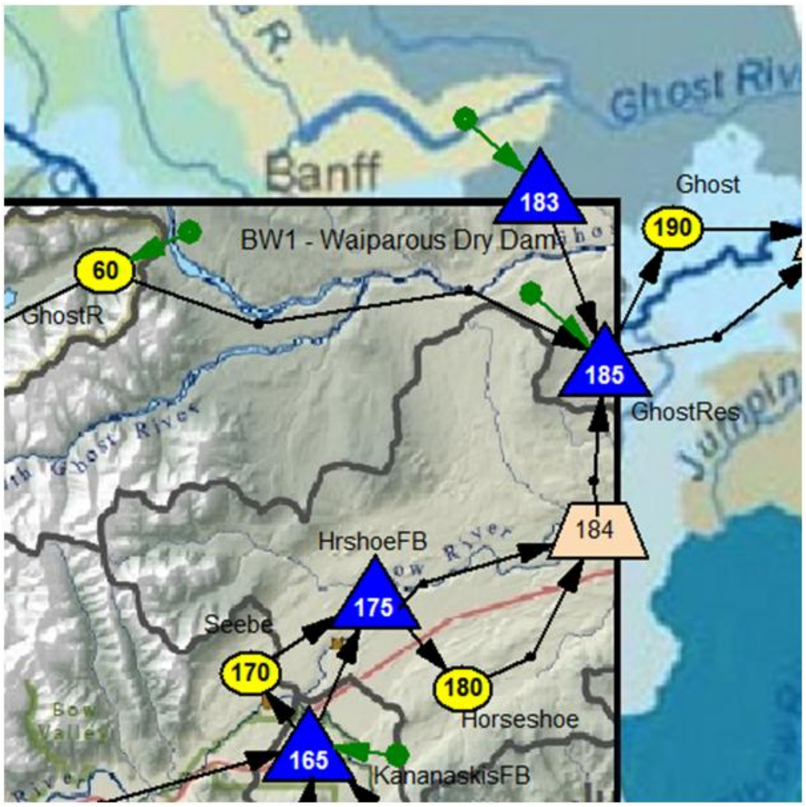

Figure 20: General location for possible Waiparous Creek dry dam (node 183) ***(not to scale and not intended to suggest specific sites)***

Use of the dry dam BW1 reduced flows in the Bow River upstream of the Elbow confluence by 78 cms in the 2013 modelled scenario, and did not affect peak flows in the 2005 modelled scenario (Figure 21).

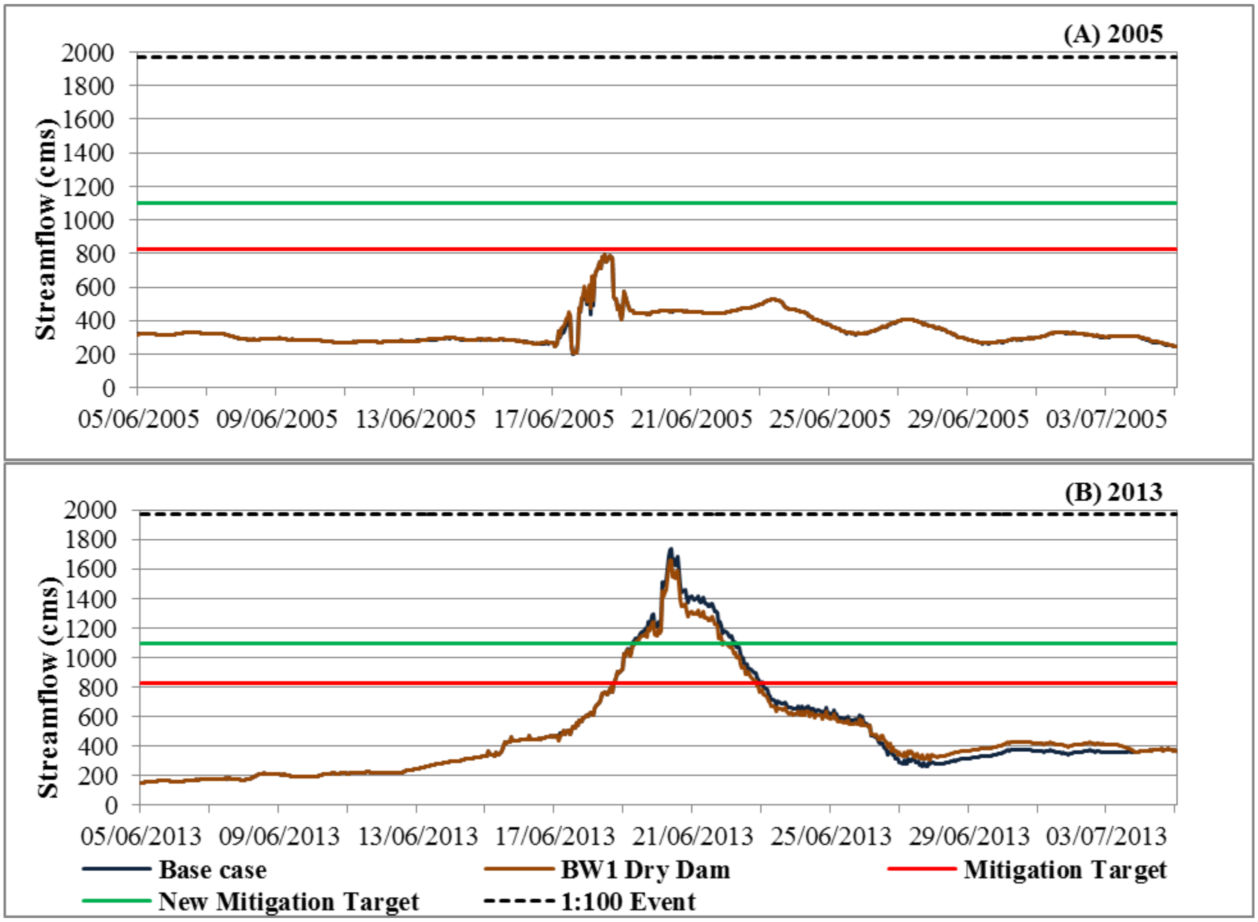

Figure 21: Comparison of streamflow in the Bow River upstream of the Bow-Elbow confluence between base case and a dry dam on Waiparous Creek (BW1) for flood control in (A) 2005 and (B) 2013

The proposed location for this structure is in a popular recreation area with valued ecosystems. A dry dam here would have major ecological and recreational impacts, which raise important but different questions. Clarification would be needed as to what recreational activities would be allowed around such structures, which would also change access to the area. Any time a permanent structure is put on a water body, it affects fisheries, mostly negatively. In the Waiparous area, westslope cutthroat trout is a species at risk that could be affected by this particular structure. Compensatory mechanisms add cost, permitting delays and operational challenges to any dam.

Dry dam between lower Kananaskis Lake and Barrier Reservoir

This option is a 50,000 cdm capacity dry dam upstream of Barrier Reservoir on the Kananaskis River (blue triangle 151 in Figure 22). Specific dimensions or locations for this facility were not provided. The dry dam would attenuate flows greater than 160 cms in the Kananaskis River.

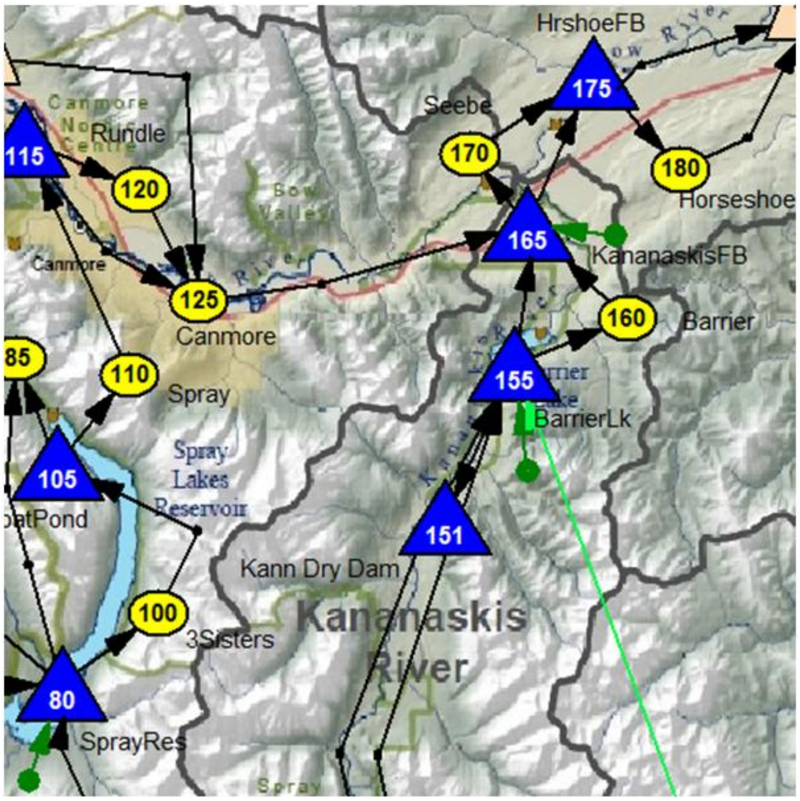

Figure 22: General location for possible Kananaskis dry dam (node 151) ***(not to scale and not intended to suggest specific sites)***

Use of the Kananaskis dry dam reduced flows in the Bow River upstream of the Elbow confluence by 143 cms in the 2013 modelled scenario, and did not affect peak flows in the 2005 modelled scenario (Figure 23).

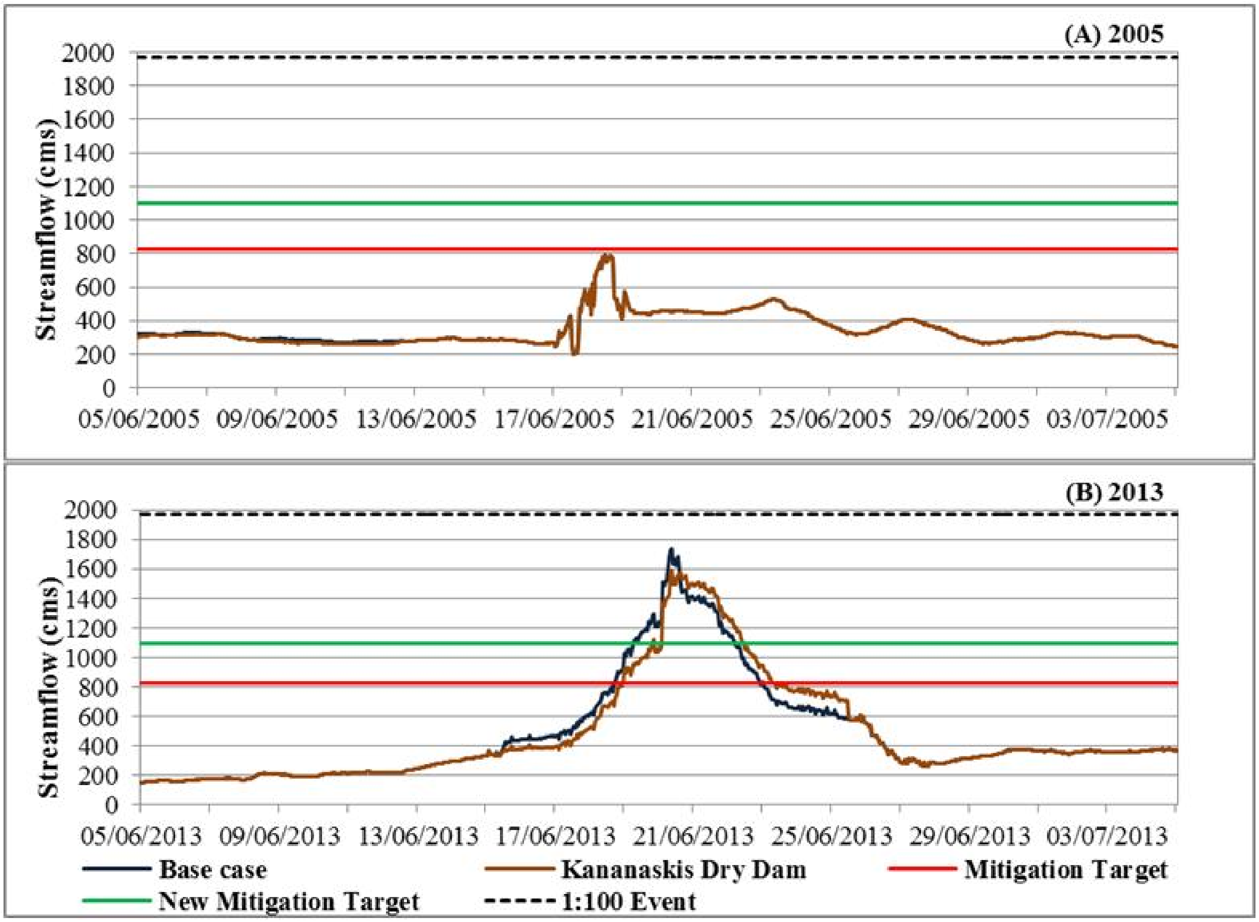

Figure 23: Comparison of streamflow in the Bow River upstream of the Bow-Elbow confluence between base case and a dry dam between lower Kananaskis Lake and Barrier for flood control in (A) 2005 and (B) 2013

As with any dry dam, there are issues related to public safety, debris management, and ecological impacts. Participants stressed the need to fully understand post-flood event releases, especially if multiple dry dams are releasing water at the same time. This option would need to be compared with potentially raising Barrier Reservoir and dike system to whatever elevation would equal this amount of temporary storage or more with potentially fewer environmental and other impacts.

Full service dam downstream of Bassano Dam ("Eyremore Reservoir")

The concept of storage on the lower part of the Bow main stem has been explored in prior work. It was identified as a potential flood mitigation option should some of the potential new storage be held as freeboard to capture high flows. In effect, part of the dam would function as a dry dam to reduce flows through Medicine Hat. A summary of the prior work is presented below. It was not explored in the working sessions of this project.

In 1977, the former Prairie Farm Rehabilitation Administration, a federal government agency, examined the option of onstream storage at the Eyremore dam site about 10.5 km north of secondary highway 539.[12] Storage capacities considered at the time (from 627,000 acre-feet to 1.6 million acre-feet) would have made this reservoir far larger than any existing reservoirs in the Bow Basin.

In the SSRB Adaptation to Climate Variability Project, Phase II,[13] Eyremore Reservoir was raised as a potential strategy to capture flows at the lower end of the Bow River system which could then be released to meet the environmental needs of the lower river as well offer potential flow augmentation and flood mitigation benefits to downstream users. For the purpose of the project, the model assigned to Eyremore was:

- Maximum live storage of 250,000 acre-feet (308,300 cdm)[14],
- A minimum flow of 1000 cfs (28.3 cms) leaving the reservoir when storage is available (400 cfs if Eyremore emptied), and
- A 100 cfs requirement that must be passed to Eyremore from Bassano dam.

Eyremore had a number of benefits to the river system and to water users. It reduced the number of days of shortage for all irrigation districts across the 30-year period of record and substantially improved the flows below Bassano Dam and downstream, by the release from Eyremore of 1,000 cfs flows. With Eyremore positioned below Bassano, it eliminates the Eastern Irrigation District's (EID) responsibility for ensuring the 400 cfs flows below Bassano are met. The flow below Bassano can now be met with stored water. Eyremore also affects BRID, which no longer needs to pass as much water through to EID. This strategy also reduces the number of river calls, which increases the amount of time TransAlta can store water, and similarly reduces the number of low flow days for Calgary.

Eyremore Reservoir would capture water further downstream, levelling out peaks and eliminating the need to calculate time of travel from Bearspaw in keeping downstream flows healthy. It would catch any additional releases by TransAlta, thus creating opportunities and flexibility to use this water below the reservoir, for example, to pulse flows in support of riparian health. Eyremore could potentially assist with flood control at Medicine Hat and could benefit the Oldman system by a) relieving pressure to supply minimum flows through Medicine Hat, and b) helping to meet the 50% apportionment requirement in dry years.

Potential disadvantages to this strategy include that it represents additional onstream storage which, among other environmental impacts, disrupts aquatic ecosystem function, and that the capital costs and time required for construction would be significant.

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[12] The exact location considered by PFRA was Section 14, Twp 18, Range 18, W4M, at 50 deg, 31 min Lat, 112 deg, 23 min Long.
[13] The report from this project is available by searching on the Alberta WaterPortal at http://www.albertawater.com/.
[14] 1 acre-foot (AF) = 1.233 cdm; 1 cubic foot/second (cfs) = 0.0283 cms.

7.2 Elbow River System

Approximately two-thirds of Calgary's flood damage risk is on the Elbow River because it has more encroachment in the flood plain, while the Bow is largely set back. This raises discussion of the importance and relative cost-effectiveness of planning and relocation to reduce encroachment in the flood plain. A number of the mitigation options considered for the Elbow River focused on mitigating peak flows through Calgary during flood events, but also considered what mitigation the options might offer to upstream communities.

Operate Glenmore for flood control

In the 2013 event, Glenmore Reservoir (Figure 24) was lowered by about 3.7 m below the crest prior to the flood, and then filled up to 1077.54 m. This attenuated the approximately 1200 cms inflow down to an outflow of 700 cms. The modelling scenario allowed Glenmore Reservoir to be lowered 4.0 m below crest and to fill to 1077.54 m.

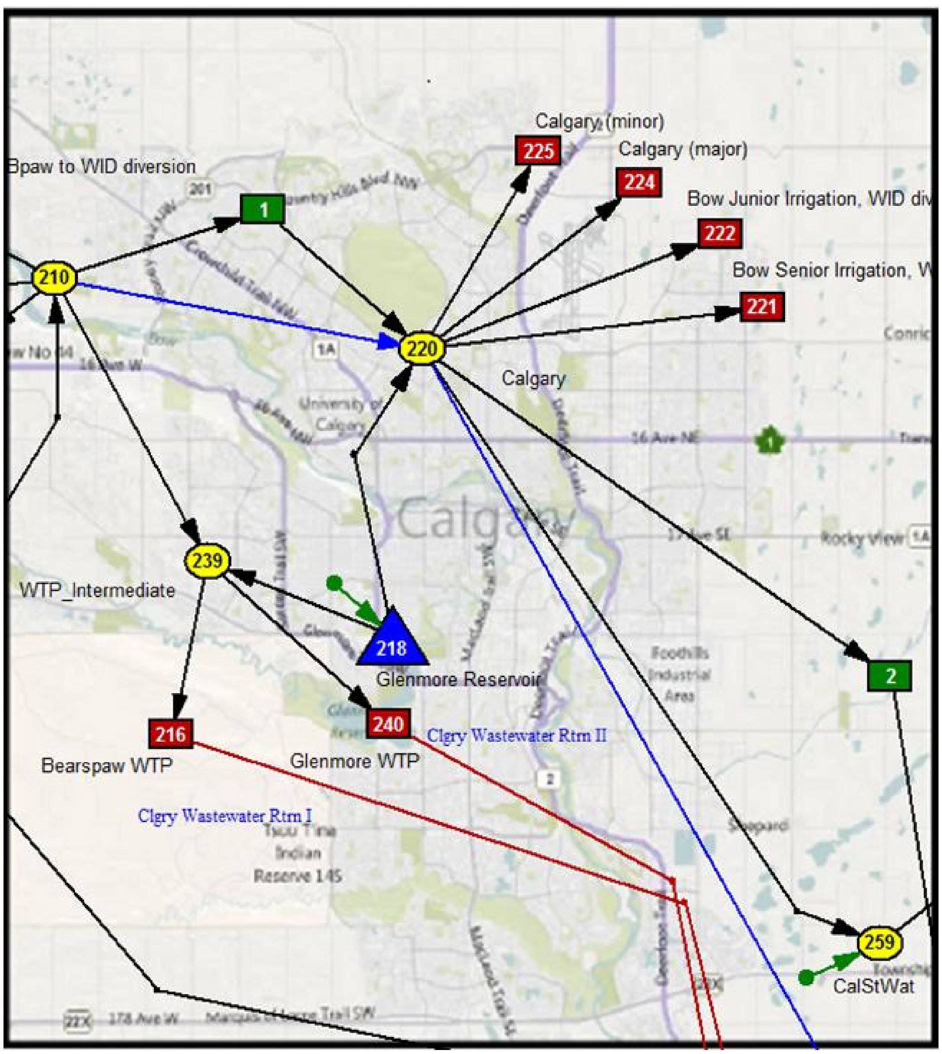

Figure 24: Modelled location of Glenmore Reservoir (node 218) ***(not to scale)***

Operating Glenmore Reservoir for flood control reduced flows in the Elbow River by 199 cms in the 2005 modelled scenario and by an additional 20 cms relative to the ~500 cms reduction already achieved in 2013 (Figure 25). This demonstrates that operators did an outstanding job of managing Glenmore Reservoir for flood control in 2013. However, it was noted that the Reservoir reached full capacity so for the last half of the flood event, outflows nearly equalled inflows. Had the storm event lasted longer, Glenmore would have been able to offer very little to attenuate the flood flows as the outflows would have had to equal the inflows.

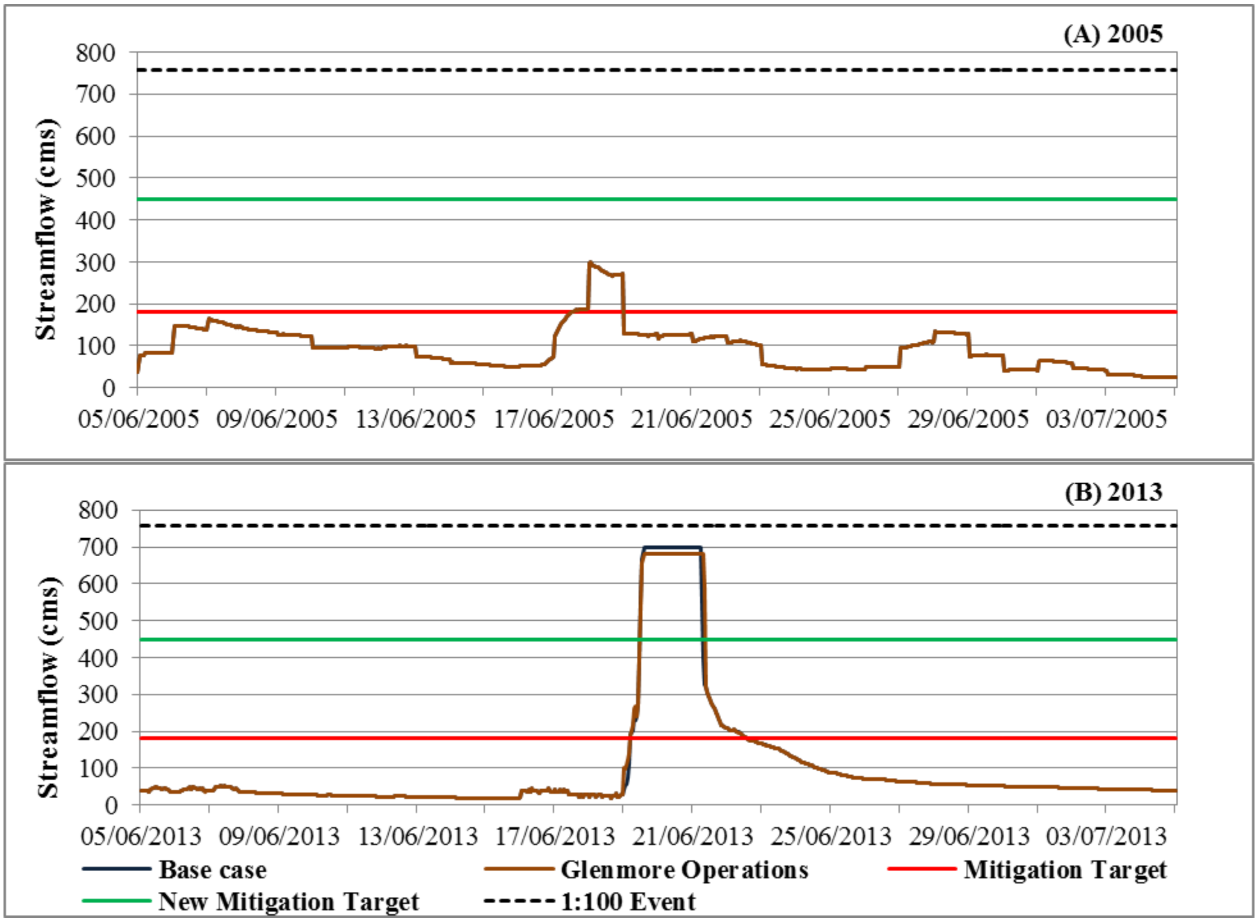

Figure 25: Comparison of streamflow in the Elbow River downstream of the Glenmore Reservoir between base case and operating Glenmore for flood control in (A) 2005 and (B) 2013

Glenmore Reservoir was built to supply water, not to attenuate floods, but proactive management in the 2013 event was nevertheless very effective. Levels cannot currently go below 4 m as this would compromise the causeway and jeopardize drinking water supply intake. In the longer term, infrastructure changes might be considered to raise Glenmore dam crest elevation or lower the intakes; but this could lead to safety concerns, and the cost of a major rebuild would need to be compared to other mitigation alternatives. Changing stop logs might allow reservoir capacity to go up by about six million cubic metres (1.5 m elevation), but their function is unclear in flood conditions with concern about the potential for overtopping and safety issues. A major capital project would be required to replace the existing stop logs with operable gates. The gates could allow for additional storage in the reservoir, which would add to the reservoir attenuation capacity for flood events.

If Glenmore Reservoir had not been aggressively lowered in 2013, and only filled to the natural crest before passing inflows, flows downstream would have been much higher, as seen in Figure 26.

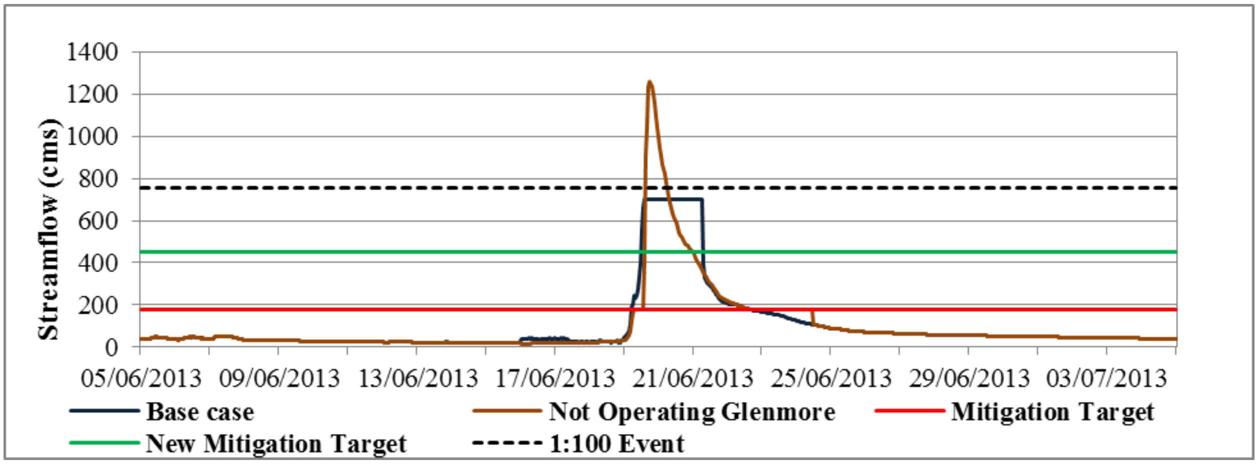

Figure 26: A comparison between the 2013 base case and not operating Glenmore Reservoir as it was done in 2013

Diversion from Glenmore to Bow River under 58th Avenue

This diversion – a long, mostly bedrock tunnel – would bypass the Elbow River through downtown Calgary, diverting flows directly from Glenmore Reservoir to the Bow River. It is conceived as an underground tunnel 8 to 10 metres in diameter with a vertical drop shaft inlet submerged below the normal operating level of Glenmore Reservoir. In this model run, the bypass had a 500 cms capacity to reduce the outflows from Glenmore into the Elbow River (Figure 27).

Figure 27: Proposed location for 58th Avenue diversion in Calgary

Use of the bypass reduced flows in the Elbow River by 120 cms in the 2005 modelled scenario, and by 500 cms in the 2013 modelled scenario (Figure 28).

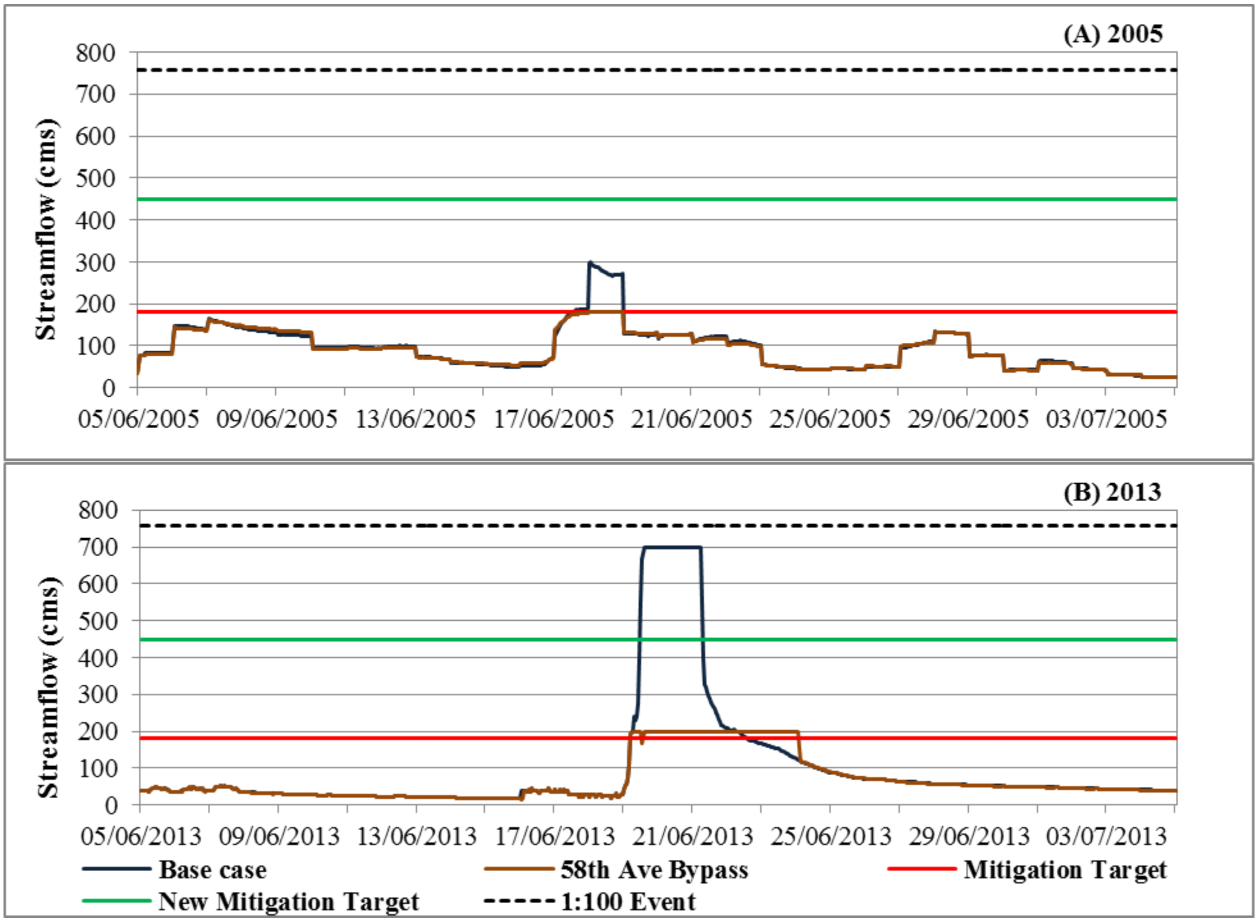

Figure 28: Comparison of streamflow in the Elbow River downstream of the Glenmore Reservoir between base case and a 500 cms diversion in (A) 2005 and (B) 2013

In addition to the cost and the extended period of disruption in a very busy part of Calgary for several years of construction, participants expressed a number of concerns about this proposed diversion. Water quality, local habitat impacts, and erosion concerns on the Bow at the outlet, even with dissipation measures are of concern. The part of Calgary that could be at risk from flooding (that is, the areas downstream of the tunnel outlet into the Bow River) has a number of sites that are likely contaminated from former uses and could be exposed and leached in a flood (e.g., former munitions plant, creosote factory, refinery, battery dump, auto wreckers, landfill). This option could affect subdivisions downstream in south Calgary (Deer Run, Riverbend, and others), potentially increasing their risk of flooding (depending on the timing of the peaks on the Bow and Elbow Rivers), making this option a solution for “part of Calgary,” not a full “Calgary” solution.

This tunnel would go under Deerfoot Trail and could affect the railway from a safety and construction standpoint. If installed at a relatively shallow depth, there could be underground fracturing, and many other detailed engineering issues would have to be safely resolved. A primary issue would be how to dissipate the flow’s energy before it gets to the Bow River. The energy dissipation requirements to slow the water in the tunnel before the outflow to the Bow are possible from an engineering perspective, but likely very expensive. Backwater effects would need to be well understood and managed to avoid the tunnel outlet creating a “wall” for the Bow River and backing flows coming down the Bow into flood-prone areas.

Downstream impacts could be significant. This diversion would not detain any flows; rather, it would pass flow that otherwise would have been slowed and detained as it flooded the local areas. If this option had been used in the 2013 event, some strongly believe that it could have bypassed enough additional flow through Calgary at the peak that would have destroyed Bassano Dam and increased flooding in Siksika and Medicine Hat. While many variables influence the timing and size of peak flows downstream, it was generally recognized that the impact of a diversion of this size would raise safety concerns for downstream infrastructure. Thus, if it were to be implemented, the spillway at Bassano would need to be increased and upgraded, and further mitigation added at Medicine Hat to address the increased downstream risks. These downstream options should be taken before the upstream diversion tunnel is constructed.

A positive aspect is that it would not likely affect Glenmore Reservoir operations beyond the normal flood flow operations. This tunnel option would likely be considered a measure of last resort for Glenmore. Perhaps it could be operated with a low level valve for use at lower stages although vortices and other issues may require a control mechanism at the downstream end of the tunnel. Water quality dependencies for the outlet on the Bow River are unclear. This is also known to be a rather expensive option and provides no benefits upstream of the Glenmore Reservoir, which may be a concern for locations upstream on the Elbow River. A more detailed engineering study of the feasibility and cost of the tunnel is underway.

Priddis Creek area diversion(s) upstream of Bragg Creek to Fish Creek with small reservoirs

This option includes a number of measures that build on the natural topography of the Elbow River before it reaches Calgary. It includes a bypass through Priddis Creek to Fish Creek with a capacity of 345 cms (see Figure 29). Very preliminary estimates suggest that a 345 cms diversion would require a channel about 50 m wide and 3 m deep, to accommodate flow depth of ~1.7 m plus an additional ~1 m of freeboard in case of blockages. It would likely have a riprap armour lining with an average diameter of about 500 mm. In the modelling, it was assumed that 35% of total streamflow to Glenmore Reservoir would be available at the intake. In addition to the diversion, a small (~250 cdm capacity) new reservoir upstream of the diversion (node 213; Figure 29), and two dry dam storage sites of ~275 cdm capacity each on Priddis Creek (nodes 219 and 226; Figure 29) were included in the model run, as well as utilizing wetland storage on both the Elbow River and on Priddis Creek.

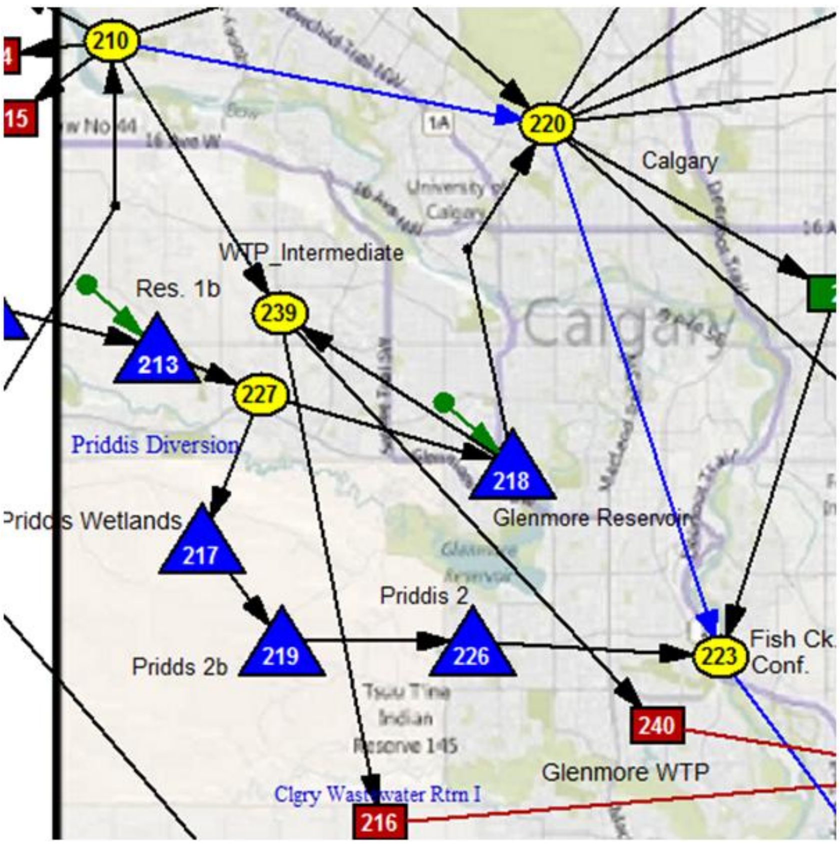

Figure 29: General location for possible Priddis Creek diversion and associated storage sites *(not to scale and not intended to suggest specific sites)*

Use of the Priddis Diversion and associated storage sites reduced flows in the Elbow River by 107 cms in the 2005 modelled scenario, and by 325 cms in the 2013 modelled scenario (Figure 30).

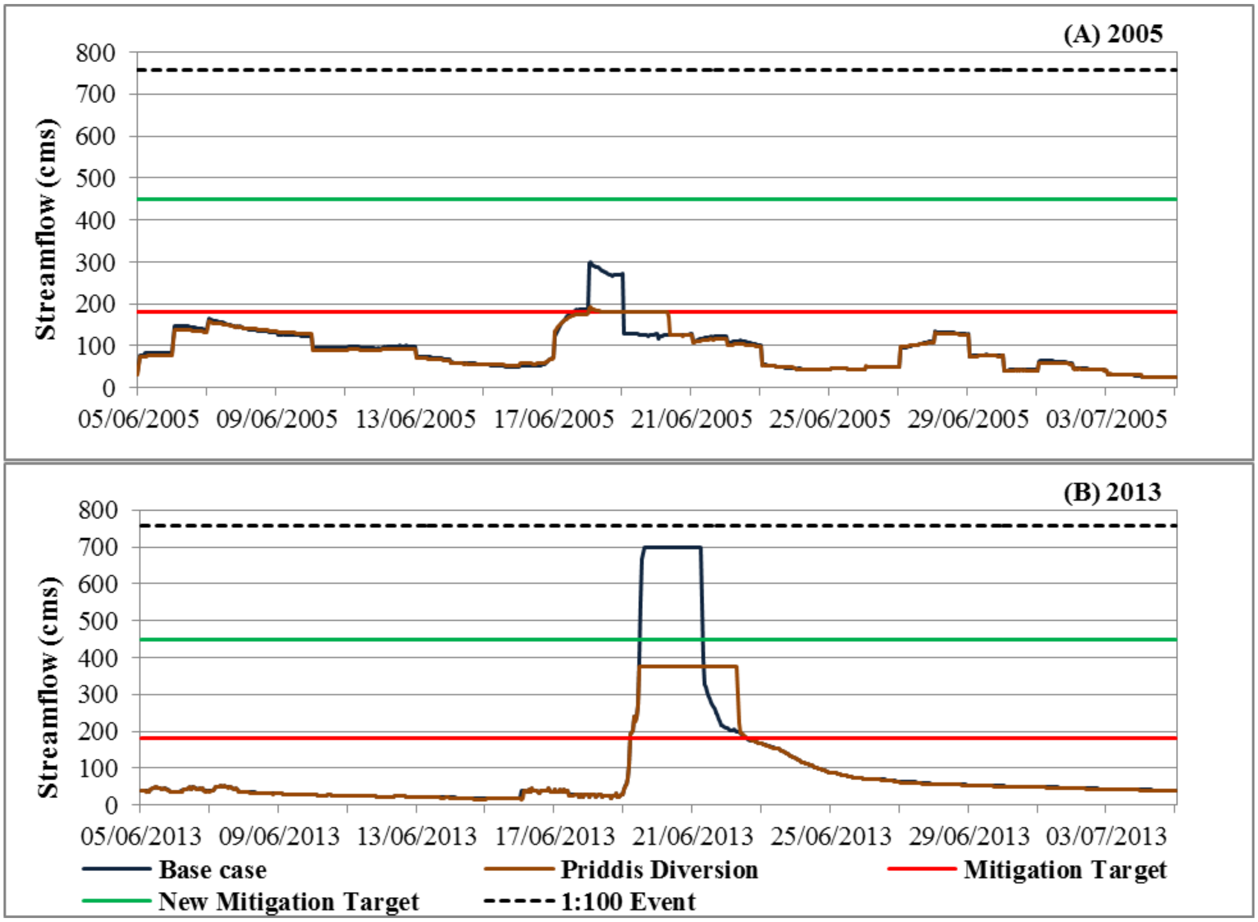

Figure 30: Comparison of streamflow in the Elbow River downstream of the Glenmore Reservoir between base case and including a Priddis Creek diversion run in (A) 2005 and (B) 2013

This option would take flows from the Elbow River and divert to the Fish Creek system. Under 2013 modelled conditions, the diversion would reduce Glenmore inflow by about 345 cms. There are advantages and disadvantages to this option. One negative is that a lot of water would be unnaturally added to this system. In 2013, flows peaked from 2 cms to 220 cms at Priddis. In a real event like 2013, high flows (probably about 200 cms) were already occurring and with additional diverted flow it could further overwhelm the natural capacity and ecosystem as a new oversized channel would be created. This diversion would raise significant concerns about effects on the area around the diversion, including the direct effect on nearly 500 landowners in the region, water supply for local communities, infrastructure impacts (roads, culverts, homes, recreation facilities, etc.), drainage, and groundwater impacts. Backwater impacts could include amplified erosion, and residence protection requirements would be costly. The Priddis Creek system already has drainage challenges as well as water quality and quantity issues. Any flood mitigation or storage options would need to consider the impact on area drainage, and how natural drainage may change as channels erode and move. These and other concerns are well understood and identified by the MD of Foothills.

Areas in this region (north of Bragg Creek) contribute to the main stem Bow and Elbow rivers and have experienced high wetland drainage and loss, which means faster runoff to both rivers, adding to peak flows. Wetland restoration done in partnership with landowners represents an opportunity during the implementation phase of Alberta's new Wetland Policy. Perhaps it could be plausible for municipalities that would benefit from such action to direct their wetland funds to this area and others to obtain more restoration and possibly more valuable locations for the same expenditure. Technical discussions leading to an appropriate wetland inventory are needed to properly see the degree of wetland loss and opportunity.

Participants raised many challenging issues in considering the Priddis Creek option on the Elbow, including:

- Operating goals, mitigation targets, and design elements should be considered early to inform the processes to develop and approve local mitigation activities.
- Land acquisition costs for any infrastructure will be a key factor.
- There will be trade-offs among stakeholders and infrastructure all along the system, including First Nations. Decision makers need to consider the matters of fairness, compensation, and relocation when it comes to transferring impacts from Calgary to others who might otherwise have been less or not at all affected. For example, the homes along the north side of the Elbow River will potentially be protected with a temporary barrier to avoid conveyance of large flows to the downtown Calgary core. This leaves the homes on the south side of the Elbow exposed to flooding, so the trade-off may be to protect Elbow south side homes or Priddis homes.
- A big concern is that Fish Creek Park suffered a great deal of infrastructure damage in 2005 and 2013 at 200 cms, so mitigation options need to consider the impacts of forcing a significantly higher flow through this system.

A positive for this option is that it would benefit Bragg Creek and other upstream communities, but as with other options the costs, benefits, risks, and trade-offs need to be examined. Abandoned irrigation canals and potential storage sites could possibly be used to disperse and get water from the Elbow to the Fish Creek system at lower flow rates to mitigate damages to Fish Creek but more detailed on-site evaluation is necessary to assess overall mitigation value.

Multiple historically identified detention sites

The model run that examined this option included three reservoirs, which were identified in previous flood mitigation studies (Figure 31):

- Reservoir Site D - Same location as EC1
  - o 2097/4935/9870 cdm capacity at 21/30/45 m dam heights
  - o Assume 10% of total inflow to Glenmore Reservoir would be available at the dam site
- Reservoir Site F – Unsure of exact location, assume upstream of McLean site (Figure 31)
  - o 1629/4380 cdm capacity at 18/30 m dam heights
  - o Assume 10% of total inflow to Glenmore Reservoir would be available at the dam site
- McLean / Priddis Site 1 – Upstream of Bragg Creek
  - o 831/2024 cdm capacity at 25/46 m dam heights
  - o Assume 65% of total inflow to Glenmore Reservoir would be available at the dam site

The reservoirs were operated to keep at an assumed normal pool elevation (i.e., operated as reservoirs to normally hold water), unless flows downstream of Glenmore would exceed the flood threshold, then water was allowed to be stored up to the maximum storage of each reservoir to attenuate flows downstream.

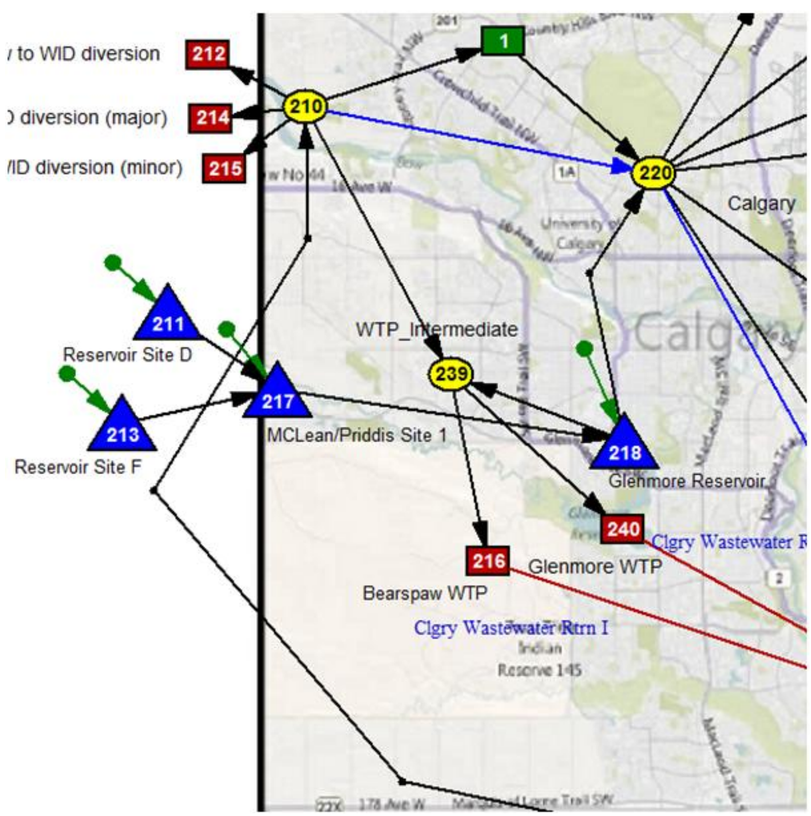

Figure 31: General location of historically identified detention sites (nodes 211, 213, and 217) ***(not to scale and not intended to suggest specific sites)***

Use of the historically identified detention sites for flood mitigation reduced flows in the Elbow River by 89 cms in the 2005 modelled scenario, and by 150 cms in the 2013 modelled scenario (Figure 32).

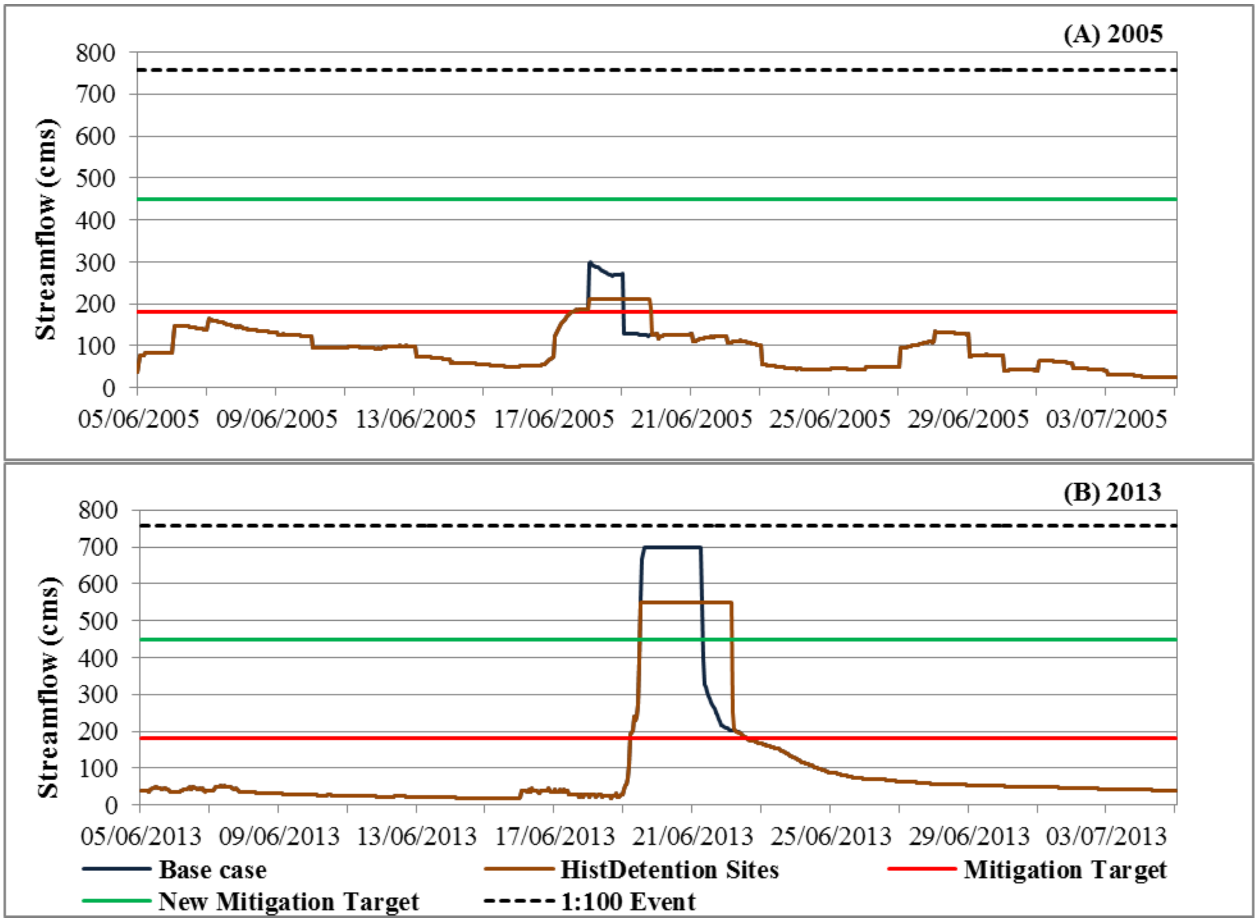

Figure 32: Comparison of streamflow in the Elbow River downstream of the Glenmore Reservoir between base case and including historically identified detention sites in (A) 2005 and (B) 2013

These locations are distributed throughout the watershed and are considered feasible for water detention. In the 2013 flood, they would have filled naturally to some extent and a closer look would be required to determine if any additional storage would have been available. In the 2013 modelled situation, Glenmore outflows would have dropped over 100 cms from 780 to 654 cms. In 2005, outflows went from 300 cms to about 230. This option has less effect on peak flows than some other options but may be less costly to build. It does not rely on a single large piece of infrastructure, but it does potentially transfer risk from urban landowners to rural landowners. They would likely be compensated but this adds a different aspect of cost and complexity compared with the risk and cost of alternatives. Disadvantages from an operations perspective are that more isolated sites will have higher operating costs; there will also be issues of access and safety. These sites would still be dammed and, like other options, need a full risk assessment and appropriate level of design and oversight.

Dry dam on Elbow River Main Stem at Quirk Creek (EQ1)

This option is a 45.6 m high dry dam facility on the Elbow River main stem at the junction with Quirk Creek, with a storage capacity of 70,279 cdm (blue triangle 213 in Figure 33). It would reduce the flow along the Elbow River upstream of Bragg Creek and, given its location, would capture inflow from 35% of the total catchment of Glenmore Reservoir. The dry dam was modelled to attenuate flows greater than 50 cms.

This proposed site appears to have been assessed in the 2008 report, *Assessment of Potential Water Storage Sites and Diversion Scenarios* prepared by MPE Engineering for Alberta Environment, which looked at potential water storage and diversion sites. EQ1 appears to match site 76 Ford Damsite Elbow River Project. While that study was considering sites for full service dams with some different requirements and purposes to a dry dam, it was ranked low (C out of A, B, C), scoring low on supply/demand, dam safety consequence, and geotechnical criteria. The considerations noted were: near provincial protected area, difficult cutoff, and upstream of Bragg Creek and the City of Calgary. Current work by the Task Force's engineering consultants appears to be assessing other potential sites including just upstream of the confluence of the Elbow River and McLean Creek, in the McLean Creek Recreational Area of Kananaskis Country.

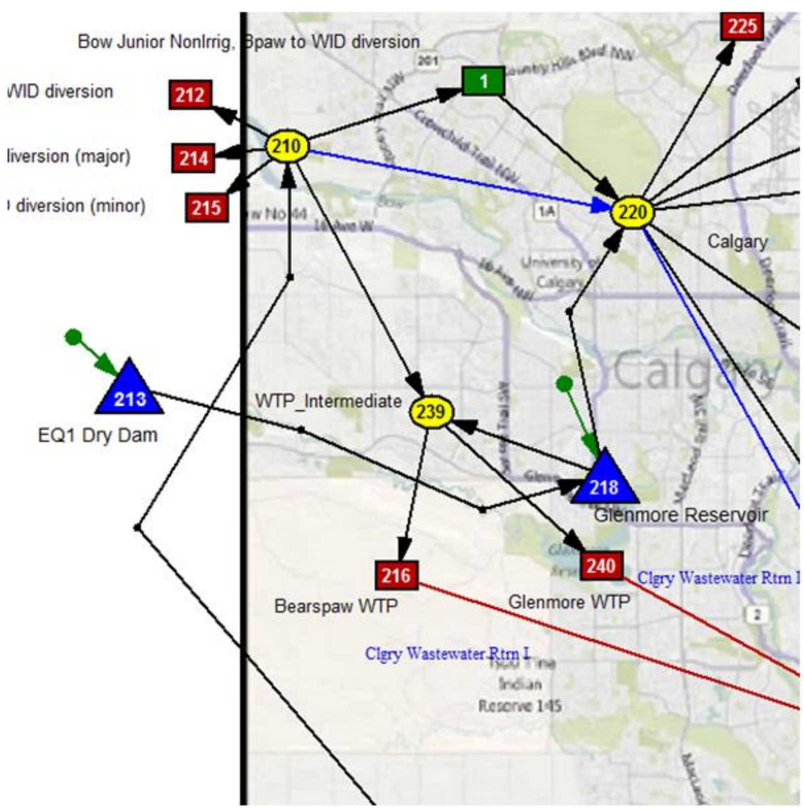

Figure 33: General location for the EQ1 dry dam on the Elbow River Main Stem at Quirk Creek (node 213) ***(not to scale and not intended to suggest specific sites)***

Use of the dry dam EQ1 reduced flows in the Elbow River by 55 cms in the 2005 modelled scenario, and by 280 cms in the 2013 modelled scenario (Figure 34).

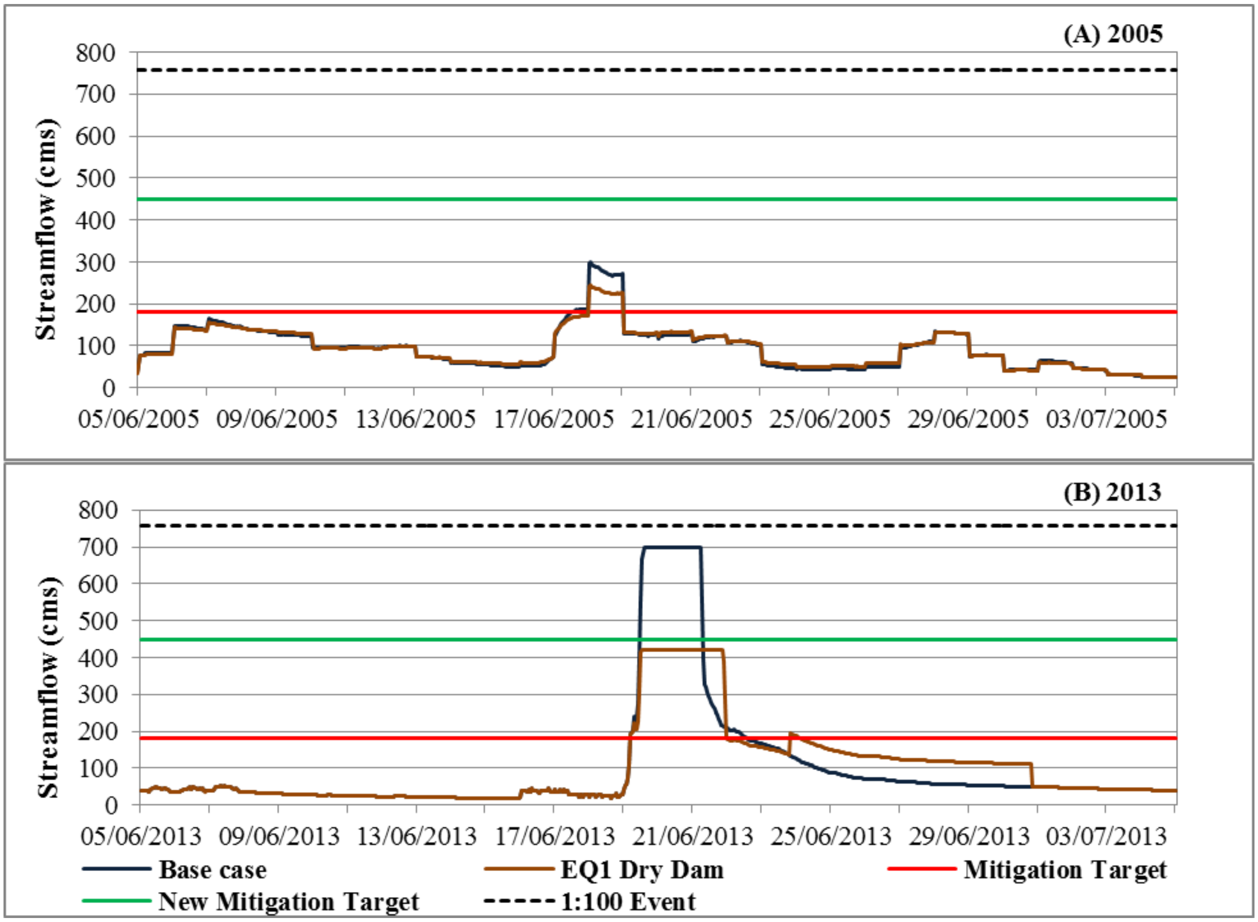

Figure 34: Comparison of streamflow in the Elbow River downstream of the Glenmore Reservoir between base case and a dry dam on Quirk Creek in (A) 2005 and (B) 2013

Like dry dams generally, this proposed option would affect fisheries and fish movement. If this dry dam backs water up to Quirk Creek and the Little Elbow, which seems likely, it may have a substantial impact on spring spawning fish, although large gates might help fish movement. It was noted that this stretch of the Elbow River accumulates massive amounts of gravel, sand, silt, and dead trees particularly during floods, which could quickly block the flow passage and impound water behind the dam. Subsequent slumping and logjams could then clog the spillway, potentially causing overtopping of the dam.

This dry dam would also have an impact on Cobble Flats day use area and any access from there when flooded. Some participants wondered if such a structure were to be built, whether it might be better as a "full service" dam to supply water for Calgary, Bragg Creek, Rocky View County, and the MD of Foothills. Storage high in the system increases the ability to address stress points through the whole system. At the same time, there is the question of whether EQ1 is too high in the system and if it would ever fill, thus limiting its flood mitigation potential. This site contains alluvial sediments, and a detailed geotechnical study would be essential to understand the groundwater dynamics of the area.

Dry dam on Canyon Creek (EC1)

This option is a 44.2m high dry dam detention facility with 12,206 cdm capacity, located on Canyon Creek about 4 km north of secondary Highway 66 (blue triangle 217 in Figure 35). It would attenuate flows greater than 20 cms in Canyon Creek upstream of Bragg Creek and capture 10% of the total streamflow to Glenmore Reservoir.

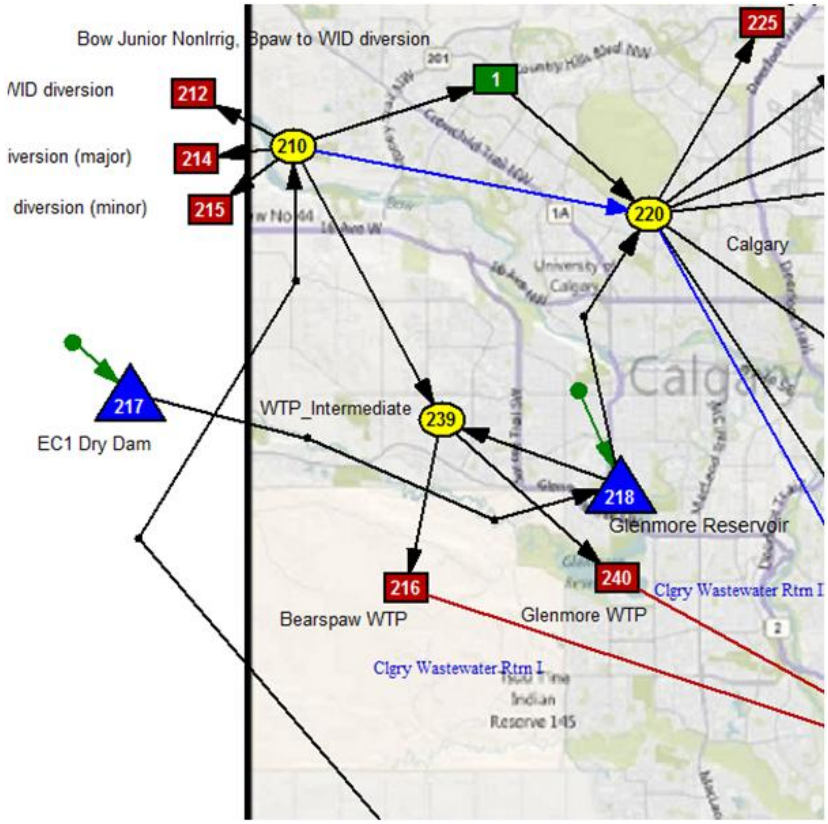

Figure 35: General location for possible dry dam on Canyon Creek (node 217)
(not to scale and not intended to suggest specific sites)

Use of the dry dam EC1 reduced flows in the Elbow River by 10 cms in the 2005 modelled scenario, and by 80 cms in the 2013 modelled scenario (Figure 36).

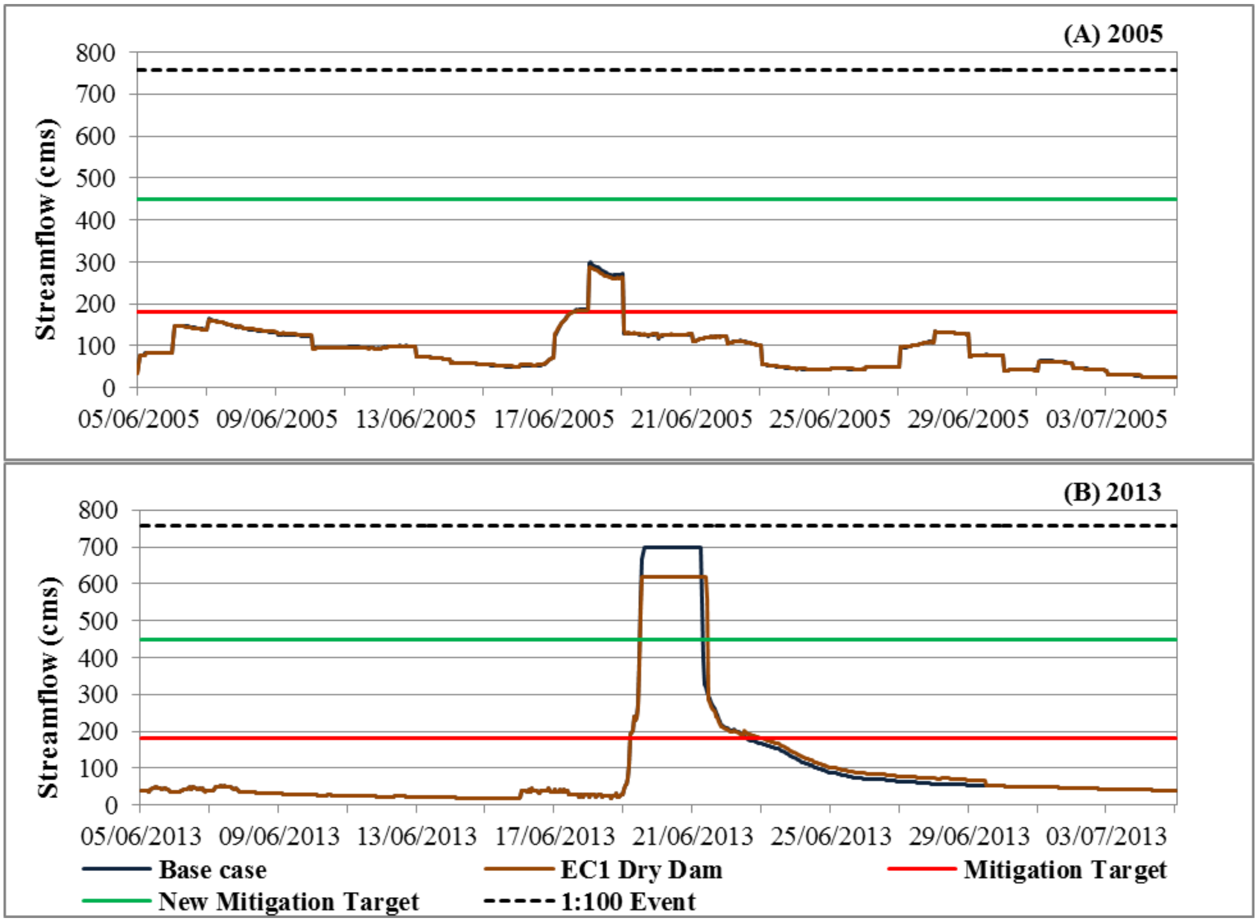

Figure 36: Comparison of streamflow in the Elbow River downstream of the Glenmore Reservoir between base case and a dry dam on Canyon Creek in (A) 2005 and (B) 2013

EC1 has a relatively small catchment area and therefore limited value. The proposed location is in a popular recreation area with valued ecosystems. There was discussion on whether Prairie Creek would perhaps be a more suitable site. As with any dry dam, there are issues related to public safety, debris management, and ecological impacts. Participants stressed the need to fully understand post-flood event releases, especially if multiple dry dams are releasing water at the same time.

Multiple small detentions instead of one

Possible small detention sites in the Elbow system are shown in Figure 37 as blue triangles labelled Dry Dams 1-5. There was no information given on specifications of this option, so the run used the following hypothetical assumptions:

- Five dry dams in series, totalling 100,000 cdm storage, with the storage capacity of each increasing as they progress downstream
- Where possible, operate to fill the upstream dams first, and then progress downstream
- Dam 1 = 10,000 cdm, captures inflow from 5% of the total catchment of Glenmore Reservoir
- Dam 2 = 15,000 cdm, captures inflow from additional 5% of the total catchment of Glenmore Reservoir (10% in total)
- Dam 3 = 20,000 cdm, captures inflow from additional 10% of the total catchment of Glenmore Reservoir (20% in total)
- Dam 4 = 25,000 cdm, captures inflow from additional 10% of the total catchment of Glenmore Reservoir (30% in total)
- Dam 5 = 30,000 cdm, captures inflow from additional 20% of the total catchment of Glenmore Reservoir (50% in total)

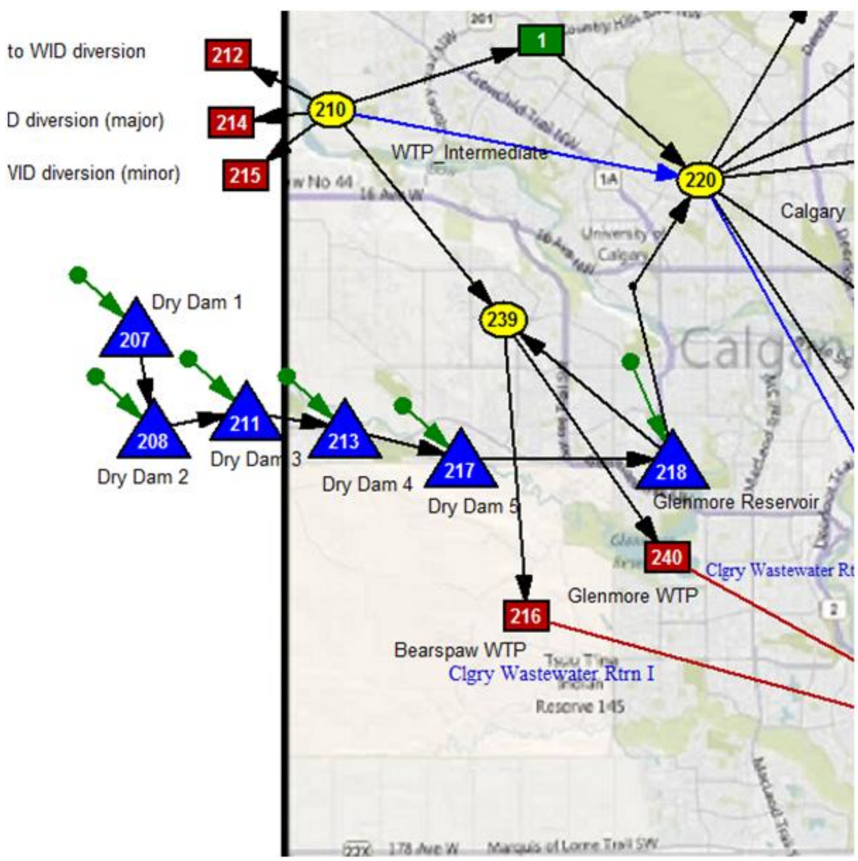

Figure 37: General locations for multiple small detentions on the Elbow River system (nodes 207, 208, 211, 213, and 217) ***(not to scale and not intended to suggest specific sites)***

Use of the multiple dry dams reduced peak flows in the Elbow River by 119 cms in the 2005 modelled scenario, and by 465 cms in the 2013 modelled scenario (Figure 38).

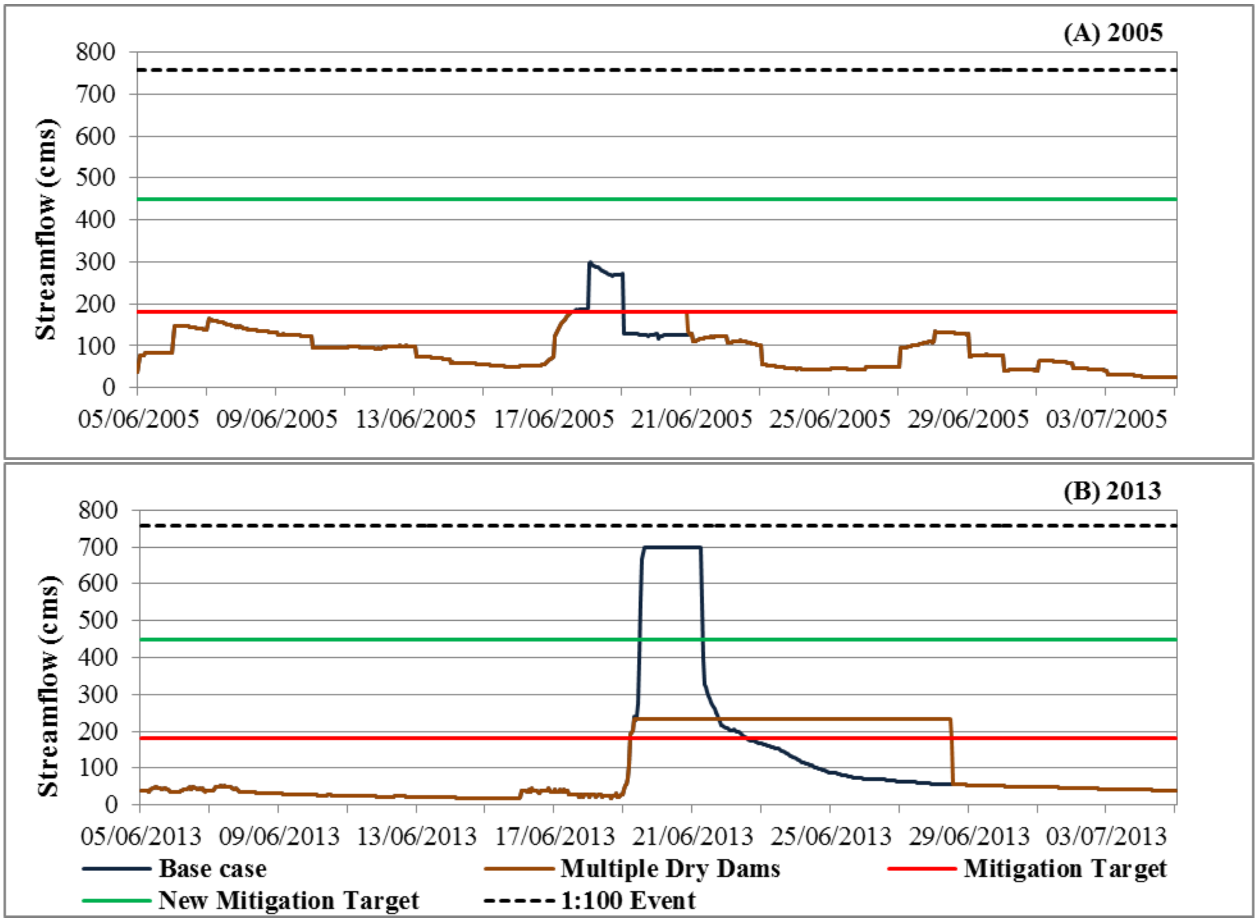

Figure 38: Comparison of streamflow in the Elbow River downstream of the Glenmore Reservoir between base case and multiple small detention sites in (A) 2005 and (B) 2013

The concept behind this option of multiple small dry dams or off stream detention sites was to improve resilience against varying sources of rainfall and runoff during future floods. Operating them in sequence can reduce the size of any single detention site and may reduce the environmental footprint of mitigation compared to a single large dry dam. As with other options, additional review and detailed evaluation would be needed prior to any decision to proceed with any or all of the conceptualized sites and sizes of each.

Expand the capacity of Glenmore Reservoir by raising FSL

This option increased the maximum elevation without uncontrolled release for Glenmore Reservoir by approximately 2.5 m to 1080 m. The reservoir was also lowered prior to a flood by 4.0 m below the crest, similar to the "Operate Glenmore Reservoir for flood mitigation" run.

Raising the maximum elevation of Glenmore Reservoir reduced flows in the Elbow River by 120 cms in the 2005 modelled scenario, and by 175 cms in the 2013 modelled scenario in addition to the mitigation provided by Glenmore operations in 2013 (Figure 39).

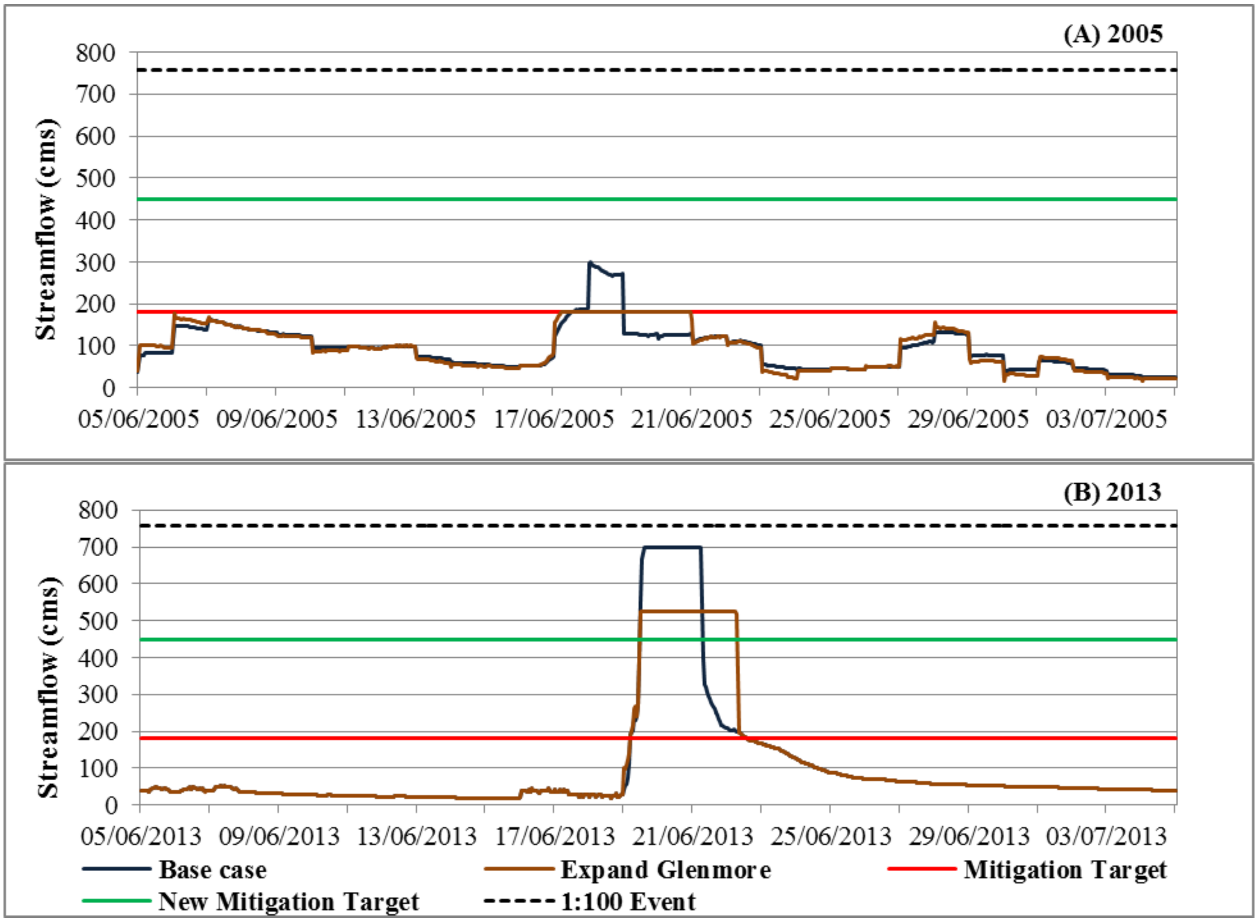

Figure 39: Comparison of streamflow in the Elbow River downstream of the Glenmore Reservoir between base case and expanding Glenmore for flood control in (A) 2005 and (B) 2013

Expanding Glenmore Reservoir by increasing FSL by 2.5 m was intended to allow for this extra drawdown and freeboard, enabling additional mitigation of outflows from the reservoir. In addition to providing some further short-term reduction in flood flows, this option should allow Glenmore to store more water prior to and during a drought for municipal purposes for Calgary and the several municipalities relying on Calgary for regional water supplies. A detailed survey of the area would be required before further consideration to evaluate any requirements for relocation or other costly effects that may make this option less attractive.

7.3 Highwood and Sheep River Systems

North Diversion

This option would divert flood flows from the Highwood River around the Town of High River, reintroducing flow back into the Highwood River downstream of the town. The bypass would be designed to divert up to 500 cms around the town, as shown in Figure 40.

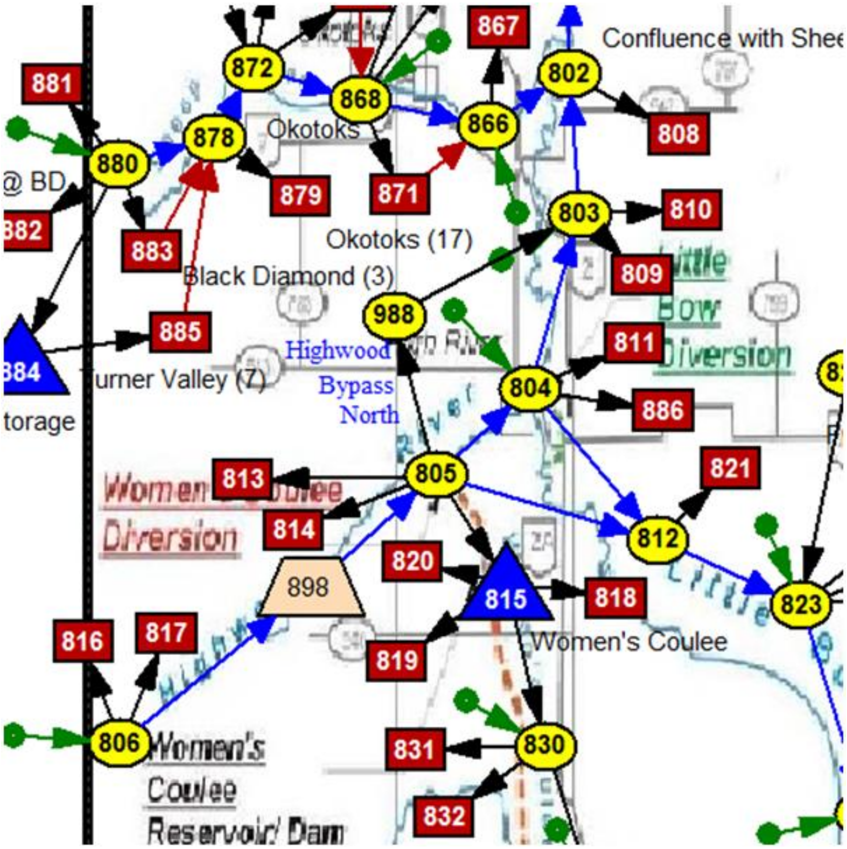

Figure 40: General location for possible Highwood North diversion. The diversion is represented by an arrow going to node 988, then returning at node 803 ***(not to scale and not intended to suggest specific sites)***

Use of the North bypass reduced flows in the Highwood River through High River by 311 cms in the 2013 modelled scenario, and did not affect peak flows in the 2005 modelled scenario (Figure 41).

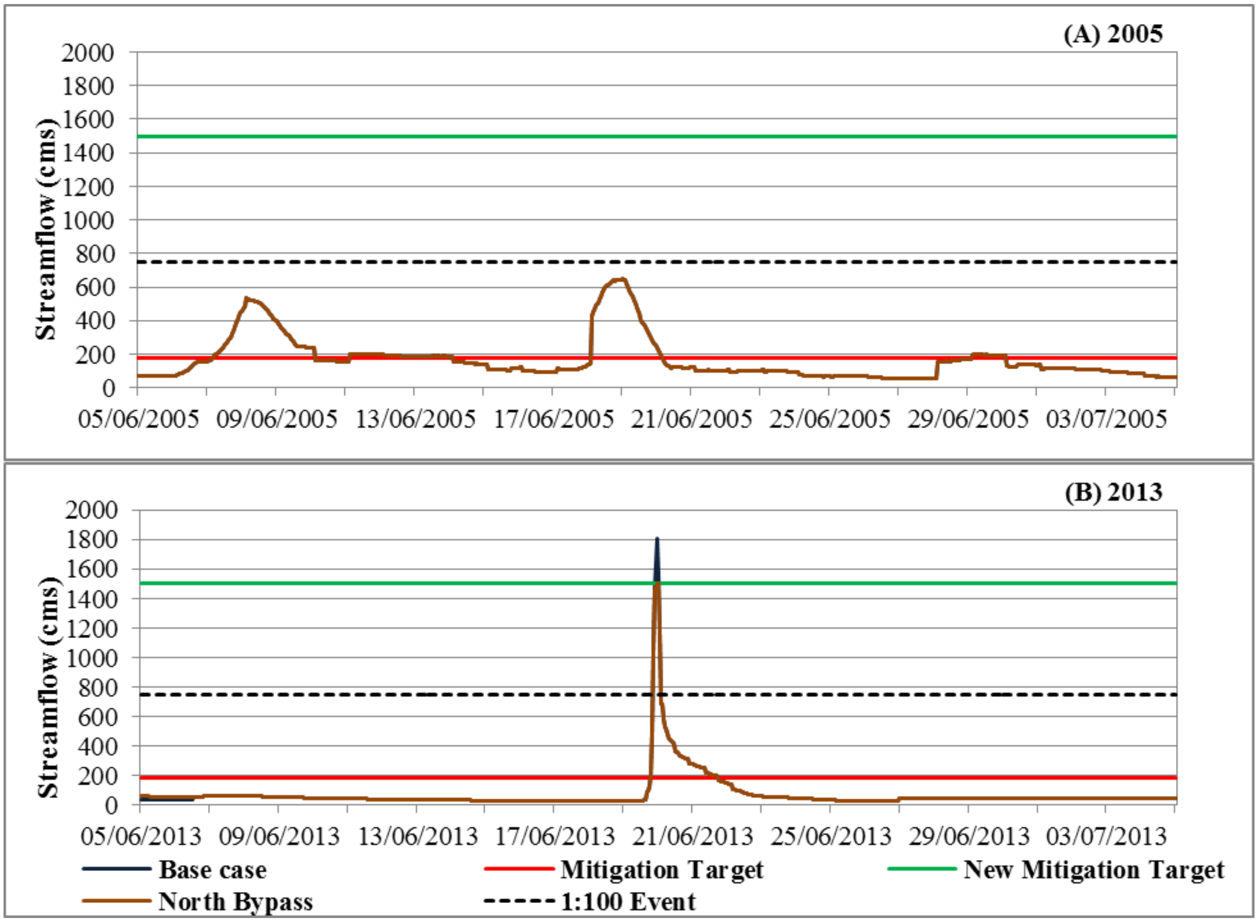

Figure 41: Comparison of streamflow in the Highwood River near High River between base case and a north bypass for flood control in (A) 2005 and (B) 2013

A very low preliminary mitigation target of 180 cms for High River was quickly revised to be higher, recognizing the Town's efforts already underway with local berming and reinforcement, which will allow the town to withstand flows of ~1500 cms or less. A North diversion was considered first to minimize the risk of increased flooding on the Little Bow River with potentially disastrous consequences for some rural landowners, Travers Dam, and downstream at Medicine Hat, which may occur with a South diversion. Subsequently, a South diversion was also proposed, and is analyzed separately, but interaction between the two diversions is complex. It was noted that it may be easier to divert into the Little Bow from an engineering perspective, but there are two dams on the Little Bow already and a dam failure on top of a flood would be the worst case.

It is understood that the proposed current northern diversion return flow locations are entering a low gradient reach of the Highwood River that is documented in the Highwood Management Plan as the most sensitive fish habitat for water management operations during open water season. Instream flow, water quality, and water temperature performance objectives are set to protect this reach and, when these objectives are triggered, first in time, first in right (FITFIR) water policy operations are activated for the water licence users in the area. Currently, activating this trigger results in reduced flow diversions to the Little Bow Basin and a potential call for reduced licensed water withdrawal from the upstream Highwood and trigger reach, depending on water licensing priorities. In drought years this can result in significant licensed water deficits, particularly to irrigation licensed use. In making the decision on this North diversion consideration has to be given to how the flow returned to the Highwood River will affect the health and performance of this sensitive reach under normal flow conditions, particularly during low summer flows. From a fisheries perspective, a North diversion that routes flow from and back into the Highwood River system would be preferable to a South diversion that routes more Highwood River flow into the Little Bow River.

If there is a commitment to build a diversion around High River, then the North diversion is shorter, less contentious, and would affect fewer people. It is “easier,” likely medium term in terms of timing, and may be the safer option in many ways. Nevertheless, moving water intentionally from one place to another with artificial diversion is contentious, value-laden, and brings legal implications for people and infrastructure that natural flooding would not. The preference is to minimize impacts and damages, but this is not just a cost-benefit argument, it is also an ethical and political decision when transfer of risk is considered. Cost-benefit analysis is needed that considers local and regional impacts on the receiving water bodies, as well as impacts to new areas inundated by the diversion that are not naturally affected by Highwood historical flood flows. Cumulative effects flood modelling scenarios should be done as part of the cost-benefit assessment, recognizing that High River’s flood infrastructure changes at different flood levels. Risks of doing nothing beyond the existing and planned changes in channel capacity through the town should also be assessed, as should the option of overland flooding outside the town.

Receiving water bodies affected by the diversion will require follow-up riparian monitoring and designation of compatible flood plain land management use to enable natural or assisted riparian habitat development and recovery. The benefits of flood flows in sustaining natural groundwater recharge in the High River and Okotoks areas were not discussed, but maintenance of groundwater recharge through the respective river reaches is important to municipal supply and groundwater discharge back to the river during low summer and winter flow periods.

South Diversion

This second option to bypass the Town of High River would be used to augment the natural overland flows (of approximately 400 cms in 2013) from the Highwood River to the Little Bow River by an extra 300 cms (Figure 42). This model run also assumed Twin Valley Reservoir would surcharge above FSL to prevent flows downstream from going above 250 cms, as flow above this level would severely damage the spillway at Travers Reservoir and present significant risk to the downstream system.

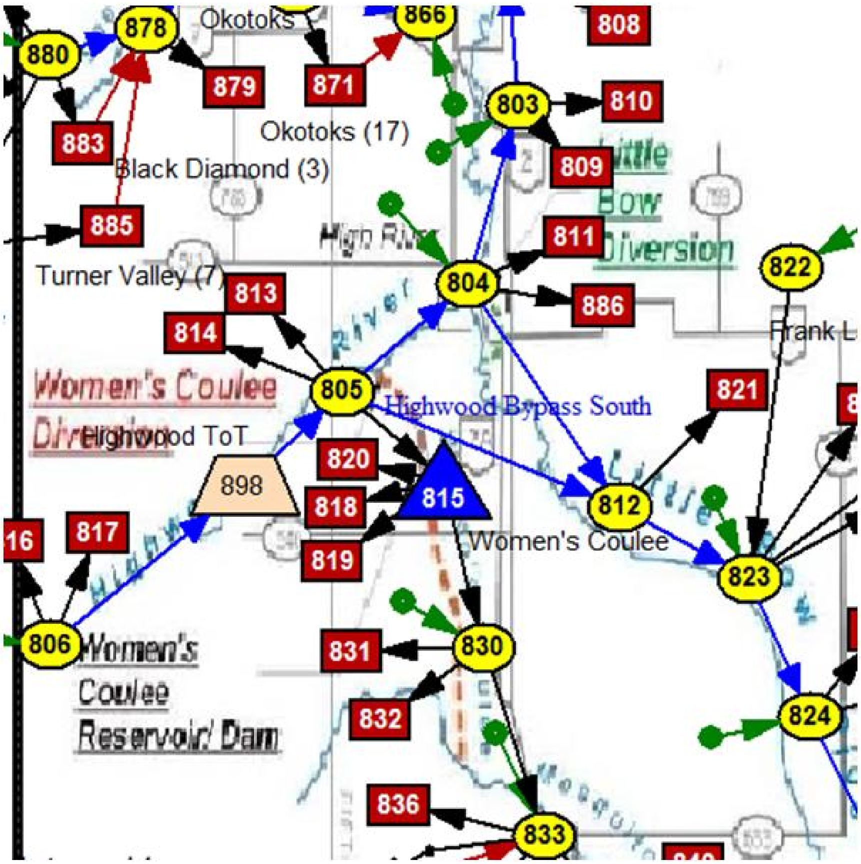

Figure 42: General location for possible Highwood South diversion. The diversion is represented by the arrow from node 805 to 812 *(not to scale and not intended to suggest specific sites)*

Use of the South bypass reduced peak flow rates in the Highwood River through High River by 273 cms in the 2013 modelled scenario, and did not affect peak flows in 2005 (Figure 43).

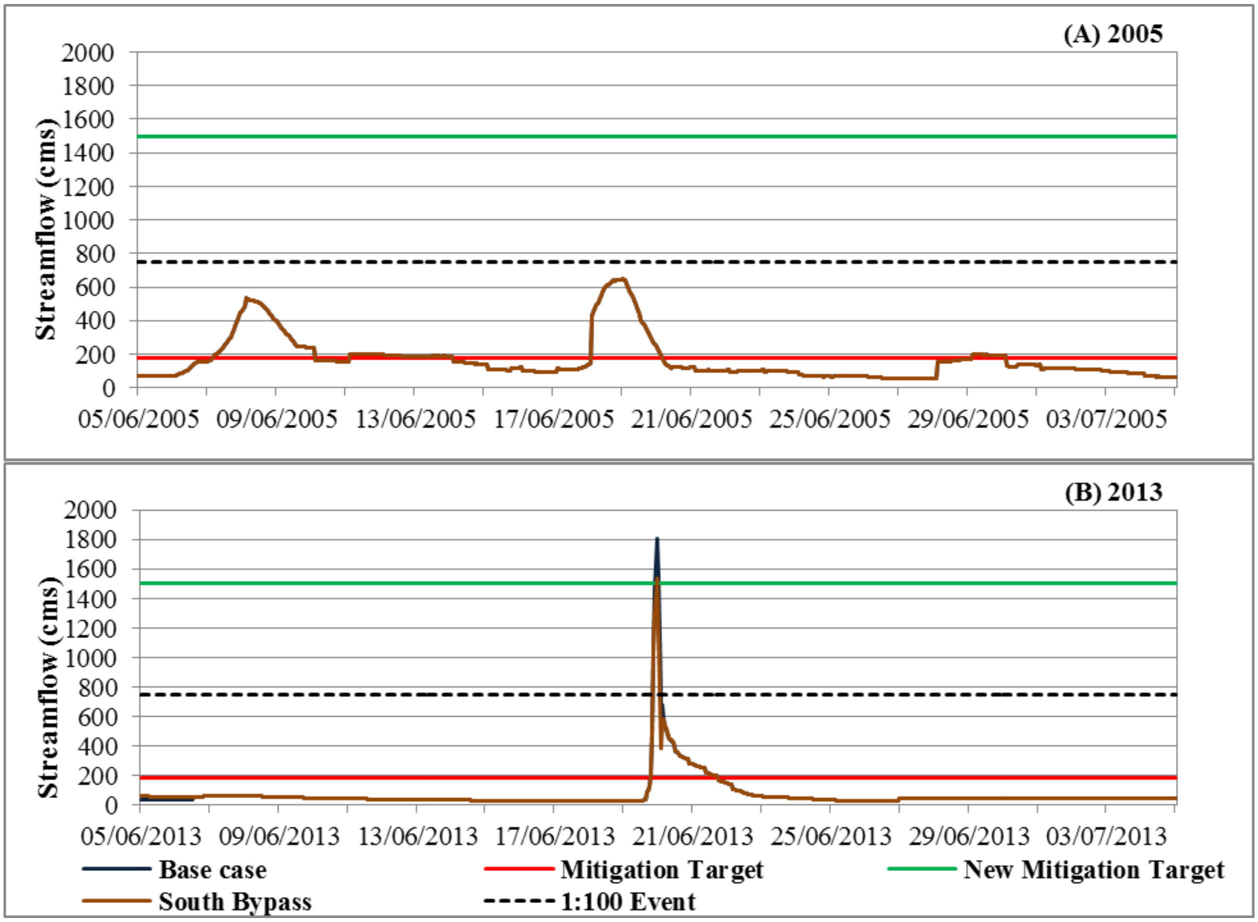

Figure 43: Comparison of streamflow in the Highwood River near High River between base case and a south bypass into the Little Bow for flood control in (A) 2005 and (B) 2013

The potential diversions for mitigating peak flows at High River raised a number of challenging questions, but participants generally thought the South diversion would be more complex and take longer to implement. In 2013, modelling done by High River suggested that 400 cms went naturally to the Little Bow via overland flow. The enhancement assessed with the model added a further 300 cms. The 400 cms flow was manageable only because it could be stored in the Twin Valley Reservoir. The Travers Reservoir spillway can only pass a flow of 250 cms and would need to be upgraded to release more. However, development has encroached on the river valley downstream of the dam possibly because of a false sense of security due to the fact that Travers has surcharged and controlled downstream peak flow rates in the past. This should not be relied upon; the Travers Reservoir spillway should be upgraded to safely accommodate higher potential flows in the future. Costly infrastructure upgrades would also be needed to storage, roads, bridges, and other infrastructure to make the southern diversion viable if the peak diverted flow rate to the Little Bow has a total flow of 700 cms. And it must be recognized that most private valley properties and other infrastructure would be damaged or lost. Costs may dictate where mitigation occurs (e.g., rural vs. Town of High River), but it is necessary to look at the region as a whole and the downstream consequences of each option.

Any decision about enhancing natural overland flow to the Little Bow as a flood mitigation option has to consider the complexity and compatibility of current land and water use in the valley and adjacent to the valley where there are agriculture and acreage homestead developments, irrigation, livestock operations, and petroleum production operations. Infrastructure associated with numerous domestic groundwater wells and municipal licensed diversion off-takes supports valley and upslope residential and agriculture developments and these must be examined as well as the large instream reservoir operations (which were done in the modelling). If enhancing and channeling the natural overland flow to the Little Bow is going to be used as a flood mitigation option, it needs to be properly managed; that is, the land must be appropriately farmed to avoid nutrient runoff and erosion.

Many of the same concerns noted for the North diversion with respect to intentional re-direction of water, cost-benefit analysis, and others apply to the South diversion too. The future growth of High River and impacts on the Little Bow need to be evaluated from both a flood and drought perspective. Part of the risk assessment would be to estimate how often either of the proposed diversions may be used. The Town of High River is working to confirm its berming plans, which are expected to accommodate a flow of ~1500 cms through the town presumably making this the new target flow at which to evaluate mitigation options. As of March 2104, the Town's plans are to install infrastructure to avoid any additional flood flow down the Little Bow beyond what was experienced in 2013 and not to build the North diversion at this time. Plans may change as new modelling and flow data are derived from the Worley Parson model and more detailed engineering studies are completed. At this time it does not appear that any dry dams on the Highwood would be necessary for High River to manage a flood similar to 2013. However, there are other upstream communities that may have an interest in control structures further upstream.

Dry dam west of Eden Valley Reserve (H5(2))

This option is a 45.5m high dry dam with capacity of 83,864 cdm, located on the Highwood River immediately west of the Eden Valley Indian Reserve (blue triangle 997 in Figure 44). It was assumed that 56% of total streamflow to High River would be available at the dry dam site. The dry dam would attenuate flows greater than 100 cms in the river.

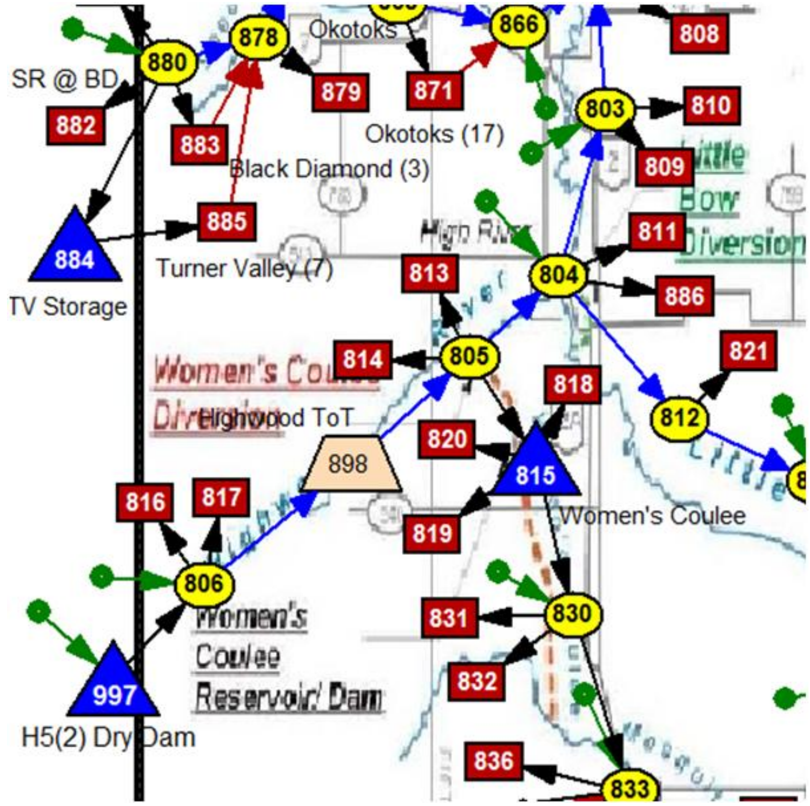

Figure 44: General location for possible dry dam west of Eden Valley Reserve (node 997) ***(not to scale and not intended to suggest specific sites)***

Use of the dry dam H5(2) reduced peak flow rates in the Highwood River by 260 cms in the 2005 modelled scenario, and by 800 cms in the 2013 modelled scenario (Figure 45).

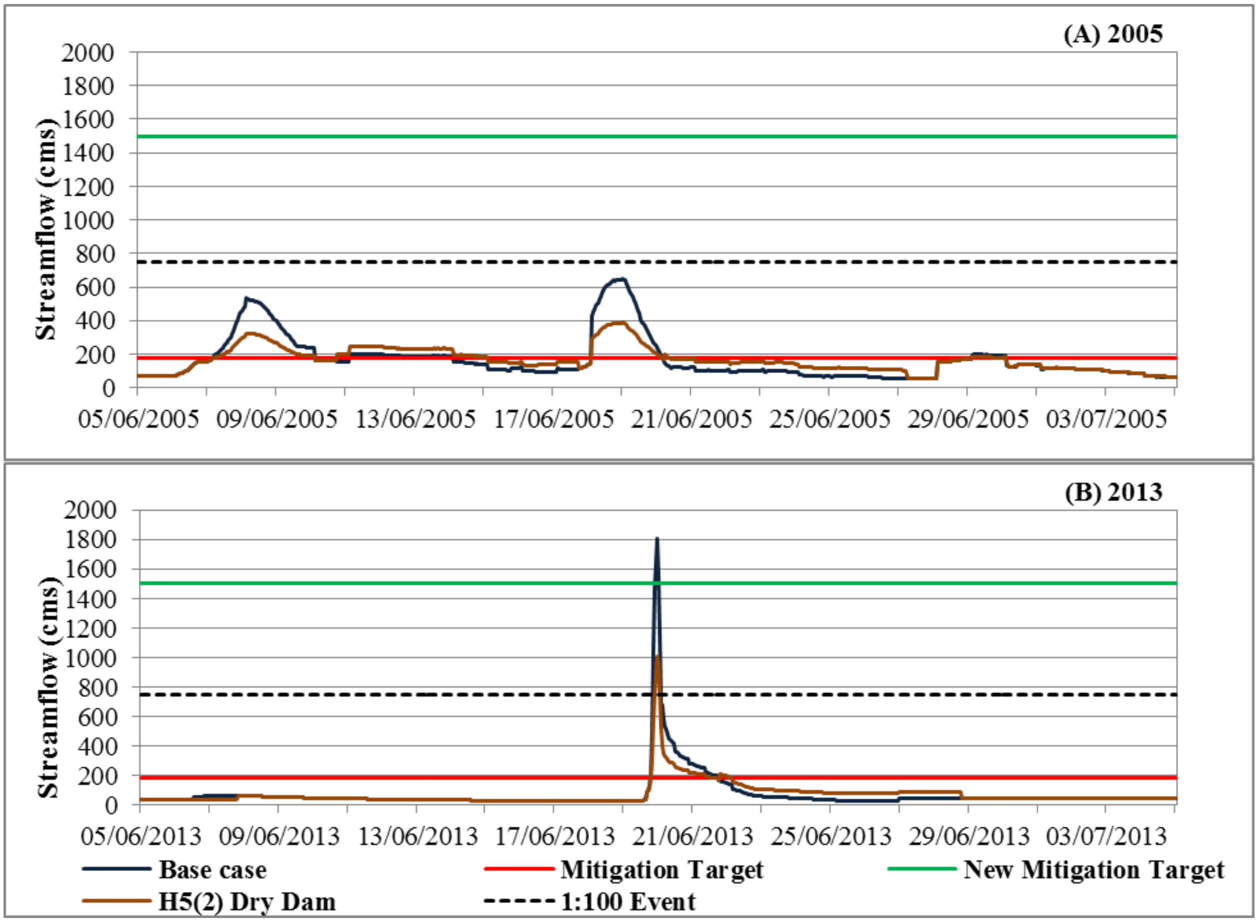

Figure 45: Comparison of streamflow in the Highwood River near High River between base case and a dry dam west of Eden Valley (H5(2)) for flood control in (A) 2005 and (B) 2013

This dry dam would affect Highway 541 which is the primary south access to Kananaskis Country. It would also have a significant effect on the character of the area, which is now relatively pristine with few management controls on it. As with other options considered for the Highwood River system, any interference with the Highwood River upstream will have significant consequences for fish habitat. This is important because the Highwood River is the compensating fishery for the Lower Bow due to dams on the Upper Bow and Elbow, providing key spawning and rearing habitat for sport fish. The current Water Management Plan is geared to protecting this fishery, but flood mitigation could change that focus. Participants also stressed that the Eden Valley Reserve should be part of this discussion.

As with any dry dam, there are issues related to public safety, debris management, and ecological impacts. Participants stressed the need to fully understand post-flood event releases, especially if multiple dry dams are releasing water at the same time.

Dry dam upstream of Longview (H2)

This option is a 48.75 m high dry dam with 40,012 cdm capacity, located on the Highwood River about 7 km upstream (northwest) of Longview, just below the confluence with Ings Creek (blue triangle 988 in Figure 46). For the modelling, it was assumed that 79% of total inflow to High River would be available in the catchment for the dry dam site. The dry dam was used to attenuate flows above 200 cms in the river.

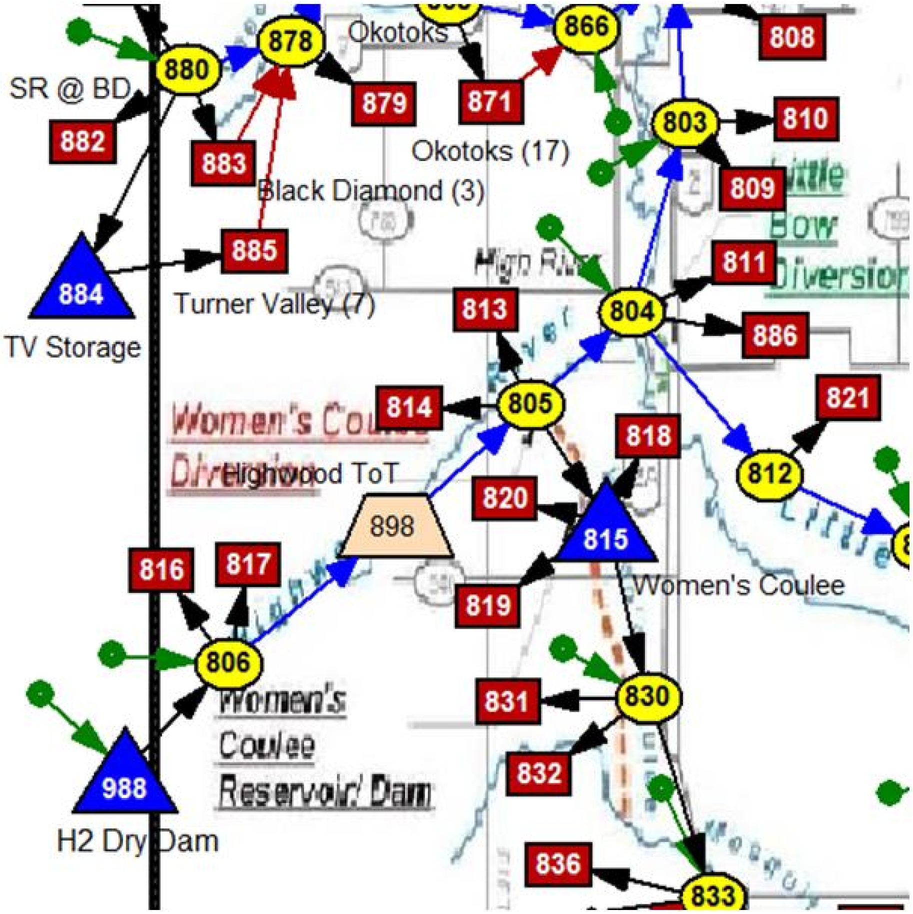

Figure 46: General location for possible dry dam upstream of Longview (node 988) ***(not to scale and not intended to suggest specific sites)***

Use of the dry dam H2 reduced peak flow rates in the Highwood River by 312 cms in the 2005 modelled scenario, and by 1183 cms in the 2013 modelled scenario (Figure 47).

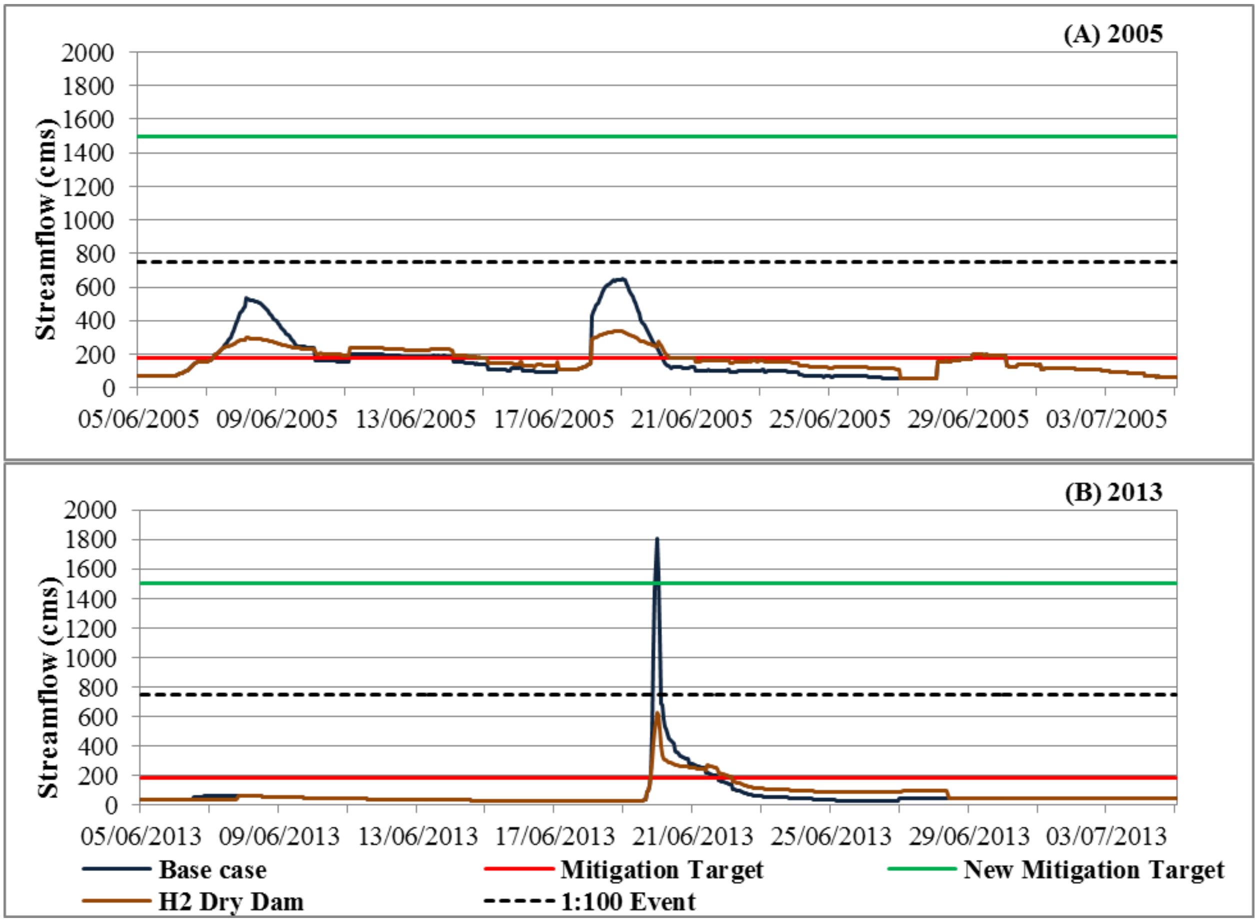

Figure 47: Comparison of streamflow in the Highwood River near High River between base case and a dry dam upstream of Longview (H2) for flood control in (A) 2005 and (B) 2013

The flow reductions achieved with this dry dam were far in excess of what would be required to mitigate flooding for the Town of High River, but the appropriate mitigation target would need to consider the other communities in the area and their current rebuilding and fortification targets. Like the dry dam west of Eden Valley Reserve, a dry dam upstream of Longview would affect Highway 541 and would have significant impacts on several Alberta Parks public recreation areas. The Highwood and Sheep are essential to the trout fishery along the Bow River, and dry dams on these river systems would have a huge impact on the sport fishing community in Calgary and beyond. Options for overland flooding of cultivated fields or rangeland in this area might also be considered.

As with any dry dam, there are issues related to public safety, debris management, and ecological impacts. Participants stressed the need to fully understand post-flood event releases, especially if multiple dry dams are releasing water at the same time.

Dry dam upstream of Turner Valley (S2)

This 45.3 m high dry dam with a capacity of 24,916 cdm capacity is located on the Sheep River about 7 km upstream (southwest) of Turner Valley, just below the confluence with Macabee Creek (blue triangle 989 in Figure 48). In the model run, it was assumed that 89% of total streamflow to Black Diamond would be available at the dry dam site, based on the catchment area to this point. The dry dam was used to attenuate flows greater than 425 cms in the river.

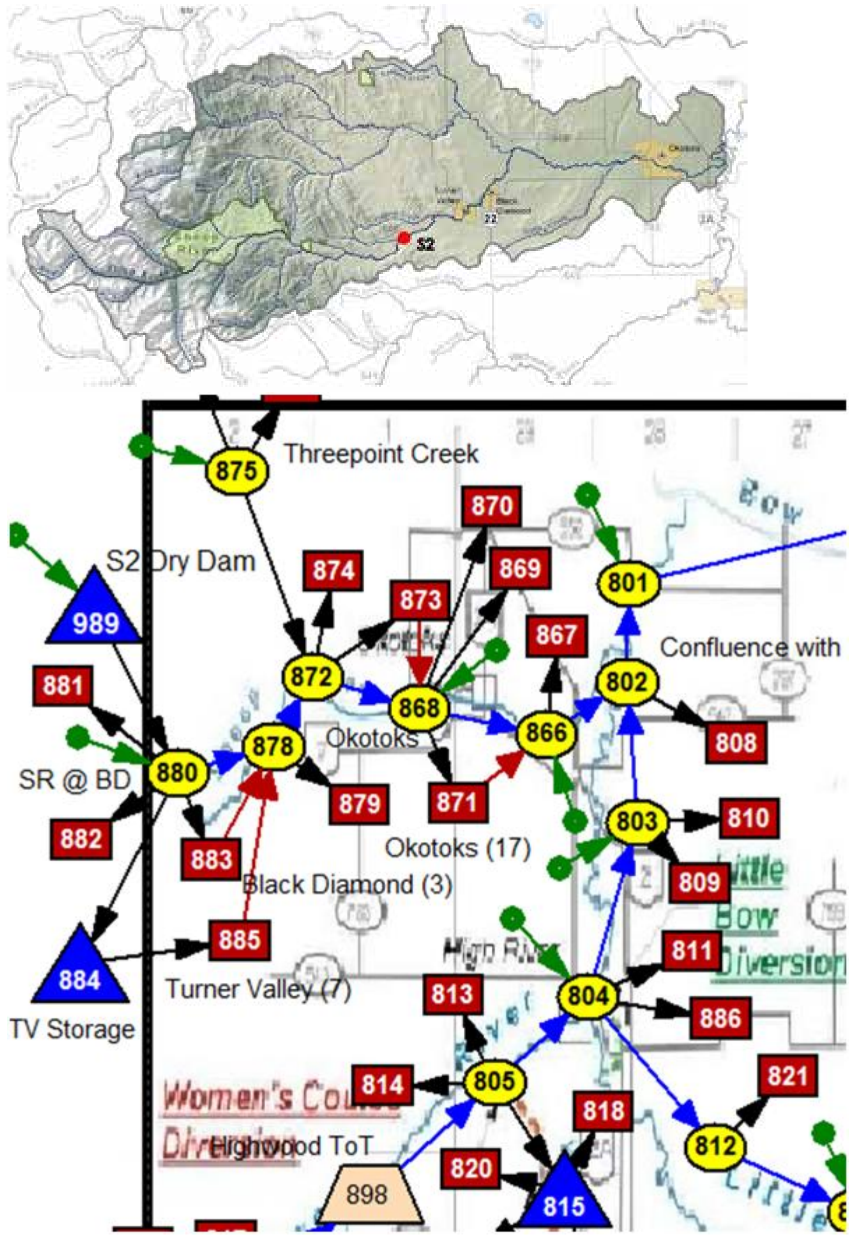

Figure 48: General location of possible S2 dry dam upstream of Turner Valley (node 989) ***(not to scale and not intended to suggest specific sites)***

Use of the dry dam S2 reduced peak flow rates in the Sheep River by 256 cms in the modelled 2013 scenario, and did not affect peak flows in the 2005 modelled scenario (Figure 49).

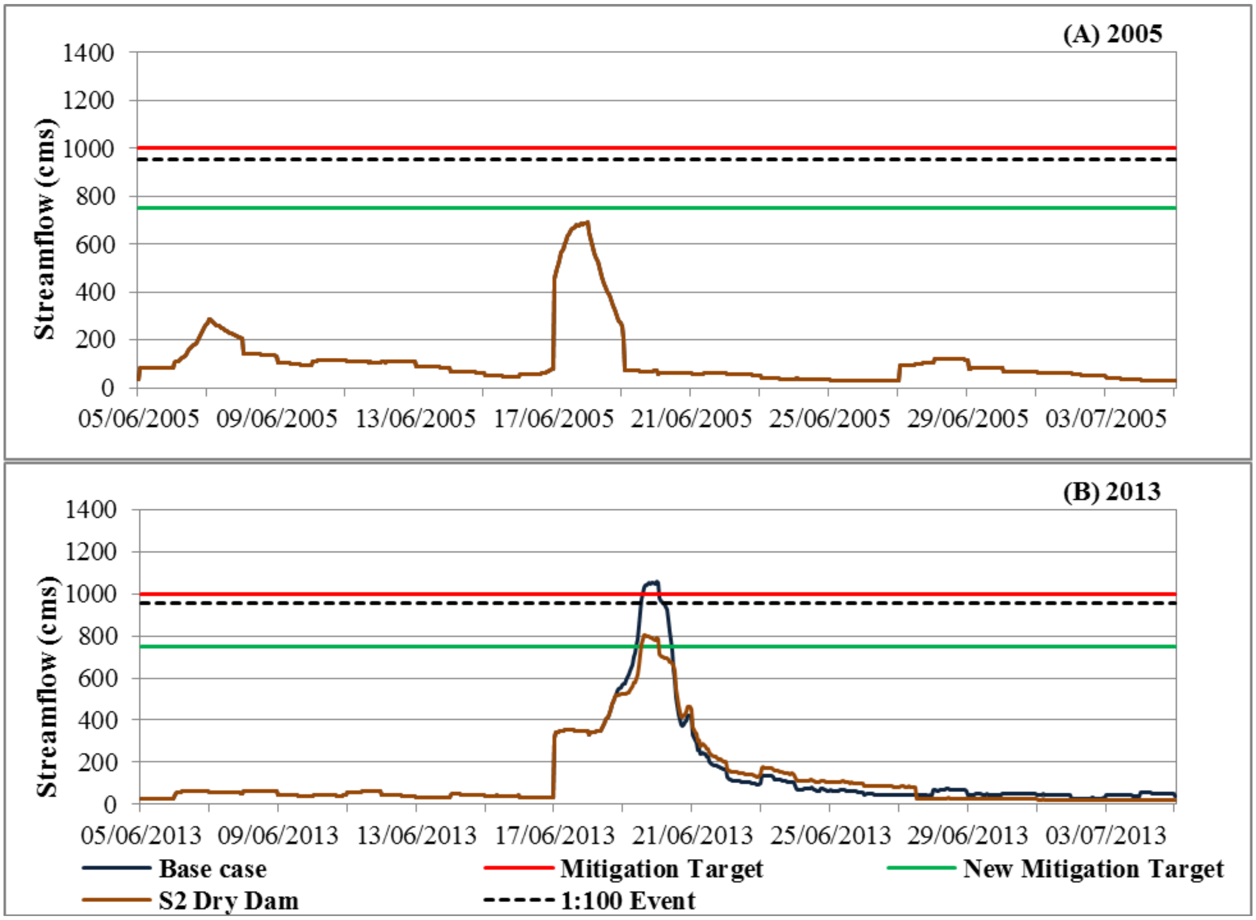

Figure 49: Comparison of streamflow in the Sheep River near Okotoks between base case and a dry dam upstream of Turner Valley (S2) for flood control in (A) 2005 and (B) 2013

In the 2005 and 2013 flood events, Okotoks received peak flow rates of 1000 cms, but the Sheep River at Black Diamond is only part of the challenge, as Threepoint Creek contributes a significant part of the flow through Okotoks. Potential offstream storage is being explored using gravel pit operations. Detention upstream of Turner Valley and at Threepoint Creek could help with a variety of floods. It was noted that a dry dam in the S2 location would help Turner Valley (600 cms is design level at Turner Valley to protect the water treatment plant), but it would affect Sheep Road.

No flood mapping exists between Black Diamond and Okotoks and this should be done with a focus on urban areas to understand the extent of floods, not just the impacts of flows. The MD of Foothills is looking at rip rap and erosion control mitigation options in eight places between Turner Valley and Okotoks.

It was noted that the Sheep River system is recognized as a highly sensitive ecosystem and also supplies water to a large area of irrigated land. If storage infrastructure is considered for this river, its potential for drought mitigation should also be assessed. As with any dry dam, there are issues related to public safety, debris management, and ecological impacts. Participants stressed the need to fully understand post-flood event releases, especially if multiple dry dams are releasing water at the same time.

Detention at Threepoint Creek Confluence

This option involves a dry dam with 50,000 cdm capacity located just upstream of the confluence of the Sheep River and Threepoint Creek (blue triangle 990 in Figure 50). The specific location or viability of proposed locations for such a structure was not part of the working group discussion or assessment. The dry dam was used to attenuate flows greater than 50 cms in Threepoint Creek.

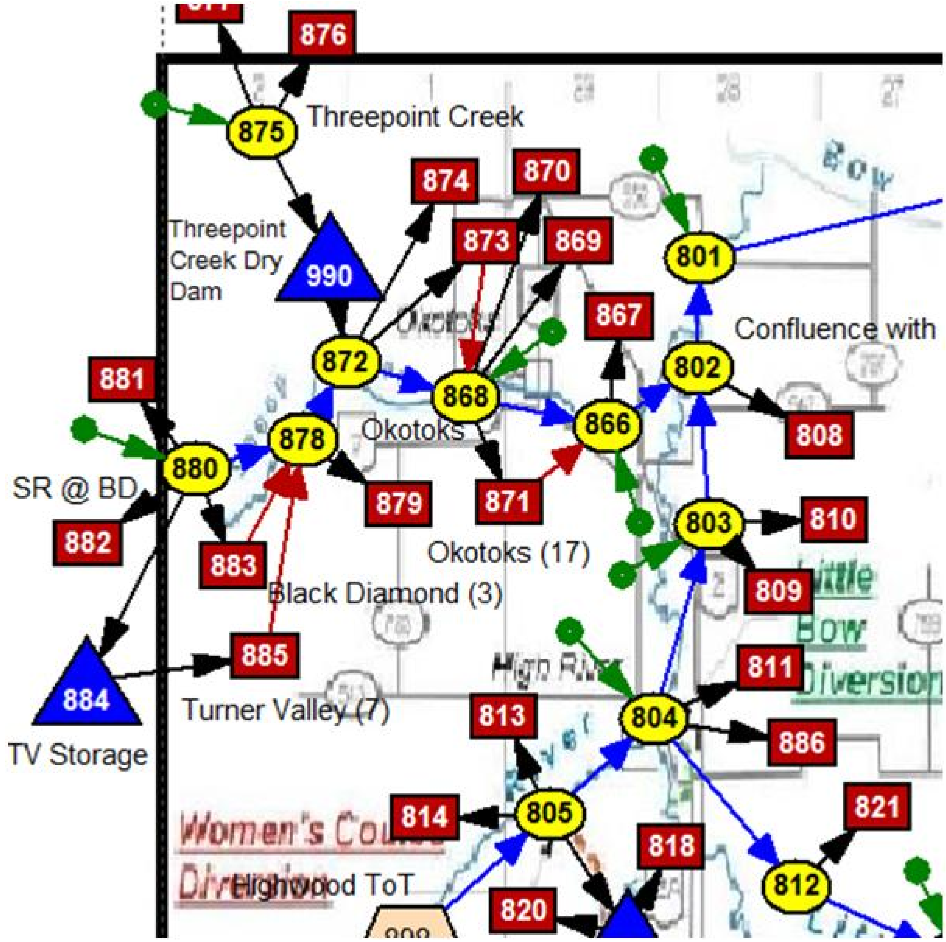

Figure 50: General location for possible dry dam at Threepoint Creek confluence (node 990) ***(not to scale and not intended to suggest specific sites)***

Use of the Threepoint Creek dry dam reduced flows in the Sheep River by 149 cms in the 2005 modelled scenario, and by 168 cms in the 2013 modelled scenario (Figure 51).

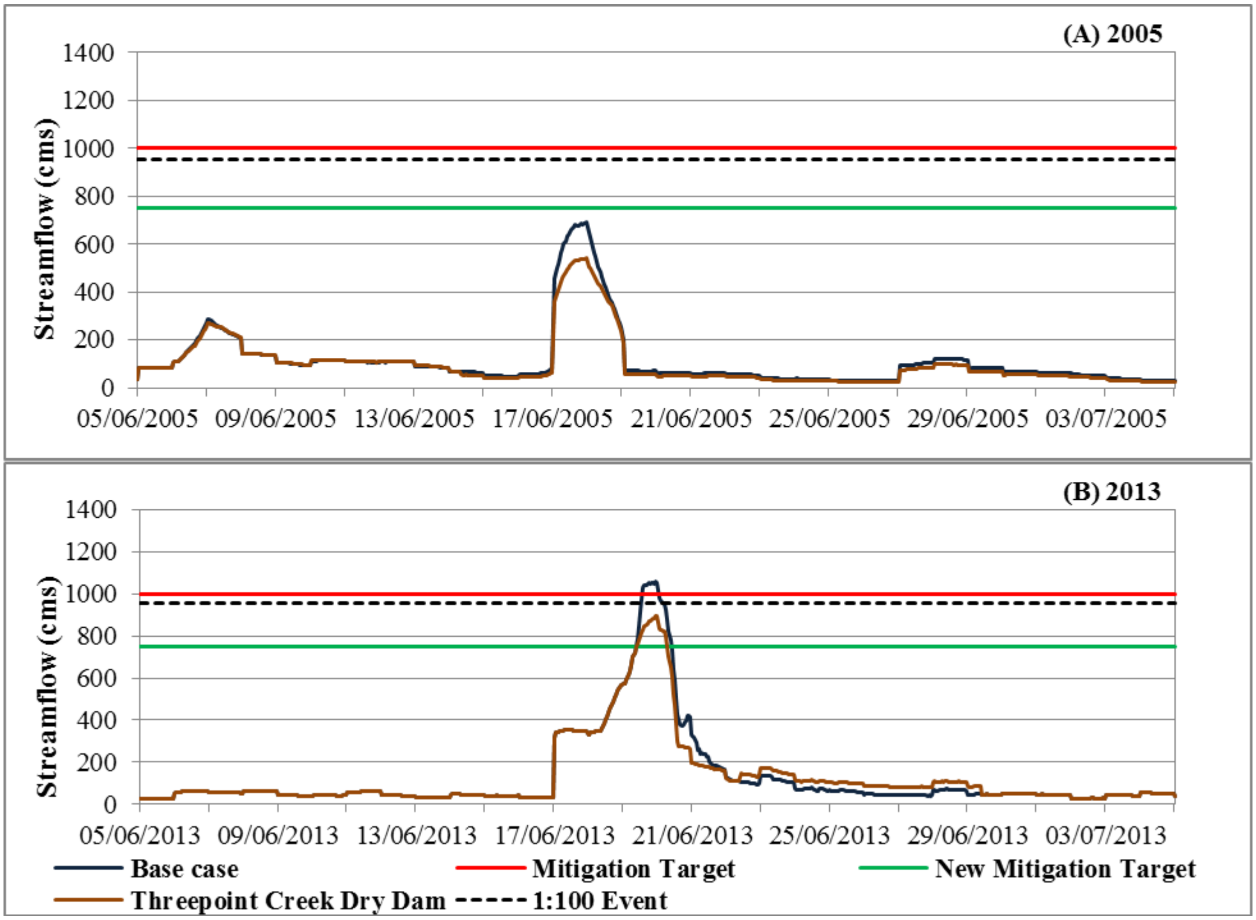

Figure 51: Comparison of streamflow in the Sheep River near Okotoks between base case and a dry dam on Threepoint Creek for flood control in (A) 2005 and (B) 2013

In 2005, most of the flow came from Threepoint Creek, not the mainstem of the Sheep River, so a dam on both would reduce flow for a variety of floods. Rural homeowners in the Threepoint Creek area and the communities around Millarville were severely affected by the 2013 flood and regularly experience flash flooding. No flood mapping exists between Black Diamond and Okotoks and this should be done, likely with a focus on urban areas and infrastructure, to understand and visualize the flood inundations associated with a range of high flows. Both Threepoint Creek and Sheep River have important fisheries so the impact of dry dams on fish habitat in the highly-valued Sheep-Highwood fishery must be considered. If a dry dam has to be considered, participants' preference was for detention at Threepoint Creek rather than upstream of Turner Valley. That said, this location would offer no benefit to homeowners upstream on the Creek. Landscape changes due to development may be a contributing factor to increased runoff, and opportunities for improved landscape management should be assessed before considering these options.

As with any dry dam, there are issues related to public safety, debris management, and ecological impacts. Participants stressed the need to fully understand post-flood event releases, especially if multiple dry dams are releasing water at the same time.

7.4 Natural Mitigation Options for the Bow Basin

Throughout this project, participants stressed the need to integrate natural landscape approaches into any solutions to deal with flood mitigation in the Bow Basin. Working with natural systems can reduce flood risk, and this sometimes means simply respecting the river and staying out of its path. Many of the comments on natural mitigation options are reflected in the discussion of three flood mitigation approaches in Section 5: Wetland Storage, Natural River Functions, and Land Management. All three approaches must be part of the flood mitigation portfolio. Natural mitigation options that were suggested and modelled for this project focused on:

- Improving wetland detention capacity of the whole Bow Basin, and
- Mitigation through land management and use throughout the Bow Basin.

As a basin, we have made decisions about development and watershed functions over a long period, which have put us in the position we are today. Restoring and enhancing wetland function to improve storage, and better land use and management practices throughout the watershed can address a variety of existing problems, not only flood mitigation. Some infrastructure solutions will likely proceed, but if we don't improve watershed functions, infrastructure will not work as well as it should and the net return on that investment will deteriorate. Improving riparian and wetland health and function and land management are crucial components of any successful, long-term flood mitigation strategy. Participants recognized that these approaches by themselves may have a limited impact on the whole system in any given year, but can have important local effects. Improving these functions provides many significant benefits that are also valuable in times of drought and under normal climate conditions.

Wetland Storage
Project participants repeatedly stressed the value and importance of wetlands in helping to mitigate floods and provide a range of environmental goods and services. A wetland inventory for Alberta is needed to document existing wetlands, loss of wetlands, the state of wetland health, and the state of riparian health for river corridors, including tributaries. Runoff vulnerability studies are also needed to identify and prioritize projects for protecting and improving watershed capacity to reduce landscape runoff and improve natural storage. Pothole wetlands were identified as being advantageous in flood mitigation because they are not connected.

Preliminary modelling was done to compare streamflow in the Bow and Elbow Rivers in 2013 with a scenario of implementing a wetland restoration program. A similar run was done for the Highwood and Sheep Rivers. Approximately 23,500 cdm of wetland storage across the entire system was assumed to be restored and function like a series of reservoirs. It is difficult to estimate wetland storage. In nature, wetlands support groundwater recharge and plant growth simultaneously, both of which are continuously adding capacity and neither of which occurs on a barren landscape. For the modelling, very basic assumptions were made about how wetlands would behave for flood mitigation. Inflow to and outflow from wetlands were determined based on the time of year (during and post-freshet), and outflow was determined using a negative exponential decay as a function of storage.

The runs show no difference in peak flows with or without wetland restoration (Figure 52 and Figure 53), but it was suggested that any impact would be more effective for low to medium flows and less for higher flows. It is unlikely that the modelling is exactly correct for this option, as it does not reflect smaller scale aspects, such as damping the timing of runoff and local effects on surface water-groundwater interactions. There are many watershed benefits of wetland retention, whether they reduce major flood peaks or not.

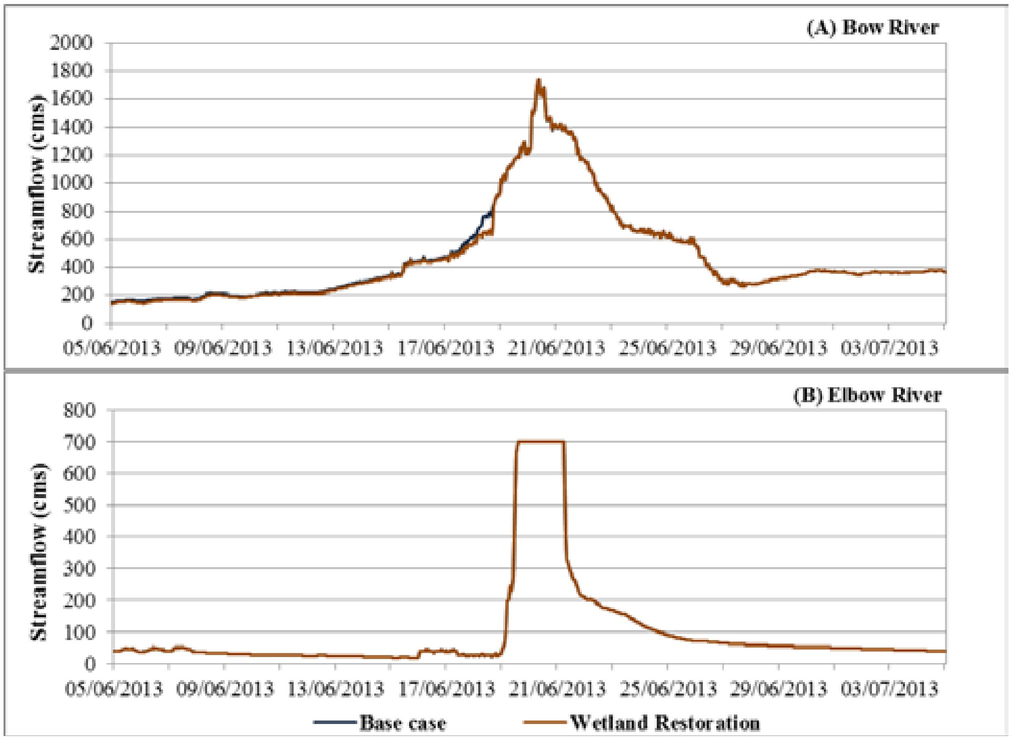

Figure 52: Comparison of streamflow in the (A) Bow and (B) Elbow Rivers in 2013 and a scenario of implementing a wetland restoration program

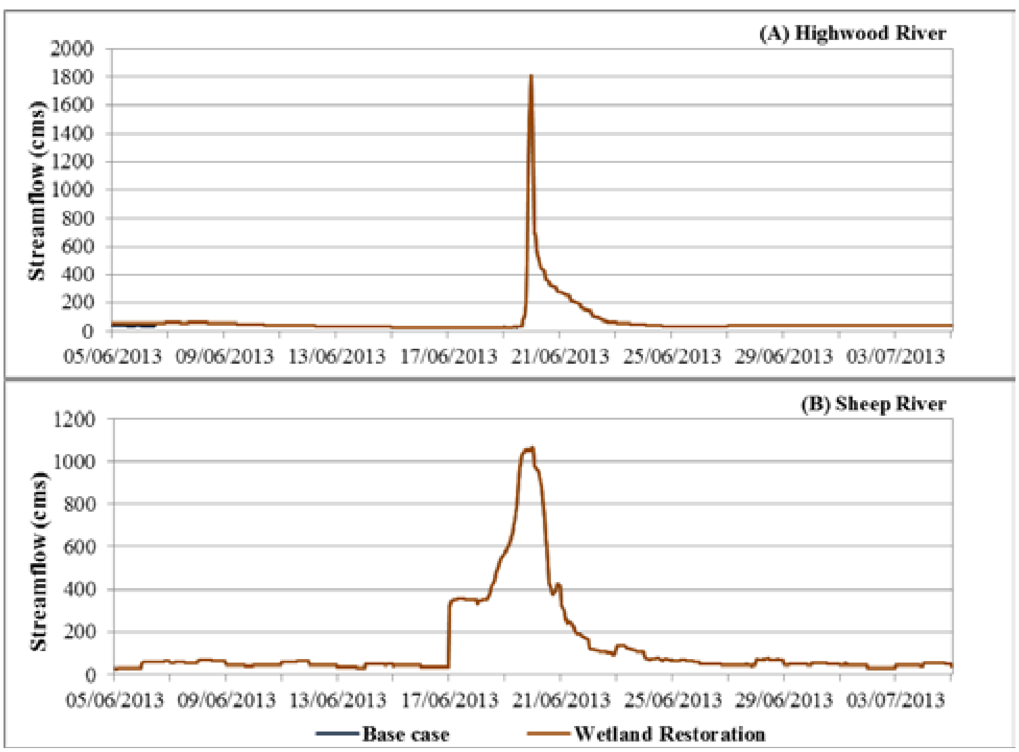

Figure 53: Comparison of streamflow in the (A) Highwood and (B) Sheep Rivers in 2013 and a scenario of implementing a wetland restoration program. Note: the lines are over-plotted.

Land Management
A key component of land management that was stressed repeatedly was “avoid flood plains.” Mitigation options can help protect existing flood plain developments, but these structures can also create a false sense of security. Land use managers and planners should take seriously the need to put new development elsewhere. As was said many times, “Getting out of the way is the only certain way to avoid flood damage.”

Lack of appropriate land management can lead to many activities that could convey flows downstream (e.g., timber harvesting practices, linear access such as roads and cutlines, off-road vehicle erosion channels). Changing land management practices could also help remove debris from the system and could have bigger impacts in smaller and/or sustained flood events. Improving land management practices would engage a number of industry sectors, recreation organizations, and communities and could have positive economic impacts depending on how it was done. It could also offer some benefits for drought mitigation (e.g., improving groundwater recharge, retaining snow pack, slowing melting).

Some modelling was done to compare streamflow in the Bow and Elbow river systems in 2013 with a scenario of implementing best land management practices (Figure 54). A similar run was done for the Highwood and Sheep systems (Figure 55). The runs show no visible impact from this option due to the fact that these runs simply applied a 1% reduction to inflows in 2013. The 1% reduction in 2013 was based on the assumption that the flood was the result of a large rain-on-snow event falling mostly in steep mountain terrain. Land management strategies are assumed to have less impact on peak flows driven by this type of extreme event. However, empirical field studies and process-based hydrological modelling studies are required to fully understand land management implications on flood mitigation. There is an opportunity to use topography to identify areas to work on first, such as reconnecting wetlands and flood plains, or reconnecting flood plains such as at the confluence of the Bow and Highwood for storage.

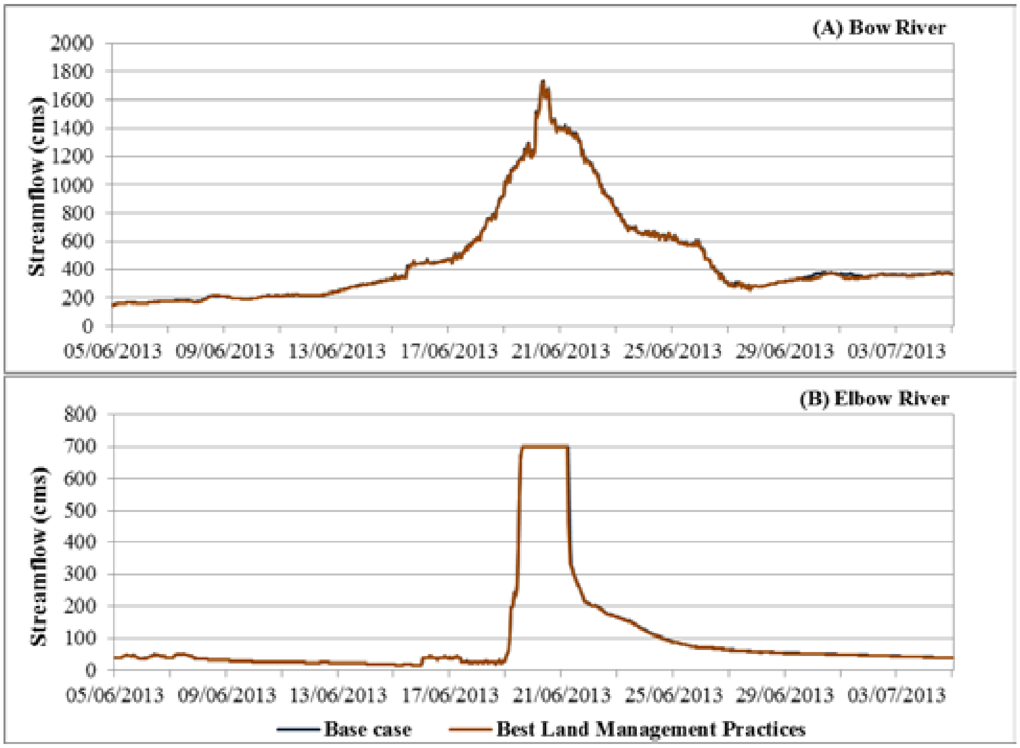

Figure 54: Comparison of streamflow in the (A) Bow and (B) Elbow Rivers in 2013 and a scenario of implementing best land management practices

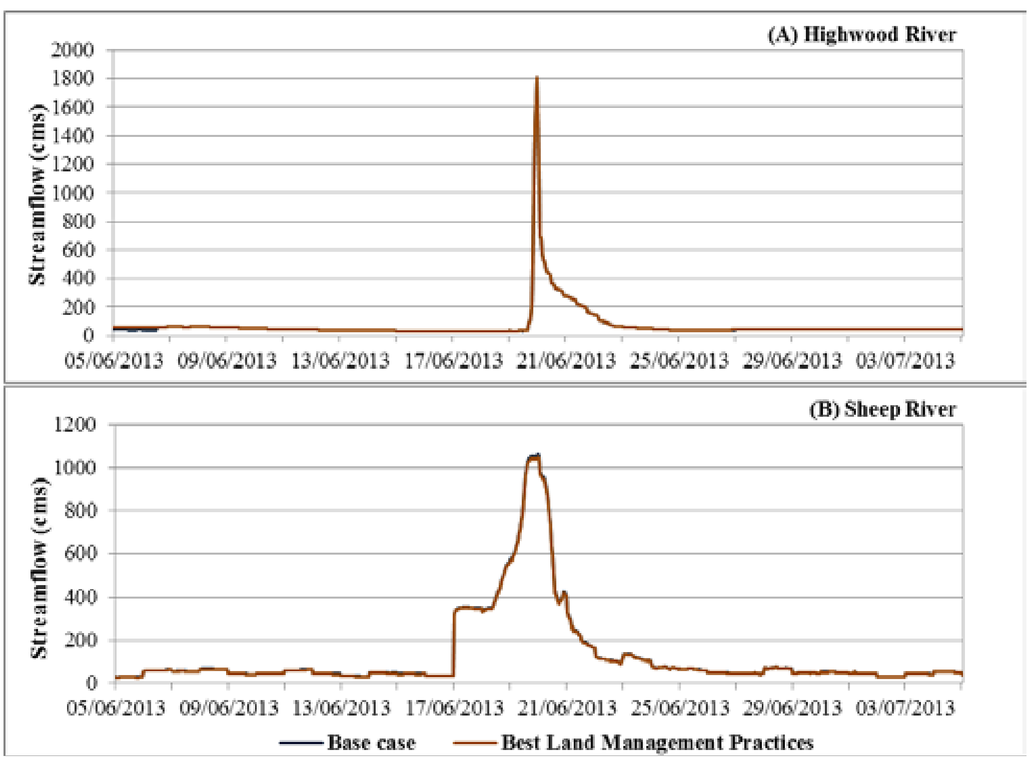

Figure 55: Comparison of streamflow in the (A) Highwood and (B) Sheep Rivers in 2013 and a scenario of implementing best land management practices. Note: the lines are over-plotted.

8 Reaching Mitigation Targets: Mitigation Combinations

A number of individual flood mitigation options showed promise on their own, and participants identified those that could be combined to achieve various mitigation targets. These combinations were developed based on several important considerations:

- Existing infrastructure should be used first and leveraged and used as effectively as possible.
- New infrastructure, particularly dry dams, is very costly and comes with a wide range of potential environmental, safety, and social consequences.
- All mitigation should be based on principles of sound watershed management.
- Resilience, flexibility, and adaptability are essential components of water management.
- A collaborative governance and decision-making process is needed to manage the system of interdependent water infrastructure. Moving water intentionally from one place to another is contentious and becomes an ethical, financial, and political decision when transfer of risk is considered.
- As described in the introduction, human safety is the first priority followed by protecting the economic core of Alberta represented by downtown Calgary, and then reducing damage to homes and other infrastructure at least cost and minimizing negative environmental and other consequences.

This section describes five mitigation combinations. The first two combinations are designed to achieve results for spring 2014 and spring 2015. The other, longer-term, combinations were developed by looking at three scenarios based on three hourly peak flow mitigation targets.

8.1 What can be done for 2014?

Much has already been done or has at least been started since June 2013. These ongoing efforts were recognized by participants as the first line of defence should flooding occur this coming spring of 2014:

- Local protection in municipalities including local berming and diking, as is being done in High River, and river bank armouring, as is being done by Okotoks to protect its water treatment plant;
- Ongoing flood preparedness efforts: emergency planning, supply replenishment, communications improvements, buyouts, and others;
- Property buyouts through the Disaster Recovery Program; and
- Continued public education and awareness around water management.

These measures are expected to continue, were assumed to be part of the combination of mitigation activities for 2014, and are in addition to the concepts that were modelled. The participants identified mitigation options that could be implemented in the Bow Basin to ensure quick action in the spring of 2014:

- Implement agreement to modify TransAlta's facility operations to provide some level of flood control
    - Based on forecasts, lower Barrier Reservoir's upper storage level rule by about 3 m (down to 1368.33 m) from 14/6 – 20/6. These dates were selected for modelling purposes to show the potential of this option; in effect, the model assumes perfect forecasting. Real activities would be based on real conditions and the best available forecasts and risk factors at the time.
    - Based on forecasts, lower Ghost Reservoir's upper storage level rule by about 5 m (down to 1186 m) from 17/6 – 21/6. These dates were selected for modelling purposes to show the potential of this option; in effect, it assumes perfect forecasting. Real activities would be based on real conditions and the best available forecasts and risk factors at the time.
    - Match 2013 flood operations for Minnewanka, Spray and Upper and Lower Kananaskis reservoirs (maintain at slightly below rule curve to enable rapid filling without major releases during a flood period).
- Operate Glenmore Reservoir for flood control
    - Lower Glenmore 4 m prior to forecast flood, and allow it to rise to attenuate flood peak.
- Put in place an integrated forecasting system to facilitate decision making on infrastructure management (releasing or holding water in reservoirs).
- Enforce wetland and land management plans and policies to stop further degradation in the headwaters; initiation of activities to build the flood mitigation potential of these natural services.
    - This could not be specifically modelled in BROM.

The BROM was applied to simulate TransAlta and Glenmore Reservoir operations for flood control. As Figure 56 shows, using TransAlta and Glenmore Reservoir operations for flood control resulted in a modelled peak flow that was reduced to 1145 cms and 680 cms in the Bow and Elbow rivers, respectively for the modelled 2013 event. The spatial flooding extent was reduced substantially along the Bow River. However, flood extent was not reduced substantially