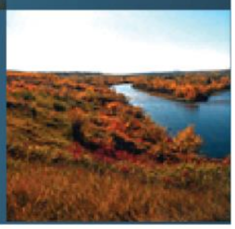

The 2013 Great Alberta Flood: Actions to Mitigate, Manage and Control Future Floods

ALBERTA waterSMART
Water Management Solutions

Final Version
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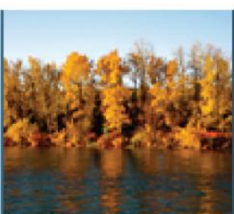

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Executive Summary

June 2013 will be remembered across Alberta as the month of the Great Flood which resulted in the loss of four lives, displaced thousands from their homes, disrupted hundreds of businesses, and caused significant damage to private and public property, land and infrastructure. The immediate responses of municipal, provincial, and federal governments and particularly the people of Alberta to help those impacted by these flood events have been exemplary. However, as the recovery efforts begin to wind-down, the daunting task of rebuilding our communities looms large on the horizon. The rebuilding program must be based on a solid understanding of the confluence of events that caused the flood, the likelihood of recurrence, the efficacy of the proposed mitigation strategies, and the impact of these strategies on the entire South Saskatchewan River Basin.

While we cannot prevent extreme weather, we believe that the weather can be better understood and that actions can be taken to reduce the likelihood of such large-scale destruction resulting from future extreme events. There is a series of logical, science-based, proactive actions that can be taken to strengthen our capacity to respond to these types of natural disasters. The purpose of this paper is to outline these specific actions to inform the policy discussions currently underway in committee rooms across the province.

A broad group of water practitioners from across Alberta, Canada and the world have participated in developing this paper. Collectively they have identified specific actions that can be taken to mitigate, manage, and control the impacts of extreme weather events resulting in floods and the inevitable opposite condition of severe drought. These are summarized into six recommendations:

1. Anticipate and plan for more extreme weather events, including both flood and drought.
2. Improve our operational capacity to deal with potential extreme weather scenarios through better modelling and data management.
3. Investigate the cost/benefit balance of investing in physical infrastructure such as on and off-stream storage, diversions, and natural infrastructure such as wetlands.
4. Consider flood risks in municipal planning and strengthen building codes for new developments in flood plains.
5. Evaluate options for overland flood insurance.
6. Manage our water resources collaboratively, following the examples of the Bow River Consortium and the Cooperative Stormwater Management Initiative, and ensure Watershed Planning and Advisory Councils (WPACs) across the province have proper authority and funding.

Contents

Introduction

June 2013 will be remembered across Alberta as the month of the Great Flood. In late June a major rain event caused massive flooding in the South Saskatchewan River Basin (SSRB), affecting tens of thousands of families throughout the region, resulting in the loss of four lives, displacing thousands from their homes, disrupting hundreds of businesses, and causing significant damage to private and public property, land and infrastructure.

The immediate responses of the municipal, provincial and federal governments and particularly the people of Alberta to help those impacted by these flood events have been exemplary. In particular in Calgary, where 26 communities were affected, the excellent cooperation and collaboration between City officials, businesses, emergency response services, and the public prevented many possible deaths (only one person died in Calgary) and ensured minimal disruption in services. The Government of Alberta (GOA) responded to the flood by pledging $1 billion in disaster recovery assistance, and the Government of Canada promised full support for flood relief. The stories of heroism and sacrifice from ordinary Albertans are abundant.

However, as the immediate response and recovery efforts begin to wind down, the daunting task of rebuilding our communities looms large on the horizon. Decisions on priorities for investment must be made by individual home and business owners, the councils of the affected municipalities and counties, and the provincial and federal governments. The preliminary estimates of the total cost of Alberta’s recovery efforts range from three to five billion dollars.

The rebuilding program must be based on a solid understanding of the confluence of events that caused the flood, the likelihood of recurrence, the efficacy of the proposed mitigation strategies, and the impact of these strategies on the entire river basin. Our analysis shows that Albertans from all parts of the province should be prepared to experience more frequent and severe weather events, including floods and droughts. Due to the urgent need for action our recommendations focus on the South Saskatchewan and Bow River basins. However the conclusions from our work have implications for the rest of Alberta and Canada.

While we cannot prevent extreme weather, we believe that the weather can be better understood and that actions can be taken to reduce the likelihood of such large-scale destruction resulting from future extreme events. There is a series of logical, science-based, proactive actions that can be taken to strengthen our capacity to respond to these types of natural disasters. The purpose of this paper is to outline these specific actions to inform the policy discussions currently underway in committee rooms across the province. As this paper was written, the goal was to engage as many thought leaders as possible in this important discussion. The contributors to this paper (listed in Appendix A) ensured that the recommendations herein represent clear, consistent, implementable, and fundable solutions.

Background

The idea for this White Paper arose from a discussion group at the Canadian Water Summit, which was held in Calgary on June 27, 2013. The discussion was hosted by IBM, and was designed and conducted by Alberta WaterSMART. Thirty water experts from across Canada and around the world participated in the discussion group.

The first draft of the White Paper was distributed to the discussion group participants, the Western Irrigation District (WID) executive, the Bow River Basin Council (BRBC) executive, the South East Alberta Watershed Alliance (SEAWA) Director, the Scientific Director of Alberta Innovates – Energy and Environment Solutions (AIEES), a small number of GOA staff members, the Chief Executive Officer of the Association of Professional Engineers and Geoscientists of Alberta (APEGA), members of the Canadian Academy of Engineering (CAE), the Hydrologics modelling team, and the Alberta WaterSMART team and board. In addition, a summary of the recommendations was posted on the Alberta WaterPortal for input and comments from the public.

This final version of the White Paper represents the contributions of several dozen water practitioners and interested members of the environment community and the public. Every effort was made by the authors to include the comments received. The contributors to this paper are listed in Appendix A. Any errors or omissions in this document are the responsibility of the authors and not the contributors.

Summary of Recommendations

There are actions that can be taken to mitigate, manage, and control the impacts of extreme weather events resulting in floods and the inevitable opposite condition of severe drought. These are summarized into six recommendations:

1. Anticipate and plan for more extreme weather events, including both flood and drought.
2. Improve our operational capacity to deal with potential extreme weather scenarios through better modelling and data management.
3. Investigate the cost/benefit balance of investing in physical infrastructure such as on and off-stream storage, diversions, and natural infrastructure such as wetlands.
4. Consider flood risks in municipal planning and strengthen building codes for new developments in flood plains.
5. Evaluate options for overland flood insurance.
6. Manage our water resources collaboratively, following the examples of the Bow River Consortium and the Cooperative Stormwater Management Initiative, and ensure Watershed Planning and Advisory Councils (WPACs) across the province have proper authority and funding.

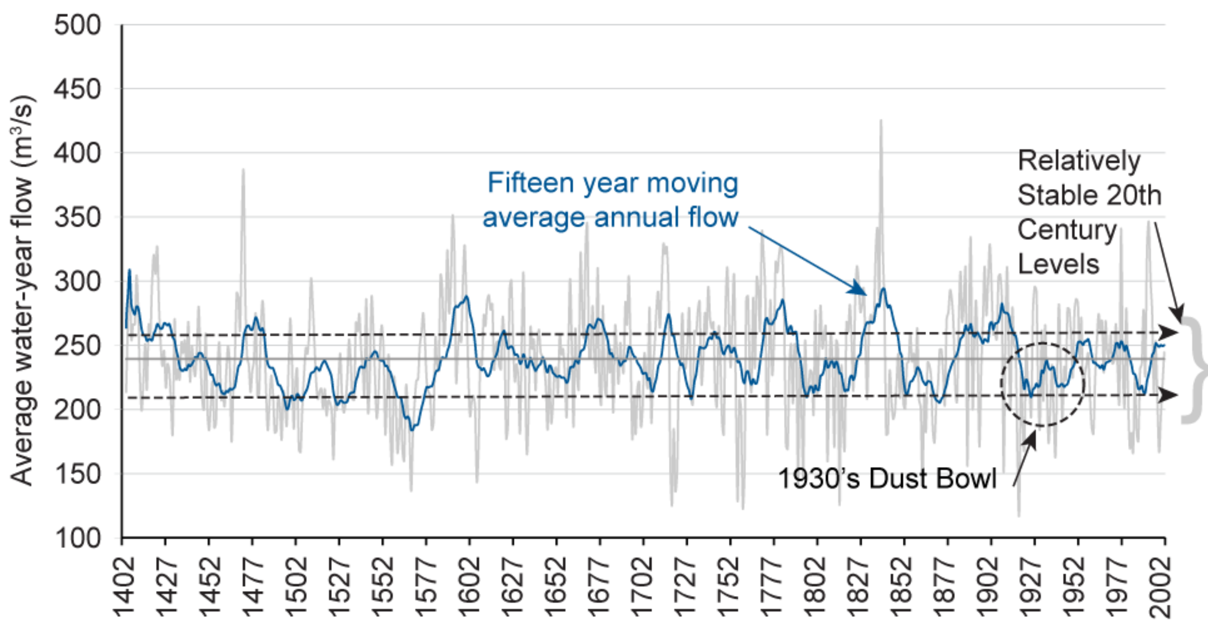
This White Paper expands on these recommendations and provides a summary of short-term actions that can be taken immediately to begin implementing these recommendations. It is hoped that all of these recommendations will help to inform the policy discussions currently underway in committee rooms across the province, as well as to educate those impacted by the flood event and anyone involved in water management activities.

1. Anticipate and plan for more extreme weather events.

Alberta, and specifically southern Alberta, should be prepared to experience larger and more frequent extreme weather events in the future, including both floods and droughts. This is important because these events have huge impacts on people and on our economy. These impacts are costly and are likely to become more costly as Alberta's population grows.

Detailed studies of historical tree ring data in southern Alberta show a remarkably consistent trend in the SSRB flows over the last 600 years. This data indicates that flood and drought events in the past were far more severe than we have experienced during the mid to late 20th century. The pre-historic record (Figure 1) suggests that we should be prepared for extreme weather events that are worse in terms of severity and frequency than the ones we have experienced in recent history. For example, the 2013 flood was one of five similar sized flood events on the Bow River in 130 years (Figure 2).

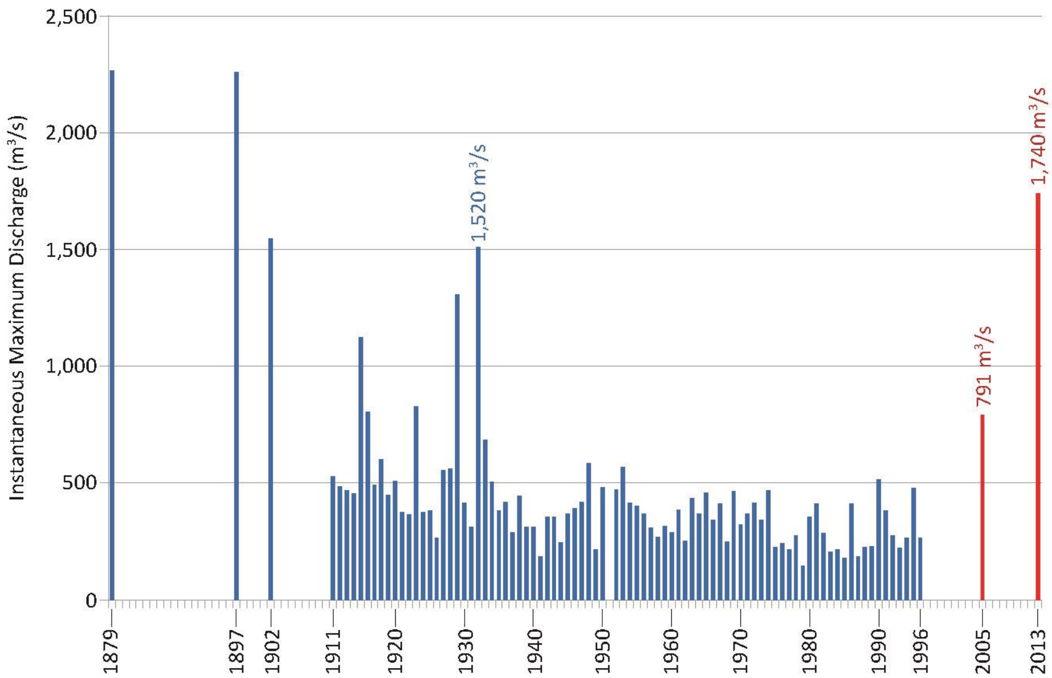
Figure 1: SSRB Flows (Bow River + Oldman River)



Source: David Sauchyn, PARC, University of Regina

History would suggest that we should consider the recorded maximum and minimum flow levels in our infrastructure and response planning. As a further complication, this planning must take drought into account, as flooding and drought can occur right after one another (e.g. 2001 and 2002 were major drought years, while 1995, 2005, 2011 and 2013 were major flood years) or even in the same year.

Figure 2: Maximum Water Discharge in the Bow River at Calgary between 1879 – 2013



Source: Modified from Neill, C.R. and Watt, W.E., 2001. Report on Six Case Studies of Flood Frequency Analysis. Prepared for Alberta Transportation and Civil Engineering Division Civil Projects. April 2001. Figure 5.1 p44

Although the Great Flood of 2013 did not have the highest flow rate in the history of the SSRB, it very likely has caused the most damage and had the largest economic impact of any extreme weather event in Canada to date. The costs of this flood will surpass the ice storm of January 1998 in Ontario and Quebec, which totalled $1.9 billion according to the Insurance Bureau of Canada (IBC).

The population of southern Alberta is currently projected to grow by sixty percent over the next thirty years (Alberta Treasury Board & Finance 2012). If development continues according to the same patterns as has occurred over the last thirty years, it is likely that damage from another major flood incident would be even more significant in terms of financial costs and physical impact than in 2013. Anticipating and planning for more extreme weather events is an important factor to consider in planning at all levels of government, as these events have a significant impact on the economy.

Before the flooding had subsided discussion had already entered the media around whether or not man made climate change contributed to the severity of the flood. Climate change is a contentious issue in Alberta that will continue to generate heated debate. However, based on the historical record as noted above, there is clearly a natural variance of the climate which requires adaptation in the short term. This paper focusses on adaptive actions to be made around water management in response to extreme events, providing space for ongoing conversations, actions, and policies regarding climate change.

Understanding the relationships between weather, river flows, population growth, and potential economic impacts is essential to planning for the future. Therefore, we make the following recommendations to better understand and plan for more extreme weather events.

- **Analyze the confluence of events that resulted in the 2013 flood.** This flood event closely resembled pre-1933 flood events. There are several theories why the maximum water discharge in the Bow River remained so low from 1933 until 2005. One theory is that there were severe forest fires in the foothills and mountains in the late 1800s and early 1900s, which could have resulted in more rapid runoff, ultimately resulting in high peak water flows. Another theory is that as the TransAlta hydro reservoirs came on-stream, they increasingly blunted the flood flows. However, neither of these theories explains the 2005 and 2013 rain events. Some work has already been done to explain changes in southern Alberta river flows based on climate variations, including the Pacific Decadal Oscillation (Alberta Innovates – Energy and Environment Solutions and WaterSMART Solutions Ltd. 2013). However more work needs to be done to understand other factors that are influencing the weather. The key meteorological, landscape, land use, and urban design factors that caused or contributed to this event in conjunction with the likely changes in frequency and magnitude of these events in future decades must be studied and debated. This analysis can then be used to signal how frequently we can expect these events in the future and their potential magnitude, allowing for better planning. The modelling work done as part of the Bow River Project and SSRB Adaptation Project is an excellent starting point and can be used to assess the impacts of flood flows, land cover, and changing weather patterns as well as the effects of various mitigation options.

- **Overlay potential development scenarios on the weather scenarios**. Land use in the South Saskatchewan watershed will change over the next thirty years as the population increases. Models such as the ALCES tool run by the ALCES Group can be used to understand how development will alter the landscape, which has a major impact on stormwater management, flood mitigation, and watershed saturation. This type of analysis is being incorporated in the current Alberta Innovates – Energy and Environment Solutions (AI-EES)-funded studies on river management in the SSRB.

- **Determine the magnitude of potential economic loss from another flood event.** As the 2013 flood has demonstrated, floods are extremely costly. An analysis of the physical and economic losses incurred in this flood, as well as other recent floods, would provide a baseline for assessing the magnitude of losses from potential future events. This type of analysis is being considered by the IBC, and they would be an excellent resource for this work. The results of this analysis would support and justify the necessary investments in planning and infrastructure that are needed to reduce the impacts of another flood.

- **Take a holistic approach when analyzing storm, flood, and drought data.** When analyzing storm, flood, and drought data, a holistic approach to hydrology assessment is required that includes data from watersheds outside of the watershed where the weather event occurred. In the case of southern Alberta, the flood history for all of the river basins with headwaters along the east slope of the Rockies needs to be examined to get a complete view of the frequency and magnitude of potential floods resulting from severe storm events along the eastern slopes. These storms are regional, not basin specific, as was shown in the 2005 event where the final rain dropped in the Red Deer basin, not the Bow basin. In addition, it would be extremely beneficial if meteorological data from across the North American continent could be shared between experts to improve monitoring capabilities. The Delft Flood Early Warning System (FEWS) program has been used in other parts of the world to assemble and analyze this type of data and could provide some guidance for Alberta.

2. Improve our operational capacity to deal with potential extreme weather scenarios through better modelling and data management.

Improving our operational capacity is integral to ensuring that the most appropriate mitigation strategies have been analyzed, developed and implemented before the next flood or drought occurs. This includes increasing modelling efforts and ensuring that drought and flood planning receive equal attention from policy-makers. Modelling should be based on the best data available. Efforts to collect more water-related data such as snowpack, precipitation, evapotranspiration, and sublimation and their effects on streamflow should be a high priority. Where possible, it is important to include the quantitative evaluation of natural ecosystem functions and services in the form of flood mitigation from forests and other natural land cover in the headwaters, wetlands and healthy riparian areas.

Considerable work is already underway in this area, but can be accelerated and improved through the following actions.

- **Ensure that data is available and easily accessible so that it can be used in modelling and planning by researchers, municipalities, provincial officials, and private property owners.** Historical and current data should be used to better understand and model the long-term trends referenced above. Researchers and planners should utilize the data from the new provincial monitoring agency to ensure consistency. The GOA has data that should be made available either through the monitoring agency or through public websites. In particular, increased data on groundwater is required for flood potential forecasts. Monitoring and research that is funded by the GOA (e.g. snowpack monitoring) should continue. When known, flood and drought risk and vulnerability should be clearly communicated to researchers and accurately portrayed. Impacts of a changing climate should be accounted for, including changing precipitation patterns, drought and heat waves.

- **Investigate back-up systems for Water Survey of Canada gauging systems to maintain data continuity during large events.** During the 2013 flood, every Water Survey of Canada gauge between Banff and Calgary went out of service prior to the peak flows occurring. TransAlta, the City of Calgary, the irrigation districts and the GOA need real-time data to operate their water retention systems. Currently a standard stream gauging system is built on the bank of the stream and is prone to being damaged or flooded. A realistic short-term action is to ensure that real-time data stations maintain integrity during the flood event. This could involve adding more gauges in more secure locations, and researching alternate systems that could initiate operation when the existing gauges are overwhelmed.

- **Improve predictive capacity through increased modelling and data management.** Models that run a variety of scenarios, using in some cases well over 80 years of gauge data, can help decision-makers understand the possible outcomes and impacts of a flood or drought event. Decision-makers should increase their use of modelling capacity to ensure that a variety of extreme weather scenarios have been taken into account in policy planning, and so that specific mitigation measures and plans can be identified, properly analyzed and implemented. Publicly available models have already been developed for some parts of Alberta (e.g. the OASIS model has been developed by the University of Lethbridge and Hydrologics, and is being applied by Alberta WaterSMART in the SSRB). Improved operational capacity can be achieved by:

    - Developing flood potential forecasts. Hydrometeorlogic data can be used to investigate the nature and extent of flood risk. The magnitude and frequency of major floods can be estimated in order to identify where funding should be allocated to support adaptation measures. As an example, Red River basin managers have developed these kinds of tools (see Warkentin1999) and some of their work should be adopted in Alberta.
    - Increasing flood risk mapping. Flood mapping for 1:200 year, 1:500 year, 1:1000 year or possibly Probable Maximum Flood events should be considered and vulnerable areas should be identified. This needs to be kept up to date, as mapping precision can decrease with time resulting in increasingly less reliable statistics.
    - Utilizing the best available technologies. Remote sensing tools should be developed and incorporated into Alberta's flood planning and response. Alberta has some of the best LIDAR inventories (remote sensing technology that uses lasers to measure distance) in the world, but there is a need for new digital elevation models to be built. Options like the American GRACE satellite and the new Canadian RADARSAT constellation satellite can be used for better surface groundwater mapping. GRACE could play a big role in understanding flooding and groundwater relationships.
    - Developing communication tools. Publicly available and user friendly tools can be developed to help engage and educate the public with respect to high flood risk areas. These tools could show the high water level mark associated with a given flooding event and outline which communities would be affected by flooding at different flow rates. Mitigation and damage reduction options can then be designed to meet each specific risk profile.
    - Increasing basin-specific modelling. Current models such as the Bow River Operational Model (BROM) should continue to be upgraded to incorporate new data and inputs such

as groundwater and smaller streams. Land cover and use, water quality, wetland, and riparian habitat data should be incorporated into the BROM.

  - Using BROM as an operational support tool. BROM should be used by water managers and reservoir operators in training exercises to help them prepare for a variety of flood and drought scenarios. This was demonstrated as part of the Bow River Project (see www.albertawater.com/Bow River Project).

- **Recognize that flood and drought planning are interconnected, and that both should receive an equal amount of attention.** Over the last decade in the SSRB the majority of water management strategies have been drought-related. Flood-related water management strategies should receive an equal amount of attention. Drought and flood mitigation strategies can be used to benefit each other; for example implementing the Bow River Project recommendations, including flexible and collaborative management, can improve environmental conditions under normal circumstances and ensure adaptive responses to either drought or flood conditions.

- **Develop a better understanding of the relationship between flooding and groundwater.** Alluvial aquifers (shallow groundwater-bearing channels connected to surface water bodies such as rivers) are vital natural infrastructure. Further investigations should be conducted in order to understand the effects of flooding on groundwater, and vice versa. Some work has been done in this area specifically by Alberta Environment and Sustainable Resource Development (ESRD), and this work should be leveraged and the data made available publicly. More specifically:

  - In the City of Calgary, there should be a detailed review of the alluvial aquifer around the Bow and Elbow Rivers to map the groundwater levels and the sensitivity to rises in river levels. This work is essential to understanding the risks to office buildings, residential homes, businesses and condominiums close to the rivers, and to determine appropriate building standards. Work that has been done to date should be made publicly available and easily accessible.
  - The hydrological cycle should be better understood in its entirety on a regional scale with respect to the SSRB. This includes a detailed understanding of the interactions and relationships between groundwater, surface water, precipitation, snow pack and related factors such as sublimation and evapotranspiration, snowmelt, aquifer recharge/discharge and variations in climate. There are academic studies of many of these elements that could support a larger integrated study. The current AIEES-funded study of The Future of Water in Alberta could perhaps use the Bow River Basin as a case study for its integrative work on water issues in Alberta.

- **Re-evaluate the potential for slumps and mudslides during flooding events.** Numerous communities in the municipalities affected by the 2013 flood are situated near the edge of steep slopes that were formed by river erosion. Steep slopes that consist of large quantities of glacial and lake sediments become unstable and may fail when materials are removed from the base of these slopes or when the ground becomes saturated. Although major slumping and mudslides did not occur in Calgary, they occurred in Canmore and other areas. The potential for these to occur in the future throughout the region should be assessed and preventive measures implemented.

- **Build upon work that has already been done.** Current and future policy should build upon work that has already been done, such as the 2006 Groeneveld Provincial Flood Mitigation Report. Unfortunately that report was not released until 2012 and is now somewhat out of date. However the basic tenets and recommendations still apply and the report should be updated and analyzed for effectiveness using the latest data and modelling techniques and then implemented where needed most. In addition, during the past decade the ALCES Group has completed several projects along the east slope drainage basins from the U.S. border, through the Oldman Basin, to the Bow River Basin upstream of Calgary. All of these projects have examined elements of water flow and water quality, among a broader suite of indicators. Other work currently underway has been identified elsewhere in this paper, including the IBC reports, the SSRB projects, and projects underway at the Universities of Alberta (Goss *et al*), Regina (Sauchyn *et al*) and Saskatchewan (Pomeroy *et al*).

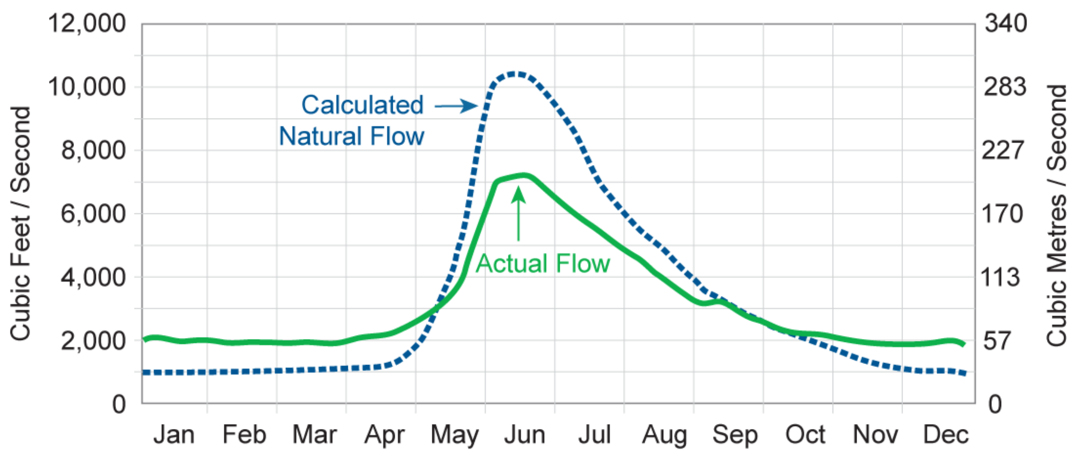
- **Engage public health professionals in assessing mitigation measures.** Floods create immediate public health risks to drinking water supplies, a risk that has been mainly dealt with by means of precautionary boil water advisories. Given the experience of the 2005 and 2013 floods, additional risk management measures for protecting drinking water and assessment of the effectiveness of boil water advisories, particularly when power outages and/or natural gas shut-offs also exist, should be pursued. There are also public health concerns with remediation efforts from flooding, including exposure to sewage contamination, growth of toxic molds and dealing with food spoilage. Public health professionals should be engaged in assessing mitigation measures to determine if better health practises and/or advice is needed for future events.

3. Investigate the cost/benefit balance of investing in physical and natural infrastructure.

Extreme weather events often catalyze discussion on the resiliency and adequacy of water infrastructure such as dams, canals, diversions, reservoirs, and natural features such as wetlands. A conversation about water infrastructure opportunities in Alberta is needed now. Billions of dollars will be spent on flood recovery and rebuilding efforts and some of this money should be invested in infrastructure to mitigate the impacts of future extreme weather events. It is important to remember that there is no one single infrastructure solution that will resolve all issues in the SSRB. The recommendations included here should be viewed as tools in a toolkit rather than either/or options. Even with properly planned and implemented infrastructure, the risks of building in flood-prone areas and the cost of recovering from a flood need to be carefully balanced.

- **Conduct cost-benefit and risk analyses to assess the best use of capital funds to support infrastructure spending decisions.** Obviously public funds are scarce and must be directed to the use which maximizes the benefits to society. After recovery from the current flood event, preventative physical and natural infrastructure initiatives should be identified, evaluated, and where justified, planned and implemented. An excellent example of how infrastructure is already being utilized to manage water flows is the management of the Bow River through the City of Calgary by the TransAlta hydro dam infrastructure during normal times (Figure 3). The benefit of this infrastructure is that it ensures a stable and steady flow of water in the Bow River; the managed flow is double the natural flow in the winter months, which ensures that the City of Calgary can operate its water treatment plants within the legislative parameters set out by the GOA. A stable flow in the winter also helps prevent ice jams and floods, and the lower than natural flow in the summer months can mitigate minor to moderate flooding. Other examples include the Glenmore Dam on the Elbow River, operated by the City of Calgary, and the Oldman Dam on the Oldman River, operated by ESRD. Other opportunities have been explored, and some new ideas are noted in this section.

Figure 3: Bow River at Calgary - Natural vs. Managed Flows (38 years data)



Source: BRBC State of Watershed Plan 2010

- **Consider all available infrastructure options**. Unnecessary impacts to natural infrastructure should be avoided wherever and whenever possible. Where pipes, intakes and outfalls are needed for municipal water, wastewater, and stormwater infrastructure, the value of natural resources that may be affected by their implementation should be considered. Decision-makers should take advantage of opportunities to retrofit river shorelines using soft engineering practises; that is the use of ecological principles and practises to reduce erosion and achieve stability of shorelines, while enhancing habitat and improving aesthetics. The redevelopment of the Detroit River shoreline is often cited as an example of successful soft engineering practise. In addition, other low-impact developments, such as porous/pervious pavement, should be considered.

- **Use the best available risk assessment tools.** Over recent years new tools have been developed to assess risk more broadly for public infrastructure. Groups such as the World Federation of Engineering Organizations look broadly and systematically at infrastructure vulnerability to climate change from an engineering perspective. Tools like the PIEVC infrastructure vulnerability protocol, developed by Engineers Canada and Natural Resources Canada and used across Canada and internationally, provide a proven approach to understanding the risks and vulnerabilities of existing infrastructures to the threats of extreme climatic events. The standards and practices developed by the PIEVC have already been tested in Alberta and could inform investment decisions as the GOA and municipal governments consider new infrastructure investments.

- **Implement the recommendations of the Bow River Project.** Over the last four years, the major water license holders on the Bow River have collaborated on developing water management protocols for the Bow River that incorporate many of the recommendations included in this White Paper. The GOA should work together with the Bow River Consortium and TransAlta to flexibly implement these recommendations. This agreement on future water management is an essential first step toward on-going, systematic improvement to the Bow River watershed, and will facilitate planning and implementation of damage reduction strategies for both future floods and droughts.

- **Utilize on-stream storage for flood control.** The Bow, the Elbow and the Oldman Rivers all have existing on-stream storage behind dams built primarily for power generation for the Bow, and water supply management for the Elbow and Oldman. Better integration of this storage capacity to embrace broader objectives of flood and drought management could significantly increase the capacity to manage extreme weather events and improve environmental conditions under normal circumstances. Current SSRB modelling can provide the structure for assessing these options. Some specific recommendations include:

    - Investigating opportunities and costs of using TransAlta storage for flood control and drought mitigation. The BROM model should be used to evaluate the extent to which reservoir capacity can be used to manage extreme weather events. The model provides for the assessment of the opportunity costs of lost power generation compared to the capacity to reduce peak flood flow. The velocity in the level of peak flood flow and elevation and the period of time in which flows are reduced can then be translated into flood flow maps to show areas where action can be taken to reduce flooding. This modelling exercise must include the downside risk of lowering reservoir levels if the expected rain/flood event does not occur or occurs at a lower than forecast amount. The key to improved risk management for flood and drought is an agreement on risk sharing and risk management among water users, taking into account maintaining appropriate environmental base flows.
    - Developing a flow/flood damage relationship for Banff, Canmore, Morley, Cochrane, Calgary, Carseland, Siksika, Medicine Hat and other significant communities and infrastructure. This information would be based on water flow rates and would demonstrate the amount of land that could be covered by water and the resulting potential economic damage at various peak flow rates. A hydrodynamic flood model should be developed and used to test flood operating strategies and trade-offs between location of available storage and potential damage.

- Evaluating multi-purpose storage and operations on the Highwood and Sheep Rivers. Some work has already been done to model the Highwood/Sheep system, and this could be the basis for assessing storage and operating options.
- Evaluating increased storage for flood control at the Glenmore Reservoir and upstream of the Elbow River for storage and power generation.
- Evaluating the potential impact of gradual accumulation of sediment in reservoirs and implementing an active reservoir sediment management plan.

- **Utilize off-stream storage more effectively for flood mitigation.** The irrigation districts have made use of man-made lakes for water storage for decades. Watershed management can be made more resilient by diversifying off-stream storage options, including increasing storage volumes or altering operating conditions. The Western, Bow River and Eastern Irrigation Districts should be engaged in a discussion as to how they can further utilize their infrastructure to help mitigate flood risks, while ensuring a robust response to drought conditions.

- **Improve management of headwater areas so that natural wetlands and riparian zones continue to act as a buffer for heavy rainfall.** The ability of the headwaters to capture and retain snowmelt and spring run-off should be optimized. The current development of the South Saskatchewan Regional Plan (SSRP) presents an opportunity to enhance flood avoidance and mitigation in southern Alberta. Headwater management should be addressed in the SSRP and could include, for example:

    - Making headwater landscape health a management priority for prairie rivers to naturally optimize water production and water quality, and to moderate the release of water throughout the spring and summer seasons.
    - Shifting from clear-cut logging to canopy-retention logging. This will help to reduce canopy snow loss while spreading out the snow melt over a longer period, and retaining the ability of the forest canopy and groundcover to intercept and retain rain.
    - Supporting high population densities of beavers in some headwaters to maximize their free ecosystem services.
    - Limiting off-road vehicles and industrial vehicles to trails and roads designed to minimize gullying and sedimentation and to avoid water source areas such as fen meadows and wetlands.
    - Investing public funds in the purchase of ecosystem services such as small check dams in coulees, wetland restoration, and/or revegetation of exposed or eroded soil from landowners in source water areas.

- **Incorporate natural infrastructure such as wetlands, riparian areas, natural storage conditions and land cover into flood and drought mitigation planning.** Utilized properly, natural infrastructure can be used as an effective long-term solution to ensure that people, infrastructure and natural systems are less vulnerable to flooding. In addition to flood control, ecosystems provide many economically beneficial services that support and protect humans and nature such as filtering pollutants, controlling erosion, producing fish and providing clean drinking water.

Moreover, natural infrastructure can have lower long-term maintenance costs than physical infrastructure. However the functions of the natural infrastructure such as wetlands must be understood to avoid unintended consequences elsewhere in the basin. The provincial wetlands strategy is needed to help guide the effective use of wetlands. In addition, the BRBC recently published the Bow Basin Management Plan (2012) which addresses wetlands, riparian areas, land use and headwaters protection. This document is in the process of being endorsed by a large number of Bow Basin stakeholders. The other WPACs in the SSRB, including the Oldman Watershed Council (OWC) and the South East Alberta Watershed Alliance (SEAWA), are also exploring natural infrastructure opportunities. Non-traditional opportunities such as gravel bed storage and aquifer storage and recovery should also be examined.

- **Investigate and identify sparsely habited or uninhabited areas that could be potentially flooded with minimal economic and environmental impact.** This measure applies to rural areas where there are large, unoccupied pieces of land. Areas where floodwaters can be diverted using an engineered system should be identified, and a system should be put in place to compensate any land or property owners for lost revenue and inconvenience. Intentional flooding did occur in some areas during the 2013 flood (e.g. in the Bow River Irrigation District) and has occurred in other jurisdictions. While flood impacts still occur, they are often not as large as they would have been if the flood waters reached more populated areas. A specific example is the Portage Diversion where channel banks (dikes) were intentionally breached in the 2011 Manitoba flood event. The dikes were breached in order to increase the capacity of the diversion channel, protecting the weir (see Manitoba 2011 Flood Review Task Force Report). This protected the urban areas by sacrificing two farms, whose owners were compensated for their losses and inconvenience. This option must be modelled and understood thoroughly to avoid unintended consequences, and requires the agreement and participation of those impacted. Intentional flooding should be more broadly considered by all parties in flood management.

4. Consider flood risks in municipal planning and strengthen building codes for new developments in flood plains.

The recent flood event revealed several weaknesses in current development practises in the urban areas in southern Alberta. Some of these practises can be addressed reasonably quickly, while others will take more time. However, all are possible within the current municipal planning structure.

- **Conduct cost-benefit and risk analyses to assess the best use of capital funds to support municipal planning and land use decisions.** As decisions are made on rebuilding existing and building new developments in flood-risk areas, it would be prudent to conduct cost-benefit and risk analyses on the costs of changing building and/or zoning codes. These costs would likely be borne by governments, as well as developers, owners and tenants. There should be some basis for evaluating the benefits of enhanced building codes and zoning plans against the costs of their implementation.

- **New municipal development in potentially flood-prone areas must be reconsidered.** Increased flood plain mapping is needed to better inform decision-makers at all levels on whether building should go ahead in flood plain areas. This mapping should include groundwater mapping as well as surface water. Much of this mapping has been done, but its existence is not widely known and not all is publicly available. In addition, as noted previously, maps must be kept current by incorporating new experience. If new development is to be discouraged in flood-prone areas, then incentives and disincentives will need to be provided in order to change the land use habits of urban developers. Examples of disincentives are higher property taxes for new developments or a requirement to have overland flood insurance for those choosing to build in a flood-prone area. Examples of incentives include provision of costs of relocation outside the flood zone. This appears to be the policy direction of the GOA in response to the 2013 event. Purchasing back lands in flood-prone areas and establishing parks and other public use spaces could provide a societal benefit for the larger community.

- **Land use planning should be connected to watershed planning.** Flood plain development is primarily an urban issue. The broader issue of land use must also be considered, particularly in rural municipalities and farming and public lands, including the effect this land has on flooding in the urban centres. It is important to model potential land cover changes that could result from threats of pine bark beetle or forest fires reducing water retention, and what improvements to water retention might result from enhanced riparian or wetlands functions. Models such as the BROM and ALCES could be used here. Some specific areas that should be considered in land use planning include:

    - Headwater basins. Headwater basins are incrementally (slowly in some, faster in others) losing their water-holding and aquifer-recharging capacity because of overlapping land uses that encourage faster overland flow of precipitation or snowmelt. Key land uses reducing groundwater infiltration and increasing overland flow are forestry, agriculture, residential construction, and the transportation network associated with forestry and energy.
    - Construction of built capital close to surface water. High levels of built capital (roads, residences, utilities, tourism, oil and gas, agriculture) have been and are being constructed close to all levels of surface water. As noted above, municipal development, as well as the construction of other capital, in potentially flood-prone areas should be reconsidered.

- **Refine our zoning and building codes.** A review of world class zoning and building code practises for office towers, condominiums, residential homes, and businesses should be undertaken. In many new office towers and condominiums in Calgary, electrical and mechanical systems are located in the lowest parking or basement levels along with the back-up generators. In this major flood, many of the parking structures and basements were flooded after the power was cut, which disabled the sump pumps. The flooding damaged or destroyed electrical and mechanical systems located at the lowest levels. Some basic redesign and relocation of these systems and addition of back-up generators above the flood line should result in less damage and faster recovery. The location of critical information infrastructure should also be based on a clear understanding of possible water penetration during a major flood event. One specific recommendation is that multi-story buildings (commercial and residential) impacted by the flood should be required to test their sump pumps to ensure that these pumps are adequately sized to remove the water that penetrated their parking structures. These sump pumps should also be placed on a separate circuit from the electrical system of the remainder of the building and linked to a backup generator that will allow the sump pumps to keep working in the event of a power shut-down. Another recommendation is that building codes should be changed to allow flood-prone residences to relocate basement density to a third floor (i.e. current codes allow for two storeys to be built, so moving the home up one storey is a possibility). Homes in flood-prone areas could be designed without basements and possibly on static or adjustable stiles (e.g. hydraulic jacks or manually operated systems). Flood-prone subdivisions could be designed with engineered walls that could be raised or lowered to desired heights around the community.

- **Recognize the importance of urban stormwater run-off management.** Flooding can have an impact on municipal stormwater and sanitary sewer systems. For example, in the community of Sunnyside in Calgary the flood protection levee largely prevented overland flooding from the Bow River, yet many houses suffered damage due to storm and/or sanitary sewer back-up. The management of urban run-off is as important as rural run-off, and the system must be designed to cope with simultaneous high rainfall and high river conditions.

- **Encourage APEGA to revise and update their practice standards to include assessment of risks due to natural disasters.** Engineers and geoscientists practice their profession under a provincial act that is administered by the Association of Professional Engineers and Geoscientists (APEGA). Many of the recommendations made above involve engineering and geology practice. A tangible action item for APEGA would be to ask its Practice Standards Committee to include an assessment of risk due to natural disasters in their risk management practice standard. This can be done either by updating the 2006 Risk Management document to include substantially greater emphasis on risk management for natural disasters, or to develop an additional document that focuses on risk management for natural disasters. This involves identifying hazards, applying risk assessment to analyze the evidence about the magnitude and probability of risks, and then developing viable alternatives to prevent or mitigate damages arising from risks. As a participant in this White Paper, the CEO of APEGA would welcome constructive suggestions about how best to harness the large volunteer professional capacity and experience that APEGA can access to make a meaningful contribution towards improved flood risk management in Alberta. This same request should be made of the other professional associations that oversee architecture, planning and installation practices in Alberta.

- **Make a variety of tools widely available to all Albertans to inform them about a future flood.** The majority of communication on the 2013 flood was carried out through social media. Many Albertans received information from Twitter, as Premier Redford, City of Calgary, Calgary Police, Mayor Nenshi, ESRD, and many others, provided constant updates. It would be worthwhile for the

GOA to consider how it could use social media as well as traditional avenues of communication as effective public communications tools both leading up to and during natural disasters.

5. Evaluate our insurance options.

Currently, overland flood insurance is not available in Canada. Historically, the provincial government, backstopped by the federal government, stepped in to provide assistance for rebuilding when overland flood damage occurred during a flood event. For a variety of valid reasons including the magnitude of the damage, the GOA appears to be reconsidering this past practice for those wanting to rebuild the same home in the same location. There is some public support for putting conditions on payouts to reduce future tax burden to the general public from another flood. It is clear that many in the most affected areas are experiencing uncertainty and very likely significant financial hardship, especially if they are retired and were depending on their home value to support their income.

The issue is whether the affected homeowners have an option to rebuild. One idea that has been noted repeatedly since the flood occurred is offering overland flood insurance for the areas in the flood plain. Overland flood insurance potentially provides an option for homeowners who can afford it to rebuild their homes along the river's edge, ensuring that these homeowners continue to pay municipal taxes. In 2010, a study (see Sandink et al 2010) was conducted by the Institute for Catastrophic Loss Reduction and Swiss Re which concluded that overland flood is insurable for Canadian homeowners. They provided a proposal to put this insurance into place. The GOA should consider whether overland flood insurance should be brought into the province. Flood insurance programs provide important economic signals about the use and management of flood plains. At a minimum, rates for flood insurance in repetitive loss areas should be actuarially sound and reflect the true risk of flooding. Higher rates could help to guide development out of some of these high value, high repetitive loss areas. This is an area that is outside our area of expertise, and more investigation needs to be done to determine if this is a concept worth pursuing.

6. Manage our water resources collaboratively.

There are a variety of players involved in water management in Alberta, including the federal, provincial and municipal governments, as well as local watershed groups, irrigation districts, hydro power companies, non-government organizations, and others. Each has a valuable role to play in water management. Improved collaboration and information sharing between these groups is required to improve flood mitigation measures, and the following recommendations support these points. It should be noted that in the aftermath of the 2013 floods there has been great cooperation between emergency organizations at all levels of government. From local volunteer fire services to regional departments responsible for roads or electrical infrastructure to the RCMP and military, all were pitching in and cooperating with acknowledged on-scene commanders. Similarly, the transportation agencies and organizations responsible for pipeline security were cooperating to manage specific crisis situations. Politicians appeared to support each other without shifting blame or raising questions of jurisdiction. These positive demonstrations of cooperation should continue through the following recommendations.

- **Support WPACs to work with their memberships to assess flood risk, consequences, and mitigation strategies, and to provide advice to GOA.** Under the *Water for Life* strategy, the WPACs have been given a specific role to play in managing water in the watershed. WPACs including the BRBC, the OWC, and SEAWA can and should take a leadership role in analyzing, evaluating, and advising on adaptation strategies to address future flood and drought circumstances. These organizations have the balanced membership and the neutral forum to convene and enable collaborative assessment of the data, to identify an array of mitigation options, and to provide leadership and advice on future water management in the Bow, Oldman and South Saskatchewan River systems. They are ready, willing and able to perform this vital function.

- **Consider creating a Provincial Water Authority.** In 2011, the Premier's Council for Economic Strategy recommended that an Alberta Water Authority be created. The driver behind this recommendation was the acknowledged risk that "within our thirty-year horizon, Alberta's current water management structure will be unable to effectively manage our water resources …" If an Authority was created as originally planned, it would be responsible for:

    - Water Information. The Authority would create and maintain a fully integrated and accessible water information system to support planning and decision-making. The need for more easily accessible data for modelling and planning purposes could be met through this central entity.
    - Water Infrastructure. The Authority would develop a long-term infrastructure plan to support effective water management, which would include on and off-stream storage facilities and natural infrastructure. The need for a review of infrastructure requirements that are appropriate for both flood and drought management could be met through the Authority.

- **Support and provide increased capacity to smaller municipalities to respond to natural disasters.** The cities of Calgary, Lethbridge and Medicine Hat were all well-equipped and ready to respond to the flood. However, smaller municipalities have less capacity to respond to natural disasters. The GOA should work with these small communities to coordinate emergency response plans and to determine where capacity gaps exist prior to the next natural disaster.

    Federal and provincial agencies should provide local governments with training, up-to-date science and data, and decision support tools to properly guide decision-making. In particular, local communities need to be informed about the full range of solutions to protect their communities, including the benefits of using natural infrastructure. This information should inform hazard mitigation, land use plans and local ordinances.

The Short-Term Response to the 2013 Great Alberta Flood

Over the next six months significant progress can be made on several of the recommendations noted above. These actions can provide evidence of tangible progress toward mitigating, managing, and controlling future floods.

1. Anticipate and plan for more extreme weather events

- Engage one of the research teams currently working on understanding weather impacts on stream flows to analyze weather patterns and trends to propose a workable theory for the occurrence of the flood. Translate this work into specific guidance that can inform weather warning systems.
- Engage existing models such as BROM to understand the specific impacts and streamflow rates generated by specific flood events.

2. Improve our operational capacity to deal with a variety of potential extreme weather scenarios through better modelling and data management.

- Open the doors to the data rooms so that all relevant data is easily accessible for modelling and planning throughout the SSRB.
- Implement the recommendations of the Bow River Project, including engaging TransAlta in the project through an economic arrangement with GOA.
- Engage one of the research teams currently working on groundwater mapping to map the alluvial aquifers around the Bow and Elbow Rivers to provide information on the interaction between the rivers and the aquifers. This will provide some guidance on the extent of the flood plain for various flood levels.
- Investigate the use of risk management tools such as PIEVC to incorporate flood risks into investment decisions on infrastructure.
- Research specific hydrometeorlogic indicators used by other jurisdictions that are used to understand the nature and extent of flood risk. Identify five indicators that Alberta should be monitoring now and in the future.

3. Investigate the cost/benefit balance of investing in physical and natural infrastructure.

- Use existing models to begin assessing engineered and natural infrastructure options for flood management and mitigation.

4. Consider flood risks in municipal planning and strengthen building codes for new development in flood plains.

- Fund a project to review and summarize best zoning and building code practises in North America, Europe and Australia related to flooding and how those can be applied to Alberta.
- Place a moratorium on new development in potentially flood-prone areas until the analyses outlined above are completed.
- Encourage APEGA to revise and update their practice standards to include consideration of risks in a flood event. Encourage other professional associations (e.g. architects, planners) to do the same.

5. Evaluate our insurance options.

- Investigate the potential for overland insurance to deal with those property owners who wish to build or rebuild in the flood plain.

6. Manage our water resources collaboratively.

- Incorporate the recommendations contained in this report into the South Saskatchewan Regional Plan.
- Support WPACs to assess flood and drought risk, consequences, and mitigation strategies.
- Consider the consolidation of water-related functions (e.g. fish, energy, irrigation) into Watershed-based Authorities to support implementation of the various Regional Land Use Plans.
- Provide increased capacity and support to smaller municipalities to deal with natural disasters.

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APPENDIX A

WHITE PAPER CONTRIBUTORS

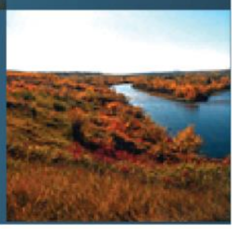
The following is a list of individuals from Alberta, Canada and the world who engaged in consultation with Alberta WaterSMART on this White Paper. Contributors were not asked to provide an endorsement of the White Paper, or of the recommended flood mitigation actions outlined within. Rather, respondents were asked to share their insights and feedback to ensure that our work adequately captured and reflected elements of the current conversation about flood mitigation and adaptation measures in the water policy community. Every effort was made to ensure that this White Paper reflected the comments received from the contributors. However, any errors and omissions in this paper are the responsibility of the authors and not the contributors.

A Compendium document has been prepared that includes the comments and discussion as received from the contributors to the extent possible and as agreed to by the contributors. Some of these contributions have already been featured on the Alberta WaterPortal to generate more conversations on the flood event and possible actions. Hopefully the excellent suggestions contained in the Compendium will be of value to the policy and decision makers in committee rooms across the province. While there are well-regarded experts that we have no doubt missed in our consultation, such exclusion was not intentional.

Expert Group	Last Name	First Name	Position	Institution or Organization
Canadian Water Summit Discussion Group	Braun	Erwin	General Manager	Western Irrigation District
	Brawn	Bob	Board Member	Alberta Water Foundation
	Cramwinckel	Joppe	Director, Water	World Business Council on Sustainable Development
	Doucette	Brian	Director of Sustainable Innovation	Suncor Energy
	Freek	Kerry	Editor	Water Canada
	Kelly	Mike	Chair; Special Advisor	Bow River Basin Council (BRBC); Alberta WaterSMART
	Kun	Karen	Executive Director	Waterlution
	Maas	Tony	Director, Freshwater Program	World Wildlife Fund (WWF)
	Olver	Tom	Marketing Manager, Natural Resources	IBM
	Piñero	Edwin	Executive Vice President and Chief Sustainability Officer	Veolia Water North America
	Renzetti	Steven	Professor of Economics	Brock University
	Riggs	Geoff	Global Business Services - Smarter Planet Project Manager, Business Development	IBM

	Shute	Dan	Chair	Western Irrigation District
	Sommerfeld	Larissa	Policy Specialist	Alberta WaterSMART
	Sturgess	Kim	CEO	Alberta WaterSMART
	Sweetman	Jon	Manager, Water Resources	Alberta Innovates – Energy and Environment Solutions (AI-EES)
	Taylor	Lorne	Special Advisor	Alberta WaterSMART
	Tenney	Doug	Vice President, Hydro Development	ATCO Power
	Van Ham	John	Manager, Environmental Stewardship	ConocoPhillips Canada
	Veljkovic	Maja	Natural Resources Executive and Research Liaison	IBM
	Watanabe	Anthony	President & CEO	Innovolve
	Wojnarowski Downes	Lisa	North America Regional Coordinator	Alliance for Water Stewardship; The Nature Conservancy
Calgary Working Group	Bennett	Mark	Executive Director	Bow River Basin Council (BRBC)
	Bjornsen	Ryan	Hydrogeologist	Alberta WaterSMART
	Eden	Lauren	Researcher	Alberta WaterSMART
	Kelly	Mike	Chair; Special Advisor	Bow River Basin Council (BRBC); Alberta WaterSMART
	Minnich	Keith	Special Advisor	Alberta WaterSMART
	Phillips	Bob	Executive Director	South East Alberta Watershed Alliance
	Sheer	A. Michael S.	Environmental Policy Analyst	HydroLogics
	Sheer	Daniel P.	Founder and President	HydroLogics
	Sommerfeld	Larissa	Policy Specialist	Alberta WaterSMART
	Zehnder	Alexander	Scientific Director, Water Resources	Alberta Innovates – Energy and Environment Solutions (AI-EES)
Engineering Working Group	Chalcroft	David B.	P.Eng., FEC, FCAE, Past President; Consulting Engineer	APEGA
	Danyluk	Darrel	P.Eng., FCAE, Vice President; Chair; Past President	World Federation of Engineering Organizations (WFEO); WFEO Committee on Engineering and Environment; APEGA
	Flint	Mark	P.Eng., CEO	APEGA
	Hrudey	Steve E.	FRSC, FSRA, IWAF, PhD, DSc(Eng), PEng Professor Emeritus at the Analytical and Environmental Toxicology Division; Councillor	Faculty of Medicine and Dentistry, University of Alberta; APEGA

	Sturgess	Kim	P.Eng., FCAE, Past President; Past Councillor	Canadian Academy of Engineering; APEGA
Additional Contributors	Brawn	Bob	Board Member	Alberta Water Foundation
	Campbell	Carolyn	Conservation Specialist	Alberta Wilderness Association; including comments from some Alberta Environment Network members
	Drury	Roger	Hydro Project Developer	TransAlta Generation Partnership
	Fennell	Jon	Principal Hydrogeologist and VP, Geosciences & Water Security	Integrated Sustainability Consultants Ltd.
	Francis	Wendy L.	Program Director	Yellowstone to Yukon Conservation Initiative
	Goheen	Kevin	Executive Director	The Canadian Academy of Engineering
	Gill	Vijay	Principal Research Associate, Transportation and Infrastructure	Conference Board of Canada
	Kern	Marshall	Associate	Bowman Centre for Technology Commercialization
	Lund	Charlie	Professional Engineer; Sunnyside Resident	Calgary, Alberta
	MacRae	Andy	Board Member; Executive Director	Alberta WaterSMART; Russell Reynolds Associates
	Meller	Brian	Hydrologist	Lethbridge, Alberta
	Raymond	Greta	Chair, Board Member	CAWST, Alberta Water Foundation
	Rood	Stewart	Professor and Board of Governors Research Chair in Environmental Science Dept. Biological Sciences	University of Lethbridge
	Sauchyn	Dave	Senior Research Scientist; Professor of Geography	Prairie Adaptation Research Collaborative (PARC); University of Regina
	Stelfox	Brad	Landscape Ecologist	ALCES Landscape and Land UseLtd.
	Thompson	Stella	Board Chair	Alberta WaterSMART
	Van Ham	Megan	Program Manager	Alberta WaterSMART
	Van Tighem	Kevin	Fourth-Generation Albertan, Professional Ecologist	Retired
	Walsh	Bryan	P.Eng. Senior Vice President	CBRE Limited



The 2013 Great Alberta Flood: Actions to Mitigate, Manage and Control Future Floods Feedback Compendium

Additional Feedback from Water Experts and Albertans

ALBERTA waterSMART
Water Management Solutions

August 2, 2013

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Introduction

This document catalogues the additional feedback from water experts and Albertans regarding "The 2013 Great Alberta Flood: Actions to Mitigate, Manage and Control Future Floods." This document includes input from water experts that, because of its level of detail and length, could not be included in the white paper (see Section I). This input is valuable and relevant, and should be consulted to gain a deeper understanding of some of the issues related to flooding.

Also included is feedback from Albertans who responded to the question posted on the Alberta Water Portal (www.albertawater.com) "How can Alberta prevent future flooding?" Albertans were encouraged to read a working draft of the white paper, which was publicly posted on the Portal, and submit their comments via Facebook, Twitter or email (see Section II).

Finally, contributors to the white paper identified several articles and resources that they felt were relevant to this discussion and that would be of value to the Government of Alberta as flood and drought preparation and planning is considered now and in the future (see Section III).

SECTION I: ADDITIONAL FEEDBACK FROM WATER EXPERTS

Carolyn Campbell
Conservation Specialist
Alberta Wilderness Association
Submission 1: Email comments on Discussion Draft v08

Comments on 'The 2013 Great Alberta Flood: Actions to Mitigate, Manage and Control Future Floods Discussion Draft v08'
July 30, 2013
By Carolyn Campbell, Alberta Wilderness Association, ccampbell@abwild.ca

Thanks for circulating this draft and providing this opportunity to comment. Overall, we urge focus on recommendations and actions that will restore and sustain watershed ecology

Prioritize headwaters land uses for watershed integrity, biodiversity and low impact recreation. This would include:

- reducing the existing network of linear disturbance (including seismic lines, logging roads and OHV trails) that reduce water absorption in rocky and vegetated surfaces and increase sediment transport. Do this through focused reclamation and serious efforts to relocate and regulate OHV recreation into less sensitive areas; flood disruption to existing trails represent a good opportunity to re-manage damaging motorized access
- replacing the current timber-supply oriented forest management with ecosystem-based forest management that buffers wetlands and tributaries, sustains rare plant communities, and yields a more natural age-class structure
- restoring and protected habitat for threatened native bull trout and westslope cutthroat trout as important indicators of water quality, healthy hyporheic (groundwater-surface water) interface zones, and overall stream ecology

We strongly disagree with the recommendation to utilize more on-stream storage for flood control. These structures are most disruptive of aquatic ecology; other solutions need to be pursued.

Expand recommendation #3 on natural infrastructure

- good to see reference to wetlands
- other important physical or natural infrastructure to emphasize include alluvial aquifers (shallow groundwater-bearing channels connected to surface water bodies such as rivers), which should be better mapped and better protected from gravel mining and other land uses that deplete their capacity to store high-flow waters

Improve watershed monitoring network for gathering management-oriented data on water quantity and quality, groundwater stock and flows, wetlands and riparian habitat, land cover and uses.

Manage cumulative impacts of human footprint on land and water with biodiversity as well as water quantity and quality in mind.

- Include biodiversity management frameworks and land disturbance limits to complement anticipated water management frameworks in regional plans

Call for stronger measures to reduce Alberta's greenhouse gas emissions

- as part of our obligation to future generations to reduce the risks of more frequent extreme weather events from climate change
- paper refers to reducing effects of future extreme weather events. Mainstream, credible scientific consensus is that man-made greenhouse gas (ghg) emissions are leading to climate change that will increase the risks of more extreme weather events in the future
- it is time for Albertans to discuss and develop serious plans to reduce our absolute ghg emissions

These recommendations are brief and informal. Please contact us for further information or clarification. Thanks again for the opportunity.

Carolyn Campbell
Conservation Specialist
Alberta Wilderness Association
Submission 2: Email comments regarding on-stream storage

Concerns with On-stream Storage for Flood Control
as further comments on 'The 2013 Great Alberta Flood: Actions to Mitigate, Manage and Control Future Floods Discussion Draft v08'

August 2, 2013
By Carolyn Campbell, Alberta Wilderness Association, ccampbell@abwild.ca
Many of these points are excerpted or paraphrased from Dave Mayhood (2010). "An Overview of River Ecology and its Implications for Simplified Hydropower Approvals in Alberta." 38 pp.

The effects of on-stream storage reservoirs depend on what is installed, where it is installed, and how it is operated, but some generalizations are possible: reservoirs replace productive flowing water habitat and riparian habitat with less productive silty, standing water habitat. They also block movement of materials downstream and movement of organisms upstream and downstream. The reservoir habitat is even poorer and downstream impacts are greater if reservoir levels fluctuate frequently.

Food webs in Alberta's Rocky Mountain and foothills headwaters rely on organic debris that enters streams from land runoff, is trapped by log jams and rocks, and is processed by bacteria, fungi and macroinvertebrates. The relatively steep gradients move sediment downstream and scour stream beds, which among other benefits provide trout with clean gravels to aerate their incubating eggs. In the middle reaches of rivers, where channels broaden and gradients decline, photosynthesis by attached algae, and processing of the fine particulate carbon produced by the coarse processors upstream, becomes more important for habitat productivity.

Within reservoirs, the gradients are flattened, sedimentation rates are high and much of the organic material is sequestered in the bottom sediments. Plankton photosynthesis is limited by turbidity. With reduced organic materials processing, there are fewer organisms to support fish in the reservoir and fewer flying adult insects for upstream sites. If the reservoir use includes hydroelectric generation with high flowthrough rates, or if the reservoir is drawn down over fall and winter, then shoreline erosion is common, which increases water turbidity and siltation. High flowthrough rates deplete plankton, while a drained reservoir bottom reduces or eliminates organisms in the bottom sediments, leaving little to support fish production.

On-stream storage also degrades upstream habitat by reducing numbers of migrant fish from downstream. These adults no longer spawn upstream, and their bodies do not enrich the upstream food web. Fish passage efficiencies rarely exceed 70%, commonly do not exceed 50 percent and often are much lower.

On-stream storage reservoirs also destroy riparian habitat, particularly if fluctuating levels do not allow functioning wetlands along the shore. Riparian zones have a disproportionate ecological importance in their watersheds: they contribute nutritional resources to the aquatic community, they help retain those resources in the channel, and they provide productive habitat for many other terrestrial plants and animals.

Changes to downstream 'productivity', in terms of biomass, are harder to generalize with on-stream storage, but there are significant changes affecting streams and aquatic communities. Peak stream flows and sediments that scour out and reshape stream channels are greatly reduced. Reduced stream flow variation possibly favours *Didymosphenia* invasive algae blooms, which are associated with reaches below dams. There are fewer migrant fish from upstream because of lower efficiency of fish passages. Winter ice cover is compromised by release of warmer reservoir water, and by breaking up ice with fluctuating water releases.

Depending on the amount of land flooded, and whether soils contain mercury in any significant quantity, reservoirs can mobilize mercury, a potent toxin that bioaccumulates. Organic decomposition can mobilize mercury, allowing it to enter the open water and the aquatic food web. Migratory fish in the reservoir can spread the contamination upstream, while water outflow and fish (depending on fish passage) can spread the contamination downstream.

The track record in Alberta for mitigation of riparian and fish habitat destruction from dam reservoirs has been poor. In the case of the Oldman River Dam, there was high motivation to accomplish effective mitigation. Significant resources were devoted to creating deep water fish habitat in the upper Crowsnest River. However, most of these sites were undermined by river flow dynamics. Efforts then shifted downstream where there was little baseline information. Overall, fish populations do not seem to have increased in proportion to habitat creation efforts. Shelter belt tree plantings have also fared poorly in effectively replacing cottonwood riparian forests (Fitch, 2008).

Alberta should avoid further degrading aquatic and riparian ecosystems by pursuing alternatives to on-stream dams and reservoirs.

Other References in addition to Mayhood (2010) cited above
Lorne Fitch (2008). “Mitigation – Cosmetics or Compensation?” in *Wild Lands Advocate*, volume 16, No. 3, pp. 4-9.

Roger Drury, P.Eng.
Hydro Project Developer
TransAlta Generation Partnership

Anticipate and plan for more extreme weather events.

In this section [of the white paper] there is an extensive discussion about the flood hydrology of the Bow River and the fact that there has been a long period (1933 – 2004) with no large floods. Several possible explanations are posed and there is a recommendation to investigate the causality of the 2013 flood. In order to do this properly, it will be necessary to look outside the geographic confines of the Bow River basin.

The big floods such as June 2013 are caused by a phenomenon known as a “Cold Low” or “Blocked Low” system. These involve a strong low pressure system moving eastward from the Pacific coast occurring in conjunction with a large high pressure system sitting in the south-central US which is circulating warm, moist air from the Gulf of Mexico up into the path of the oncoming Low. These are huge weather systems and the track they follow eastward determines where the maximum precipitation occurs. The track, or “path” is heavily influenced by the course of the jet stream at the time. The storm center can occur anywhere from northern Wyoming, up through Montana and all the way to Jasper.

In order to study this properly, you have to look at all of the major river basins with headwaters along the east slope of the Rockies (including Montana) to get the full picture. I just scanned the WSC [Water Survey of Canada] records and what you see is that some very large floods have occurred in the Oldman, North Saskatchewan and Athabasca rivers in recent decades, whereas hardly any have occurred in the Bow and Red Deer during the same period. There is also commonality. The same 1915 flood that occurred in the Bow at Calgary also resulted in the annual peak flow in the Oldman at Lethbridge, the North Saskatchewan at Edmonton and the Athabasca at Athabasca. At Edmonton, this 1915 event is the largest flood on record and the famous photo of a train sitting on the Low Level Bridge to keep it from being lifted and washed away is from this event. The point being that this commonality emphasizes how huge these storm systems are. Had this event tracked farther south, it would have been a different story.

All of these big floods are caused by Cold Low events. A preliminary theory might be that some type of atmospheric circulation pattern is determining which basin gets hit at what time. To say that there have been no big floods in the Bow recently, although true, is not a complete assessment. A more correct statement would be that the big storms that cause these floods have not tracked through the Bow Basin recently. I think it will be critical to look at flood history for all of these river basins to get a complete view of the frequency and magnitude of potential floods along the eastern slopes. If the hydrology assessment simply looks at each river basin independently, it misses the fact that these storms occur on a regional basis, not a basin specific basis.

Improve our operational capacity to deal with a variety of potential extreme weather scenarios through better modelling and data management.

I agree in general with the points raised in this section but it is important to recognize that all the modelling in the world does not help you when real-time data fails. During the 2013 flood, every single WSC gauge between Banff and Calgary went out of service prior to the peak flows occurring.

I think an important action item would be to investigate backup systems at gauging stations to try and maintain data continuity during large events. A standard stream gauging station is built on the bank of the stream and is prone to being damaged or flooded just like any other infrastructure along that stream. It would be really valuable for real-time operators like TransAlta if some research could be done on alternate systems that could kick into operation when the standard gauge went out of operation. Sonic systems don't work because of all the sediment transport in the water but possibly an array of laser water level sensors located outside the active stream channel? I don't know the answer but this would be a valuable item to pursue.

Wendy Francis
Program Director
Yellowstone to Yukon Conservation Initiative

The actions and recommendations appear to be weighted toward predicting and responding to future flood events, rather than preventing them or minimizing their severity. Of the six recommendations, only numbers 3 and 4 include actions that would improve nature's ability to modify future flood impacts. And while there are sometimes extremely specific recommendations regarding flood preparedness (e.g., testing sump pumps in office buildings) those regarding land use planning and management are extremely general and brief. At the Yellowstone to Yukon Conservation Initiative (Y2Y), we think there are practical, cost-effective measures that can be taken to mitigate the severity of future floods. Indeed, we think this should be the first priority.

It is highly likely that the way our forested headwaters are managed (with a priority given to timber harvesting, energy exploration and development, and motorized access) contributed to the severity of last month's floods. We currently have an unprecedented opportunity to influence the way in which Alberta's headwaters are managed. The government currently is putting the final touches on the draft South Saskatchewan Regional Plan (SSRP), anticipated to be released by this fall. It will set the stage for land management policy and practices throughout southern Alberta for years, if not decades. The SSRP will provide the foundation for management decisions that will have a significant impact on whether or not Alberta's headwater forests provide flood prevention, reduction and mitigation services. When forested headwaters are clear-cut, they lose their ability to absorb and hold back water, just as if they had been burned or killed by beetles.Y2Y believes that the SSRP must require a change in forest management policy to require forestry practices to preserve natural flood prevention and minimization services. Some specifics include a reduction in the number and size of clear-cuts, with a move toward practices that maximize the ability of forests to capture and retain precipitation, and reducing densities of access routes into headwaters (which contribute to erosion and whose hard surfaces are unable to absorb as much moisture).

I should add that I have read Kevin Van Tighem's suggestions for the white paper, including more specifics with regard to headwaters management, and concur in the entirety of his comments.

It would be extremely timely for the white paper to include reference to the SSRP and the opportunity that it presents to enhance flood avoidance and mitigation through the appropriate management of headwater forests. The opportunity to refer to the SSRP exists in the second bullet on page 13, which mentions pine bark beetles and forest fires, but not logging practices, and also mentions land use planning, but not the specific and imminent opportunity of the SSRP. The SSRP also should be mentioned in the short-term opportunities at the conclusion of the paper.

Brad Stelfox
Landscape Ecologist
ALCES Group

Living at the River's Edge: Some Context of the 2013 Bow River Basin Flood

The 2013 flood of the Bow River basin has triggered a long-overdue conversation about the natural and man-made factors that caused or contributed to these types of events. Across society, people are now asking pointed questions that relate to mitigation, prevention, headwater management, overlapping land uses, floodplain infrastructure, climate change, and flood proofing.

The WaterSMART White Paper provides an excellent broad overview of the complexity of this watershed issue and makes clear that integrated solutions are required to meaningfully address this challenge. Appropriately, the WaterSMART report identifies that both engineering and landscape management approaches are required if watershed integrity of the Bow River basin is to be conserved and risk to infrastructure is to managed at an acceptable level.

As a resident of the Sunnyside community in Calgary, our neighborhood was extensively flooded and most families experienced serious damage to their basements, and in some cases, structural damage to their homes. In comparison to the residents of lower Benchlands, High River, and many other communities, we escaped relatively unscathed. In the aftermath of these events, we are told that those who have experienced flooding are expected to go through the emotions of anger, denial, depression and acceptance. For most affected by the flood, there is a basic need to understand what happened and what factors contributed to an event that so forcefully changed our lives. Over the next several months, more information will certainly come forward to help residents better understand the weather, landscape, and land use dynamics that shaped this massive event, but a few thoughts are respectfully offered below to help put some of these dynamics into context.

During the past five years, the ALCES Group has completed two Bow River basin watershed studies examining the effects of land use (forestry, energy, agriculture, residential, transportation, recreation) and climate on watershed integrity. One of these studies (the Upper Bow Basin Cumulative Effects Study) examined the entire basin upstream of Calgary. The other study focused on the Ghost River watershed, an important headwater basin within the Bow River system. For those wanting to understand the detailed findings, these reports can be downloaded from the ALCES website (www.alces.ca).

These studies underscore the large amount of natural variation in environmental conditions that characterize the headwater landscapes of southwest Alberta. Year-to-year and decade-to-decade change in precipitation, temperature, and fire create a wide range of natural variation in levels of groundwater saturation, river flow, and water quality. The episodic nature of this natural variation is such that rare events (massive floods or sustained drought) are not commonly observed in any given year and may take multiple generations to witness the full variation of Mother Nature. But we must be careful not to confuse uncommon with unimportant, for it is these relatively rare events that define the form and function of the Bow River and its tributary basins. Many of us witnessed one of these infrequent events firsthand this June. The improbable combination of a large moisture-laden low-pressure system, stalled against a high-pressure ridge created by a fold in the jet stream, lead to a massive precipitation event that fell extensively throughout the Bow River basin, including the drainages of the Ghost, Elbow, Sheep and Highwood rivers. This hydrological event was made even more impressive because some of the rain fell directly on a deep snowpack (which melted rapidly) while in other areas the rain fell on frozen or saturated groundwater. With limited capacity of the landscape to absorb the billions of cubic meters of water flowing downhill under the force of gravity, the outcome was a foregone certainty. All watercourses, from the smallest of tributaries to the largest mainstem rivers, quickly swelled, overtopped their banks and spread waters across their floodplains in a fashion that has re-occurred hundreds of times since glacial ice sheets retreated several thousand years ago.

What made this 2013 event of immense interest (and anxiety) was the magnitude of physical and economic damage to infrastructure it caused. Long-term river flow records indicate the

2013 flood was about the largest recorded for the Ghost River and 5th largest flow on the Bow River - yet it caused, by far, the greatest economic loss. The obvious point here is that a vast amount of infrastructure (houses, roads, schools, business complexes, industrial facilities, recreational facilities) has been constructed on floodplains and riverside benches in the past several decades. As Alberta's main economic urban engine, Calgary and its surrounding communities have converted vast investment dollars into physical infrastructure – much of which is located directly along waterways. As these communities have sprawled outward, much of this growth has occurred along the very mainstem rivers (Bow, Ghost, Elbow, Highwood) that originally attracted Alberta's pioneers and gave birth to the initial settlements. It has been the inevitable collision between high floodwater volume and dense floodplain infrastructure that lead to this unprecedented economic disaster.

While one does not need to invoke climate change scenarios to explain a single large flood event (such as the 2013 flood), the science of climate change universally points to these types of events becoming more frequent and of greater magnitude. Ignoring the role of climate change in the dynamics of current and future water flow in the Ghost River and the Bow River basin has immense risk to all land uses and citizens. Perhaps the 2013 flood will catalyze a more mature and science-based conversation about, and appreciation for, the critical "driver" of climate change. We ignore this conversation at great peril.

The findings of the ALCES projects in the Bow River and Ghost River basins highlighted the importance of land use in affecting the flow and performance of water quality, landscape integrity, and wildlife to the residents and users of these watersheds. Were these land uses responsible for the flood and the destruction it caused? Our analyses revealed that the portion of these basins allocated for logging, agriculture, transportation, residential, recreation, and the oil and gas sector can profoundly alter surface and subsurface movement of water and the amounts of nutrients and sediment entering water. In addition, the extent to which best management practices are adopted can mitigate risks caused by land use and water. Key management practices that reduce flood risk include protecting riparian forests (including those along small tributaries), leaving more live trees within cutblocks, improved cattle grazing practices, and careful selection of road/trail networks for forestry, oil and gas, and recreation. When all of these best management practices are deployed collectively, headwater landscapes can provide Albertans with improved performance of ecosystem services and significantly reduce the frequency and cost of floods that cause economic disruption. Would these improved land use practices, if fully deployed, have prevented the events of June 2013? Not likely! The magnitude of this foothill and mountain rainfall event was so extreme that it would have likely generated extreme surface water and sediment runoff even under conditions of progressive land management. That said, society must not lose sight of the long term importance of sustainable watershed management. It would be unwise to use the volatility of natural systems as an excuse for poor land management practices. In hindsight, the most relevant "best management practice" would have been to avoid construction of new infrastructure within flood plains and lower benches, and to relocate, where possible, existing infrastructure away from these features. The carnage observed by those who live and work in these basins can be viewed as a reminder of the raw power of natural ecosystems. It is also a wake-up call of how these "rare" events can become more frequent in a climate change world, especially if society continues its historical preference to building infrastructure so close to waterways.

During the extended periods of time, often measured in multiple decades, that occurs between flood events, it is all too easy for generations living in the “gentle times” to forget the lessons learned by past flood survivors. Societies in general, and governments specifically, have a responsibility to remember these lessons, and to build policies and infrastructure that intelligently reflect the force and destructive potential of natural systems.

As long as there has been people, they have been drawn to water for food, industry, recreation, and viewscapes. Our challenge is to balance these amazing benefits with the flood risks that inevitably accompany “living at the river’s edge”.

Brad Stelfox, Landscape Ecologist, ALCES Group; bstelfox@alces.ca

Steward Rood
Professor and Board of Governors Research Chair in Environmental Science
University of Lethbridge

We've been undertaking analyses of floods along all of the rivers in the SSRB and I'm attaching our prior paper relating to flood-flow attenuation of the Bow River [see Appendix D]. The historic river flows do indeed indicate that the dozen dams and reservoirs upstream of Calgary attenuate at least minor and moderate floods. An unfortunate consequence is that this leads to a false sense of security and expanded development in the lower elevations. Consequently when a major flood inevitably happens, the economic cost is vastly increased.

Relative to this, the Elbow valley through Calgary is a classic case. A half-century ago there would have been simple cabins along the river and flooding would have caused only slight damage. Over time, and especially following the Glenmore Dam, the cabins were expanded into homes and basements were excavated, vastly increasing the vulnerability. The next unfortunate step was that the modest homes were replaced by river-side mansions and this further increased the vulnerability and especially the cost.

I'm not convinced by the first point in the report recommendations and this is a suggestion that repeatedly arose after the floods. This is the prospect that floods will be more common and/or more severe. While this is indeed consistent with the 'climate intensification' model, there are actually opposing factors, which are shown in the historic record. With winter warming (which is certain), there are changes in the rain vs. snow patterns and subsequent snow-packs and melt. Annual mountain snow-packs may thus be declining and more confidently, spring melt is earlier. The consequence may actually moderate flooding since earlier melt is more gradual. Rains may or may not be getting more severe, but the timing may also be critical. Major river flooding in the SSRB requires the convergence of two conditions: (1) saturated water-sheds, and (2) intense rain. Even if '(2)' changes, I think that the earlier melt might slightly uncouple the two factors.

This is somewhat speculative but consistent with the historic records. Further, as indicated in the flood report, there has apparently been a recent decrease in flooding along the Bow River. This opposes the proposal that floods are getting worse and from the historic record my view is that 'Calgary has been overdue for a major flood'.

The High River case is discouraging since there's such a clear and extensive history of flooding. If you sort through the archival photos at the museum in High River and then coordinate photos with river flows, the conclusion is that it's possible to float a canoe down main-street about once a decade. This town is unfortunately situated in a natural overflow zone, in which the very dynamic Highwood River regularly overflows its shallow banks and the flood water flows overland into the Little Bow River, which commences right in the Town.

Flooding in High River was major and costly in 1995 and 2005 brought three smaller floods that also led to considerable property damage. While the 2013 flood was indeed more severe, the largest reason that the 2013 event will be much more costly than the 1995 event is that the town population has doubled (around 7K to 14K). And very unfortunately, some of the newer subdivisions are east of the older town and in a low-lying basin where the massive pond formed (and persists). There might have been the view that this area was less vulnerable since it's further from the river but this neglects the key aspect that 'water flows downhill'. If one looks at older air photos and early survey maps, we find that that area was commonly a complex of wetlands and thus it was naturally very low and wet, and with limited drainage.

These are the types of things that should be sorted through and I thus strongly support the initiative.

Finally, I've got 2 MSc students analyzing the flood history for the rivers draining the central Rocky Mountains region of AB, BC and MT, including those of the SSRB. Our intent is to better understand prospective impacts of climate change and to test the 'climate intensification' theory. This task fits nicely with our Functional Flows research program and we should have the key analyses by the end of 2013. We will be glad to learn more about what others are up to.

Dave Sauchyn, Ph.D., P.Geo.
PARC, University of Regina
Submission 1: Email regarding Discussion Draft v08

Comments on "The 2013 Great Alberta Flood: Actions to Mitigate, Manage and Control Future Floods - Discussion Draft v08"

This report is an excellent platform for launching a wider, more inclusive discussion the causes and mitigation of the impacts of climate extremes in Alberta and the 2013 floods in particular. WaterSMART deserve thanks for taking the initiative. As with any draft report from a single source, especially when timing is critical, it reflects the expertise of the authors and advisors who in this case have an engineering and hydrology orientation. This certainly is an appropriate expertise, but the associated biases provide minimal space for a review of non-structural strategies for mitigation and management of the impacts of extreme weather events. Specifically the report could benefit from the input of scientists and practitioners with an interest in source water protection, rural land use planning, landscape conservation, and watershed (versus river) hydrology. The report is not devoid of this perspective, for example, there is the recommendation to "Incorporate natural infrastructure such as wetlands, riparian areas, natural storage conditions and land cover into flood and drought mitigation planning." However, there is more scope for softer watershed-scale planning and ecosystem-based approaches in the context of recommendations1, 2 and 6.

The report is tactical with the multiple references to drought, as for example "ensuring that drought and flood planning receive equal attention from policy-makers will help us be better prepared for increased weather variability ". Besides common issues and mitigation strategies, most scholars and practitioners recognize that drought is the more serious problem in western Canada (although now is not a good time to admit this). While flooding has immediate and severe consequences, it is confined to floodplains and adjacent areas; drought impacts are creeping and widespread and much more costly. Financial losses from the drought of 2001-02 in the Prairie Provinces (mostly AB and SK) were estimated at $3.8B almost 4 times the projected cost of the Alberta 2013 flood.

Regarding the recommendations

1. Anticipate and plan for more extreme weather events, including both flood and drought.
2. Improve our operational capacity … through better modeling and data management.

These refer to the work of my research group and thus I naturally concur with this advice and the more specific recommendation

- Conduct a study to analyze the confluence of events that resulted in the 2013 flood.

However, in my opinion, before we proceed with more research, we need to do a better job of defining the broader scientific context. Remarks like "Alberta should be planning for even more extreme weather events - both in frequency and in cost" strongly imply that Alberta's climate is changing, and yet nowhere in the report can I find the terms "climate change" or "climatic change" (nor would I expect to find "global warming"). Does the avoidance of this terminology reflect a sensitivity when dealing with the GoA or is it simply that authors chose not to explicitly refer to climate change? The report wisely suggests that "More work needs to be done to understand any other factors that are influencing the weather, resulting in more extreme events. This analysis can then be used to signal how frequently we can expect these events in the future and their potential magnitude, allowing for better planning." And yet language in this report, and other reporting (media) of the floods, implies that the link between global warming and extreme weather is a given, a scientific fact. To maintain scientific credibility we have be very careful with statements that suggest, or can be interpreted to mean, that the flood of 2013 was the result of global warming. I would be pleased to provide the authors of this report, or anyone else, with a plain language summary of the evidence and uncertainties regarding the link between a warming climate and extreme events.

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PARC, University of Regina
Submission 2: Contribution regarding global warming and extreme weather events

Global warming and extreme weather events: The scientific evidence and uncertainty

The Problem

In their wake, weather disasters, like Hurricane Katrina, super storm Sandy, the Russian Heat wave of 2010, and the Alberta flood of 2013, are often attributed to global warming, at least by some journalists and government officials. Most scientists, however, would regard a connection between global warming and extreme weather as a hypothesis, and point out that a single event is simply weather. There is a strong temptation to attribute extreme weather to a changing climate, for at least three reasons:

1. Humans inherently and consistently discount the future, including the longer-term consequences of a changing climate. Floods and storms are an effective reminder of the impacts of unexpected weather conditions; it's a wake up call and convenient device for leveraging action from government to prevent the emerging impacts of climate change.

2. Because weather and climate are driven by energy from the sun, it follows that extra heat trapped by greenhouse gases should speed up the climate processes that produce excessive and damaging water and wind.

3. With each weather disaster, governments react with relief but also programs and structure to reduce damage from future events. In western Canada, much adaptation, "the process of adjustment to actual or expected climate and its effects", has occurred in response to flooding and drought (e.g. the Winnipeg floodway, PFRA, changing land use patterns and farming practices), even though only recently has the link been made between extreme weather and climate change. Weather disasters and global warming require a similar adaptive response to prevent adverse effects, whether or not they are linked geophysically. Dealing now with extreme weather is good preparation for the adaptations that will be required to sustain economies and communities in a changing climate; and especially if weather events become more severe as a consequence of climate change.

Attributing a single extreme weather event, or even several events, to climate change is contrary to the definition of weather and climate, and the important distinction between them. Mark Twain said it best: "weather is what we get, climate is what we expect". On any given day in Alberta, we can get almost any type of weather; snow has occurred in every month and mid-winter warm spells are not uncommon. But we expect certain types of weather in each season based on our past experience with weather over a number of years. For a climate scientist that number of years is 30; climate 'normals' are the summary of 30 years of weather data. This statistical summary includes not only monthly and seasonal averages, but also the range of extremes. In late June 2013, the residents of Canmore did not expect more than 220 millimeters of rain in 36 hours, nearly half of the annual average rainfall, but that's what they got. If climate is 'the weather we expect', then unexpected weather is an indication of either climate change or a larger range of natural climate variability than we've previously experienced.

If climate is the statistics of weather, then climate change is change in weather statistics. A change in the mean, variability or extremes has to persist for decades or longer before it can be declared a climate change. Average weather occurs often and thus trends in average conditions can be identified with a few decades of weather data. Extremes, on the other hand, are rare occurrences and thus many years would have to transpire before there are enough storms or floods to describe their statistical characteristics and many more years before a change can be detected in their frequency or magnitude.

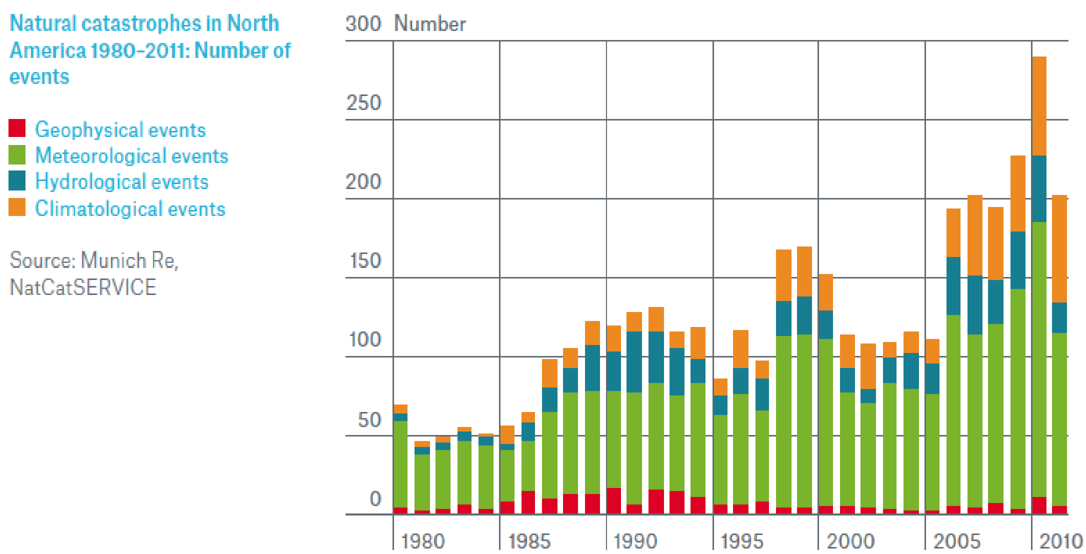
The relevant question about the Alberta Flood of 2013 is not 'was it caused by global warming' but rather 'is it part of a pattern of weather extremes of increasing frequency and severity'. There is a growing body of scientific evidence to address the question of whether a warmer climate is more volatile. This brief report is a summary of this evidence, which comes two sources: the direct observations of weather and the modeling of the climate system. The uncertainties also are considered. They are large. The most challenging climate variable, spatial scale and type of region for climate change research are precipitation, regional scale, and regions with high climatic variability. This describes southern Alberta and the problem of flooding and drought.

The Evidence – Observations

The expectation that a warming climate will include more frequent and severe extreme weather is supported by the direct observation of historical weather events. However, because extreme events are rare, there are relatively few observations to identify changes in their frequency or intensity. The most robust analyses are global in scope using data from a large number of sources and locations.

For obvious reasons, some of the best record keeping for natural disasters is by major insurance companies, including the German-based Munich Reinsurance. In a 2012 report 'Severe weather in North America', Munich Re documented the number of natural catastrophes in North America from 1980 to 2011. The graph below from that report shows a significant increase in the number of damaging meteorological (weather), hydrological and climatologically events. This trend, which also exists in other parts of the world, could simply reflect rising global population and increasing exposure of communities and infrastructure to climate variability and weather extremes. With expanding population, people have built in more vulnerable settings such as coastlines, floodplains, and mountain slopes. If these social and economic factors accounted for the increase in the number of weather disasters, then the same explanation should apply to all natural catastrophes irrespective their cause. But Munich

Re also plotted the number of geophysical events (earthquakes, volcanic eruptions, tsunamis) each year, and there has been little or no change, even a slight decline since the mid 1990s. If populations are expanding, especially into mountains and along coastlines, they are more exposed to these geophysical events that are unrelated to weather and climate. Munich Re therefore reached the conclusion that North America is suffering increasing damage from floods, drought and storms as the result of global warming. Some commentators have suggested that insurance companies may be subject to some bias; weather disasters are escalating their liability and they are compelled to document this and find a cause.



A review of scientific literature by the Intergovernmental Panel on Climate Change (IPCC, 2012 – see Further Reading) suggests that the statistics of most weather variables are changing. However the statistical significance of these trends, and the agreement among studies, depends on the climate variable and in particular its geographical uniformity. Whereas heat is always present to some degree, precipitation is episodic in time and space. Therefore trends in temperature-related extremes are more reliable than for precipitation-related variables and global-scale trends are more reliable then those at a regional scale. The most robust trends in climate extremes are global observations of a decrease in the frequency of cold days.

Researchers have medium to low confidence in the interpretation of trends in hydro-climatic extremes. Only at a global scale can there be some confidence that anthropogenic effects contribute to an intensification of extreme precipitation. Large-scale ocean-atmosphere oscillations strongly influence the timing and amounts of precipitation and stream flow. This influence or teleconnection is manifest as inter-annual to decadal variability that tends to mask any regional trends imposed by anthropogenic global warming. It prevents robust conclusions about changes in atmospheric circulation that control the global redistribution of water. One change in atmospheric circulation that is detected with some confidence is a latitudinal shift in circulation features (storm tracks and jet streams) towards the poles. This has implications for Canada. The analysis of weather records from across Canada has revealed that, in general, precipitation is increasing across the country. The one major exception is southern Alberta and western Saskatchewan, where there has been a small decrease in annual precipitation. At the same time, however, the intensity of rainfall seems to be on the rise, with fewer storms producing less annual precipitation but with greater intensity (mm/day). An increasing number of heavy precipitation events, notably in North America, is the precipitation-related trend that is detected with the greatest confidence. There is still insufficient evidence to draw conclusions about global trends in drought and severe local storms, including tornadoes and hail.

Because there are statistically significant and consistent trends in heavy precipitation events and changes in temperature-driven snowmelt processes, there is some evidence that suggests flooding has increased in magnitude and frequency. However, the evidence differs among regions according to the causes of flooding, including snowmelt but also land use and engineering structures, and the availability of data from gauging stations. Therefore there still is low confidence and agreement for observations of flooding.

Evidence – Model Simulations

Weather and water observations are the basis for understanding recent climate variability and are the baseline against which future climate changes are measured. However, instrumental records tell us little about the climate to expect in the future, unless there is a very good understanding of the causes of the observed variability and proof that it will continue to occur in a climate modified by human activities. A theoretical understanding of the climate system, and all projections of future conditions, comes from climate models "the only credible tools for simulating the response of the global climate system to increasing greenhouse gas concentrations" (IPCC).

Most of the theory behind an increasing severity and number of extreme weather events is related to the intensification of the hydrological cycle. Because about three-quarters of the earth is ocean, and water has a very high heat capacity, the oceans are storing most of the extra heat trapped by greenhouse gases. Evidence for accelerated evaporation from the oceans includes studies that document a clear increase in salinity of warm ocean water, and an increase in river flow into the oceans. The other important factor, delivering more water from the oceans to the continents, is the greater capacity of warming air to store water vapour. Other hypotheses are related to a poleward shift in the trajectory of major storm tracks and the influence of the rapid loss of arctic sea ice on the circulation of the atmosphere in the northern hemisphere. The warming of the Arctic, at a faster rate than the rest of the world, is causing a lesser difference in temperature and air pressure between low and high latitudes in the Northern Hemisphere. This may be causing the jet stream, the very strong westerly air current 10-15 km above the earth, to slow down and form large meanders. As storm systems follow a slower and more meandering jet stream across North America, rain could fall for extended periods of time at any location producing higher river levels.

The reliability of model projections of future climate depends very much on the climate variable of interest and the resolution of the model relative to processes and variables. Climate scientists use two indicators of certainty in the projection of climate changes. The quality of a climate model experiment is measured in terms of its capacity to simulate historical climate conditions. The level of confidence in a climate change scenario depends on the agreement among climate models. There is high confidence in robust results, those that are similar results irrespective of the model and methods.

The most robust climate projections are of mean annual global temperature averaged over decades, and the related changes, such as trends in Arctic sea ice extent, global mean sea level and ocean heat content. With the substantial warming anticipated in the 21st century, global increases in the frequency and magnitude of maximum daily temperatures and decreases in cold extremes are virtually certain.

The least reliable model output is anything related to precipitation at the regional scale. Therefore, there is low confidence in the modeling of small storms such as tornadoes, thunderstorms and hail; current climate models cannot resolve these small weather systems. Drought on the other hand is a feature of the hydro-climatic that spans larger areas, and also results from high temperatures, and thus there is a medium confidence in the simulation of future droughts in a warmer climate.

It is likely that, over much of the globe, the frequency of heavy rainfalls, and/or the proportion of total precipitation from heavy rain, will increase in the 21st century. This applies in particular to high latitudes, and to winter in the northern mid-latitudes (Alberta). Environment Canada scientists did some of the first and most cited modeling studies of extreme precipitation. They determined that the amount of maximum daily precipitation that historically occurred once every 20 years is likely to occur with a frequency of once in five years to once in 15 years by the end of the 21st century. In some regions, including Alberta, increases in heavy precipitation will occur despite projected decreases in total precipitation. Physical reasoning suggests that projected increases in heavy rainfall, and accelerated snowmelt with higher temperatures, will lead to more severe and frequent local flooding. Confidence in the model simulation of flooding is low, however, because the causes of regional changes are complex. For example, in Alberta future flooding should more often result from heavy rain, whereas historically rapid snowmelt has been a major cause.

Whereas numerical models are able to reliably simulate the changes in the earth's energy balance and related affects, the response of the circulation of the atmosphere to global warming is highly uncertain and yet the regional aspects of climate change are controlled by atmospheric dynamics, including teleconnections between large scale climate oscillations and regional climate variability (in the case of Alberta, between El Niño South Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) and inter-annual and decadal climate variability). There is low confidence in projections of changes in large-scale patterns of natural climate variability. Model projections of changes in ENSO variability and the frequency of El Niño events are inconsistent, and thus there is low confidence in projections of changes in this important mode of internal climate variability.

The significant disparity in the ability of existing climate models to simulate mean states versus extremes, the climate of large versus small areas of the globe, and temperature versus precipitation is a problem of the inherent complexity of the climate system and how scientists have chosen to model (simplify) climate change primarily as a perturbation to the earth's heat and radiation balance. The dominant conceptual framework, the anthropogenic (CO_2) forcing of linear trends in temperature and other variables that define mean climate, is problematic for scientists and journalists; especially when weather departs from a monotonic warming trend. A shift in climate variability, and the severity of extreme weather events, is as likely an outcome of human modification of the atmosphere as a thermodynamically forced linear trend. The defining feature of global warming may be changes in the magnitude of climate variability rather then a monotonic upward trend in temperature implied by the terminology global warming.

The most challenging impacts of climate change are not trends in temperature by rather shifts in the distribution of water supplies between seasons, years and watersheds, and changes in the frequency and severity of extreme weather events (e.g., flooding and drought). Thus, for many regions, the most relevant climate changes are the least understood. For the foreseeable future, regional climate regimes will be dominated by natural variability, especially where it is characteristically high, as in western Canada for example.

Further reading:

Intergovernmental Panel on Climate Change (2012) "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation" Available at http://ipcc-wg2.gov/SREX/ This is a very important document and the 19-page Summary for Policymakers (if not 594 page full report) should be required reading for anyone with an interest or opinion on climate change.

SECTION II: FEEDBACK FROM ALBERTANS

- The biggest point is the leadership! Someone (including the government) has to be out there taking on these challenges.

- There are lots of places in Calgary where you can stand on a bluff and look at the river valley. The valley is a path cut by the river over millennia and now slowly filling with houses, hard surfaces, waste water treatment plants, rip rap and high rise buildings. It's pretty easy to see the places where the water will go during a flood event and equally easy to see how it will travel there.

  How about re-establishing some natural buffer zones? Yes, costly, but more costly than flood repairs? That's a long term project. In the short term, some king somewhere should outlaw building within 500 meters to a kilometer of a river bank and start a fund to buy existing properties.

- Discussion has occurred regarding the development of wetlands and natural water sources (and I add protection) to control flooding. While this is a good idea, it can make problems worse than before if not managed correctly. If the wetlands are allowed to build up in height ahead of time, staging can occur where there is a momentum of water towards the outlet then bursting over and making the peak flow higher than would have been. This can greatly intensify flooding. Someone would need to be responsible for promptly controlling the level of the wetlands and would need to be notified ahead of time. I have witnessed this first hand during my work in this field. They can be valuable for flood control.

- The lack of water licencing policy that is in tune with modern demands. The current policy is out of date by many decades and does not have the flexibility to deal with the inevitable shortage (drought).

  One feature the next policy requires is the concept of needs based on priority of uses with domestic use ranking high. It needs to include the available groundwater resource of which there is a great deficit of factual knowledge. It needs to include some flexibility for quantities (and qualities) available over time as the natural flows fluctuate over the seasons.

- In terms of reducing the negative impacts of floods the key issue as I see it is awareness. Information helps with this but zoning, development regulations and insurance regulations are going to be the key tools for implementing this. We need to move out [of] the flood plains and there should be no disaster assistance for those who rebuild in a flood plain. Development has a double negative impact. First, it increases the probability and intensity of downstream floods but reducing the effectiveness of the flood plain in dispersing the energy of water. Second, the developments in the flood plain take the lion’s share of resources for flood preparedness and response before, during and after the flood event but have the lowest per unit yield.

- When I talk to non-water people about the recent flooding, they frequently bring up the Winnipeg diversion ditch and ask why we don't do something similar here. When I describe the problem of wetland drainage in the watershed to the south, vs. up-slope rainfall in the foothills, these non-water people understand that Winnipeg's frequent flooding problems are largely man-made while ours is due to extreme meteorological conditions -- oversimplified, I know, but those are the basics.

  I believe that we have a huge responsibility to all the residents of the Bow River Basin to manage our headwater areas so that our natural wetlands and riparian zones continue to act as a buffer for heavy rainfall. Can you imagine the flooding that would have occurred if our wetland areas and riparian zones had already been turned into ditched or paved areas of near-instantaneous runoff during a time of extreme rainfall?

- While the five flood prevention issues mentioned will help they are really meant to facilitate evacuation and reaction, with the exception of number 3 which suggests paying attention to infrastructure. Infrastructure is the overlook[ed] key component to flood mitigation. We have a network of 12 dams upstream of the population centers on the Bow river. Those dams are old and have been filling in with sediment for over a century in some cases. The dams and reservoirs dampen flood events if managed properly. The reservoirs have lost huge storage capacity volume over the decades and their ability to dampen floods has been grossly diminished. The reality is neither government nor industry has any idea how much upstream storage capacity has been lost because this issue is ignored until there is a crisis event. This occurs because it is out of sight and out of mind to the larger population. Even senior bureaucrats pay little attention to the matter, and the reality is that Alberta as a whole has little expertise in this critical area.

  Gradual accumulation of sediments is a slow process that tends to be ignored. Most of the sediment accumulates underwater below the median reservoir supply level where it is not visible which has the effect of removing it from popular, political, social, and engineering consciousness. In our part of the world the rates are relatively slow and the bulk of the sediment moves in pulses around spring flood events. However events such as the one we recently experienced move a colossal volume of material of all sizes ranging from Nano-sized flocculated clays to rocks the size of automobiles. As a result, the net effect of decades and centuries of accumulation goes unnoticed by the untrained eye that does not have a comparative time perspective. Industry, afraid of the potential expense, has made conscious effort to down play and divert attention away from this issue on few occasions when it has surfaced. In general government has taken a complacent assumption that somebody else, members of a future generation, will find a miracle solution when todays inventory of reservoirs become seriously affected by sediment. The reality is we have already reached the point of serious consequences. If you are serious about addressing flooding in the Bow River Sub basin the government of Alberta must address reservoir sedimentation head on and implement an active reservoir sedimentation management plan that amortizes the cost over decades and centuries and splits the cost up amongst the primary benefactors of the reservoirs. Entities in industry make huge profits off the reservoirs on the Bow and put absolutely nothing back to maintain the sustainability of the reservoirs and preserve upstream water storage capacity.

I recommend the following: the Government of Alberta in open and transparent consultation with all relevant ministries and stakeholders [should] undertake to study and quantify the current state of the water storage reservoirs in the Bow River sub basin, upstream of the major population centers. The study should have the following objectives:

- Quantify the original (New Construction) water storage capacity of all 12 sub basin reservoirs individually, by compiling all historical survey and bathymetric data from Government and industry sources.
- Design and execute a comprehensive program for acquisition of modern and up to date survey and bathymetric data.
- Accurately compute and quantify the current upstream water storage capacity and accurately compute and quantify the volume of water storage capacity that has been lost due to reservoir sedimentation over the past century. Rate of original storage volume lost per year should be calculated per reservoir and reservoir half-life calculated.
- Accurately compute and quantify the volume of sediment that has accumulated in each reservoir over the last decades and century.
- Classify sediments accumulated in each reservoir as top-set, mid-set, and bottom-set beds as well as by size, type and hydraulic sorting of material that the sediment in each reservoir is composed of.
- Undertake a sediment transport study that quantifies the deliverability of each main individual upstream reservoir tributary.
- Design a study to look at all options for active reservoir sediment management and preservation of upstream water storage capacity.

Brian Meller
Hydrologist
Lethbridge AB

In response to your flooding forum, I submit that part of the issue isn't so much that there hasn't been floodplain mapping, as this has existed since the 1980's. The issues to me are that (1) the validity of the mapping varies as the database increases, and (2) floodplain zoning hasn't respected the variability in these limits, nor has it built in a sufficient safety margin to respect the fact that flooding can exceed our scientific expectations, as has just occurred. This raises an interesting question as to whose fault is it that so much development has taken place within the flood-prone areas, and who is therefore responsible to pay for it?

Kevin Van Tighem
Retired, Fourth-Generation Albertan, Professional Ecologist

Recommended additions to the draft report arising from the June 27, 2013 Alberta Water Summit, addressing the question *"What can we do to mitigate these flood situations in the future?"*

Although generally I think it's a strong report, in my view the emphasis on restoring and optimally managing the headwaters needs to be strengthened. This year, our problem was flooding; in future years we will face summer drought too. Restoring the sponginess of the headwaters landscapes is essential for dealing with both problems. We need to optimize the ability of our headwaters to capture and retain snowmelt and spring rains, rather than to release it in increasingly early and intense spring runoff events.

The 2013 flood was exacerbated by linear disturbances and road compaction in the headwaters. After the flooding I went back into the Waiparous, Wind Creek and other valleys to see what I could learn about the way water came out of those landscapes. I saw three causes of major gullying indicating concentrated runoff:

- alpine drainage gullies that blew out (unavoidable with that volume of rain and such thin vegetation cover);
- roads, off-road vehicle tracks and trails running up or across slopes (avoidable with fewer, better designed roads and aggressive reclamation of unneeded ones); and
- steep-gradient streams that got overloaded (could be partially mitigated with less funneling of runoff to the stream by above-noted trails and roads and by more friction on the floodplain by way of beaver dams.

Where logging had been completed and haul roads reclaimed and covered with slash, I found little sign of gullying but there is no question that the intense rainfall mostly ran off these sites and into nearby creeks for lack of tree canopy and understory vegetation to trap and retain moisture.

Margaret Creek (local name for an unnamed tributary of the Waiparous) has a robust beaver population. Its banks were intact with no evidence of erosion and flood debris on the willows and bog birch showed that the runoff from this valley was spread out and slowed due to the dams that reduced hydrological head and spread the water into floodplain willow thickets and sedge meadows.
Given these observations and other insights I've gotten from two years of research for a book I'm currently working on, ***I recommend that flood mitigation planning incorporate the following specific landscape management measures:***

1. **Revise land use policies for the area west of Highway 22 to make headwaters landscape health the dominant over-riding management priority**. All land use and regulatory decisions should be framed around the linked imperatives of: **maximizing water production** (through snow accumulation and runoff retention), **maximizing water quality** (through riparian

protection and wetland health), and **spreading out the annual hydrograph as optimally as possible** (by retaining snow cover as late into the spring as possible, protecting shallow groundwater from early release to the surface, and encouraging small impoundments in side drainages and smaller streams). Headwaters landscape health results from all three of these factors, not one or two of them; in other words, policy approach that integrates all three management imperatives is essential.

2. **Shift from clear-cut logging to canopy-retention logging designed to reduce canopy snow loss while spreading out the snow melt over a longer period, while retaining sufficient forest canopy and ground-cover to intercept and retain rainfall**. Research out of the U of A has shown that tree canopies and trunks retain a high proportion of the water that falls in normal rain events.

3. **Manage for maximum population densities of beavers** to maximize their free ecosystem services; either eliminate or significantly curtail by way of quotas, the trapping of beavers in the headwaters of the Oldman, Bow and Red Deer Rivers.

4. **Limit off-road vehicles and industry vehicles to a limited number of trails and roads specifically designed to minimize gullying and sedimentation** (i.e. laid across the grain of the landscape and fitted with effective, well-maintained, flow deflectors) **and to avoid water source areas** such as fen meadows, wetlands, etc. The current degree of landscape abuse from unplanned off-road recreation should never have been allowed to become so well-established. It clearly contributed to the intensity of this year's flooding by concentrating overland flow from that very intense rainfall and enabling it to flush rapidly into nearby streams.

5. There are numerous locations where well-designed small check-dams in coulees and shallow basins could lead to the development of riparian vegetation and retard runoff during heavy rainfalls. Planned well, they could also help with livestock distribution issues resulting both in less streambank damage by cattle and fewer areas of concentrated grazing on uplands – both of which are factors that contribute to the severity of flooding effects on streams and, consequently, on downstream communities and infrastructure. Riparian vegetation sequesters carbon and sustains several species of at-risk species. For all these reasons, **investment of public funding in a program to encourage private landowners to install small catchments in headwater areas** may be another appropriate policy option for reducing the risk of future intense floods and summer droughts.

Thanks for the opportunity to contribute to the development of a comprehensive policy response to this year's flooding that will reduce the risk of future flood damages.

Kevin Van Tighem
Retired, fourth-generation Albertan, professional ecologist

Bill Wahl

An open letter to the Citizens of Alberta
Flood Recovery and/or Flood Prevention

My name is Bill Wahl and I am frustrated!!

Like others in Medicine Hat and Southern Alberta we live in proximity of the South Saskatchewan River (have for 40 years) and have been affected by flooding, all-be-it not this year due to the installation of a high tech backflow preventer after the 1995 flood. We are thankful to family and friends who helped us move out of our home and for better preparedness of disaster services.

The main reason for my frustration is that I always thought that the dams on the tributaries of the South Saskatchewan River were there in part to help us out during times of impending floods. The Alberta Government meetings after the ’95 flood reported that flooding was caused by a severe precipitation event that occurred in very close proximity to the Oldman River Dam. That and a combination of technical issues caused by washed out flow sensors, telephone communications and the short time from onset of precipitation to significant increases in inflow did not give dam operators sufficient time to spill water ahead of high water entering the dam. Although dam safety was never an issue, water was released from the dam at a rate no greater then inflow. So what happened this year? According to records obtained from Alberta Environment and Sustainable Resource Development, the 2013 peak was ~5590 cm3/s and the 1995 peak was ~4200 cm3/s. The gauging station reports of the 2013 peak was more than 1m higher than 1995. The cross section of the river valley at other locations will affect this value to some extent. Levels in Medicine Hat never reached those predicted with an increase of 50 cm3/s increase in flow rate over 1995 reported. Persons who experienced the 1995 levels commented on water levels about 20 cm higher; all this being enough to cause significantly damage in Medicine Hat. How is it that the dam[s] that impact our flow rate could not have done more to mitigate flood issues this year given the knowledge gained from the ’95 flood, and new technologies for weather forecasting? We have experienced more floods in the past 20 years than the first 20 years of living by the river.

Using the internet, phone, and communicating with acquaintances I have learned a few things. My first conversation was with an engineer who works with a team of others who oversee Dam Maintenance and Integrity. During our conversation he kept referring to the ‘owners and operators’ when discussing dams and reservoirs. After farther prompting I learned that **the majority of large Alberta dams and reservoirs are privately owned and operated. Most of water contained in these facilities is used for irrigation which has an economic benefit to both owner and user; or, for the production of hydroelectricity which is sold back to the grid for consumer use. It is to the owners and operators benefit to keep water levels in their facilities as high as is safe to do so. Most of the dams and reservoirs upstream from the South Saskatchewan River were at or around 98% of capacity prior the June flood. It appears that only the Ghost Lake and Reservoir near Cochrane was overly high, and it looks like they had already moderated two significant inflow events. The purpose of a reservoir or dam is specified in its licence; owner/operators function within guidelines provided by the**

Alberta Government. They have considerable autonomy and the Alberta Government cannot mandate that they lower their water reserves in an attempt to mitigate flooding. Their main priorities are to maintain a quantity of water to best meet their intended purpose without adversely effecting dam integrity.

My next contact was an acquaintance now retired after being involved with the Alberta Water Commission. He confirmed what I had learned from the Dam Safety Engineer and added some additional information. Two of the major dams in the Saskatchewan River System, the Oldman and the Dickson on the Red Deer, are operated for different priority purposes.

The Oldman is a strategic impoundment created to meet the needs of the downstream irrigation districts, which have their own infrastructure to manage day to day water call needs. The Oldman is typically lowered over the course of the summer as licenced demand exceeds natural river flow. The Oldman reservoir is filled the following year with the spring freshet and early summer precipitation. Each irrigation district will have their internal reservoirs at preferred levels by the end of the irrigation season (end of Oct). This also allows the Oldman some flexibility going into summer depending upon moisture reserves, precipitation, and degree of expected snow melt in the cordillera. As we have seen, if the Oldman reservoir gets too full, they will release water according to established guidelines and also to ensure the structural integrity of the dam itself. Operators are very cognizant of the impact of flood flows downstream; regularly managing small peak flows to keep the river below bank full, and operating during large events to attenuate the peak to the extent possible.

The Dickson Dam upstream of the City of Red Deer has a slightly different mandate. The priority for the reservoir is to provide stable downstream flows between 40-50cm3/s. This supplements natural flow and contributes to the Instream Flow Needs and Water Conservation Objectives that have been established to ensure aquatic health and assimilation of contaminants from downstream urban centres such as the Cities of Red Deer and Drumheller. Another purpose of the Dickson is to ensure a minimal flow regime throughout the winter, essentially for the same purpose as mentioned above. One of the secondary functions of the Dickson is to help manage downstream flood attenuation, particularly for Red Deer. It is interesting to note that Red Deer and Drumheller did not sustain the same flood damage that was experienced farther south in part because of less precipitation. Part of the operational complexity for the Dickson involves providing recreational levels of water in the reservoir that has, over time, become known as Glennifer Lake. It is a well beaten path in Alberta where reservoirs built for domestic or agricultural use have become recreational destinations surrounded by expensive developments. **Dam and reservoir usage and guidelines vary and the province has little appetite for adjusting the existing operational policies for the dams. However, there could be room to gain some efficiencies of use that would benefit downstream users, especially in times of water shortages or to assist in downstream flood attenuation.**

A telephone call to the Department of Municipal Affairs resulted with me being contacted by a representative of the Alberta Environment and Sustainable Resource Development. This was extremely helpful, confirming that operating guidelines for Waterton, St Mary and Oldman require the reservoirs to be drawn down over the course of the summer to a maximum level for the winter, balancing the probability of filling the next year and the probability of needing to manage a large snow pack and run off in the spring. as high as is safe. Issues of not having enough water would be very concerning on many fronts. Even with advanced weather forecasting it is difficult to totally predict what might occur in the various catch basins of the South Saskatchewan River System. The farther away from the mountains the water travels, the more difficult it is to predict flow rate and rise. This was experienced in Medicine Hat as the crest forecast of the 2013 was delayed numerous times. The Oldman Dam did store incoming water in the flood pool and the surcharge zone. Outflow from the reservoir was increased very soon after inflows became significant and continued to increase in sync with inflows until the peak flow occurred. Operations did not lower levels in anticipation of increased water flow into systems to the north. It was also interesting to find out there are no dam/reservoirs upstream from the Glenmore Dam in Calgary but there are more numerous dams upstream from Calgary on the Bow. **Dam and reservoir owners and operators do not work collectively to proactively mitigate flooding by lowering levels in anticipation of high stream rates and levels downstream. It was suggested we need a review of the purpose and operation of dams in Alberta. The GOAl would be to determine whether water management can better meet daily requirements of water use and consumption as well as mitigate potential environmental catastrophes that storms and climate change might cause. This would be to everyone's advantage.**

Do I feel a little bit better? Perhaps a little**, I think pressure needs to be put on the Alberta Government to make flood attenuation a huge priority.** Consider the disruption that would have resulted to transportation of goods and commodities if bridges in Medicine Hat would have gone out. The destruction of public and private property in southern Alberta was massive as a result of this flooding. We need to ask the question: what did the managers of the Diefenbaker Dam in Saskatchewan do to regulate the increased inflow so that flooding did not happen as it did in 1995? All Albertans are contributing financially to the flood recovery efforts as provincial and municipal administration redirect funding from other initiatives into the recovery process. When multiple insurance claims are paid out, some companies increase all premiums in an attempt to top up reserves. There are municipal administrations like Edmonton who have created a series of dry ponds that are sports playing fields until they are required to become reservoirs to store excess water that storm sewers can't handle. I am sure that there are coulees and valleys on crown land near some of our large dams that might be put into service in a similar way. Over the years Albertans have contributed more than $4,000,000,000.00 of taxes and revenue into the formation and development of our dams and reservoirs; perhaps it's time to formulate a new model of how this network is managed.

Sincerely,

Bill

SECTION III: ADDITIONAL RESOURCES

Past Floods

For a look at past flood events in Alberta, two articles were provided. The first is from the *Calgary Daily Herald's* Monday, July 3, 1929 front page paper, which reported on the severe flooding in southern Alberta. Similar damages occurred in both the 1929 and 2013 floods (e.g., wreckage of Bowness Park and the Zoo). For the full front page, see http://www.ourfutureourpast.ca/newspapr/np_page2.asp?code=NBBP0848.JPG

The second article, called the "Bow River Enigma" was published in the *High Country News* in July 2013. The article gives an overview of the past flood events on the Bow River, and can be accessed on page 6 of the document: http://www.highcountrynews.ca/pdfs/current.pdf

Flood Prevention Measures in Canada

Informal notes from Jim Bruce on flood prevention measures in Canada:

PARTIAL HISTORY OF FLOOD PREVENTIVE MEASURES IN CANADA

1954 - Oct. 14-16: **Hurricane "HAZEL"** rainfalls cause extensive loss of life and damages in southern Ontario centred on the Humber River.

1955 – 1960: **Flood Plain Mapping** based on the Hazel rainfall centred over watersheds in the region to delineate flooded areas, or areas that would have been flooded, were carried out by the Conservation Authorities Branch, Dept. of Planning and Development in collaboration with River Valley Conservation Authorities. CA's, municipalities and provinces moved to prevent or inhibit development in flood-designated areas – mostly through their designation as parkland and with the Meteorological Service a flood warning system.

1975 - **Federal cabinet,** increasingly concerned about many large payouts under their disaster assistance program, adopted the **Flood Damage Reduction Program (FDR).** It was administered by Inland Waters Directorate of Environment Canada as a cost-shared program with the provinces, under the **Canada Water Act of 1970.**

The program was to:

1. Map flood plains in all threatened areas,
2. Agree to "designate" the flood plain and use federal, provincial and municipal powers and spending authorities to inhibit further development, (e.g. limit CMHC mortgage insurance)

3. Where extensive developments already existed, provide for floodways, dykes and similar preventive measures. **(e.g. Fraser River dykes)**
4. The federal government agreed to not pay disaster assistance for developments built in flood plains after they were mapped and designated. (However some Ministers could not resist handing out cheques in affected areas after floods.)
5. In some provinces sub-agreements on cost-shared flood forecasting services were negotiated (e.g. New Brunswick, Manitoba).**By 1992: The number of designated [flood plain] areas per province was as follows:***

- **Alberta:** 4 (St. Albert, Cochrane, Medicine Hat, Fort McLeod) Note: Alberta came late to the agreement but conducted further mapping unilaterally.
- **British Columbia:** 62***
- **Manitoba:** 16***
- **New Brunswick:** 8
- **Newfoundland:** 16
- **Nova Scotia:** 5
- **Ontario:** 64***
- **Quebec:** 24
- **Saskatchewan:** 16***
- **Northwest Territories:** 9
- **No agreement with Yukon**

1990 – 2000: Federal government phased out the FDR program with all agreements concluded by 2000.

2005: Severe flooding ("100 year flood") Southern Alberta – Report recommending preventive actions similar to FDR program, but broader, led by Alberta MLA and later Agriculture Minister G. Groeneveld, completed in 2006 – widely released only in 2012.

2013: Severe flooding southern Alberta with flows in Calgary slightly less than those proposed for flood-plain mapping in a 1979 report of Montreal Engineering to the Provincial Ministry of Transport.

*Flooding: Environment Canada 1993: 171pp

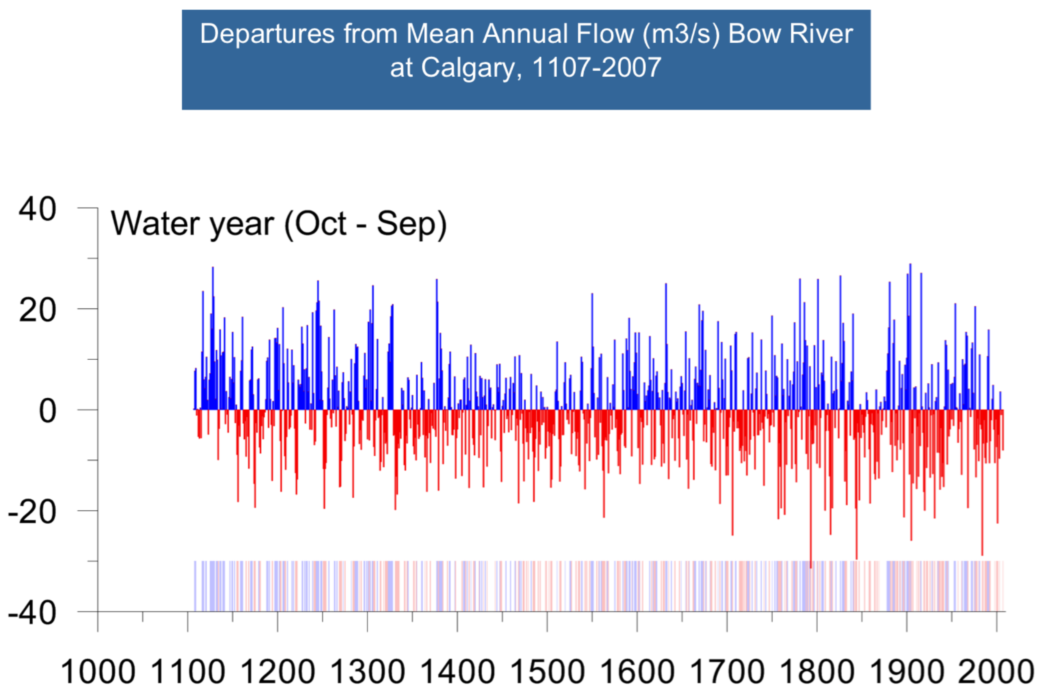
****** Note 1: It should be noted that while many of these flood plain maps are still in use, changes in land use upstream and changes in climate (e.g. more frequent intense rains) require that they be up-dated periodically. This is not systematically done in Canada.*

Note 2: The federal disaster assistance program remains on a "dollar-per-capita" formula, with federal contribution amounting to 50% of the costs for the second and third dollar costs per person, in the province affected, and rising to 90% for very damaging disasters (e.g. floods) causing more than $5 per capita losses.

J.P.Bruce, July 10th, 2013

Departures from Mean Annual Flow – Bow River at Calgary

Chart from Dave Sauchyn, Ph.D. and P.Geo from the Prairie Adaptation Research Collaborative (PARC).



"Last fall we completed a project for the City of Calgary in support of their drought mitigation plan. We produced a tree-ring reconstruction of the Bow River for the period 1107-2007. That record is attached [see above]. Note that it's a record of mean annual flow and not flooding. Water causes trees to grow but floods do not necessarily. It's possible to have a flood in a dry year although they tend to occur in wet years. Thus the tree rings show that 2005 and 1995 were wetter than average years but there were other years that were much wetter - they may or may not have been flood years. The message from the long tree-ring record is that the climate is more variable than we think - because our perception of the river is based on our personal experience and instrumental gauge records. The tree rings show that the basin can be much wetter and also much drier then we've experienced."

Additional Resources

Rood, Stewart B. et al. 1999. "Influence of Flow Regulation on Channel Dynamics and Riparian Cottonwoods Along the Bow River, Alberta." ***Rivers*** **Volume 7, Number 1, pages 33-48.**

> This article was provided by Stewart Rood, Professor and Board of Governors Research Chair in Environmental Science at the University of Lethbridge. This paper focuses on flood-flow attenuation of the Bow River and finds that historic river flows indicate that the dozen dams and reservoirs upstream of Calgary attenuate at least minor and moderate floods.

The Nature Conservancy. 2013. "Hurricane Sandy Disaster Recovery Principles." The Nature Conservancy. Accessed online at:
http://www.housedems.ct.gov/shore/pubs/TNC_post_Sandy_policy_principles_final.pdf

> This document was provided by Lisa Wojnarowski Downes, North America Coordinator for the Alliance for Water Stewardship and the Nature Conservancy. She thought the recovery principles outlined in this document would be relevant to flood planning in Alberta.

The 2013 Great Alberta Flood: Actions to Mitigate, Manage and Control Future Floods

Additional Feedback Compendium – Part II

September 20, 2013

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Introduction

This document catalogues additional feedback received from water experts and Albertans upon the August 2013 release of the Alberta WaterSMART White Paper titled "The 2013 Great Alberta Flood: Actions to Mitigate, Manage and Control Future Floods." This input is valuable and relevant, and is included in this document so that policy-makers can consult it and gain a deeper understanding of some of the issues related to flooding.

SECTION I: ADDITIONAL FEEDBACK FROM WATER EXPERTS

Rick Ross
Executive Director
Canadian Water Resources Association

My comments are very supportive of the overall document. I reviewed the document starting at the executive summary and am extremely supportive of recommendations one through six. The overland flood insurance that is not currently available in Canada could become a tool for restricting access to the floodplains for construction. Regulations could read that the government does not support and will not provide funding for any disaster which occurs in an area that has been refused flood insurance at the time of original construction/reconstruction.

For immediate, six month actions:

- The flood risks and building codes definitely need to be tightened and the flood risk parameter needs to be increased from a 25 year flood to a minimum of 100 year flood based on the historical and recorded flows. This is because as we construct and narrow the floodway, we will increase the level of the floods and storms that are becoming more extreme. And therefore, the risks will become higher.
- The rebuilding program that we are currently undertaking in Alberta needs to be precautionary for the future. No government funds should be expended in floodways without a caveat filed on the land confirming that there will never again be flood disaster support for that property as part of the agreement for funding. I agree with more support for relocation than for rebuilding. We should never sleep in a floodplain.
- We need a greater awareness of the possible major floods that could occur due to a storm event occurring downstream of the impoundment areas of dams, on or off stream.
- A stronger caveat could be a refusal to issue any rebuilding permits for construction in floodways. An Alberta example from the early 1950s in Lethbridge [is that] immediately following a flood that washed out residences in the River Valley, no reconstruction was allowed. That particular area has now been turned into a city park, tourist attraction (basement foundations are still visible) and wildlife centre.
- I have reservations about creating a provincial water authority as the awareness of the province's water variety is not where the population resides and weighting of population will not help water decisions. Better to give the WPACs more independent authority and set up a venue for them to cooperate in.

Slobodan P. Simovic, Ph.D., P.Eng.
Professor, Department of Civil and Environmental Engineering
Director Engineering Studies, Institute for Catastrophic Loss Reduction
University of Western Ontario

The PIEVC risk assessment tool mentioned in the report may not be [a] sufficiently powerful risk assessment procedure. I have developed and implemented an original procedure in flood risk assessment for the City of London (two recent papers that may be of use to you are attached). This procedure is now used by the Insurance Bureau of Canada in the development of so called MRAT - Municipal Risk Assessment Tool.

See attached:

Bowering, Elizabeth A. et al. 2013. "A flood risk assessment to municipal infrastructure due to changing climate part I: methodology." Urban Water Journal.

Peck, Angela M. et al. 2013. "A flood risk assessment to municipal infrastructure due to changing climate part II: case study." Urban Water Journal.

SECTION II: FEEDBACK FROM ALBERTANS

Rob Motherwell

Admittedly, in my opinion, the volume of flow in this event was too great for reservoir storage capacity to make too much of a difference in preventing downstream flooding with the volume of water this June. I do believe that it can make a big difference in skimming the peak flow in smaller flow events; but that would have to be confirmed by hydrologists. Also returning the reservoir storage capacity to its original volume may possible help reduce the peak elevation of the downstream flow (which could be the difference between just basement versus basement and main-floor). [You would have to] model it to properly know the answers.

I am not a hydrologist. I put this together based on my own research. All of the information would need to be verified but I am happy to share it for the purpose of a broader discussion on potential infrastructure mitigation measures – sustainability, etc.

Please see the attached power point presentation. There is a 1972 provincial and federal study in sedimentation of the Glenmore Reservoir. Please see reference to the key elements and data of the study in the power point. Also, I refer you to the Reservoir Sedimentation Handbook and the concepts of sustainable reservoir management outlined therein.

I did try to get a copy of the Flood Management Plan under FOIP last year so I could try to understand how the plan may potentially impact us as downstream residents [in Calgary]; I was denied under an exemption in the act which prohibits distribution of a "Crisis Management Plan."

I did find it odd that the very people that the plan is in place to protect are not allowed to access to review the plan so they can be 1) aware or 2) provide input to the plan contents.

See attached:

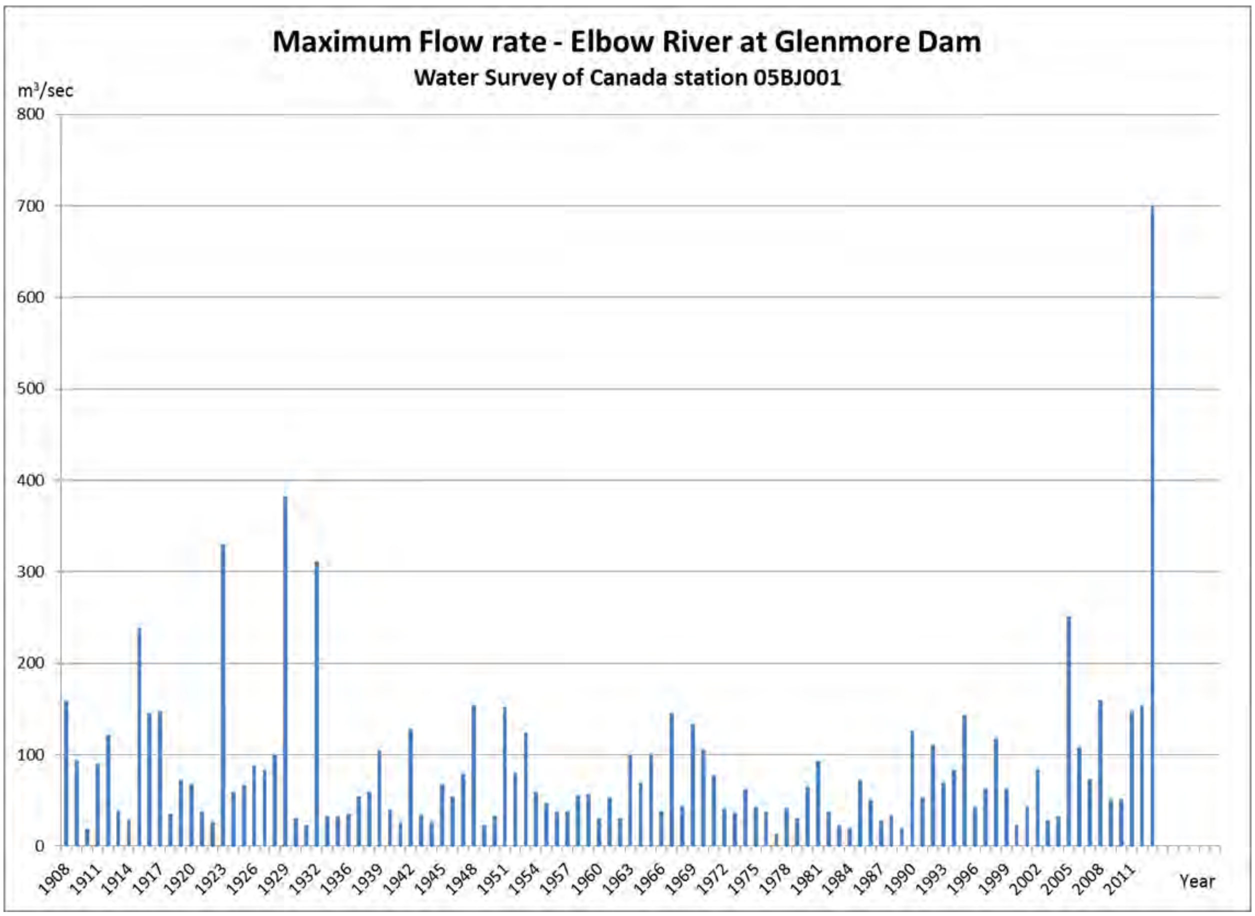
> *Motherwell, Rob. 2012. "Glenmore Reservoir Sedimentation and Storage Loss: The Need for a Proactive Sustainable Reservoir Operating Plan for the Benefit of Future Generations of Calgarians." Presented to Ward 11 Alderman Mr. Brian Pincott, December 6, 2012.*
>
> *Motherwell, Rob. "Sedimentation Process Historical Comparison."*

SECTION III: ADDITIONAL RESOURCES

Maximum Flow Rate of the Elbow River

The 2013 peak flow of Elbow River is relatively much higher than the Bow compared to historic peak flows. For the Elbow, 2013 is much higher than any previous recorded peak flows, in fact 80% higher than the previous peak in 1929 assuming it was 385cms as an approximation from the chart below.

Figure 1: Maximum Flow Rate – Elbow River



Source: Water Survey of Canada

Urban Water Journal
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/nurw20

A flood risk assessment to municipal infrastructure due to changing climate part I: methodology

Elisabeth A. Bowering [a], Angela M. Peck [a] & Slobodan P. Simonovic [a]
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RESEARCH ARTICLE

A flood risk assessment to municipal infrastructure due to changing climate part I: methodology

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Extreme rainfall events that are occurring more frequently as an effect of climate change and variability are causing increasing damages to municipal infrastructure. A methodology is developed to quantify the risk to municipal infrastructure from climate change-related flooding. The risk is measured using a combination of flow/frequency, stage/damage and damage/frequency curves. The measure of risk is termed the Risk Index and calculated for each infrastructure element within a municipality. The risk is aggregated and summed by spatial unit and presented in the form of risk tables and maps. The risk index takes into account both quantitative and qualitative information obtained from research and interviews with technical experts. The results from the application of the methodology to a municipality will lead to better policy and informed decision making.

Keywords: flood risk assessment; floodplain management; spatial risk; climate change; risk mitigation

1. Background

Climate studies have shown that warming trends are linked to global changes in the hydrological cycle (Bates *et al.* 2008). One of the main consequences is an increase in extreme precipitation events such as flooding and droughts (Roy *et al.* 2001, Prudhomme *et al.* 2003, Lemmen and Warren 2004, Cunderlik and Simonovic 2007, Kharin *et al.* 2007). Infrastructure is traditionally designed using codes and standards based on the historic climate data which is no longer sufficient for the climate loads experienced by the infrastructure today. Walsh *et al.* (2011) indicate that flooding extremes are a climate impact for which adaptation strategies, particularly in urban areas, are required.

The incidence and damages caused by inland flood disasters have increased over the past 50 years. The most common factor that affects the value of damage caused by flooding is socio-economic. That is population growth, a concentration of wealth in flood-prone areas and an increased dependence on technology (Board on Natural Disasters 1999, Tucker 2000, Bates *et al.* 2008, Barredo 2009, Munich Re 2010). According to Bates *et al.* (2008) the economic losses resulting from the flood events occurring in the period from 1996–2005 are five times as great as the losses incurred during the period from 1950–1980. With the development of more flood protection measures, a heightened sense of security is created and more expansion occurs in areas at high risk to flooding. Thus, any insufficiency in the flood control structures has the potential to lead to catastrophic damages.

Within Canada, a national committee was created to investigate the impacts that climate change will have on the municipal infrastructure. The main finding was that the failure of Canada's public infrastructure will become common due to changes in climate (PIEVC 2008). Consequently there is a need to identify the specific public infrastructure that demonstrates a high risk of failure due to climate change caused events and quantify that risk. This paper puts forth a methodology to assess the risk to municipal infrastructure under climate change caused flood events. The risk is assessed using quantitative and qualitative measures together in a novel approach that enables input from local experts. Additionally, the spatial distribution of risk is quantified and mapped.

Traditional flood risk assessments are damage-based which implies that the risk is quantified in terms of dollars of damage that result from a flood event. These damages are either tangible (direct and indirect) or intangible (Lekuthai and Vongivessomjai 2001). A number of spatial methodologies have been developed to quantify the direct damages due to flooding. One technique that is commonly used considers solely buildings to quantify the damages to the study area (Betts 2002, Fedeski and Gwilliam 2007). A benefit of this method is that less input data are required. However, the downside is that the resulting risk assessment does not accurately portray the effect of the

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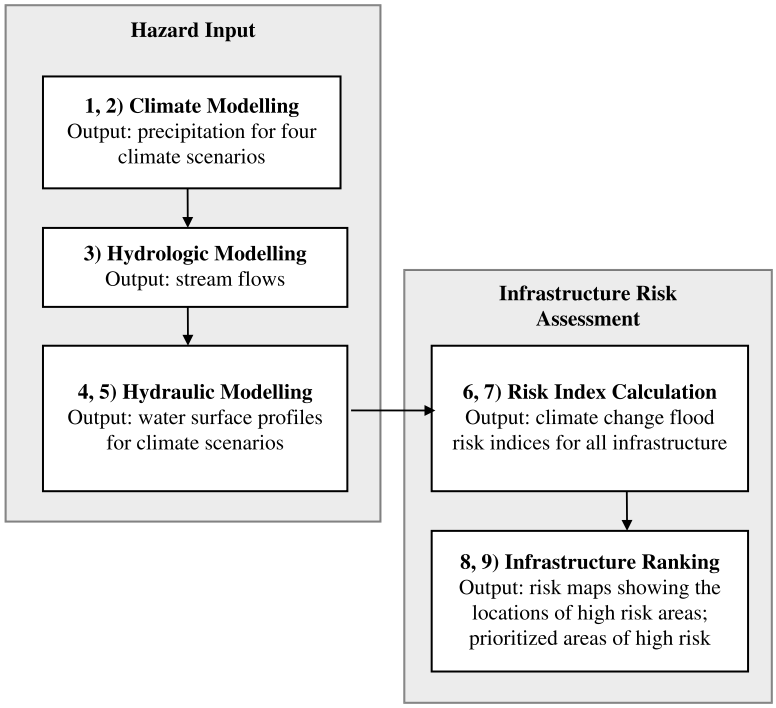

Figure 1. Climate change flood risk to municipal infrastructure study procedure.

flood on the municipal infrastructure in its entirety and therefore is not particularly useful for municipal planning.

A more detailed application of the first method uses the risk-based floodplain management practice described by Sayers *et al.* (2002) whereby stage/damage, stage/rainfall and rainfall/frequency curves are combined to produce a final damage/frequency curve. Yang and Tsai (2000) use a similar approach in their model for flood risk assessment termed GIS-based Flood Information System which produces a damage/frequency curve that is applied per unit area. The damage is calculated based on major land use, area and depth of inundation. This model produces a broader representation of loss as compared to Betts (2002) and Fedeski and Gwilliam (2007). However, it only considers damages based on one flood event and does not account for climate change or intangible damages.

Within the UK, Risk Assessment of flood and coastal defense systems for Strategic Planning (RASP) estimates the flood risk contributed by the flood defense structures within the system for each 1 km by 1 km impact zone. The assessment is based on work by Hall *et al.* (2005). This approach does not consider the risk to municipal infrastructure that is not protected by the flood defense system. Also in the UK, the National Flood Risk Assessment (NaFRA) is a comprehensive method that assesses risk based on expected annual damage (EAD), likelihood of flooding and location, type, condition and performance of flood defense systems in England and Wales. With all of these methods, however, there is still a lack of methodologies which allow for the incorporation of climate change scenarios to infrastructure design (Auld *et al.* 2006).

Many studies have been done to look at the affect that climate change induced flooding will have on urban areas. These studies use similar approaches mentioned above, combining future flood predictions, land use changes and spatial output of risk (Kirshen *et al.* 2008, Arnbjerg-Nielsen and Fleischer 2009, Bouwer *et al.* 2010, de Moel *et al.* 2011, Morita 2011, Storch and Downes 2011, te Linde *et al.* 2011, Feyen *et al.* 2012). A common factor in all of these studies is that they do not consider specific public infrastructure. That is, the damages are based on land use mapping and as such the results do not identify specific infrastructure at risk. To look at how specific municipal infrastructure may be affected, Ashley *et al.* (2005) applied four future climate scenarios of rainfall on storm drainage facilities in the UK. This study gave results on how to address risk specific to the storm drainage networks. There is a lack of studies done on calculating the potential damages and risk due to climate change flooding on all public infrastructure within a municipality at a small scale resolution.

To address this gap, this paper presents a methodology for assessing the risk to municipal infrastructure due to climate change-caused flooding. The risk assessment incorporates input from global climate models downscaled

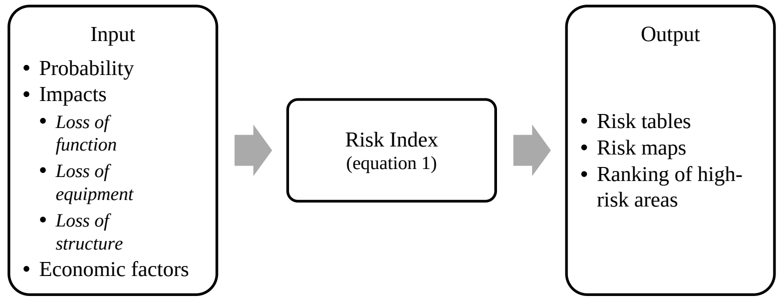

Figure 2. General risk assessment process.

using a weather generator to simulate ranges of climate scenarios. The risk is calculated for each infrastructure element and aggregated within spatial units to determine overall risk to a municipality. The spatial risk is then ranked and mapped to be used as input to municipal planning. Figure 1 shows the methodology in its entirety. The hazard analysis part includes climate modelling, hydrologic and hydraulic modelling. The second part includes risk index calculation and infrastructure ranking according to level of risk. Each step of the process generates as output, the input for the following step

The research presented in this paper follows the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS) project entitled: 'Assessment of

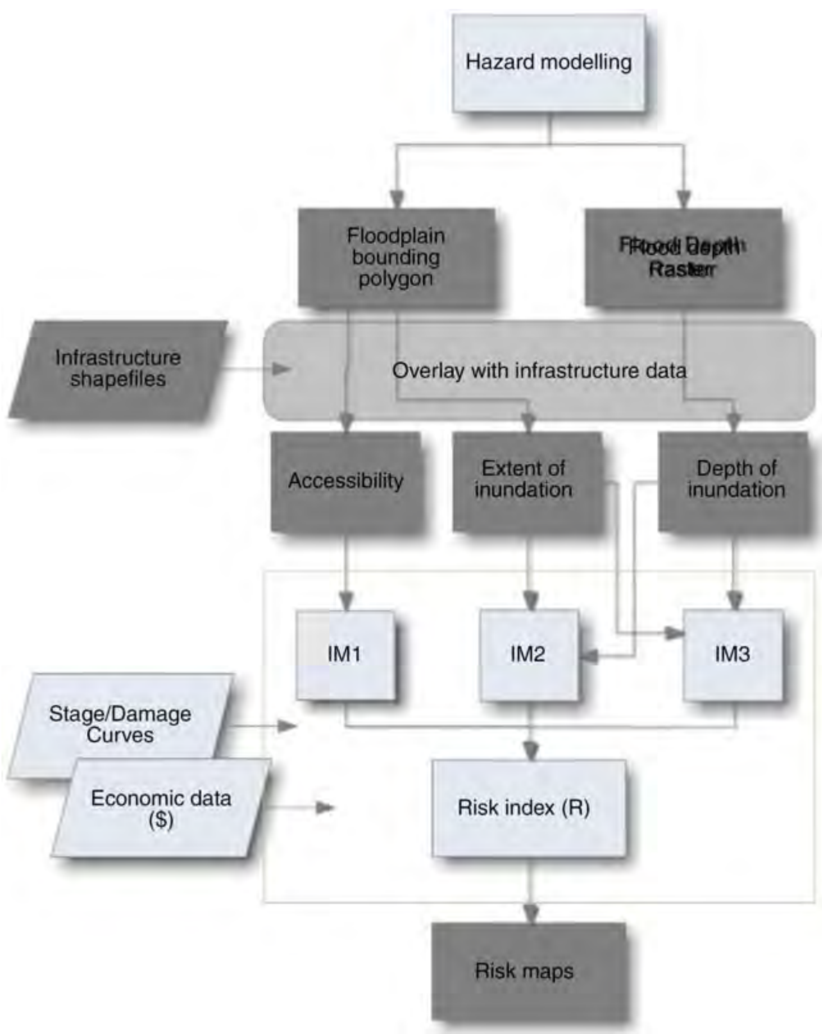

Figure 3. Risk assessment process showing integration of spatial analysis – dark grey indicates steps involving GIS.

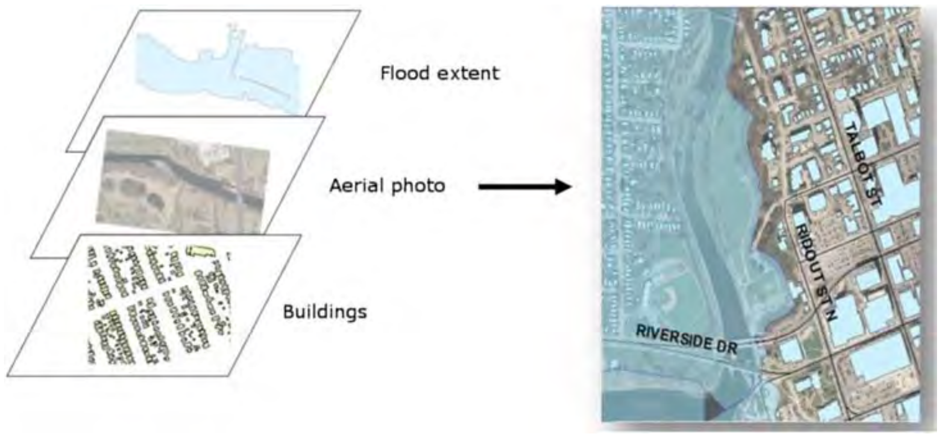

Figure 4. Combining layers of data in GIS to extract inundation information for risk calculation.

Water Resources Risk and Vulnerability to Changing Climatic Conditions' (Cunderlik and Simonovic 2005, 2007). Research done by Eum *et al.* (2011) provided the climate and hazard modelling used as input to the infrastructure risk assessment methodology as shown in Figure 1.

The streamflow data for selected return periods from both upper and lower bound climate scenarios (Eum *et al.* 2011) are run through the hydraulic model with GIS extension, HEC-GeoRAS to produce the hazard (floodplain) mapping. These flood profiles derived from the climate scenarios provide the hazard input for the infrastructure risk assessment. The use of upper and lower bound climate scenarios allows a range of risk to be calculated based on worst case and best case scenarios.

The paper first presents the methodology developed to assess the risk to municipal infrastructure from climate change-related flooding. The methodology follows four main steps: (i) data collection on municipal infrastructure for a specified area of interest, (ii) calculation of risk index for each infrastructure element under each climate scenario, (iii) aggregation and mapping of risk indices across the area of interest and (iv) ranking of high-risk areas using socio-economic factors. Finally the summary and conclusions of the research are provided.

2. Presentation of methodology

This research provides a comprehensive spatial flood risk assessment methodology to evaluate the risk to each infrastructure element within a municipality given varying climate change scenarios. The methodology is designed for floodplain risk assessment. However, it has the potential to be adapted to evaluate the risk from other climate change hazards such as changes in temperature extremes. Figure 2 shows the overview of the risk assessment procedure.

The main steps in the climate change infrastructure risk assessment are: (a) data collection on municipal infrastructure for specified region; (b) calculation of risk index for each infrastructure element, for each flood scenario; (c) aggregation and mapping of risk indices across the region to display the overall risk to municipal infrastructure due to flooding as a result of climate change; and (d) ranking areas of high risk using multi-objective ranking to include socio-economic factors.

The data collection focuses on identifying the current condition and responses of infrastructure to the climate hazard to determine the impact of the event on the infrastructure. This is used as input (see Figures 2 and 3) to calculate the risk. Risk is calculated as a product of a hazard probability and impact of flooding. The general process involves first determining the variables and constants to be used in the Risk Index Equation. These input variables are: the probability, impact multipliers and economic factors. Once these have been determined the risk index is calculated. The risk indices are then tabulated and displayed in risk maps. Finally, the high-risk areas are identified and ranked using varying weighting schemes with socio-economic factors to aid in the decision making and climate change adaptation.

The methodology furthers the risk-based floodplain management practice that is described by Sayers *et al.* (2002). That is, the hazard magnitude and frequency are identified and the potential consequences and impacts are evaluated and combined with the depth/damage curves. This leads to the creation of a damage/probability relationship which can be used in floodplain management. However, rather than using land use characteristics in a broad resolution, specific infrastructure elements are used to assess the risk.

The spatial unit used for risk index calculation is a Dissemination Area (DA). This area is defined by Statistics Canada (2007) as 'a small, relatively stable geographic unit composed of one or more adjacent dissemination blocks. It is the smallest standard geographic area for which all census data are disseminated'. Dissemination Areas are chosen as the spatial unit because of their usefulness in data analysis. As the definition suggests, they offer the highest resolution for which spatial analysis using any Statistics Canada data may be performed. This allows for the risk assessment to be combined with any Statistics Canada data such as socio-economic vulnerability indicators while maintaining the maximum spatial resolution. In addition, the DAs are created based on population (400 to 700 persons) and respect census boundaries (Statistics Canada 2007). This means they will be stable and minimize data suppression.

The risk is calculated for each type of infrastructure (be it a bridge, section of road or building). Further, risk is calculated for every infrastructure element within each type. The values can then be aggregated to determine the overall risk to the municipality. Figure 3 expands on the general process described by Figure 2. It shows the methodology undertaken to calculate the risk index for each infrastructure element, for each scenario, beginning with the output from the final hazard modelling – the flood extent and depth. The methodology involves the use of GIS as a tool for collecting and organizing data in the beginning stages, analyzing and exporting the hazard data, analyzing and exporting the vulnerability data, and finally presenting the results spatially. This integration of spatial analysis is also shown in Figure 3.

Figure 4 shows the process by which spatial analysis is used to extract the data used in the risk assessment. The input data consists of three layers – the hazard data (including the depth and extent of inundation), the ortho-imagery of the study region, and the spatial infrastructure data. The three layers are combined in GIS to extract the required attributes. These attributes include information on depth and extent of inundation at each infrastructure element within the study region.

The highest at-risk areas are then selected and ranked by combining risk to infrastructure with various socio-economic factors and using multi-objective Compromise Programming (Simonovic 2009). The ranking enables decision makers to have input on which factor is most important to them. This is useful for decision and policy making in terms of mitigating future disasters and adapting to climate change (Kubal *et al.* 2009).

The output of the methodology is the spatial visualization of risk in the form of colour-coded risk maps. These maps display the risk to the specific infrastructure and the risk across a wider region for each climate scenario.

2.1 Risk Index

A novel indicator is introduced to assess the risk to each infrastructure element. This original indicator is termed the Risk Index, R. The risk index allows for the comparison of risk across each infrastructure category and can be aggregated to show the risk to a region. The index incorporates both the quantitative and qualitative risk to address the objective and subjective uncertainties in the data. It is used to rank the infrastructure across the area of interest to aid in the prioritization of infrastructure maintenance with respect to floodplain management. The mathematical expression of the index is:

$$R_{keqj} = P \times \sum_{i=1}^{3} (EF_{jike} \times IM_{jike}) \qquad (1)$$

where:

- R_{keqj} is the risk index for each infrastructure element of type k in DA q (\$CAD);
- q is the DA;
- j is the climate scenario;
- P is the probability of occurrence of the hazard event (dimensionless);
- EF_{jike} is the economic factor for each climate scenario, j, impact category, i, infrastructure type, k, and each infrastructure element, e (\$CAD);
- IM_{jike} is the impact multiplier (fraction of damage sustained for each scenario, impact, infrastructure and element);
- e is the infrastructure element;
- k is the infrastructure type (building = 1, bridge = 2, barrier = 3, critical facility = 4, pollution control plant = 5 and road = 6); and
- i is the impact category, from 1 to 3, representing function, equipment/contents and structure, respectively.

Spatially, the methodology must define and analyze the following sets of data:

- J: the geographic area covered by the floodplain for a given climate scenario;
- Q: the DAs within the boundaries of J;
- K: all infrastructure types contained in Q (from 1 to 6 as described in Equation (1)); and
- E: all infrastructure elements for each set of K

Mathematically, the relationship between all classes of data is described by the following set notation:

$$E \subset K \subset Q \subset J \qquad (2)$$

The risk index is calculated for each element of each set. By summing the risk indices within the set the total risk may be found for any set, up to and including each climate scenario, J.

The first term in Equation (1) is probability of occurrence, P. The probability of occurrence in this case is the return period of the flood event. Thus for a 250 year flood, $P = 0.004$. For each return period of interest, the hydrologic and hydraulic modelling is carried out, resulting in water depth and extent for each flood event. The infrastructure risk assessment is repeated in its entirety for each flood extent generated by the hydraulic analysis.

The second term is the economic factor (EF_{jike}) for each climate scenario, j; impact category, i; infrastructure type, k; and infrastructure element, e. The impact categories refer to the response of the infrastructure to the hazard. Infrastructure experiences varying failure modes during a flood event. The responses include both direct and indirect damages (such as loss of structural integrity or loss of productivity, respectively). The methodology focuses on three major impacts that a flood has on municipal infrastructure that are used to quantify risk. These impacts are: (1) loss of function; (2) loss of equipment; and (3) loss of structure. Loss of function ($i = 1$) refers to the degree to which the infrastructure can no longer perform to the level with which it was intended. This is a measure of the fraction of function lost as a result of the flooding. The loss of function multiplier is calculated using spatial analysis. Loss of equipment ($i = 2$) measures the percent of equipment (non-structural) that is lost due to inundation. Some infrastructure categories (bridges, roads and pipe networks for example) do not have equipment and therefore this impact is neglected. The final impact category, loss of structure ($i = 3$), refers to the fraction of physical structure lost as a result of the flood. 'Structure' is defined as any permanent component of the infrastructure.

The economic factor is a measure of the economic cost (in 2009 $CAD) for the particular infrastructure. This measure typically uses a percent estimate of indirect costs for loss of function, replacement value of the equipment or contents and the replacement value of the structure for EF_{j1ke}, EF_{j2ke} and EF_{j3ke} respectively.

The final term in Equation (1) is the impact multiplier (IM_{jike}). There are three impact multipliers considered which are associated with the aforementioned impact categories. IM_{j1ke} is the impact multiplier associated with loss of function; IM_{j2ke} is the impact multiplier associated with loss of equipment and IM_{j3ke} is the multiplier associated with loss of structure. These three multipliers are used to quantify the effects of inundation or flooding on the infrastructure. Each multiplier is a number belonging to [0, 1] where 0 denotes no change (no loss of function, no loss of equipment and no loss of structure) and 1 represents complete loss.

The variable IM_1 can take the value [0, 1]; where 0 represents complete functionality and a value of 1 represents entire loss of function. In this research, transportation, buildings and flood protection infrastructure are considered to have IM_1 equal to 1 if they are inundated. Buildings and critical facilities are assigned an IM_1 of 1 if they are inundated or if all access to the structure is cut off. Flood protection structures (dykes) have an IM_1 value of 1 once their design capacity has been reached.

Some infrastructure types can function at partial capacity during a flood event - some functionality of the infrastructure may be preserved even when it is inundated. Partial loss of function may include limited access to an essential building and interrupted service. For example in the case of critical infrastructure, partial loss of function occurs when some, but not all, of the access routes to fire stations, emergency management services (EMS), hospitals and schools are blocked by floodwaters. Equation (3) shows the calculation of the loss of function multiplier for a critical facility ($k = 4$).

$$IM_{1,4e} = \frac{(n - r)}{n} \tag{3}$$

where:

n is the total number of major access routes; and
r is the number of these routes obstructed by floodwaters.

The entrance to a fire or EMS building is counted in the total number of routes, n, to allow for the building to have partial access if all major (arterial or primary) routes are flooded but the building is not inundated.

In the case of schools and hospitals, the loss of function multiplier is calculated based on the total number of access routes within one intersection from the building. Therefore in Equation (3) the variable n takes on the value of the total number of intersections adjacent to the property (as opposed to only the major routes). This is done to more accurately represent the directionality of access. The directionality of access describes the nature of the infrastructure. Fire and EMS have vehicles and personnel leaving the building to service an emergency, whereas schools (acting as emergency shelters) and hospitals receive people.

The second impact multiplier, IM_2, is an estimate of the fraction of equipment lost as a direct result of inundation. Equipment is considered building contents or in general, non-structural components of the infrastructure. For residential buildings, equipment refers to personal belongings, furniture, small electrical appliances, tools or anything that would generally be expected to be taken during a move (Water's Edge et al. 2007). Infrastructure that does not possess equipment (e.g. roads) is assigned a value of 0 for IM_2 variable. Stage-damage curves are used to derive the percent lost.

The final impact multiplier, IM_3 measures the degree to which the structural integrity of an infrastructure is compromised as a result of flooding. This research considers flood depth as the main flood-caused load parameter used in risk assessment. The IM_3 variable is a measure of both quantitative and qualitative structural loss. The methodology takes an innovative approach in the incorporation of qualitative and subjective data with quantitative data. Qualitative analysis uses fuzzy set theory to adjust values based on subjective input and differences in risk perception. The result of qualitative analysis is used to modify quantitative risk to capture stakeholder opinions. This approach considers the condition of an infrastructure, its failure mechanisms and its response to flood loads. The calculation of IM_3 includes the impact that an infrastructure's condition has on its response to flooding. Condition of an infrastructure may be based on its age, maintenance and other important factors relating to an infrastructure's ability to resist and recover from damage. For this research, the specific factors influencing an infrastructure's condition were obtained during interviews with experts on municipal infrastructure. The combination of qualitative data with quantitative data provides for a more comprehensive representation of risk.

The quantitative deterministic component of IM_3 is calculated using stage-damage curves. These curves use the inundation depth as input to estimate the level of damage an infrastructure may sustain as a result of being flooded. Stage-damage curves should be specific to the infrastructure type, construction material and the structure's location. These curves are commonly used in the assessment of flood-based damage and provide more accurate information when they have been developed for a specific municipality.

Recently updated stage-damage curves are available from the Flood Damage Estimation Guide (Water's Edge et al. 2007) for residential, commercial and industrial buildings in Ontario. The curves are based on data from Southern Ontario and the results have been updated to account for inflation. They were prepared for the Ontario Ministry of Natural Resources.

Stage-damage curves are required for all infrastructure types to quantify the deterministic component of structural damage (IM_3). However, these curves are not available for each infrastructure type encompassed by this research. Therefore, stage-damage curves must be created for transportation structures (roads, bridges and culverts) and PCPs. This is done by examining regional flooding case studies and through interviews with local infrastructure experts in each field. Interviews are conducted separately with experts on each of the aforementioned infrastructure to answer questionnaires pertaining to the response of the infrastructure to flooding and the damages they have seen in their experience. These questionnaires, along with the regional flooding case studies are then compiled into stage-damage curves. These curves are used to estimate the percent of structural damage that may be expected based on the experience and opinion of experts and they are used in estimation of IM_3 during the calculation of the final risk index.

The qualitative element of IM_3 is used to quantify the subjective uncertainty associated with potential failure of the infrastructure system. Assessment of subjective uncertainty is conducted with the assistance of experts. Qualitative component of IM_3 allows for the measure of partial failure as well as for the impact of the structure's current conditions on its response to flooding as perceived by experts in the field. This qualitative component is termed the fuzzy reliability index (*FRE*) (El-Baroudy and Simonovic 2004). The fuzzy reliability index uses fuzzy set theory to measure the performance of the infrastructure in the event of failure.

The premise for the combination of the fuzzy reliability index with the quantitative structural loss measure is that the condition of the infrastructure will affect the amount of structural damage sustained by the infrastructure during a flood. The condition of the infrastructure is not quantified by the stage-damage curves and therefore the input of persons most familiar with municipal infrastructure may provide a more accurate assessment of risk. To account for this, the condition of infrastructure is measured using fuzzy analysis through an interview process.

Fuzzy set theory is used to address ambiguity and uncertainty in data (Simonovic 2009). It allows for partial membership in a set or subset by quantifying the degree of belonging to the set (Zimmerman 2001). As applied in this methodology, fuzzy set theory is used to measure the extent of failure of an infrastructure element upon inundation; enabling the response to be characterized as complete failure (a membership of 1 in the set of failure), no failure at all (a membership value of zero) or some partial failure – membership between 0 and 1.

The use of the fuzzy set theory allows for different opinions on what constitutes acceptable failure. It is used to define the degree to which the system has failed while taking into consideration how individuals perceive a degree of 'acceptable' failure. The ability to measure varying levels of failure is particularly significant when a very large number of infrastructure elements are under consideration. It assists in the prioritization of infrastructure by separating infrastructure that may be less resilient to flooding.

Functions describing the membership of an element to a certain set are created through interviews. An individual's responses are based on previous experiences and current risk perceptions. The belonging of an element to a particular set are functions otherwise known as membership functions. The *FRE* (second component of IM_3) uses two membership functions to measure an infrastructure's performance: system-state membership function and acceptable level of performance membership function. The *FRE* is calculated based on the area of

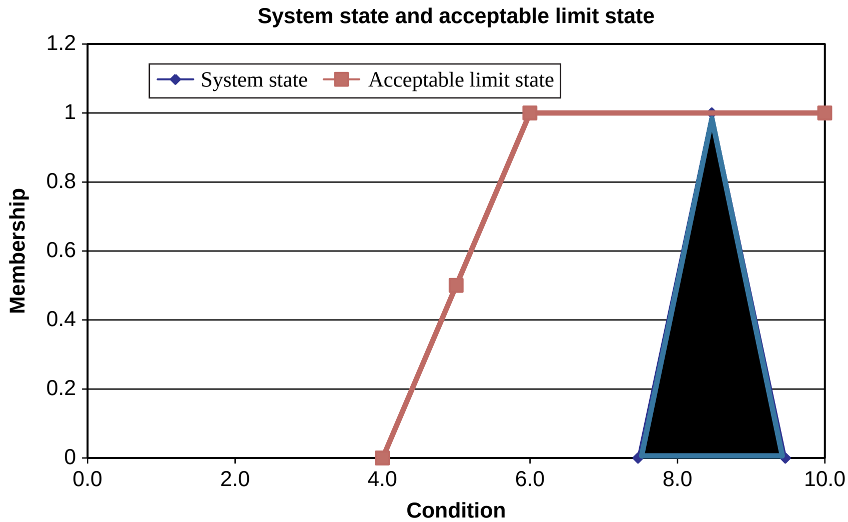

Figure 5. System state and acceptable limit state curves. Shaded area indicates area of overlap.

overlap between these two curves. This overlap is considered acceptable partial system failure. In most cases, the larger the acceptable partial failure, the more risk the expert is willing to accept.

Membership functions are created that describe the current state of each infrastructure as well as its acceptable level of performance. The system-state membership function describes the condition of an infrastructure element based on factors such as age, material, maintenance and design life. Some factors may influence the condition of an infrastructure more than others. To determine what these factors are and to what level they contribute to the condition of infrastructure, interviews are conducted with various departments within a municipality. Questionnaires are provided that ask the interviewees to rate the condition of the infrastructure based on given values of the factors listed above. These are compiled to generate curves that link the condition to each factor. Using the infrastructure dataset, conditions are then assigned to each infrastructure element.

The second set of curves – the acceptable level of performance functions – is created for each infrastructure type. These curves are also created using input from municipal experts. The expert is asked to rank how acceptable are the given conditions of the infrastructure. These given conditions, associated with the rank of acceptability are used to define what an acceptable performance of an infrastructure is. This definition is subjective and responses may be different for each decision maker based on their previous experience, education, expertise and personal perception of risk. By incorporating these different risk perceptions, risk can be better represented.

As previously mentioned, *FRE* is calculated using the area of overlap between the system-state and acceptable level of performance curves. The fuzzy compatibility measure (*CM*) is used to measure the extent of this area (Simonovic 2009). *CM* is calculated using a weighted area method since the higher the membership, the more significant the value is. *CM* is calculated using the following equation:

$$CM_e = \frac{WOA_e}{WASS_e} \tag{4}$$

where:

WOA is the weighted overlap area between system state membership function and acceptable level of performance curve; and
WASS is the weighted area of system state function

In instances where there are multiple acceptable levels of performance, the fuzzy reliability index can be calculated using the equation derived by El-Baroudy and Simonovic (2004):

$$FRE_e = \frac{\max\limits_{p \in K}\{CM_1, CM_2, \ldots, CM_p\} \times LR_{\max}}{\max\limits_{p \in K}\{LR_1, LR_2, \ldots, LR_p\}} \tag{5}$$

where:

$LR_{\max}$ is the reliability measure of acceptable level of performance with which the system-state has the maximum compatibility value (CM);
LR_p is the reliability measure of the 'p' acceptable level of performance;
CM_p is the compatibility measure for system-state with the 'p' acceptable level of performance; and
K is total number of defined acceptable levels of performance.

In this case, there is only a single value for acceptable level of performance provided from interview responses. Therefore, *FRE* is directly calculated as the overlap area of the two curves.

A *FRE* value of 1 indicates that the system-state is fully within the acceptable region of level of performance; indicative of a safe system. Conversely, an *FRE* value of 0 signifies no overlap between the system-state and acceptable level of performance, indicating the system in a complete failure state. Therefore the desirable state occurs at maximum overlap between the system state and acceptable level curves; a high *FRE* value.

A triangular distribution shape to represent the system state for a particular infrastructure is assumed. Other distribution shapes are described in Simonovic (2009). This shape describes the state of an infrastructure element based on its age, structural properties and infrastructure-specific factors which contribute to an infrastructures current state of condition. Condition is measured on a relative scale of zero to ten [0–10], where a value of 10 represents an infrastructure in perfect condition. The acceptable limit state curves are trapezoidal and are based on what is considered to be acceptable condition for each infrastructure type; a value of 0 is completely unacceptable and a value of 10 considered completely acceptable. The combination of acceptable level of performance and system state curves provides for the calculation of the fuzzy compatibility measure mentioned previously. When the acceptable limit state curve increases to 1 (most acceptable condition), an increase in *CM* indicates an increase in the infrastructure's condition being acceptable (i.e. likely to incur less damage). Figure 5 shows the overlap between an acceptable level of performance and current system state. In this figure, there is total overlap indicating a safe system.

During a flood event, the condition of an infrastructure element will affect its structural loss measure (IM_3). Therefore, to calculate IM_3 the fuzzy risk component and the deterministic components must be combined. An increase in the compatibility measure indicates less risk to a particular infrastructure. Thus, an infrastructure element that is considered to be in unacceptable condition will experience higher damage than an infrastructure element considered to be in excellent condition. To represent this inverse relationship in the calculation of the loss of structure impact multiplier (IM_3), the following equation is used:

$$IM_{3e}(CM_e) = \begin{cases} 1, & CM_e = 0 \\ \mathrm{Min}(1, LS_e \times (1/CM_e)), & CM_e > 0 \end{cases} \quad (6)$$

where:

IM_3 is the impact multiplier related to loss of structure;
CM is compatibility measure; and
LS is percent damage from the stage-damage curves for a particular infrastructure element, e.When CM is 0, the structure is considered completely unsafe or experiencing total loss ($IM_3 = 1$). The stage damage curves are assumed to represent damage to a structure at a completely acceptable limit state. As such, for $0 < CM < 1$, risk to the infrastructure will increase proportionally. A CM value of 1(completely acceptable) will yield $IM_3 = LS$.

This innovative procedure of combining qualitative and quantitative measures of risk provides a more representative estimate of climate change flood risk to infrastructure. The condition state of an infrastructure just prior to a flood event can be used to better estimate the response, failure mode and potential damages in the event of a flood.

Once each term has been determined and combined to calculate the risk index per element, the risk indices are summed to determine the overall risk per DA, set Q. These indices are then normalized to allow for enhanced understanding of the risk index. A limitation with using normalized values is data suppression. In cases where there is a very large, dominant risk value, the differences between the remaining values are minimized and some values are suppressed to such small values as to become seemingly unimportant. Therefore, it is necessary to also examine the non-normalized (original) values for use in comparison between scenarios and for the Compromise Programming multi-objective analyses.

GIS is then used to process the risk indices to form the final risk maps. The maps display the risk to each DA as a summation of the individual risk to each infrastructure item within the boundaries (set Q). Where an element crosses a DA boundary, the infrastructure is assumed to contribute equal risk to both areas.

3. Summary/conclusions

The integrated risk assessment of municipal infrastructure due to climate change methodology is introduced to address the need for a comprehensive, city-wide, infrastructure risk assessment. The Risk Index is introduced to calculate the hazard and vulnerability of a city's infrastructure, and is then input to risk maps for visualization and prioritization. The method of combining GIS tools for spatial analysis, with the calculation of the risk index, is a powerful technique that allows for an overall visualization of risk to the city by DA combined with the ability to identify the risk to each infrastructure element contained within the DA. The result is the opportunity to make informed decisions on funding and adaptation policies and prioritize engineering action to address the risk in the city. By implementing a comprehensive infrastructure risk assessment a city can mitigate future damages.

The summary procedure of the risk assessment methodology applied is as follows:

(1) Gather data and determine the infrastructure elements to be analyzed.
(2) Pre-process the data for compatibility with GIS software in preparation for steps 3 and 4.
(3) Overlay maps of the infrastructure with the flood inundation scenarios.
(4) Extract the flood depths for each scenario at each infrastructure location.
(5) Calculate the Risk Index for each infrastructure element based on the inundation depth, expected impacts and associated costs.
(6) Rank the infrastructure with respect to the Risk Indices, presenting the result as both maps and tables.

This is an iterative process from steps 1 through 5 requiring continual re-working as data insufficiencies are discovered or new data is acquired. The final maps are created using GIS.

The spatial risk analysis methodology is developed as an important tool for quantifying the risk to municipal infrastructure due to climate change. By combining spatial analysis and data processing software, a comprehensive risk assessment that calculates the risk to each infrastructure element in the municipality can be performed. Further, it introduces a method by which the risk to each infrastructure element within the municipality can be aggregated by DA to provide a spatial distribution of risk. The resulting risk maps and prioritized list of at-risk areas provide decision makers and policy experts with information that is key to successful floodplain management. Mapping the spatial variability of risk is an integral part of the municipal decision making process and provides an accessible means for communicating the results of the analysis with the experts and decision makers. It allows for spatial risk and vulnerability, which may otherwise be lost, to be incorporated in the assessment. For further study the methodology is applied to the City of London, Canada as a case study by Peck *et al.* (2013).

3.1 Limitations and future work

The risk assessment methodology used in the study is data intensive. This may increase the time required to apply the methodology, particularly if the area of study does not have a spatial dataset of infrastructure or a well-organized method of infrastructure attribute documentation.

During interviews with technical experts it may be difficult to obtain multiple individual responses as opposed to a group response. Thus there is the potential for suppression of individual opinion which affects the use of the fuzzy set theory analysis and description of risk perception.

The methodology considers only infrastructure located within the identified flood extent (fluvial flooding). In reality there is a potential for flooding of properties which are not in the floodplain. This may be due to sewer surcharges coming back through in-home fixtures, spouting through manholes to spill over onto roads, or due to insufficient capacity of catch pits (pluvial flooding). Further work can be done in this area to expand the methodology to include flooding in other areas.

There is an additional area to investigate with this methodology which is to include more details in the analysis to account for flow velocities and duration of flooding. Incorporating these factors into the assessment will lend to an even greater understanding of the specific impacts the flooding may have on the infrastructure specifically and study area in general.

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A flood risk assessment to municipal infrastructure due to changing climate part II: case study

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RESEARCH ARTICLE

A flood risk assessment to municipal infrastructure due to changing climate part II: case study

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Flooding often has devastating consequences. It is important to understand the evolution of these risks as climate changes. Municipal infrastructure is designed using historical data that no longer accurately represents current climate conditions, indicating infrastructure may underperform. The purpose of this study is to apply a new methodology for the assessment of climate change caused flood risk by Bowering *et al.* (2013) to the City of London, Ontario, Canada. Floodplain maps derived from climate, hydrologic and hydraulic analyses provide direct input into risk assessment procedure. Inundated infrastructure and high risk areas are identified in tables and maps for two climate and two hydraulic scenarios. Results indicate the most critical flood scenario is the 100 year climate change upper bound and high risk is driven by expensive infrastructure located in the floodplains. Results of the study are used as the support for climate change adaptation policy development and emergency management.

Keywords: climate change; flood risk; geographic information system (GIS); infrastructure; water resources management

1. Introduction

Currently, municipal infrastructure is designed to codes and standards that do not consider the impacts of changing climatic conditions. As the climate changes, infrastructure is often unable to cope with the increased capacity required for satisfactory performance and consequently is not able to adequately perform the function it was designed for. In many regions of the world, as weather patterns change and the frequency of extreme events increases (Intergovernmental Panel on Climate Change (IPCC) 2007), it is likely that the risk of infrastructure failure will also increase (Auld and MacIver 2006). Society relies on the safety and integrity of infrastructure on a daily basis. Communities depend on infrastructure for shelter, work, access, emergency and culture. Even a small increase in extreme events and climate variability can result in a great damage to municipal infrastructure (Freeman and Warner 2001, Institute for Catastrophic Loss Reduction (ICLR) 2010). It is therefore important to understand the risks and consequences to municipal infrastructure under changing climatic conditions.

Warming trends are linked to global changes in the hydrologic cycle (IPCC 2007). As a result, there is an increase in the occurrence of precipitation extremes (floods and droughts). In the Upper Thames River Basin (Ontario, Canada), previous studies (Cunderlik and Simonovic 2005, 2007, Eum and Simonovic 2009, Eum *et al.* 2011) suggest climate change may contribute to the following phenomena:

- Increase in precipitation amounts during the spring and fall seasons;
- Decrease in precipitation during winter months;
- Increase in frequency of severe precipitation events;
- Shift in seasonality of precipitation events;
- Increase in overall annual average temperature;
- Increase in minimum and maximum expected temperature extremes, where winter months from November to April are expected to warm faster than summer months of May to October (consistent with IPCC findings); and
- Shift in snowmelt timing.

These changes have the potential to damage natural, physical and social systems in the basin. Municipal stakeholders and decision makers are often interested in regional climate change responses on a shorter time scale than global models provide. The outputs of the global circulation models (GCMs) are often insufficient to accurately represent changes in climatic conditions on a local level. Global models tend to have coarse resolution (spatially) and are sometimes temporally incompatible with regional scales of interest (Cunderlik and Simonovic 2005). To study the impacts of climate changes on a local level, downscaling techniques are often implemented to interpret GCM outputs (Cunderlik and Simonovic 2007, Prodanovic and Simonovic 2007). There are multiple ways in which this may be achieved. This research adopts the use of a Weather Generator (WG) to downscale the output

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from GCMs to address spatial and temporal uncertainties and generate various future climate scenarios (Sharif and Burn 2006).

Prodanovic and Simonovic (2007) performed rigorous calculations and determined that 100 year precipitation events are expected to occur more frequently than before; that is, the probability of an event of similar magnitude is now once in 30 years. Consequently, climate change demands a review of current floodplain regulations, practices and management at the municipal level. Current design capacity of storm sewer infrastructure may be exceeded under new loads imposed by climate change. In order to reduce adverse effects of climate change and prevent underperformance of critical infrastructure systems, it is necessary for stakeholders to understand potential climate change effects and develop adaptation strategies (Prodanovic and Simonovic 2007). Regional risk assessment can help target particular locations and flag infrastructure for further climate change impacts research which can guide climate change adaptation efforts and finances in the appropriate directions. In addition to climate change effects, land use changes and urbanization often reduce available water storage capacity, further contributing to more flooding (Kundzewicz 2003). It is the vulnerability of population, infrastructure and property that determines the level of damage and loss during a natural disaster (ICLR 2010). Risk, as mentioned in Kundzewicz (2003) and as considered in this research, is taken as the product of the probability of an extreme event occurring and its adverse consequences.

The main objective of this paper is the application of an innovative risk assessment methodology to the City of London, Ontario, Canada with the purpose of identifying areas where municipal infrastructure is at greater risk of incurring damages as a result of increased flooding due to climate change. The approach to risk assessment is the application of the procedure described in detail by Bowering *et al.* (2013). The following sections describe the generic risk assessment structure, the application of this procedure to the City of London, Ontario, Canada and results of the case study.

2. Risk assessment methodology

The methodology used in this paper is presented in detail by Bowering *et al.* (2013). Risk assessment methodology uses GCM data that are downscaled by a weather generator (WG), to provide input for hydrologic and hydraulic modeling. Hydraulic modelling generates depths as output for use in delineating the floodplain area for municipal flood risk assessment. Work done by Eum *et al.* (2011) provides the hydrologic and hydraulic inputs required for the implementation of the flood risk assessment methodology.

The developed procedure for risk assessment (Figure 1) is generic and may also be applied to other cities to determine climate change flood risk. An original indicator is introduced to assess the risk to each infrastructure element called Risk Index (RI). The proposed RI captures the consequences and damages to infrastructure as a result of flooding. The mathematical expression of risk in general terms is:

$$Risk = Probability\ of\ hazard \times Consequence \tag{1}$$

Consequence is considered to be comprised of a variable pertaining to the economic value of an infrastructure element and the damage impact a flood may cause. A more descriptive form of the risk index is:

$$Risk\ Index = Probability\ of\ hazard \times \Sigma(Economic\ Value \times Impact\ Multiplier) \tag{2}$$

The risk index enables risk across each infrastructure category to be compared and can be aggregated to determine risk for a particular area. The index incorporates both quantitative and qualitative risks to address objective and subjective uncertainties in the data. This index is used to prioritize infrastructure across a region.

Implementation of the risk assessment methodology is as follows:

(1) Data collection;
(2) Development of comprehensive municipal infrastructure list;
(3) Gathering input from municipal stakeholders;
(4) Repeat (1) to (3) iteratively with stakeholder involvement until the infrastructure list is finalized and there is sufficient data for risk assessment;
(5) Pre-processing of available data from various sources to ensure compatibility;
(6) Extraction of flood inundation levels for all infrastructure elements in the flood plains;
(7) Risk index calculation;
(8) Presentation of risk index in the form of tables and maps;
(9) Prioritization of infrastructure with respect to risk index for policy making.

Risk index is calculated for each infrastructure element in comprehensive spreadsheets and used to prepare summary risk tables and risk maps. Areas of high risk are identified and used for developing municipal adaptation policies that address climate change impacts on infrastructure.

3. Case study

3.1 Introduction

The City of London continues to experience riverine flooding on an annual basis. The impact of flooding on

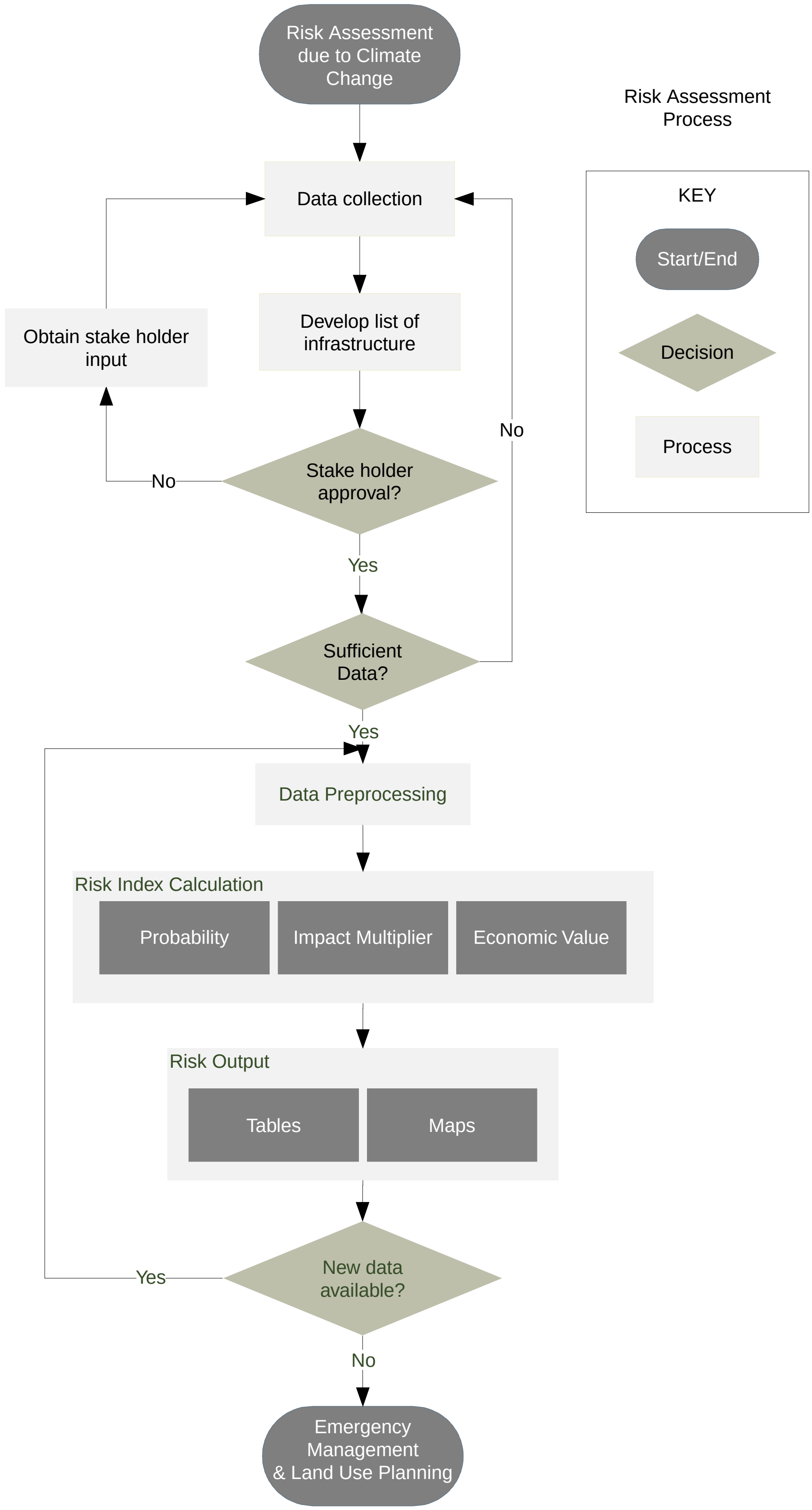

Figure 1. Flowchart of risk assessment methodology.

Figure 2. Location of London, Ontario within Canada.

municipal infrastructure is a function of flood characteristics and infrastructure characteristics. This risk assessment considers flood depth and extent as the flood characteristics which impact municipal infrastructure, and infrastructure specific to this case study.

3.2. Description of the basin

The City of London is located between lakes Huron and Erie in southwestern Ontario, Canada (Figure 2) and is located in the Thames River basin. The Thames River and its tributaries: Dingman, Stoney, Pottersburg, Medway and Mud Creek flow through the City (Figure 3) (Community of London Environmental Awareness Reporting (CLEAR) 2006). The Thames River originates North of Stratford and just East of Woodstock in the wetlands of Tavistock, and drains into Lake St. Clair. The basin is prone to flooding with historical events recorded back to the 1700s. In response to frequent historical flooding, an extensive system of dams and dykes was built to protect the City from floods. The Thames River upstream of the City is attenuated by the Fanshawe, Pittock and Wildwood Dams. The Fanshawe Dam plays a major role in controlling water flow within the City. The dam's primary purpose is to protect the City during flood conditions by storing water in an upstream reservoir. The reservoir is also used to augment low flows during the summer season to meet consumer demands, provide for recreational activities and generate hydroelectricity.

The City of London has multiple dyke structures lining the Thames River including: West London, Broughdale, Ada-Jacqueline, Nelson-Clarence, Riverview and the Coves dykes. The West London Dyke (WLD) is the longest dyke in the City, spanning 2.2 km and protecting over 1100 structures behind the West bank of the Thames near downtown London making it one of London's most significant flood protection structures (Goldt 2006). The dyke is a gravity structure consisting of earth fill with poured in place concrete facing supported by a concrete toe (Stantec 2006). It is owned by the City of London and operated by the local conservation authority, the Upper Thames River Conservation Authority (UTRCA).

The City of London has experienced substantial growth within the last 40 years (CLEAR 2006) and has a population of about 352,000 (City of London 2010). Urban sprawl continues to spread outwards from the downtown core into suburbs and onto agricultural land. Fanshawe College, the University of Western Ontario, and its affiliates all bring large populations of students to the area, many of whom are renters concentrated near campuses in high density housing in close proximity to the North Thames River in flood-prone areas. As a national leader in healthcare services, the City is also home to an increasing elderly population.

Water quality of the Thames River and its tributaries is generally considered poor, though improving. The water quality is affected by agricultural runoff pollutants, industrial waste, and sediment deposition. The City has a well-documented history of flooding dating back to the 18th century. One of the worst floods in London's history occurred in 1937 (Figure 4a). This flood was responsible for millions of dollars in damages to local roads, railways and businesses (UTRCA 2010). This flood is also largely the reason for the implementation of a comprehensive network of flood protection structures in the City including

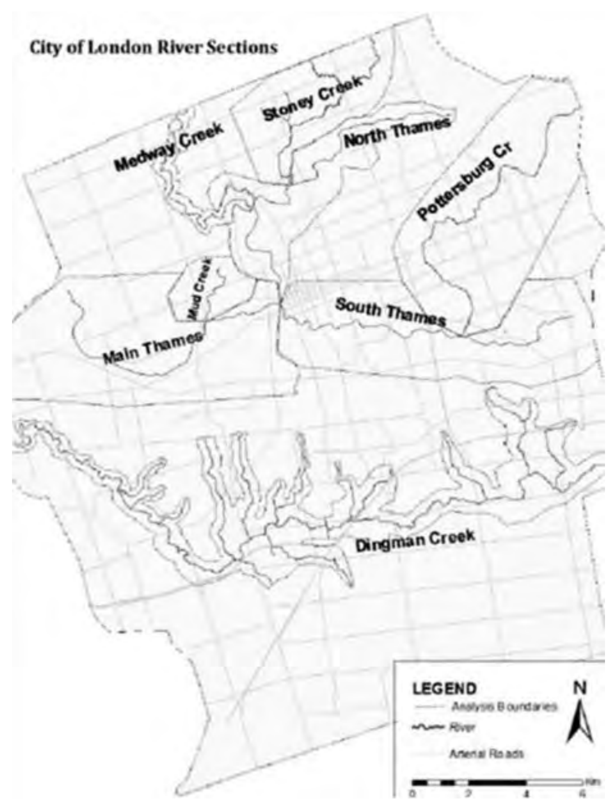

Figure 3. Thames River and its tributaries within the boundaries of the City of London.

Figure 4. (a) The 1937 flood of the Thames River, London, Ontario (UTRCA 2010). (b) The 2008 flood of the Thames River, London, Ontario (Sredojevic 2008).

dykes, dams and floodgates. Flooding has also occurred on a smaller scale more recently in the winter and springs of 2008 and 2009. Presently, floods continue to cause damage to municipal infrastructure and inconvenience local residents, services and industry (Figure 4b).

3.3 *Municipal infrastructure*

The City of London played a critical role in determining the infrastructure to include in this study. The selection process was iterative and placed an emphasis on infrastructure that is owned and operated by the City and infrastructure with direct impacts on public health and safety. Infrastructure considered to have insufficient available data was removed from the study under approval of City stakeholders. Technical experts, City counsellors and engineers worked together to compile a list of critical infrastructure to consider in the climate change flood risk assessment. The final list includes: flood protection structures (flood gates, dams, dykes), bridges (pedestrian, vehicular, culverts), roads (arterial), critical facilities (Emergency Medical Services (EMS), fire stations, police stations, hospitals, schools), water treatment facilities (pollution control plants) and buildings (commercial, residential, industrial, institutional). It is important to consider damages to each infrastructure type independently because each responds differently to flooding.

Bridges and culverts documented in the City's Bridge Management System (City of London 2003) are included in the risk assessment. Their main modes of failure include scouring and erosion at the embankments and piers. Debris impact from flooding could also cause structural and aesthetic damages. The functionality of a bridge is considered to be lost when the deck is submerged and people can no longer safely cross the bridge, or when emergency management personnel otherwise deem it unsafe and close it.

Critical facilities are defined in this study as the buildings which provide essential or emergency services and include: hospitals, emergency medical services (EMS), fire stations, police stations, pollution control plants and schools. Many of these services are especially important during a flood event and therefore are studied separately from the rest of the building infrastructure. They experience similar structural impacts as regular buildings but are more expensive infrastructure to build and repair, as well as also generally containing more expensive equipment and contents. It is assumed that critical facilities will be closed and/or evacuated in the event of inundation, but access to these facilities during a flood may still be important so the number of alternate routes to and from these facilities is considered in the risk assessment.

The City of London has six pollution control plants (PCPs): Southland, Greenway, Vauxhall, Oxford, Adelaide and Pottersburg. Together the plants have the capacity to handle approximately 298 ML/day (CLEAR 2006). Currently Pottersburg, Adelaide and Greenway experience difficulty discharging during extreme flow events. Emergency overflows are in place to manage the discharge in addition to a bypass at Pottersburg. The PCPs are located in low lying areas along the Thames River and its tributaries. Due to the location of the plants within the floodplain, accessibility during a flood event is a concern. Vulnerable components of the pollution control plant include the tanks, clarifiers and electrical equipment.

Roads are a critical network in the event of any disaster as they allow for evacuation and rescue access for emergency services. Primary failure mechanisms for an inundated roadway include scour of the embankments and subsoil (washout) and rutting. Other failure modes include total collapse due to extreme scour and surface wear from debris impact. One of the most common impacts of flooding on a roadway is that it decreases its design life (Mills 2007), so replacement or repair may become necessary after a flood event, especially when restoring access to critical facilities.

Only existing infrastructure is considered in the current assessment. The risk methodology is developed in relation to existing infrastructure elements, but is flexible and may be adapted to include additional infrastructure where appropriate.

3.4 Spatial distribution of risk

To capture the spatial variability of flood risk, the calculation and spatial presentation of results is done in spatial units called Dissemination Areas (DAs). These areas are defined by the Statistics Canada as small, relatively stable geographic regions for which all Statistics Canada data are disseminated. There are 19,177 DAs within the province of Ontario; 527 of these are within the boundaries of the City of London (Statistics Canada 2010). Spatial presentation of flood risk provides for identification and prioritization of regions exposed to high risk from flooding for more effective municipal decision making including emergency management and land use planning.

3.5 Flooding scenarios

Two climate scenarios are used in this case study: climate change lower bound scenario (CC_LB); and climate change upper bound scenario (CC_UB). These two scenarios were selected to best represent the lower and upper bounds of a range of possible climate change impacts for the Upper Thames River Basin. All of the climate scenarios within these bounds are equally likely to represent future climate (Simonovic 2010). The *lower bound climate change scenario* (CC_LB) represents a future climate where greenhouse gas (GHG) concentrations are reduced, development is controlled and clean-practice policies are implemented. This scenario is produced by shuffling and perturbing local historical climate data. The *upper bound climate change scenario* (CC_UB) on the other hand, represents a potential future climate where GHG emissions continue to increase, combined with rapid urbanization and growth. This scenario is generated by integrating GCM data with the historical climate data and then shuffling and perturbing these data to produce a modified climate record. The CC_UB scenario may be considered the critical case for extreme precipitation and high flow analyses (Simonovic 2010). These climate change scenarios are not intended to predict the future (Hall *et al.* 2005) but function as future climate possibilities used in this study to better understand the range of potential climate change impacts.

In addition to two climate scenarios, two hydrologic scenarios were selected for consideration: 100 year and 250 year return period floods. The current regulations require the use of these two scenarios. Presently, development is prohibited within the 100 year floodplain and development is limited, but not restrictive within the 250 year floodplain. These two scenarios are modeled for both climate scenarios (CC_LB and CC_UB). A fifth scenario is selected to represent the current state of the system. This scenario captures the 250 year flood for current climate conditions and it is named 250_UTRCA. Flood plain extent and water depth data corresponding to this scenario were provided by the UTRCA.

In summary, this study considers four climate change scenarios plus an additional scenario (to represent the current conditions) as follows: 100 CC_LB, 100 CC_UB, 250 CC_LB, 250 CC_UB and 250_UTRCA. Risk analysis is completed for each of the five scenarios to assess climate change impact on municipal infrastructure in the city of London. Results are used to determine high risk scenarios and identify locations where risk or change in risk is the greatest.

Climate modeling results include long sequences of precipitation data. Hydrologic calculations take the precipitation data as input to produce the streamflow data for each climate scenario. Streamflows are used as input into the hydraulic model (HEC-RAS) and water surface profiles are generated for each of the five climate scenarios for the Thames River and its tributaries. The water surface profiles generated in HEC-RAS are exported and processed spatially in GIS using HEC-GeoRAS software; this provides a link between HEC-RAS output and geospatial locations. The depth of water for each grid cell location is calculated by intersecting the water surface profile with the regional topography of the City of London represented by Digital Elevation Model (DEM) to produce maps of both, spatial extent and inundation depth (Figure 5). These maps are produced for the Thames River and its tributaries within the boundary of the City and are used as input for the flood risk assessment. The detailed description of the risk analysis input preparation (including climate modelling, hydrologic modelling and hydraulic modelling) is in Eum *et al.* (2011).

3.6 Risk assessment

The following section describes the implementation of the risk assessment procedure detailed in Bowering *et al.* (2013) to the City of London.

Inundated infrastructure for each of the climate scenarios is determined by visual inspection of the floodplain extent in GIS; infrastructure within the floodplains is considered for further analyses. For the City of London, over 1000 buildings, 85 bridges and four PCPs are inundated in all of the considered scenarios (Table 1). At each of these locations the maximum depth of water is extracted from the GIS file and is used to assess the potential damages. The outcome of the analysis is presented in the form of multiple risk maps for each climate scenario: total risk; risk to a particular type of infrastructure; the difference in risk between scenarios; and others. Multiple risk tables are used to describe these

Figure 5. The 100 CC_LB scenario floodplain and river centerline overlapping aerial photograph at the location of the University of Western Ontario, London, Canada.

maps in more detail. Risk is considered to be the product of probability and consequence (Equation (1)), or more specifically as probability, impact and economic multipliers (Equation (2)).

3.6.1 *Probability*

The probability of a flood event occurring is related to the return period of an extreme flow event and represented spatially as a floodplain. The probability of the 100 CC_LB and 100 CC_UB climate scenarios are equivalent (1%); indicating both scenarios are *equally likely* to represent potential future climate for the City of London. Similarly, the 250 CC_LB, 250 CC_UB and 250 UTRCA scenarios have the same 0.4% probability of occurrence; these scenarios are also *equally likely* to occur, however are less likely to occur than the 100 year climate scenarios.

3.6.2 *Impact multipliers*

The risk assessment methodology considers three variables called Impact Multipliers (IM_j), to capture potential consequences of flooded infrastructure: loss of function (IM_1), loss of equipment (IM_2), and loss of structure (IM_3). The loss of function (IM_1) multiplier quantifies the degree to which an infrastructure is no longer capable of performing its designated function. This variable differs for each type of infrastructure, based on its intended use. PCPs in the City can maintain partial functionality even barring minor equipment damages.

The loss of equipment (IM_2) multiplier quantifies the percent of non-structural equipment that is lost or damaged due to inundation. Consideration is given to direct and indirect damages resulting from a loss of equipment or contents. For certain infrastructure, this multiplier works in conjunction with the loss of function multiplier (IM_1) to consider that during flood events equipment may function at full, partial or zero capacity. Certain infrastructure (transportation and flood protection structures) do not have associated operating equipment; therefore this multiplier is negligible.

Loss of structure (IM_3) multiplier is calculated using a combination of qualitative and quantitative data to provide a more comprehensive representation of risk. Quantitative data include estimates of the ability of a particular infrastructure component to withstand direct damages caused by flooding and the additional consequences related to inundation depth. The quantitative component of IM_3 is determined using local stage-damage curves specific to infrastructure type, construction material and location. Recent stage-damage curves for residential, commercial and industrial buildings in Ontario are available from the Flood Damage Estimation Guide (Ministry of Natural Resources 2007). The curves are prepared for the Ontario Ministry of Natural Resources and are based on data from Southern Ontario and are used in risk assessment for estimation of monetary damages to infrastructure in the

Table 1. Extent of inundation and infrastructure inundation for four climate scenarios plus additional Upper Thames River Conservation Authority (UTRCA) scenario.

	100 CC_LB	100 CC_UB	250 CC_LB	250 CC_UB	250 UTRCA
Inundation area (km^2)	23.0	25.8	26.0	27.9	24.6
Infrastructure					
Buildings	1110	2535	2517	2706	1762
Bridges	85	88	89	91	89
Critical facilities	3	6	6	6	3
Dykes	1	4	4	4	4
PCPs	4	4	4	4	4
Roads (seg)	112	152	151	164	147

City of London. Where stage-damage curves were not available, these curves were assumed based on research, historical observations and professional judgement provided by local engineers. The qualitative component of IM_3 quantifies the subjective uncertainty associated with potential failure of the infrastructure system by utilizing fuzzy set theory. Subjective uncertainty describes the impact of maintenance, age, material deterioration and similar factors, on the potential failure of an infrastructure element. The fuzzy approach involves gathering information from local experts (City personal, experts from the UTRCA and other institutions) through interviews to incorporate the expertise and experience of decision makers into the risk assessment procedure. These interviews are used to provide more detailed input into relationships between the physical condition of an infrastructure element and its response to flooding. Interviewees were asked to respond to a series of questions relating to how physical condition of an infrastructure element (based on age, materials, maintenance and frequency of use) affects the degree of damage incurred during a flood. The interview responses were used to form fuzzy membership functions which were applied as weighting factors in the risk index calculation. The City of London keeps a record of municipally owned infrastructure (roads, bridges, PCPs) and their current condition in files such as the Bridge Management System, Pavement Quality Index and Maintenance Records. This present-state of infrastructure condition is then used in conjunction with the fuzzy membership functions, inundation depths and stage-damage curves to calculate IM_3 for each infrastructure element.

One drawback of this approach is suppression of individual risk perceptions. When administering questions to groups of participants, individual responses from City experts appeared to be suppressed as agreement or consensus responses were provided. This limits somewhat the value of interview responses and the fuzzy approach; a greater number of respondents are more desirable to capture variances in risk perception. In this study, lower and upper bound responses were assumed based on the original consensus response provided by interviewees.

3.6.3 Economic multipliers

Economic loss refers to the potential for monetary damage incurred by an infrastructure element as a result of a flood. Therefore, an emphasis is placed on infrastructure that is expensive to replace or repair. This is consistent with the City's priority of protecting and investing in infrastructure that could potentially reduce financial losses in the event of a flood. There is an economic impact multiplier (EM_1, EM_2, EM_3) associated with each impact multiplier (IM_1, IM_2, IM_3). The values for each economic impact multiplier (EM_j) were obtained from various sources including the City of London, the Municipal Property Assessment Corporation (MPAC), the Statistics Canada and the Upper Thames River Conservation Authority (UTRCA). These values do not represent market value of the infrastructure; they are the cost associated with replacing or repairing an infrastructure element after flood damage. For all IM_j the Consumer Price Index (CPI) is used to express the value in 2009 dollars and provide consistent and comparable damage values for all infrastructure types. A CPI of 113.7 is used in this case study for the reference year (2009). Using CPI to modify values considers the impacts of inflation and prevents more recent infrastructure from skewing the risk analysis. Generally, as the flood depth increases the potential damages to infrastructure also increases.

4. Results

Results of the study are presented using risk tables and maps. These types of output provide information that is useful to municipal decision makers. Maps created in ArcGIS provide a spatial representation of risk while tables provide detailed numerical information about risk within the City. Using maps and tables together provides insight into climate change caused risk and provides for effective and informed decision making. Tables and maps are related to each other by way of a GIS tool; the risk indices from tables are linked to spatial units (DAs) in GIS. Using this method, risk indices are graphically displayed for each climate scenario across the entire City in GIS. It is possible to identify areas of high risk in the maps and use corresponding tables to identify which infrastructure is contributing most to the high risk.

The total value of flood risk due to climate change is shown in Table 2. These tables represent total risk across the entire city and are spatially independent. The 250 CC_UB scenario has the greatest depth and extent of flooding (Table 1) however, overall risk is highest in the 100 CC_UB scenario. The difference in flood depth and extent does not compensate for the fact that the 250 year flood event is significantly less likely to occur than a

Table 2. Final Risk Index (dimensionless) for four climate change scenarios plus additional Upper Thames River Conservation Authority (UTRCA) scenario for all infrastructure. Risk Index is spatially independent.

	100 CC_LB	100_CC UB	250 CC_LB	250 CC_UB	250 UTRCA
Risk Index	5,730,000	9,840,000	3,668,000	5,004,000	3,188,000

100 year event. Thus, the 100 CC_UB scenario may be considered the most critical climate scenario. Tables and maps are related to each other and by way of a GIS tool that enables the risk indices from tables to be linked to spatial units (DAs) which make it possible to graphically display risk indices for each climate scenario spatially across the entire City. The total risk maps are produced for each climate scenario (100 CC_LB; 100 CC_UB; 250 CC_LB; 250 CC_UB) and the additional 250 UTRCA scenario considering all infrastructure within the City (Figure 6a–e). These maps easily identify areas of focus for climate change adaptation efforts. High risk areas are identifiable by dark shades of colour, lower risk areas are lighter in colour and those areas unaffected by riverine flooding are the lightest.

The area immediately behind West London Dyke is of particular importance. This area is low lying land that consists typically of commercial and residential development. In the 100 CC_LB scenario, the area behind West London Dyke is not flooded (Figure 7). However, in the remainder of the scenarios (100 CC_UB, 250 CC_LB, 250 CC_UB, and 250 UTRCA) the area becomes inundated, flooding houses, businesses and schools (Figure 8). Similarly, the Broughdale Dyke provides insufficient protection under all five scenarios. River water would enter behind the dyke and trap water, inundating an expensive residential area. Many of these structures would require major repair or replacement in the event of a flooding scenario that breaches the dyke.

In many cases for all five scenarios, the high risk areas contain bridges or PCPs that experience high levels of inundation in all five climate scenarios. These are expensive infrastructure with large economic impacts when they are impacted by flooding. Therefore these infrastructure contribute significantly to high risk areas.

Comparisons are made between the different scenarios and differences in risk are represented in tables and maps. These comparisons are important for developing climate change adaptation priorities. Comparisons between analyzed scenarios make it possible (a) to identify deficiencies in the current flood protection, (b) to identify areas where infrastructure may be underperforming, and (c) to determine the 'most critical' scenario. For illustrative purposes the comparison between 250 UTRCA and 250 CC_UB scenarios is presented next.

4.1 Comparison between 250 UTRCA and 250 CC_UB scenarios

The purpose of comparing the 250 UTRCA and the 250 CC_UB scenarios is to determine the contribution of climate change to change in flood risk. There is an increase in risk across the City of approximately 57% between the current regulatory floodplain (250 UTRCA) and the 250 CC_UB scenarios. Areas where there are large differences in risk are of particular interest (Figure 9), as these identify locations where the flood risk may presently be underestimated. Generally, the 250 CC_UB scenario has greater inundation extent and depth than the 250 UTRCA scenario; this contributing to higher risk in most areas along the river. In particular, risk changes are most significant along Pottersburg Creek (a tributary of the Thames River). These differences can be attributed to a culvert that is unable to convey the increased flows along the river. As a result, the river backs up at the culvert and floods nearby residential areas. Currently, the culvert is under designed for increased climate loads represented by the CC_UB scenario (Figure 10). Flooding in the low land where PCPs are built also results in high damages for both scenarios. Risk differences are highest in these areas due to high levels of inundation. These areas may benefit most from specific climate change policy and adaptation measures.

5. Recommendations

The results of the study provide insight in the climate change-caused flood risk to municipal infrastructure within the City of London, Ontario, Canada. Based on the risk assessment the following three types of recommendations (engineering; operational; and policy and regulatory) are provided to the City Council to assist in developing a viable climate change adaptation policy. The brief summary of recommendations includes:

5.1 Engineering recommendations

(1) Improve data collection and reliability;
(2) Survey high risk regions to obtain more detailed information pertaining to flood proofing measures, building contents and people who may be more susceptible to flood damages;
(3) Resurvey bank slopes and infrastructure over water;
(4) Expand risk assessment to include additional infrastructure;
(5) Refine stage-damage curves for the City to reflect regional conditions and previous historic flooding events and to improve the accuracy of flood risk assessment;
(6) Modify risk assessment for dynamic flood simulation to better represent temporal changes in the flood risk.

5.2 Operational recommendations

(1) Create detailed emergency plans for all pollution control plants in the floodplain. To maintain

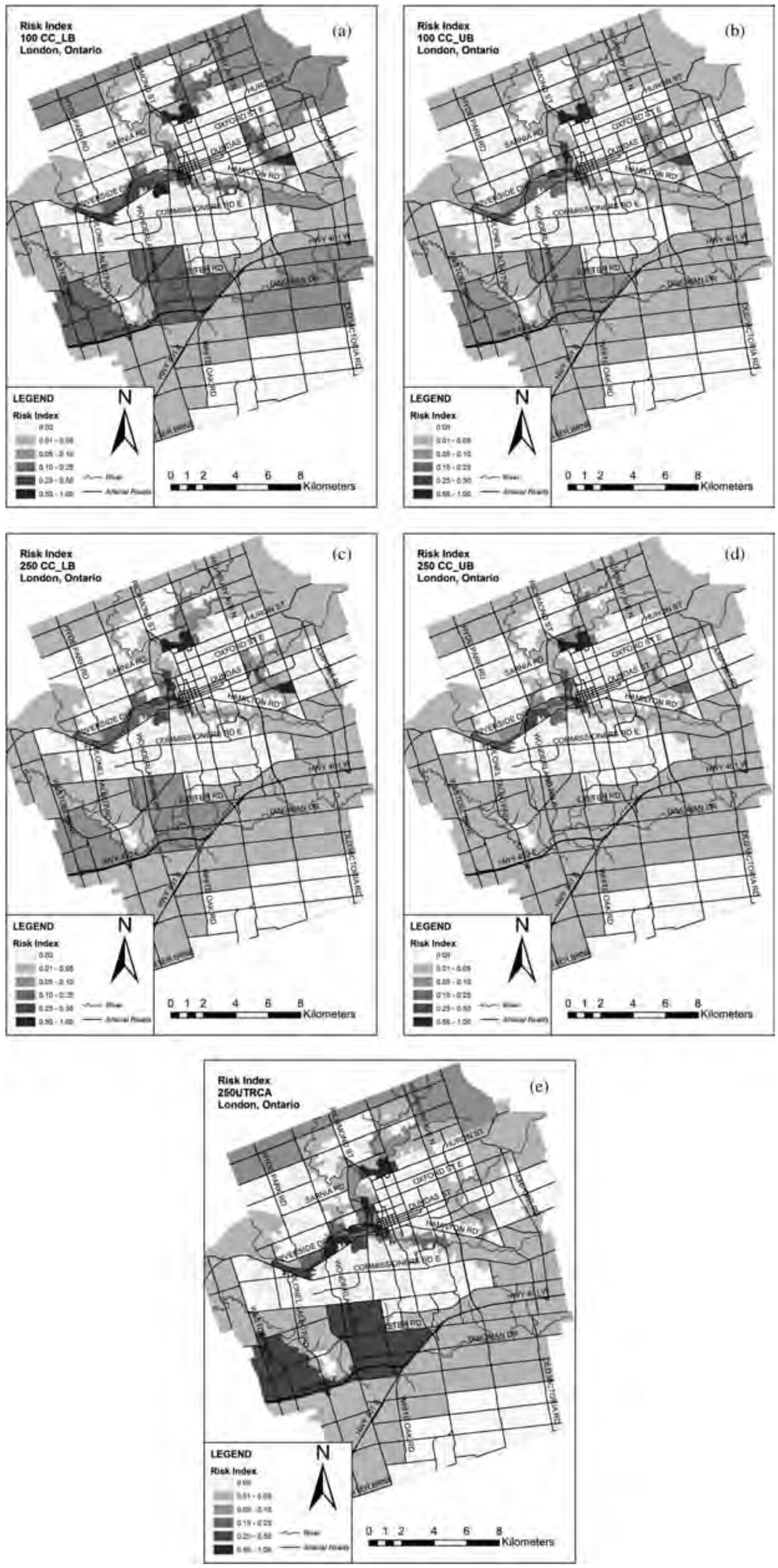

Figure 6. (a) Risk across the City of London classified from zero (lightest) to one (darkest) for the 100 year climate change lower bound (100 CC_LB) scenario. (b) Risk for the 100 year climate change upper bound (100 CC_UB) scenario. (c) Risk for the 250 year climate change lower bound scenario (250 CC_LB). (d) Risk for the 250 year climate change upper bound scenario (250 CC_UB). (e) Risk for the 250 year Upper Thames River Conservation Authority (UTRCA) scenario (250 UTRCA) that represents current conditions.

Figure 7. Aerial of West London Dyke inundation under 100 CC_LB scenario in GIS.

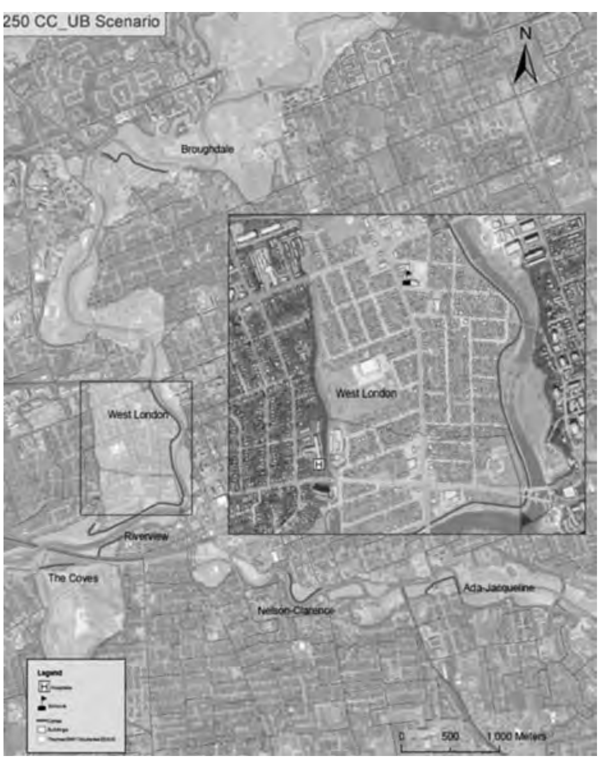

Figure 8. Aerial of West London Dyke inundation under 250 CC_UB scenario in GIS.

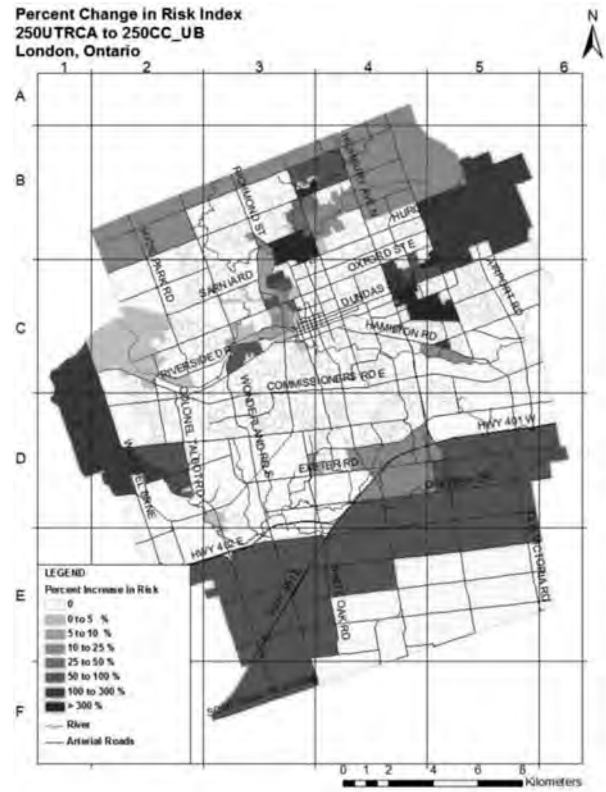

Figure 9. Percent change in risk between 250 Upper Thames River Conservation Authority (UTRCA) and 250 year climate change upper bound (CC_UB) scenarios for the City of London, Ontario.

Figure 10. The Thames River backs up at a culvert on a tributary of the Thames River (Pottersburg Creek) under the 250 year climate change upper bound (250 CC_UB) scenario, flooding nearby residential areas.

functionality of the plant during a flood event, it is recommended that the PCPs raise, or make mobile, essential operational equipment. It would be beneficial for these plants to also have a flood recovery plan to outline procedures to manage and maintain the PCP after a flood event.

(2) Improve documentation of historical records of flood events and associated damages to the City owned infrastructure. Damages to building structure, foundation, equipment, contents and lost profits can be used to improve flood damage estimates.

5.3 Policy and regulations recommendations

(1) Include social and environmental considerations in the climate change-caused flood risk assessment. Natural disasters have an impact on infrastructure, as is the focus of this study; in addition, flooding also has social and environmental implications. Social and environmental vulnerabilities can influence risk by modifying the magnitude and spatial distribution of risk. Social vulnerability is based on the concept that a population exposed to flooding is susceptible to suffering physical, emotional or psychological distress. Environmental vulnerability is the susceptibility of sensitive natural areas to flood effects. Identifying vulnerable populations and environmentally sensitive areas can aid emergency management and increase the effectiveness of disaster response and recovery actions. These areas can be targeted for social and environmental resiliency improvement programs and specific adaptation strategies;
(2) Reconsider current floodplain regulations; regularly update floodplain maps and modify the current floodplains to include potential climate change impacts. Cost-benefit analysis could help determine the cost of risk reduction;
(3) Initiate climate change impacts into the design and maintenance of municipal infrastructure by designing to new standards and increase regular inspections and maintenance of high risk infrastructure.

At the London City Council meeting of July 25, 2011 all the recommendations of the presented study were accepted for further implementation.

6. Conclusions

The increasing hydrological demand due to climate change is resulting in an underperformance of municipal infrastructure. Based on flood history and future climate projections for the area, the City of London can expect an increase in severe precipitation events that will lead to increase in flood risk. Climate change may bring physical hazard of flooding to areas which have not previously been exposed, putting them at high risk to incur damages. To capture changes in the climate, two climate scenarios are considered in this application of risk assessment: climate change lower bound (CC_LB) and climate change upper bound (CC_UB). Both the CC_LB and CC_UB scenarios are considered for the 100 and 250 year return periods and the historical UTRCA scenario considers the 250 year return period to produce five total climate scenarios for risk assessment: 100 CC_LB, 100 CC_UB, 250 CC_LB, 250 CC_UB and 250 UTRCA. A comprehensive risk assessment procedure has been applied to the City of London (Ontario, Canada) to address the potential impacts of flooding due to climate change. Risk is expressed as the product of probability and consequence and is assessed both quantitatively and qualitatively to capture multiple types of uncertainty. Risk indices are produced for each of the five climate scenarios and areas of high risk in the City are identified and recommended for further investigation. The results of the climate change study provide useful insight into the potential impacts of climate change on municipal infrastructure in the City of London, Ontario.

(1) Flood risk to municipal infrastructure within the city is estimated to increase by 57% as a consequence of climate change in a 250 year event. This will significantly increase the demand on current infrastructure, which may not have the capacity to handle the increase. Areas of high risk should be targeted for future infrastructure rehabilitation, emergency management and land use planning activities. These high risk areas are currently situated behind the Broughdale and West London dykes. High risk areas often contain expensive infrastructure such as: bridges, buildings and PCPs.
(2) The 100 CC_UB scenario is the most critical climate change risk scenario. Although this scenario may incur lower financial damages, the overall risk is greater because the probability of this event occurring is greater than the 250 year scenarios. This is an important consideration in future floodplain management, land use planning and policy decisions. Areas which were historically in the 250 year floodplain which are now in the 100 year climate change floodplains may not be prepared to handle the additional loads and more frequent flooding.
(3) Risk results in the forms of tables and maps can provide useful information for decision making in areas of engineering, operations and policy.

Future work can include improving GIS local databases and updating hydraulic surveys of the Thames River and its tributaries. It may be beneficial to survey high risk areas to determine emergency preparedness and flood proofing measures. Flooding also has large social and environmental impacts; persons with disabilities or limited access to resources may experience difficulties evacuating in the event of a flood. Biologically sensitive areas may have difficulties in recovering from a flood. Therefore, the flood risk may be altered when considering the inclusion of social and environmental factors. This study demonstrates the importance of initial and continuing collaboration between academia, climate change scientists and local politicians.

Acknowledgements

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Glenmore Reservoir Sedimentation and Storage Loss

The Need For a Proactive Sustainable Reservoir Operating Plan for the Benefit of Future Generations of Calgarian's

Presented to Ward 11 Alderman Mr. Brian Pincott
by Rob Motherwell December 6, 2012

Why Do We Care About Sedimentation of The Glenmore Reservoir?

- Health and Safety
  - Live (or Active) storage reduces the flood risk for downstream residents by “skimming” the peak flows
  - Peak flows are often short in duration and live reservoir storage capacity can be enough to make a significant difference in preventing dangerous flooding
  - As sedimentation progresses at some point live storage will be significantly compromised, if not possibly already
  - 40% of the City gets its water supply from the reservoir – if not managed sustainably eventually the fresh water supply storage will be impacted
  - People move into the flood fringe knowing there is a natural risk of flooding but also understanding that a properly maintained reservoir does provide limited protection
- Protection of Personal and Commercial Property
  - Flood protection provided by the reservoir also protects commercial and residential property in the flood fringe from potential damage
  - What is the tax assessed or market value of all of the downstream flood fringe property put at incremental risk if the reservoir operations are mismanaged?
- Protection of Recreation & Habitat
  - What are the impacts on Sailing, Canoeing, Birds & Fish?

1972 Study on Sedimentation of Glenmore Reservoir

- Sedimentation in Glenmore Reservoir, Calgary, Alberta by (Hollingshead, Yaremko and Neill 1972)Department of Indian and Northern Development, Water Resources Division, Alberta Department of Environment & Research Council of Alberta
  - Confirmed the original full supply storage capacity of Glenmore Reservoir 28.4*10^6 Cubic Meters (23,000 Acre Feet)
  - Confirmed that nearly 10% of original full supply capacity was lost to sedimentation by 1968 (2,200 Acre Feet)
  - Confirmed that average annual deposition of sediment in Glenmore at 75,200 Cubic Meters a year (61 Acre Feet per year)

1972 Study on Sedimentation of Glenmore Reservoir

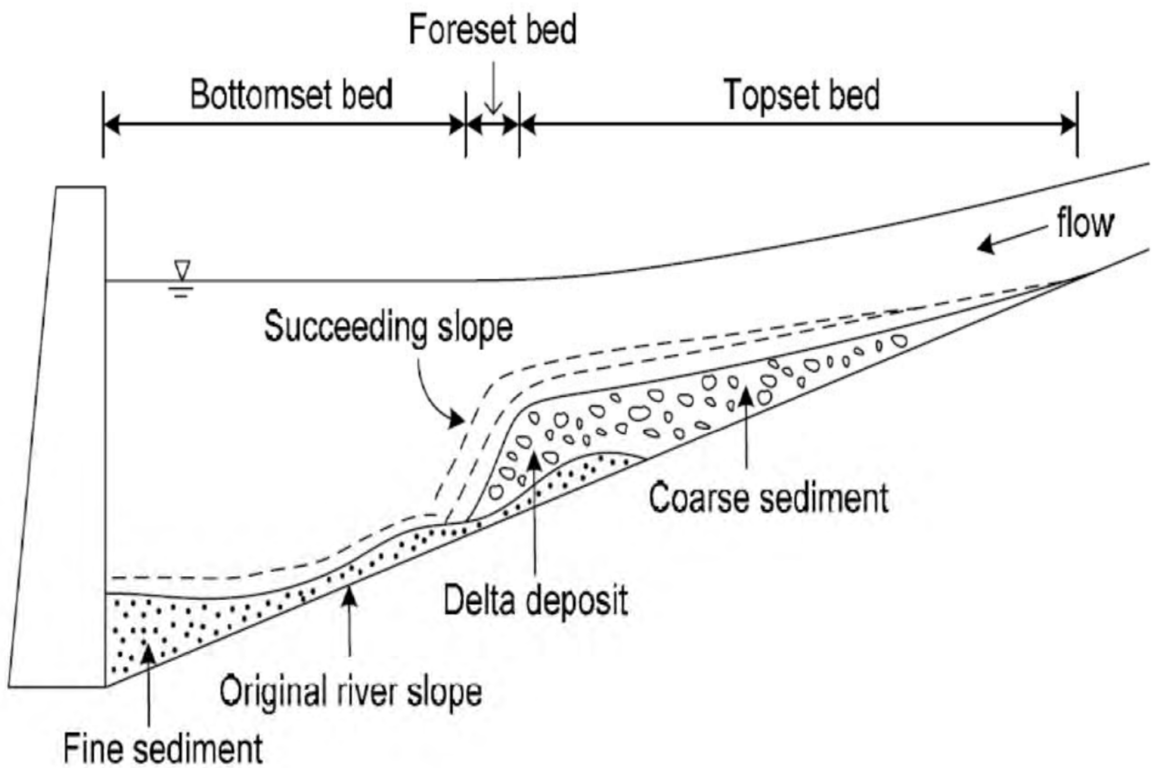


Figure 2-1. Typical flow and deposition of reservoir

1972 Study on Sedimentation of Glenmore Reservoir

The grey shaded area shows the growth of the sediment deposit in the Glenmore Reservoir in the form of a delta or topset beds as of 1968

Does the City have a plan to preserve our water storage capacity?

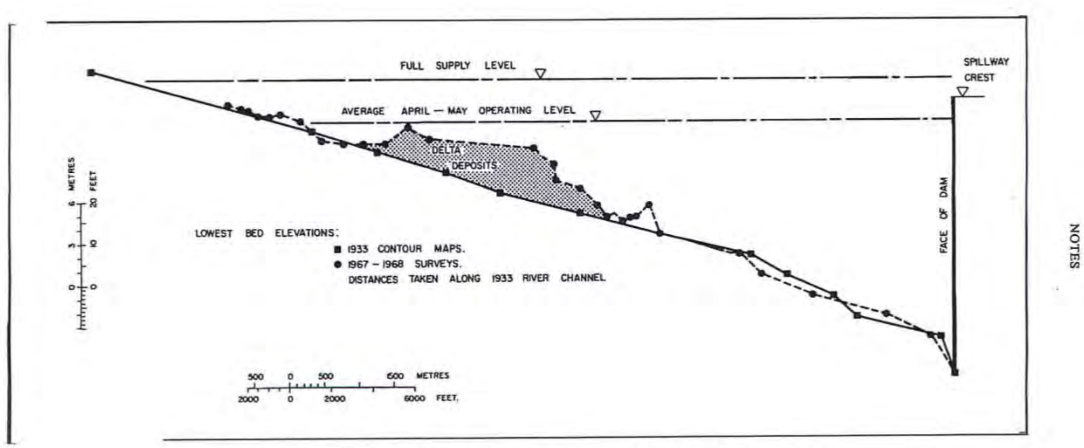


FIG. 3. Longitudinal profile through reservoir along alignment of original river channel

What does the profile look like in 2013?

What is the City's plan to ensure the Glenmore Reservoir remains a sustainable water storage reservoir?

1972 Study on Sedimentation of Glenmore Reservoir

This 1962 Air Photo shows the prograding delta of sediments or topset beds at the western end of the reservoir at low supply (Weaselhead)

FIG. 2. Aerial photograph of exposed delta deposits in reservoir (1962).

112

CAN. GEOTECH. J. VOL. 10, 1973

How much sediment deposition or delta growth has occurred by 2013?

1972 Study on Sedimentation of Glenmore Reservoir

The grey shaded area shows the visible growth of the sediment deposit in the Glenmore Reservoir in the form of a delta or topset bed as of 1968

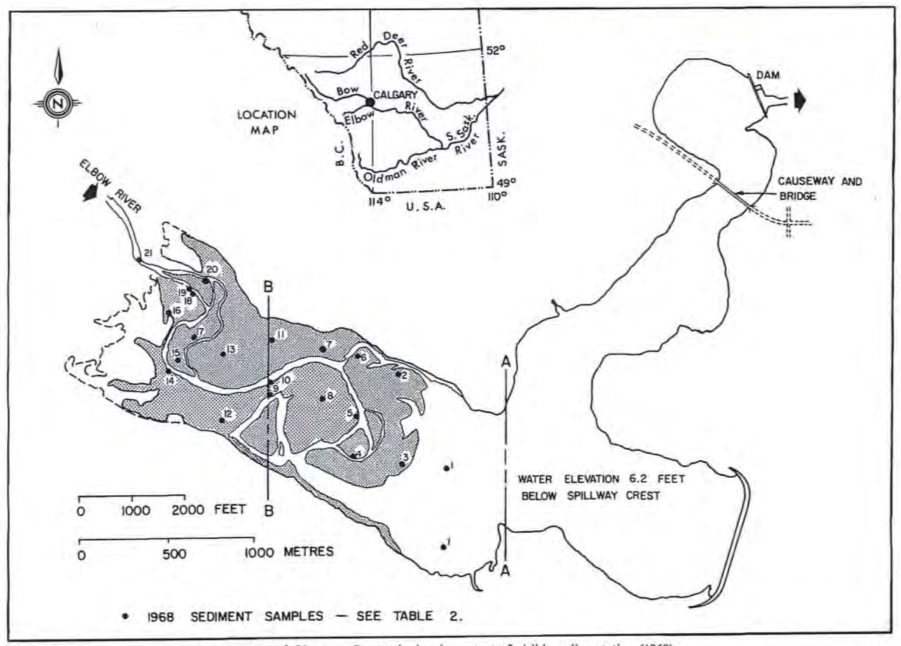


FIG. 1. Plan of Glenmore Reservoir showing extent of visible sedimentation (1968).

1972 Study on Sedimentation of Glenmore Reservoir

- Trap Efficiency Rate is 88% (88% of sediment coming into the reservoir stays in the reservoir)
- **Projected amount of storage full of sediment by 2013** using previous rates (61 Acre Feet year)of an additional 2,745 Acre Feet or a total of 4,945 Acre feet **= *<u>22%</u>***
- **The joint 1972 Federal and Provincial study cautions**:

"It is disturbing, however, to discover that applications of estimated river sediment rating curve to the flow records of the preconstruction period 1908-32 (which includes 7 of the 8 highest floods on record) would produce a sediment inflow estimate many times greater than for the postconstruction period 1932-68"

1972 Study on Sedimentation of Glenmore Reservoir

Federal and Provincial Study on Glenmore Reservoir concludes

"Nevertheless it seems prudent to assume that the useful storage life of the present reservoir for storage purposes is not greater than a century or two"

So what is the City's plan once the reservoir has filled in with sediment and the reservoir is not useful for water storage purposes?

Glenmore Reservoir 2006 Bathymetric Survey

The white shows the exposed delta at a supply elevation at 0.7 meters above the lowest practical operating level

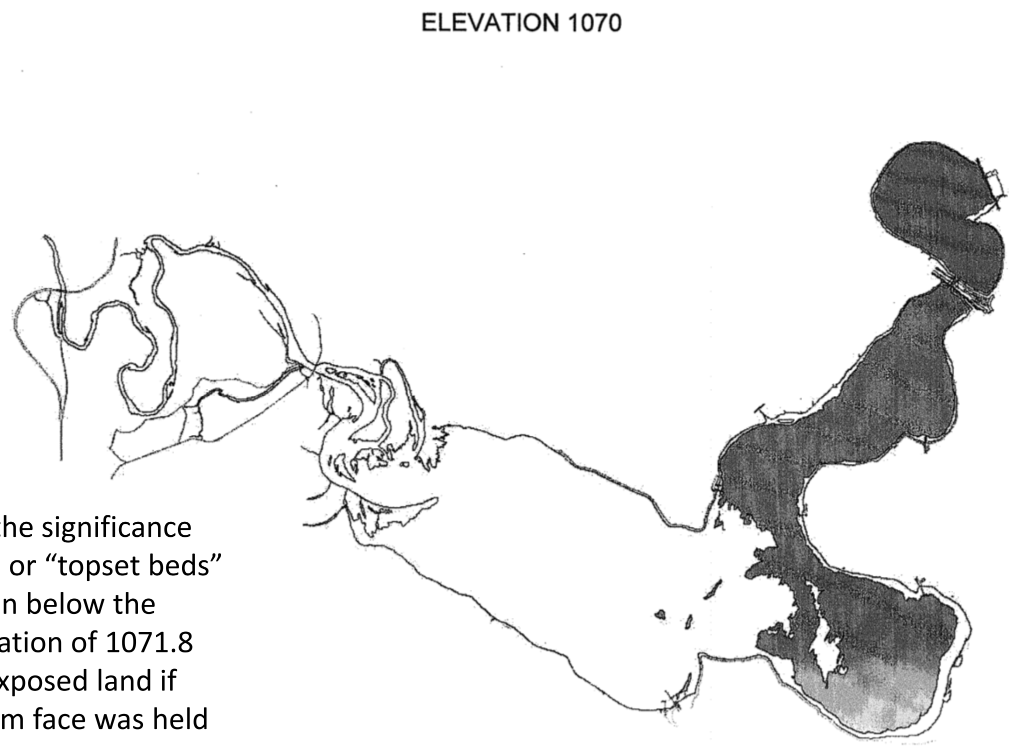
City of Calgary FOIP 00026

ELEVATION 1072.5

Sediment Infill or exposed land above 1071.8 meters (minimum practical operating pool conditions) elevation should represent a loss in Live Storage when compared to original storage

Glenmore Reservoir 2006 Bathymetric Survey

Sediment Infill above 1071.8 meters elevation should represent a loss in Live Storage



Aerial view shows the significance of the delta growth or “topset beds” - reservoir elevation below the lowest control elevation of 1071.8 meters – white is exposed land if the water at the dam face was held at 1070 meters

Low Supply Spring of 2012

June 11, 2012 The visible Topset Beds (Delta encroachment)
Looking to North Glenmore Park from the Sailing School

Low Supply Spring of 2012

June 11, 2012 The visible Topset Beds (Delta encroachment) Looking North North East from the bike point on the bike path approximately 350 meters east of the City of Calgary Sailing school – estimated supply elevation of 1072 meters

June 2012 Low Supply Level

From the previous photos the red outline is an approximation of the exposed topset beds (delta – no water) during low supply in June of 2012 – estimated reservoir water elevation of 1072 meters

June 2012 Low Supply Level

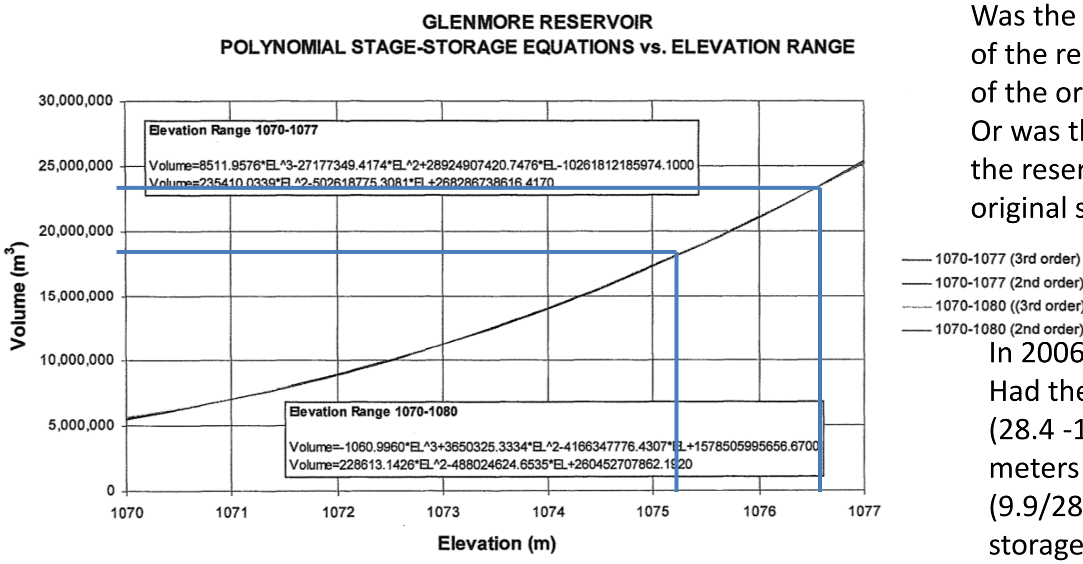
- October 25 Correspondence from Paul Fesko Manager, Strategic Services for The City of Calgary, Water Resources *"Crest elevation of Glenmore dam is 1075.33 m. The City can draw Glenmore Reservoir to elevations as low as 1071.0 m or lower but because the active storage is so restricted at these levels and the ability to operate the water intakes for potable water supply become impacted, there is rarely merit to draw level below 1071.8m"*
- Any water volume in the reservoir above 1071.8 is live storage which can be used for flood control
- Correspondingly any sedimentation occurring in the reservoir catchment at an elevation above 1071.8 will directly reduce the reservoir live storage (flood protection)

Glenmore Reservoir 2006 Bathymetric Survey

City of Calgary FOIP 00020

The original storage volume of the reservoir in 1932 was confirmed to be 28,400,000 cubic meters

At City stated spillway crest (Fesko Oct 25 2012) of 1075.3 meters the 2006 reservoir storage volume appears to be approximately 18,500,000 cubic meters



In 2006:
Was the volume storage capacity of the reservoir 18.5/28.4 or *65%* of the original storage volume?
Or was the storage capacity of the reservoir 22.5/28.4 or 79% of original storage volume?

In 2006:
Had the reservoir filled in with (28.4 -18.5) or 9.9 million cubic meters of sediment and (9.9/28.4) lost *35%* of the original storage volume to sediment?
Or had the reservoir filled in with (28.4-22.5) or 5.4 million cubic meters of sediment and lost 19.1% of the original storage volume to sediment?

How much of original storage has been lost? What is the current storage capacity?

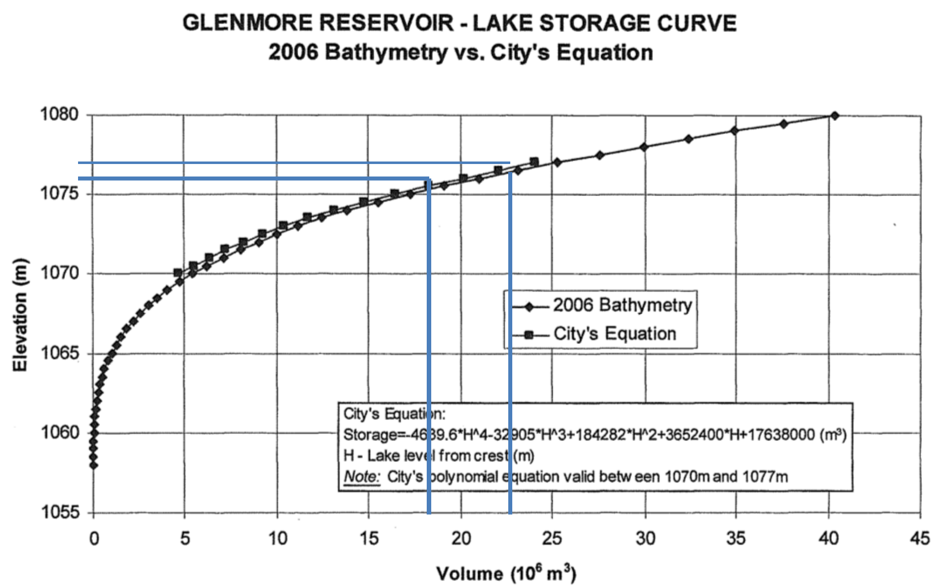
City Water Resources will not give written confirmation of what percentage of the reservoir storage capacity (total volume) has filled in with Sediment – We don't understand why they will not provide written clarification ?

Glenmore Reservoir 2006 Bathymetric Survey

City of Calgary FOIP 00019

The original storage volume of the reservoir in 1932 was confirmed to be 28,400,000 cubic meters

At spillway crest (Fesko – Oct. 25 2012) of 1075.3 meters the 2006 reservoir storage volume appears to be approximately 18,500,000 cubic meters



To date the Water Resources will not give written confirmation of what percentage of the reservoir storage capacity (total volume) has filled in with Sediment – We don't understand why?

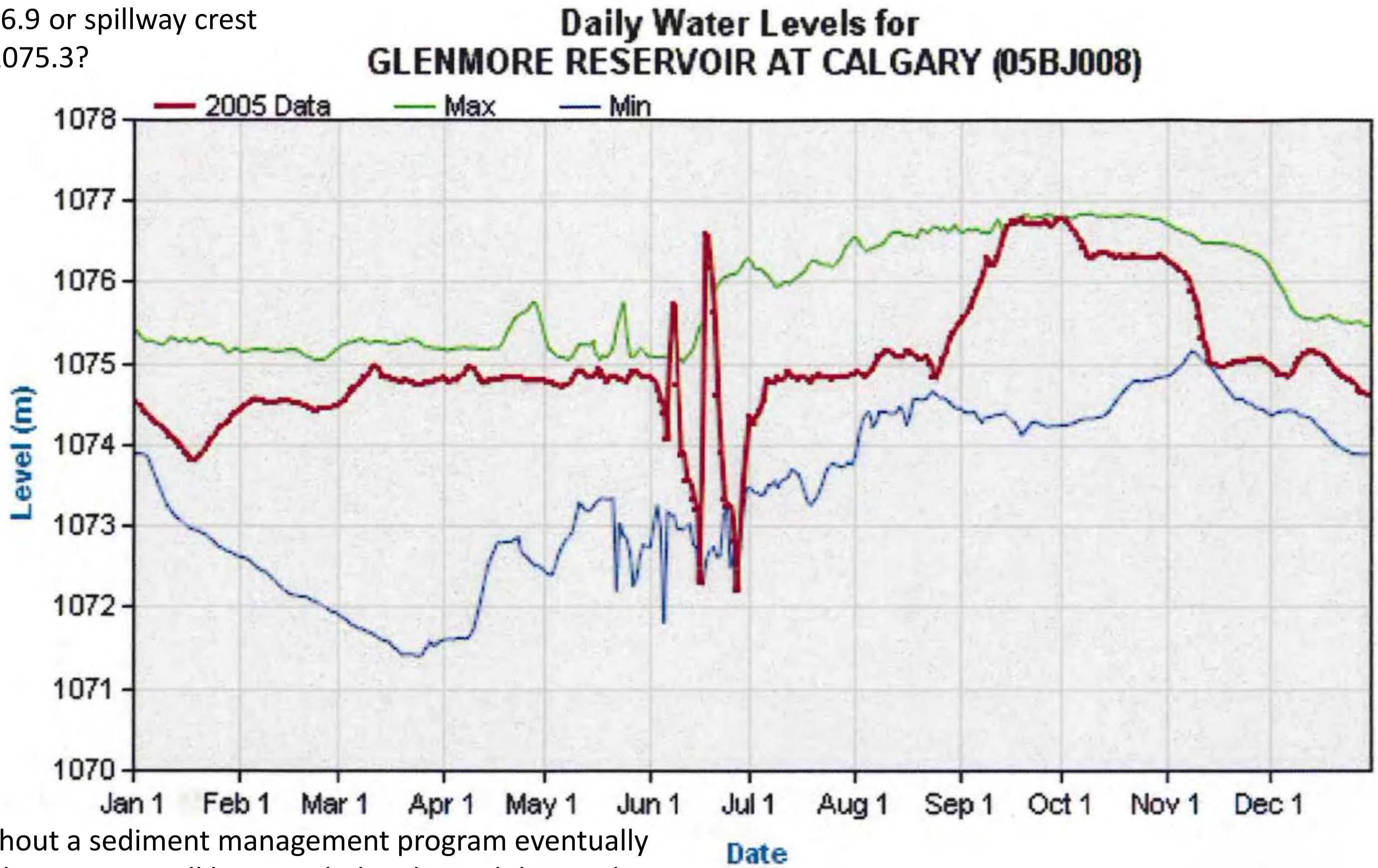
In 2006:
Was the volume storage capacity of the reservoir 18.5/28.4 or *65%* of the original storage volume?
Or was the storage capacity of the reservoir 22.5/28.4 or 79% of original storage volume?

In 2006:
Had the reservoir filled in with (28.4 -18.5) or 9.9 million cubic meters of sediment and (9.9/28.4) lost *35%* of the original storage volume to sediment?
Or had the reservoir filled in with (28.4-22.5) or 5.4 million cubic meters of sediment and lost 19.1% of the original storage volume to sediment?

How much of original storage has been lost? What is the current storage capacity?

Glenmore Reservoir Storage Levels

We need confirmation of what the Full Supply Level is used for storage volume calculations – 1076.9 or spillway crest of 1075.3?



Without a sediment management program eventually the live storage will be curtailed and our ability to skim peak flows will curtail with it. Lack of a plan to manage sediment **will lead to greater flood safety risk**

This chart shows how live storage was used effectively to mitigate flooding in two large events in 2005

Live storage absorbed a significant amount of peak flow during the flood events

Despite this there was widespread flooding as storage did completely fill up and control capabilities were lost but the live storage volume appears to have helped mitigate the extent of flooding to a significant extent by absorbing (Skimming) potentially upwards of 15.5 million cubic meters of water from part of 2 distinct peak flow events in June 2005?

1972 Profile and Live Storage

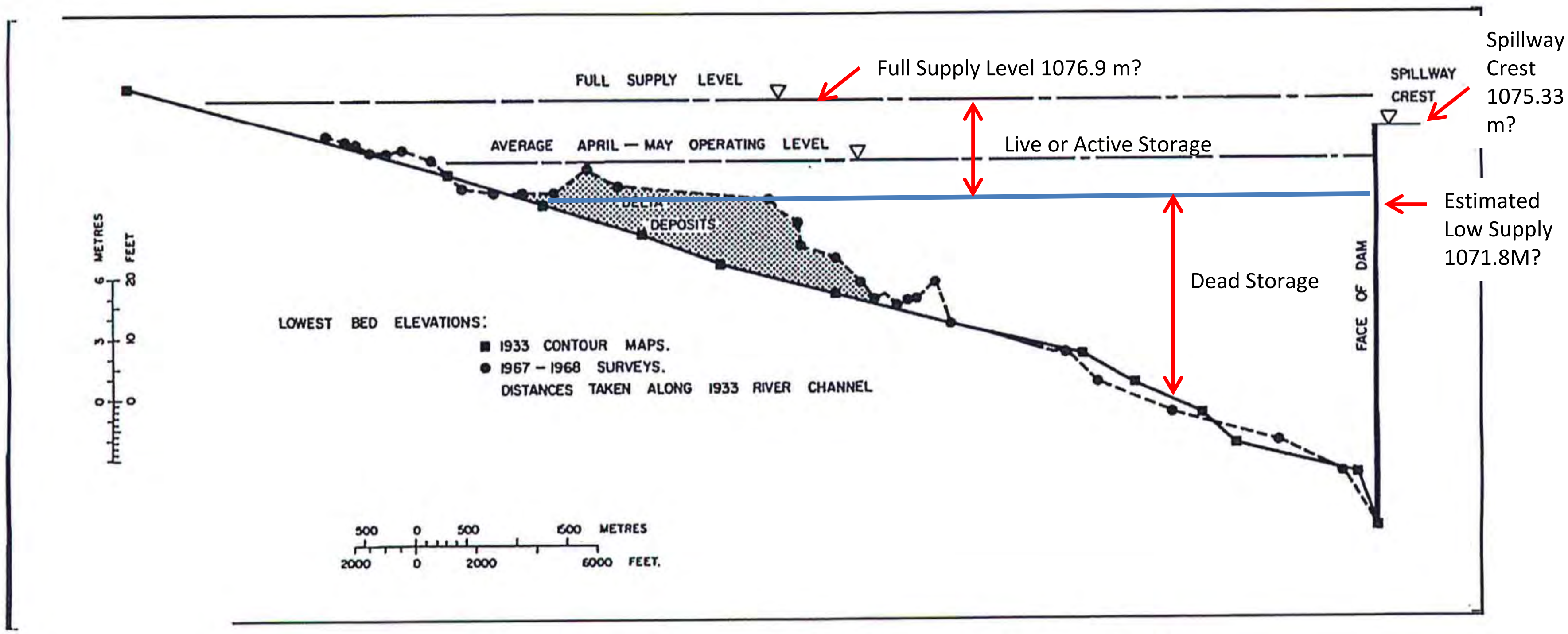


FIG. 3. Longitudinal profile through reservoir along alignment of original river channel

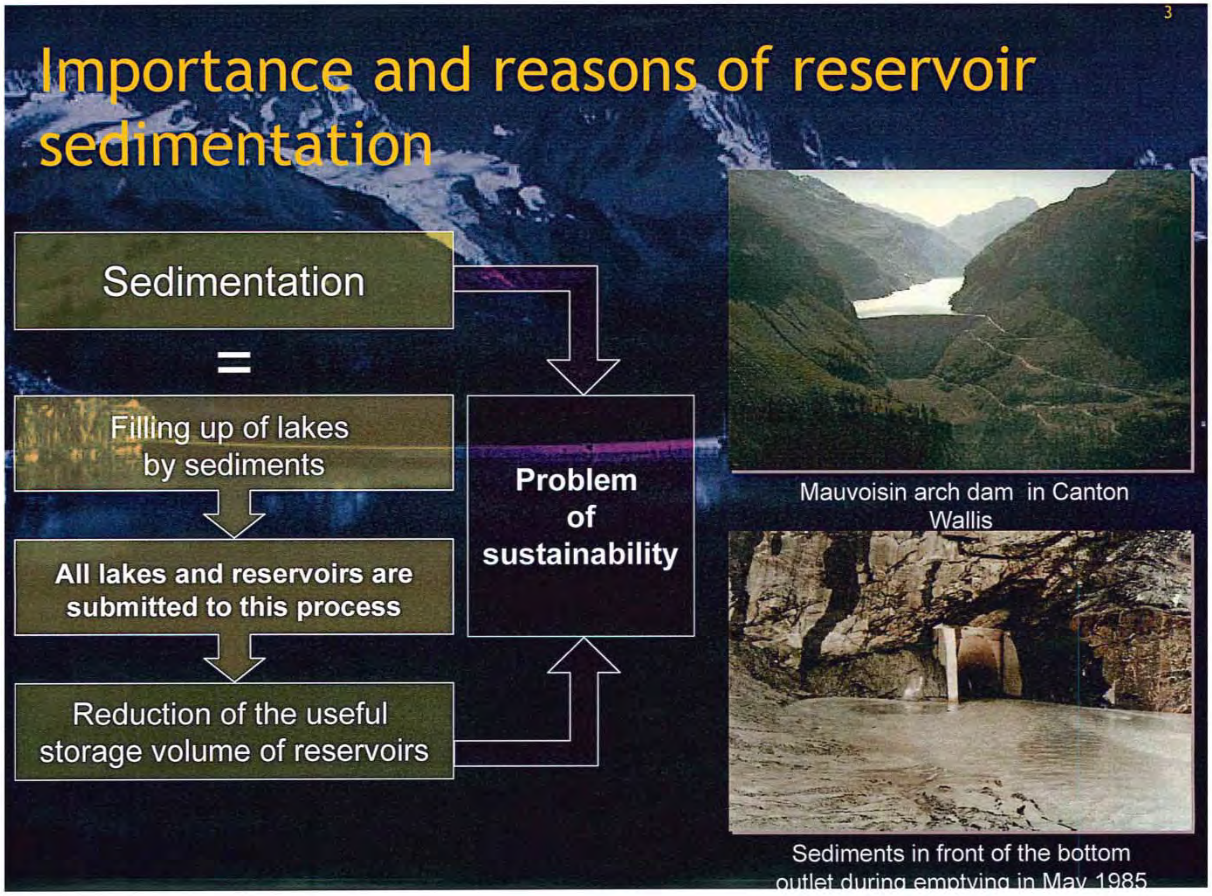
What does this Profile look like in 2006? 2013? How much storage is left today?

Note : Supply and storage level estimates were achieved by applying the vertical scale to the Spillway Crest Elevation provided by Paul Fesko October 25, 2012

Reservoir Sedimentation Handbook

- Reservoir Sedimentation Handbook, Design and Management of Dams, Reservoirs, and Watersheds for Sustainable Use (Morris and Fan 1998) – the hydrologists "go to" guide on sustainable water reservoir management
  - All man made reservoirs are subject to sedimentation and storage volume loss over time
  - The rate of storage loss is a function of numerous variables such as, trap efficiency, annual bed load or suspended load, size of reservoir etc.

There is World Wide Recognition of This Problem



Reservoir Sedimentation Handbook

– It is an accepted fact amongst hydrologists that all man made water reservoirs have a defined "usable life" if reservoir volume storage capacity is not proactively maintained by managing sediment
– "Usable life" is the period in which the reservoir may be operated for its original or modified purpose
– Hydrologists use "half life" as an indicator as to when sediment will *severely interrupt reservoir operations*

Reservoir Sedimentation Handbook

- Phases of water reservoir lifespan
  - **Preimpoundment Sediment Balance** – before dam construction sediment inflow equals sediment outflow
  - **Stage 1 Continuous Sediment Trapping** – after dam construction sediment inflow is greater than sediment outflow
  - **Stage 2, Main Channel and Growing Floodplain** – sedimentation reaches the spillway crest
  - **Stage 3, Full Reservoir Sediment Balance** – sediment inflow and outflow are essentially in long-term balance (once discharge of course bed load material is achieved) The dam has lost its useful storage capability

Reservoir Sedimentation Handbook

- "There has been a tacit assumption that somebody else, members of a future generation, will find a solution when today's reservoirs become seriously affected by sediment. However, sedimentation problems are growing as today's inventory of reservoirs ages, and severe sediment are starting to be experienced at sites worldwide, including projects of national importance."
- "**Sediment management in reservoirs is no longer a problem to be put off until the future; it has become a contemporary problem**"
- "If future generations are to benefit from essential services provided by reservoirs it will largely through the preservation and continued utilization of existing reservoir sites, not a shrinking inventory of potential new sites"

Reservoir Sedimentation Handbook

- "Conversion of sedimenting reservoirs into sustainable resources which generate long term benefits requires fundamental changes in the way they are designed and operated"
- "It requires that the concept of a reservoir life limited by sedimentation *be replaced by a concept of <u>managing</u> both water <u>and sediment</u> to sustain reservoir function*"

Reservoir Sedimentation Handbook

- "Sustainable use is achieved by applying the following basic sediment control strategies
  - Reduce Sediment Inflow
  - Route Sediments
  - Sediment Removal
  - Sediment Placement

  The cost and applicability of each strategy will vary from one site to another and also as a function of sediment accumulation. However, even the largest of reservoirs will eventually be reduced to small reservoirs by sedimentation and , *sooner or later, will require sediment management*."

Numerous Examples of Proactive Sustainable Sediment Management Plans

Sedimentation and the Future of Reservoirs in Kansas

The U.S. government made significant investments in building reservoirs in the 1950s and 1960s, which changed much of the rural environment in Kansas. Although many reservoirs were built with a projected lifespan of 150 to 200 years, current projections indicate these lifespans could be cut short by 50 to 100 years. Sedimentation is reducing water-storage capacity of these reservoirs, and deposited sediments containing nutrients, trace metals, and endocrine disrupting compounds are significantly affecting reservoir water quality. Scientists have documented changes in sediment load and water quality, and citizens have watched reservoirs "shrink" over past decades. Bridges that once spanned water now sit above a "mud flat" of sediment.

The Dust Bowl of the early 1900s had dramatic social, biological, and physical consequences in Texas, Oklahoma, and Kansas and resulted in dramatic technological changes in land management. The "Mud Bowl" resulting from reservoir sedimentation poses an even larger threat that demands corrective action based on sound science and practical, affordable technologies.

Protecting reservoirs from sedimentation will:

- result in overall water conservation (i.e., maximize reservoir water storage, minimize water loss during storm events, and improve water conservation management);
- require widespread implementation of conservation measures; this requires us to evaluate, understand, and influence producer management behaviors that affect implementation of conservation measures as well as sedimentation and future functioning of reservoirs;
- involve participants from a variety of disciplines including agriculture, engineering, hydrology, sociology, economics, and others;
- affect water savings on a large scale not only by conserving and protecting existing reservoir resources but also by retaining more soil and water on land; and
- be crucial to agriculture and rural life, especially in Kansas, and encompass a variety of community, economic, environmental, health, and social issues.

This publication brings together leading scientific knowledge from many academic disciplines and identifies technological solutions that will protect and conserve federal reservoirs. The following white papers evaluate threats to sustainability of federal reservoirs, causative factors behind these threats, and technological solutions along with their scientific underpinnings and propose future research needed to improve sustainability of these vital water resources and landscapes to which they are connected. Our aim is to advance interdisciplinary science, research, collaboration, and problem solving to achieve a key goal: sustaining supplies of abundant, clean water in Kansas.

W. L. Hargrove

W.L. Hargrove
Director, Kansas Center for Agricultural Resources and the Environment (KCARE)

There is World Wide Recognition of This Problem

"Among the many sessions of the Third World Water Forum held in Kyoto, Japan in March 2003, there was one titled 'Sedimentation Management Challenges for Reservoir Sustainability'. Two main messages emerged from that session:

- Whereas the last century was concerned with reservoir development, the 21st century will need to focus on sediment management; the objective will be to convert today's inventory of non-sustainable infrastructures for future generations

- The scientific community at large should work to create solutions for conserving existing water storage facilities in order to enable their functions to be delivered as long as possible, possibly in perpetuity."

Numerous Examples of Proactive Sustainable Sediment Management Plans

Conclusions

- The Glenmore Reservoir provides a critical role for flood protection and water supply for the citizens of Calgary
- Storage volume in the Glenmore Reservoir appears to be diminishing at an alarming rate (1972 Federal /Provincial Study – 2006 Bathymetric Survey)
- Lack of implementation of proactive measures to preserve the reservoir storage capacity is potentially:
  - Putting the City's water supply at risk
  - Increasing the potential safety risk of downstream residential and commercial residents located in the flood fringe
  - Increasing the potential for significant residential an commercial property damage within the flood fringe
  - Having a negative impact on the recreation and wildlife habitat

The Need for Acknowledgement Acceptance and Action – Our Opinion

- City of Calgary Water Resources should confirm the percentage of original reservoir storage capacity which has been lost to sedimentation
- City of Calgary Water Resources has an obligation to inform and advise the public of:
  - the current percentage and volume of original reservoir storage loss
  - the potential consequences from the loss of storage capacity in the Glenmore Reservoir
- City of Calgary Water Resources needs to design and implement proactive strategies, in line with known best practices, to preserve the Glenmore Reservoir storage capacity for the benefit of current and future generations of Calgarian's
- City of Calgary Water Resources should acknowledge, understand and accept the fact that lack of a proactive sediment management plan in the Glenmore Reservoir will;
  - Increase the potential safety risk for a significant number of residents in the flood fringe
  - Increase the potential risk for residential and commercial property damage
  - Potentially result in a significant reduction in our capability to manage the City's Water supply
  - Have a negative impact on recreation (sailing, rowing, Moyie, fishing etc.) and potential wildlife habitat

Reference Terms

- "Live Storage" is the portion of the reservoir that can be used for flood control and downstream releases. It is the reservoir volume above the lowest controllable level
- "Dead Storage" the volume of reservoir storage below the lowest controllable level. This portion of storage cannot be used for flood control and downstream releases
- "Flood Control Capability" is the amount of water the dam can regulate during flooding. It is generally the volume of live storage

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Sedimentation Process
Historical Comparison

Sept.1952 standing water in reservoir at north end of Ghost Reservoir

Sept. 2009 at reservoir full supply showing bed aggradation and delta formation at the north end of Ghost Reservoir

- This shows the dramatic amount of fluvial-clastic sediment fill that has accumulated in the north end of the Ghost Reservoir in the 56 years between these to accounts. Also noteworthy is a reduction in freeboard on the bank of about 9 feet.
- Original Standing Water Depth was estimated at the deepest point to be greater than 10 feet deep in 1929
- Has changed from standing backwater to a braided flow pattern perched on an elevated gravel delta platform (topset bed)
- With the infill the standing backwater has now moved approximately 300 meters down reservoir

North Ghost Sedimentation

Oct 1937 - standing water, reservoir at full supply

Aug 2001 -reservoir at full supply backwater is completely filled in with bedload sediment

“The effects of backwater *from the reservoir* have reduced the transport capacity, increased the propensity for deposition of sediment, and promoted aggradation. This has ultimately resulted in a rise in bed levels and a reduction in the bed slope.”

Sediment Deposition in North Ghost

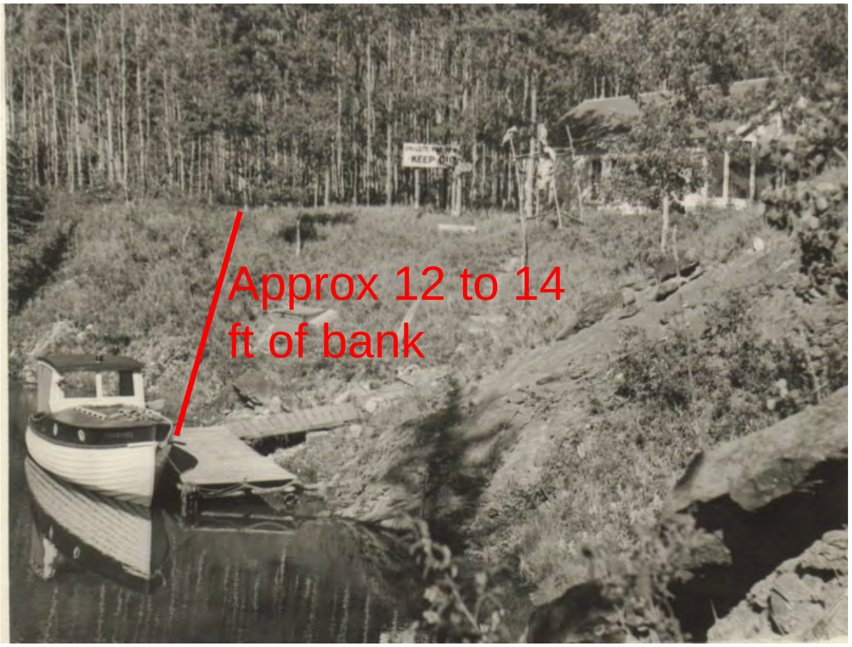
- Topset beds
- North Ghost 1952 (left) vs 2011(right)

North Ghost Sedimentation

North Ghost Reservoir in full supply 1934. Boat operating at speed in deep, standing water

North Ghost Reservoir in full supply Sept, 2009 – taken from the same location

North Ghost Reservoir Sedimentation



The boat is 5.0 feet high & has 7-9 feet of bank above the roof accounting for photographic parallax. Reservoir at full supply 1937

Reservoir at full supply 2009. Approx. only 4.5 feet of bank remains

The actual reservoir bed is approx. 8-10' below the water surface elevation (left). As the north end of the Ghost reservoir has filled in with fluvial-clastic material the amount of freeboard on the bank has been reduced from greater than 14 feet (including portion under water) to approximately only 4.5 (now above ground) feet at this particular point.

North Ghost Reservoir

Fall 1952

Feb 26, 2011

- The ice is currently well above the rock outcrop on the left side of the photo. Note the bank used to be more than a full house height above standing water

North Ghost Reservoir

Reservoir at full supply 1934. Boat operating at speed at reasonable water depth

Reservoir at full supply July, 2007

These photos show bed load deposition, aggradation and sedimentation in the North end of the Ghost Reservoir.

A Local Alberta Example of Reservoir Sedimentation

1943 painting of North end of Ghost Reservoir by Roland Gissing. This rendition shows the reservoir at full supply in the fall of 1943

Loss of 6.5 feet of freeboard on the bank in 8 years.

April, 2001. There was 8 ft of bank above the water.

Sept 17th, 2009. A dramatic reduction in freeboard on the bank.

These two photos taken from the same place 8 years apart demonstrate how fast aggradation can occur as natural bed load movement is interrupted

Shows Aggradation in North Ghost over 8 year period

April, 2001

Sept 17th, 2009

Measurement bars depicting true vertical height.

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