Calgary

Source Water Protection Plan

Protecting The City of Calgary's Source Watershed through Proactive Collaboration

DRAFT From Forests to Faucets, Glaciers to Glasses, Catchments to Customers

December 2017

EXECUTIVE SUMMARY

The City of Calgary is committed to the delivery of high quality, safe drinking water to the communities we serve, which include over 1.3 million people. All public health and safety standards are met in Calgary's treated water, and Calgary's drinking water consistently ranks high in taste competitions. This exceptional performance is due in part to the high quality of our ***source water*** – the natural waters of the Bow and Elbow Rivers prior to withdrawal and treatment as municipal water supplies. In turn, the quality of our source water depends on the condition of the lands that collect and drain water downstream towards our drinking water treatment facilities. Also known as our ***source watershed***, this 9,000 km^2 area generates and filters water through a vast network of glaciers, mountains, forests, grasslands, rivers, streams, and wetlands, as well as through agricultural landscapes and upstream communities.

However, a clean supply of source water in perpetuity is not guaranteed. As pressures such as urban and regional growth and climate change build, we need to safeguard the high quality water we enjoy today. ***Source water protection*** is a coordinated risk management approach that functions as the first line of defence in a multi-barrier approach to providing safe, clean drinking water. Effective source water protection must consider a wide array of land and water values and interests. In recognition of this, extensive engagement was undertaken prior to developing this Plan. Feedback obtained emphasized the importance of linking public health and environmental stewardship in source water protection, and the need for collaborative, integrated approaches to land and water management. Based on what we heard, our Vision for source water protection is:

VISION: The City of Calgary's source watersheds continue to provide ***clean, high quality water supplies***, through proactive stewardship and management.

How to Use This Plan

Source water protection goals and actions form the backbone of this Plan. These flow from provincial direction, and key policy drivers, including public health, environmental stewardship, and cost-effective service delivery. The Plan provides a road map with a common direction and priorities, while synthesizing and building on existing data and initiatives. Intended users of the Plan include: City of Calgary staff, other government agencies, industries, landowners, non-government organizations, and many other stakeholders across a wide range of jurisdictions and knowledge domains. By taking action today, we can protect the quality of our drinking water for current and future generations.

Provincial direction	**South Saskatchewan Regional Plan** • Enhanced integrated watershed management • Building sustainable communities			
Vision	The City of Calgary's source watersheds continue to provide clean, high quality water supplies through proactive stewardship and management			
Key drivers	• Proactive protection of public health • Environmental stewardship and conservation • Minimizing future water treatment capital and operating costs			
Guiding principles	Integrating land and water management		Collaborating through partnerships and watershed stewardship	
Goals	**GOAL 1** Enhance land use planning to protect the source watershed	**GOAL 2** Promote innovation in stormwater management to protect source water quality	**GOAL 3** Leverage partnerships and stewardship for risk mitigation	**GOAL 4** Effectively involve stakeholders and citizens through education and research
Five-year actions planned	Develop and implement **recreation management strategies** and actions for the Bearspaw Reservoir	Prioritize **erosion and sediment control inspections** and enforcement within The City's source watersheds	Develop a **wildfire management strategy** with fire management agencies to proactively mitigate fire risks	Conduct a **traditional use study** to explore First Nations' traditional knowledge on water and watersheds
	Develop **drinking water protection zone** overlays and integrate with The City's statutory and regulatory instruments	Evaluate and implement **stormwater management requirements** to meet source water quality objectives	Conduct a **watershed conservation study** to evaluate options to protect vulnerable source watershed lands	Provide guidance to **university research projects** in Calgary's source watersheds
	Integrate source water protection priorities in **regional land use and servicing plans and provincial regulations**	Prioritize **riparian, wetlands and green infrastucture projects** within The City's source watersheds	Update **emergency response plans** for spills and increase co-ordination with industry	Develop a **source water education plan** to promote community and regional actions to reduce risk

Legend

- Action applies only to source watershed areas within Calgary city limits
- Action primarily applies to source watershed areas outside Calgary city limits
- Action applies to source watershed areas both within and outside City limits

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INTRODUCTION

Source water protection is the first line of defence to minimize the risk of drinking water contamination. Together with drinking water treatment and risk mitigation within the water distribution system, source water protection is part of a multi-barrier approach to providing clean, safe drinking water to our customers (Figure 1). Source water protection reflects the inherent diversity and unique attributes of natural waters, watershed landscapes, local governance and institutions.

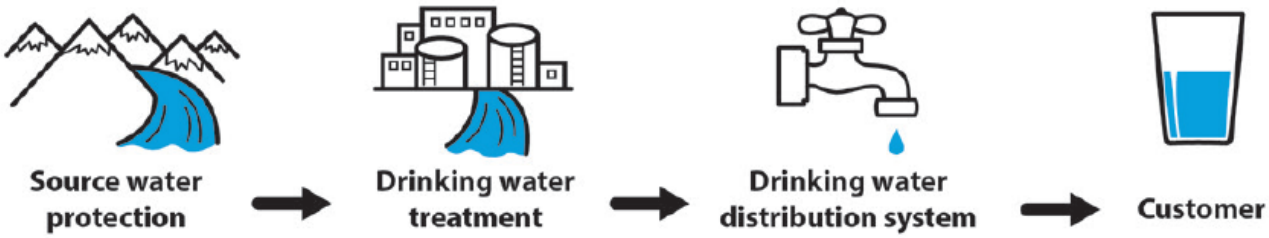


Figure 1. The City of Calgary's Multi-Barrier Approach to Safe Drinking Water

Source Water: Water in its natural or raw state, prior to being withdrawn for treatment and distribution as a drinking water supply.

The City of Calgary's source water is associated with the Bow and Elbow watersheds upstream from the Bearspaw and Glenmore water treatment plants.

Successful protection of source water involves the development and implementation of plans to prevent or minimize pollution. Successful source water protection programs share six basic elements [1, 2]:

- A source water protection program ***vision***
- Source water ***characterization***
- Source water protection ***goals***
- Source water protection ***action plan***
- **Implementation** of the action plan
- Periodic ***evaluation and revision***

Source Water Protection Drivers for Calgary

Key drivers for developing a Source Water Protection Plan include:

- **Proactive protection of public health** for current and future generations
- **Greater awareness of the need for environmental stewardship and conservation**, including cumulative effects management addressing multiple stressors, such as land use change and climate change
- **Potential to minimize costs,** including operational costs for water treatment, or deferred capital costs for future upgrades to treatment infrastructure
- **Increasing development pressures** throughout our source watersheds, both within and upstream of Calgary

Integration with Other Planning and Regulatory Frameworks

A wide range of regulations, policies, plans, and strategies relate either directly or indirectly to source water protection in Alberta and the Calgary region (Figure 2). Legislation, regulations and standards are in place for many land use planning procedures, and for regulating water-related environmental risks associated with various industries. Water utilities in Alberta are also required to prepare Drinking Water Safety Plans (DWSP), which include qualitative risk evaluations and mitigation actions in a source-to-tap framework. This Source Water Protection Plan builds on the foundation provided by The City's Drinking Water Safety Plan.

The Plan also integrates and coordinates with the South Saskatchewan Regional Plan, the Calgary Municipal Development Plan, the Bow Basin Watershed Management Plan, various subwatershed plans, and evolving regional planning requirements. The City also complies with all regulatory requirements for operating drinking water, wastewater, and stormwater systems.

Source Water Protection Plan: Relationships to Other Regulations and Planning Processes

Source water protection is related to many other processes at provincial, regional, and local scales. This Plan complements existing governance frameworks, and aims to avoid the duplication of roles.

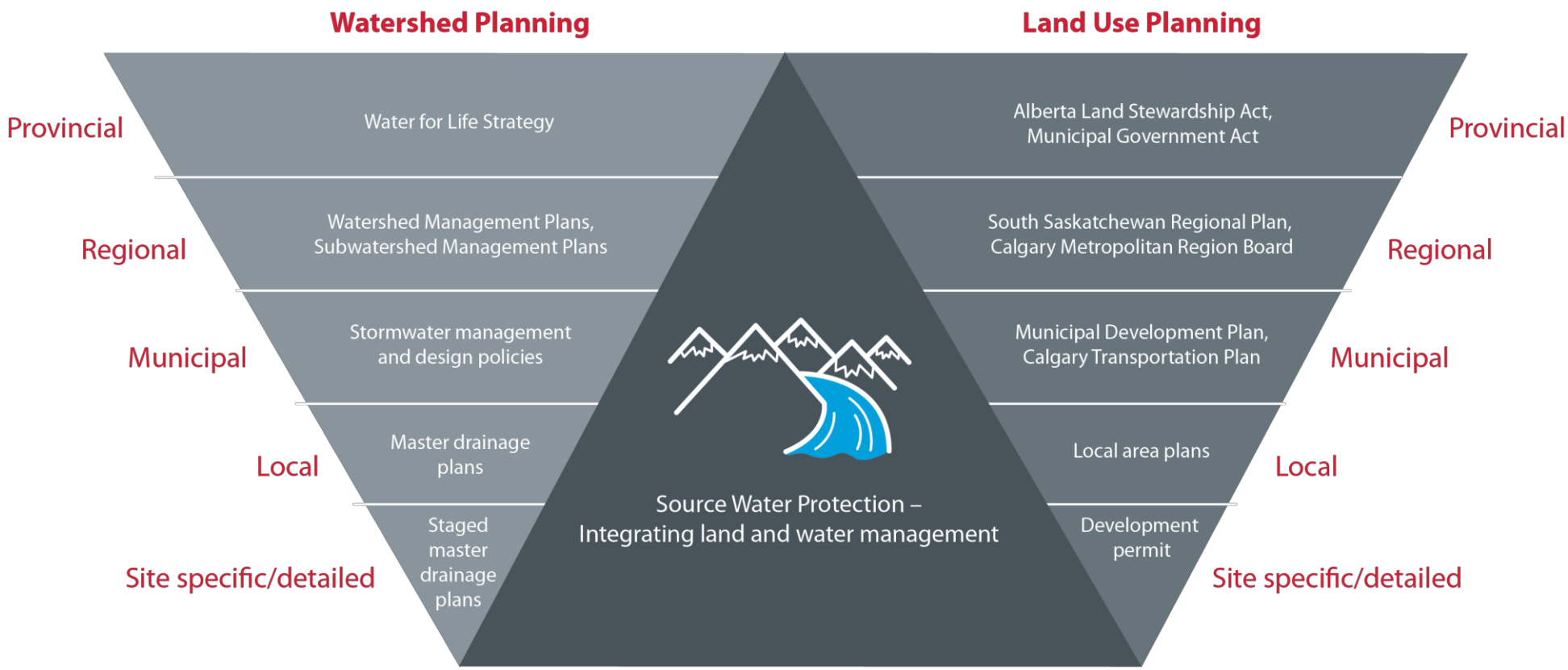


Figure 2. Source Water Protection and Integrated Watershed Management

A Focus on Water Quality

This Plan focuses primarily on water quality issues. Risks associated with water quantity, such as drought and flooding, are addressed through other plans and actions.

Plan Organization and Structure

This plan characterizes Calgary's source watersheds, identifies risks, and provides a vision, goals, and action plan to maintain the high quality of The City's source water supplies over the long term. The document sets a common direction, framework, and priorities for source water protection, while synthesizing and building on existing information and initiatives. The Plan includes the following sections:

- **Source Water Values and Vision**
- **Characterization of Calgary's Source Watersheds**
- **Source Water Protection Goals**
- **Source Water Protection Action Plan**
- **Source Water Protection Implementation to Date**
- **Plan Evaluation and Revision Procedures**
- **Appendix A:** Engagement
- **Appendix B:** Source Watershed Risk Characterization

The City of Calgary's Stewardship of Downstream Receiving and Source Environments

The scope of this Plan focuses on Calgary's source watersheds upstream of the City's boundary. However, The City also manages wastewater and stormwater to reduce impacts on downstream receiving environments and water users. The City owns and operates a wide range of innovative wastewater and stormwater infrastructure. As a reflection of success to date, the amount of sediment pollution load to the Bow River from Calgary has been kept under 2005 levels, despite recent rapid urban growth and development. The City is also striving for urban land use patterns that reduce our impacts on the Bow and Elbow River watersheds.

SOURCE WATER VALUES AND VISION

Calgary's source watersheds include many valued landscapes and resources. Land and water resources in our shared source watersheds help produce not only clean source water to downstream users, but also generate revenue and jobs, food and forest products, opportunities for recreation and tourism, and a wide range of other ecological services and benefits. Working landscapes involving agriculture, forestry, hydroelectricity generation, and aggregate mining are all present in Calgary's source watershed. The watershed also includes diverse communities that people call home. Biodiversity is also a key value to consider, as a green network of mountains, forests, rivers, riparian areas, and wetlands support diverse species in our source watersheds. These various resources and values must be respected and integrated with the goal of maintaining high quality source water supplies for downstream users. Autonomous municipalities, private landowners, and industries within our source watersheds also have various rights that go along with their responsibilities.

First Nations Watershed Values

Since time immemorial, land and water resources in the region have been used for traditional purposes by indigenous peoples. Calgary's source watersheds overlap the traditional territories of all Treaty 7 First Nations, including:

- The Niitsitapi or Blackfoot Nation, which includes the Siksika, Kainai, and Piikani tribes
- The Nakota Sioux (Stoney) Nation, comprising the Chiniki, Bearspaw, and Wesley bands, who also have substantial reserve lands in the Bow River source watershed
- The Tsuut'ina or Beaver people, who also have substantial reserve lands in the Elbow River source watershed

"The Story of Moh-kinsstis says that before there was the place we call Calgary, the First Peoples were stewards of this land. At the confluence of two rivers, the lifeblood of our city, our cultures converged and our story began."

-Mayor Naheed Nenshi's Proclamation of Reconciliation, March 27, 2014

This Plan honours indigenous values, and encourages ongoing dialogue and collaboration with First Nations as well as the Metis Region 3 during implementation. Engagement to date has been undertaken to understand indigenous cultural values, and to begin to build deeper relationships between City staff and First Nations on watershed issues. This is consistent with the spirit and intent of The City's *Indigenous Policy* [3]. During implementation, The City aims to elaborate on actions for areas of common interest that are mutually beneficial to both The City and indigenous peoples.

Quotes from Treaty 7 First Nations Traditional Knowledge Keepers Related to Source Water

"*We believe the Creator put us here for stewardship and to ensure the environment is protected."*

"Water is the source of who we are."

"Wetlands and rivers are part of that sacred connection and (this) needs recognition."

"In our community, literacy is about understanding that everything is connected and acknowledging that sacred kinship."

-City of Calgary *Indigenous Policy Framework 2017*

Stakeholder Values

Extensive stakeholder engagement was undertaken as an input to this Plan. Key values emphasized by stakeholders included the links between public health and environmental stewardship in source water protection. The need for a collaborative approach and coordination among groups were also seen as key elements of source water protection. Source water protection was also seen as a proactive management approach, in contrast to a reactive or crisis management approach that waits for major problems to become apparent before taking action. Appendix A provides additional details on engagement and communications undertaken during Plan development.

Land stewardship, holistic thinking, and connection to place were important themes heard from both First Nations and stakeholders during engagement activities.

Importance of Water Quality to Calgarians

In addition to the more in depth stakeholder and First Nations engagement, this Plan was also informed by previous surveys of Calgarians on water and watersheds to reflect customer and citizen perspectives. Surveys consistently show strong support for the importance of high quality drinking water. Recently, an Ipsos Reid poll showed over 96% of all Calgarians rate the quality of drinking water as "*very important*".

Source Water Protection Vision

A formal vision has been established, to provide focus and direction to help align source water protection activities. The vision statement was developed using stakeholder input and reflects: (i) public values, confirmed through citizen surveys; (ii) Treaty 7 First Nations' perspectives, and (iii) stakeholder input gathered from government, industry, and non-government organizations.

VISION: The City of Calgary's source watersheds continue to provide ***clean, high quality water supplies***, through proactive stewardship and management.

CALGARY'S SOURCE WATERSHEDS

All municipal water utilities draw their water from a source environment. For The City, this includes surface water in the Bow and Elbow Rivers. This water is ultimately generated by the source watershed, which includes all lands which collect water that flows downstream to a municipal drinking water treatment plant. The City has two source watersheds associated with each of its two drinking water plants:

- **Bow River Source Watershed:** A 7,768 km^2 source watershed upstream from the Bearspaw water treatment plant on the Bow River
- **Elbow River Source Watershed:** A 1,227 km^2 source watershed upstream from the Glenmore water treatment plant on the Elbow River

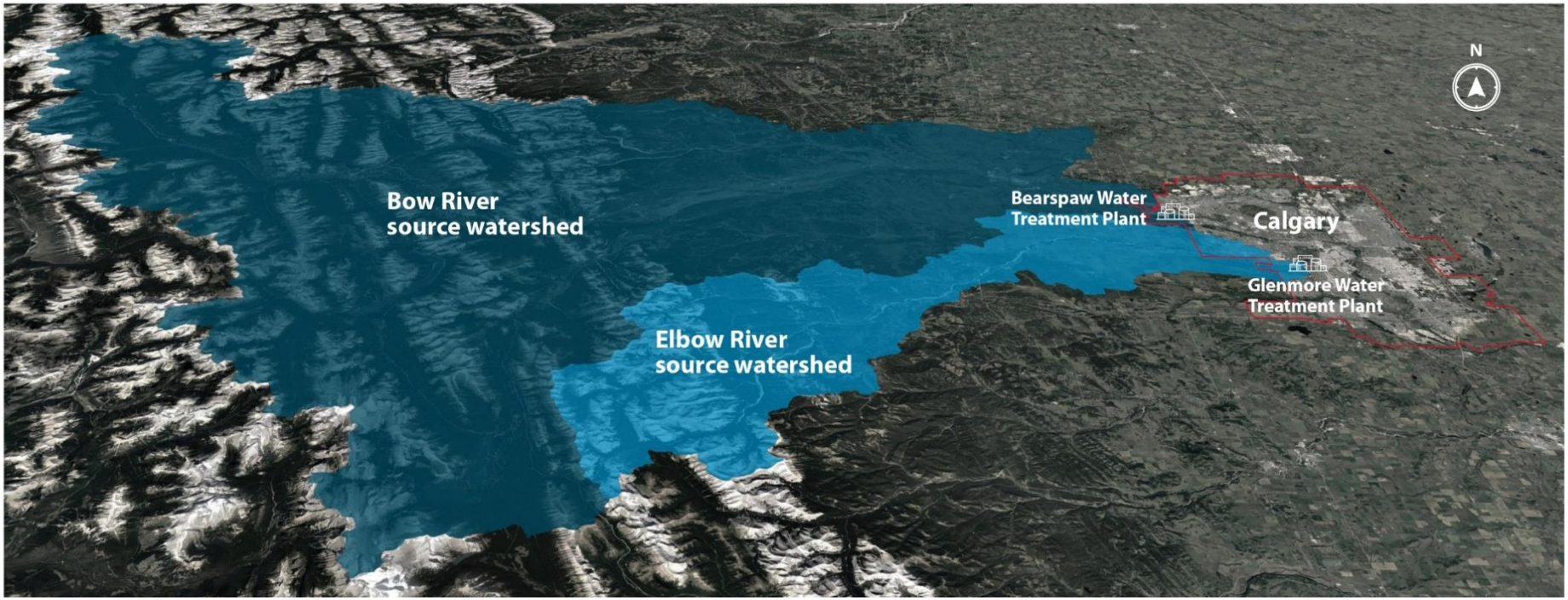


Figure 3. The City of Calgary's Source Watersheds

The boundaries of Calgary's two source watersheds include areas upstream from The City's water intakes. Boundaries were delineated based on topography and stormwater infrastructure.

Bow River Source Watershed

The City's Bow River source watershed includes 7,768 km^2 of the Bow River Basin upstream from the Bearspaw Water Treatment Plant (BWTP). There are two intake locations for this plant. The first location is in the Bearspaw Reservoir at the dam, located just west of Calgary. TransAlta Utilities operates the Bearspaw Dam, located in Rocky View County. The second intake is located further downstream, directly in the Bow River near Stoney Trail within The City of Calgary.

Figure 4. The Bearspaw Reservoir

Elbow River Source Watershed

The City's Elbow River source watershed includes 1,227 km^2 of the Elbow River Basin upstream from the Glenmore Water Treatment Plant (GWTP). The plant's intakes are located in the Glenmore Reservoir at the dam. The Glenmore Reservoir is within City of Calgary limits, and the Glenmore Dam is owned and operated by The City. In addition to water supply, the Glenmore Reservoir also provides flood protection and is a popular site for non-motorized boating and recreation.

Figure 5. The Glenmore Reservoir

Jurisdictions and Land Ownership

The majority of Calgary's source watershed is owned by the Crown, administered by the provincial or federal governments (Figure 6). Fortunately, almost two thirds of the source watershed area is designated as parks, primarily in Banff National Park, followed by provincial parks. Rocky View County's jurisdiction also extends over 12 per cent of the source watershed, with most of these lands in private ownership in close proximity to City limits. First Nations reserves make up 8 per cent of the source watersheds. The City has jurisdiction over a very small portion (0.7 per cent) of the total area. A map of the jurisdictions is shown in Figure 7.

Bow River Source Watershed Jurisdictions

The mountainous headwaters upstream of the Bearspaw treatment plant are mostly within Banff National Park. Provincial parks and wildland areas are also prominent, particularly in the Ghost, Spray, and Kananaskis subwatersheds, as well as Glenbow Ranch Provincial Park between Cochrane and Calgary along the Bow River (Figure 7).

Rural municipal districts in the Bow River source watershed include Rocky View County, the Municipal District of Bighorn, and the Kananaskis Improvement District. Cochrane is the largest major settlement outside of Calgary, followed by Canmore, Banff, and Lake Louise. The Stoney Indian Reserve (including the community of Morley), and a small portion of the Tsuut'ina Indian Reserve are also located in this source watershed. Approximately 19 km^2 representing just 0.2 per cent of this source watershed lie within Calgary's city limits. Major Calgary parks located in the Bow River source watershed include Haskayne Legacy Park and Bearspaw Legacy Park.

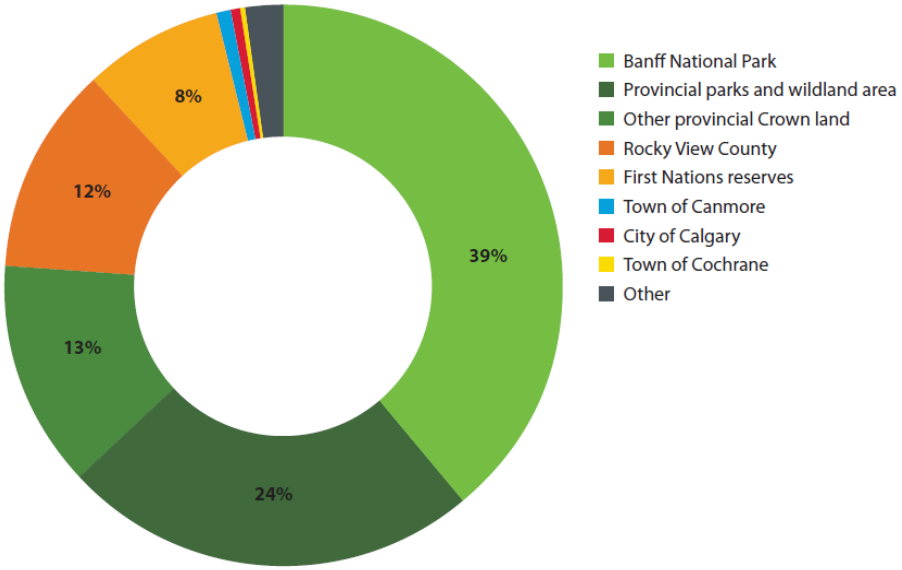


Figure 6. Jurisdictions in Calgary's Source Watersheds

Elbow River Source Watershed Jurisdictions

The upper headwaters of the Elbow River source watershed include extensive provincial parks and public recreation areas in Kananaskis Country, including the Don Getty and Elbow-Sheep Wildland Provincial Parks. Rocky View County, including the hamlet of Bragg Creek, has jurisdiction over 20 per cent of the lower watershed, followed by the Tsuut'ina Nation at 14 per cent.

Almost 45 km^2 of SW Calgary lies upstream from the Glenmore Reservoir, representing 3.6 per cent of the Elbow River source watershed. Almost half of this area has been protected over the years by The City in large municipal parks, including South and North Glenmore Park, Weaselhead Flats, and the Clearwater Legacy Park. The other half of this area includes many Calgary communities both north and south of the reservoir that drain stormwater into the Glenmore Reservoir.

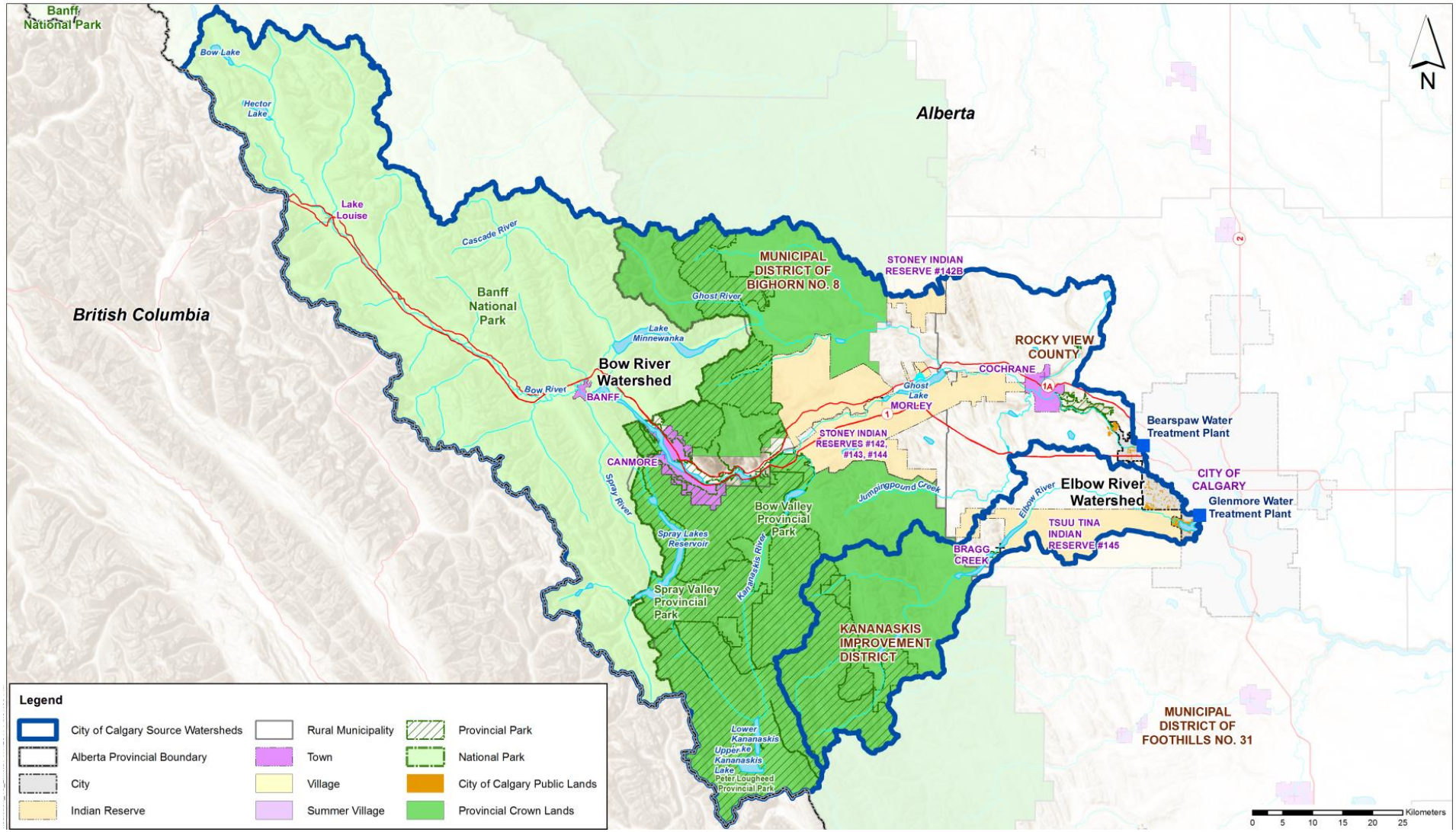


Figure 7. Map of Jurisdictions in Calgary's Source Watersheds

Land Cover

Forests dominate Calgary's source watersheds, with almost half of the total area in forested land cover (Figure 8). Exposed rocky mountainous areas are also a very common land cover type, occupying over a quarter of the source watershed. Glaciers make up only 1 per cent of the two source watersheds, with most of these concentrated at the highest elevations in the headwaters of the Bow River basin. Grasslands and shrublands combined cover about 17 per cent of the area, followed by cultivated agriculture at 5 per cent. Developed lands currently occupy about 4 per cent of the source watershed, and are concentrated within Calgary, as well as Cochrane, Rocky View County, and Canmore. Figure 9 shows a map of land cover in the study area.

Mountains + Glaciers	Forests	Grasslands + Shrubs	Cultivated Agriculture	Developed Lands
26%	44%	17%	5%	4%

Figure 8. Illustration of Land Cover Types in Calgary's Source Watersheds

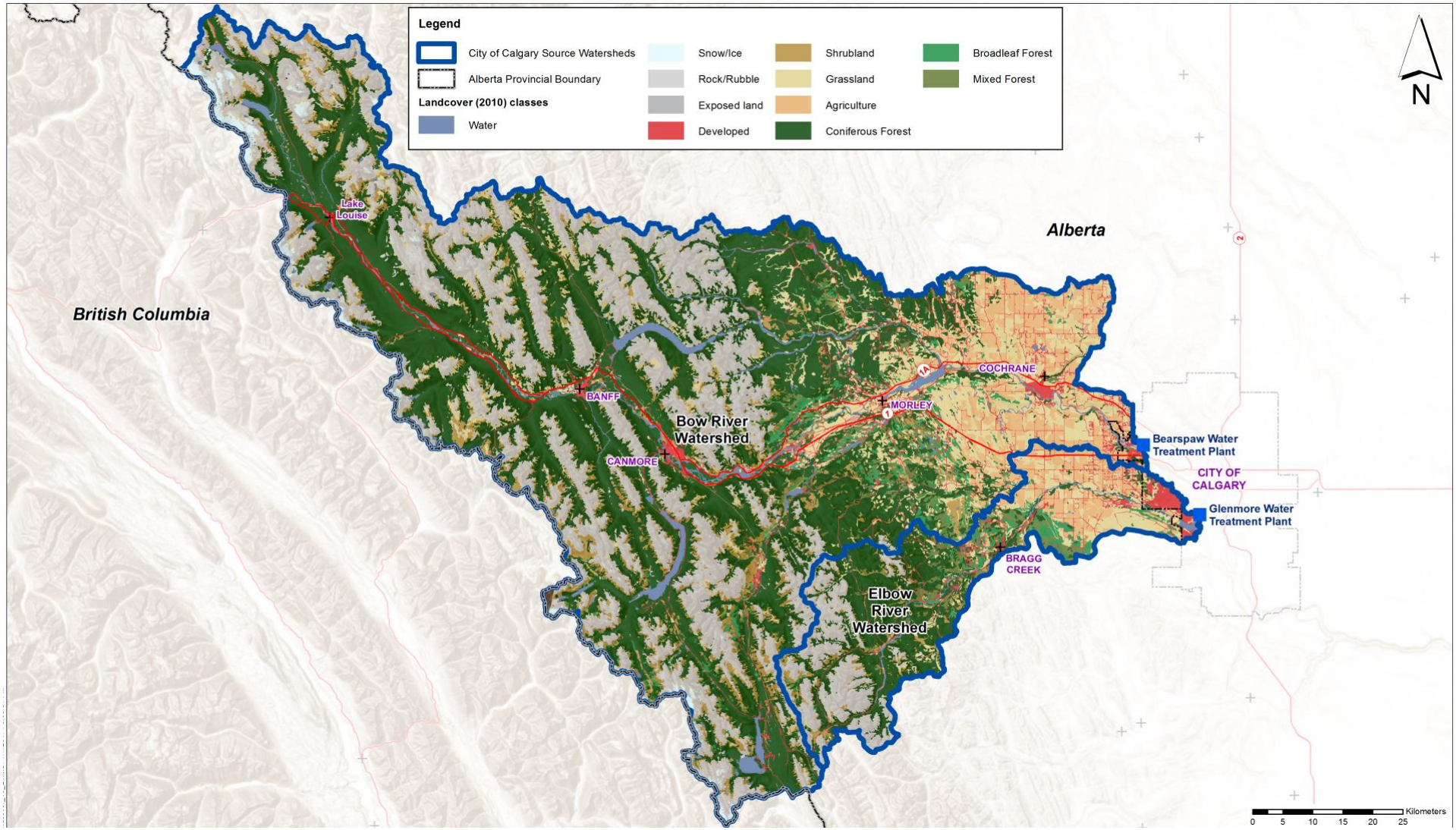


Figure 9. Map of Land Cover in Calgary's Source Watersheds

Source Water Quantity

The majority of Calgary's source water originates as rain and snow in the Rocky Mountains and Foothills west of Calgary. Typical flows on the Bow and Elbow Rivers are shown in Figure 10. In addition to strong seasonal variation, periodic wet and dry cycles also affect southern Alberta. Major droughts in the past have included droughts in the 1400s, 1700s, 1800s, and early 19th century [3]. In addition, modern climate change is expected to increase the frequency and magnitude of extreme events such as drought and flash flooding [4, 5].

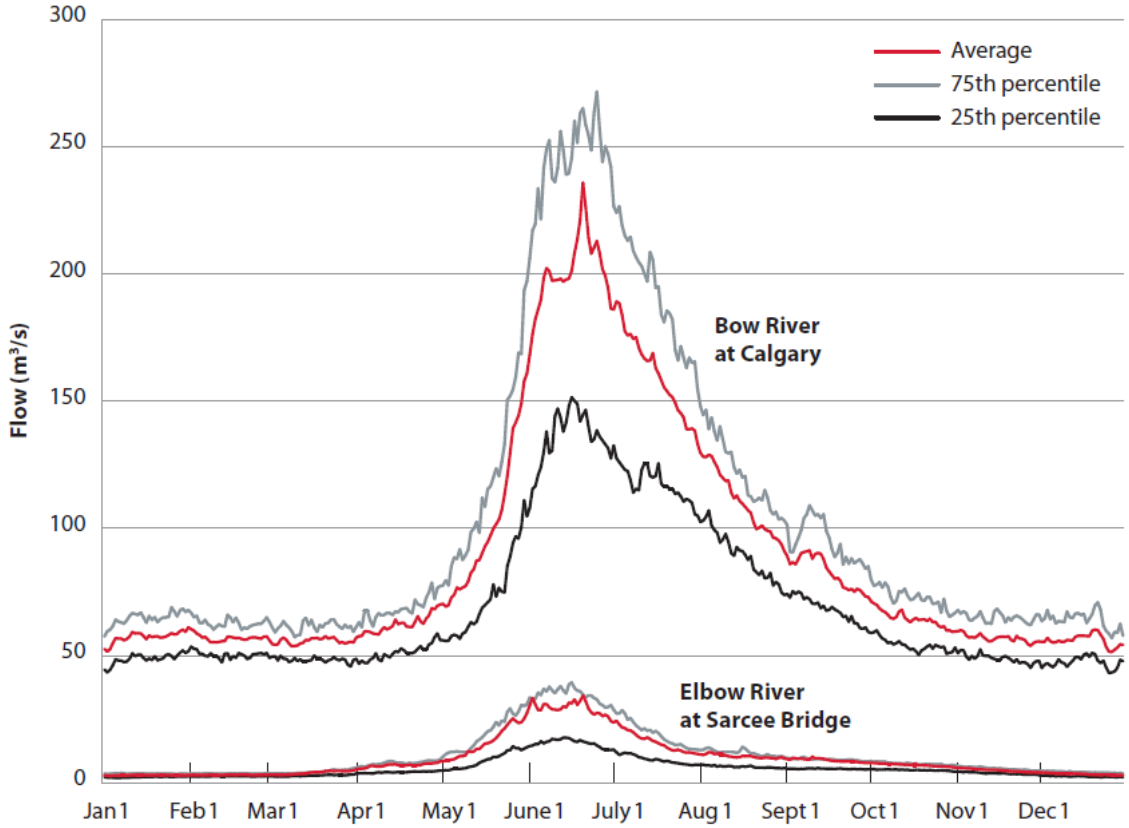


Figure 10. Typical Flows of the Bow and Elbow River Source Water Supplies

Water Quantity and Quality Synergies

Although this Plan focuses primarily on water quality issues, there are synergies between water quality and water quantity issues that require coordination and integration.

For example, high flows are usually accompanied by high turbidity. In contrast, low flows result in less dilution of wastewater effluent and stormwater runoff, resulting in higher concentrations of contaminants in our rivers.

Time of Travel

The time of travel for contaminants moving through a watershed can be important to prioritize locations for source water protection efforts. Time of travel is influenced by a number of factors, including flow velocities in rivers and streams, distance to the intake, and residence times of water in upstream reservoirs. The time water spends in reservoirs – also known as reservoir residence time – is particularly important, as this influences processes such as settling of sediments, UV degradation from sunlight, and microbial activity in reservoirs. It can be very difficult for treatment plant operators to receive notice and react to spills or releases from travel times are short from upstream areas.

Table 1 and Figure 11 summarize travel times to The City's source water intakes from various locations in the source watersheds. In general, travel times to The City's intakes range from several months for those areas upstream of the Kananaskis Lakes, to less than a day from areas adjacent to the Bearspaw Reservoir. During floods, travel times can be dramatically reduced. For example, travel time through the Bearspaw Reservoir is about 19 hours on average, but is reduced to less than 2 hours during major floods [6].

Table 1. Average* River Travel Times and Reservoir Residence Times

River Reach	Waterbody Type	Annual Average *Residence Time* / Travel Time
Bow River Source Watershed		
Lower Kananaskis Lake	Reservoir	*113 days*
Bow River at Banff to Ghost Reservoir	River	28 hours
Ghost Reservoir	Reservoir	*17 days*
Bow River at Cochrane to Bearspaw Reservoir	River	6 hours
Bearspaw Reservoir	Reservoir	*19 hours*
Elbow River Source Watershed		
Elbow River – Bragg Creek to Glenmore Reservoir	River	19 hours
Elbow River – Sarcee Bridge to Glenmore Reservoir	River	1.6 hours
Glenmore Reservoir	Reservoir	*37 days*

**Annual averages are shown, but vary considerably with river flows*

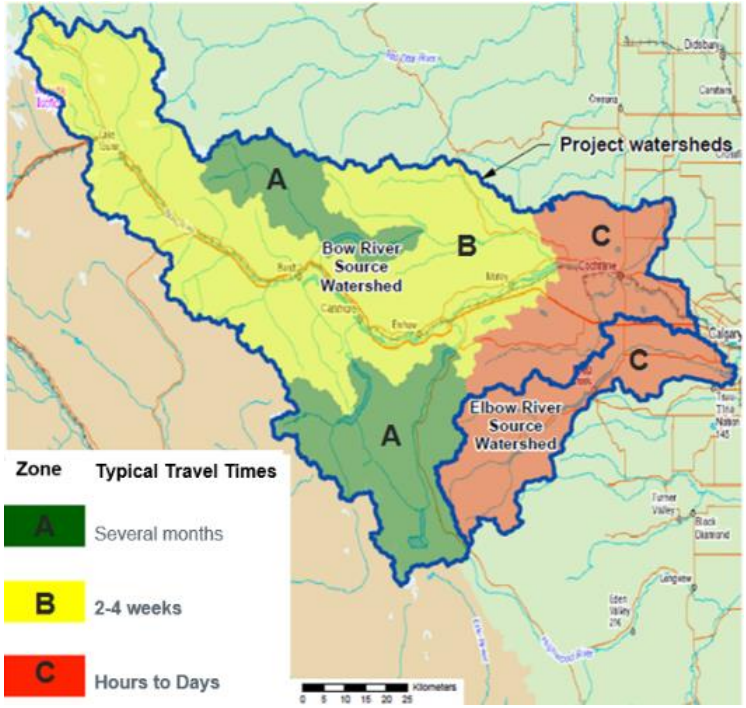


Figure 11. Broad Travel Time Zones in Calgary's Source Watersheds (DRAFT)

Source Water Quality

Understanding source water quality is key to ensure protection of public health. The City conducts extensive source water quality sampling at our drinking water treatment facilities and throughout the source watershed. Water quality parameters monitored include:

- Turbidity as a measure of water clarity
- Total organic carbon (TOC), which originates from the decomposition of plant materials
- Nutrients, including the various different forms of phosphorus and nitrogen
- Metals, including naturally occurring metals and those associated with human land use or industry
- Pesticides that may be applied on agricultural lands or in residential areas
- Organic contaminants commonly associated with industrial processes and waste disposal sites
- Microbiological contaminants from human and/or animal faeces, such as *E.coli*
- Nuisance organic compounds produced by naturally occurring bacteria, algae and fungi that can create taste and odour issues and in some cases can have toxic properties
- Radiological parameters
- Other physical-chemical parameters, including pH, temperature, ions, etc.

Of all the water quality parameters monitored, 62 have provincially regulated Maximum Acceptable Concentrations (MAC) for finished drinking water. Thirteen of these parameters (including nutrients, metals, anions, and radionuclides) are naturally occurring and typically detected in the source water, but at concentrations several hundred times lower than the established MAC.

Turbidity, total organic carbon, and enteric protozoa are the most important source water quality parameters driving current water treatment operations. These parameters affect the day to day operation and optimization of the water treatment plants, and are the key factors influencing future infrastructure planning. Organic compounds associated with taste and odour issues and a range of other organic chemicals are also key to consider for source water protection, as discussed below.

Public health regulations for drinking water control the quality of treated water entering the distribution system. Source water quality generally determines the level of treatment required to make water safe to drink.

Turbidity is a term used to describe water clarity. High turbidity is caused by particles of clay, silt, and fine organic and inorganic matter suspended in water, and can be influenced by high river flows and related processes of erosion. Calgary's source waters demonstrate seasonal changes in turbidity, with peak levels coinciding with the mountain snowpack melt in late spring and early summer. Turbidity also shows strong variation from year to year. Depending on the nature of the suspended matter, implications for water quality and treatment differ. Over the last decade, significant upgrades were made to both water treatment plants to improve their ability to treat water during high turbidity events. The success of these upgrades was illustrated during the June 2013 flood, when The City continued to produce clean water despite extremely high turbidity in our source water.

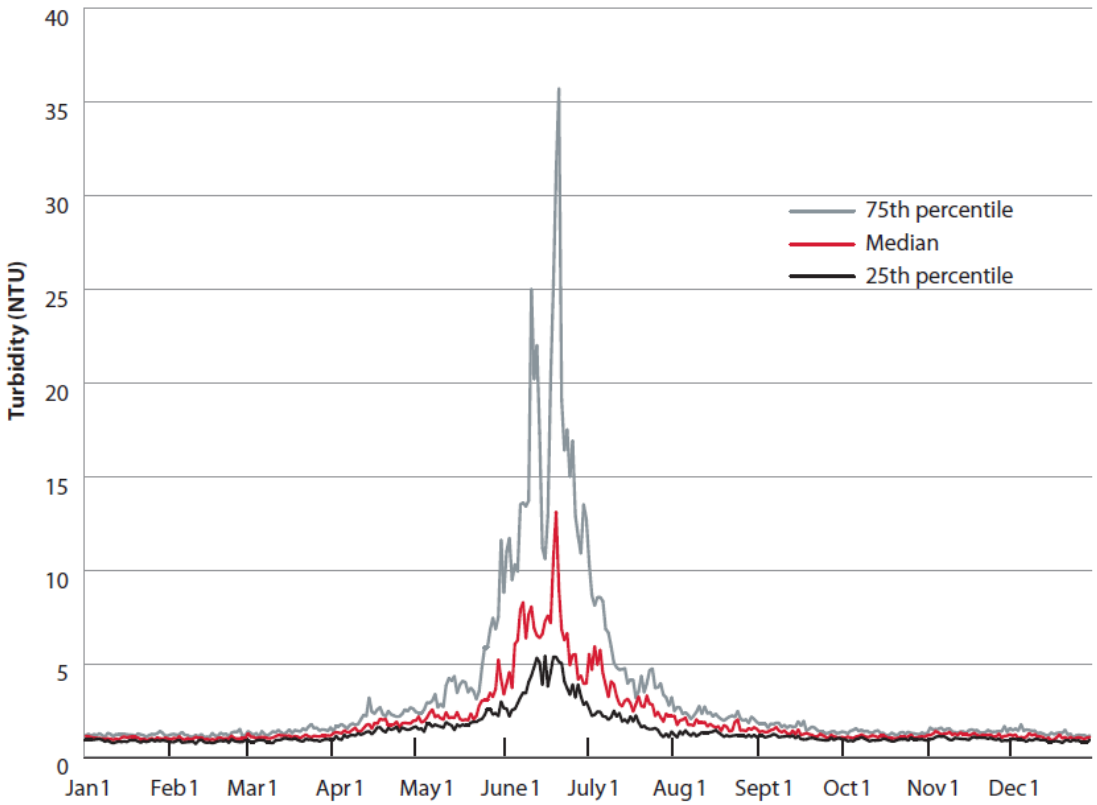


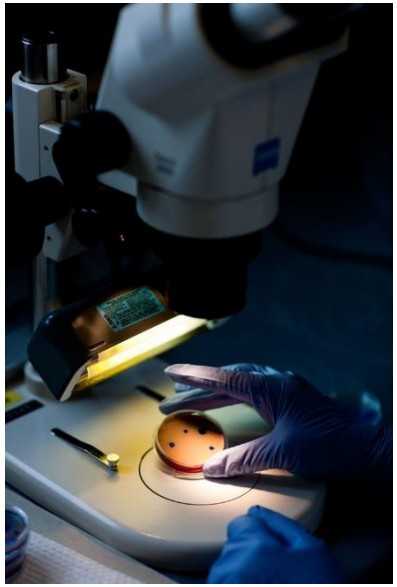
Figure 12. Seasonal Turbidity at the Bearspaw Treatment Plant

Water Quality Changes due to Runoff

Spring runoff often causes dramatic, mostly natural changes to water quality. Figure 12 graphs seasonal trends in turbidity. October through March show consistently low values, but there is typically high variability during May, June and July due to high runoff and associated erosion. TOC, nutrients, and *E. coli* follow similar patterns over the year. Although The City's water treatment system is designed to handle these turbidity spikes, costs for water treatment chemicals can increase by 3 to 5 times during runoff events.

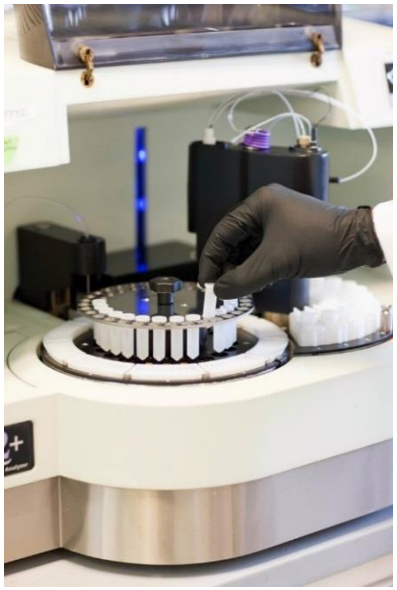
High flows can also have the benefit of diluting many of the low concentration contaminants that cannot be treated at The City's plants. Therefore, based on existing treatment capacities, source water quality protection could be considered as most important during low flow drought conditions.

Enteric protozoa such as *Cryptosporidium* and *Giardia* are the main pathogens of concern for drinking water. Their occurrence in source water is due to contamination by human or animal faeces. Scientific evidence shows that Calgary has sufficient drinking water treatment processes to treat current and historic protozoa levels found in Calgary's source waters. However, significant increases of protozoa in source waters could trigger the need for additional disinfection.



Taste, Odour and Algal Toxins

Tastes and odours can be imparted to water by a number of different chemicals. Some of the most potent are volatile organic compounds (VOCs) produced by naturally occurring algae and bacteria. Although algal blooms can happen under natural conditions, nutrient inputs such as phosphorus and nitrogen from upstream sources tend to increase the frequency and magnitude of algal blooms. Some algae can also produce toxic chemicals, although to date these have not been observed in Calgary's source watersheds. For additional details, see Appendix B.



Total Organic Carbon (TOC) is important to water treatment, as increases in TOC can lead to increased treatment costs. Increased TOC that is not accompanied by increased turbidity can increase operational complexities and reduce efficiencies, since dissolved organic carbon is more difficult to remove than solids. TOC is also a precursor to the formation of Disinfection By-Products (DBP) during chlorine disinfection. DBPs can result from chemical reactions between disinfectants and natural organic matter. In sufficient concentrations, DBPs can pose risks to public health, although current water treatment practices and monitoring indicates that Calgary's treated water remains within regulatory limits for DBPs.

Other Organic Compounds (Pesticides, Hydrocarbons, Volatile Organic Compounds, PAHs)

Calgary's source waters are routinely monitored for synthetic and naturally-occurring organic compounds, including pesticides, polycyclic aromatic hydrocarbons (PAHs), hydrocarbons and volatile organic compounds (VOCs). Since 2007, 103 different compounds have been tested, 53 of which have Canadian Drinking Water Quality Guidelines because of their potential public health risks. Over 1,800 samples from The City's raw water intakes were analyzed for organics between 2007 and 2016, and less than 1 per cent of these samples had detections. Levels detected in both the raw and finished drinking water were below drinking water guidelines in all cases. Maintaining high quality source waters with respect to organics is important, since some of these compounds are not effectively removed by standard drinking water treatment processes.

Emerging substances of concern

Emerging substances of concern (ESOCs) are found in products people use on a daily basis, and include pharmaceuticals, hormones, detergents, plasticizers, and flame retardants. ESOCs can make their way into surface waters via domestic and industrial waste, and urban and agricultural runoff. As technology continues to advance, it is easier to detect these substances at minute concentrations in water (i.e. parts per trillion or lower); however, this does not necessarily indicate that they pose a risk to human health or the environment. The World Health Organization conducted a review of pharmaceuticals in drinking water in 2012 and came to the conclusion that "appreciable adverse impacts on human health are very unlikely at current levels of exposure" [7].

Monitoring for ESOCs in Calgary's source water has been ongoing since 2007, and an ESOC Strategy was implemented in 2016. Since then, monthly monitoring has been conducted internally for 14 indicator compounds at the raw intakes of both water treatment plants, and semi-annual testing has been conducted externally for an additional 116 ESOCs. In total, 202 different ESOCs have been tested in Calgary's source water since 2007, and only 6 of these substances have been detected, all of which are indicators of wastewater impacts from upstream communities. Of the indicator compounds tested on a monthly basis, the most frequently detected is caffeine, which has been observed in 18% and 5% of samples from the Glenmore and Bearspaw raw intakes, respectively. However, it must be emphasized that the concentrations detected are minute at 32 parts per trillion or lower. The concentrations of caffeine occasionally detected in Calgary's source waters are comparable to or lower than those found in other surface waters across North America [8]. The City is also working with government and University partners to gather information and conduct research on ESOCs to proactively advance the state of the science, inform regulatory agencies, and protect public health and the environment.

Parts per Trillion in Perspective

A caffeine concentration of 32 parts per trillion would take about 12.5 million glasses of water to equate to the amount of caffeine in one cup of coffee.

Watershed monitoring program

Established in the 1980s and expanded over time, The City of Calgary's Watershed Monitoring Program conducts monthly sampling of rivers, tributaries, and reservoirs in the region, including 22 sites in Calgary's source watershed. This program complements the detailed daily monitoring of source water at the treatment plants. Historical records of water quality help monitor changing watershed conditions over time and implications for source water protection. Changes in water quality in smaller tributaries or specific reaches can serve as early warnings of deteriorating water quality, and can help pinpoint the locations of contamination sources.

Water Quality Index

The federal water quality index (WQI) is used to track overall water quality conditions for rivers in a watershed. The index translates detailed data on multiple water quality parameters into a score from 0-100 along with a descriptor (e.g., 'Excellent', 'Good', 'Marginal', 'Poor'). The Bow River typically has 'Excellent' water quality, while the Elbow River typically has 'Good' water quality.

Bow River Source Watershed

Overall, the Bow River and the Bearspaw Reservoir provide excellent, high quality source water to the Bearspaw Water Treatment Plant (Table 2). The Jumpingpound Creek tributary site shows the greatest departures of water quality from guidelines, although water quality is still considered 'Good' in this creek (Table 2). Jumpingpound Creek generally has higher nutrients, higher TOC, and higher turbidity compared to the Bow River, most likely due to agriculture.

In addition, the Province maintains a monitoring site at Cochrane where a variety of pesticides are monitored. Between 2009 and 2015, only the herbicides 2,4-D and Mecoprop (MCPP) were detected, at frequencies of 18% and 7% of samples, respectively. However, maximum concentrations detected remained much lower than federal and provincial guidelines for aquatic health and drinking water.

Table 2. Summary of Calgary's Watershed Monitoring Program: Bow River Source Watershed

Bow River Source Watershed		
Monitoring Site	**Sampling Frequency**	**Summary of Water Quality**
Bow River below Ghost Dam	Monthly, year round	Excellent (100)
Bow River at Highway 22		Excellent (97)
Bow River Below Bearspaw Dam		Excellent (100)
Tributaries		
Ghost River at Benchlands	Monthly, year round	Excellent (100)
Jumpingpound Creek at the Mouth		Good (82)
Bearspaw Reservoir		
Bearspaw Reservoir West	Monthly, May to September	Oligotrophic*
Bearspaw Reservoir Centre		
Bearspaw Reservoir East		

*River values based on WQI; reservoir value based on trophic status (oligotrophic represents a desirable low nutrient status)

Trophic State Index

The Carlson Trophic State Index for chlorophyll *a* is used to measure algal productivity, as an indicator of the nutrient status for reservoirs. It is typically used to classify water bodies into three categories: Oligotrophic, Mesotrophic, or Eutrophic. For drinking water and recreational uses, oligotrophic conditions are desirable as they have the lowest potential for harmful algal blooms to occur.

Elbow River Source Watershed

There are fourteen City monitoring sites in the Elbow River source watershed (Table 3). A gradual deterioration of water quality has been observed when moving from upstream to downstream through the watershed, ranging from the most upstream site (Cobble Flats), which

has a perfect WQI score of 100 (Excellent), to an overall rating of 87 (Good) at the Weaselhead Footbridge. The changes are primarily due to gradual increases in TSS and total phosphorus associated with more developed land uses and associated stormwater inputs.

The largest increase in sediment and total phosphorus is observed between the Twin Bridges site and Sarcee Bridge, which reflects the transition from rural to urban land uses and increasing stormwater inputs. Other parameters, such as TOC, metals, *E. coli* and protozoa also demonstrate similar increases as the Elbow River approaches the Glenmore Reservoir.

Pesticides have been monitored in the Elbow River at the upstream end of the Glenmore Reservoir for over 10 years. Of the 72 pesticides investigated, only 6 have been detected, with the herbicides 2,4-D and MCPP detected most frequently. Their presence is due to the cumulative impacts from upstream sources, including urban stormwater inputs and diffuse overland drainage from various land uses in the watershed. However, maximum concentrations of pesticides still remain significantly lower than federal and provincial guidelines for aquatic health and drinking water. Four major tributaries to the Elbow River are also monitored as part of the Watershed Program (Table 3). Despite having overall 'Good' water quality, these tributaries contain significant amounts of TSS, nutrients and TOC.

Table 3. Summary of Calgary's Watershed Monitoring Program: Elbow River Source Watershed (2014-2016)

Elbow River Source Watershed		
Monitoring Site	**Sampling Frequency**	**Summary of Water Quality**
Elbow River above Cobble Flats	Monthly, May to October	Excellent (100)
Elbow River above Bragg Creek	Monthly, year round	Good (90)
Elbow River at Highway 22 Bridge		Good (92)
Elbow River at Twin Bridges		Good (87)
Elbow River at Sarcee Bridge		Good (86)
Elbow River at Weaselhead Foot Bridge		Good (87)
Tributaries		
Prairie Creek near Mouth	Monthly, May to October	Excellent (100)
McLean Creek near Mouth		Good (88)
Lott Creek near the Mouth		Good (88)
Bragg Creek at the Mouth	Monthly, year round	Good (88)
Glenmore Reservoir		
Glenmore Reservoir – Head Pond	Monthly, May to September	Oligotrophic*
Glenmore Reservoir – Mid-Lake		
Glenmore Reservoir – Heritage Cove		
Glenmore Reservoir – Weaselhead		

*River values based on WQI; reservoir value based on trophic status, where oligotrophic represents a desirable low nutrient status

The Glenmore Reservoir

Generally, the Glenmore Reservoir currently provides high quality source water. Water quality in the Glenmore Reservoir also tends to improve as water moves from the Weaselhead Natural Area through the reservoir to The City's source water intake. This occurs because natural processes in the reservoir facilitate the removal of particulate matter, nutrients, metals and protozoa as water passes through the reservoir. The reservoir tends to maintain low nutrient conditions - classified as 'oligotrophic' - which is ideal for source water (Figure 13). However, there is a risk that this delicate balance could be disturbed by land use change in the watershed combined with climate change. If nutrient inputs cause the reservoir to change to medium productivity conditions (mesotrophic) or high productivity conditions (eutrophic), source water quality will degrade, leading to a range of management issues.

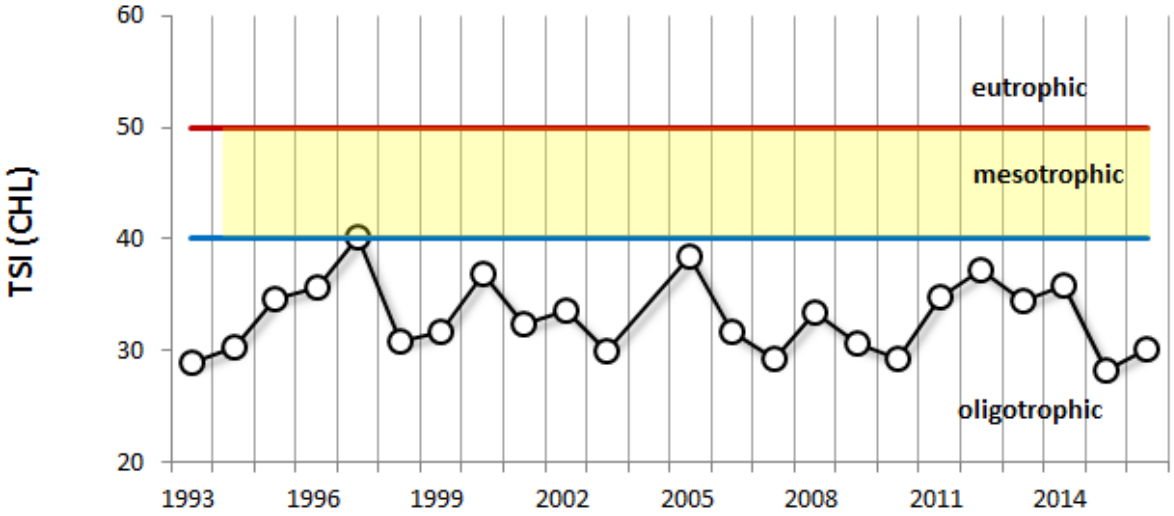


Figure 13. Trophic State Index (Algae Productivity) in the Glenmore Reservoir Over Time

Sediment, Nutrients, and Flood Dynamics in the Glenmore Reservoir

Most of the fine sediments that are deposited in the Glenmore Reservoir are washed or scoured past the dam during high flow events.

The trophic index also tends to decrease in the Glenmore Reservoir the first few years following a flood (e.g., 2005, 2013) (Figure 13). This indicates that the natural removal of sediment from the reservoir during high flow events may also be contributing to its' desirable low-nutrient status.

Summary of Source Water Quality Issues

The City's extensive water quality monitoring shows both the Bow and Elbow Rivers provide high quality source water to The City's water treatment plants. However, the cumulative effects of land use changes and climate change may result in future issues such as more taste and odour issues due to algal blooms, or an increase in real or perceived public health risks due to Emerging Substances of Concern (ESOCs). As a smaller river, the Elbow River is expected to be more susceptible to future source water quality changes compared to the Bow River, as a result of lower dilution rates in the Elbow. By implementing proactive source water protection strategies today, we can help mitigate these risks and maintain high source water quality for the future.

Source Watershed Risks

Assessing source water risks is a critical precursor to source water protection planning. To achieve this, The City worked with a multidisciplinary consulting team to complete a *Source Watershed Assessment and Risk Characterization* (SWARC) study. This study drew from and integrated with provincial direction including the *Drinking Water Safety Plan* process, as well as the federal government's Source-to-Tap guidelines [7], and the American Water Works Association's Source Water Protection Standard [2]. The methodology included mapping and spatial analyses, and a synthesis of information to assess and prioritize risks. Risks were prioritized in relation to one another based on the likelihood of risks occurring, and the consequence of risks should they occur.

Identified risks do not imply that actual impacts to source water are occurring. Risks have the *potential* to contaminate source waters *if* something goes wrong (e.g., a spill, major forest fires).

Small impacts from multiple activities can also have cumulative impacts that gradually degrades water quality over time.

Key Risk: Stormwater Pollution

One of the highest risks to Calgary's source water was identified as stormwater pollution from current and future developments. Currently, almost 200,000 people live in Calgary's source watershed, with the vast majority residing within 30 km of Calgary's intakes. This population is projected to more than double to almost 400,000 people over the next 50-70 years. Stormwater quality is highly variable and shows significant spikes in pollutants in an unpredictable manner, and has the potential to degrade Calgary's source water either chronically through ongoing loading of low concentrations of pollutants, or acutely due to spill events or runoff after severe storms. For stormwater, hydrocarbons and a variety of other organic compounds were identified as the highest risks, due to the lack of current treatment capabilities and lower overall management effectiveness of current regulations and best practices. Pesticides, inorganics, and enteric pathogens were identified as secondary concerns. Impacts to water quality during construction activities were also identified as concerns.

Key Risk: Wildfire

Widespread, high intensity forest fires are also a key high risk for Calgary's source watershed. Fires are known to impact water quality in several ways, and could pose significant challenges to source water quality. Changes to water chemistry from burned watersheds after fires occur include higher concentrations of nutrients, metals, dissolved organic carbon, and other organics, which can pose challenges for treatment [8, 9] (See Appendix B for details). Fire retardants used in firefighting operations could also pose some level of risk to source water quality. Fortunately, the dry conditions of summer 2017 did not cause any large wildfires in Calgary's source watershed. However, widespread fires in the region, including the Verdant wildfire in Kootenay National Park, and the Kenow wildfire in and around Waterton National Park highlight the potential for severe wildfire in Calgary's source watersheds. Large, widespread wildfires are also likely to become more frequent due to climate change [26].

Specific source watershed locations with the highest overall risks of contamination to Calgary's drinking water have been determined, based on combinations of burn probability mapping and source watershed vulnerability mapping, and are shown in Appendix B.

Other Risks

In addition to the top two source water risks described above, moderate risks identified include: contamination introduced from transportation corridors, wastewater, recreation, industrial discharges, livestock, use of pesticides on crops and country residential areas, oil pipeline spills, a rail line spill near Bearspaw, and algal blooms. Many other risks were ranked as lower risks overall, based on biophysical factors, location in the watershed, existing regulations and management practices, and current water treatment capabilities.

It should also be noted that lower priority risks do not necessarily imply no management concern, as the cumulative effects of multiple stressors can also degrade water quality [10, 11].

Investing in Source Water Protection Makes Good Business Sense

Investments in source water protection not only protect public health and help The City of Calgary maintain the high quality of drinking water citizens have grown accustomed to, but will also help to avoid expensive infrastructure investments required to treat water. Many other municipalities have found that proactive expenditures to protect source water can be more cost effective than building and operating more advanced treatment facilities.

Current Drinking Water Treatment Infrastructure

Water treatment processes at Calgary's two plants include:

- Pre-treatment utilizing a ballasted clarification process
- Clarified water basins
- Filtration with gravity flow and multi-media filters
- Chemical disinfection with sodium hypochlorite
- Clearwell for disinfection contact time and storage

Currently, the most frequent challenge faced by Calgary's water treatment plant operators is the need to remove high levels of suspended solids. Treatment processes have been selected and designed to deal with this. In contrast, current infrastructure and operations are not designed to treat hydrocarbons, pesticides, ESOCs, or other organics. Although to date these have largely been absent from our source waters, if source water quality degrades, more advanced treatment processes would be required.

The costs of upgrading both the Glenmore and Bearspaw Water Treatment Plants with more advanced treatment processes could reach **$350 million of capital** costs for construction, and an additional **$5.5 million / year annual operating costs** for ongoing operations and maintenance. This benefit in associated avoided costs that we derive from the high quality of our watershed and rivers is known as an "ecosystem service"- or a benefit that people obtain from nature [16].

Other Ecosystem Services in our Source Watersheds

In addition to clean source water for drinking water utilities, our high quality source watershed also provides many other ecosystem services to people. For example, recreational fishing contributes approximately $25 million/year to Calgary businesses, and the regional contribution of fishing-related activities is approximately $114 million/year annually. Regional recreational paddling activities also contribute over $50 million per year to the local economy. *Source: Calgary River Users Alliance* [52]

Which River Does Your Water Come From?

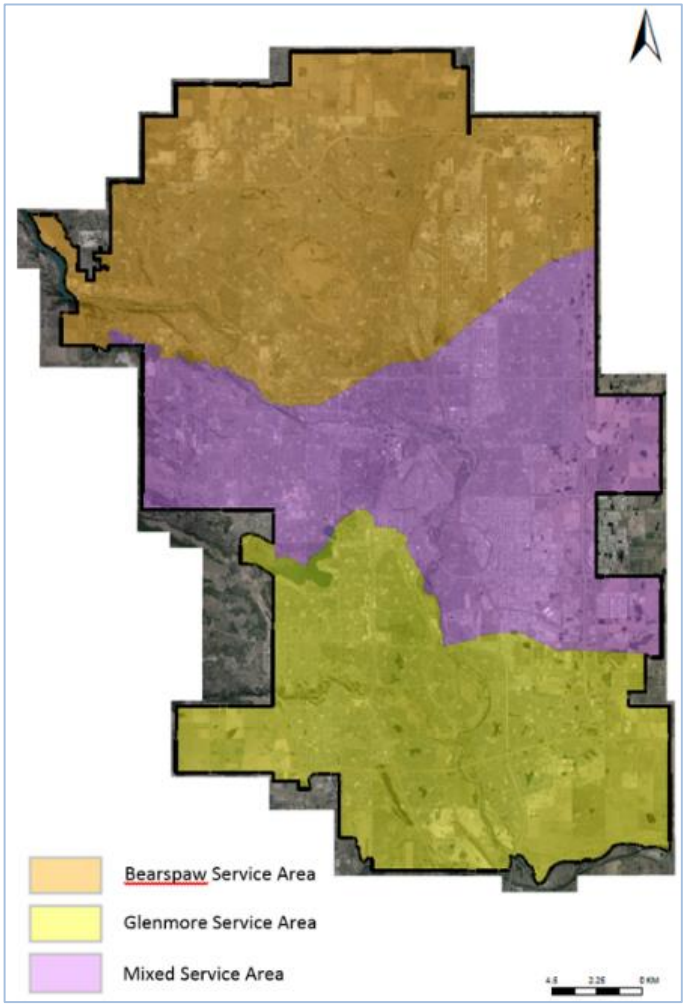


Figure 14. Typical Potable Water Service Areas in Calgary-DRAFT

Typically, the Bearspaw plant supplies treated Bow River water to the northern half of Calgary, and the Glenmore Plant provides treated Elbow River water to the southern half of Calgary. A wide swath through the middle of Calgary-including downtown and many inner city communities- is usually a blended mix of water sourced from both the Bow and Elbow Rivers.

Typical conditions are shown in Figure 14. However, all of Calgary's water mains are connected to one another. As a result, the water source at different locations changes regularly in response to production and pumping volumes, operational strategies, or situations within the rivers and reservoirs.

SOURCE WATER PROTECTION GOALS

Strategic source water protection goals provide focus for a source water protection program. The City of Calgary's goals for its' long-term Source Water Protection Program are based on proactively preventing, reducing, or mitigating key source water quality risks, as part of a multi-barrier approach to providing safe, clean, high quality drinking water. The following goals have been carefully selected based on risk priorities, customer commitments, and stakeholder engagement:

GOAL 1: Enhance land use planning to protect the source watershed

Why is enhancing land use planning important?

Our source watersheds face significant future population growth and land use changes. As this unfolds, additional guidance and tools for planning decisions will be needed to more proactively balance community growth with source water risk mitigation. Maintaining source water quality over the long term requires careful attention within the land use planning process - both within and outside of Calgary city limits - to improve integration with source water protection.

GOAL 2: Promote innovation in stormwater management to protect source water quality

Why is stormwater management important?

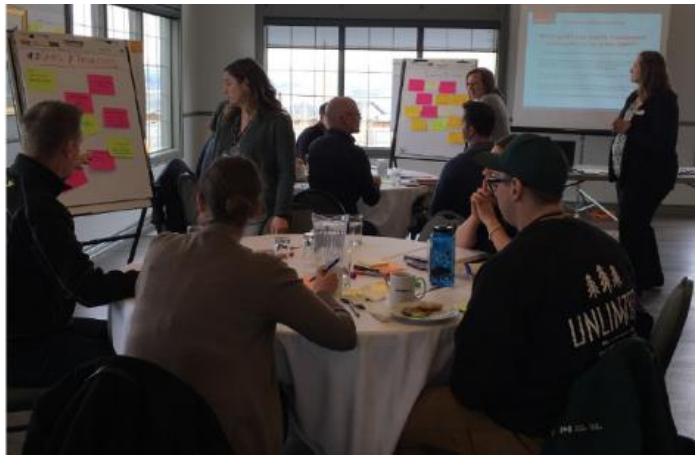
One of the highest risks to Calgary's source water is stormwater pollution from current and future developments. To mitigate these impacts and prevent source water quality deterioration, careful attention to innovative stormwater management techniques will be required for both new and existing developments.

GOAL 3: Leverage key partnerships for risk mitigation

Why is leveraging key partnerships important?

Partnerships are absolutely critical, since most of the source watershed is well outside of the jurisdiction of The City of Calgary. Experience and case studies from around the world demonstrate that effective partnerships are a requirement for an effective source water protection program. By leveraging and building on existing organizations and programs and "connecting the dots" - rather than reinventing the wheel - local and regional partner capacity and momentum can be built more quickly to address source water risks [51]. By leveraging key partnerships, additional funding can be obtained, while source water protection "champions" can be developed in multiple communities of practice. For Calgary, partnerships are particularly important to proactively mitigate the impacts of wildfires on water quality and to help protect vulnerable source watershed lands.

GOAL 4: Effectively involve stakeholders and citizens through education and research



Why is effective stakeholder and citizen involvement important?

Many industries, stakeholders, and citizens work, live, and play throughout Calgary's source watersheds. Every one of these can have a role to play in helping to realize Calgary's long-term source water protection vision. By providing opportunities for individuals to connect and become involved with protecting the Bow and Elbow River source watersheds, lasting and meaningful relationships with our watershed can be built. Best practice case studies show that by effectively involving people through education and research, municipal utilities can help better achieve source water protection objectives by [17]:

- Leveraging expertise from multiple knowledge domains
- Promoting learning and understanding by all parties
- Improving community relations

SOURCE WATER PROTECTION ACTION PLAN

Action priorities for implementation have been grouped under the four goals, and categorized by general location (Figure 15).

Provincial direction	**South Saskatchewan Regional Plan** • Enhanced integrated watershed management • Building sustainable communities			
Vision	The City of Calgary's source watersheds continue to provide clean, high quality water supplies through proactive stewardship and management			
Key drivers	• Proactive protection of public health • Environmental stewardship and conservation • Minimizing future water treatment capital and operating costs			
Guiding principles	Integrating land and water management		Collaborating through partnerships and watershed stewardship	
Goals	**GOAL 1** Enhance land use planning to protect the source watershed	**GOAL 2** Promote innovation in stormwater management to protect source water quality	**GOAL 3** Leverage partnerships and stewardship for risk mitigation	**GOAL 4** Effectively involve stakeholders and citizens through education and research
Five-year actions planned	Develop and implement **recreation management strategies** and actions for the Bearspaw Reservoir	Prioritize **erosion and sediment control inspections** and enforcement within The City's source watersheds	Develop a **wildfire management strategy** with fire management agencies to proactively mitigate fire risks	Conduct a **traditional use study** to explore First Nations' traditional knowledge on water and watersheds
	Develop **drinking water protection zone** overlays and integrate with The City's statutory and regulatory instruments	Evaluate and implement **stormwater management requirements** to meet source water quality objectives	Conduct a **watershed conservation study** to evaluate options to protect vulnerable source watershed lands	Provide guidance to **university research projects** in Calgary's source watersheds
	Integrate source water protection priorities in **regional land use and servicing plans and provincial regulations**	Prioritize **riparian, wetlands and green infrastucture projects** within The City's source watersheds	Update **emergency response plans** for spills and increase co-ordination with industry	Develop a **source water education plan** to promote community and regional actions to reduce risk

Legend

- Action applies only to source watershed areas within Calgary city limits
- Action primarily applies to source watershed areas outside Calgary city limits
- Action applies to source watershed areas both within and outside City limits

Figure 15. From Vision to Actions: An Overview of Calgary's Source Water Protection Program

A Key Best Practice from Other Jurisdictions: Drinking Water Protection Zones

Drinking Water Protection Zones include the land and water areas surrounding municipal source water intake pipes [13]. The purpose of these zones is to prevent or mitigate contamination risks, due to activities or land uses occurring near municipal source waters. Policies in these zones can prohibit or restrict specific activities or land uses, or require a higher standard of design or regulation.

Overlay zones can be integrated into the land use planning system to require planning and development standards and procedures over and above those in the underlying land use zone or district. High risk activities or land uses are often prohibited, such as industrial land uses, storage facilities for hazardous materials, gas stations and car repair garages, and dry cleaning facilities. Risk management plans can also be developed with business and property owners within the overlay.

Implementation Case Studies

These types of overlay zones have been established in many jurisdictions, and have been called Intake Protection Zones (IPZ) (Ontario), Water Intake Overlay Zones (Nova Scotia), Watershed Protection Areas (Washington state), Watershed Protection Overlay District (New York), Watershed Critical Areas (North Carolina), or Public Drinking Water Source Areas (Western Australia).

Land use restrictions and best practices within the overlay zones are typically applied in a tiered manner based on proximity to the source water intake. For example, in Ontario, three categories are used for each drinking water intake, including: (1) IPZ-1: areas immediately adjacent to the intake pipe (typically a 1 km radius around the intake, with an additional 120 m setback on land from the shoreline) (Figure 16), (2) IPZ-2: an area upstream where a spill might reach the intake pipe before the plant operator can react (Figure 16), and (3) IPZ-3: a larger part of the watershed where contaminants might find their way to the intake [13].

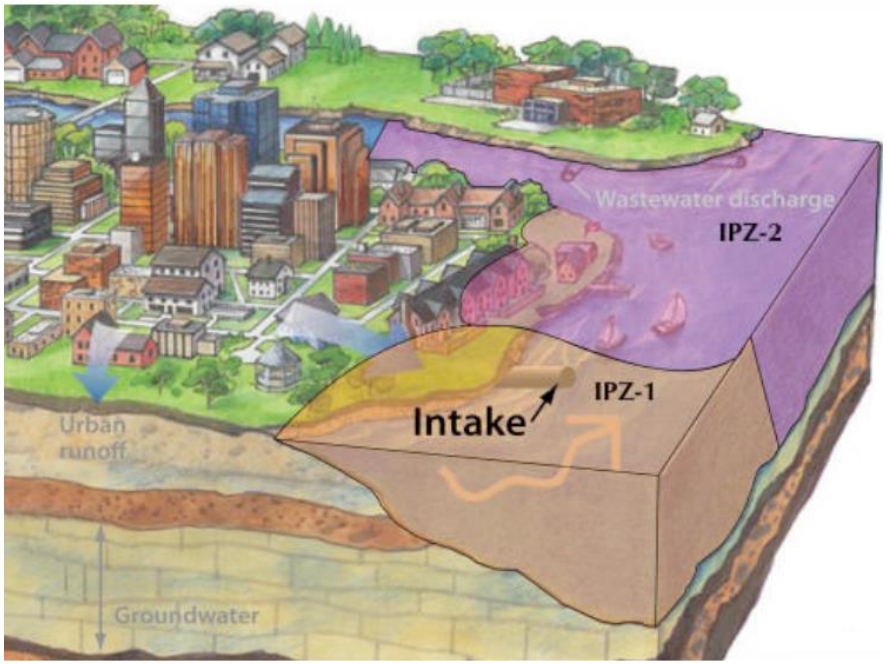
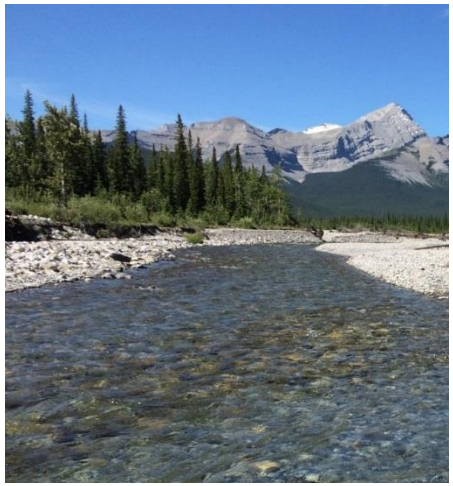


Figure 16. Illustration of Intake Protection Zones (Source: Rideau Valley Conservation Authority, Ontario)

Some municipalities have even gone as far as to restrict maximum site imperviousness of land uses within these zoning overlays to reduce stormwater pollution (e.g., San Antonio, Texas; Austin, Texas; Greensboro, North Carolina). Other municipalities (e.g., Whatcom County, Washington) have watershed overlay zone regulations requiring cluster housing development, extremely high standards of stormwater management, and mandatory retention of trees and native vegetation.

SOURCE WATER PROTECTION IMPLEMENTATION: PAST, PRESENT, AND FUTURE



This Plan is just the latest chapter in a long history of source water protection. Many past decisions reflect a long history of source water protection. Selected key actions implemented to date by The City of Calgary are summarized in Figure 18.

In addition to The City's past actions, many agencies, groups, industries, and individual citizens have executed actions that have played a role in maintaining the high source water quality we enjoy today. These actions go back well over a hundred years, and are too numerous to list within this Plan. However, for an overview and description of various watershed management activities and regulations in the source watershed, see Appendix B.

37th St. SW Stormwater Trunk Project: Water Quality Enhancements

In 2017, as part of the relocation of the 37th St. SW Stormwater Trunk, The City is improving the quality of stormwater draining to the Glenmore Reservoir by installing an oil-grit separator to capture hydrocarbons and sediment and improve water quality. In the near future, a stormwater pond facility will also be installed to further improve stormwater quality through the removal of nutrients.

Future Implementation Strategy

Implementation of the identified source water protection actions in this Plan is anticipated to involve partnerships with many others, to leverage resources across a wide range of jurisdictions, domains, and disciplines. Coordination, collaboration, integration, and innovation are anticipated to be the hallmarks of Plan implementation.

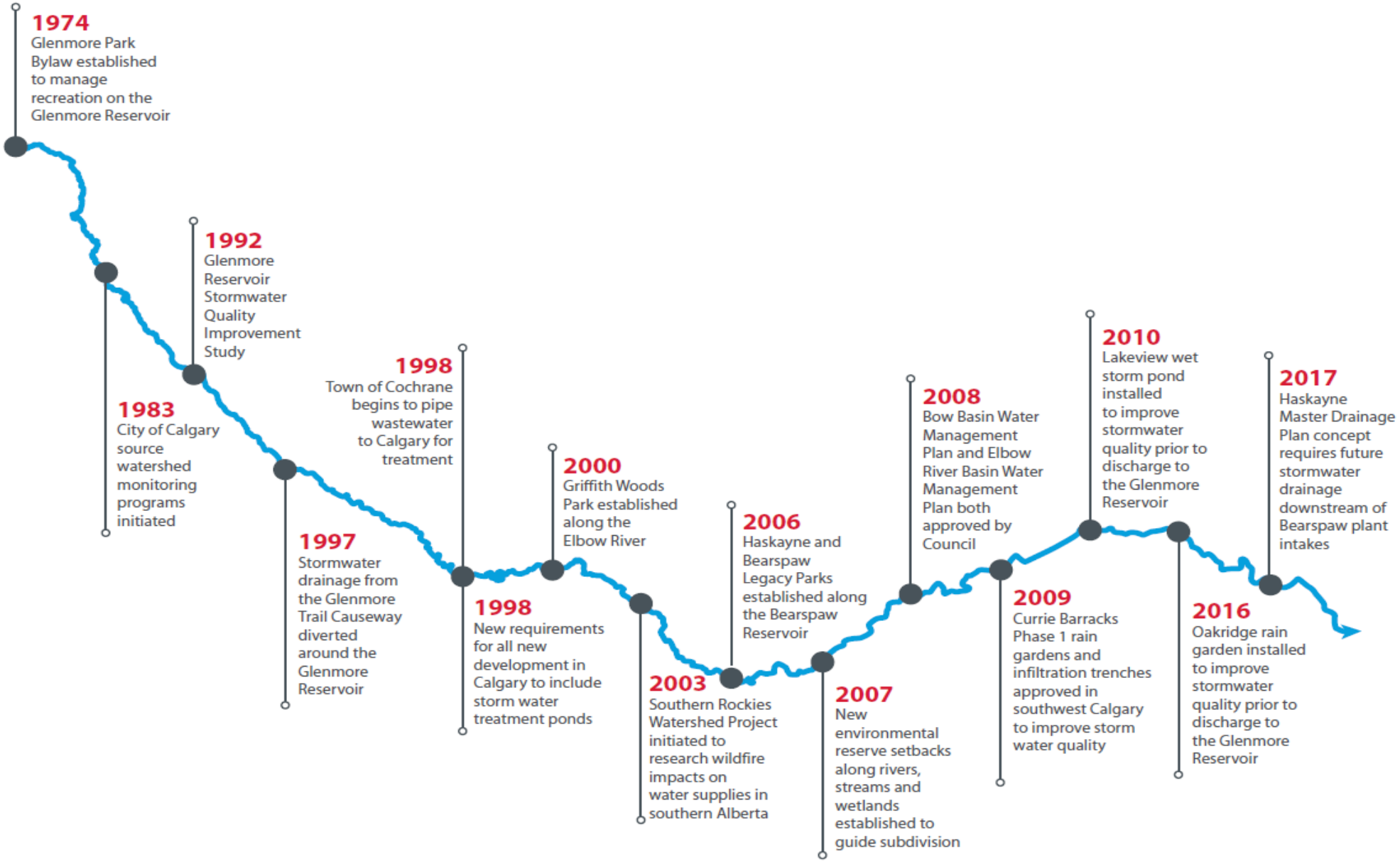


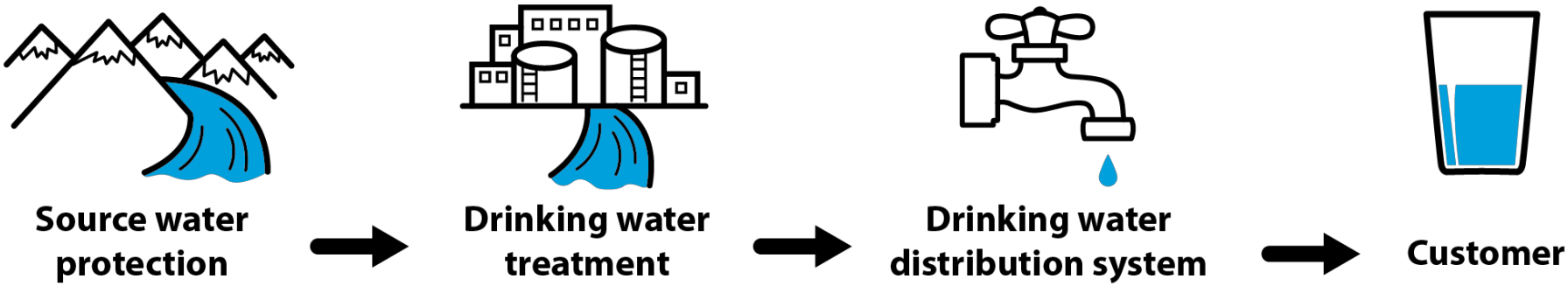
Figure 17. History of Source Water Protection Actions Recently Implemented by The City of Calgary

PLAN EVALUATION AND REVISION PROCEDURES

This Plan will be reviewed and evaluated every 5 years to update water quality trends and document progress and issues. The formal review will take a results-based approach, and should include an evaluation of:

- Source water quality monitoring data and trends
- Any significant incidents in the source watersheds
- New scientific or technical research findings
- New regulatory or planning initiatives
- Evaluation of successful source water protection actions implemented
- Challenges and obstacles encountered during implementation of the Plan, and lessons learned

A wholesale revision of the Plan should occur every 10 years to ensure it is relevant and up to date. Additional formal stakeholder and public engagement is anticipated to occur prior to Plan revisions. The review will feed into an adaptive management approach, addressing results in the context of our dynamic source watersheds. In a spirit of continual improvement, Plan revisions may require modifications or additions to the vision, goals, risk register, action priorities, timelines, key stakeholders, or program resourcing.



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LIST OF ACRONYMS

AAF – Alberta Ministry of Agriculture and Forestry
ABMI – Alberta Biodiversity Monitoring Institute
AER – Alberta Energy Regulator
ATV – All Terrain Vehicle
AWWA – American Water Works Association
BMP – Best Management Practices
BRBC – Bow River Basin Council
BWTP – Bearspaw Water Treatment Plant
CCME – Canadian Council of Ministers of the Environment
DBP – Disinfection By-Products
DEM – Digital Elevation Model
DOC – Dissolved Organic Carbon
DWSP – Drinking Water Safety Plan
EPEA – Environmental Protection and Enhancement Act
ESOC – Emerging Substance of Concern
FMP – Forest Management Plan
GIS – Geographic Information System
GWTP – Glenmore Water Treatment Plant
IPZ Intake Protection Zone
MAC – Maximum Acceptable Concentration
NRCB – Natural Resources Conservation Board
SLS – Spray Lake Sawmills
SSRP – South Saskatchewan Regional Plan
SWARC – Source Watershed Assessment and Risk Characterization
SWPP – Source Water Protection Plan
VOC – Volatile Organic Compound
WMA – Wildfire Management Area
WQI – Water Quality Index

GLOSSARY OF TERMS

Bioretention Area: A landscaped plant bed that captures and filters stormwater. They can differ in design and size from small residential rain gardens to large engineered bioretention areas.

Disinfection Byproducts: Chemicals produced during the water treatment process, caused by reactions between disinfection agents and organic materials or ions naturally occurring in water.

Drinking water protection zone: The land and water areas surrounding municipal source water intake pipes, which are managed to prevent or mitigate contamination risks.

Ecosystem services: The benefits people obtain from nature. These include provisioning services such as clean water supplies, regulating services such as flood and disease control, and cultural services such as spiritual, recreational and cultural benefits [16].

Multi-barrier approach: An integrated system of procedures, processes and tools that collectively prevent or reduce contamination of drinking water from source to tap to reduce risks to public health (CCME 2004).

Source water: Water in its natural or raw state, prior to withdrawal for treatment and distribution as a drinking water supply.

Source water protection: (i) Taking action to prevent contaminants from reaching water sources; (ii) A site-specific process designed to maintain or improve the condition of water sources through a proactive, multi-barrier approach for managing risks.

Source water protection plan: A plan identifying required actions (management practices, statutory or regulatory changes, etc.) needed to mitigate existing and future threats to source water quality, which establishes priorities and a timetable for the plan's implementation (AWWA 2007).

Source water risk: The chance or possibility of a threat causing harm to the functioning of the drinking water system or to human health [7].

Source watershed: The land areas from which water drains downstream and provides raw water supplies for a drinking water utility.

Source watershed assessment: A study that defines the land area contributing to a public water system identifies the major potential sources of contamination that could affect the drinking water supply, and then determines how susceptible the public water supply is to this potential contamination (AWWA 2007).

Watershed vulnerability: Reflects the ease with which contaminants, *if* present, could be mobilized downstream based on the intrinsic properties of the land and subsurface in different areas.