WILDLIFE

6

The Astotin Creek watershed lies between two areas of regionally important wildlife habitat: The Beaver Hills Moraine, and the North Saskatchewan River valley. Habitat along the creek and its tributaries can support movement by large mammals, such as deer and moose, as well as sustaining a variety of medium and smaller species, including amphibians, mice, breeding birds, waterfowl, hawks, and owls, and even carnivores like weasels and coyote. Semi-aquatic mammals are also common in creek and wetland habitat areas, including beaver, whose dam-building can create flooding concerns, but also help sustain vegetation, wildlife and even soil moisture conditions. An understanding of ecologically important habitats and species diversity in the Astotin Creek watershed is essential to sustaining and enhancing its resiliency.

6.1 Methods

6.1.1 LITERATURE REVIEW

The ecological resources within Strathcona County have been well-studied in past years and past work provided a comprehensive background of the historical and current biophysical conditions within the County's portion of the Astotin Creek watershed. A review of previous studies helped to understand important habitat areas, trends in their condition and wildlife known to use the watershed. This information also helped identify gaps to be filled through field surveys. The literature review included resource such as:

- Fish and Wildlife Management Information System (FWMIS) (AEP, 2021b)
- Landscape Analysis Tool (LAT) (AEP, 2021c)
- Various studies and guidelines, including the following documents prepared for Strathcona County:
    - Assessment of Environmental Sensitivity and Sustainability in Support of the Strathcona County MDP Review (Spencer, 2005)
    - Prioritized Landscape Ecology Assessment of Strathcona County (Geowest, 1997)

The environmentally sensitive features within the County portion of the Astotin Creek watershed were last mapped for the 2005 Assessment of Environmental Sensitivity and Sustainability (Spencer, 2005). It, and the Prioritized Landscape Ecology Assessment of Strathcona County (PEMA areas, Geowest, 1997) have helped inform land use direction in the County Municipal Development Plan, as well as the County's current environmental protection initiatives. Reviewing mapping from these documents and comparing against land cover mapping updated as part of this study confirmed areas with long-standing conservation interest, as well as ecological significance.

Riparian habitat associated with Astotin Creek and its tributaries is a key ecological feature in the Astotin Creek watershed, important for a variety of reasons, including wildlife movement, filtration of contaminants and resilience in the face of changing climate conditions. The ideal width for riparian buffers is dependant on management goals, and the types of stressors that may affect the riparian zone. To develop a better understanding of the management factors that should be considered to maintain the ecological health of riparian habitat, we reviewed academic, consultant and other literature addressing aquatic, vegetation and wildlife movement aspects of riparian health.

6.1.2 WILDLIFE SPECIES CHARACTERIZATION

As described in more detail below, potential wildlife use of the three assessment reaches was characterized using the following data sources and field surveys:

- Citizen Science Nature App Data (iNaturalist and NatureLynx)
- Amphibian Surveys
- Remote Camera Surveys (Small Aquatic Mammal (SAM) and Large Wildlife)
- Breeding Bird Surveys (BBS)
- Incidental wildlife and habitat observations during field program components

6.1.2.1 Nature App Data

As described in Section 5.1.1, iNaturalist data collected by citizen scientists provided additional wildlife observations from across the Astotin Creek watershed. The original Astotin Creek watershed mapped by the County was used to establish a 'project' in iNaturalist and NatureLynx to solicit new observations and to identify and download observations from each app. Data were then analysed using a Geographic Information System (GIS) to extract observations from the updated watershed area, and the three assessment reaches within the watershed. Data were categorized by broad species grouping (e.g., birds, insects, mammals, amphibians), and observations were totalled to determine species richness (total species) and total observations (as an indicator of abundance) for the respective areas of the watershed. While our field data were described using Simpson's Index, we could not use this biodiversity index for iNaturalist data, since the level of citizen survey effort across the three assessment reaches or species groups was not known, or likely to be equal. The Simpson's index allows comparison across study areas based on the number and abundance of species, but comparison assumes a roughly equal survey effort.

The iNaturalist records included observations from 1970 to 2021, with the bulk of observations from 2019 onward, covering a broad range of wildlife species. Although generated from informal / uncontrolled survey effort, the observations did generate a broader listing of species than would be possible to collect in a single field season. These data were used to compare species richness against the more structured inventory surveys conducted for this study in the summer of 2021.

6.1.2.2 Remote Camera Surveys

Remote cameras were deployed within each of the three assessment reaches, at sites with similar deciduous forest habitat. As noted above, the Upper, Middle and Lower Assessment Reaches of the Astotin Creek have different levels of human disturbance and habitat fragmentation (rural residential development, agriculture, and a combination of agricultural and industrial development, respectively). Camera traps attempted to capture information about wildlife species active along the creek, given the respective differences in disturbance.

Motion triggered cameras (Reconyx) were installed within these three watershed assessment locations, and at a fourth location at the boundary of Elk Island National Park (EINP) (Figure 6-1). Cameras were set to record three photos after being triggered, which helped with species identification. Semi-aquatic mammal (SAM) cameras were positioned near the creek edge, in a location where riparian wildlife use could be captured. For SAM camera traps, the wildlife camera is mounted on the back of a rectangular, wooden box, with a transparent top to allow light to penetrate. The box set-up has been used elsewhere in the Beaver Hills Biosphere, by Dr. Glynnis Hood, to identify cryptic riparian species such as small and medium-sized mammals (including muskrat and beaver), but also waterfowl and other water birds. Traditional wildlife camera traps were also established at these same sites to capture larger-bodied species such as deer and coyote that might use the creek as part of a travel corridor to access habitat across the landscape. SAM cameras ran over an approximate one-month period between May 20, 2021 and June 24, 2021, and collected 4747 images, of which 1282 (27%) were blanks. Since large and small and medium-sized species were observed on the SAM cameras, traditional wildlife camera traps were set up to record over a one-week period from June 18, 2021 to June 25, 2021, to supplement existing observations.

Photos were analyzed to create a record of species detected per day, to quantify activity in terms of frequency of observation. This analysis helped account for animals that stayed around the cameras for some time, triggering multiple photographs of what was likely the same individual (especially true of birds on the SAM cameras). Species richness (count of all species observed), total observations and the Simpson's index of biodiversity (Simpson's index) were used to describe biodiversity within each assessment reach.

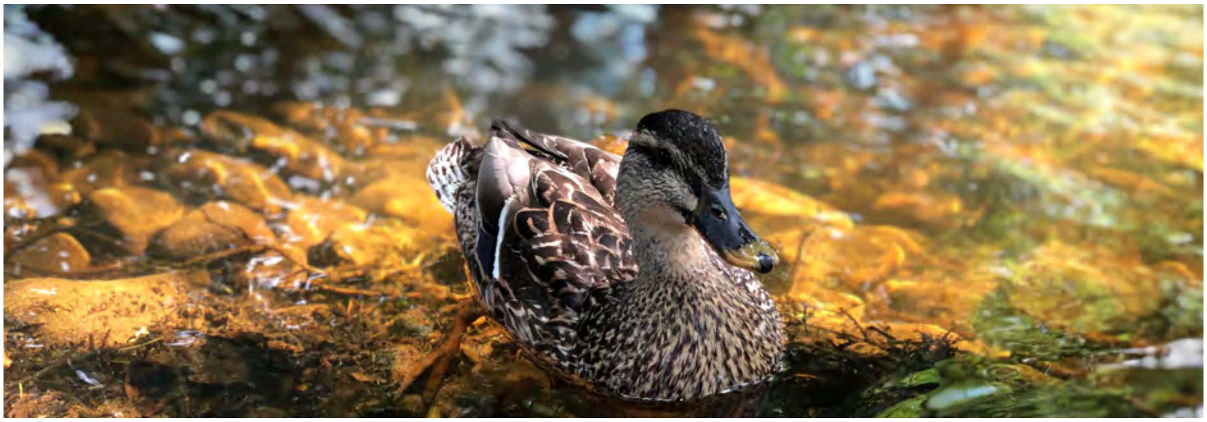
Simpson's index is particularly useful for these types of assessments, since it helps to differentiate sites dominated by an abundant (or more readily observed) species from sites with a variety of species and similar abundance (or in this case, frequency of daily observations). Dr. Hood also provided SAM data from the four sites, classified to show species frequency of observation and proportion of sites with observations using Timelapse 2.0, a remote camera analysis software, Essentially, this suite of measures helped to identify areas of higher diversity of species, in terms of both numbers and abundance.

6.1.2.3 Amphibian Surveys

Amphibian surveys were conducted on the evening of May 10, 2021, in wetland locations selected for potential breeding bird and vegetation survey sites, a stratified sample of habitat types representative of the three assessment reaches (Figure 6-1). The survey was completed later in the breeding season, but still within the activity period for species found in the Astotin area. Surveys were conducted from roadsides, as near to proposed survey sites as possible, since land access could not be confirmed before the surveys. Survey methods followed ESRD Sensitive Species Inventory Guidelines (Government of Alberta, 2013). Nocturnal surveys were conducted 30 minutes after sunset and involved a listening period of 10 minutes to survey for amphibians identifiable by call. Number of distinct groups detected was recorded, with an estimated presence of single, a pair or five or more individuals. Additional, incidental observations were collected during other fieldwork, and provided supplemental, visual observations over the summer 2021 field program.

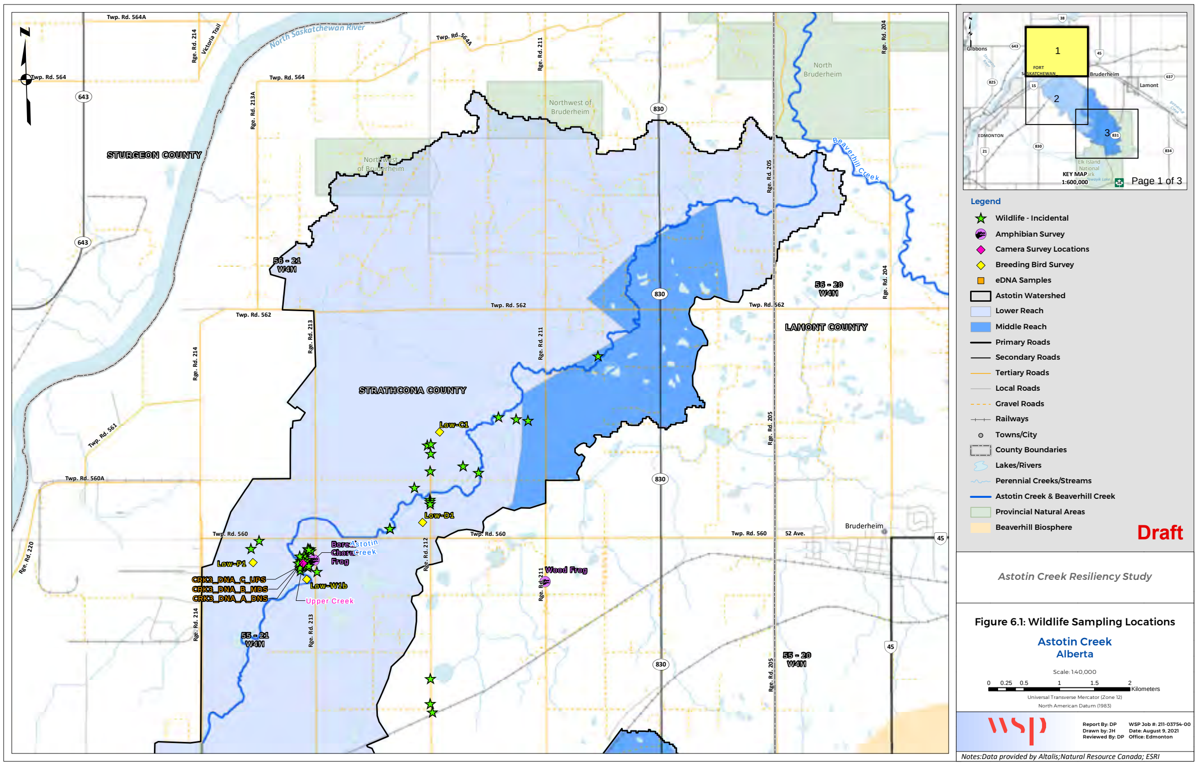
6.1.2.4 Breeding Bird Surveys

Breeding bird surveys were conducted in the wetland, creek / riparian edge, pasture, deciduous and coniferous forest locations selected for vegetation survey (Figure 6-1) following standard point count procedures (Government of Alberta, 2013). Access was available at this time, and surveys were done within the representative habitat, as near to the middle of the respective habitat as possible, given the fragmentation created by clearing for land use. Surveys were conducted over June 13 and 14, 2021, between one half hour before sunrise until 10:00 am, and collected breeding bird occurrence data within a 50 m radius plot. Occurrence records included the number of individuals, and species, which were used to determine species richness, total observations, and the Simpson's index for the habitats within each of the three assessment reaches.



Highlighted Geographical Area within County	**Environmental Sensitivity Rating**	**Characteristics Important for Wildlife**
Southeast Corner	High	• Abundance of native vegetation in wetland and upland areas that provide high quality habitat for many diverse species • Link between Elk Island National Park and the rest of the Astotin Creek watershed, which highlights the importance of maintaining connectivity for species dispersal in this area
Cooking Lake Area	Moderate - High	• Area surrounding Cooking Lake has been largely cleared for agriculture and therefore only had a moderate sensitivity rating • Cooking Lake itself is a highly sensitive feature that provides wildlife habitat
Lake Network between Sherwood Park and Cooking Lake	High	• Abundance of wetland areas and network of small lakes • Fragmented woodlands due to agricultural activities results in high ratio of forest edge to forest interior habitat
East and Central Strathcona County	High (Areas of Moderate)	• High concentration of headwaters • Areas of isolated creeks that are surrounded by degraded areas with little native vegetation
West Boundary of Elk Island National Park and the Cooking Lake/ Blackfoot Reserve	High (Areas of Low-Moderate)	• Abundance of native vegetation provides connectivity between Elk Island National Park, Cooking Lake-Blackfoot Reserve and the areas of Cooking Lake, Hastings Lake, the Ministik Bird Sanctuary and Miquelon Lake Provincial Park
North Strathcona County	High	• Extensive and diverse native vegetation characterized by predominantly sandy soil, allowing for jack pine mixed wood forest that is not available elsewhere in the County • Ecological linkage between North Saskatchewan River Valley and Elk Island National Park • Protected by three provincial Natural Areas (North Bruderheim Sandhills, Northwest of Bruderheim and Astotin Natural Areas)

Figure 6 -1 Environmental Sensitives Mapping



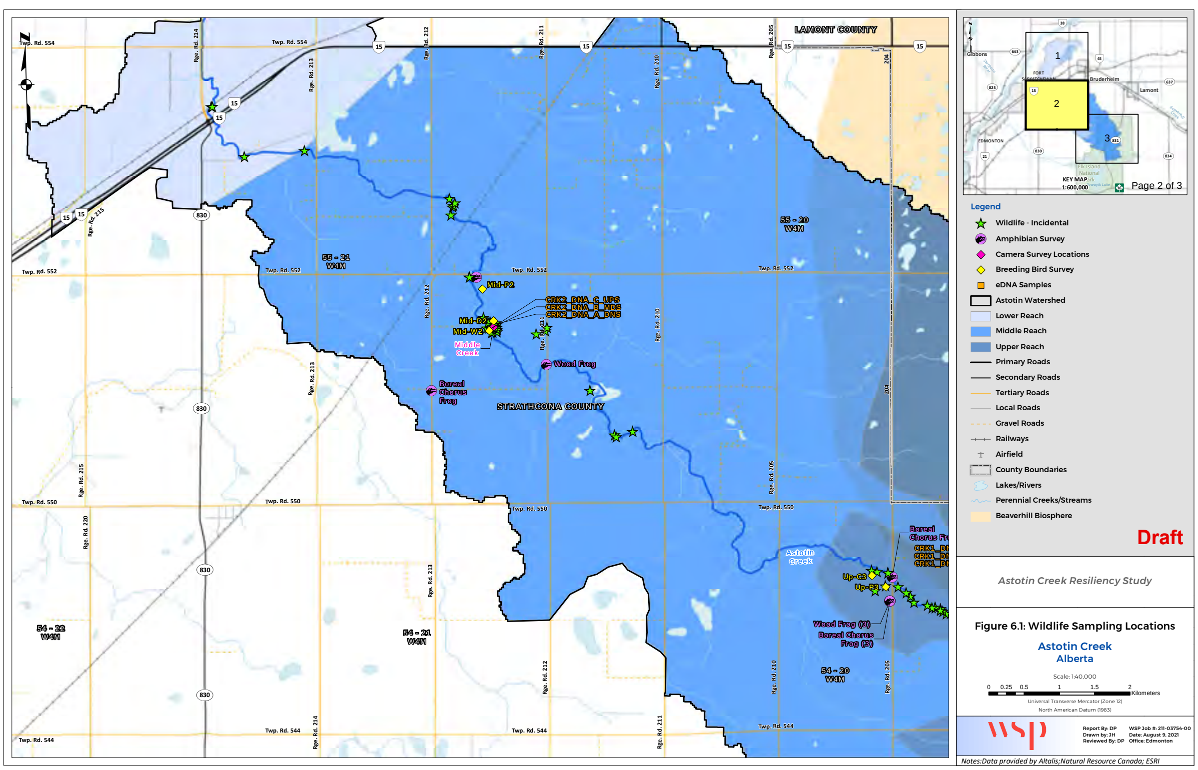


Figure 6 -1 Wildlife Sampling Locations

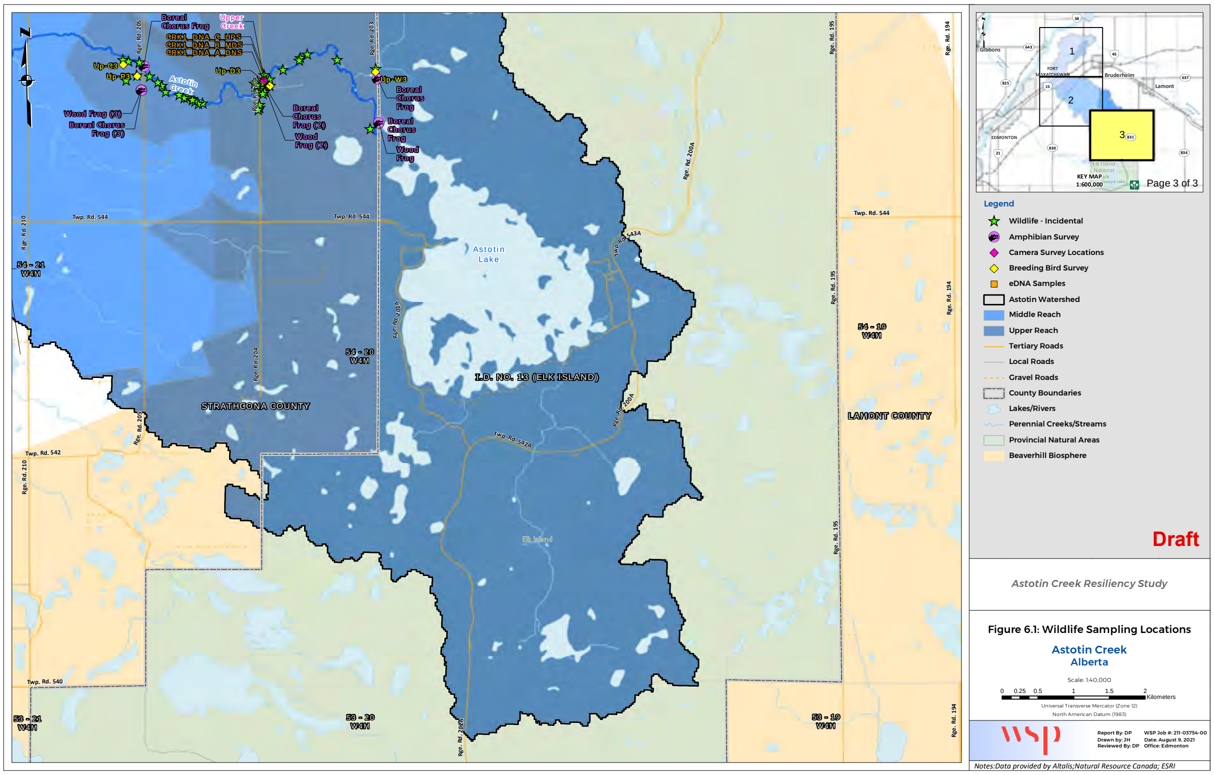


Figure 6 -1 Wildlife Sampling Locations

6.1.2.5 Incidental Wildlife Observations

Incidental wildlife observations and habitat data were collected during other field program components and compiled to supplement wildlife characterization. Locations of observations are indicated on Figure 6-1. Species observations were combined with those from amphibian, breeding bird and camera trap surveys to calculate overall biodiversity measures (species richness, total observations) for the three assessment reaches. Simpson's index could not be used for this combined analysis since survey effort was not equivalent across all survey types. The combined results could, however, be compared to the nature app data, to assess our current survey results relative to past observations.

6.2 eDNA Assessment

Certain species are so rarely seen that they may not be detected without intensive survey effort (Sales, et al. 2019), including semi-aquatic and aquatic mammals like river otter, mink, water shrew, and northern bog lemming[3] . These four species reflect part of a riparian food chain and were used to assess potential impacts of bioaccumulation due to exposure to any contaminants present in creek water. Surveys for these species can also provide a baseline useful for future monitoring of ecosystem health. Exposure risks were assessed using water quality results completed as part of this study. To help confirm the presence of these four riparian carnivores, which are thought to use creek and wetland habitats through the Beaver Hills Moraine, and between Elk Island National Park and the North Saskatchewan River valley, we used eDNA survey and analysis techniques (Appendix C).

Assay methods have recently been developed by Dr. Glynnis Hood at the University of Alberta and InnoTech Alberta for these species, as a rapid method of assessment for species indicative of ecosystem health but challenging to inventory (Appendix C). With assistance of InnoTech Alberta, we collected three sub-samples at the three wildlife camera trap sites (total of 9 samples) for eDNA analysis (Figure 6-1). Samples were analyzed by InnoTech and data helped to determine species presence and assess risks, if any, in comparison to water quality results from this current study.

[3] Semi-aquatic animals are dependant on water habitat for most of their daily requirements, while aquatic animals are found exclusively in water. Aquatic carnivores found in this area include American mink, northern river otter, and water shrews. Semi-aquatic small mammals include meadow and western jumping mice, and pygmy, dusky, and arctic shrews, feeding on a variety of insect and aquatic invertebrate prey. They, and the semiaquatic, omnivorous muskrats and herbivorous beaver and northern bog lemmings, form part of the prey base of local aquatic carnivores

At each camera site, the three subsamples were drawn from the creek by pumping the water sample directly from the creek through a microfilter apparatus (see Appendix C for full methodology). A target of 5 L of water was pumped through the microfilter, changing microfilters as required to accommodate blockages from fine particulates in the water. Sampling produced an average of three microfilter samples per sub-sample site. Analysis was completed first using a universal primer to confirm presence of mammalian eDNA, then using the species specific primer for the four target species on any sample with sufficient eDNA.

6.3 Existing Conditions

6.3.1 RIPARIAN BUFFERS

Astotin Creek ranges from 5 m to 15 m wide across its channel (see Section 7.2.3) and it lies within a shallow valley with varied levels of natural and human influence on riparian habitat (see Section 5.2.5). Clearing has extended nearly to the edge of the creek bank in some parts of the watershed, most notably in the Middle Assessment Reach (See Figure 1 in Appendix B). The differences in riparian intactness in the three assessment reaches raises a question of the ideal riparian buffer, relative to ecological health. The width of riparian vegetation adjacent to a waterbody can influence water quality, aquatic ecosystem health and wildlife and plant diversity. The ideal riparian buffer is dependant on these management objectives for a given area. To help evaluate the current condition of riparian habitat along the creek, we reviewed the literature on riparian buffers, to identify key determinants of ecological health.

Riparian buffer strips provide critical ecosystem services and wildlife habitat. The literature suggests that the first 15 m (50 feet) of vegetated buffer have substantial benefit in protecting and enhancing water quality through temperature control, streambank stability and sediment control, minimization of direct human impact and pollutant removal (i.e., nutrients, pesticides, bacteria, total suspended solids and metals) (Brian, et al., 2018; Kilcore et al., 2009). Recommended riparian buffer widths are highly variable in previous studies depending on environmental context, and management goals. Larger buffers are needed for water quality management if increased sediment and pollutant loading is anticipated from agricultural activities or run-off along steeper slopes

(DeCecco and Brittingham, 2005). The literature generally agrees that a minimum buffer width of 30 metres provides a reasonable level of protection for water quality and this buffer has been adopted by Strathcona County and the City of Edmonton for protection of wetland and other waterbodies (City of Edmonton, 2006; ESRD, 2012). However, determining an appropriate riparian buffer in terms of wildlife movement and habitat is more complex as it depends on the land use, habitats, and vegetation cover around the creek, and the species anticipated to occur in the area.

Riparian buffers provide valuable habitat for wildlife and are critical for supporting biodiversity that in turn can help support resilient ecosystems and ecological services. Species richness for plant and animal communities is often high in forested riparian areas (Gregory et al., 1991). These areas offer proximity to water, forage, cover and woody vegetation and are often used as refuge and wildlife corridors (DeCecco and Brittingham, 2005). River valleys offer good ungulate habitat and provide good browse and thermal cover for deer, moose and elk, especially in the winter (ESRD, 2012). Studies have shown that species such as white-tailed deer utilize riparian zones almost twice as much as non-riparian areas, as an anti-predation strategy (Naiman and Decamps, 1997). River and stream valleys also offer terrain relief for hiding cover, even with limited tree cover, and thus offer secure travel corridors for larger animals to move across their home range.

Key ecological services provided by naturally vegetated buffers include:

- Water quality protection by filtering out sediments, nutrients, and contaminants
- High species richness, due to proximity to water, forage, cover, and varied habitat structure (trees, shrubs, and grasses/forbs)
- Hiding cover for animal movement, nesting, and foraging activities
- Thermal tree cover for ungulates and other species

In general, recommended riparian buffer widths are wider for wildlife management than those for water quality management. To provide food, shelter and meet the life-history needs of species in the area and function as a movement corridor, riparian buffer strip guidelines range from 30 metres to more than 500 metres, though 50 metres has been suggested as the minimum area for supporting the majority of riparian obligate species (Fischer and Fischenich, 2000; Stoffyn-Egli and Willison, 2011). While wider buffers generally support more species, both narrow and wide buffers are important for maintaining bird diversity due to the edge and interior habitats that are required for the life histories of different species (Wenger, 1999). Riparian habitats within the Astotin watershed can provide life requisites for a variety of mammal, bird and amphibian species. Small mammals often prefer riparian areas over upland areas because of the superior habitat provided and greater food availability, water, stable temperatures, and friable soils that allow for burrowing (Klapproth and Johnson, 2009). Many large mammals require a larger, connective buffer to facilitate travel across the landscape to meet their territorial and habitat needs, while other mammals can use smaller buffers if they use it for only part of their needs (e.g., deer for movement cover). Mammals likely to be found in the Astotin Creek watershed, and commonly associated with riparian forests include beaver, mink, muskrat, and river otter (Pattie and Fisher, 1999). One of the larger mammals known to utilize the Astotin Creek watershed, including the areas within Elk Island National Park, are black bears (Pattie and Fisher, 1999). Black bears potentially use buffers that provide brushy cover and mature hardwoods for hiding, denning and mast (conifer cone)

production (Klapproth and Johnson, 2009).

While utilizing these riparian areas, certain mammals can also influence the structure of streams and riparian zones and thus influence the diversity of aquatic communities (Wenger, 1999). Such species are sometimes considered to be ecosystem engineers, such as beavers (Hood and Larson, 2015; Jones et al., 1997). As noted in Section 2.1.5, beavers have been shown to enhance amphibian, vegetation and aquatic invertebrate populations (Anderson et al., 2015; Hood and Bayley, 2009; Hood and Larson, 2014). The diversity of wildlife using and interacting with the riparian buffer is dependant on the condition of riparian buffer strips, as a wildlife corridor or as part of home range or territory requirements, as well as the enhancements provided by species like the beaver.

As suggested above, adjacent land use and human disturbance are important to consider in managing riparian areas. An appropriate width of vegetated buffer (ideally, treed, or shrubby) will help maintain wildlife species using the riparian areas, and the ecological benefits they can provide. Industrial operations and agricultural activities generally discourage wildlife from utilizing the area. Specifically, where Astotin Creek is surrounded by agricultural land use right to the creek edges, the lack of riparian vegetation and resulting fragmented habitat may limit wildlife movement, or other habitat use. Where riparian buffers are maintained, vegetation can help protect the creek from a variety of impacts from adjacent land use. Land development reduces the performance of forest riparian buffers by directly altering vegetation structure and spatial configuration (Wasser et al., 2015). Disturbed riparian areas are prone to colonization by non-native (invasive or weedy) plants, which are not as effective as native plants at stream stabilization and do not provide forage for wildlife (ESRD, 2012). Such species can also affect agricultural crop values, since they spread quickly and outcompete cereal crop species triggering need for herbicide controls. Structurally diverse riparian buffers that consist of a mix of herbaceous plants, shrubs and trees are better able to remove sediments, absorb nutrients and support more diverse species. Foraging activities of beaver, deer, and moose help to maintain that plant diversity, in terms of community structure and composition (Hood and Bayley, 2009), which in turn can provide other ecological goods and services including sustaining water, even in times of drought (Hood and Bayley, 2008; Hood et al., 2018). Vegetative characteristics such as cover, snags, decayed logs, and high organic soil all attract different species, enhancing biodiversity (Klapproth and Johnson, 2009). Restoration of both species composition and plant community structure can help support the biodiversity that drives these ecological benefits.

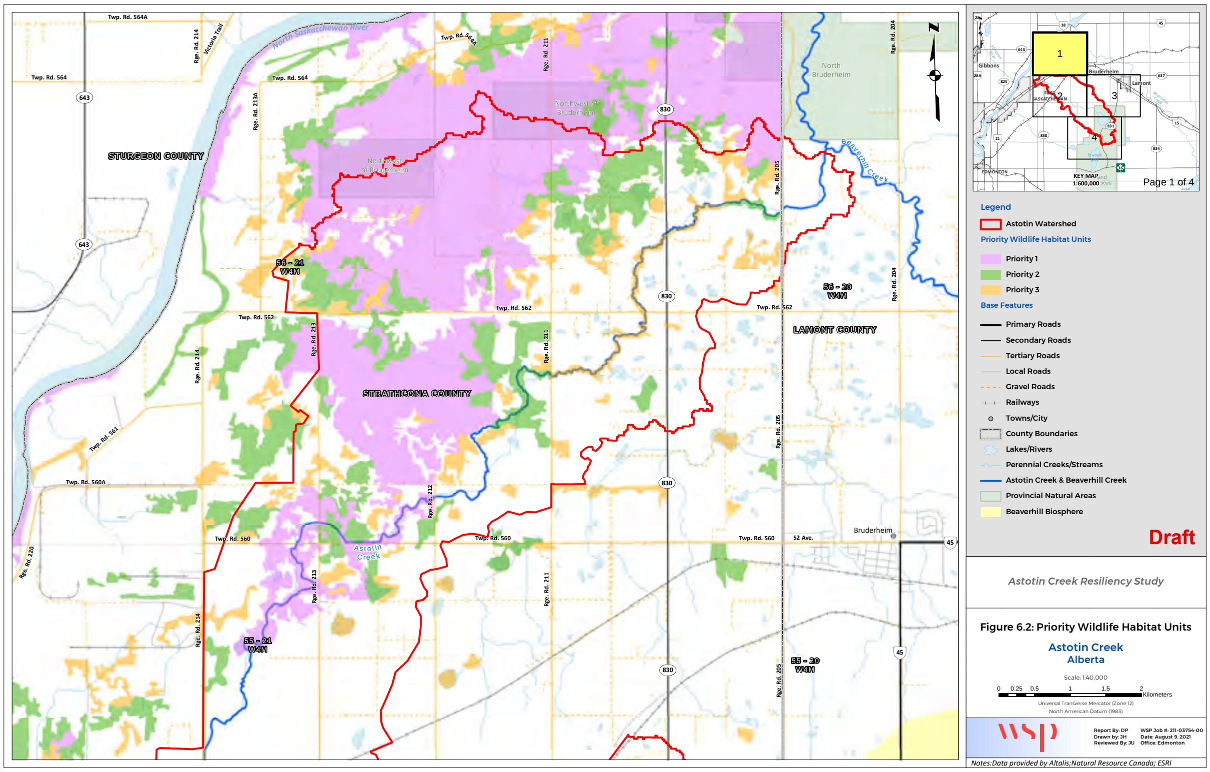
Riparian buffers are becoming especially important for conservation under future climate change conditions. In addition to being wildlife corridors, buffers also provide a refuge from increasing temperatures (Krosby et al., 2018). Vegetation that provides cover for terrestrial species also shades streams and maintains cooler temperatures for aquatic species. To address climate change influences on stream ecosystems, riparian management should consider adjacent land use and human disturbance and the resulting stressors that may inhibit species movement and habitat suitability of the riparian buffer.

Astotin Creek is a particularly valuable wildlife corridor connecting two important conservation areas: The North Saskatchewan River Valley and Elk Island National Park. Through Elk Island, wildlife and plant species can move and propagate, accessing additional lands throughout the Beaver Hills Moraine. Riparian health in the Lower Assessment Reach was previously assessed relative to riparian structural patterns (Chen, 2009). Poor riparian health was strongly associated with factors such as riparian forest cover, road construction and channel slope, which again reinforces the importance of understanding the negative effects of riparian land use. In terms of ongoing planning and management of the Astotin Creek watershed, identifying priority wildlife habitat for conservation and restoration is critical in balancing land development and long-term sustainability of the Astotin Creek watershed.

6.3.2 ENVIRONMENTAL SENSITIVITIES MAPPING

Strathcona County's current Municipal Development Plan (MDP) aims to enhance the environmental management of the County by providing a comprehensive long-term land use policy framework for future development. The County's 2021 Environmental Framework has formalized recognition of the value of air, water, land and natural systems to the quality of life of its residents, and now also promotes cooperative management among internal and external stakeholders and County residents to help sustain the County's natural assets. The MDP and the County's land use planning policy both rely on two previous environmental reviews that identified sensitive areas and resources for conservation. Those resources provide important context for evaluating biodiversity of the Astotin Creek watershed at a landscape scale (i.e., in terms of habitat distribution and ecological functions).

The 1997 Prioritized Landscape Ecology Assessment (PLEA) project identified prioritized natural features and wildlife habitats across Strathcona County for the conservation easement program initiated in 1996 (Geowest, 1997). PLEA mapping zones have informed land development in the County, by identifying environmental sensitivities, including ecological connectivity for protection or restoration. Priority wildlife habitat units (WHUs) were qualitatively grouped within a three-level hierarchy. Across Strathcona County, 22.3%, 10.2% and 6.6% of the total area were categorized into three primary habitat types – upland, wetland and lake WHUs respectively (Geowest, 1997). Priority 1 WHUs were identified in the eastern and south-eastern extent of the Cooking Lake Upland, but also in the southern Redwater Plain and the North Saskatchewan River ecodistricts where limited adjacent land use has allowed for extensive blocks of native vegetation to remain intact (Geowest, 1997). These latter two areas lie partly in Lower Astotin Assessment Reach. Examples of Priority WHUs from the Lower Assessment Reach include the Astotin, Northwest of Bruderheim and North Bruderheim Natural areas, and the naturally vegetated lands between them. These areas were also highlighted by an AEP assessment of wetland ecological health within the Industrial Heartland, which identified 12,000 wetlands covering 8% of the Industrial Heartland area, many of which have remained undisturbed by development (Cobbaert et al., 2011). Within the Middle Assessment Reach, the riparian habitats along Astotin creek and its tributaries were identified as Priority 1 lands, mainly for their potential to support natural water and wildlife linkages across these lands (Figure 6-2).



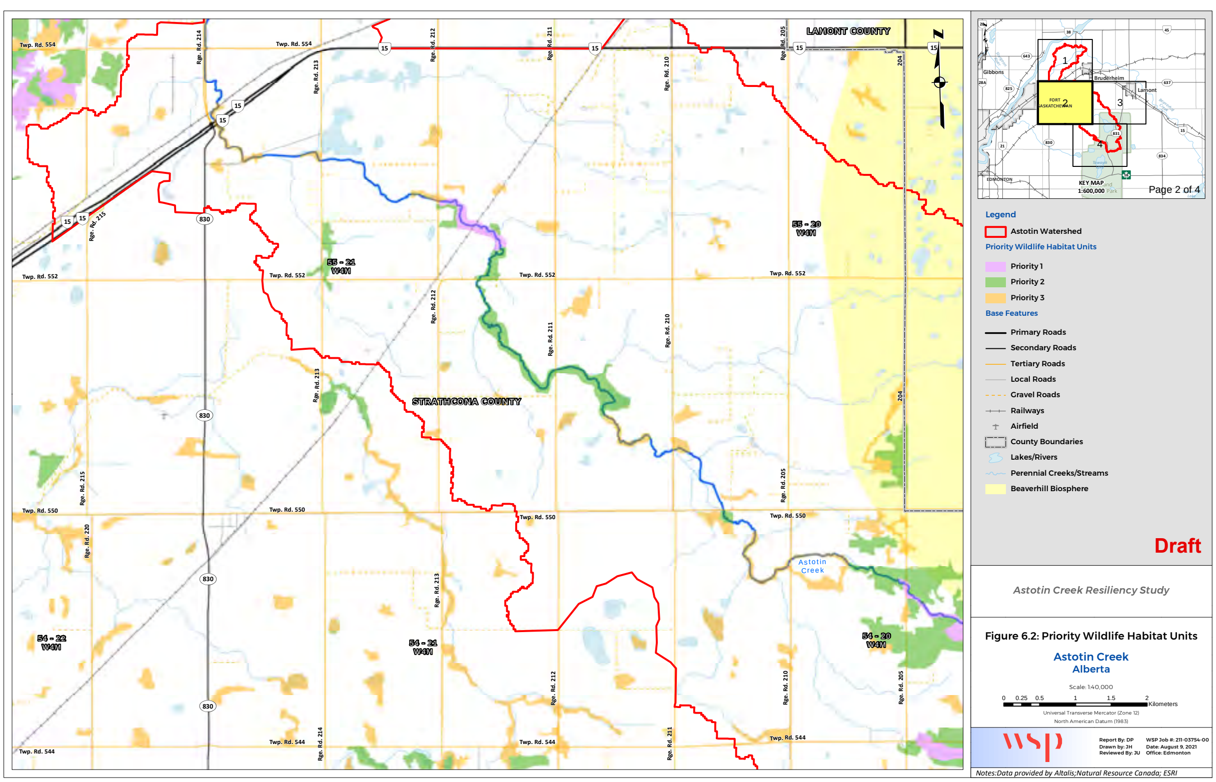
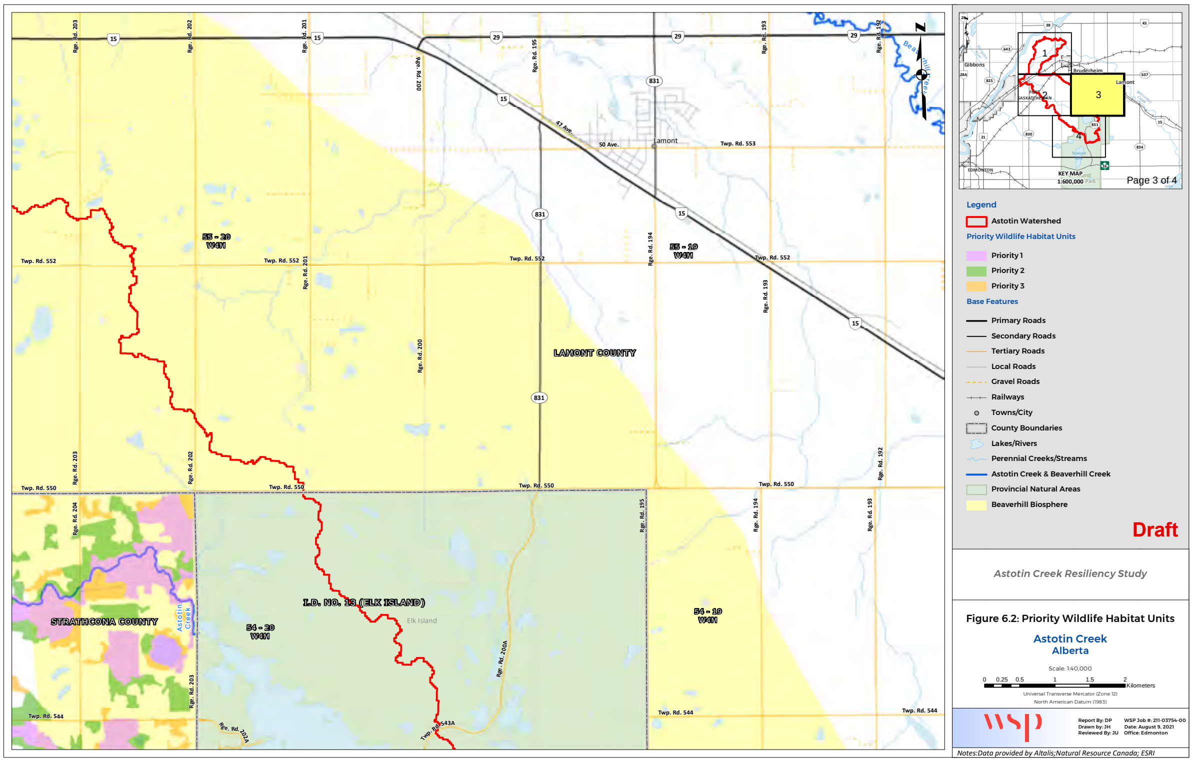


Figure 6 -2 Priority Wildlife Habitat Units



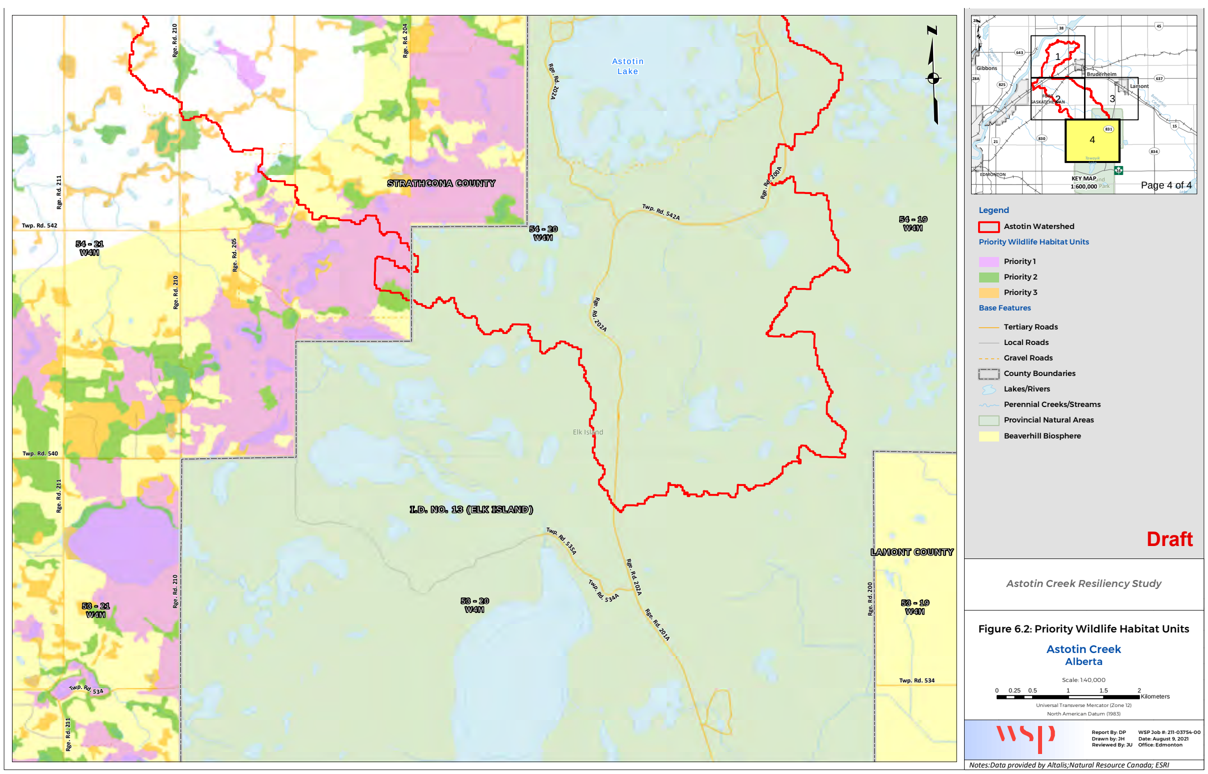


Figure 6 -2 Priority Wildlife Habitat Units

Source: Spencer (2005)

As an update to the PLEA, Spencer (2005) completed an assessment of environmental sensitivity and sustainability to highlight valuable areas of the County to assist in the 2007 update to the MDP. In this assessment, sensitive areas were identified from updated mapping of wildlife habitat, ecological connectivity and rare species observations, mapping of recharge and discharge waterbodies (with connection to groundwater) and mapping of lower agricultural soil capabilities (and less value for agricultural use). Sensitive sites within the Astotin area identified from this study are summarized below in Table 6-1. Areas of High Environmental Sensitivity Rating typically involved several interacting natural features. For example, areas with abundant wildlife or wetland habitat such as the lands in the Upper Astotin Assessment Reach, or sites that may offer ecological connections to other natural areas (e.g., between the North Saskatchewan River and Elk Island National Park) would have high to moderate-high rating. The sandy soils near the confluence of Astotin Creek with Beaverhill Creek are another relevant example. Such areas can support unique vegetation, some of which is conserved in the two provincial natural areas noted above.

Table 6 - 1 Environmental Sensitives Mapping

Highlighted Geographical Area within County	**Environmental Sensitivity Rating**	**Characteristics Important for Wildlife**
Southeast Corner	High	• Abundance of native vegetation in wetland and upland areas that provide high quality habitat for many diverse species • Link between Elk Island National Park and the rest of the Astotin Creek watershed, which highlights the importance of maintaining connectivity for species dispersal in this area
Cooking Lake Area	Moderate - High	• Area surrounding Cooking Lake has been largely cleared for agriculture and therefore only had a moderate sensitivity rating • Cooking Lake itself is a highly sensitive feature that provides wildlife habitat
Lake Network between Sherwood Park and Cooking Lake	High	• Abundance of wetland areas and network of small lakes • Fragmented woodlands due to agricultural activities results in high ratio of forest edge to forest interior habitat

East and Central Strathcona County	High (Areas of Moderate)	• High concentration of headwaters • Areas of isolated creeks that are surrounded by degraded areas with little native vegetation
West Boundary of Elk Island National Park and the Cooking Lake/ Blackfoot Reserve	High (Areas of Low-Moderate)	• Abundance of native vegetation provides connectivity between Elk Island National Park, Cooking Lake-Blackfoot Reserve and the areas of Cooking Lake, Hastings Lake, the Ministik Bird Sanctuary and Miquelon Lake Provincial Park
North Strathcona County	High	• Extensive and diverse native vegetation characterized by predominantly sandy soil, allowing for jack pine mixed wood forest that is not available elsewhere in the County • Ecological linkage between North Saskatchewan River Valley and Elk Island National Park • Protected by three provincial Natural Areas (North Bruderheim Sandhills, Northwest of Bruderheim and Astotin Natural Areas)

Source: Spencer (2005)

6.3.3 WILDLIFE SPECIES OF MANAGEMENT CONCERN

Wildlife species of management concern are generally considered to include rare species protected under federal or provincial legislation, or species considered at risk due to declining populations. Other species of concern can include ‘nuisance’ species, those that come into conflict with humans, either due to their effects on human land or property, or through due to risk of harm to humans, livestock or pets. Examples include beavers, whose damming and tree cutting activities can create flooding and aesthetic impacts on adjacent landowners. Skunks, coyotes and porcupines are also sometimes considered nuisance species. The County has established its Vertebrate Nuisance Control Policy to encourage humane means of control, as well as a process for County and landowner approaches to management. Currently however, the ecological benefits of these species are not recognized in the policy, nor are considerations for alternative, non-lethal management options that could help sustain these benefits.

Rare wildlife species are protected by either provincial or federal legislation due to concerns with population declines, and associated loss of ecological functions such species may provide (AEP, 2017; ESRD, 2014; GOC, 2021). AEP's online FWMIS is a provincial tracking database with fish and wildlife observations that have been mapped in the province. Records from this database were used to identify historical occurrences of managed species within the updated Astotin Creek watershed area. The FWMIS and the AEP Landscape Analysis Tool (LAT) also identify areas of management concern, such as high biodiversity areas and sensitive species ranges, which can provide additional, higher level information on potential areas of concern.

Historical occurrences of species of management concern recorded within the Astotin Creek watershed are listed in in Table 1 of Appendix C (AEP, 2021b). Two amphibian species, 40 birds and 6 mammals listed as being of management concern provincially or federally have been observed in the Astotin Creek watershed area. Most of these are listed as 'Sensitive' provincially; they are of concern due to recent population declines. Two are federally protected under the Species at Risk Act as endangered (little brown bat and long-eared bat), four are threatened and one is of special concern. Two species are considered 'At Risk' species and six 'May Be at Risk' species have been identified by the province, with populations low enough to risk extinction. Many of these species are tracked federally by COSEWIC or provincially by the Alberta Conservation Committee and have been designated with additional determinations of risk (see Table 1, Appendix C). Examples include the two bat species noted above which are recognized federal and provincially, as well as migratory songbirds and waterbirds such as the Canada warbler, a riparian forest specialist and the Western grebe, typically associated with wetlands and lakes.

A review of the FWIMIS and LAT species range maps for sensitive wildlife species indicates that the Astotin watershed overlaps sensitive ranges for sharp-tailed grouse (Tympanuchus phasianellus) and bald eagle (Haliaeetus leucocephalus) (AEP 2021b; AEP, 2021c). Bald eagles would not typically nest in this area, but they do use riparian forests adjacent to larger waterbodies during migration. Sharp-tailed grouse have not been seen in the Astotin Creek watershed, according to FWMIS, and suitable grassland habitat is relatively limited. The Lower Astotin Assessment Reach (primarily within 056-21 W4M) also overlaps a Key Wildlife and Biodiversity Zone associated with the North Saskatchewan River valley, identified due to its potential to support regional wildlife movement.

6.3.4 FIELD RESULTS

The NatureLynx dataset did not return any wildlife observations for the Astotin Creek Resiliency Study. This app is relatively new and has had limited use by the public so far. The iNaturalist dataset returned over 3300 observations of 231 different species within the original Astotin watershed area, including 4 amphibian, 5 arthropod, 89 bird, 116 insect and 17 mammal species. The number of species occurring in each assessment reach are summarized below (Table 6-2). A detailed list of species reported within the Astotin watershed, based on the iNaturalist dataset is presented in Table 2, Appendix C. Plant species from the iNaturalist dataset are reported in the Vegetation section of this report (Section 5.2.2).

Table 6 - 2 Number of Species Identified in Each Assessment Reach in iNaturalist

Class	Number of Species		
	Upper Reach	Middle Reach	Lower Reach
Amphibia (Amphibians)	4	-	-
Arachnida (Arthropods)	5	-	-
Aves (Birds)	*81*	*8*	*7*
Insecta (Insects)	**110**	**3**	**6**
Mammalia (Mammals)	**17**	**4**	**1**
Species Richness	**217**	**15**	**14**

Note: '-' indicates no species identified.

Most species observations were in the Upper Assessment Reach. Since the Upper Watershed overlaps with Elk Island National Park, higher species observations may be linked to the rich biodiversity in the park as well as more active citizen scientists in the park area. This area has high environmental value associated with the extensive native vegetation that connects Elk Island National Park with several other high value areas within the Beaver Hills Moraine to the south: Cooking Lake-Blackfoot Provincial Recreational Reserve, Hastings Lake, the Ministik Bird Sanctuary and Miquelon Lake Provincial Park (Spencer, 2005). Insect observations were particularly high in this assessment reach. This is again attributed to use of iNaturalist in and near EINP and does not necessarily mean that it has the highest insect biodiversity, only a high number of observations.

While the iNaturalist dataset was valuable in providing an overview of biodiversity within the Astotin watershed based on previous observations, the field data provided a more structured analysis of species occurring within the watershed based on known survey effort. Results from the breeding bird, amphibian and remote camera surveys as well as incidental observations collected during the field program are summarized below (Table 6-3 and in Appendix C). In terms of species richness, the Upper Assessment Reach and Lower Assessment Reach were comparable at 40 species and 43 species, respectively; the Middle Assessment Reach had slightly lower species richness at 37 species (Table 6-3).

Table 6 - 3 Wildlife Species Identified in Each Assessment Reach During 2021 Field Programs

Class	Number of Species		
	Upper Reach	**Middle Reach**	**Lower Reach**
Amphibians	2	2	1
Birds	31	27	33
Mammals	*7*	*8*	*9*
Species Richness	**40**	**37**	**43**

Results of the species-specific surveys are further broken down below to provide an analysis of biodiversity, for each wildlife survey. Within the breeding bird surveys, it was expected that species richness would be highest in the Upper Assessment Reach, followed by the Lower and Middle Assessment Reaches respectively given the variables influencing biodiversity within each region. While this was true for the Upper Assessment Reach area, the Simpson's Biodiversity Index showed that the Middle Assessment Reach was more diverse in species than the Lower Assessment Reach, when considering species abundance (Table 6-4). A lower Simpson's Index value indicates that species observations are dominated by one or two very abundant species. Although there was a higher level of human disturbance within the Middle Assessment Reach, these survey sites were located within a broader, naturally vegetated floodplain area (Figure 6-1). The Middle Assessment Reach sites were not representative of the entirety of this section of the creek and had a wider riparian buffer that supported a mixture of forest and grassland habitats in addition to edge habitat. Such sites would be expected to support a relatively high diversity of bird species. A lack of access prevented sampling in other areas, where clearing had created much narrower riparian habitat zones.

Table 6 - 4 Summary of 2021 Breeding Bird Survey Counts by Assessment Reach

Class	Number of Species		
	Upper Reach	**Middle Reach**	**Lower Reach**
Total Observations	46	31	93
Species Richness	24	17	22
Simpson's Biodiversity Index	*0.97*	*0.94*	*0.66*
Diversity Rank	**High**	**Med**	**Low**

Analysis of the wildlife camera survey observations showed an interesting and unexpected pattern of species richness, with highest species richness in the Lower Assessment Reach, followed by the Middle and Upper Assessment Reaches (Table 6-5). However, the Upper Assessment Reach ranked highest followed by the Lower Assessment Reach and Middle Assessment Reach in terms of the Simpson's Biodiversity Index. Again, lower Simpson's Index values indicate dominance by a few species, and less diverse communities: The Upper Assessment Reach had the highest diversity rank, then the Lower Assessment Reach and lastly, the Middle Assessment Reach. Both the breeding bird and wildlife camera results are likely linked to more extensive patches of native habitat available in the Upper and Lower Assessment Reach. Such data also lend support to past habitat assessment done by Geowest (1997) and Spencer (2005), which identified the retained habitat in these areas as high priority for conservation, for wildlife habitat and ecological connectivity value.

Table 6 - 5 Summary of 2021 Remote Camera Survey Observations by Assessment Reach

Class	Number of Species			
	Upper Reach	**Middle Reach**	**Lower Reach**	**Elk Island National Park**
Total Observations	19	84	170	61
Species Richness	7	12	19	17
Simpson's Biodiversity Index	*0.87*	*0.76*	*0.81*	*0.89*
Diversity Rank	**High**	**Low**	**Medium**	**N/A**

Only two amphibian species were detected during the field program, boreal chorus frog (Pseudacris maculata) and wood frog (Lithobates sylvatica). Canadian toad, a species of management concern, has been observed in Elk Island National Park over several years, including spring this year (pers. comm., B. Eaton), but were not observed in our amphibian or incidental surveys. While these two amphibian species were largely present throughout the entire watershed, more amphibians were observed in the Upper Assessment Reach based on the average observations per site in each reach (Table 6-6). Amphibians are often a good indicator of the overall health of an aquatic ecosystem, however, as described in Section 7.2.4, very few parameters exceeded protection criteria for aquatic life. The Upper Assessment Reach also offers large areas of natural habitats, connected with Elk Island National Park and potential source populations. Amphibians may also prefer this reach because it does not experience the same disturbance impacts on riparian habitat from land use as in the other more developed parts of watershed.

Table 6 - 6 Summary of 2021 Amphibian Survey Observations by Assessment Reach

Scientific Name	Common Name	Number of Observations			
		Upper Reach	**Middle Reach**	**Lower Reach**	**Total**
Pseudacris maculata	Boreal Chorus Frog	8	1	1	10
Lithobates sylvatica	Wood Frog	6	1	0	7
# Sampled sites		***5***	***3***	***1***	***9***
Average Observations/Site		**2.8**	**0.7**	**1.0**	**1.9**
Species Richness		**2**	**2**	**1**	**2**

***Note: Number of amphibians indicate groups detected; each group represents an estimate of >5 individuals.**

A lower overall species richness observed in the Middle Assessment Reach is likely related to the effects of past land development. This area is characterized by remnant native riparian and upland vegetation, low connectivity along the creek where clearing has come very near the creek bank, and very low connectivity across developed uplands. The Upper Assessment Reach and Lower Assessment Reach were comparable in species diversity, and both generally have larger natural patches that offer a variety of habitats (forest, shrub and meadow/pasture). These areas also supported beaver populations, which in turn can create ponded areas that can add to overall habitat and species diversity through their manipulations of aquatic and riparian habitat (Hood and Bayley, 2009; Hood and Larson, 2014; Naiman et al., 1984).

6.3.5 eDNA ANALYSIS RESULTS

The eDNA results identified species that had not been previously detected in the wildlife camera program, or in iNaturalist observations, including American mink at all three camera survey sites, and Northern bog lemming at the Upper and Lower Assessment Reach camera sites. American water shrew had relatively strong analysis signals at the Upper Assessment Reach site, and weak signals at the other two sites, however, the eDNA primer used for analysis had relatively low sensitivity. Results for this species should be interpreted cautiously. River otter were not detected at any of the three sites, but have been detected from a site in Ministik in a concurrent University of Alberta research program, conducted by Dr. Glynnis Hood from the University of Alberta and with analysis by InnoTech Alberta (pers. comm., G. Hood).

Factors such as flow volume and velocity, stream morphology and substrate composition can influence transport of eDNA in lotic (stream) systems (Fremier et al., 2019; Curtis, et al., 2020), and so the distance around the sample site from which the surveyed animal would be active is difficult to determine. The three creek camera sites are assumed to be sufficiently far apart to represent independent samples. The period in which the animals were active around the site is more limited. In lentic (lake and pond) systems, eDNA is assumed to reflect animal activity in the past two to four weeks (Dejean et al., 2011, Barnes et al., 2014). In lotic (stream) systems, eDNA persistence is typically shorter (Harrison et al., 2019).

The ability of eDNA analysis techniques to detect rare and cryptic species can be extremely helpful when assessing species at the landscape level, with higher detection rates relative to standard inventory methods, including wildlife cameras. Sales, et al. (2020), for example, readily detected species of conservation concern like water voles, field voles and red deer in a riverine landscape in the United Kingdom using aquatic eDNA techniques: three to six replicate eDNA water samples produced detection rates equivalent to 5 to 30 weeks of camera trapping. However, as the authors note, linking detections to specific habitats is more challenging, particularly in stream systems where DNA material could be deposited at the sample site, or carried through upstream flows, or overland flows from adjacent lands. Positive results from eDNA methods in this study do indicate activity within the adjacent lands, and in the case of mink, may indicate more widespread activity along all creek assessment reaches and immediately adjacent lands. We did not detect American mink, Northern bog lemming or American water shrew in the four weeks of SAM camera trapping effort at these same eDNA sample sites. Additional camera survey effort, more specific camera locations in species-specific habitat, or a different survey method may be required to confirm site-specific habitat use.

The lack of a specific location to link habitat use and water quality conditions makes it challenging to draw conclusions about potential impacts of water quality, and regardless, water quality parameters were generally within regulatory criteria during this study. However, the detection of habitat use within the assessment reaches, by species tied to aquatic habitats will be helpful for future monitoring efforts. The absence of these species could indicate a reaction to changes in water quality.

Site	UniCOI Amplification Test	*Synaptomys borealis* Northern Bog Lemming	*Neovison vision* American Mink	*Lontra canadensis* River Otter	*Sorex palustris* American Water Shrew
	For all groups	For all groups	For all groups	For all groups	For all groups
Controls					
CRK1	Up / Mid / Down	Up / Mid / Down	Up / Mid / Down	Up / Mid / Down	Up / Mid / Down
CRK2	Up / Mid / Down	Up / Mid / Down	Up / Mid / Down	Up / Mid / Down	Up / Mid / Down
CRK3	Up / Mid / Down	Up / Mid / Down	Up / Mid / Down	Up / Mid / Down	Up / Mid / Down

Table 6 - 7 Results from qrtPCR analysis of eDNA samples (water samples) collected from three sites along Astotin Creek, AB.

6.4 Summary

Wildlife biodiversity and abundance is closely linked to available habitat in terms of areal extent, and variety of habitats. The amount of naturally vegetated land in the Upper and Lower Assessment Reaches is more extensive than in the Middle Assessment Reach, and comprises forest, grassland and wetland habitats, as well as the creek. The higher variety of species – the species biodiversity –in these areas is not surprising, given this context. Yet wildlife species were also abundant in the Middle Assessment Reach and had a surprising level of diversity. This speaks to the capacity of the riparian zone of the creek to sustain biodiverse wildlife communities, as a functional unit. It also speaks to the opportunity to enhance these values, and the ecological goods and services (EGS) they provide.

The extent of naturally vegetated riparian buffer width can affect various EGS, including biodiversity, water quality protection, and soil moisture levels due to shallow groundwater flow. There is no ideal width that will protect all relevant riparian buffer values, but in general, a 30 m buffer is recommended for water quality protection, and wider widths for biodiversity and wildlife movement (up to 500 m). As noted in the riparian intactness assessment in Section 5.2.5, past disturbance and clearing of the riparian buffer in the Middle Assessment Reach has been extensive, which is likely to have affected many of these functional values. The level of biodiversity seen in this study though, suggest opportunity for restoration. Similar opportunities exist along the minor tributaries and drainage ways throughout this part of the watershed. These same recommendations are suggested in provincial guideline documents, such as Stepping Back from the Water - A Beneficial Management Practices Guide for New Development Near Water Bodies in Alberta's Settled Region (ESRD, 2012). The ALUS Canada (Alternative Land Use Services) program offers similar restoration ideas, designed to benefit agricultural use, as well as the environment.

Past studies have identified larger naturally vegetated areas as environmentally significant lands or high priority PEMA lands, across the watershed, to protect ecological connectivity, and help maintain wildlife populations. Our findings confirm the value of such sites for regional biodiversity conservation.

Beaver use was evident in each of the three assessment reaches, but often also associated with high biodiversity. Although beaver activities along Astotin Creek are thought to cause flooding and other damage that create human -wildlife conflicts, they can also provide a variety of ecological benefits. New tools are emerging to help maintain beavers on the landscape, while minimizing the conflicts they can cause. Alternative management techniques such as 'beaver deceivers', pond levellers and similar devices can control flood damage while still allowing beavers to remain on the landscape. Innovative methods such as compensation for land flooded by beaver could also be developed (e.g., through an ALUS program) to help sustain beaver ponds in strategic locations (e.g., within high priority habitat units, or as 'stepping stones' along the creek to maintain ecological connectivity).

FISH AND AQUATIC HABITAT

7

Astotin Creek and its tributaries have the potential to sustain various aquatic species. As noted in the wildlife discussion above (Section 6), the creek and riparian wetland areas can support water birds, semi-aquatic mammals, and prey species such as aquatic invertebrate populations. The creek and tributaries receive waters from overland run-off, and thus these species can be affected by potential pollutants from human and natural sources. Water quality is a key determinant of aquatic habitat quality, in addition to physical characteristics of the creek and adjacent riparian habitat.

7.1 Methods

7.1.1 FISH PRESENCE

A review of historical fish capture data within Astotin Creek was compiled using AEP online FWMIS on July 14, 2021 (AEP, 2021b). The FWMIS search examined Astotin Creek from the headwaters to the downstream confluence with Beaverhill Creek

7.1.2 FISH SPECIES OF MANAGEMENT CONCERN

The results of the FWMIS search were reviewed for the presence of fish species of management concern. This included fish species listed under Schedule 1 of the Species at Risk Act (SARA) (GOC, 2021) and the Alberta Wildlife Act (Province of Alberta, 1997), as well as those ranked by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC; GOC, 2021) and the Alberta Wild Species General Status Listing (AEP, 2017).

7.1.3 FISH HABITAT

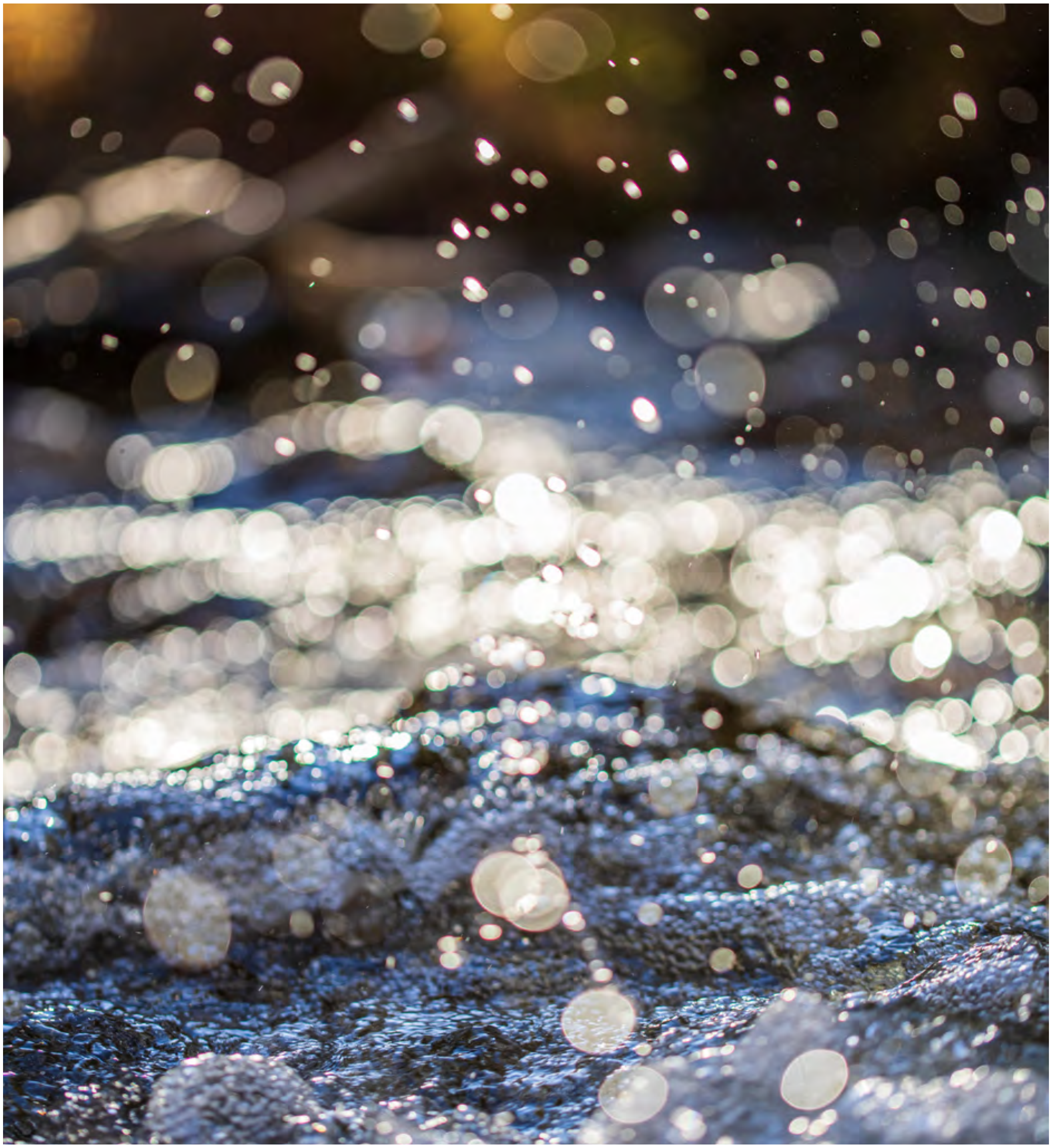
A fish habitat assessment (FHA) on Astotin Creek was completed between May 26, 2021 and June 14, 2021 by a Qualified Aquatic Environmental Specialist (QAES) and a field assistant, from the headwaters at the Elk Island National Park boundary (Astotin Lake) to the downstream boundary of Strathcona County (Figure 7-1). The FHA was completed using a modified version of the Level 1 Fish Habitat Assessment procedures outlined in the Fish Habitat Assessment Procedures (Johnston and Slaney, 1996) to document existing habitat conditions and identify areas of Astotin Creek where habitat has been degraded. Prior to the field survey, a classification system of habitat type (i.e., riffle, run, pool, flat, impoundment) was developed based on features likely to be within Astotin Creek.

Where possible, data describing the following habitat features were collected at the start of each habitat type:

- Habitat type (riffle, run, pool, flat, impoundment)
- Photographs (upstream, downstream, left downstream bank, right downstream bank)
- Channel characteristics (wetted and bankfull widths, depths, and dominant/subdominant instream cover)
- Streambed characteristics (dominant and subdominant substrate composition)
- Bank characteristics (e.g., bankfull height, stability, and dominant/subdominant riparian vegetation)
- Instream barriers (e.g., perched culvert, debris accumulation, beaver dam)

Fish habitat, vegetated cover (instream and riparian), substrate composition, bank materials and stability were assessed visually. Wetted and channel width, depths, and bank heights were measured with a measuring stick.

Fish habitat potential for spawning, rearing, overwintering and migration in Astotin Creek were rated (as nil, poor, moderate, good) according to the ability to support species known, or likely, to be present within the watercourse (Nelson and Paetz, 1992; Scott and Crossman, 1998). Ratings were based on habitat characteristics such as depth, substrate composition, and cover, and the life history requirements of fish species potentially present within Astotin Creek.



7.1.4 WATER QUALITY

Surface water samples were collected at five sampling points (Table 7-1, Figure 7-1) within Astotin Creek on June 29, 2021. An Aqua-Troll 600 multiparameter sonde was used to collect in-situ water chemistry measurements of temperature, dissolved oxygen, pH, total dissolved solids, conductivity, and turbidity at the five sampling points.

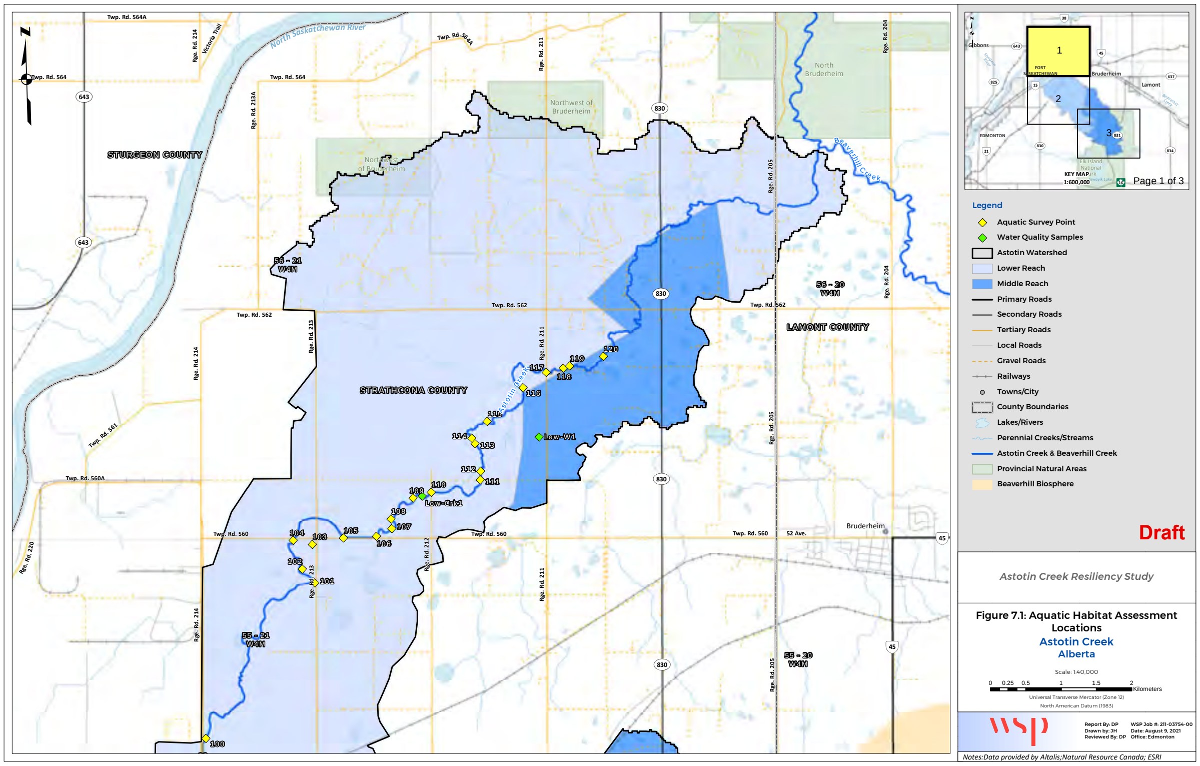
Table 7 - 1 Water Quality Sampling locations

Site Name	UTM (NAD 83)
Up-WQ1	12U 376097E 5951667N
Up-Crk1	12U 374556E 5952349N
Mid-Crk2	12U 367314E 5956345N
Low-Crk3	12U 364805E 5963283N
Low-WQ3	12U 371648E 5968091N

Our sampling protocols followed recommended industry best practices detailed in Guidelines for Quality Assurance and Quality Control in Surface Water Quality Programs in Alberta (Alberta Environment, 2006). Field instruments were calibrated by Rice Resources Inc. prior to use in the field.

All samples, including a trip blank, were collected in laboratory-prepared sample bottles with appropriate preservative in a manner preventing contamination of the sample bottle or cap. Once the sample was collected, the cap was replaced, and the sample bottle was placed back in the cooler and delivered to AGAT laboratories.

The laboratory certificate of analysis indicates that all analysis and quality control requirements and limits for holding time were met, with no quality control issues that would materially affect results. The methods used to complete the required analysis and the QA/QC checks are detailed on the laboratory analytical reports (Appendix D).



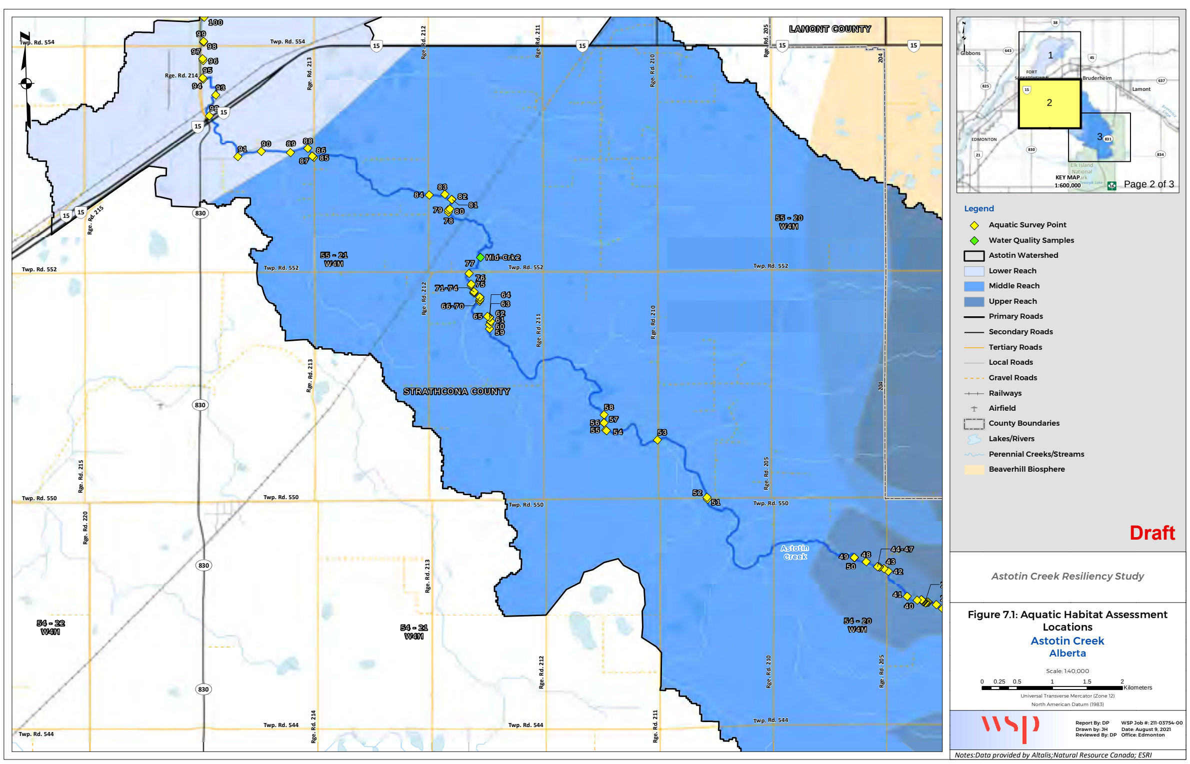


Table 7 - 1 Aquatic Habitat Assessment Locations

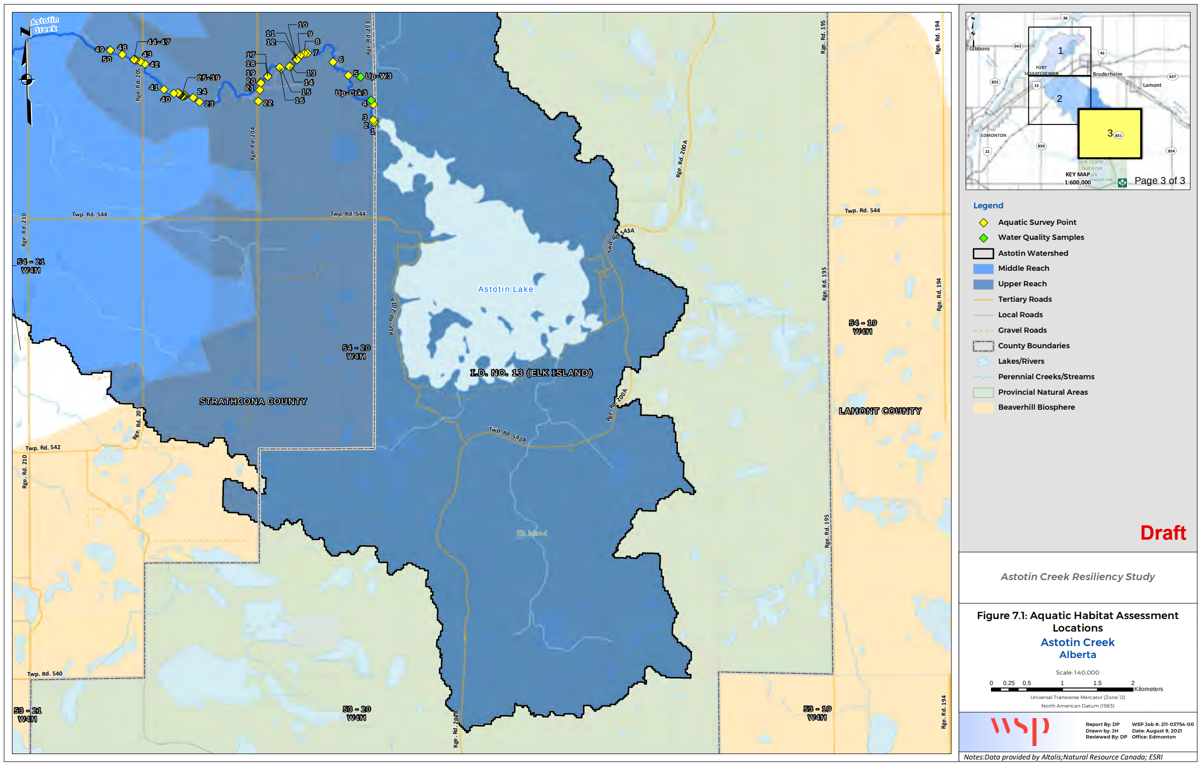


Table 7 - 1 Aquatic Habitat Assessment Locations

All surface water samples were analyzed and compared against the Alberta Environmental Quality Guidelines for Alberta Surface Waters – Protection of Aquatic Life and Agricultural Water Users (AEQGASW; [AEP, 2018]) and the Canadian Environmental Quality Guidelines for the Protection of Aquatic Life and Agricultural Water Users (CEQG; Canadian Council of Ministers of the Environment [CCME], 2021). These guidelines were used to identify potential water quality exceedances for the following parameters:

- Total Suspended Solids (TSS)
- BOD
- Total Phosphorus
- Total Dissolved Phosphorus
- Total Kjeldahl Nitrogen
- Nitrates
- Ammonia Nitrogen
- Chloride
- Escherichia coli
- Total metals
- Chlorophyll-A
- Organochlorine Pesticides
- Triazine Herbicides.

7.2 Existing Conditions

7.2.1 FISH PRESENCE

A total of six fish species have been historically documented within Astotin Creek (AEP, 2021b). All these fish species records occurred downstream, within the Lower Assessment Reach. This is likely due to the amount of industrial activity that has occurred, resulting in increased sampling effort. It may also relate to connectivity to the North Saskatchewan, and deeper water in this reach (up to 1.3 m depth, see Section 7.2.3 below). Table 7-2 lists the species historically documented within Astotin Creek. Most are small minnow species that are tolerant of low oxygen levels (particularly stickleback), and able to survive in shallower waters (Nelson and Paetz, 1992). Suckers will often spawn in tributaries of larger rivers (Nelson and Paetz, 1992), and their presence may be linked to spring spawning activities of populations from the North Saskatchewan River.

Table 7 - 2 Historical Fish Presence within Astotin Creek

Family	Scientific Name	Common Name	Species Code	Legislated Protection		Scientific Review or Recommendation	
				SARA1 (Federal)	Wildlife Act2 (Provincial)	COSEWIC3 (Federal)	General Status4 (Provincial)
Catostomidae (suckers)	Catostomus catostomus	longnose sucker	LNSC	No status	Not listed	Not assessed	Secure
	Catostomus commersonii	white sucker	WHSC	No status	Not listed	Not assessed	Secure
Cyprinidae (carps and minnows)	Notropis atherinoides	emerald shiner	EMSH	No status	Not listed	Not assessed	Secure
	Pimephales promelas	fathead minnow	FTMN	No status	Not listed	Not assessed	Secure
	Rhinichthys cataractae	longnose dace	LNDC	No status	Not listed	Not assessed	Secure

SOURCE:
1 SPECIES AT RISK ACT (SARA [GOC, 2021])
2 WILDLIFE ACT – WILDLIFE REGULATION (PROVINCE OF ALBERTA, 1997)
3 COMMITTEE ON THE STATUS OF ENDANGERED WILDLIFE IN CANADA (COSEWIC [GOC, 2021])
4 ALBERTA WILD SPECIES GENERAL STATUS LISTING (AEP, 2017)

7.2.2 FISH SPECIES OF MANAGEMENT CONCERN

No fish species of management concern were historically identified occur within Astotin Creek, based on FWMIS records. This does not mean fish species of management concern are not present within Astotin Creek, only that historical capture has not occurred within this system to date.

7.2.3 FISH HABITAT

Astotin Creek is a fourth order permanent watercourse that originates at Astotin Lake and generally flows in northwest before reaching its confluence with Beaverhill Creek. Astotin Creek has defined bed and banks, with average bankfull depth 0.7 m (ranging from 0.23 m to 1.8 m). Average wetted width was 12.4 m (range of 0.55 m to 231 m). Average bankfull width was 14.1 m (range of 1.3 m to 231 m). Average depths were 0.23 m (range of 0.01 m to greater than 1.3 m). Collected habitat data can be found and site photographs can be found in Appendix D.

Within the Upper Assessment Reach, the dominant habitat type was characterized as a shallow run with mainly fines/organics substrates. The subdominant habitat type consisted of flat/impounded habitat characterized by low velocities and more fines/organic substrate deposition. Sections of the Upper Assessment Reach had riffle habitat characterized by increased velocities and mix of fines/organics and coarse substrates (i.e., small and large gravel, cobble and boulder). The average wetted width within the Upper Assessment Reach was 5.5 m (range of 0.55 m to 65.1 m). The average bankfull width within the Upper Assessment Reach was 8.9 m (range of 1.4 m to 98 m). The average depth was 0.52 m (range of 0.01 m to greater 1 m). The channel banks within the Upper Assessment Reach were mainly stable with areas of instability. The riparian area consisted of a mix of deciduous forests and grass/forbs with canopy cover between 0% - 20%.

Within the Middle Assessment Reach, the dominant habitat was also characterized as a shallow run with mainly fines/organics substrates. The subdominant habitat type consisted of flat/impounded habitat characterized by low velocities and more fines/organic substrate deposition. Sections of the Middle Assessment Reach had riffle habitat characterized by increased velocities and a mix of fines/organics and coarse substrates (i.e., small and large gravel, cobble and boulder). The average wetted width within the Middle Assessment Reach was 3.17 m (range of 1.05 m to 40 m). The average bankfull width within the Middle Assessment Reach was narrower than in the Upper Assessment Reach, at 3.85 m (range of 1.3 m to 11 m). Average depth was also shallower at 0.23 m (range of 0.04 m to 0.77 m). The channel banks within the Middle Assessment Reach appeared to be stable to moderately unstable with some areas of instability. Areas of instability resulted from the lack of riparian vegetation between agricultural lands and Astotin Creek. The riparian area was generally well vegetated with mainly grass and forbs, but with areas of little to no riparian coverage due to agricultural land right to the edge of Astotin Creek. The average canopy coverage was between 0% - 20%.

Within the Lower Assessment Reach, the dominant habitat type was mainly flat/impounded habitat characterized by low velocities and increased fines and organic deposition. The subdominant habitat type was shallow run with occasional riffle habitat. The shallow run habitat was characterized by flowing water and increased fine/organic substrates. Riffle habitat was characterized by areas of increased velocities and a mix of coarse substrates intermixed between fine substrates. The average wetted width within the Lower Assessment Reach was wider than the upstream reaches at 37.7 m (range of 1.3 m to 231 m). The average bankfull width within the Lower Assessment Reach was 37.86 m (range of 2.65 m to 231 m). Average depth was 0.37 m (range of 0.07 m to 1.3 m). The channel banks within the Lower Assessment Reach appeared to be mainly stable with a well vegetated riparian area. The riparian area was well vegetated and comprised of grass/forbs and areas of woody vegetation (trees and shrubs) with canopy coverage between 0% - 20%.

Beaver activity was evident throughout the sections of Astotin Creek we accessed for fish habitat assessment. A total of 17 active dams were identified in the Upper Assessment Reach, 14 in the Middle Assessment Reach and 6 in the Lower Assessment Reach. We could not access the entirety of the creek length within the County due to access limitations, but survey effort was relatively similar in the three watershed areas. The lower number of dams in the Lower Assessment Reach could be related in part to creek width here, as wider creek channels can be difficult for beavers to dam and maintain. Beaver management may remove more dams in this area as well since industrial landowners may control dams to reduce flooding risk on their lands. In other areas of the watershed, beaver dams are removed by the County at landowner request, and where County roads are at risk. About 40 to 50 complaints are received annually, depending on the water conditions that year (this includes problems ranging from dams and flooding to loss of ornamental trees). Landowners can also remove dams on their lands, should they choose. Over such an extensive area, removal efforts may not be as frequent, particularly if beaver activity is not impacting land use.

Table 7-3 describes the quality of fish habitat for various life stages within the assessment reaches of Astotin Creek. Overall, Astotin Creek provides moderate to good quality fish habitat potential throughout the assessed parts of the creek. Shallow areas and low flow conditions may limit the Upper Assessment Reach to small-body species tolerant to hypoxia conditions. The habitat identified within the assessment reaches of Astotin Creek is widely available and no unique or limiting habitat (e.g., spawning gravels) was identified.

Table 7 - 3 Habitat Quality Ratings within the Assessment Reaches of Astotin Creek

Habitat	Quality Rating	Rationale
Spawning	Moderate	• Limited coarse substrate for gravel-spawning species is present. • Small and large gravels within almost equal amounts of fines do not provide high quality spawning beds. • Submergent / emergent instream vegetation, small and large woody debris provide spawning surfaces for non-gravel spawning species (i.e., cyprinids).
Rearing	Moderate	• Sufficient instream and overhead cover from vegetation and large and small woody debris, undercut banks.
Overwintering	Poor to Moderate	• Limited deep pools, except for beaver impoundments, were observed within the assessment reaches. • Shallower areas may freeze to bottom. • Deeper areas (> 0.9 m) may not freeze to bottom during the winter and could be available for hypoxia-tolerant species (i.e. brook stickleback) • Likely that larger body species that make their way up Astotin Creek will migrate downstream to larger systems.
Migration	Moderate to Good	• Physical barriers to fish passage included man-made weirs and perched culverts. • Numerous beaver dams observed within Astotin Creek (all reaches) may be creating temporary barriers to large bodied fish.

7.2.4 WATER QUALITY

The laboratory analysis of the tested routine and indicator water quality parameters was compiled and compared against the AEQGASW Protection of Aquatic Life and Agricultural Water Users and the CEQG Protection of Aquatic Life and Agricultural Water Users. Table 7-3 provides a summary of those parameters that were at or exceeded these guidelines. Full laboratory analysis results for routine and indicator parameters can be found in Table 1, Appendix D.

The results of the analyses found fluoride exceeded the Protection for Aquatic Life (PFAL) guideline at all sampled sites but was below the criteria for agricultural land use (range of 0.23 to 0.40 mg/L). Fluoride is a naturally occurring mineral that enters natural waters through erosion of sedimentary rock, including shale and in precipitation (McNeely et al., 1979). It is important for bone development and is often added to drinking water for tooth and bone health (Pollick, 2004). High levels of exposure can cause health problems, but such levels are generally linked to pollution sources. Levels in natural waters are typically less than 1.0 mg/L, but groundwater levels can be higher, particularly in dry seasons (McNeely et al., 1979). Fluoride levels in the North Saskatchewan River at Edmonton are typically about 0.1 mg/L, below the Canadian standard for drinking water of 0.7 mg/L (EPCOR, 2021). Fluoride levels in upper aquifer groundwater wells in Strathcona County ranged from 0 to 6.9 mg/L and averaged 0.5 mg/L, also suggesting a natural source in local surficial geology (HCL, 2001).

Human-caused pollution sources of fluoride include municipal sewage, which can contain fluoridated drinking water, and industrial plant operations (BC Ministry of Environment, no date). However, no significant sewage or industrial sources exist in the Upper and Middle Assessment Reaches, and Lower Assessment Reach levels were similar to upstream concentrations, again, suggesting a more generalized, natural source. Given the extent of potential groundwater recharge through this area (HCL, 2001; and see Section 4.2), interaction of surface and groundwater seems possible, and may explain these consistent exceedances across the watershed.

Other exceedances did not appear to follow a consistent pattern:

- Total dissolved solids were at agricultural criteria levels at the Low Creek 3 location, in a large ponded area created by beaver damming activities.

- E. coli was slightly above criteria for agricultural use at the UpCrk 1 site, downstream of a small subdivision area, and about 2 km from the Elk Island boundary. Levels were double this criteria level at the Low Crk 3 site, within pasture lands leased for cattle grazing, but not currently stocked with cattle.

- Manganese was above both the PFAL and Agriculture criteria at three locations: at the Elk Island boundary, the Mid-Crk2 in the Middle Assessment Reach, and the Low WQ3 site at the downstream County boundary.

Total dissolved solids (TDS) can be high due to various inputs from run-off, including dissolved ions such as nitrogen and phosphorous nutrients or various salts. The relatively low field measures of conductivity help to explain the potential cause of exceedance at the Low Crk3 site (Table 7-4). Conductivity

measures the concentrations of dissolved ions (charged compounds that can carry electrical current). The low conductivity at this site suggests that the high TDS may be related to dissolved organic compounds, which are generally uncharged molecules (Dodds and Whiles, 2010). This site was a large ponded area flooded by beaver damming activities, and there were signs of active beaver use and deep organic wetland soils. Total suspended solids, a measure of particulates (e.g., sediment) and organic material present in an undissolved form, was high at Low Crk 3 (16 mg/L), suggesting TDS may be linked to organics suspended in the ponded area. Beaver dams have been found to affect concentrations of organic carbon in water, as well as sediment conditions (Ecke et al., 2017).

Escherichia coli (fecal coliforms) can enter water through various sources, including manure, sewage and run-off from development areas, but also from wildlife and waterbirds (e.g., at sites with high density of waterfowl, Pandey et al., 2014). Water quality standards typically highlight E. coli levels for human health reasons; in natural waters exceedances can be challenging to trace, given the variety of sources. Run-off from agricultural lands can result in high E. coli levels, given the accumulation in streams, a main receiving waterbody (Pandey et al., 2014). In this case though, only the lands surrounding Low Crk 3 were in an agricultural context, and most of the upstream drainage area was under crop production, rather than grazing use. It is possible that stormwater contributions are contributing to E. coli levels at this site, but it is more likely that the high levels at both it and the Up WQ1 site are related to waterbird activity within ponded areas at these sites. There are no obvious sources of manure or sewage release at either location, but both sites are associated with beaver dams that can attract high densities of water birds. The Low Crk3 site is an active beaver pond; a dam at the Up WQ1 site was recently removed, but upstream habitat in Astotin Creek was well used by waterfowl, based on observations during various surveys over the summer of 2021.

Manganese is also a naturally occurring mineral that co-exists with iron in geologic and soil deposits and is a biologically essential element (GOC, 2016; CCME, 2019). It can be found in surface and groundwater, dissolved from soil or geologic deposits. In Alberta, levels in natural waters typically range from 0.05 µg/L to 3.3 mg/L (CCME, 2019), and the exceedances are much higher than typical levels. Anthropogenic sources include industrial discharges, mining and landfill leaching, which can release dust and particulates to surface waters (GOC, 2016). Water chemistry conditions can also affect solubility of naturally occurring manganese, especially for manganese salts (e.g., organic carbon content, cation exchange capacity, pH, and mineral and particulate content). Solubility increases in acidic conditions, with water hardness, and during decomposition of organic matter. No industrial sources are located near the three sites with exceedances, and pH levels were generally slightly basic (Table 1 Appendix D, Table 7-4). Hardness was higher in downstream sites than the Upper Assessment Reach sites (Up-Crk1 and UP-Crk1).

Each site did have some level of ponding created by current or past beaver activity (a dam was recently removed at Up WQ1). Although each site had some water flow, ponding could have increased organic decomposition (anerobic bacterial activity is often higher in beaver ponds, Ecke et al., 2017)). Organic materials that accumulate in beaver pond sediments and in the water column can provide abundant resources for bacterial decomposition. Like iron, manganese can affect the taste and colour of water, which is the typical complaint relative to drinking water quality (GOC, 2016). High levels can have toxicity effects on aquatic organisms though effects have not been well studied. Chronic exposure limits of 0.6 to 1.9 mg/L have been identified for British Columbia based on a literature review to address an acknowledged data gap about ecological risks (Reimer, 1999). Although exceeding criteria limits, levels at these three sites were near the lower limit for chronic exposure, and within the range of Alberta's natural waters.

Table 7 - 4 Water Quality Results – Routine and Indicator Parameters in Exceedance of Guidelines

Parameter	Water Quality Guidelines				Up-WQ1	Up-Crk1	Mid-Crk2	Low-Crk3	Low-WQ3
	EQGASW		CEQG						
	PFAL	Agriculture	PFAL	Agriculture					
Total Dissolved Solids (mg/L)	NS1	500	NS	500	317	323	442	507	485
Fluoride (mg/L)	NS	1	0.12	1	0.26	0.23	0.40	0.26	0.30
Escherichia coli (MPN/100 mL)	NS	100	NS	100	62	119	9	214	8
Manganese (mg/L)	NS	NS	0.3-0.42	0.2	0.727	0.021	0.754	0.075	0.454
Electrical Conductivity (µS/cm)	NS	1000	NS	NS	570	582	767	857	839
Total Suspended Solids (mg/L)	NS3	NS	NS3	NS	11	19	6	16	6

Notes:
1 NS = So standard
2 The CWQG for manganese (i.e. long-term guideline) is found using the CWQG calculator in Appendix B of the Scientific Criteria Document for the Development of the Canadian Water Quality Guidelines for the Protection of Aquatic Life: Manganese
3 Exceedance is linked to disturbance. A maximum increase of 25 mg/L from background in the short-term (24 hrs), and an increase of 5 mg/L from background for periods longer than one day. indicates harmful change.

The laboratory analysis of total metals was compiled and compared against the AEQGASW Protection of Aquatic Life and Agricultural Water Users and the CEQG Protection of Aquatic Life and Agricultural Water Users. Table 7-5 compiles a summary laboratory analysis for total metal parameters in exceedance of the guidelines. Full laboratory analysis results of total metal parameters can be found in Table 2, Appendix D. Slight exceedances of trace metals, including arsenic, cobalt, manganese, iron, mercury, and selenium were detected across many of the sites, relative to the PFAL and agricultural guidelines. The consistency in levels and distribution across these sites suggests that these levels are related to natural soil conditions rather than a potential pollution source.

Another potential explanation could be past beaver management activities. Beaver ponds accumulate sediments behind the dam due to natural settling in the slower water. Various metals can be dissolved in these waters or held in these sediments, bound to organic particulates, or as precipitates formed after reaction with other ions in the water (Ecke et al., 2017). While most of these metals are naturally occurring, deposition can concentrate them in the pond area, particularly with long established ponds. A well-studied example is mercury, one of the exceedances noted here (e.g., see the meta-analysis by Ecke et al., 2017). Mercury, in both the more toxic methylmercury and total mercury forms have been found to be higher in ponded areas upstream of dams, and in pond organisms through bioaccumulation. There has been much debate regarding potential downstream mobilization of these potential contaminants due to dam breach (whether natural or through human management). Ecke et al. (2017) found that these effects were relatively small compared to upstream reference sites for most parameters, but methyl mercury above the dam was twice that of upstream sites. They note that the effect is reduced over time. Methyl mercury and bioaccumulation effects have been found to be higher at new dam-pond sites than long-established sites, as inorganic mercury in the newly flooded area is more readily converted to the methylated form soon after flooding. Ironically, frequent breaking of dams may acerbate methyl mercury contamination in the watershed, replacing flooding with a potentially more hazardous issue.

Mercury is found in many environments, and naturally cycles from methylmercury to inorganic mercury, the dominant chemical form (US Geological Service, 2009). Methyl mercury contamination is mainly a concern in areas with high levels of mercury in local soils (e.g., in Northern Alberta lakes), or from contamination, or in situations where the conversion rate from mercury to methylated forms becomes unbalanced (US Geological Service, 2009). Waters with lower pH and high dissolved oxygen favor conversion to methyl mercury, factors not generally applicable to well established beaver ponds. Methyl mercury is taken up through ingestion and can accumulate in fish, and other aquatic species; human exposure is typically through consumption of affected fish. The levels of inorganic mercury found in the Astotin Creek sites were slightly above the EQGA SW Protection of Aquatic Life limits (0.002 mg/L), but below limits for agricultural use (ranging from 0.0017 to 0.0068 mg/L), suggesting low potential for toxicity to humans or livestock, but some potential risk to aquatic species, depending on methyl mercury conversion rates.

Table 7 -5 Water Quality Results – Total metal parameters in exceedance of guidelines

Parameter	Water Quality Guidelines				Up-WQ1	Up-Crk1	Mid-Crk2	Low-Crk3	Low-WQ3
	EQGASW		CEQG						
	PFAL	Agriculture	PFAL	Agriculture					
Arsenic (mg/L)	0.005	0.025	0.005	0.025	0.003	0.004	0.007	0.003	0.011
Cobalt (mg/L)	0.0015-0.00181	0.05	NS	0.05	<0.0009	<0.0009	0.0022	<0.0009	<0.0009
Iron (mg/L)	NS	5	0.3	5	0.6	1	1.2	<0.1	0.8
Manganese (mg/L)	NS	0.2	0.3-0.482	0.2	0.865	0.160	1.34	0.130	0.892
Mercury – Ultra Low Level (mg/L)	0.000005	0.003	0.000026	0.003	0.000020	0.000017	0.000017	0.0000061	0.000018
Selenium (mg/L)	0.0023 / 0.0014	0.02	0.001	0.02	0.0017	0.0025	0.0068	0.0031	0.0041

Notes:
1 EQGASW Table 1.3 - Guideline based on hardness at each sample location. Range represents site-specific minimum and maximum guideline values (Government of Alberta, 2018).
2 The CWQG for manganese (i.e. long-term guideline) is found using the CWQG calculator in Appendix B of the Scientific Criteria Document for the Development of the Canadian Water Quality Guidelines for the Protection of Aquatic Life: Manganese
3 EQGASW Table 1 - Alert Concentration for Selenium (Government of Alberta, 2018)
4 EQGASW Table 1 - Guideline Concentration for Selenium

The laboratory analysis of pesticide parameters was compiled and compared against the AEQGASW Protection of Aquatic Life and Agricultural Water Users and the CEQG Protection of Aquatic Life and Agricultural Water Users in Table 3, Appendix D. The results of the analyses indicated all sample pesticide parameters had concentrations below detection limits.

The in-situ water chemistry was complied and compared against the AEQGASW Protection of Aquatic Life and the CEQG Protection of Aquatic Life. Laboratory measures were also used to confirm field readings and detect potential issues. Except for dissolved oxygen (DO), all in-situ water quality measurements were within the AEQGASW and CEQG for the Protection of Aquatic Life. DO within Astotin Creek ranged from 2.27 mg/L to 7.98 mg/L (Table 7-6). DO levels within Up-WQ1 were below the CCME guidelines for all life stages of fish species within a warm-water system (6.0 mg/L, CCME, 1999). DO increased in downstream locations but fell below guidelines where Astotin Creek leaves Strathcona County (Low-WQ3). The low level of DO at Low-WQ 3 was likely due to the sampling location of the probe.

Biological oxygen demand (BOD) indicates the level of available organic carbon, a key driver of productivity of a given site, by measuring the demand oxygen for chemical and biological (respiration) reactions in a water sample. It is often used to detect problems linked to sewage discharge to aquatic systems, but in natural waters, it can indicate elevated levels of organic materials from vegetation, which may be present as dissolved, particulate or suspended organic carbon (Dodds and Whiles, 2010). BOD was highest in Up-WQ1 (12 mg/L, compared to levels of 3 to 4 mg/L at other sites). A beaver dam was recently removed from this site and may be linked to the high BOD levels. Organic carbon has been found to be higher downstream of dams, and in impounded areas (Ecke et al., 2017). Dam removal generally exposes organics that have accumulated in the pond bottom to erosion, and it is possible that the elevated BOD at this site relates to recent dam removal, and increased mobilization (and availability) of organic carbon. BOD will have an obvious effect on DO, as available oxygen will be more rapidly used at locations with higher BOD, and the organic carbons sources that drive it. DO was lowest at Up-WQ1, confirming this predicted effect.

Conductivity and total dissolved solids readings at Mid-Crk2, Low-Crk3 and Low-WQ3 were extremely low in comparison to Up-WQ1 and Up-Crk1 and were likely inaccurate readings. These data were not included in the analysis, and laboratory levels were instead used in our assessment. The field reading for pH at Mid-Crk2 was also lower than the laboratory result, and the laboratory results was used in our assessment.

Table 7 -6 In-Situ and Laboratory Water Chemistry in Astotin Creek

Parameter	Up-WQ1	Up-Crk1	Mid-Crk2	Low-Crk3	Low-WQ3
In-Situ Results					
Conductivity (μS/cm)	**405.95**	488.47	N/A 1	N/A	N/A
Dissolved oxygen (DO) (mg/L)	**2.27**	5.91	7.98	7.8	2.992
pH	**7.81**	8.02	6.61	8.64	8.04
Total dissolved solids (ppm)	**262.25**	339.54	880	N/A	N/A
Temperature (°C)	**24.59**	21.26	24.35	26.16	23.31
Turbidity (NTU)	**16.91**	82.08	35.14	2.97	3.07
Laboratory Results					
Conductivity (μS/cm)	**570**	582	767	857	839
pH	**7.86**	8.00	7.9	8.19	8.00
Total dissolved solids (TDS) (ppm)	**317**	323	442	507	485
Total suspended solids (TSS) (ppm)	**11**	19	6	16	6
Biological oxygen demand (BOD) (mg/L)	**12**	3	4	4	3

1 Reading not available due to meter reading error.
2 Low DO likely due location of the probe in slow moving water.

7.3 Summary

Aquatic health, and resiliency is determined in large part by the condition of the lands adjacent to water. An effective riparian zone is influenced by many factors including the size, topography and geology of the watershed, which in turn affect the rate of runoff and the type of contaminants that could be introduced (ESRD, 2012). For fish bearing watercourses, a minimum 30 m riparian buffer should be maintained to help protect water quality (see Section 6.2.1), particularly in flatter areas. Where terrain is more hummocky, as in the Upper Assessment Reaches, runoff could create more erosion risk, particularly in areas with erodible soils. The wider, naturally vegetated riparian buffers in the Upper and Lower Assessment Reaches provide good protection from contaminants potentially introduced through surface run-off. They also provide natural shading that enhances aquatic habitat for a variety of species and helps moderate water temperature.

As noted in Section 5.2.5, the naturally vegetated riparian zone has been reduced in the Middle Assessment Reach by past land development, and closer examination during the fish habitat assessment confirmed effects on creek bank stability and vegetation condition. Restoration of these riparian buffer zones will help enhance aquatic habitat quality through this reach. Similarly, retention of wetlands adjacent to the creek channel can provide additional flood storage, and mitigate peak flood flows, as well as enhancing aquatic water quality, habitat diversity, and species diversity. Areas where cultivation and land clearing have removed or disturbed these wetlands offer other possibilities for 'nature-based' solutions to flood management, and enhanced resiliency of the creek ecosystem.

Undersized culverts and bridges were discussed in more detail in Section 4.1 and one perched culvert was found during the hydrological survey (where access was available). Other perched culverts may occur along the creek system. From a fish and aquatic habitat perspective, these sites are a barrier to upstream movement, and limit movement of fish and aquatic species along the creek, but also recolonization of areas affected by drought or other periodic natural or human disturbance. Replacement of undersized or perched infrastructure would help restore aquatic biodiversity and the ecological benefits provided by such species.

CLIMATE ANALYSIS

8

8.1 Introduction

8.1.1 Major flooding events in Astotin Creek have caused significant challenges for the people who live and work in the Astotin Creek watershed, for the agricultural and industrial activities that are vital to the region, and for local ecosystems. To understand how climate change may influence future flooding and drought of Astotin Creek, we analyzed future climate projections related to climate hazards of concern in Strathcona County. Based on this analysis, we developed preliminary recommendations to enhance resilience of the Astotin Creek watershed to climate change impacts.

This section summarizes the outcomes of two technical notes, a climate change exposure assessment of all relevant climate hazards and a more focused study on climate change variables and flooding. These technical notes can be found in full in Appendix E.

Climate Change and Resiliency

Climate in Western Canada is predicted to shift in several ways, with differences in seasonal temperatures and precipitation and more frequent severe storm events. A resilient watershed will have capacity to rebound from drought and flood events, and help sustain human and environmental well-being, without significant, or costly, intervention.

8.2 Current Climate

Strathcona County has a humid continental climate with an average annual temperature of 2.6˚C. Summers are typically warm and sunny (daily maximum highs of 22.0˚C), while winters are cold and dry (daily minimum lows of -17.1˚C). Historically, the region receives an average of 446 mm of precipitation per year and 110.7 cm of snowfall per year (Environment and Climate Change Canada [ECCC], 2020). Flooding and drought conditions in Astotin Creek is influenced by the local climate and geography. On any given year, these climatic factors have the potential to contribute to large floods. This potential has been further complicated by changing land use patterns in the area. The County has responded to past events with emergency mitigation measures such as road closures, pumping and monitoring flood conditions to protect roads and private homes and property (see Section 4.1.2)These climatic factors can also result in drought conditions, resulting in water shortages, impacting agriculture and farmers and potentially increasing the likelihood of wildfires occurring. The County has been responding to previous events through providing support for farmers, providing guidance on saving water and putting restrictions in place.

Recent observations of changing water flow and volume in some parts of the watershed suggest a risk of more frequent and severe flooding and drought events in the future. The County is taking a proactive, adaptive management approach to protect public safety and economic investments, maintain water quality and quantity, and conserve local ecosystems and ecological functions.

8.3 Future Climate Projections

Increased greenhouse gas emissions are causing a long-term rise in global temperatures, which is leading to changes in weather around the world.

We can use future climate projections to help us understand what conditions to prepare for, which are based on different climate scenarios or 'Representative Concentration Pathways' (RCP) that bring together a range of leading climate models (Figure 8-1). For this project, we considered projections for both the 'active' scenario (RCP4.5) and the 'passive' scenario (RCP8.5). The active scenario assumes that the global community makes progress on reducing greenhouse gas emissions, while the passive or 'business-as-usual' scenario assumes a steady increase in emissions until fossil fuel supplies start to decline. For climate change adaptation and resilience planning, we use the passive scenario to help us prepare for the worst while still working to improve future outcomes (Van Vuuren et al., 2011).

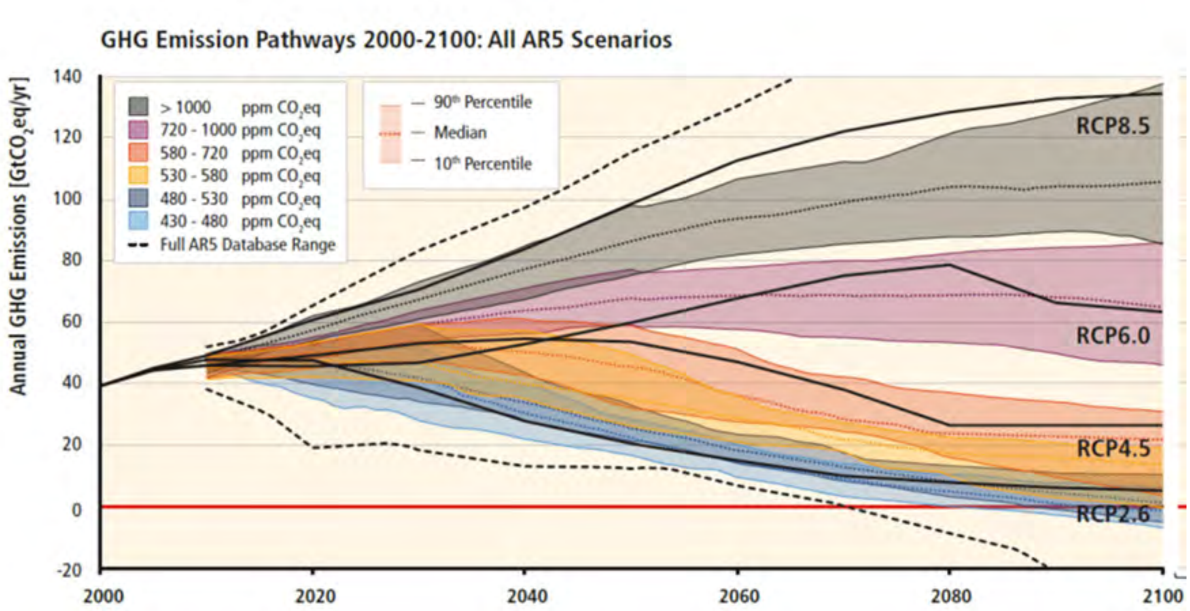


Figure 8 -1 GHG emissions for each RCP scenario until 2100 (IPCC, 2014)

Effects of climate change are particularly notable in Canada, where our northern latitudes are resulting in a rate of warming approximately twice the global average. This is caused by several feedback cycles such as the melting of snow and ice in high latitudes and land warming faster than oceans (Bush and Lemmen, 2019). In coming years, communities across the country will face increasing impacts that affect people, buildings and infrastructure, natural systems, and the economy. We need to prepare to navigate the challenges of a changing climate and to take advantage of opportunities that may arise.

8.4 Climate Change Exposure Assessment

We completed an exposure assessment for Astotin Creek to understand how people, livelihoods, infrastructure, and ecological goods and services might be adversely affected by changing climate conditions. This exposure assessment identified climate variables that may impact Astotin Creek and assessed how the climate variables may change in the future. We considered both those climate variables that relate directly to flooding (e.g., extreme precipitation) and those that have a more indirect influence (e.g., wildfire). Climate variables related to drought (e.g., precipitation and drought index) were also considered.

The exposure assessment helped us link relevant climate hazards with future climate projections and anticipated trends. It showed that we can be reasonably confident about trends related to increasing temperatures, such as changing winter conditions. Strong trends for extreme precipitation and moderate trends for spring fluvial flooding due to freshet were also shown in the climate projections. For the exposure assessment, the long-term horizon and the passive scenario has been selected to capture the greater changes in climate trends and to adopt a conservative approach for the assessment of climate risks. The outcomes of the exposure assessment are summarized for the passive scenario in the far future (2051-2080) in Table 8-1 below, with the full report available in Appendix E.

Table 8 -1 Summary of projections and trends for selected climate variables relevant to Astotin Creek Watershed for 2051-2080 under the passive scenario.

Climate variable	Projection summary	Trend	Magnitude
Spring fluvial flooding due to freshet	Winter and spring precipitation are projected to increase, though snow formation could be inhibited by increases in mean winter temperature, possibly resulting in a decreased severity of freshet events. Mean temperatures for the spring months are projected to increase which could result in more extreme freshet events. Spring precipitation is also expected to increase which could also intensify freshet episodes.	–	• Annual number of ice days -28% • Mean March temperature +4.9˚C • Spring precipitation +28%
Summer fluvial flooding due to long extreme precipitation events	Summer precipitation is projected to increase slightly, with a larger projected increase in maximum 5-day precipitation. This has been shown to correlate with summer fluvial flooding.	↑	Maximum 5-day precipitation in a 30-year period +12.5%
Extreme precipitation	As temperature increases, a 7% increase in precipitation can be expected for every degree of warming. This has been used to inform the flood modelling for this assessment.	↑	• Mean and extreme precipitation statistics • +33.8% • 24-hour 1:100 year max precipitation • 90.8 mm to 121.5 mm
General increase in temperatures	Mean annual temperature, maximum summer temperature and minimum winter temperature are all projected to increase.	↑	Mean annual temperature +4.3˚C
Heat waves	The region is projected to experience more than double the number of annual heat waves in the long term. The length of heat waves is also expected to increase.	↑	Annual number of heat waves +2.9
Droughts and water shortages	The number of dry days where rainfall is less than 1 mm is projected to remain stable over the century. However, the Palmer Drought Severity Index (PDSI) shows an increase in relative dryness over time.	↑	PDSI -1.3
Wildfires	While Astotin Creek has not historically been exposed to large forest fires, an increase in summer temperatures and dry, windy days could increase future occurrences.	↑	• Maximum summer temperature +4.4˚C • Annual number of dry and windy days +50%

Climate variable	Projection summary	Trend	Magnitude
Low temperatures and freeze-thaw cycles	Mean winter temperatures are projected to increase, while the number of frost days (<0˚C) and the number of freeze-thaw cycles are projected to decrease.	↓	Annual number of freeze-thaw cycles -18%
Snow accumulation	Winter and spring precipitation are projected to increase, though snow formation could be inhibited by increases in mean winter temperature.	↓	Mean winter temperature +4.9˚C
Strong wind and storm activity	No robust trend is found for average wind speed during all seasons.	–	

8.5 Climate Change & Flooding

In addition to the climate change exposure assessment, we completed a more focused study on both spring and summer flooding in the Astotin Creek watershed. We evaluated the factors that drive flood events, analyzing historical data and exploring the influence of future climate projections for each factor. We also considered implications of general increases in annual precipitation and land use change caused by wildfires.

The technical note summarizing this study is available in Appendix E. The results of this technical note are to be considered with caution. We were only able to analyze data for one weather station located 30 km from Astotin Creek for the 1982-2020 period. Throughout this period, we identified the following historical flooding events, which can be split between those that happened in the spring and those in summer.

Year	Date of occurrence	Type of flood event
1982	April 24	Spring
1983	June 26	Summer
1997	April 4	Spring
1997	June 23	Summer
2007	May 5	Spring
2011	July 23	Summer
2018	April 21	Spring

Dynamics of flood events are also very complex and require further hydrological modelling to increase confidence.

8.6 Spring Flooding Events

Alberta experiences two distinct snowmelt seasons that influence the occurrence of spring flooding in the Astotin Creek watershed:

i. Snow accumulates on the plains from November to April reaching a maximum by the end of winter. Snowmelt typically occurs abruptly over a short period in April, as temperatures begin to rise with the onset of spring.

ii. Snow accumulates in the Rocky Mountains from October to April. Snowmelt typically occurs gradually from April to June (Government of Alberta, 2018).

Astotin Creek is located in the plains, where thawing snow and ice can cause flooding (i.e. freshet episodes) and inundation of low-lying areas. Table 8-2 identifies the major spring flood events that have occurred since 1980.

Table 8 -2 Major historical spring events between 1980 and 2020 in Pointe-aux-Pins

Year	Date of occurrence	Annual maximum flow (m3/s)
1982	April 24	5.88
1997	April 4	4.43
2007	May 5	4.67
2018	April 21	4.63

Source: ECCC (2021)

Freshet flow and timing are contingent on three overlapping factors: winter snowpack and winter temperatures; spring temperatures; and the amount and timing of spring precipitation. Overall, for a major freshet episode to occur in Astotin Creek, we found that one of the two conditions are necessary (but not always sufficient on their own):

- At least 50 cm of snowpack should be accumulated by the end of winter, and/or
- At least 40 cm with a rapid snowmelt of at least 10 cm in 48 hours.

We summarize key considerations for each factor below.

8.6.1 WINTER SNOWPACK & WINTER TEMPERATURES

The greater the snow in the plains, the greater the risk for localized flooding issues. We found that Astotin Creek is more likely to experience major freshet episodes when there is a large snowpack at the end of winter and rapid snowmelt at some point in April.

8.6.1.1 Historical Data Analysis

Historically, the area has received an average of 110.7 cm of snow per year with snow falling between the months of October and May (ECCC, 2020). Figure 8-2 shows that major historical spring flood events (in 1982, 1997, 2007, and 2018, as marked with diamonds) are observed only when snow accumulation in March and April is much higher than the historical average. Important to note that large snow accumulation does not automatically lead to high water flows, with the pace of snowmelt an important factor as well.

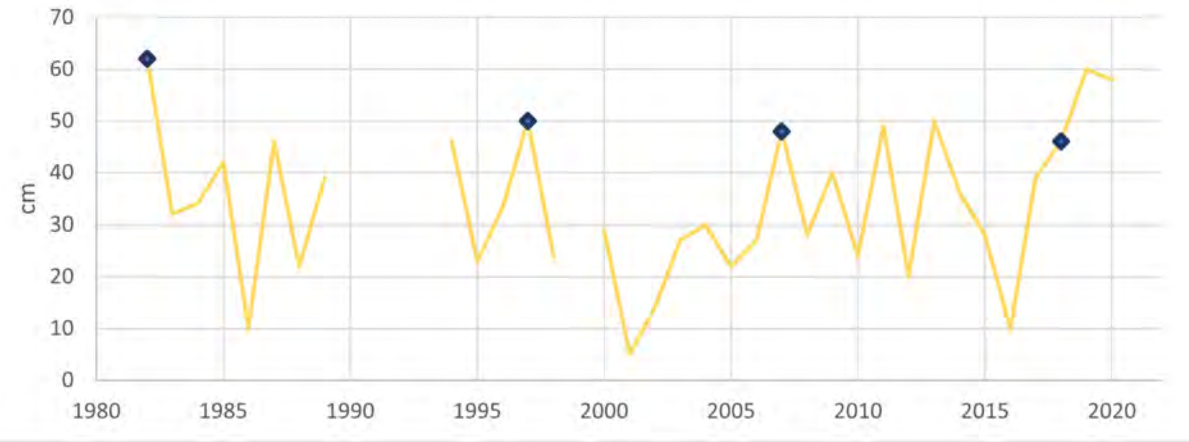


Figure 8 -2 Annual maximum snow depth in March-April at the Elk Island National Park station

8.6.1.2 Future Climate Projections

Climate projections show that winter and spring precipitation is projected to increase by 15% and 20% under the passive scenario. However, whether the projected increase in precipitation falls as snow or rain is dependent on temperature.

If the winter is colder and more precipitation falls as snow and does not melt until the spring, the freshet flow will be higher. That said, as climate projections show a projected increase in mean winter temperature, the amount of precipitation falling as snow may be lower. In addition, the number of days during which the temperature does not exceed 0˚C are projected to decrease by nearly 30%. These projections indicate a potential decrease in the amount of winter snowpack, which could result in lower freshet flows when the snowpack melts.

8.6.2 SPRING TEMPERATURES

If temperatures rise rapidly in the spring and the water content in snow is high, the risk of freshet flooding will also be high. Conversely, a low gradual change in temperature and night-time temperatures remaining below 0˚C can significantly decrease the risk of flooding.

8.6.2.1 Historical Data Analysis

We analyzed historical data on spring temperatures to test three hypotheses:

- Hypothesis 1: Freshet episodes often happen when the surface air temperature rises sufficiently (assessed by looking at the evolution of mean temperature in April).

- Hypothesis 2: Freshet episodes often happen when temperatures rise quickly (assessed by looking at the maximum 48-hour temperature increase in April).

- Hypothesis 3: Night-time temperatures remaining below 0˚C can significantly reduce the risk of flooding (assessed by looking at the average daily minimum temperature in April).

The results showed that spring temperature indicators do not explain why high-water flows were recorded in Astotin Creek between 1982 and 2020. However, there was a clear relationship between water flows and rapid snowmelt. Figure 8-3 shows how maximum water flows, and the maximum pace of snowmelt can line up within a year (with 10 days or less between occurrences), confirming a causal relationship (lower values mean that the maximum water flow and maximum pace of snowmelt occur almost at the same time).

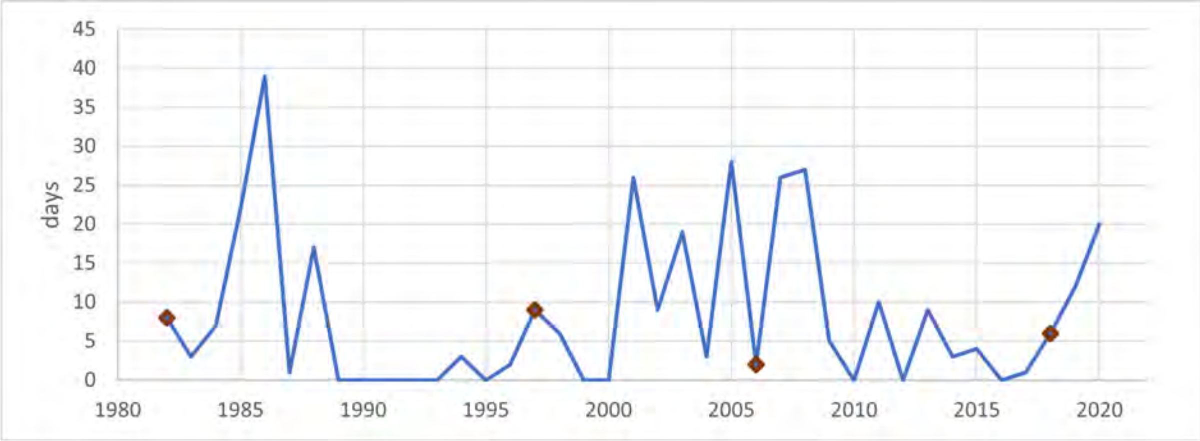


Figure 8 -3 Time interval between maximum snowmelt and maximum flow within each year at the Elk Island National Park station

8.6.2.2 Future Climate Projections

Climate projections suggest that the transition from colder to warmer weather will begin to start earlier in the year (e.g., from May 10th to April 20th by the 2080s), which could trigger more rapid snowmelt events. Projection data also shows that mean temperatures for the spring months (March, April, and May) are all projected to increase by the 2080s. Although the study into historical data showed little trend with the likelihood of flooding, increasing spring temperatures could cause freshet flooding events if they result in a higher maximum 48-hour snowmelt.

8.6.3 AMOUNT & TIMING OF SPRING PRECIPITATION

Spring precipitation can impact the volume of freshet that heads into the water system. If snowmelt that leads to a freshet episode coincides with heavy rainfall, it could intensify the freshet episode bringing more water (and thus, runoff) into the watershed.

8.6.3.1 Historical Data Analysis

Historical data shows that heavy precipitation during snowmelt is likely to play a role in 75% of major freshet events (with at least 30 mm of rain), according to historical data of the Elk Island National Park station (Figure 8-4). However, historical data also shows that not all heavy precipitation events resulted in a flood.

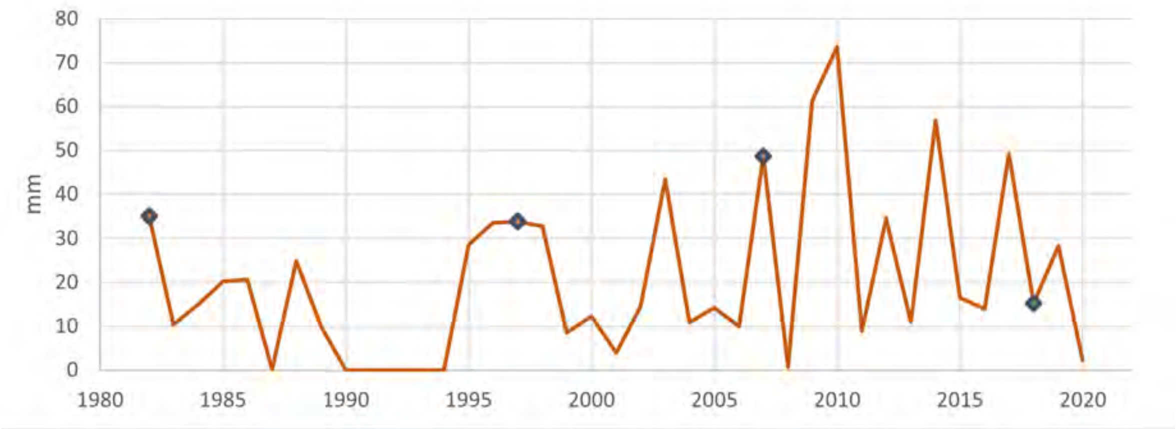


Figure 8 -4 Total liquid precipitation in April at the Elk Island National Park station

8.6.3.2 Future Climate Projections

When looking at climate projections, spring precipitation is projected to increase by 28% (23 mm on average) under the 'passive' scenario. Increased volumes of water moving through the system could result in increased flood hazard for Astotin Creek.

8.7 Summer Flooding Events

Unlike spring episodes, summer flood episodes do not necessarily result from the melting of the snowpack, as melting will have already occurred from increased temperatures during the spring months. Instead, increased creek flow generally results from periods of heavy rainfall.

8.7.1 HISTORICAL DATA ANALYSIS

Major summer events typically occur between June and September, with largest episodes recorded in June in the recent past decades. (ECCC, 2021)

According to the historical data from the nearest weather station, **the main trigger for a summer flood is rain event where more than 90 mm falls over a five-day period between June and September** (Table 8-3). If such an event occurs, there is approximately a 40% chance of flooding in Astotin Creek.

Table 8 -3 Highest Historical Water Flows and Maximum 5-day Precipitation between 1980 and 2020

Year	Annual maximum 5-day precipitation (mm)	5-day precipitation before the flood (mm)	Maximum flow (m3/s)
1983	133	102	11.80
1997	94	94	6.76
2011	92	61	6.69

[4]Missing value on July 18th, 2011.

8.7.2 FUTURE CLIMATE PROJECTIONS

Looking at future climate projections, there is an expected 12.5% increase in annual maximum five-day precipitation events by the end of the century under the passive scenario. This means that heavy summer rainfall could happen with greater frequency and severity, leading to greater flooding events. Due to the current and anticipated land use in the Astotin Creek watershed, heavy summer rainfall could also impact water quality due to increased surface runoff from agricultural and industrial land into Astotin Creek.

We used climate projections from 16 climate models to assess the likelihood of a heavy rainfall event that could trigger flooding of Astotin Creek (i.e., maximum five-day precipitation higher than 90 mm). We found that by 2051-2080 without any mitigation measures, there will likely be a 40% chance of major flooding every six years on average due to heavy precipitation episodes during summer months, compared to every eight years in the recent decades. Important to note is that that confidence in these results is relatively low due to high discrepancies across climate models; the results thus need to be considered carefully.

8.8 Climate Change & Drought

Droughts, while affecting water availability, can also have implications for the water quality in water bodies such as Astotin Creek, as water flows decrease and could make the area more susceptible to intense flooding if the ground becomes hard, preventing infiltration of intense precipitation and increasing surface run off.

Climate projections do show an increase in summer temperatures and a decrease in the number of dry days, indicating that drought conditions may not become more frequent. However, there is also research that shows that in the Western Prairie Provinces, where freshwater is already scarce, climate change and human modifications to catchments have already reduced the summer flows in major rivers when demand is greatest, and this is expected to worsen Ref (Schindler and Donahue, 2006). In addition to this, when looking at relative dryness, calculated from temperature and precipitation data for the Palmer Drought Severity Index (PDSI) (Cook et al., 2015), a rapid decrease can be seen, projecting that drought conditions will be more likely in the future. Given the contrasting trends in climate projections, confidence in an overall trend in drought conditions is moderate.

Drought and Flooding

Droughts can increase risk of flooding events. As heat evaporates moisture from the upper soil layers, they become hard, especially in areas with clay soils. Once rain falls again, water runs off, rather being absorbed into the soil, intensifying run-off volume.

8.9 Summary

8.9.1 MEAN ANNUAL PRECIPITATION

Mean precipitation is an important climate variable to consider because it can affect changes in Astotin Creek flow conditions. Future climate projections show that precipitation regimes are likely to change overall and that we can expect an 11% increase in annual precipitation under the passive scenario in the long term. While an increase in annual precipitation may not directly cause flooding, it can contribute to increased flows in Astotin Creek, which may increase the likelihood of other events causing flooding (e.g., freshet, extreme precipitation). However, we need to be careful when drawing conclusions about this relationship. There is great variability among different climate models for future precipitation, and many other factors that will influence flow and water levels in Astotin Creek, including freshet events, changes to winter and summer temperatures, snow accumulation and melt rates, and land use changes.

8.9.2 LAND COVER CHANGES CAUSED BY WILDFIRES

Land disturbance from wildfires can contribute to local flooding even after the fire is extinguished. As forests and hillsides are burned, damage to trees, plants, root systems, and the soil can increase the potential for flooding and mudslides during heavy rainfall events. This effect can last for years until after vegetation has regrown and stabilized the soil. Until soil is stabilized, there is also an increased risk of sediment in runoff which could impact water quality (Alberta Water Portal, 2016).

Astotin Creek has historically been exposed to few large wildfires. Between 2006 and 2018, the largest wildfire recorded near Astotin Creek occurred in May 2011, when more than 70 ha were burnt. Six other fires were recorded during the same period, but the total associated area burned is less than 10 ha (Government of Alberta, 2021). Furthermore, the region includes forested areas that could serve as fuel for wildfires in the future. Recent studies on the future occurrence of wildfires in Canada show that Western Canada will experience an increase of at least 50% in the number of dry, windy days that let fires start and spread (Wang et al., 2017). Studies also suggest that wildfires could burn twice as much average area per year in Canada by the end of the century as has burned in the recent past (Flannigan, 2020). Important to note is that confidence on climate projections related to wildfires is only moderate.

8.9.3 TEMPERATURE

Mean annual temperature, maximum summer temperature and minimum winter temperature are all projected to increase. This may have implications for water quality as well as potential impacts for aquatic ecosystems throughout the watershed. For example, higher water temperatures can promote the growth of harmful algal blooms. Some harmful algal blooms may produce toxins which can impact humans and animals (Environmental Protection Agency, 2020).

Climate Change and Land Management

Climate patterns in this area are predicted to shift in terms of precipitation and temperature. Flooding and drought may increase, but also other risks, including wildfire and algal bloom outbreaks. Resiliency can include various nature-based and low-carbon solutions to help reduce these risks.

8.10 Additional Climate Considerations

8.10.1 FACTORS CONTRIBUTING TO FLOOD RISK

Based on the climate change exposure assessment and study on climate change variables and flooding, we have identified several factors that increase flood risk for Astotin Creek. We have separated these into two categories: primary factors that directly increase flooding risk and secondary factors that can indirectly increase flooding risk depending on their interactions with primary factors:

Primary factors:

- Large snowpack at the end of winter contributing to spring fluvial flooding due to freshet. The size of the snowpack is projected to decrease in the future as a result of higher winter temperatures inhibiting snow formation.
- Rapid snowmelt contributing to spring riverine flooding due to freshet, caused by temperatures or rainfall in spring. Rapid snowmelt could increase as projections show that spring temperatures and rainfall are expected to increase.
- Extreme precipitation events contributing to summer riverine flooding. Summer precipitation and maximum 5-day precipitation is projected to increase in the future.

Secondary factors:

- Increase in mean annual precipitation, which may contribute to an increased likelihood of other events causing flooding (e.g., freshet, extreme precipitation).
- Land cover changes caused by more frequent wildfires, which can increase the potential for flooding.

8.10.2 FACTORS CONTRIBUTING TO WATER QUALITY

Other climate variables have the potential to impact the water quality of Astotin Creek. For example, rising water temperatures may affect habitats and local species impacting biodiversity. Additionally, water quality may be impacted by increased runoff during intense storms, increased sediment in runoff following a wildfire event, or increased runoff due to drought conditions.

8.10.3 FACTORS CONTRIBUTING TO WATER SCARCITY

Water scarcity is caused by drought conditions and the relative dryness of the area. This is assessed by considering future projections in temperature and precipitation, which show a rapid increase in dryness and therefore indicating a higher likelihood of drought conditions in the future.

9

SUMMARY AND CONCLUSIONS

The Astotin Creek watershed has a long history of human use, development and environmental conservation interest. Balancing those various interests in developing a resiliency plan for this area will be a challenge, one that requires considerations from these different management interests. Such an approach is consistent with the County's 2021 Environmental Framework, and its vision for holistic planning and management. The sections above have described the biophysical and hydrological conditions of the Astotin Creek watershed. Drawing on the County's existing policy tools and their management objectives for water, land and environmental management, preliminary recommendations consistent with these established management goals have been summarized below. **Note that these are not stand-alone actions, but rather high-level guidance to be considered in the development of the Resiliency Action Plan**.

Enhancing resiliency of the watershed must address predicted climate change impacts. Two preliminary recommendations for the Astotin Creek Action Plan relative to climate include the following:

- **Account for future climate projections in the development of flood resilience measures**. For all recommended actions, including infrastructure solutions, nature-based solutions, and land-use decisions, it is important that we account for changing climate conditions over time. For example, when replacing culverts or designing SWMFs, they should be sized with future precipitation projections in mind, so that they are not overwhelmed as rainfall increases throughout the century. This will help us to develop solutions that reduce risk in the near-term and into the future.

- **Take a low-carbon resilience approach where possible**. We need to implement a variety of measures to reduce the risk of flooding from Astotin Creek in the face of changing climate conditions. However, it is important to be aware that some measures have the potential to increase greenhouse gas emissions that are driving climate change (e.g., concrete-intensive solutions), exacerbating flood risk over time. For this reason, we should seek to emphasize nature-based solutions and other low-carbon resilience solutions that further climate change mitigation and adaptation goals at the same time.

With this framing in mind, the sections below outline challenges and opportunities for the three main land use areas in the Upper, Middle and Lower Assessment Reaches.

9.1 Challenges and Opportunities for Agricultural Areas

The Middle Assessment Reach is designated by County land use policies for large agricultural holdings, with the intent to conserve good agricultural lands for crop and pasture use. Agricultural holdings are also found in the Upper Assessment Reach, but tend to be isolated crop and pasture areas, rather than extending across broad landscapes. Rural residential or industrial land use is not permitted in the Middle Assessment Reach and the landscape will likely not experience any significant clearing or infrastructure development. Some rural residential development is possible in the Upper Assessment Reach, but at low density in keeping with conservation management objectives in this area. The creek channel has logjams and accumulation of woody debris resulting from past flood events, as well as fences and other anthropogenic features that reduce the creek's discharge capacity. Some culverts and bridges are undersized and may also influence flooding during large precipitation events. Given future climate change impacts, with more frequent and intense storms, interspersed with periodic drought, flood protection and water retention will be critical to sustain agricultural use of these areas.

From an engineering perspective, removing fencing and other anthropogenic features from the creek channel will help improve flows, as well as replacing undersized culverts and bridges identified in the Astotin Creek Resiliency Study Drainage Master Plan. While clearing log jams and woody debris from the channel would improve flow, it may also disturb habitat for aquatic species and change aquatic habitat conditions. Selective removal of natural materials around culverts and locations where it may add to flooding risk would be helpful.

From an environmental perspective, the most obvious impact to the creek and its tributaries in agricultural areas is past clearing that has reduced the vegetated riparian buffer zone, with potential impacts to water quality and quantity, biodiversity, and the aesthetics of this part of the creek. Water quality impacts appear related to natural sources but could also be linked to erosion and sediment run-off sources. Pesticide and herbicide levels were below criteria, which speaks to sound management of agricultural producers in the area. However, the low density of wetland habitat within this part of the watershed is also likely related to agricultural use, which has often encouraged land clearing and cultivation of temporary and seasonal marsh lands. Removal of wetlands has also reduced the ability of these lands to moderate flood intensity, which can accelerate run-off directly to the creek, increase erosion and sediment loading and carry nutrients and other potential contaminants into the creek and its tributaries. The County's partnership with Alberta Environment and Parks in the provincial Wetland Replacement Program provides a means to restore or replace wetlands within this region, which can also enhance resiliency by enhancing water availability. In drought, creek flows and wetlands (whether on-stream, beaver impoundments or isolated wetlands) can help sustain soil moisture levels.

The effects of past clearing were already evident in the 1997 Prioritized Landscape Ecology Assessment (PEMA) mapping (Geowest 1997) and the riparian intactness analysis showed vegetated buffers remain very narrow through much of the Middle Assessment Reach. Riparian buffers were almost entirely missing in the minor tributaries and drainage ways that feed the main creek, as well as along the creek itself. Restoration of the minimum 30 m buffer is still possible though, given the high-quality soils through this area, and existing, naturally vegetated areas. Simply allowing natural succession to fill in the buffer width would help restore a protective zone along the creek width. It would also help to support ecological connectivity, and potentially also wildlife movement. A more challenging opportunity would be wetland restoration, although again, riparian wetlands, depressional areas adjacent the creek may be practical candidate sites. Again, the County's participation in the provincial Wetland Replacement Program provides means for restoration, provided candidate sites can be identified. Manoeuverability of field equipment around wetlands can be challenging with the larger equipment used today, but restoration areas along the edge of fields would pose less of an obstacle. The Alternative Land Use Services (ALUS) program offers project examples for alternative farming practices that can help restore riparian buffers and wetlands.

Beaver flooding concerns were raised by agricultural landowners in several agricultural areas in the watershed, and particularly in the Upper Assessment Reach area. Since this area is closer to Elk Island National Park, and source populations, trapping and dam removal are not likely to provide a long-term solution since recolonization is likely within a short time. Active beaver dams were relatively abundant through the Upper and Middle Assessment Reaches, which may be related to the generally narrower width of the creek through this area. The Lower Assessment Reach is flatter, and the creek tended to widen out into large, deeper ponded areas amenable to beavers, without damming. As noted in Section 7.2.4, frequent breakage of dams can have other impacts on water quality and aquatic health. Newly flooded areas can convert the naturally occurring mercury held in soils to the more toxic methylated form (Ecke et al., 2017). Breached dams will also release sediments and organic materials that accumulate behind dams over time, and the dissolved chemicals in these waters. Co-existence may be more effective in addressing beaver flooding issues, facilitated by emerging conflict management alternatives.

Various non-lethal management tools are available that allow co-existence with beaver, by controlling flooding extent. Beaver County and the Blackfoot-Cooking Lake Provincial Recreation Area participated in a pilot project to test these devices, which have since operated with minimal maintenance for seven years (Hood et al., 2018). Elk Island National Park has also recently begun using pond leveller devices. Other jurisdictions have recognized the potential of beaver to help restore wetlands and riparian areas through beaver reintroductions (Stoffyn-Egli and Willison, 2011; Vehaoja, 2016), or to help buffer other risks, such as wildfire (Fairfax and Whittle, 2020) and flood attenuation (Westbrook et al., 2020). Lessons learned from beaver reintroductions into areas of extirpation (e.g., England and Scotland) offer approaches to address localized and unanticipated landowner concerns through open and sustained dialogue and co-management with land managers (Auster, et al., 2021).

Other conservation tools could include compensation options to landowners, through a program similar to the ecosystem services compensation projects established by ALUS (www.alus.ca). These programs are specifically targeted to agricultural landowners and are designed to provide supports to farmers and ranchers to restore wetlands, install riparian buffers, and other enhancements for erosion control, flood and drought mitigation and habitat conservation.

Specific opportunities to incorporate resiliency in agricultural areas include:

- Replace undersized culverts and bridge crossings with consideration for future climate conditions, including extreme precipitation events.

- Consider measures that will help reduce greenhouse gas emissions (e.g., nature-based solutions, rather than materials requiring additional processing such as concrete production).

- Re-establish vegetation along Astotin Creek where native vegetation buffers are less than 30 m.
- Where bank erosion issues are evident, develop site-specific bank stabilization initiatives to address sediment release, and stream meander onto adjacent lands.
- Work with landowners to establish and maintain native vegetation buffers along wetland and riparian areas, restore and protect wetlands and implement alternative beaver mitigation measures, through voluntary programs or initiatives such as those offered through ALUS and application of the County's Wetland Conservation Directive and Wetland Replacement Program.
- Limit new development within the Upper Assessment Reach to maintain native vegetation as extensive stands, which will help attenuate flood levels, maintain water quality filtration and sustain water levels here, and downstream along the creek.

9.2 Challenges and Opportunities for Industrial Development

Industrial development has been strategically focused in the Industrial Heartland area, in the Lower Assessment Reach area, and future development is anticipated to add new plant facilities and support businesses related to the petrochemical sector. Currently undeveloped lands support extensive forest, wetland and grassland habitat, including unique habitats associated with sandy soils. Three land parcels have been conserved in two provincial Natural Areas. Road and rail development are extensive through this area, and creek flow is conveyed through culverts and bridge sites. The terrain is relatively level through this area, and stream gradients are low, which has created large, on-stream ponded sections of the creek. Beaver are also active in this area, but there were fewer beaver dams than upstream, where dams are more readily constructed and maintained.

Stormwater flows from existing industrial sites are collected in stormwater facilities for treatment before release to the creek. Future development will likely increase the need for stormwater management and treatment and reduce natural overland flows, following the drainage requirements and development densities established for the Designated Industrial Zone.

Water quality testing from within the Industrial Heartland, and at the County boundary, where Astotin Creek joins Beaverhill Creek, did not find exceedances that could be clearly linked to the current industrial activities in this area. Instead, the few exceedances seemed linked to natural sources, including eroded soils, biogeochemical processes in ponded areas, and potentially also groundwater inputs. Regardless, as industrial development increases in this area, stormwater treatment will become more critical to ensure contaminants from processing activities (e.g., dust, sediment and air emissions) are not carried into the creek. Culvert and bridge sizing will also require attention to ensure adequate flood flow capacity, with consideration for future climate conditions, as noted above.

As lands are developed, retention of natural wetlands, where possible, can help to moderate flood levels by capturing some overland flow prior to release to the creek. Maintaining the minimum 30 m riparian buffer will help reduce water quality impacts but given the proximity of these lands to the river, and the two Natural Areas, wider buffers would be recommended, to ensure secure movement between natural areas. Additional conservation to retain strategic steppingstones and larger habitat patches as this area is developed would also help to sustain biodiversity of this area. Such sites would also help maintain ecological connectivity between immediately adjacent lands (i.e., the North Saskatchewan River Valley and Middle Assessment Reach) and along the Upper Assessment Reach to the moraine lands beyond, as ecological restoration projects are implemented.

Key opportunities to enhance resiliency in the industrial area include many of those for agricultural areas, but add to them specific natural area conservation efforts:

- Replace undersized culverts and bridge crossings with consideration for future climate conditions, including extreme precipitation events.
- Consider resiliency measures that will help reduce greenhouse gas emissions (e.g., nature-based solutions, rather than materials requiring additional processing such as concrete production).
- Maintain vegetation along Astotin Creek to a minimum 30 m riparian buffer, and wider near protected areas and larger patches of habitat to maintain ecological connectivity.
- Where bank erosion issues are evident, develop site-specific bank stabilization initiatives to address sediment release, and stream meander onto adjacent lands.

- Work with current and new industry development proponents to establish and maintain native vegetation buffers along wetland and riparian areas, restore and protect wetlands and implement alternative beaver mitigation measures, through voluntary programs or initiatives such as those offered through ALUS, and application of the County's Wetland Conservation Directive and Wetland Replacement Program.

- Consider strategic acquisition of larger naturally vegetated parcels than can provide larger or diverse habitat areas, or unique habitats (e.g., sand dune areas and jack pine plant communities), through the Legacy Lands Directive, or environmental or conservation easements. The Designated Industrial Zone Pilot Project is currently exploring environmental management improvements relative to Ecosystem Capacity that may also offer opportunities to incorporate strategic conservation targets.

9.3 Challenges and Opportunities for Ecological Restoration

The sections above have focused on developed areas across the Astotin Creek watershed, with some mention of the natural habitats available in those areas. In general, natural habitat is more limited in the Middle Assessment Reach, but some habitat still remains, mainly in riparian areas where clearing has not extended to the creek edge. In the Upper and Lower Assessment Reaches though, natural forest, wetland and grassland habitat is quite abundant, often in larger, contiguous stands and with mixtures of wetland types. Such habitat diversity can also drive biodiversity, by supporting a range of species adapted to these habitats. In turn, those habitats and the species potentially using them can attract attention and stewardship of local and regional residents. Indeed, this appears to be the case, with numerous species observations recorded in iNaturalist, including many in the area adjacent to Elk Island National Park.

This biodiversity is also supported by effective ecological connections to habitat such as Elk Island National Park, and the North Saskatchewan River valley. Larger protected areas can help to sustain plant and wildlife populations in the surrounding areas as dispersing young seek out their own territory and plant seeds are spread by wildlife, wind or water. Contiguous habitat adjacent to protected areas can also sustain species that require large home range sizes such as moose and deer, as well as carnivores like mink, fisher or black bear, recently found to use habitat across the Beaver Hills Moraine, and surrounding lands. While many of these species may enhance the quality of life for residents, some conflict can arise with others such as beaver and black bears. Flooding issues have already been noted by local residents in the Upper Assessment Reach, and dam removal efforts were evident throughout this reach. Black bears have recently been increasing their range south of the North Saskatchewan River, with more frequent observations, including during this study. Conflict management and public awareness programming may be required to facilitate co-existence with these species, in addition to mitigation measures to reduce human and property risks.

Biodiversity plays an important role in supporting healthy ecosystems, through provision of services such as pollination, control of populations considered to be pests as well as erosion control, nutrient removal and other functions noted above. For such species to be maintained in these areas, both ecological corridors and access to required habitat must be available in the adjacent lands, as is currently the case in the Upper and Lower Assessment Reaches. The value of these habitats has been recognized in past ecological studies used to inform land use planning policies, including the PEMA areas and Priority Landscapes (Geowest, 1997; Spencer, 2005). Provincially, the unique sandy and wetland habitats in the Lower Assessment Reach have been recognized with protection of two provincial Natural Areas. The County too, has conserved lands through environmental reserve and conservation easements and outright land purchase for conservation, including a large parcel in the Upper Assessment Reach at which several populations of a rare plant species (Houstonia longifolia, long-leaved bluets) were identified. Past records of other rare species including several very rare, S1 non-vascular species have been reported across the watershed. Clearly the natural habitats within the watershed are helping to sustain its biodiversity, as well as that in adjacent protected areas.

Aquatic habitat is an obvious, but sometimes overlooked asset within watersheds with smaller creeks, such as the Astotin Creek watershed. Stream habitats were varied along the 48 km section of Astotin Creek surveyed in this study, with run, riffle and pool reaches distributed within the Upper, Middle and Lower Assessment Reaches. Each habitat type can support a variety of species, including semi-aquatic mammals, waterfowl, shorebirds, breeding birds, amphibians, and reptiles, and the aquatic invertebrates and plant species that form the base of the aquatic food web. Aquatic biodiversity can thus be quite high, particularly when considering other terrestrial species that may be attracted to the lush growth and water resources in these areas.

Key challenges in restoring and sustaining ecological features in an area with human use include balancing disturbance impacts, potential for human-wildlife conflict and habitat loss. Opportunities for achieving this balance do exist though, and as noted above, will often benefit human land uses as well. Key opportunities in the Astotin Creek watershed include the measures noted above, as well as programs to reduce human-wildlife conflict:

- Replace undersized culverts and bridge crossings with consideration for future climate conditions, including extreme precipitation events.
- Consider measures that will help reduce greenhouse gas emissions (e.g., nature-based solutions, rather than materials requiring additional processing such as concrete production).
- Re-establish vegetation along Astotin Creek where native vegetation buffers are less than 30 m.
- Where bank erosion issues are evident, develop site-specific bank stabilization initiatives to address sediment release, and stream meander onto adjacent lands.
- Work with landowners to establish and maintain native vegetation buffers along wetland and riparian areas, restore and protect wetlands and implement alternative beaver mitigation measures, through voluntary programs or initiatives such as those offered through ALUS and application of the County's Wetland Conservation Directive and Wetland Replacement Program.
- Limit new development within the Upper Assessment Reach to maintain native vegetation as extensive stands.
- Consider strategic acquisition of larger naturally vegetated parcels than can provide larger or diverse habitat areas, or unique habitats (e.g., sand dune areas and jack pine plant communities), through the Legacy Lands policy, or environmental or conservation easements.

- Develop public awareness programs to track wildlife -human conflict (e.g., with beaver and black bear) particularly in areas adjacent Elk Island National Park. Consider implementation of programs such as 'Bear Aware' to avoid creating attractants (e.g., garbage, compost piles) or deterrent measures to avoid beaver impacts on private lands (e.g., beaver deceivers, pond levellers, exclusion fencing).

REFERENCES & GLOSSARY

10

10.1 References

Alberta Agriculture and Forestry. (2020). Alberta Soil Information Viewer. Retrieved August 2021 from https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag10372.

Alberta Amphibian & Reptile Conservancy. (n.d.). Species. Retrieved August 2021 from http://savingalbertasherps.org/.

[ABMI] Alberta Biodiversity Monitoring Institute. (2010). Land cover mapping data. Retrieved from https://abmi.ca/home/data-analytics/da-top/da-product-overview/Data-Archive/Land-Cover.html

Guidelines for Quality Assurance and Quality Control in Surface Water Quality Programs in Alberta. Alberta Environment. (2006).

[AEP] Alberta Environment and Parks. (2017). Alberta Wild Species General Status Listing - 2015. Revised March 1, 2017. http://aep.alberta.ca/fish-wildlife/species-atrisk/albertas-species-at-risk-strategy/general-status-of-alberta-wildspecies/documents/SAR-2015WildSpeciesGeneralStatusList-Mar2017.pdf

[AEP] Alberta Environment and Parks. (2018). Environmental Quality Guidelines for Alberta Surface Waters.

[AEP] Alberta Environment and Parks. (2021a) Alberta Conservation Information Management System (ACIMS). Retrieved July 2021 from https://www.albertaparks.ca/acims-data/

[AEP] Alberta Environment and Parks. (2021b). Fish and Wildlife Management Information System (FWMIS). Retrieved July 2021 from http://aep.alberta.ca/fish-wildlife/fwmis/accessfwmis-data.aspx

[AEP] Alberta Environment and Parks. (2021c). Landscape Analysis Tool (LAT). Retrieved July 2021 from https://maps.alberta.ca/LAT/Viewer/?TermsOfUseRequired=true&Viewer=LAT.

[ESRD] Alberta Environment and Sustainable Resource Development. (2012). Stepping Back from the Water - A Beneficial Management Practices Guide FOR New Development Near Water Bodies in Alberta's Settled Region. https://open.alberta.ca/dataset/1c70eb43-a211-4e9c-82c3-9ffd07f64932/resource/6e524f7c-0c19-4253-a0f6-62a0e2166b04/download/2012-SteppingBackFromWater-Guide-2012.pdf

[ESRD] Alberta Environment and Sustainable Resource Development. (2014). Species Assessed by Alberta's Endangered Species Conservation Committee. Government of Alberta.

Alberta Parks. (2018). Species Conservation Ranks. Retrieved July 30, 2021 from https://www.albertaparks.ca/albertaparksca/management-land-use/alberta-conservation-information-management-system-acims/tracking-watch-lists/species-conservation-ranks/.

Stormwater Management Guidelines for the Province of Alberta. Municipal Program Development Branch. Alberta Environmental Protection. (1999).

Guidelines for Rare Vascular Plant Surveys in Alberta. Edmonton, AB. [ANPC] Alberta Native Plant Council. (2012).

Alberta Water Portal. (2016). How wildfires impact a watershed. https://albertawater.com/how-wildfires-impact-a-watershed

Alberta Conservation Information Management System Ecological Community Tracking Last. Alberta Tourism, Parks and Recreation. Allen, L. (2014).

Linking aquatic and terrestrial environments: can beaver canals serve as movement corridors for breeding amphibians? Animal Conservation, 18(3): 287-294. Anderson, N.L., Paszkowski, C.A., & Hood, G.A. (2015).

Auster, R.E., Barr, S.W. & Brazier, R.E. (2021). Improving engagement in managing reintroduction conflicts: learning from beaver reintroduction, Journal of Environmental Planning and Management, 64:10, 1713-1734, DOI: 10.1080/09640568.2020.1837089

Environmental conditions influence eDNA persistence in aquatic systems. Environmental science & technology, 48(3), pp.1819-1827. Barnes, M.A., Turner, C.R., Jerde, C.L., Renshaw, M.A., Chadderton, W.L. and Lodge, D.M., 2014.

BC Ministry of Environment. (n.d.). Water quality – ambient water quality criteria for fluoride. BC MOE Water Protection and Sustainability Branch. https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/water-quality-guidelines/approved-wqgs/fluoride-tech.pdf

Beaver Hills Initiative. (2015). UNESCO Beaver Hills Biosphere Reserve Nomination Application. https://www.beaverhills.ca/learn/projects/project/beaver-hills-biosphere-reserve-nomination-application

A Review of the Use of Buffer Strips for Maintenance and Enhancement of Riparian Ecosystems. Prepared for Eastern Ontario Model Forest, Kemptville, Ontario. Brian, M., Hickey, C. & Doran, B. (2002).

Brodo, I. M., Sharnoff, S. D., Sharnoff, S., & Canadian Museum of Nature. (2001). Lichens of North America. Yale University Press.

Canada's Changing Climate Report. Government of Canada. Bush, E. & Lemmen, D.S. (Eds.). (2019).

Canada Land Cover Inventory. (2015). Published by Government of Canada. https://open.canada.ca/data/en/dataset/4e615eae-b90c-420b-adee-2ca35896caf6

Canadian Council of Ministers of the Environment. (1999). Canadian Water Quality Guidelines for the Protection of Aquatic Life – Dissolved Oxygen (freshwater).

Canadian Council of Ministers of the Environment. (2019). Canadian Water Quality Guidelines for the Protection of Aquatic Life – Manganese (dissolved). https://www.ccme.ca/en/res/manganese-en-canadian-water-quality-guidelines-for-the-protection-of-aquatic-life.pdf

Canadian Council of Ministers of the Environment. (2021). Canadian Environmental Water Quality Guidelines – Summary Table. https://ccme.ca/en/summary-table

Chen, H. (2009). Assessing Riparian Health of Astotin Creek of Central Alberta [Master of Science Thesis, University of Alberta].

City of Edmonton. (2006) Background Report: Guidelines for Environmental Reserve (ER) Dedication for Wetlands and Other Water Bodies – November 2006. https://www.edmonton.ca/city_government/documents/PDF/Background_Report_Wetland_Buffer_ER_Dedication_Guidelines.pdf

Cobbaert, D., Robinson, M., Trites, M., & Dam, A. (2011). An assessment of wetland health and values in Alberta's Industrial Heartland. Alberta Environment.

Cook, B.I., Ault, T.R. and J.E. Smerdon. (2015) Unprecedented 21st century drought risk in the American Southwest and Central Plains. Climatology, 1(1).

Cornell University. (2021). All About Birds. Retrieved August 2021 from https://www.allaboutbirds.org/news/.

COSEWIC. (2007a). COSEWIC Assessment and Status Report on the Common Nighthawk

Chordeiles minor in Canada. Committee on the Status of Endangered Wildlife in Canada.

COSEWIC. (2007b). COSEWIC Assessment and Status Report on the Olive-side Flycatcher Contopus cooperi in Canada. Committee on the Status of Endangered Wildlife in Canada.

COSEWIC. (2009). COSEWIC Assessment and Status Report on the Horned Grebe Podiceps auratus in Canada. Committee on the Status of Endangered Wildlife in Canada.

COSEWIC. (2011). COSEWIC Assessment and Status Report on the Barn Swallow Hirundo rustica in Canada. Committee on the Status of Endangered Wildlife in Canada.

COSEWIC. (2012a). COSEWIC Assessment and Status Report on the American badger Taxidea taxus in Canada. Committee on the Status of Endangered Wildlife in Canada.

COSEWIC. (2012b). COSEWIC Assessment and Status Report on the Western Toad Anaxyrus boreas in Canada. Committee on the Status of Endangered Wildlife in Canada.

COSEWIC. (2013). COSEWIC Assessment and Status Report on the Little Brown Myotis lucifungus, Northern Myotis septentrionalis and Tri-colored Bat Perimyotis subflavus in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC. (2014). COSEWIC Assessment and Status Report on the Western Grebe Aechmophorus occidentalis in Canada. Committee on the Status of Endangered Wildlife in Canada.

COSEWIC. (2017). COSEWIC Assessment and Status Report on the Rusty Blackbird Euphagus carolinus in Canada. Committee on the Status of Endangered Wildlife in Canada.

Curtis, A.N., Tiemann, J.S., Douglass, S.A., Davis, M.A. and Larson, E.R., 2021. High stream flows dilute environmental DNA (eDNA) concentrations and reduce detectability. Diversity and Distributions, 27(10), pp.1918-1931.

DeCecco, J.A. & Brittingham, M.C. (2005). Riparian Buffers for Wildlife. PennState Extension. https://extension.psu.edu/riparian-buffers-for-wildlife

Dejean, T., Valentini, A., Duparc, A., Pellier-Cuit, S., Pompanon, F., Taberlet, P. and Miaud, C., 2011. Persistence of environmental DNA in freshwater ecosystems. PloS One, 6(8), p.e23398.

Dodds, W. & Whiles, M. (2010). Freshwater ecology, Concepts and environmental applications of limnology (2nd ed.). Academic Press.

Ecke, F., Levanoni, O., Audet, J., Carlson, P. Eklöf, K., & Hartman, G. (2017). Meta-analysis of environmental effects of beaver in relation to artificial dams. Environmental Research Letters, 12(11): 113002.

Environment and Climate Change Canada. (2020). Climate Normals.

Environment and Climate Change Canada. (2021). Water Level and Flow.

Environmental Protection Agency. (2020). Climate Change and Harmful Algal Blooms. https://www.epa.gov/nutrientpollution/climate-change-and-harmful-algal-blooms

EPCOR. (2021). Facts about fluoride. https://www.epcor.com/products-services/water/water-quality/Pages/facts-about-fluoride.aspx

Fairfax, E. and Whittle, A. (2020), Smokey the Beaver: beaver-dammed riparian corridors stay green during wildfire throughout the western USA. Ecol Appl. Accepted Author Manuscript. doi:10.1002/eap.2225

Fischer, R.A. & Fischenich, J.C. (2000). Design Recommendations for Riparian Corridors and Vegetated Buffer Strips. https://apps.dtic.mil/sti/pdfs/ADA378426.pdf

Fisher, C. & Acorn, J. (1998). Birds of Alberta. Lone Pine Publishing.

Flannigan, M. (2020). Fire and Climate Change. https://sites.ualberta.ca/~flanniga/climatechange.html

Flora of North America Editorial Committee. (Eds.). (1993). Flora of North America North of Mexico [Online]. Retrieved July 30, 2021 from http://beta.floranorthamerica.org.

Fremier, A.K., Strickler, K.M., Parzych, J., Powers, S. and Goldberg, C.S., 2019. Stream transport and retention of environmental DNA pulse releases in relation to hydrogeomorphic scaling factors. Environmental science & technology, 53(12), pp.6640-6649.

[Geowest] Geowest Environmental Consultants Ltd. (1997). Prioritized Landscape Ecology Assessment of Strathcona County, Alberta (Document #: 8363 EEP Environmental and Open Space Planning 5930.) Prepared for Strathcona County, May 5, 1997.

Government of Alberta. (2013). Wildlife Management – Sensitive Species Inventory Guidelines. https://open.alberta.ca/publications/sensitive-species-inventory-guidelines

Government of Alberta. (2018). Snow Does Not Equal Flood: Alberta's Snowmelt and its Impact on Alberta Rivers. https://open.alberta.ca/dataset/d80d5e09-9afc-4b65-a24c-25d46b26fc75/resource/bc17fd13-3391-449c-98ed-1f79ee26bf7b/download/aep-rfc-factsheet-snowmelt-impact-alberta-rivers.pdf

Government of Alberta (2021). Historical Wildfire Database. https://wildfire.alberta.ca/resources/historical-data/historical-wildfire-database.aspx

Government of Canada. (2016). Manganese in drinking water. Federal-Provincial-Territorial Committee on Drinking Water. https://www.canada.ca/en/health-canada/programs/consultation-manganese-drinking-water/manganese-drinking-water.html#a4

Government of Canada. (2021). Species at Risk Public Registry. Retrieved July 2021 from http://www.registrelep-sararegistry.gc.ca/search/SpeciesSearch_e.cfm

Gregory, S.V., Swanson, F.J., McKee, W.A. & K.W. Cummins, K.W. (1991). An ecosystem perspective of riparian zones. BioScience, 41:540–551.

Harrison, J.B., Sunday, J.M. and Rogers, S.M., 2019. Predicting the fate of eDNA in the environment and implications for studying biodiversity. Proceedings of the Royal Society B, 286(1915), p.20191409.

Hood, G.A., Hvenegaard, G.T., & McIntosh, A. (2018). Natural goods and services in a mixed use landscape. Prepared for Beaver County. University of Alberta, Augustana Campus.

Hood, G.A., & Bayley, S.E. (2008). Beaver (Castor canadensis) mitigate the effects of climate on the area of open water in boreal wetlands in western Canada. Biological Conservation, 141: 556-567.

Hood, G.A., & Bayley, S.E. (2009). A comparison of riparian plant community response to herbivory by beavers (Castor canadensis) and ungulates in Canada's boreal mixed-wood forest. Forest Ecology and Management, 258(9): 1979-1889.

Hood, G.A. & Larson, D.G. (2014). Beaver-created habitat heterogeneity influences aquatic invertebrate assemblages in boreal Canada. Wetlands, 34(1): 19-29.

Hood, G.A. & Larson, D.G. (2015). Ecological engineering and aquatic connectivity: a new perspective from beaver-modified wetlands. Freshwater Biology, 60(1): 198-208.

Hood, G.A., Manaloor, V. & Dzioba, B. (2018). Mitigating infrastructure loss from beaver flooding: A cost-benefit analysis. Human Dimensions of Wildlife, 23(2): 74-116.

Hydrogeological Consultants Ltd. (2001). Strathcona County Regional groundwater assessment. Parts of Township 050 to 057 Range 20 to 24 W4M. Prepared for Agriculture and Agri-Foods Canada.

iNaturalist. (2021). iNaturalist, California Academy of Sciences and the National Geographic Society. Retrieved July 2021 from https://www.inaturalist.org/pages/about

IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team Pachauri, R.K & & Meyer, L.A (Eds.)]. IPCC.

International Union for Conservation of Nature. (2019). Nature based solutions for societal needs – a standardized approach for design and verification of interventions. Retrieved October 2021 from https://www.iucn.org/sites/dev/files/content/documents/2019/iucn_global_nbs_standard_-_public_consultation.pdf

Johnston N.T. & Slaney, P.A. (1996). Fish Habitat Assessment Procedures. Watershed Restoration Technical Circular No. 8 (revised April 1996 with errata). Watershed Restoration Program, B.C. Ministry of Environment, Lands and Parks and Ministry of Forests.

Jones, C.G., Lawton, & Shachak, M. (1997). Positive and negative effects of organisms as physical ecosystem engineers. Ecology, 78 (7): 1946-1957.

Kershaw, L., Gould, J., Johnson, D., & Lancaster, J. (200)1. Rare Vascular Plants of Alberta. The Alberta Native Plant Council, University of Alberta Press.

Kilgore, C., Gunther, R. & Rupprecht, R. (2009). Riparian and Wetland Buffers for Water Quality Protection. https://www.stormh2o.com/home/article/13004950/riparian-and-wetland-buffers-for-waterquality-protection.

Klapproth, J.C. & Johnson, J.E. (2009). Understanding the Science Behind Riparian Forest Buffers: Effects on Plant and Animal Communities. Virginia Cooperative Extension. https://vtechworks.lib.vt.edu/bitstream/handle/10919/48063/420-152_pdf.pdf?sequence=1&isAllowed=y

Krosby, M., Theobald, D.M., Norheim, R. and McRae, B.H. (2018). Identifying riparian climate corridors to inform climate adaptation planning. PLOS OnePLOS One, https://doi.org/10.1371/journal.pone.0205156

MacDonald, G.A. (2009). The Beaver Hills Country: A history of land and life. AU Press, Athabasca University.

Matters, S. & Hood, G. (2016). An analysis of the history of Aboriginal peoples in the Beaver Hills, Alberta, Canada. The Canadian Journal of Native Studies, XXXVI (2), 149-166.

McNeely, R.N., Neimanis, V.P. & Dwyer, L., (1979). Water quality source book. A guide to water quality parameters. Inland Waters Directorate, Water Quality Branch, Environment Canada.

Naiman, R.J., McDowell, D.M., & Farr, B.S. (1984). The influence of beaver (Castor canadensis) on the production dynamics of aquatic insects. Verhandlungen der Internationalen Vereinigung fur Theoretische and Angewandte Limnologie, 22:1801-1810

Naiman, R. & Decamps, H. (1997). The Ecology of Interfaces: Riparian Zones. Annual Review of Ecology and Systematics. 28. 10.1146/annurev.ecolsys.28.1.621.

[NRC] Natural Regions Committee (2006). Natural Regions and Subregions of Alberta. Compiled by D.J. Downing and W.W. Pettapiece. Government of Alberta. Pub. No. T/852.

NatureLynx. (2021). ABMI NatureLynx. Retrieved July 2021 from https://naturelynx.ca/

Nelner, T.B. and Hood, G.A. (2011). Effects of agriculture and beaver on winter biodiversity of mammals. Wildlife Biology, 17: 326-336.

Nelson, S.N, & Paetz, M.J. (1992). The Fishes of Alberta (2nd ed.). The University of Alberta Press.

Northwest Hydraulic Consultants. (2014). Nisku Flood Hazard Study – Blackmud Creek. Prepared for Alberta Environment and Parks.

Pandey, P.K., Kass, P.H., Soupir, M.L., Biswas, S. & Singh, V.P. (2014). Contamination of water resources by pathogenic bacteria. AMB Express, 4(15). https://doi.org/10.1186/s13568-014-0051-x

Pattie, D. & Fisher, C. (1999). Mammals of Alberta. Lone Pine Publishing

Pollick, H.F. (2004). Water Fluoridation and the Environment: Current Perspective in the United States. Int J Occup Environ Health, 10:343–350

Proulx, B. (2018). Strathcona County grapples with flooding. Fort Saskatchewan The Record, April 26, 2018. Retrieved September 22, 2021 https://www.fortsaskatchewanrecord.com/2018/04/26/strathcona-county-grapples-with-flooding

Province of Alberta. (1997). Wildlife Act: Wildlife Regulation, Alberta Regulation 143/1997.

With amendments up to and including Alberta Regulation 157/2021.

Reid, F. (2006). A Field Guide to mammals of North America. The Peterson Field Guide Series.

Reimer, P.S. (1999). Environmental effects of manganese and propose freshwater guidelines to protect aquatic life in British Columbia [Master's Thesis, University of British Columbia].

Sales, NG, McKenzie, MB, Drake, J, et al. Fishing for mammals: Landscape-level monitoring of terrestrial and semi-aquatic communities using eDNA from riverine systems. J Appl Ecol. 2020; 57: 707–716. https://doi.org/10.1111/1365-2664.13592

Schindler, D.W. and Donahue, W.F., 2006. An impending water crisis in Canada's western prairie provinces. Proceedings of the National Academy of Sciences, 103(19), pp.7210-7216.

Scott, W.B. & Crossman, E.J. (1998). Freshwater Fishes of Canada (2nd ed.). Galt House Publishing Ltd.

Semenchuk, G. A. (2007). The atlas of Alberta breeding birds: A second look. Federation of Alberta Naturalists.

Spencer Environmental Management Services Ltd. (2005). Assessment of Environmental Sensitivity and Sustainability in Support of the Strathcona County MDP Review. Prepared for Strathcona County.

Stanley Associates Engineering Ltd. (1998). Lamont Flood Risk Mapping Study. Prepared for Alberta Environmental protection River Engineering Branch.

Stantec Consulting Ltd. (2016). Alberta's Industrial Heartland Stormwater Drainage Study. Edmonton, AB.

Stoffyn-Egli, P. & Willison, J.H. M. (2011). Including wildlife habitat in the definition of riparian areas: The beaver (Castor canadensis) as an umbrella species for riparian obligate animals. Environmental Reviews. 19. 479-494. 10.1139/a11-019.

Strathcona County. (2017, March 27). A rich and plentiful country [Video]. YouTube. https://www.youtube.com/watch?v=Em0oo4oThBw

Strathcona County. (2018). Heartland Industrial Area Structure Plan - Bylaw 21-2018. Strathcona County, AB.

Strathcona County. (2020). Municipal Development Plan Bylaw 20-2017. Strathcona County, AB: Strathcona County.

Strathcona County. (2021a). Best Management Practices for Stormwater Management Facilities. Strathcona County, AB: Strathcona County.

Strathcona County. (2021b). Strathcona County Design and Construction Standards. Strathcona County, AB: Strathcona County.

[USGS] US Geological Service. (2009). Mercury in the Environment. Fact Sheet 146-00 (October 2020). Retrieved 25 October 2021 https://www2.usgs.gov/themes/factsheet/146-00/

Van Vuuren, D.P., J. Edmonds, M. Kainuma, K. Riahi, A. Thomson, K. Hibbard & T. Masui (2011). The representative concentration pathways: an overview. Climatic Change, 109(1 2): 5-31.

Vehkaoja, M. (2016). Beaver in the drainage basin: an ecosystem engineer restores wetlands in the boreal landscape. MSc. Thesis, University of Helsinki.

Wang, X., Parisien, M.A., Taylor, S.W., Candau, J.N., Stralberg, D., Marshall, G.A., Little, J.M., and Flannigan, M.D. (2017). Projected changes in daily fire spread across Canada over the next century. Environmental Research Letters, 12 (2), 025005. https://doi.org/10.1088/1748-9326/aa5835

Wasser, L., Day, R. & Taylor, A. (2015). Quantifying land use effects on forested riparian buffer vegetation structure using LiDAR data. https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/ES14-00204.1

Wenger, S. (1999). A Review of the Scientific Literature on Riparian Buffer Width, Extent and Vegetation. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.498.8482&rep=rep1&type=pdf

Westbrook, C.J., Ronnquist, A., & Bedard-Haugn. (2020). Hydrological functioning of a beaver dam sequence and regional dam persistence during an extreme rainstorm. Hydrological Processes. https://doi.org/10.1002/hyp.13828.

Westworth, D.A. and L.J. Knapik, 1987. Survey of Significant Natural Features, Strathcona County. Prepared for Strathcona County.

Wildlife Conservation Society Canada. (2020). Alberta Community Bat Program. Retrieved August 2021 from https://www.albertabats.ca/batprofiles/

Yarmey, N.T. & Hood, G.A. (2021). Resident perceptions of human-beaver conflict in a rural landscape in Alberta, Canada. Human Wildlife Interactions, 14(3): 476-486.

10.2 Glossary

Adaptation: Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Adaptive management: Systematic process for continually improving management policies and practices by learning from the outcomes of operational programs.

Anthropogenic: Relating to or resulting from the influence of human beings on nature.

Assessment Reach: A section of the Astotin Creek watershed that has experienced a common type of development, used to evaluate ecological and hydrological features, and potential management options.

Bankfull width: Stream width at the point where water just starts to overflow into the active flood plain.

Bathymetry: The measurement of water depth at various places in a body of water.

Catchment: A catchment is an area of land where water collects when it precipitates, often bounded by hills.

Chernozemic soils: Soils that develop under grasslands.

Climate: The weather conditions prevailing in an area in general over a long period, typically a minimum of 30 years. Climate differs from weather in that weather reflects short term (minute, hourly, daily, weekly, seasonal) conditions of the atmosphere and does not denote the long-term trends.

Climate change: Any significant long-term change in the expected patterns of average weather of a region over a significant period of time, usually averaged to a minimum of 30 years.

Conductivity: A measure of the concentrations of dissolved ions (charged compounds that can carry electrical current).

Digital elevation model (DEM): A 3D computer graphics representation of terrain elevation data.

Ecological Goods and Services (EGS): The natural resources, and beneficial aspects linked to functional ecosystems that support human well-being (e.g., clean air and water, adequate water supply, flood and drought protection, recreational use and others).

Exposure: Presence of people, livelihoods, assets, services, resources or infrastructure in place in a specific region that could be adversely affected by climate change.

Flood Regime: Watershed response to intense meteorological events such as rainfall and snowmelt.

Freshet: Flooding caused by heavy rain or snow melt.

Freeze-thaw cycle: Number of days where maximum temperature is above 0˚C and the minimum temperature is below 0˚C. Under these conditions, it is likely that some water at the surface was both liquid and solid at some point during the day.

Gleysols: Soils that develop in depressional areas that are periodically wet (e.g., due to seasonal flooding).

Heat wave: Minimum of a three-day period when temperatures exceed 30˚C.

Hydraulic: Related to flowing water.

Hydrology: The science of explaining the water system.

Hydrometric: Related to the monitoring of flow and water level.

Hydrometric station: A station on a water body (usually river or creek) recording streamflow data.

LIDAR: Light Detection and Ranging data is collected through remote sensing methods and used to map ground and full surface topography. Pulsed laser light is used to measure the distance between the ground and any surface objects, including infrastructure or natural vegetation, and an airborne sensing unit to determine relative elevations of ground surface and full surface layers.

Low-carbon resilience: Measures which bring together climate mitigation and adaptation strategies .

Luvisolic soils: Soils that develop under forested cover.

Mast Production: Production of fruit by a population of trees and/or shrubs.

Mitigation: Reducing the amount of greenhouse gases in the atmosphere by reducing the sources of greenhouse gases or increasing the sinks which accumulate and store the gases.

Moraine: Deposits of gravel, sand, and silt from the melting of stagnant glacial ice.

Nature-based Solutions: Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (IUCN, 2019).

Non-vascular Plants: Plants that do not have tissues that can convey water and minerals, and instead absorb them directly from the plant surface (e.g., mosses and lichens).

Organic Soils: Soils that are composed of mainly organic material (e.g., peat), not mineral soils.

Representative concentration pathways (RCP): A greenhouse gas concentration trajectory scenario adopted by the IPCC. The four scenarios (RCP2.6, RCP4.5, RCP6, and RCP8.5) represent the range of possible climate policy outcomes for the 21st century. RCP2.6, the most optimistic scenario, assumes aggressive mitigation while RCP8.5 is the "business-as-usual" scenario with little or late change.

Total Dissolved Solids: Total dissolved compounds, including ions (charged) and uncharged molecules (e.g., organic compounds), used to measure total chemical composition of water in water quality studies.

Total Suspended Solids: Total suspended (undissolved) solids, including sediment, organic (carbon-based) that are larger than 2 microns (µm) in size.

Vascular Plants: Plants that have tissues that can convey water and minerals (e.g., most trees, shrubs, grasses and forbs).