APPENDIX A
HYDROLOGY

A

Photograph 1 – Example of a breached beaver dam

Photograph 2 – Example of beavers actively building new dams

Photograph 3 – Example of a beaver dam under the bridge

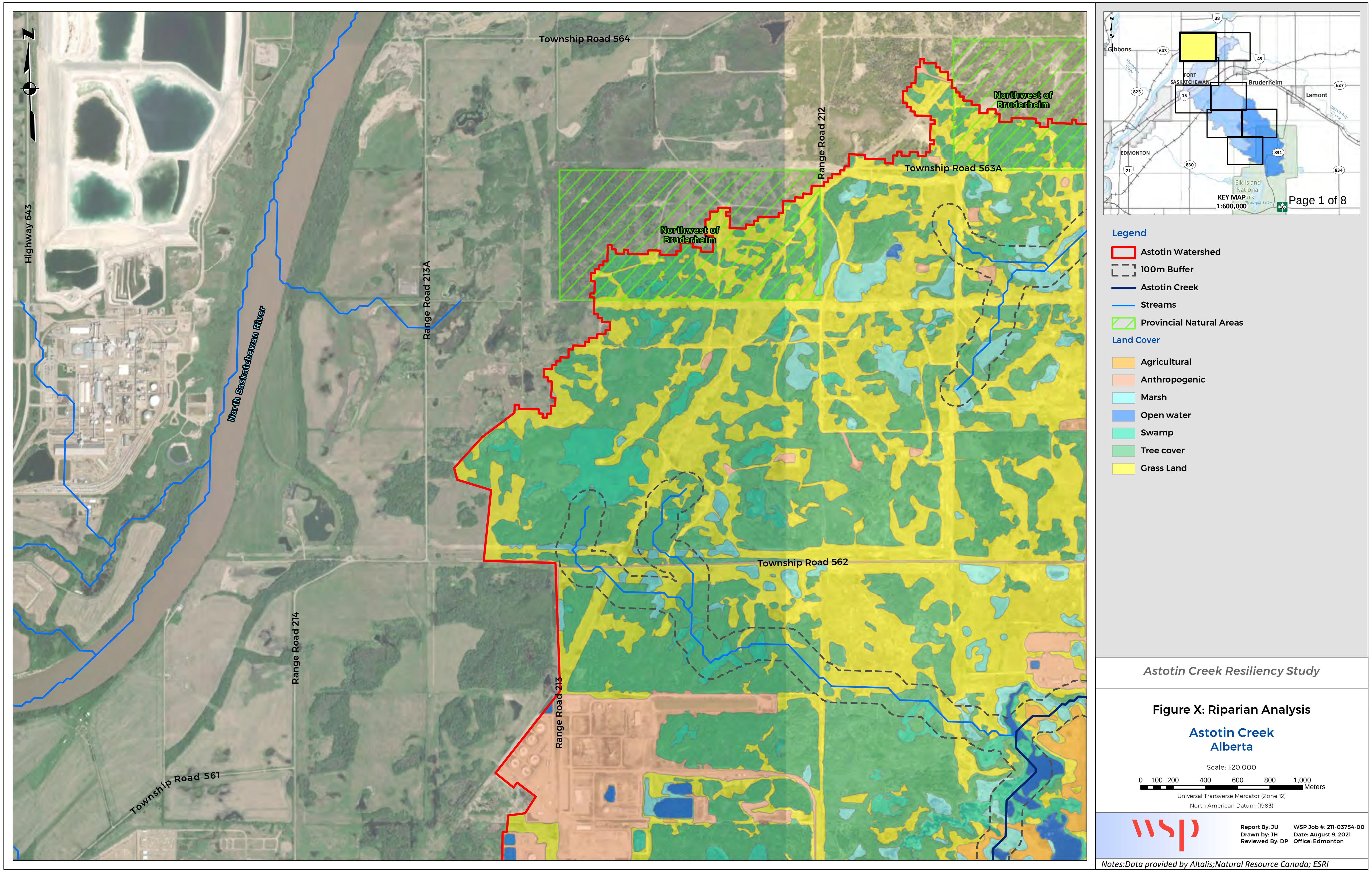
Photograph 3 – Example of a beaver dam under the bridge

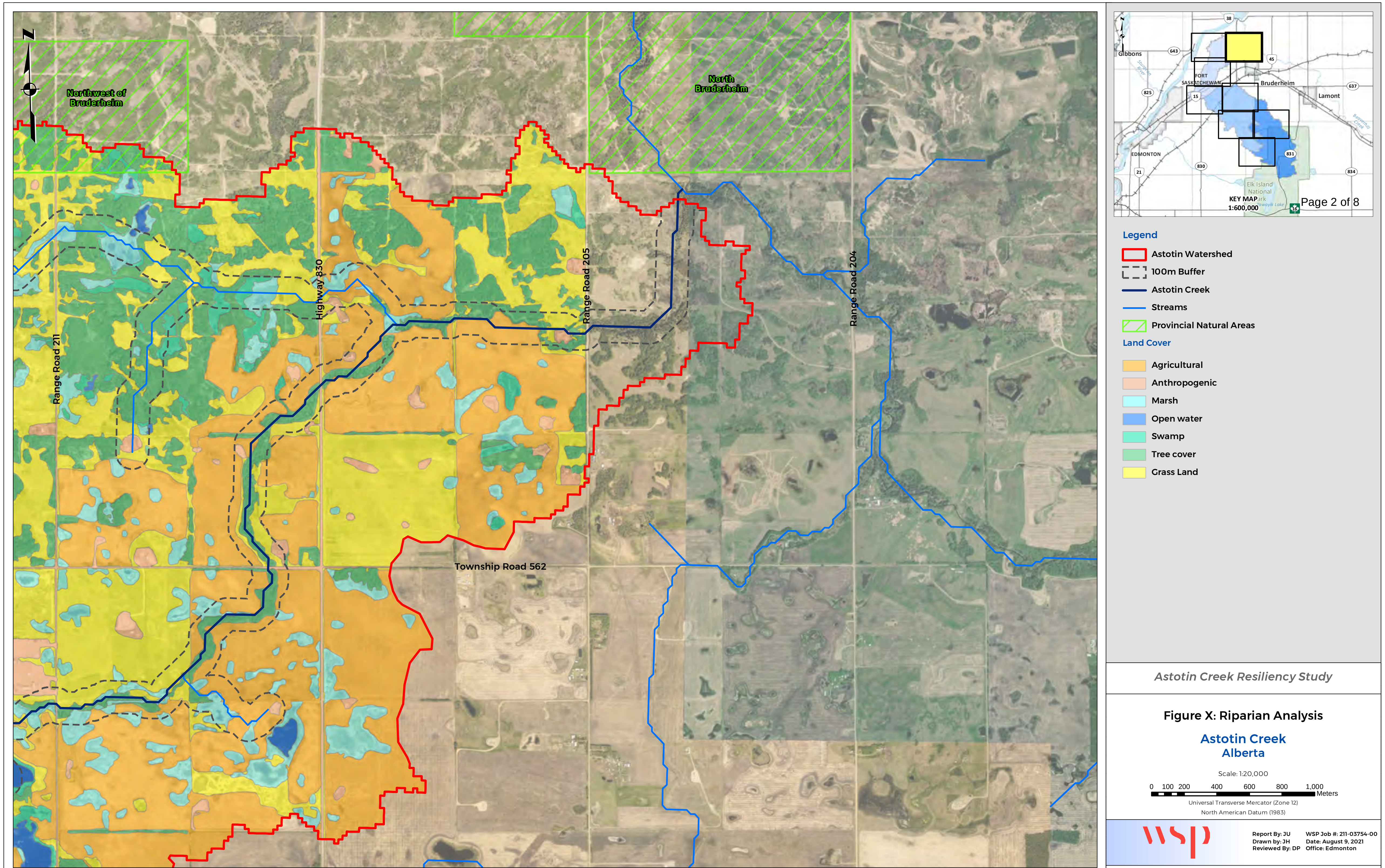
Photograph 5 – Examples of culverts blocked with woody debris

Photograph 5 – Examples of culverts blocked with woody debris

APPENDIX B
VEGETATION

B


Township Road 564
Township Road 563A
Township Road 562
Township Road 561
Highway 643
Range Road 213A
Range Road 212
Range Road 214
Range Road 213
North Saskatchewan River
Northwest of Bruderheim
Northwest of Bruderheim
Gibbons
FORT SASKATCHEWAN
Bruderheim
Lamont
EDMONTON
Elk Island National Park
KEY MAP
1:600,000
Page 1 of 8
Legend
Astotin Watershed
100m Buffer
Astotin Creek
Streams
Provincial Natural Areas
Land Cover
Agricultural
Anthropogenic
Marsh
Open water
Swamp
Tree cover
Grass Land
Astotin Creek Resiliency Study
Figure X: Riparian Analysis
Astotin Creek
Alberta
Scale: 1:20,000
0 100 200 400 600 800 1,000 Meters
Universal Transverse Mercator (Zone 12)
North American Datum (1983)
Report By: JU
Drawn by: JH
Reviewed By: DP
WSP Job #: 211-03754-00
Date: August 9, 2021
Office: Edmonton
Notes:Data provided by Altalis;Natural Resource Canada; ESRI


Northwest of Bruderheim
North Bruderheim
Highway 830
Range Road 205
Range Road 204
Range Road 211
Township Road 562
Gibbons
FORT SASKATCHEWAN
Bruderheim
Lamont
EDMONTON
Elk Island National Park
KEY MAP 1:600,000
Page 2 of 8
Legend
Astotin Watershed
100m Buffer
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wsp
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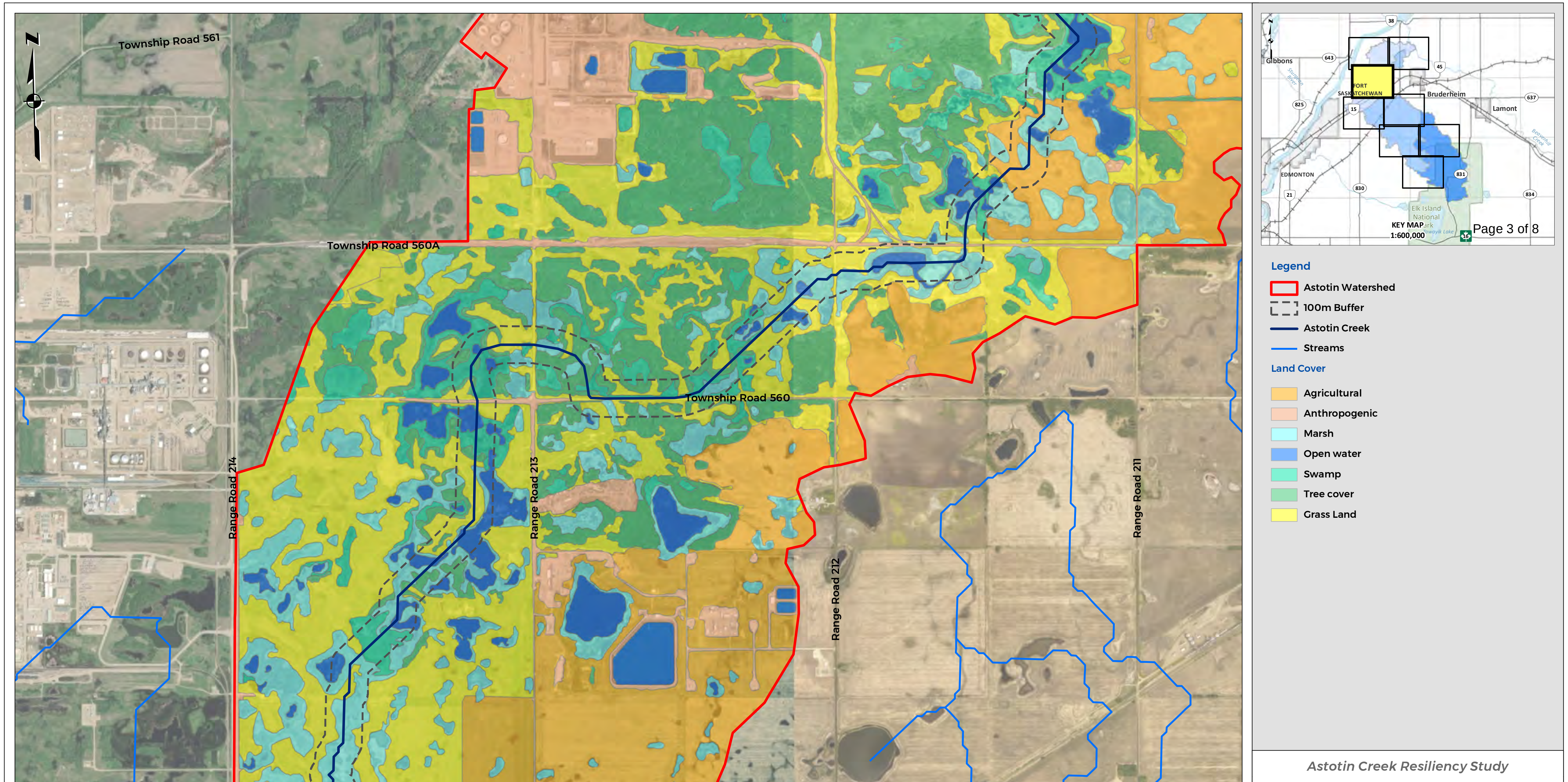

Figure X: Riparian Analysis

Astotin Creek
Alberta

Scale: 1:20,000

0 100 200 400 600 800 1,000 Meters

Universal Transverse Mercator (Zone 12)
North American Datum (1983)

Report By: JU
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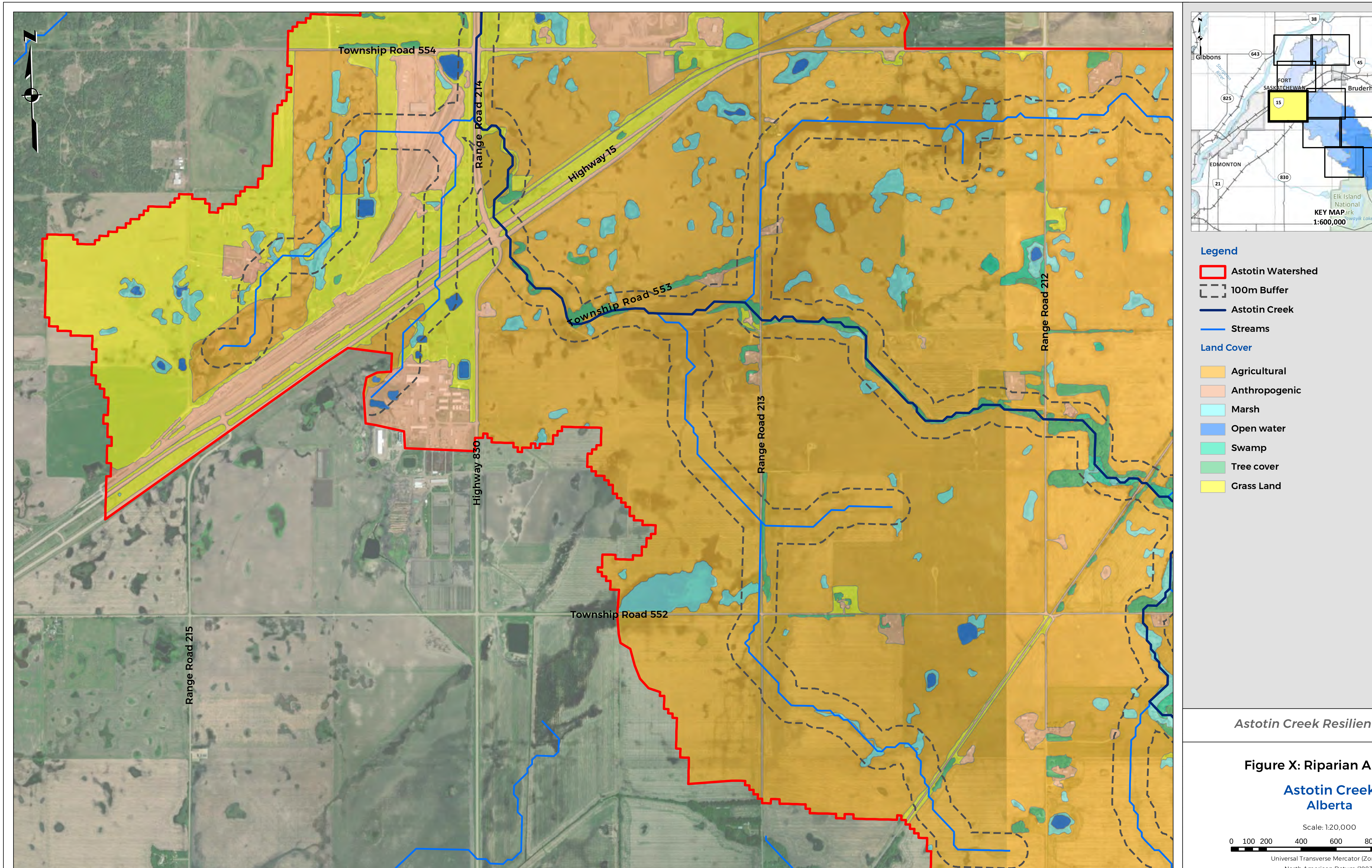
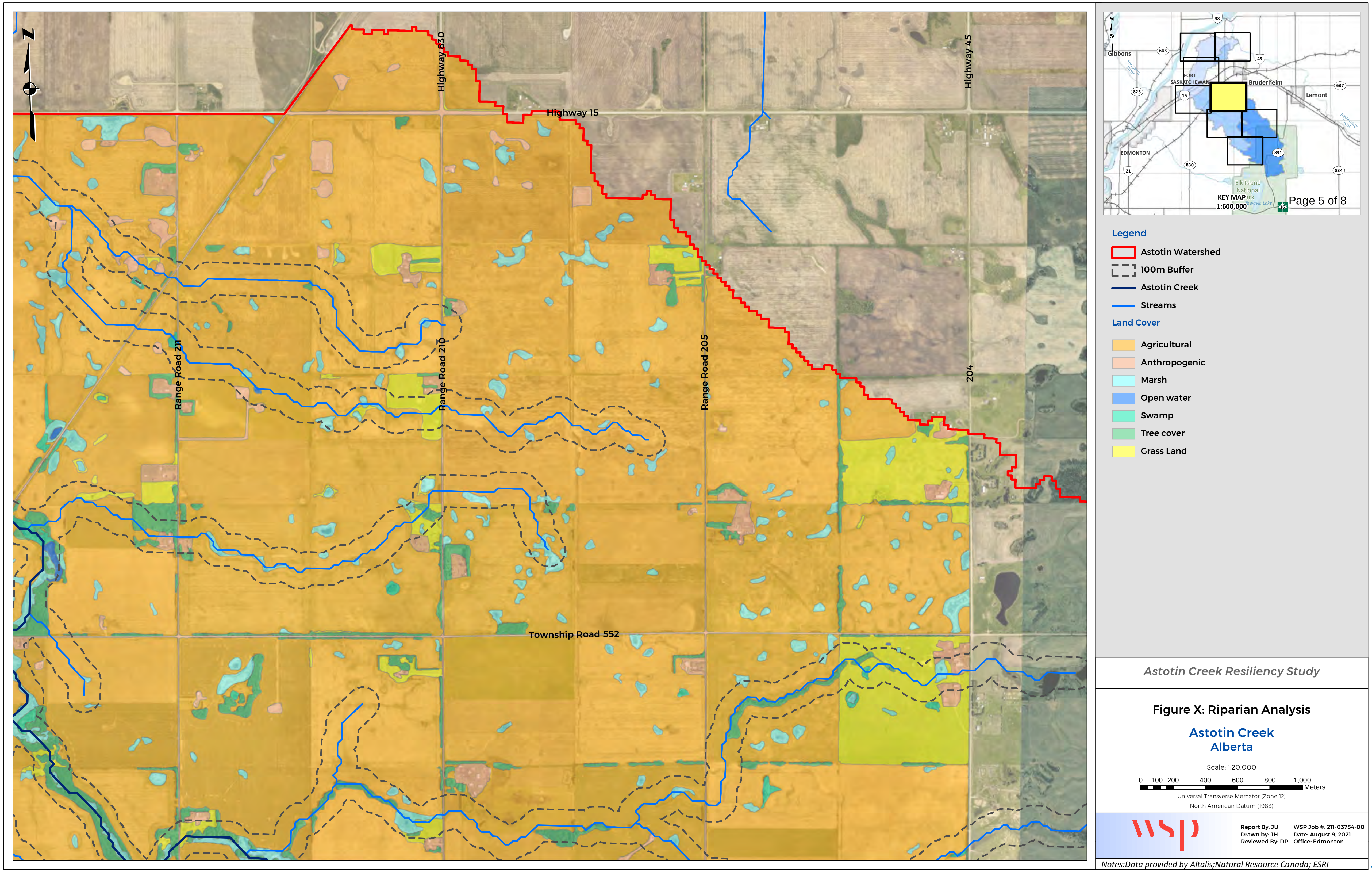


Township Road 554
Range Road 214
Highway 15
Township Road 553
Range Road 212
Highway 830
Range Road 213
Township Road 552
Range Road 215
Gibbons
EDMONTON
KEY MAP
1:600,000
Legend
Astotin Watershed
100m Buffer
Astotin Creek
Streams
Land Cover
Agricultural
Anthropogenic
Marsh
Open water
Swamp
Tree cover
Grass Land
Alberta
Scale: 1:20,000
0 100 200 400 600



Highway 830
Highway 15
Highway 45
Range Road 211
Range Road 210
Range Road 205
204
Township Road 552
Gibbons
643
38
45
FORT SASKATCHEWAN
Bruderheim
637
Lamont
825
15
EDMONTON
21
830
831
834
Sturgeon River
Beaverhill Creek
Elk Island National Park
Tawayik Lake
16
KEY MAP
1:600,000
Page 5 of 8
Legend
Astotin Watershed
100m Buffer
Astotin Creek
Streams
Land Cover
Agricultural
Anthropogenic
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0 100 200 400 600 800 1,000 Meters
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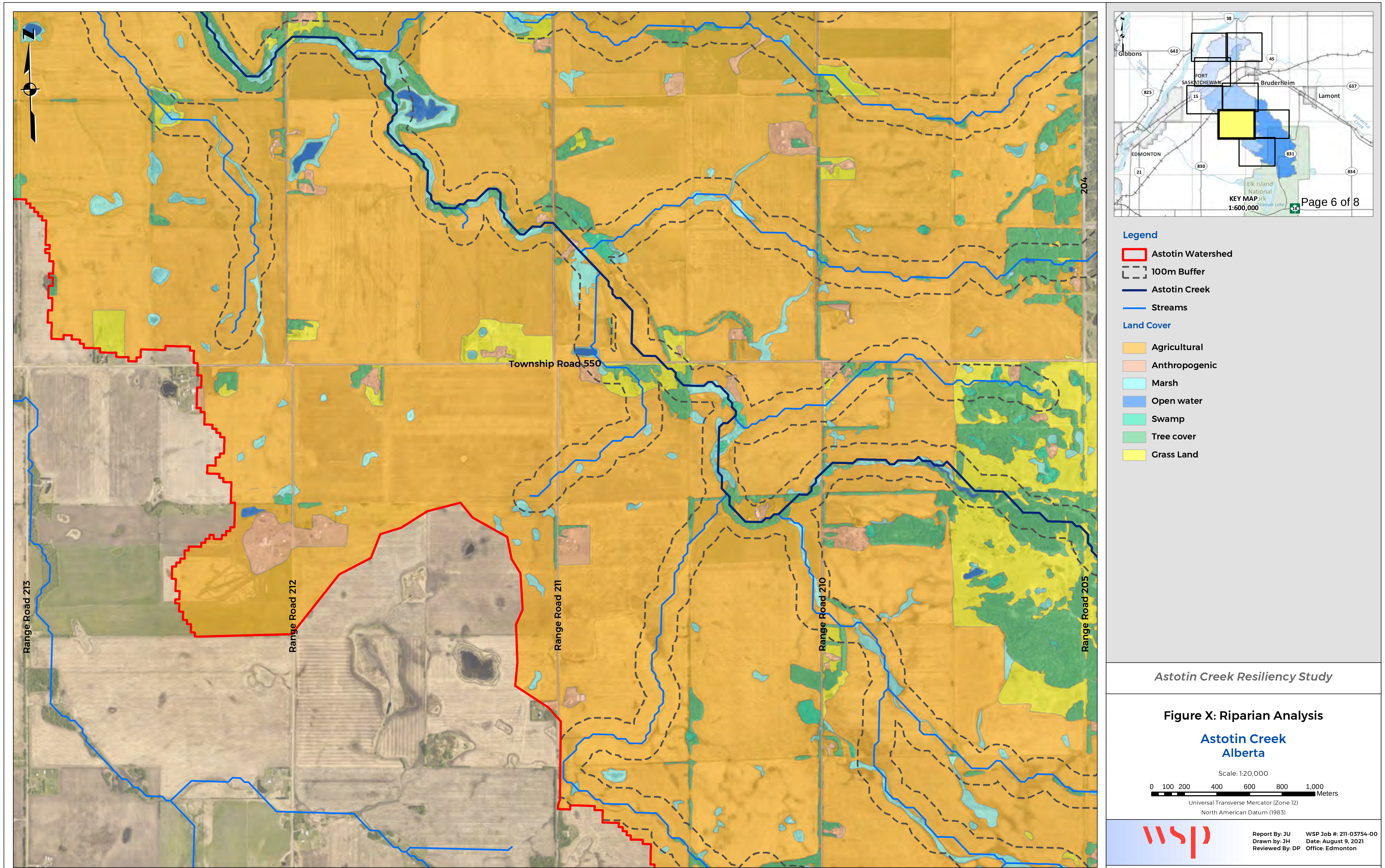
Township Road 550
Range Road 213
Range Road 212
Range Road 211
Range Road 210
Range Road 205
204
Gibbons
Bruderheim
Lamont
FORT SASKATCHEWAN
EDMONTON
Elk Island National Park
KEY MAP
1:600,000
Page 6 of 8
Legend
Astotin Watershed
100m Buffer
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0 100 200 400 600 800 1,000
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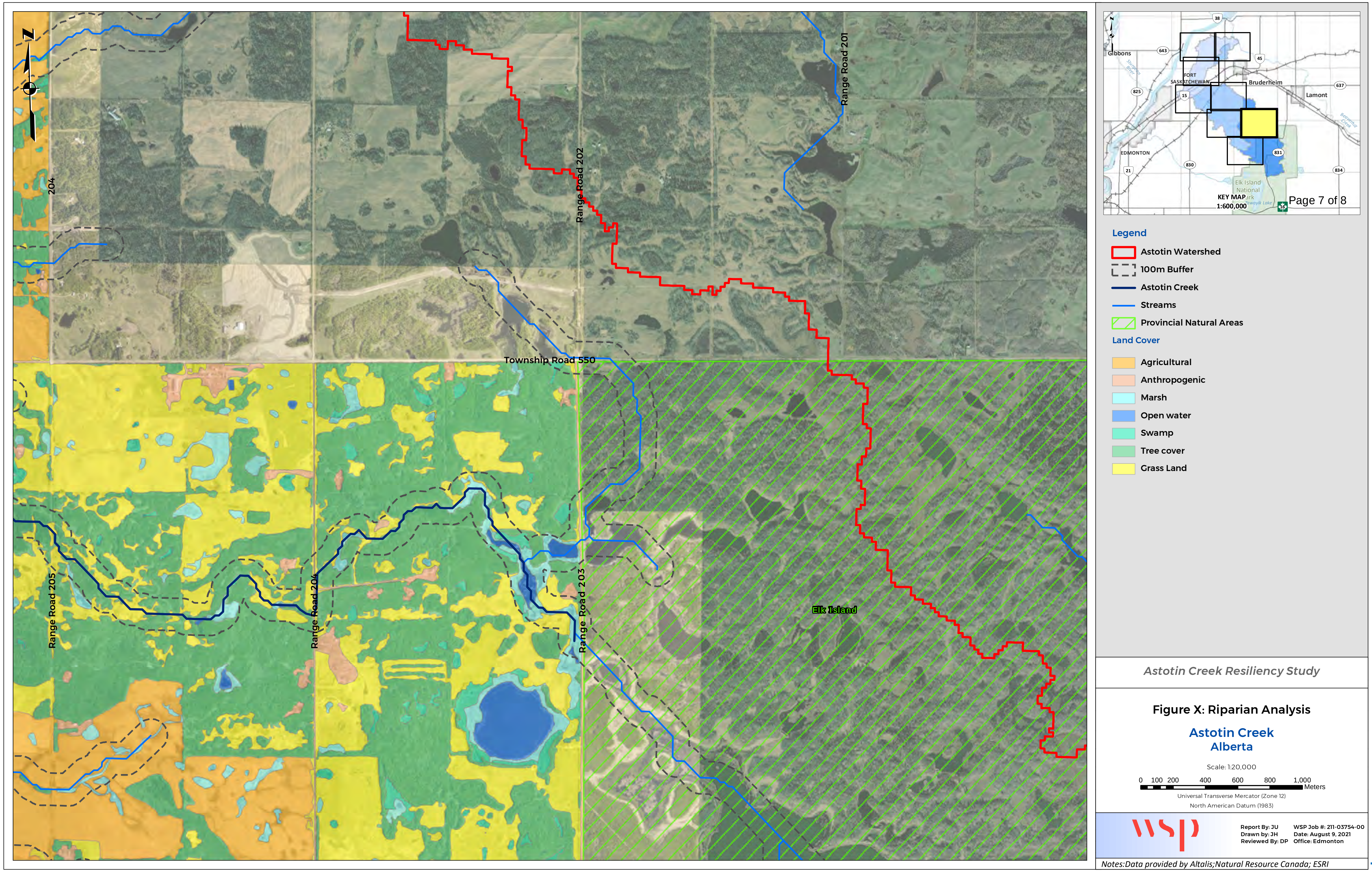
Range Road 201
Range Road 202
204
Township Road 550
Range Road 205
Range Road 204
Range Road 203
Elk Island
Page 7 of 8
KEY MAP
1:600,000
Gibbons
Bruderheim
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EDMONTON
Legend
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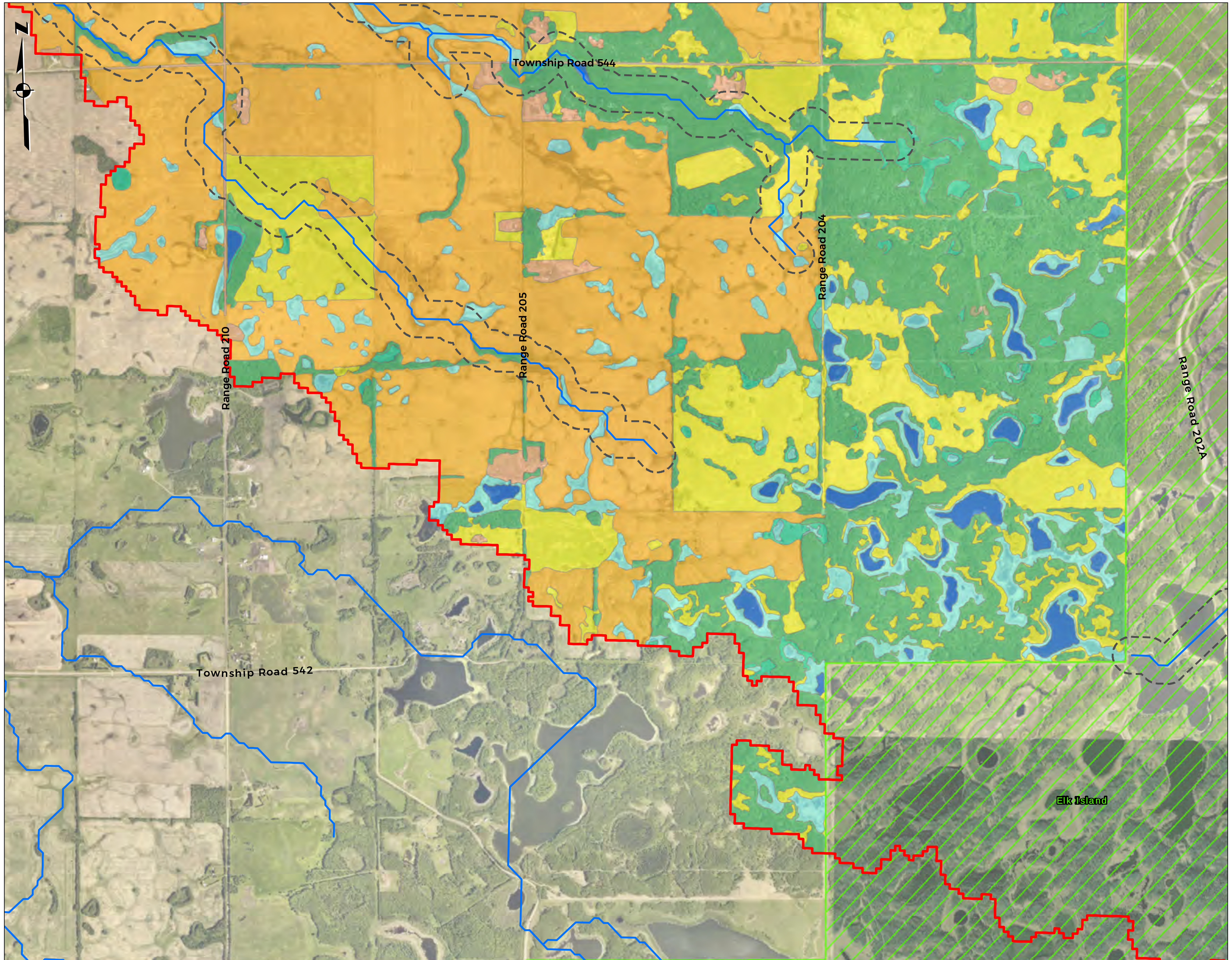
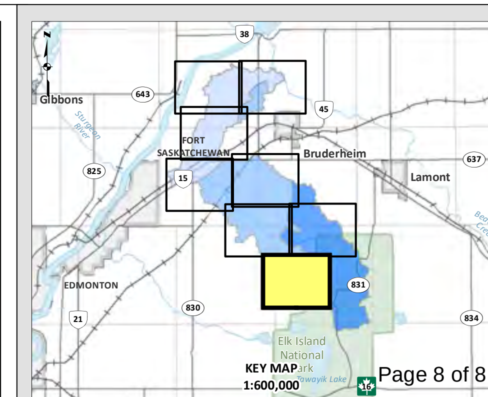
Notes:Data provided by Altalis;Natural Resource Canada; ESRI





Legend

- Astotin Watershed
- 100m Buffer
- Streams
- Provincial Natural Areas

Land Cover

- Agricultural
- Anthropogenic
- Marsh
- Open water
- Swamp
- Tree cover
- Grass Land

Astotin Creek Resiliency Study

Figure X: Riparian Analysis

Astotin Creek
Alberta

Scale: 1:20,000

0 100 200 400 600 800 1,000 Meters

Universal Transverse Mercator (Zone 12)
North American Datum (1983)

Report By: JU
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WSP Job #: 211-03754-00
Date: August 9, 2021
Office: Edmonton

Notes:Data provided by Altalis;Natural Resource Canada; ESRI

Table 1: Vegetation Species Summary

Common Name	Scientific Name	Origin	S_Rank	Track Status	7 sites UPPER TOTAL	2 sites MIDDLE TOTAL	7 sites LOWER TOTAL
agrimony	*Agrimonia striata*	Native	S4	Do not track	2	1	-
absinthe wormwood	*Artemisia absinthium*	Exotic	SNA	Do not track	1	-	-
alfalfa	*Medicago sativa*	Exotic	SNA	Do not track	1	-	-
alsike clover	*Trifolium hybridum*	Exotic	SNA	Do not track	2	-	1
American brooklime	*Veronica americana*	Native	S5	Do not track	-	1	-
American Golden Dock	*Rumex fueginus*	Native	S5	Do not track	2	-	1
annual bluegrass	*Poa annua*	Exotic	SNA	Do not track	-	-	2
aspen	*Populus tremuloides*	Native	S5	Do not track	3	1	3
awned sedge	*Carex atherodes*	Native	S5	Do not track	3	-	3
balsam poplar	*Populus balsamifera*	Native	S5	Do not track	4	1	2
basket willow	*Salix petiolaris*	Native	S5	Do not track	1	-	2
beaked hazelnut	*Corylus cornuta*	Native	S5	Do not track	3	1	3
beaked willow	*Salix bebbiana*	Native	S5	Do not track	-	-	-
Bebb's sedge	*Carex bebbii*	Native	S5	Do not track	1	-	-
biennial cinquefoil	*Potentilla rivalis*				-	1	-
bishop's-cap	*Mitella nuda*	Native	S5	Do not track	2	-	1
bluejoint	*Calamagrostis canadensis*	Native	S5	Do not track	3	-	1
blunt-leaved sandwort	*Moehringia lateriflora*	Native	S5	Do not track	1	-	-
bog violet	*Viola nephrophylla*	Native	S4	Do not track	-	-	1
bracted honeysuckle	*Lonicera involucrata*	Native	S5	Do not track	2	-	2
broad-leaved water-plantain	*Alisma triviale*	Native	S5?	Do not track	-	-	1
brook cinquefoil	*Potentilla rivalis*	Native	S4	Do not track	1	-	-
bulb-bearing water-hemlock	*Cicuta bulbifera*	Native	S4	Do not track	1	-	-
bunchberry	*Cornus canadensis*	Native	S5	Do not track	3	-	1
Canada anemone	*Anemone canadensis*	Native	S5	Do not track	2	-	2
Canada anemone	*Anemone canadensis*	Native	S5	Do not track	-	-	-
Canada buffaloberry	*Shepherdia canadensis*	Native	S5	Do not track	1	-	-
Canada thistle	*Cirsium arvense*	Exotic	SNA	Do not track	3	2	4
caraway	*Carum carvi*	Exotic	SNA	Do not track	1	-	-
celery-leaved buttercup	*Ranunculus sceleratus*	Native	S5	Do not track	2	-	1
choke cherry	*Prunus virginiana*	Native	S5	Do not track	1	-	1
cicer milk vetch	*Astragalus cicer*	Exotic	SNA	Do not track	-	-	1

Table 1: Vegetation Species Summary

clasping-leaved twisted-stalk	*Streptopus amplexifolius*	Native	S5	Do not track	1	-	-
common blueberry	*Vaccinium myrtilloides*	Native	S5	Do not track	1	-	-
common blue-eyed grass	*Sisyrinchium montanum*	Native	S5	Do not track	1	-	1
common cattail	*Typha latifolia*	Native	S5	Do not track	1	-	2
common chickweed	*Stellaria media*	Exotic	SNA	Do not track	-	-	1
common comandra	*Comandra umbellata*	Native	S5	Do not track	-	-	1
common dandelion	*Taraxacum officinale*	Exotic	SNA	Do not track	6	1	1
common fireweed	*Chamerion angustifolium*	Native	S5	Do not track	1	1	-
common goat's-beard	*Tragopogon dubius*	Exotic	SNA	Do not track	1	-	1
common horsetail	*Equisetum arvense*	Native	S5	Do not track	3	-	7
common pink wintergreen	*Pyrola asarifolia*	Native	S5	Do not track	1	-	-
common nettle	*Urtica dioica*	Native	S5	Do not track	4	-	2
common plantain	*Plantago major*	Exotic	SNA	Do not track	1	1	-
common ragweed	*Ambrosia artemisiifolia*	Native	S3	Do not track	-	1	-
common reed	*Phragmites australis*	Native	S4	Do not track	1	1	-
common tall manna grass	*Glyceria grandis*	Native	S5	Do not track	1	-	-
common yarrow	*Achillea millefolium*	Native	S5	Do not track	4	-	1
cow parsnip	*Heracleum maximum*	Native	S5	Do not track	1	1	1
cream-colored vetchling	*Lathyrus ochroleucus*	Native	S5	Do not track	1	-	-
creeping spike-rush	*Eleocharis palustris*	Native	S5	Do not track	-	1	2
crested wheatgrass	*Agropyron cristatum*	Exotic	SNA	Do not track	1	-	-
dewberry	*Rubus pubescens*	Native	S5	Do not track	3	1	2
Dewey's sedge	*Carex deweyana*	Native	S4	Do not track	2	-	-
downy brome	*Bromus tectorum*	Exotic	SNA	Do not track	1	-	-
dusky willow	*Salix melanopsis*	Native	S3	Do not track	-	-	1
early blue violet	*Viola adunca*	Native	S5	Do not track	2	-	-
false mountain willow	*Salix pseudomonticola*	Native	S4	Do not track	1	-	-
false Solomon's-seal	*Maianthemum racemosum*	Native	S5	Do not track	1	-	2
field mouse-ear chickweed	*Cerastium arvense*	Native	S5	Do not track	1	-	-
fringed brome	*Bromus ciliatus*	Native	S5	Do not track	1	-	-
flat-leaved willow	*Salix planifolia*	Native	S5	Do not track	-	-	1
fowl bluegrass	*Poa palustris*	Native	S5	Do not track	2	-	1
glaucous willowherb	*Epilobium glaberrimum*	Native	S1	Do not track	1	-	-
golden bean	*Thermopsis rhombifolia*	Native	S5	Do not track	-	-	1

Table 1: Vegetation Species Summary

green alder	*Alnus viridis*	Native	S5	Do not track	2	-	-
hair-like sedge	*Carex capillaris*	Native	S5	Do not track	1	-	-
hairy-fruited sedge	*Carex lasiocarpa*	Native	S4	Do not track	-	-	1
hairy wild rye	*Leymus innovatus*	Native	S5	Do not track	1	-	1
hard fescue	*Festuca trachyphylla*	Exotic	SNA	Do not track	-	-	1
heart-leaved buttercup	*Ranunculus cardiophyllus*	Native	S4	Do not track	-	-	1
hemp-nettle	*Galeopsis tetrahit*	Exotic	SNA	Do not track	2	1	2
hungry willow	*Salix famelica*	Native	S4	Do not track	1	-	-
Kentucky bluegrass	*Poa pratensis*	Native	S5	Do not track	6	1	2
knight's plume moss	*Ptilium crista-castrensis*	Native	S5	Do not track	1	-	-
large-leaved yellow avens	*Geum macrophyllum*	Native	S5	Do not track	2	-	1
limestone rockcress	*Boechera grahamii*	Native	S5	Do not track	1	-	-
long-leaved bluets	***Houstonia longifolia***	**Native**	**S3**	**Track all extant and selected historical EOs**	1	-	-
long-leaved chickweed	*Stellaria longifolia*	Native	S5	Do not track	4	-	-
low-bush cranberry	*Viburnum edule*	Native	S5	Do not track	2	-	-
low goldenrod	*Solidago missouriensis*	Native	S5	Do not track	-	-	1
low milkweed	*Asclepias ovalifolia*	Native	S3	Do not track	-	-	2
marsh hedge-nettle	*Stachys pilosa*	Native	S5	Do not track	-	1	2
marsh ragwort	*Tephroseris palustris*	Native	S5	Do not track	1	-	-
marsh skullcap	*Scutellaria galericulata*	Native	S5	Do not track	1	-	-
marsh willowherb	*Epilobium palustre*	Native	S4	Do not track	1	-	-
marsh yellow cress	*Rorippa palustris*	Native	S5	Do not track	3	1	-
narrow-leaf willow	*Salix exigua*	Native	S3S4	Do not track	1	-	-
narrow spinulose shield fern	*Dryopteris carthusiana*	Native	S5	Do not track	-	-	2
nodding beggarticks	*Bidens cernua*	Native	S5	Do not track	1	1	-
northern bedstraw	*Galium boreale*	Native	S5	Do not track	2	1	3
northern black currant	*Ribes hudsonianum*	Native	S5	Do not track	-	-	1
northern fairy candelabra	*Androsace septentrionalis*	Native	S5	Do not track	1	-	1
northern gooseberry	*Ribes oxyacanthoides*	Native	S5	Do not track	-	1	2
northern willowherb	*Epilobium ciliatum*	Native	S5	Do not track	3	1	1
Nuttall's rock cress	*Arabis nuttallii*	Native	S3	Do not track	1	-	-
palmate-leaved coltsfoot	*Petasites frigidus var. palmatus*	Native	S5	Do not track	1	-	2

Table 1: Vegetation Species Summary

paper birch	*Betula papyrifera*	Native	S5?	Do not track	3	-	-
pasture sagewort	*Artemisia frigida*	Native	S5	Do not track	-	-	1
perennial sow-thistle	*Sonchus arvensis*	Exotic	SNA	Do not track	1	1	1
Philadelphia fleabane	*Erigeron philadelphicus*	Native	S5	Do not track	1	2	-
plains wormwood	*Artemisia campestris*	Native	S5	Do not track	1	-	-
prairie cinquefoil	*Potentilla pensylvanica*	Native	S5	Do not track	-	-	1
prairie sagewort	*Artemisia ludoviciana*	Native	S5	Do not track	-	-	1
prickly rose	*Rosa acicularis*	Native	S5	Do not track	5	1	5
pussy willow	*Salix discolor*	Native	S5	Do not track	2	-	1
red and white baneberry	*Actaea rubra*	Native	S5	Do not track	-	-	2
red elderberry	*Sambucus racemosa*	Native	S4	Do not track	1	-	2
red-osier dogwood	*Cornus stolonifera*	Native	S5	Do not track	2	-	-
reed canary grass	*Phalaris arundinacea*	Native	S5	Do not track	2	1	-
Richardson's alumroot	*Heuchera richardsonii*	Native	S5	Do not track	-	-	1
Rocky Mountain fescue	*Festuca saximontana*	Native	S5	Do not track	1	-	1
rough cinquefoil	*Potentilla norvegica*	Native	S5	Do not track	3	1	-
Sartwell's sedge	*Carex sartwellii*	Native	S4	Do not track	-	-	1
saskatoon	*Amelanchier alnifolia*	Native	S5	Do not track	2	1	2
Schreber's moss	*Pleurozium schreberi*	Native	S5	Do not track	1	-	-
seaside buttercup	*Ranunculus cymbalaria*	Native	S5	Do not track	1	-	-
short-awned foxtail	*Alopecurus aequalis*	Native	S5	Do not track	1	1	1
showy aster	*Eurybia conspicua*	Native	S5	Do not track	1	-	-
showy fleabane	*Erigeron speciosus*	Native	S4	Do not track	-	1	-
silvery-flowered sedge	*Carex foenea*	Native	S4	Do not track	-	1	-
skunk currant	*Ribes glandulosum*	Native	S5	Do not track	1	-	1
slough grass	*Beckmannia syzigachne*	Native	S5	Do not track	-	-	1
small bedstraw	*Galium trifidum*	Native	S5	Do not track	3	-	-
small bottle sedge	*Carex utriculata*	Native	S5	Do not track	1	-	2
small-fruited bulrush	*Scirpus microcarpus*	Native	S5	Do not track	1	-	-
smooth brome	*Bromus inermis*	Exotic	SNA	Do not track	1	-	2
snakeroot	*Sanicula marilandica*	Native	S4S5	Do not track	1	-	-
snowberry	*Symphoricarpos albus*	Native	S5	Do not track	2	1	4
spotted coralroot	*Corallorhiza maculata*	Native	S4	Do not track	1	-	-
spotted touch-me-not	*Impatiens capensis*	Native	S4	Do not track	2	-	-

Table 1: Vegetation Species Summary

spreading dogbane	*Apocynum androsaemifolium*	Native	S5	Do not track	-	-	1
spreading sweet cicely	*Osmorhiza depauperata*	Native	S5	Do not track	2	-	-
spreading sweet cicely	*Osmorhiza depauperata*	Native	S5	Do not track	-	-	1
spring water-starwort	*Callitriche palustris*	Native	S5	Do not track	1	1	-
stair-step moss	*Hylocomium splendens*	Native	S5	Do not track	1	-	-
star-flowered Solomon's-seal	*Maianthemum stellatum*	Native	S5	Do not track	1	1	3
sweet-scented bedstraw	*Galium triflorum*	Native	S5	Do not track	4	1	3
tall buttercup	*Ranunculus acris*	Exotic	SNA	Do not track	-	1	-
tall lungwort	*Mertensia paniculata*	Native	S5	Do not track	1	-	2
three-flowered avens	*Geum triflorum*	Native	S5	Do not track	2	-	-
toad rush	*Juncus bufonius*	Native	S5	Do not track	-	-	1
tufted hair grass	*Deschampsia cespitosa*	Native	S5	Do not track	3	1	-
turion duckweed	*Lemna turionifera*	Native	S5	Do not track	2	-	3
veiny meadow rue	*Thalictrum venulosum*	Native	S5	Do not track	2	1	3
water arum	*Calla palustris*	Native	S4S5	Do not track	-	-	1
water parsnip	*Sium suave*	Native	S5	Do not track	1	-	-
water sedge	*Carex aquatilis*	Native	S5	Do not track	-	-	1
western Canada violet	*Viola canadensis*	Native	S5	Do not track	2	-	2
western dock	*Rumex occidentalis*	Native	S5	Do not track	1	-	-
white clover	*Trifolium repens*	Exotic	SNA	Do not track	1	-	-
white spruce	*Picea glauca*	Native	S5	Do not track	3	-	2
wild lily-of-the-valley	*Maianthemum canadense*	Native	S5	Do not track	2	1	1
wild mint	*Mentha arvensis*	Native	S5	Do not track	2	-	1
wild red raspberry	*Rubus idaeus*	Native	S5	Do not track	1	1	3
wild sarsaparilla	*Aralia nudicaulis*	Native	S5	Do not track	1	-	3
wild strawberry	*Fragaria virginiana*	Native	S5	Do not track	5	1	1
wild vetch	*Vicia americana*	Native	S5	Do not track	2	-	2
wire rush	*Juncus balticus*	Native	S5	Do not track	-	-	1
woolly sedge	*Carex pellita*	Native	S5	Do not track	-	-	1
yellow avens	*Geum aleppicum*	Native	S5	Do not track	2	-	-
yellow water crowfoot	*Ranunculus gmelinii*	Native	S5	Do not track	2	1	1
Total Observations					216	45	154
Species Richness					122	43	92

Photograph 1: Pasture, Upper Basin
RP05-P1, looking east | June 15, 2021

Photograph 2: Pasture, Lower Basin
RP11-P2, looking north | June 17, 2021

Photograph 3: Deciduous Stand, Upper Basin
RP11-P2, looking north | June 17, 2021

Photograph 4: Deciduous Stand, Middle Basin
RP06-D2, looking east | June 16, 2021

Photograph 5: Conifer Stand, Upper Basin
RP04-CF1, looking east | June 15, 2021

Photograph 6: Conifer Stand, Lower Basin*RP06-D2, looking*
RP08-CF2, looking west | June 16, 2021

Photograph 13: Long-leaved bluets
Located on an old road south of RP04-CF1 in the Lower Basin | June 16, 2021

Photograph 14: White cockle | *June 15, 2021*

Photograph 15: Tall buttercup | *June 16, 2021*

Photograph 7: Wetland, Upper Basin
RP01-W1, looking north | June 15, 2021

Photograph 8: Wetland, Lower Basin
RP12-W3, looking east | June 17, 2021

Photograph 9: Creek
RP03-C1, looking west | June 15, 2021

Photograph 10: Creek, Middle Basin
RP07-C2, looking north | June 16, 2021

Photograph 11: Long-leaved bluets
Near RP05-P1 within the old gravel pit area in the Upper Basin | June 15, 2021

Photograph 12: Long-leaved bluets
North of RP05-P1 within the old gravel pit area in the Upper Basin | June 15, 2021

APPENDIX C
WILDLIFE

C

TABLE 1

WILDLIFE SPECIES OF MANAGEMENT CONCERN WITH POTENTIAL TO OCCUR WITHIN ASTOTIN WATERSHED

Common Name	Scientific Name	Legislated Protection		Historical Presence in Watershed			Preferred Habitat
		Provincial[1]	Federal[3]	Lower	Middle	Upper	
Amphibians							
Canadian Toad	*Anaxyrus hemiophrys*	May Be at Risk	Not At Risk		X	X	Occur widely throughout Alberta along riverbeds, ponds and sandy lake shores. After breeding they can be found in grasslands, aspen parklands and boreal forests. Overwintering occurs in communal burrows (Alberta Amphibian and Reptile Conservancy, n.d.).
Western Toad	*Anaxyrus boreas*	Sensitive	Special Concern[4]			X	Require aquatic and upland habitat to complete their life cycle. They breed in variety of riparian areas and hibernate in upland habitat that contain sandy soils with sufficient detritus to provide thermal cover (COSEWIC, 2012b).
Birds							
Alder Flycatcher	*Empidonax alnorum*	Sensitive	N/A	X	X	X	Will build nests in bush or shrub, in the fork made from branches. Habitat is near wet areas, such as beside swamps, or muskegs as well as in the plants along streams. Are known to be in willow, birch, or alder patches that are also beside wet areas (Cornell University, 2021; Semenchuk, 2007).
American Bittern	*Botaurus lentiginosus*	Sensitive	N/A	X			They are found in shallow freshwater wetlands and brackish marshes with tail, dense emergent vegetation; migrants may visit ditches, wet fields and urban ponds. They breed above the waterline in a dense cattail or bulrush marsh and lay 3 to 6 eggs (Cornell University, 2021).
American Golden-Plover	*Pluvialis dominica*	Secure	N/A	X	X		Habitats consist of meadows, cultivated or short grass fields, sod farms, lake shores, and mudflats (Cornell University, 2021; Fisher and Acorn, 1998).

Common Name	Scientific Name	Legislated Protection		Historical Presence in Watershed			Preferred Habitat
		Provincial[1]	Federal[3]	Lower	Middle	Upper	
American Kestrel	*Falco sparverius*	Sensitive	N/A		X	X	American Kestrel live in open areas covered by short ground vegetation and are attracted to human-modified habitats such as pastures and parkland as well as clear-cuts and open, dry forests and often near heavily developed urban areas. They nest in a tree cavity or nest box and lay 3 to 7 eggs (Cornell University, 2021).
American White Pelican	*Pelecanus erythrorhynchos*	Sensitive	Not at Risk			X	They are found in lakes, slow-moving rivers and large, open marshes. They breed on isolated, mostly barren islands on undisturbed lakes, they lay 2 to 3 eggs (Cornell University, 2021).
Bald Eagle	*Haliaeetus leucocephalus*	Sensitive	Not at Risk	X	X	X	Nest in forested areas adjacent to large water bodies, avoiding areas of heavy disturbance if possible. However, they are tolerant of human activity while feeding and can be found fishing around dumps, reservoirs and dams (Cornell University, 2021).
Baltimore Oriole	*Icterus galbula*	Sensitive	N/A	X		X	Prefer open woodlands, forest edges and small tree patches including parks and backyards. Hanging nests are built in the upper branches of deciduous trees (Cornell University, 2021).
Barn Swallow	*Hirundo rustica*	Sensitive	Threatened, Special Concern[4]	X	X	X	Nest largely on artificial structures, including barns and other outbuildings, garages, houses, bridges and road culverts (COSEWIC, 2011).
Barred Owl	*Strix varia*	Sensitive, Species of Special Concern[2]	N/A			X	Nest in natural tree cavities or on top of broken trees. Can be found in mature mixed and coniferous woodlands, riparian areas, and swamps with trees (Cornell University, 2021; Semenchuk, 2007).
Black Tern	*Chlidonias niger*	Sensitive	Not at Risk	X	X	X	Nest on water, in emergent vegetation or on matted floating vegetation. Can be found near shallow freshwater marshes, ponds and lakes (Cornell University, 2021; Fisher and Acorn, 1998).

Common Name	Scientific Name	Legislated Protection		Historical Presence in Watershed			Preferred Habitat
		Provincial[1]	Federal[3]	Lower	Middle	Upper	
Black-backed Woodpecker	*Picoides arcticus*	Sensitive	N/A	X			Cavity nests are excavated in tree trunks or limbs. This species can be found in coniferous stands but prefer recent burns for forging (Cornell University, 2021; Fisher and Acorn, 1998).
Black-crowned Night-heron	*Nycticorax nycticorax*	Sensitive	N/A			X	Require aquatic habitat for foraging and terrestrial vegetation for cover. Nests are built away from predators in a tree or emergent vegetation (Cornell University, 2021).
Black-necked Stilt	*Himantopus mexicanus*	Sensitive	N/A	X			Nests are built on the ground, in slight depressions or scrapes near marshy lakes or ponds. Foraging habitat is found along shorelines, mudflats, and flooded fields. (Cornell University, 2021; Fisher and Acorn, 1998).
Black-throated Green Warbler	*Dendroica virens*	Sensitive	N/A	X			Primarily occupy conifer forests but are known to occupy conifer dominated mixedwoods as well. Nests are built mid canopy (1-3 m) from the ground close to the trunk (Cornell University, 2021; Semenchuk, 2007).
Broad-winged Hawk	*Buteo platypterus*	Sensitive	N/A	X			Prefer mature deciduous or mixed-deciduous forests with natural openings for foraging and nesting. Nests are built in the lower canopy, in the main tree crotch with 2 to 4 eggs (Cornell University, 2021).
Canada Warbler	*Wilsonia canadensis*	At Risk	Threatened, Special Concern[4]		X		Breed in mixedwood forest with a shrubby and mossy understory often near water. Nests are built amongst dense shrubs low to the ground or in an upturned root ball (Cornell University, 2021).
Clark's Nutcracker	*Nucifraga columbiana*	Sensitive	N/A	X			Occupy open coniferous forests from 900 to 3500 m in elevation. This species is dependent on pine forests and are often associated with whitebark or limber pine forests at higher elevations during the breeding season (Cornell University, 2021).
Common Nighthawk	*Chordeiles minor*	Sensitive	Threatened, Special Concern[4]	X		X	Open habitats devoid of vegetation such as sand dunes, beaches, logged areas, burned-over areas, forest clearings, rocky outcrops, rock barrens, prairies, peatbogs and pastures (COSEWIC, 2007a).

Common Name	Scientific Name	Legislated Protection		Historical Presence in Watershed			Preferred Habitat
		Provincial[1]	Federal[3]	Lower	Middle	Upper	
Common Yellowthroat	*Geothlypis trichas*	Sensitive	N/A	X		X	Nest in dense shrub vegetation within riparian habitats, prairies or open forests near water (Cornell University, 2021; Semenchuk, 2007).
Eastern Kingbird	*Tyrannus tyrannus*	Sensitive	N/A	X	X		Will nest both in tree cavities and on branches of trees, can be found around areas that are open such as bushes near rivers, forest edges, shelterbelts, roadsides. Willow and birch shrubs, as well as riparian areas are also common places for them to be found (Cornell University, 2021).
Eastern Phoebe	*Sayornis phoebe*	Sensitive	N/A	X	X		Will build nests in a culvert, cliffs or bridge, under ledges and build nests out of mud. Can be found near lakes, streamside, farms, roadsides, towns and forest edges and clearings (Cornell University, 2021).
Forster's Tern	*Sterna forster*	Sensitive	N/A		X		Occupy freshwater or brackish marshes, where nests are built in emergent vegetation along sheltered shorelines, islands or floating mats away from predators (Cornell University, 2021).
Grasshopper Sparrow	*Ammodramus savannarum*	Sensitive	N/A	X			Occur in grasslands, prairies, hayfields, and open pastures with little to no scrub cover and often with some bare ground (Cornell University, 2021).
Great Blue Heron	*Ardea herodias*	Sensitive	N/A			X	Nesting occurs in large breeding colonies located within 5 km of foraging sites. Colonies are located in trees or on top of large shrubs near lakes or ponds (Cornell University, 2021).
Great Gray Owl	*Strix nebulosa*	Sensitive	N/A	X		X	Prefer dense, wet conifer forests near natural edges such as meadows or bogs for hunting. Nesting occurs in abandoned hawk, eagle, or raven nests near foraging grounds (Cornell University, 2021).
Horned Grebe	*Podiceps auritus*	Sensitive	Special Concern[4]	X	X	X	Breeds in semi-permanent or permanent fresh to brackish water ponds or marshes and shallow lake bays with vegetated borders (COSEWIC, 2009).

Common Name	Scientific Name	Legislated Protection		Historical Presence in Watershed			Preferred Habitat
		Provincial[1]	Federal[3]	Lower	Middle	Upper	
Least Flycatcher	*Empidonax minimus*	Sensitive	N/A	X	X	X	Breed in semi-open deciduous and mixedwood forests along forest edges. Nests are built in a deciduous tree in the lower to middle canopy (Cornell University, 2021).
Northern Goshawk	*Accipiter gentilis*	Sensitive	Not at Risk	X		X	Northern Goshawk are found at almost any habitat from sea level to alpine and they regularly hunt in estuaries in winter. They breed in mature forests, preferably a combination of mature trees with intermediate canopy coverage and small open areas and they lay 2 to 4 eggs (Cornell University, 2021).
Olive-sided Flycatcher	*Contopus cooper*	May Be at Risk	Threatened, Special Concern[4]	X			Open areas containing tall trees or snags for perching. Open areas may be forest openings, forest edges near rivers, muskeg, bogs or swamps, or human-made openings, burned forest or semi-open mature forest (COSEWIC, 2007b).
Pied-billed Grebe	*Podilymbus podiceps*	Sensitive	N/A	X	X	X	Breed in open water and constructs a floating nest anchored for emergent vegetation. Forage on aquatic invertebrates, small fish and amphibians (Cornell University, 2021; Semenchuk, 2007).
Pileated Woodpecker	*Dryocopus pileatus*	Sensitive	N/A	X		X	Occupy mature deciduous and mixedwood forests with large dead or decaying trees. They also frequent suburban areas with large woodland patches (Cornell University, 2021).
Purple Martin	*Progne subis*	Sensitive	N/A			X	Breed in open forests foraging over open habitats such as streams, parks, open fields and towns. Nesting occurs in woodpecker cavities or more commonly communal nesting occurs in man-made boxes (Cornell University, 2021).
Rusty Blackbird	*Euphagus carolinus*	Sensitive	Special Concern[4]	X	X		Nest in coniferous-dominated forest adjacent to wetlands (such as slow-moving streams, peat bogs, sedge meadows, marshes, swamps or beaver dams) (COSEWIC, 2017)
Sandhill Crane	*Grus canadensis*	Sensitive	N/A	X			Breed in open wetland habitats with a shrub or treed riparian edge. Also occupy upland grassy sites during migration (Cornell University, 2021).

Common Name	Scientific Name	Legislated Protection		Historical Presence in Watershed			Preferred Habitat
		Provincial[1]	Federal[3]	Lower	Middle	Upper	
Sora	*Porzana carolina*	Sensitive	N/A	X	X	X	Nests are built on the ground in areas of dense riparian vegetation on mounds of vegetation or attached to plant stems, suspended above water (Cornell University, 2021, Semenchuk, 2007).
Sprague's Pipit	*Anthus spragueii*	Sensitive, Species of Special Concern[2]	N/A	X			Breed mostly in native mixed-grass prairie, usually in vegetation no more than 15-30 cm tall. Tolerate of some grazing but do no build nests in overgrazed areas (Cornell University, 2021, Semenchuk, 2007).
Trumpeter Swan	*Cygnus buccinator*	Sensitive, Species of Special Concern[2]	Not at Risk			X	Breeding occurs in shallow, undisturbed water bodies with abundant aquatic vegetation. They require large open bodies of water for landing and take-off (Cornell University, 2021).
Western Grebe	*Aechmophorus occidentalis*	At Risk, Threatened[2]	Special Concern[4]			X	Nest on stands of emergent vegetation in marshes and lakes with stable water levels, large areas of open water and sufficient prey populations (COSEWIC, 2014).
Western Wood-pewee	*Contopus sordidulus*	May Be at Risk	N/A	X	X		Nests on a horizontal tree branch, habitat is made of open mixedwood forests, dominated by deciduous trees and riparian woods (Cornell University, 2021).
White-winged Scoter	*Melanitta fusca*	Sensitive, Species of Special Concern[2]	N/A	X			They are found in estuaries, bays, inlets, large lakes and slow-moving rivers. They nest on the ground under dense vegetation, away from water and lay 6 to 14 eggs (Cornell University, 2021).
Mammals							
American Badger	*Taxidea taxus*	Sensitive	N/A	X			Primarily occupy non-forested grassland and shrubland with coherent soils for burrowing. Occasionally occur in early seral habitats along forest corridors (COSEWIC, 2012a).
Fisher	*Martes pennanti*	Sensitive	N/A	X		X	Prefer dense forested areas with hollow, logs, stumps and burrows for cover (Pattie and Fisher, 1999).

Common Name	Scientific Name	Legislated Protection		Historical Presence in Watershed			Preferred Habitat
		Provincial[1]	Federal[3]	Lower	Middle	Upper	
Little Brown Bat	*Myotis lucifugus*	May Be at Risk	Endangered[4]			X	Summer colonies can be established often in rock crevices and outcrops, and cliffs as well as large-diameter trees. Foraging occurs along waterways, forest edges and in gaps in the forest (COSEWIC, 2013). Known winter roosts include mines and caves (Pattie and Fisher, 1999).
Long-tailed Weasel	*Mustela frenata*	May Be at Risk	Not at Risk	X			Prefer open area with pockets of dense vegetation near water (Reid, 2006)
Northern Long-eared Bat	*Myotis septentrionalis*	May Be at Risk	Endangered[4]			X	Prefer northern boreal forests of Alberta. Maternity colonies can be established often in rock crevices and outcrops as well as large-diameter trees. Foraging occurs in forested areas or along forest edges. Known winter roosts include mines and caves (Pattie and Fisher, 1999).
Silver-haired Bat	*Lasionycteris noctivagans*	Sensitive	N/A			X	Roost in cavities or crevices of large diameter decaying trees during summer months, preferring deciduous stands. Roosting sites can be more varied during migration and may include buildings and bat houses (Wildlife Conservation Society Canada, 2020).

Source:

1 Alberta Wild Species General Status Listing (AEP, 2017)
2 Species Assessed by the Conservation Committee (ESRD, 2014)

3 Species at Risk Act (SARA; GOC, 2021)

4 Committee on the Status of Endangered Wildlife in Canada (COSEWIC; GOC, 2021)
Note: The primary source for provincial and federal legislation presented are the Alberta Wild Species General Status Listing1 and the Species at Risk Act3. Species may be protected under additional legislation and therefore have multiple status listings; secondary listings follow the main designation, and are indicated by the footnote.

TABLE 2

WILDLIFE SPECIES IDENTIFIED IN EACH ASSESSMENT REACH IN INATURALIST

		Site		
Scientific Name	**Common Name**	**Upper Watershed**	**Middle Watershed**	**Lower Watershed**
Amphibia				
Boreal Chorus Frog	*Pseudacris maculata*	x		
Western Tiger Salamander	*Ambystoma mavortium*	x		
Western Toad	*Anaxyrus boreas*	x		
Wood Frog	*Lithobates sylvaticus*	x		
Arachnida				
Bronze Jumping Spider	*Eris militaris*	x		
Furrow Orbweaver	*Larinioides cornutus*	x		
Goldenrod Crab Spider	*Misumena vatia*	x		
Plum Finger Gall Mite	*Eriophyes emarginatae*	x		
N/A	*Tibellus maritimus*	x		
Aves				
American Avocet	*Recurvirostra americana*	x		
American Bittern	*Botaurus lentiginosus*	x		
American Coot	*Fulica americana*	x		x
American Robin	*Turdus migratorius*	x		
American Tree Sparrow	*Spizelloides arborea*			
American White Pelican	*Pelecanus erythrorhynchos*	x	x	
American Wigeon	*Mareca americana*	x		
Bald Eagle	*Haliaeetus leucocephalus*	x		
Barrow's Goldeneye	*Bucephala islandica*	x		
Black Tern	*Chlidonias niger*	x		x
Black-backed Woodpecker	*Picoides arcticus*	x		
Black-billed Magpie	*Pica hudsonia*	x		
Black-capped Chickadee	*Poecile atricapillus*	x		
Blue-winged Teal	*Spatula discors*	x		
Bonaparte's Gull	*Chroicocephalus philadelphia*	x		
Boreal Owl	*Aegolius funereus*	x		
Brewer's Blackbird	*Euphagus cyanocephalus*	x	x	
Brown-headed Cowbird	*Molothrus ater*	x		
Bufflehead	*Bucephala albeola*	x		
Canada Goose	*Branta canadensis*	x		
Canvasback	*Aythya valisineria*	x		
Cedar Waxwing	*Bombycilla cedrorum*	x		
Cinnamon Teal	*Spatula cyanoptera*	x		
Clay-coloured Sparrow	*Spizella pallida*			x
Common Goldeneye	*Bucephala clangula*	x		
Common Loon	*Gavia immer*	x		

Common Raven	*Corvus corax*	x		
Common Redpoll	*Acanthis flammea*	x		
Common Tern	*Sterna hirundo*	x		
Dark-eyed Junco	*Junco hyemalis*	x		
Double-crested Cormorant	*Phalacrocorax auritus*	x		
Downy Woodpecker	*Dryobates pubescens*	x		
Eared Grebe	*Podiceps nigricollis*	x		
Eastern Kingbird	*Tyrannus tyrannus*	x		
Eastern Phoebe	*Sayornis phoebe*	x		
Evening Grosbeak	*Coccothraustes vespertinus*	x		
Forster's Tern	*Sterna forsteri*	x		
Franklin's Gull	*Leucophaeus pipixcan*	x		
Gadwall	*Mareca strepera*	x		
Golden Eagle	*Aquila chrysaetos*	x		
Great Blue Heron	*Ardea herodias*	x		
Great Grey Owl	*Strix nebulosa*	x		
Great Horned Owl	*Bubo virginianus*	x		
Greater Scaup	*Aythya marila*	x		
Greater Yellowlegs	*Tringa melanoleuca*	x		
Green-winged Teal	*Anas crecca*	x		
Hairy Woodpecker	*Dryobates villosus*		x	
Horned Grebe	*Podiceps auritus*	x		
Least Sandpiper	*Calidris minutilla*	x		
Lesser Scaup	*Aythya affinis*	x		
Lesser Yellowlegs	*Tringa flavipes*	x		
Mallard	*Anas platyrhynchos*	x		
Merlin	*Falco columbarius*	x		
Mourning Dove	*Zenaida macroura*		x	
Myrtle Warbler	*Setophaga coronata coronata*	x		
Northern Goshawk	*Accipiter gentilis*	x		
Northern Shoveler	*Spatula clypeata*		x	
Pied-billed Grebe	*Podilymbus podiceps*	x		
Pileated Woodpecker	*Dryocopus pileatus*	x		
Pine Grosbeak	*Pinicola enucleator*	x		
Redhead	*Aythya americana*	x		
Red-necked Grebe	*Podiceps grisegena*	x		
Red-tailed Hawk	*Buteo jamaicensis*	x	x	
Red-winged Blackbird	*Agelaius phoeniceus*	x	x	
Ring-billed Gull	*Larus delawarensis*	x		
Ring-necked Duck	*Aythya collaris*	x		
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	x		
Rough-legged Hawk	*Buteo lagopus*	x		
Ruddy Duck	*Oxyura jamaicensis*	x		x

Ruffed Grouse	*Bonasa umbellus*	x		x
Semipalmated Plover	*Charadrius semipalmatus*	x		
Slate-coloured Junco	*Junco hyemalis hyemalis*	x		
Solitary Sandpiper	*Tringa solitaria*	x		
Song Sparrow	*Melospiza melodia*	x		
Sora	*Porzana carolina*	x		
Swainson's Hawk	*Buteo swainsoni*			x
Tennessee Warbler	*Leiothlypis peregrina*	x		
Tree Swallow	*Tachycineta bicolor*	x		
Trumpeter Swan	*Cygnus buccinator*	x		
Turkey Vulture	*Cathartes aura*	x		
Virginia Rail	*Rallus limicola*	x		
Western Tanager	*Piranga ludoviciana*	x		
White-throated Sparrow	*Zonotrichia albicollis*	x		
Willet	*Tringa semipalmata*	x		
Wilson's Snipe	*Gallinago delicata*		x	
Yellow Warbler	*Setophaga petechia*	x		
Yellow-bellied Sapsucker	*Sphyrapicus varius*	x		
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*			x
Yellow-rumped Warbler	*Setophaga coronata*	x		
Insecta				
13-spotted Lady Beetle	*Hippodamia tredecimpunctata*	x		
Adroit Tiger Beetle	*Cicindela lengi versuta*			x
American Emerald	*Cordulia shurtleffii*	x		
Arctic Skipper	*Carterocephalus palaemon*	x		
Bald-faced Hornet	*Dolichovespula maculata*	x		
Bedstraw Hawkmoth	*Hyles gallii*	x		
Black Meadowhawk	*Sympetrum danae*	x		
Black-spotted Falsehorn	*Temnostoma excentrica*	x		
Bold-feathered Grass Moth	*Herpetogramma pertextalis*	x		
Boreal Long-lipped Tiger Beetle	*Cicindela longilabris*			x
Cabbage White	*Pieris rapae*	x		
Canadian Tiger Swallowtail	*Papilio canadensis*	x		
Cherry-faced Meadowhawk	*Sympetrum internum*	x		
Clouded Sulphur	*Colias philodice*	x		
Cold-country Caterpillar Hunter	*Calosoma frigidum*	x		
Common Aerial Yellowjacket	*Dolichovespula arenaria*			x
Coreopsis Beetle	*Calligrapha californica*	x		
Currant Eulithis Moth	*Eulithis propulsata*	x		
Dark Marbled Carpet	*Dysstroma citrata*	x		
Dot-tailed Whiteface	*Leucorrhinia intacta*	x		
Dreamy Duskywing	*Erynnis icelus*	x		

Early Aspen Leafroller Moth	*Pseudexentera oregonana*	x		
Elegant Prominent	*Pheosidea elegans*	x		
Emerald Spreadwing	*Lestes dryas*	x		
European Skipper	*Thymelicus lineola*	x		
Flame-shouldered Dart	*Ochropleura implecta*	x		
Forest Tent Caterpillar Moth	*Malacosoma disstria*	x		
Four-spotted Gluphisia Moth	*Gluphisia avimacula*	x		
Four-spotted Skimmer	*Libellula quadrimaculata*	x		
Glover's Silk Moth	*Hyalophora gloveri*	x		
gold-and-brown rove beetle	*Ontholestes cingulatus*	x		
Goldenrod Gall Fly	*Eurosta solidaginis*	x		
Great Spangled Fritillary	*Speyeria cybele*	x		
Green Comma	*Polygonia faunus*	x		
Green Immigrant Leaf Weevil	*Polydrusus formosus*	x		
Greenish Blue	*Icaricia saepiolus*	x		
Grey Comma	*Polygonia progne*	x		
Grizzled Tussock Moth	*Dasychira grisefacta*	x		
Half-black Bumble Bee	*Bombus vagans*	x		
Hobomok Skipper	*Lon hobomok*	x		
Hummingbird Clearwing	*Hemaris thysbe*	x		
Lake Darner	*Aeshna eremita*	x		
Lance-tipped Darner	*Aeshna constricta*	x		
Langton's Forester	*Alypia langtoni*	x		
Larder Beetle	*Dermestes lardarius*	x		
Large Lace-border Moth	*Scopula limboundata*	x		
Large Marble	*Euchloe ausonides*	x		
Large Ruby Tiger Moth	*Phragmatobia assimilans*	x		
Large Snout	*Hypena edictalis*	x		
Lesser Black-letter Dart	*Xestia c-nigrum*	x		
Margined Calligrapher	*Toxomerus marginatus*	x		
Margined Carrion Beetle	*Oiceoptoma noveboracense*	x		
Meadow Flies	*Chrysotoxum*	x		
Milbert's Tortoiseshell	*Aglais milberti*	x		x
Mourning Cloak	*Nymphalis antiopa*	x		
Mustard White	*Pieris oleracea*	x		
Narrow-banded Pond Fly	*Sericomyia militaris*	x		
Narrow-headed Marsh Fly	*Helophilus fasciatus*	x		
Nevada Bumble Bee	*Bombus nevadensis*	x		
Northern Cloudywing	*Thorybes pylades*	x		
Northern Crescent	*Phyciodes cocyta*	x		
Northern Pearly-eye	*Lethe anthedon*	x		
Northwestern Phoenix Moth	*Eulithis xylina*	x		
Omnivorous Leafroller	*Archips purpurana*	x		

One-eyed Sphinx	*Smerinthus cerisyi*	x		
Orange-spined Drone Fly	*Eristalis nemorum*	x		
Orange-spotted Drone Fly	*Eristalis anthophorina*	x		
Painted Lady	*Vanessa cardui*	x		
Pale Beauty	*Campaea perlata*	x		
Pale Glyph	*Protodeltote albidula*	x		
Pine Measuringworm Moth	*Hypagyrtis piniata*	x		
Pink-edged Sulphur	*Colias interior*	x		
Plain Plume Moth	*Hellinsia homodactylus*	x		
Police Car Moth	*Gnophaela vermiculata*	x	x	
Poplar Borer	*Saperda calcarata*	x		
Propelling Click Beetle	*Pseudanostirus propolus*	x		
Red Admiral	*Vanessa atalanta*	x		
Red Flat Bark Beetle	*Cucujus clavipes*	x		
Red-cross Shield Bug	*Elasmostethus cruciatus*	x		
Red-disked Alpine	*Erebia discoidalis*	x		
Red-spotted Admiral	*Limenitis arthemis*	x		
Rose Hooktip	*Oreta rosea*	x		
Round-necked Longhorn Beetle	*Clytus ruricola*	x		
Satyr Comma	*Polygonia satyrus*	x		
Say's Burying Beetle	*Nicrophorus sayi*	x		
Sedge Sprite	*Nehalennia irene*	x		
Seven-spotted Lady Beetle	*Coccinella septempunctata*	x		
Sharp-lined Yellow	*Sicya macularia*	x		
Sigmoid Prominent	*Clostera albosigma*	x		
Silvery Blue	*Glaucopsyche lygdamus*	x		
Slender Meadow Katydid	*Conocephalus fasciatus*			
Snowberry Clearwing	*Hemaris diffinis*	x		
Soothsayer Dart	*Graphiphora augur*	x		
Speckled Green Fruitworm Moth	*Orthosia hibisci*	x		
Spiny Leaf Gall Wasp	*Diplolepis polita*	x	x	
Spotted Grass Moth	*Rivula propinqualis*	x		
Spotted Tussock Moth	*Lophocampa maculata*	x		
Square-patched Carpet Moth	*Perizoma basaliata*	x		
St. Lawrence Tiger Moth	*Arctia parthenos*	x		
Taiga Bluet	*Coenagrion resolutum*	x		
Toothed Somberwing	*Euclidia cuspidea*	x		
Tufted Apple Bud Moth	*Platynota idaeusalis*	x		
Twelve-spotted Tiger Beetle	*Cicindela duodecimguttata*	x		
Twin-spotted Sphinx	*Smerinthus jamaicensis*	x		
Two-striped Grasshopper	*Melanoplus bivittatus*	x		
Variable Darner	*Aeshna interrupta*	x		

Variegated Meadowhawk	*Sympetrum corruptum*	x		
Virginia Ctenucha Moth	*Ctenucha virginica*	x	x	
Virginian Tiger Moth	*Spilosoma virginica*			x
Western White	*Pontia occidentalis*			x
Western White Admiral	*Limenitis arthemis rubrofasciata*	x		
White Triangle Tortrix	*Clepsis persicana*	x		
White-spotted Pond Fly	*Sericomyia lata*	x		
White-spotted Sawyer Beetle	*Monochamus scutellatus*	x		
Woolly-tailed Marsh Fly	*Helophilus hybridus*	x		
Yellow-dusted Cream Moth	*Cabera erythemaria*	x		
Mammalia				
American Bison	*Bison bison*	x	x	
American Black Bear	*Ursus americanus*	x		
American Red Squirrel	*Tamiasciurus hudsonicus*	x		
Canadian Beaver	*Castor canadensis*	x	x	
Coyote	*Canis latrans*	x		
Deer Mouse	*Peromyscus maniculatus*	x		
Moose	*Alces alces*	x		x
Mule Deer	*Odocoileus hemionus*	x		
Muskrat	*Ondatra zibethicus*	x	x	
Northern Flying Squirrel	*Glaucomys sabrinus*	x		
Plains Bison	*Bison bison bison*	x	x	
Rocky Mountain Mule Deer	*Odocoileus hemionus hemionus*	x		
Short-tailed Weasel	*Mustela erminea*	x		
Snowshoe Hare	*Lepus americanus*	x		
Striped Skunk	*Mephitis mephitis*	x		
Wapiti	*Cervus canadensis*	x		
White-tailed Deer	*Odocoileus virginianus*	x		
Species Richness		217	15	14

TABLE 3

NUMBER OF SPECIES OBSERVATIONS DURING FIELD SURVEYS

Common Name	Scientific Name	Upper Watershed	Middle Watershed	Lower Watershed	Total
Amphibians					
Boreal Chorus Frog*	*Pseudacris maculata*	11	5	2	**18**
Wood Frog*	*Lithobates sylvatica*	8	1		**9**
Birds					
Alder Flycatcher	*Empidonax alnorum*			1	**1**
American Coot	*Fulica americana*	3		111	**114**
American Crow	*Corvus brachyrhynchos*		2		**2**
American Kestrel	*Falco sparverius*		1		**1**
American Redstart	*Setophaga ruticilla*		1		**1**
American Robin	*Turdus migratorius*	7	2	1	**10**
American Wigeon	*Anas americana*		1	1	**2**
Baltimore Oriole	*Icterus galbula*		2		**2**
Black Tern	*Chlidonias niger*			2	**2**
Black-And-White Warbler	*Mniotilta varia*			1	**1**
Black-Capped Chickadee	*Poecile atricapillus*	1	1		**2**
Blue Jay	*Cyanocitta cristata*	4			**4**
Blue-Winged Teal	*Anas discors*	5	8	51	**64**
Brown-headed Cowbird	*Molothrus ater*			1	**1**
Canada Goose	*Branta canadensis*	2	1		**3**
Cedar Waxwing	*Bombycilla cedrorum*			1	**1**
Chipping Sparrow	*Spizella passerina*	2			**2**
Clay-Colored Sparrow	*Spizella pallida*	4	6	6	**16**
Common Raven	*Corvus corax*	1			**1**
Common Yellowthroat	*Geothlypis trichas*	1		2	**3**
Dark-Eyed Junco	*Junco hyemalis*	2	1		**3**
Eastern Kingbird	*Tyrannus tyrannus*		2	1	**3**
Eastern Phoebe	*Sayornis phoebe*			1	**1**

Franklin's Gull	*Leucophaeus pipixcan*		1		**1**
Gadwall	*Anas strepera*			2	**2**
Great Blue Heron	*Ardea herodias*	5	14	1	**20**
Green-winged Teal	*Anas crecca*	5	6	3	**14**
House Wren	*Troglodytes aedon*	1	3		**4**
Least Flycatcher	*Empidonax minimus*	1	5	2	**8**
Lesser Scaup	*Aythya affinis*	2			**2**
Mallard	*Anas platyrhynchos*	6	38	23	**67**
Northern Shoveler	*Anas clypeata*			5	**5**
Northern Waterthrush	*Seiurus noveboracensis*	1		2	**3**
Olive-sided Flycatcher	*Contopus cooperi*		1		**1**
Red-Breasted Nuthatch	*Sitta canadensis*	2			**2**
Red-Eyed Vireo	*Vireo olivaceus*			4	**4**
Redhead	*Aythya americana*	3			**3**
Red-necked Grebe	*Podiceps grisegena*			1	**1**
Red-tailed Hawk	*Buteo jamaicensis*	1	2	4	**7**
Red-winged Blackbird	*Agelaius phoeniceus*	3	1	14	**18**
Ruddy Duck	*Oxyura jamaicensis*			8	**8**
Savannah Sparrow	*Passerculus sandwichensis*	1		4	**5**
Sharp-shinned Hawk	*Accipiter striatus*	2			**2**
Song Sparrow	*Melospiza melodia*		3	2	**5**
Sora	*Porzana carolina*	1		19	**20**
Tree Swallow	*Tachycineta bicolor*	3	2		**5**
Tern Spp.	-			1	**1**
Turkey Vulture	*Cathartes aura*	1			**1**
Western Tanager	*Piranga ludoviciana*	1	1		**2**
White-Throated Sparrow	*Zonotrichia albicollis*	2	1	1	**4**
Wilson's Snipe	*Gallinago delicata*	1		1	**2**
Wood Duck	*Aix sponsa*		2		**2**
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*			1	**1**
Yellow Warbler	*Dendroica petechia*	3	8	1	**12**
Mammals					
American Black Bear	*Ursus americanus*	4			**4**

American Red Squirrel	*Tamiasciurus hudsonicus*	2			**2**
Beaver	*Castor canadensis*	11	15	4	**30**
Coyote	*Canis latrans*	1	1	2	**4**
Deer	*Odocoileus spp.*		1	3	**4**
Long-tailed Weasel	*Mustela frenata*			1	**1**
Moose	*Alces alces*	2	5	1	**8**
Mule Deer	*Odocoileus hemionus*		2		**2**
Muskrat	*Ondatra zibethicus*	1	6	5	**12**
Northern Pocket Gopher	*Thomomys talpoides*			1	**1**
Western Jumping Mouse	*Zapus princeps*		1	3	**4**
White-tailed Deer	*Odocoileus virginianus*	1	1	9	**11**

Note:

‘-‘ indicates no species identified.

Number of amphibians indicate distinct groups detected at any time or location; each group represents an estimate of >5 individuals.

Data are summarized from amphibian, breeding bird and wildlife camera surveys, as well as incidental observations.

Using eDNA to Detect Select Semi-aquatic Mammals Along Astotin Creek

Brian Eaton, Susan Koziel, and Jim Davies

Final Report

For
Dr. Dee Patriquin
Sr. Environmental and Regulatory Planner
WSP
Edmonton AB

February 16, 2022

Table of Contents

List of Tables

List of Figures

Executive Summary

Environmental DNA (eDNA) is an innovative approach to the monitoring of biota, and is especially useful in the detection of rare and elusive species that are difficult to monitor using traditional methods. In this project, we used eDNA methods to sample three different reaches of Astotin Creek, Alberta, for four species of semi-aquatic mammals (American Mink (*Neovison vison*), River Otter (*Lontra canadensis*), Water Shrew (*Sorex palustris*), and Northern Bog Lemming (*Synaptomys borealis*)) as part of a watershed resiliency study.

Of the three sites from which we obtained environmental (water) samples, we detected the DNA from American Mink and American Water Shrew at all 3 sites, the Northern Bog Lemming at 2 sites, and the River Otter at none. The results from the eDNA analysis can be compared to data collected using other sampling approaches (e.g. wildlife cameras) to provide field validation of the method.

Introduction

Collecting environmental samples and using molecular techniques to attribute DNA fragments in those samples to specific taxa is a powerful tool for detecting species. This environmental DNA (eDNA) approach has shown great promise as a monitoring and sampling technique in terms of sensitivity (important for the detection of rare and elusive species (Jerde et al. 2011)), cost-effectiveness (Dejean et al. 2012; Davy et al. 2015), and in creating archives of DNA that can be analyzed with new primers or techniques on a *post hoc* basis (Dysthe et al. 2018).

Detection of rare and elusive species is one of the most common applications of eDNA techniques, especially in situations where traditional sampling methods are costly and/or difficult. Semi-aquatic mammals can be challenging to detect, as many are elusive and/or occur at low density. Collection and molecular analysis of water samples from streams is a potentially cost-effective approach to monitoring the occurrence of these species along a watercourse.

In this project we used TaqMan primer sets for the detection of four species of semi-aquatic mammals known to occur in the Beaver Hills region of Alberta to determine their presence along Astotin Creek at three points between Elk Island National Park and the North Saskatchewan River. Target species included: American Mink (*Neovison vison*), River Otter (*Lontra canadensis*), Water Shrew (*Sorex palustris*), and Northern Bog Lemming (*Synaptomys borealis*). This project was in support of a larger Astotin Creek watershed resiliency assessment that WSP, under the lead of Dr. D. Patriquin, was performing for Strathcona County.

Study Area

The objective of this project was to use eDNA techniques to sample three separate reaches of Astotin Creek between Elk Island National Park and the North Saskatchewan River (Figure 1) for the four target species. For each reach, eDNA samples were collected near a wildlife camera that had been installed by WPS along the creek. One eDNA sample (designated as the “Mid” sample) was collected close to the camera site, a second was collected approximately 50 m upstream from this point (designated “Up”), and the third was collected 50 m downstream from the camera site (designated “Down”) (Figure 2). The GPS points for each sampling location are provided in Table 1.

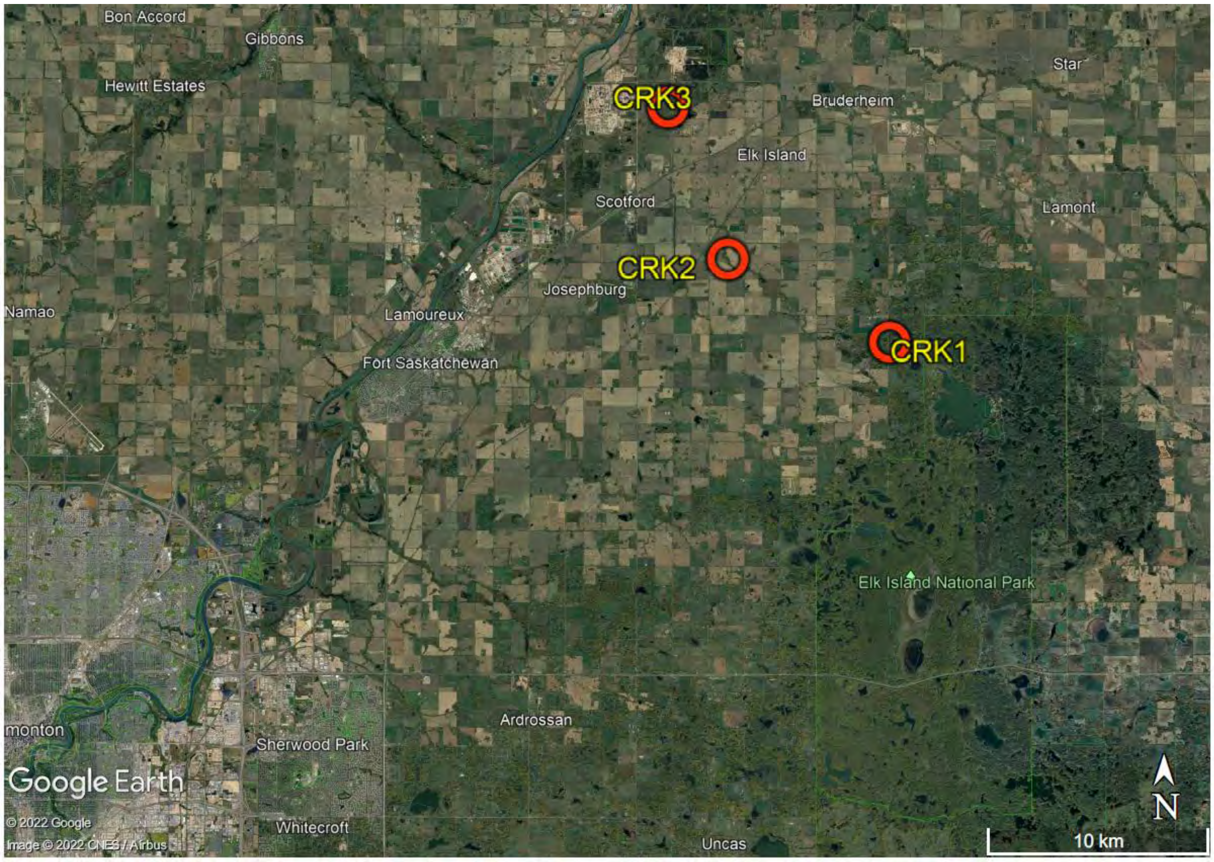

Figure 1. Overview map of the study area. CRK1 is just west of Elk Island National Park, where Astotin Creek originates in Astotin Lake. CRK3 is near the downstream end of the creek, as it approaches the North Saskatchewan River.

Figure 2. Example of distribution of sampling locations at a study site. Locations (yellow circles) are approximately 50 m apart along the stream. Note the location of the wildlife camera near the middle sampling location.

Table 1. Location for each eDNA sample collection point.

Sample location	Coordinates
CRK1-Down	53.70472,-112.90097
CRK1-Mid	53.70493,-112.9007
CRK1-Up	53.70471,-112.90028
CRK2-Down	53.73902,-113.01175
CRK2-Mid	53.73872,-113.01186
CRK2-Up	53.73859,-113.01218
CRK3-Down	53.80071,-113.0527
CRK3-Mid	53.80043,-113.05312
CRK3-Up	53.80018,-113.05309

Methods

Target Species. The species of interest for this study included River Otter (*Lontra canadensis),* American Mink (*Neovison vison*), Water Shrew (*Sorex palustris*), and Northern Bog Lemming (*Synaptomys borealis*). Because these species are elusive and/or typically occur at low local abundance, they can be a challenge to monitor using traditional sampling methods.

Sample Collection System. Environmental water samples were collected in the field using a peristaltic pump (Eijkelkamp Soil & Water, Giesbeek, the Netherlands, item #M-1223E) driven by a cordless drill which forced water through a set of filters that captured eDNA for subsequent analysis (Figure 3). Filters were contained in a housing (Sartorius, Gottingen, Germany item# 16508B), and included a 0.45 µm mixed cellulose ester membrane (Pall, Port Washington, USA Item# 64191) sandwiched between two 5 µm PTFE membranes (Tisch Scientific, North Bend, Ohio, USA item# SF14687). The first 5 µm membrane served as a pre-filter – removing larger material from the water stream, while the second provided physical support to the 0.45 µm membrane, which could perforate under the pressures generated by the peristaltic pump if left unsupported. Only the 0.45 µm membrane was used as a source of eDNA for analysis.

The 5 um membranes were autoclaved after installation in the filter housings (121°C for 15 minutes) to minimize the chance of contamination by ambient eDNA. Pre-sterilized 0.45 µm membranes were then aseptically inserted between the 5 µm membranes, thereby avoiding thermal damage to the relatively delicate 0.45 µm membrane. A 3 m length of soft silicone tubing (McMaster Carr, Aurora, Ohio, USA item # 5041K744) was attached to each filter housing. The assembled apparatus was placed inside a Ziploc® bag, which was not opened again until just prior to sample collection.

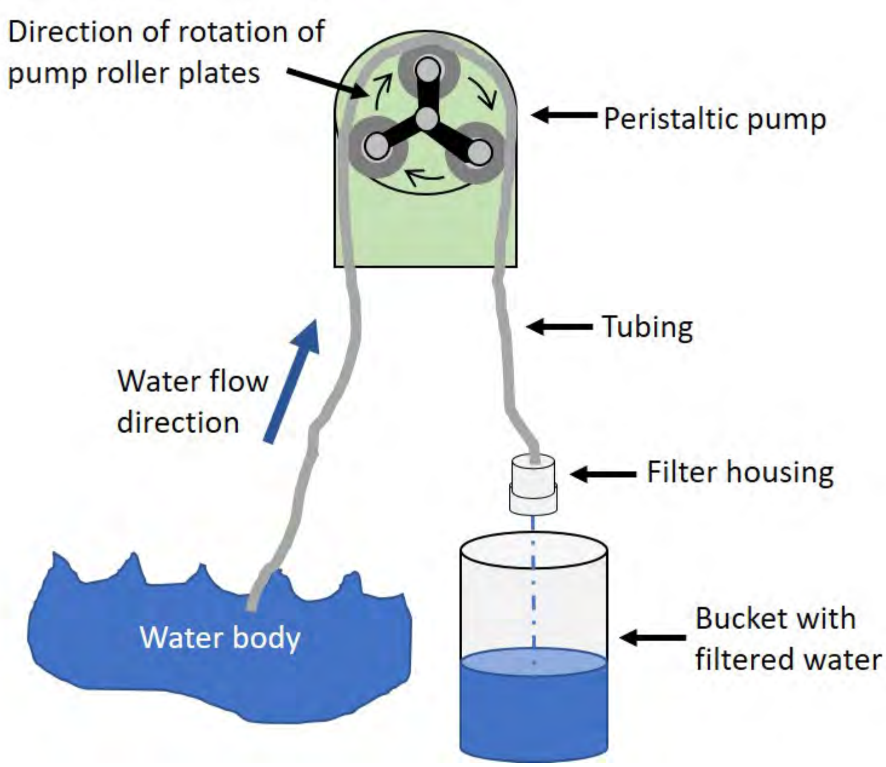

Figure 3. Schematic diagram of system used to collect environmental water samples. Note that the pump is driven by a cordless drill (not visible in diagram).

Sample Collection. InnoTech accompanied personnel from WSP to collect environmental samples for eDNA analysis on June 18, 2021 . Each environmental sample was collected by attaching the inflow end of the tubing to an extendable fiberglass pole using a laboratory clamp (Figure 4). The tubing was then threaded through the peristaltic pump which was attached to a stainless-steel rod which had been driven into the bank (Figure 5). Once the inflow end was submerged in water, a drill connected to the pump was run continuously until the target volume of water had been collected in a bucket. The target volume of water was 5 L for each sample; however, because of filter clogging issues, this was rarely achieved, and the mean volume collected varied from 2.5 to 5 L per sampling location (mean = 3.5 L; Table 2). During sampling, when the amount of water flowing through the filter was greatly reduced, the filter assembly was replaced with a new one; 2 to 4 filters (mean = 3) filters were used at each of the sampling locations (Table 2).

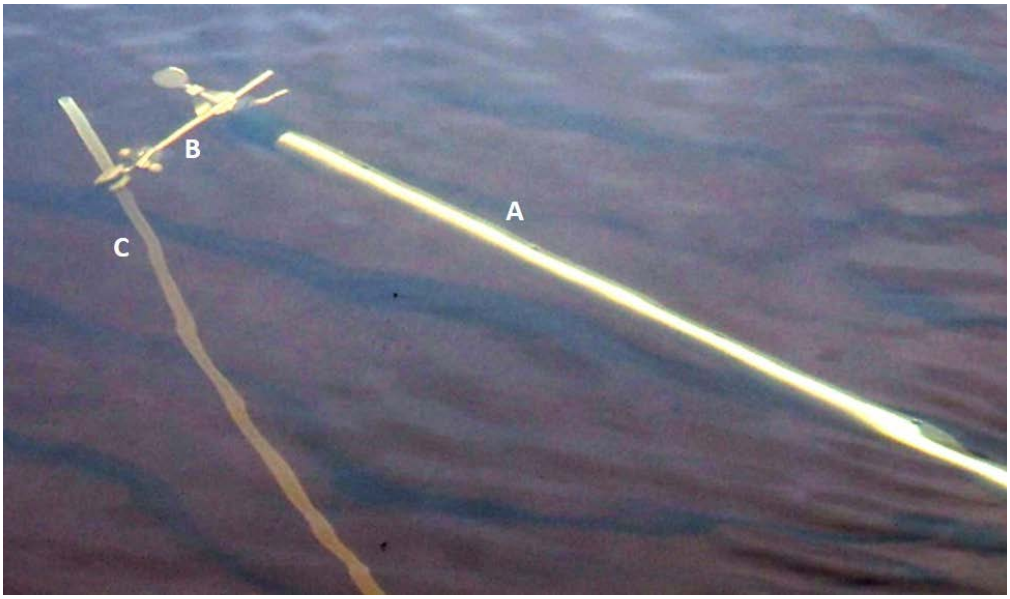

Figure 4. Tubing attached to extendable pole using a laboratory clamp.
Key: A. Extendable pole, B. Laboratory clamp, C. Intake tubing for sampling assembly.
Photograph taken during sampling – all structures are underwater.

Figure 5. Cordless drill powering peristaltic pump.
The silicone tubing (orange in colour) is visible within the housing of the pump, and the filtration assembly hangs at the right side of the mounting rod.

Table 2. Number of filters used, and volume of water filtered, at each sampling location.

Sample location	Number of filters used	Total volume of water filtered (L)
CRK1-Down	3	3
CRK1-Mid	4	3
CRK1-Up	2	2.5
CRK2-Down	3	3.25
CRK2-Mid	3	3
CRK2-Up	3	3
CRK3-Down	3	4
CRK3-Mid	2	5
CRK3-Up	4	4.5

Once filtration was complete, the tubing was removed from the water while the drill continued to run, purging most of the water from the filter housing; this facilitated sample preservation. The tubing was then removed from the pump rotor and the filtration assembly coiled and returned to its original Ziploc® storage bag. The bucket's contents were dumped away from the stream and its interior sprayed with 10% bleach; the end of the extendable pole and the laboratory clamp were also sprayed with the bleach solution.

If the flow rate of water through the filtration system became significantly reduced during sampling - indicating substantial clogging of the filters - the filter assembly was swapped out for a new one by removing the current assembly at the Luer lock and replacing it with a new one. Multiple filters were required at every site sampled along Astotin Creek (Table 2).

During sampling, care was taken to avoid contact between either end of the filtration assembly and sediment/soil at the site, as such contact may be a source of contamination (Dejean et al. 2011; Thomsen et al. 2012; Thomsen and Willerslev 2015). Typically, field personnel are instructed not to step into the water before taking a sample, to avoid suspending sediment in the water column, or contaminate the sample with DNA from other sites. This was the practice followed at the CRK1 and CRK2 sites. At CRK3, however, Astotin Creek ran into an expansive marsh with shallow flooded margins and lacked a clear channel, making it necessary to wade into the water for a short distance to access appropriate sampling points (e.g., not too shallow, open, etc.). This was accomplished by walking slowly, observing the extent of any sediment plume that was created (if any), and extending the sampling pole to its maximum length to ensure we were drawing our sample from well away from where we were standing. This was important because DNA fragments can adhere to sediment and may remain largely intact for a longer period when buried in the sediment than when suspended in the water column (Turner et al. 2015; Weltz et al. 2017; Harper et al. 2019). Therefore, pulling sediment into our samples could have introduced DNA that had been deposited some time prior to this study, potentially falsely indicating the recent presence of the target species.

Field Blanks. In addition to environmental samples, field blanks (5 L of bottle water) were collected at the beginning of the sampling day, as well as after each sampling session at each site, for a total of 4 blanks over the course of the day.

Sample Preservation. Samples (i.e., the material captured by 0.45 um filter membranes) were preserved by desiccation (Carim et al. 2016, McKelvey et al. 2016, Sepulveda et al. 2019). After a sample was collected, filter assemblies were returned to the lab, and the inflow and outflow hose barbs were disconnected from the filter housing. Then the two halves of the housing were partially unscrewed, and the housing was placed inside a Ziploc® bag containing 67.5 g of silica gel desiccant (Sigma-Aldrich, St. Louis, USA item# 13767-2.5KG-R). Once sealed within the desiccant bag, the housing was jostled about until a number of desiccant beads were lodged in the dead space between the walls of the housing and the membrane support platforms (Figure 6). This was done to eliminate excess moisture in the sample housing while minimizing the potential for sample contamination (e.g., by contact between the filter membranes and the exterior of the filter housing). The housings remained untouched within the desiccant bags until they were processed for DNA extraction at InnoTech Alberta's laboratory.

Figure 6. Filter housing in desiccant bag.
Note that beads are present within the housing but cannot contact the filters themselves.

Extraction of Creek Water Filters. Total DNA was extracted from 0.45 µm filters using a Qiagen DNeasy PowerWater Kit (Cat# 14900-100-NF). The protocol was modified to use a Spex 2010 Geno/Grinder (www.spexsampleprep.com/2010genogrinder) during the lysis step where filters were placed in the bead tubes and shaken with grinding beads for 2.5 minutes at 1500 rpm with 2 mL of lysis buffer.

All filters were extracted separately (each filter is considered a biological replicate). For each biological replicate, three technical replicates were done, resulting in a minimum of nine reactions per study site (there could be more than nine for cases where more than three filters were used per site). Note that biological replicates are performed to incorporate both method reproducibility and inter-method variability into eDNA surveys (Delmont et al. 2012). In cases where mutiple filters were used at a sampling location because of clogging, each filter was extracted and analyzed independently to minimize potential carry-over of inhibitory factors that might be present in the debris and/or sediment that caused the clogging.

Extracted eDNA samples were stored at -80C until they were quantified on a Nanodrop OneC (Thermofisher catalog #ND-ONEC-W) and normalized to 1 ng/µL. Four of the 31 sample filters had a DNA concentration less than 4 ng/µL and an A260 nm/A230 nm absorbance ratio (a measure of DNA purity) of below 1.0, indicating a high chance of PCR inhibition. Therefore, unnormallized TaqMan reactions containing 2 µL of undiluted sample were tested.

Analysis of Creek Water Filters. An initial universal COI2 primer set Sybr assay, which amplifies DNA from all vertebrates and some invertebrates, was used with the extracted sample to assess if the DNA collected in the field was amplifiable, and to determine if there was any carryover of inhibitors from the initial sample. Therefore, following the extraction step, 2 µL of each sample was used in a qrtPCR reaction, along with BioRad iTaq™ Universal SYBR® Green Supermix (BioRad, Hercules, California, Catalog # 1725125) containing 500 nM of each univesal primer, in a 10 µL Sybr reaction.

If a sample passed the initial amplification test, species-specific assays (Table 3) were performed using 2 µL of creek water eDNA, 1 mM of species-specific primer set, and 250 nM labelled probe in a 10 µL TaqMan reaction along with BioRad iTaq™ Universal probes Supermix (BioRad, Hercules, California, Catalog # 1725132). This was repeated for each of the four target species.

Table 3. Details related to primer sets used for each of the target species.

Species	Primer set name	Sequences	Annealing temp. (°C)	Sensitivity	Cross-reactivity
Northern Bog Lemming	Sbor1	Forward – AGACACAACAACAGCATT Reverse – ATAAGCAGATGAAGAATATGGA Probe – [6FAM] AACTATGGCTGATTAATCCGATATATACA [BHQ1]	61	1/10,000,000	None
Mink	Nvis1	Forward – TAGACAAAGCCACCTTAA Reverse – GTTTCATGGAGGAATAATAG Probe – [6FAM] TCCTGCCATTCGTCATCTC [BHQ1]	61	1/10,000,000	None
River Otter	Lcan2	Forward – AGAATGAATCTGAGGAGGGT Reverse – GGGTGGAAGGGGATTTTG Probe – [6-FAM] ATGAAGGAATAGGAGGTG [BHQ-1]	58	1/1,000,000	None
Water Shrew*	Spal3	Forward – GTAGAATGAATCTGAGGK Reverse – GTGTAATAGGGGTGAAAG Probe – [6FAM] AACCCCCTYAACACACCMCC [BHQ1]	58	1/100,000	May detect otter at very high CT (Cycle Threshold) values (44+ cycles)

* This primer set exhibited relatively low sensitivity and would benefit from additional validation; results from use of this primer set should be interpreted with caution at this time.

Analysis of Molecular Data. eDNA samples were first scored on their ability to produce a PCR product using a universal COI primer set. Samples unable to produce such a product were removed from the dataset on the presumption that no amplification was possible – either because of inadequate levels of DNA, DNA that was too degraded to serve as a viable PCR template, or excessive PCR inhibition. Samples which did not produce a PCR product using the universal primer set were classified as "Failed amplification of universal primer".

Samples that passed the universal primer tests were analyzed using all four species-specific primers. For each creek sample and species-specific primer set, the amount of DNA amplified (ng/uL) per reaction was calculated using a standard curve developed using DNA extracted from tissue samples to determine the amount of species-specific PCR product in each sample. The blanks, as well as the nonspecific controls, were observed and the maximum amount of PCR product from these reactions was used as the limit to determine a negative read (i.e., all reads with lower amounts were considered negative and represented non-detects for the target species) for each run; these were classified as "No read".

A cluster analysis was done next and samples which fell outside the cluster, but not under the limit for a negative read, were classified as exhibiting low amplification; these were scored as "Weak average read", which can be interpreted as a potential detect of the target species. Those samples with DNA amplification levels that fell inside the cluster or above were classified as "Stong average read" and were considered positive detections of DNA from the target species.

Results

Field Blanks. Analysis of the bottled water blanks suggested that contamination in the field was minimal. Of the 12 technical replicates (3 technical replicates for each blank), 2 exhibited amplifiable DNA, with one showing a weak read for American mink, and a second showing a weak read for American water shrew (Table 4). Extractions from blank samples are expected to have very little DNA and are commonly not amplifiable in species-specific assays, depending on the freshness of the bottled water used to produce the blank sample. Positive results from extraction blanks when using universal assays are not unexpected and often represent bacterial, fungal, or trace human DNA picked up when sampling or prepping equipment.

A blank with nuclease-free water is run as a quality control with all plates and primer sets during the molecular analysis steps. In the event that a control picks up contamination, the entire plate is typically re-run. In this project two qPCR quality control blanks were weakly postive for a single target species each. The first was on a mink assay plate on which a single technical rep had a higher, though not positive, reaction; this was due to contamination by a positive control, as the field control well on the assay plate was directly adjacent to a cell with the highest concentration of positive control used in developing the standard curve. This contamination was due to a minor pipetting error, which was flagged immediately during the pipetting process. The second hit was from the water shrew assay and occurred at the very extreme edge of cycling where specificity of the primers breaks down, and was well within the range where non-specific binding occurred during the tissue validation process; this plate was re-run as a precaution. The low level of contamination in this project suggests that the collection and handling methods used in the field were acceptably rigorous.

Environmental Samples. One sample from each of the creek sites exhibited strong inhibition when tested with the univeral COI primer. Four other samples showed low levels of inhibiton; most of these were associated with the CRK1 site. Undiluted (e.g., unnormalized) samples were used in subsequent species-specific analyses, as previous experience has shown that this is the best course of action in cases where inhibition is occuring.

Results of the analysis of the environmental samples are provided in Table 4. Samples shown in green in Table 4 produced a strong signal indicating a definite positive test, while samples coded as orange produced a weak signal which could be indicative of a false positive. Red colouring indicates samples which produced no signal at all, and these are considered a non-detect for the target species in question. Grey indicates that a sample failed the universal primer test, and was therefore dropped from further analysis.

For the environmental samples, American Mink DNA was detected at all three sites, while River Otter DNA was detected at none of the sites. Northern Bog Lemming DNA was detected at the CRK1 and CRK3 sites; however, based on weight of evidence, it would be considered a *maybe* for these sites. The single weak detection for this species at CRK2 would be considered a non-detect. American Water Shrew DNA signals were relatively strong at one site, and less strong at the remaining two sites; the sensitivity of this primer set is relatively low and requires additional validation, so these results should be interpreted with caution.

Table 4. Results from qrtPCR analysis of eDNA samples (water samples) collected from three sites along Astotin Creek, AB. See the key below the table for interpretation of the colour codes used in the table. Each block in the table represents an individual filter.

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		Red, Red, Red, Red	Red, Red, Red, Red	Red, Orange, Red, Red	Red, Red, Red, Red	Red, Red, Red, Orange
CRK1	Up	Grey, Green, Green	Grey, Red, Green	Grey, Orange, Orange	Grey, Red, Red	Grey, Orange, Green
	Mid	Orange, Orange, Grey, Green	Red, Red, Grey, Orange	Orange, Orange, Grey, Orange	Red, Red, Grey, Red	Green, Green, Grey, Green
	Down	Green, Green	Red, Red	Red, Red	Red, Red	Orange, Red
CRK2	Up	Green, Orange, Green	Orange, Red, Red	Orange, Green, Red	Red, Red, Red	Red, Red, Red
	Mid	Green, Green, Green	Red, Red, Red	Green, Red, Orange	Red, Red, Red	Red, Red, Green
	Down	Green, Green, Green	Red, Red, Red	Red, Green, Red	Red, Red, Red	Red, Green, Green
CRK3	Up	Green, Green, Green	Red, Green, Red	Orange, Green, Orange	Red, Red, Red	Orange, Red, Red
	Mid	Green, Orange	Red, Red	Green, Orange	Red, Red	Red, Green
	Down	Green, Green, Grey, Green	Orange, Red, Grey, Red	Green, Green, Grey, Orange	Red, Red, Grey, Red	Green, Red, Grey, Red

KEY: Red = No Read
Green = Strong Average Read
Orange = Weak Average Read
Grey = Failed amplification of Universal primer

Discussion

Given the low concentration of DNA recovered from the filters, and the potential for DNA shed from a semi-aquatic mammal to be distributed non-randomly at a site, some adjustments to both the sampling protocol and the molecular protocols could be made to optimize the use of eDNA for detecting the target species. This could include the use of composite samples, in which a single assembly is used to filter standard aliquots (e.g. 1 L of water) at multiple locations (e.g., 10 or 15 locations rather than the current 3) at a sampling site. This could be done with three different filters to provide replication, so the materials consumed would remain the same as the current approach, but the spatial coverage of the sample would be increased.

Sampling efficacy might also be enhanced by targeting specific periods (e.g., seasons) when the species of interest would most likely be present in the study area, and habitat types most likely to attract the target species. Optimizing the extraction process to maximize the amount of total DNA obtained from the water samples could improve the sensitivity of the approach.

The high senstivity of eDNA analysis makes it useful for the detection of rare and elusive species, but intepreting the results of eDNA studies in lotic systems must be done within the context of the local landscape, and the scale of the question being asked. For Astotin Creek, for example, it would be hard to predict how far the eDNA associated with each target species may have travelled in the stream, as this can be influenced by a range of factors such as flow volume and velocity, stream morphology, and substrate composition and character (Fremier et al. 2019; Curtis et al. 2020). However, the 3 sampling sites in this study were far enough apart that they can, in all likelihood, be considered as indpendant of one another. Another challenge with lotic systems is with understanding how much of the recent past is represented by the sample. In lentic systems, it is often assumed that the eDNA in a sample represents biota that were present at the site within the previous 2 – 4 weeks (Dejean et al. 2011; Barnes et al. 2014); in lotic systems, persistence of eDNA is typically shorter (Harrison et al. 2019).

Comparison of the results of an eDNA approach with those obtained using other sampling methods (e.g., wildlife cameras) can provide an important test of the efficacy of eDNA as a monitoring method, and result in improvements to the eDNA sampling and analysis methods. If possible, the results of the eDNA work should be compared with the images captured on the wildlife cameras used in the larger project to determine if images of mink were captured at the same sites as the eDNA signal for these animals was detected.

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APPENDIX D
FISH AND AQUATIC HABITAT

D

TABLE 1

WATER QUALITY RESULTS - ROUTINE AND INDICATOR PARAMETERS

Monitoring Well	Sample Date	Electrical Conductivity (µS/cm)	Sodium Adsorption Ratio	pH	Total Dissolved Solids (mg/L)	Total Suspended Solids (mg/L)	Ion Balance (%)	Total Alkalinity (mg/L)	Hardness (mg $CaCO_3$/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Hydroxide (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Sulphate (mg/L)	Nitrate-N + Nitrite-N (mg/L)	Nitrate-N (mg/L)	Nitrate mg/L	Nitrite-N (mg/L)	Nitrite (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Biochemical Oxygen Demand (BOD) (mg/L)	Total Dissolved Phosphorus (mg/L)	Escherichia coli (MPN) (MPN/100 mL)	Chlorophyll-a (µg/L)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Iron (mg/L)	Manganese (mg/L)
EQGASW - PFAL		NS	NS	**6.5-9.0**	NS	**NOTE[1]**	NS	**20[2]**	NS	NS	NS	NS	120	NS	**429[3]**	NS	**3.0**	NS	0.06 - 0.20[4]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**0.3**	NS
EQGASW - Agriculture		**1000[5]**	**5**	NS	**500**	NS	NS	NS	NS	NS	NS	NS	**100**	1	NS	**100**	NS	NS	10	NS	NS	NS	NS	**100**	NS	**1000**	NS	NS	NS	NS	NS
CEQG - PFAL		NS	NS	**6.5-9.0**	NS	NOTE	NS	NS	NS	NS	NS	NS	120	**0.12**	NS	NS	NS	**13**	**0.06**	NS	NS	NS	NOTE	NS	NS	NS	NS	NS	NS	**0.3**	0.3 - 0.48[6]
CEQG - Agriculture		NS	NS	NS	**500**	NS	NS	NS	NS	NS	NS	NS	**100**	1	1000	**100**	NS	NS	10	NS	NS	NS	NS	**100**	NS	**1000**	NS	NS	NS	5	**0.2**
Low-Crk 3	29-Jun-21	857	0.68	8.19	507	16	111	281	418	343	<5	<5	30.8	0.26	123	<0.02	<0.02	<0.5	<0.01	<0.05	2.5	4	0.549	214	20.9	101	40.2	11.1	32.1	<0.1	0.072
Low-WQ 3	29-Jun-21	839	0.49	8.00	485	6	111	363	438	443	<5	<5	31.9	0.30	46.0	<0.02	<0.02	<0.5	0.02	0.05	2.0	3	0.500	8	15.6	113	37.8	15.0	23.4	<0.1	0.454
Mid-Crk 2	29-Jun-21	767	0.57	7.90	442	6	112	377	399	459	<5	<5	8.3	0.40	31.9	<0.02	<0.02	<0.5	<0.01	<0.05	2.2	4	0.149	9	10.1	105	33.2	11.2	26.2	<0.1	0.754
UP-Crk 1	29-Jun-21	582	0.48	8.00	323	19	112	287	294	350	<5	<5	4.2	0.23	16.5	<0.02	<0.02	<0.5	0.02	0.06	1.9	3	0.371	119	12.2	74.1	26.5	10.9	18.8	0.1	0.021
UP-WQ1	29-Jun-21	570	0.77	7.86	317	11	105	273	239	333	<5	<5	4.6	0.26	25.3	<0.02	<0.02	<0.5	<0.01	<0.05	4.2	12	1.16	62	10.3	50.7	27.2	17.9	27.5	0.3	0.727
No Guideline																															
Trip Blank	29-Jun-21	<5	0	3.35	<0.6	<3	13	<5	<1	<5	<5	<5	<1.0	<0.01	<1.0	<0.02	<0.02	<0.5	<0.01	<0.05	<0.1	<3	<0.005	<1	<0.25	<0.3	<0.2	<0.6	<0.6	<0.1	<0.005

Note:

"<" - Below laboratory detection limits; detection limits are less than the applied guideline

NS - No Standard

EQGASW - PAL - Environmental Quality Guidelines for Alberta Surface Waters - Table 1. Surface Water Quality Guidelines for the Protection of Freshwater Aquatic Life (Government of Alberta, 2018)

EQGASW - Agriculture - Environmental Quality Guidelines for Alberta Surface Waters - Table 2. Water Quality Guidelines for the Protectuin of Agricultural Water Users (Government of Alberta, 2018)

[1] EQGASW Table 1 - During high flow or for turbid waters: Maximum increase of 25 mg/L from background levels at any time when background levels are between 25 and 250 mg/L. Should not increase more than 10% of background levels when background is ≥250 mg/L

[2] EQGASW Table 1 - Guideline (20 mg/L) is a minimum value for healthy surface water; the guideline can be lowered to represent site specific natural conditions (Government of Alberta, 2018)

[3] EQGASW Table 1.7 - Guideline varies with hardness at each sample location (Government of Alberta, 2018)

[4] EQGASW Table 1.4 - Guideline varies with chloride at each sample location. Range represents site-specific minimum and maximum guideline values (Government of Alberta, 2018)

[5] EQGASW Table 2.1 - Irrigation water quality guidelines for sodium adsorption ratio (SAR) and electrical conductivity (EC) (Government of Alberta, 2018)

CEQG - Canadian Environmental Quality Guidelines - Water Quality Guidelines for the Protection of Aquatic Life

CEQG - Canadian Environmental Quality Guidelines - Water Quality Guidelines for the Protection of Agriculture

[6] 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

Bold indicates the most stringent guideline

Shading indicates values above the applied guideline

TABLE 2
WATER QUALITY RESULTS - TOTAL METAL PARAMETERS

Monitoring Well	Sample Date	Aluminum (Al) (mg/L)	Antimony (Sb) (mg/L)	Arsenic (As) (mg/L)	Barium (Ba) (mg/L)	Boron (B) (mg/L)	Cadmium (Cd) (mg/L)	Chromium (Cr) (mg/L)	Chromium (III) (Cr^{3+}) (mg/L)	Chromium (VI) (Cr^{6+}) (mg/L)	Cobalt (Co) (mg/L)	Copper (Cu) (mg/L)	Iron (Fe) (mg/L)	Lead (Pb) (mg/L)	Manganese (Mn) (mg/L)	Mercury - Ultra Low Level (Hg) (mg/L)	Molybdenum (Mo) (mg/L)	Nickel (Ni) (mg/L)	Phosphorus (P) (mg/L)	Selenium (Se) (mg/L)	Silver (Ag) (mg/L)	Sodium (Na) (mg/L)	Thallium (Th) (mg/L)	Uranium (U) (mg/L)	Zinc (Zn) (mg/L)
EQGASW - PFAL		NS	NS	**0.005**	NS	1.5	**0.00033 - 0.0037[1]**	NS	0.0089	**0.001**	**0.0015 - 0.0018[1]**	0.007	NS	**0.007[1]**	NS	**0.000005**	0.073	**0.11 - 0.17[1]**	NS	0.002[2] / 0.001[3]	**0.00025**	NS	**0.0008**	0.015	0.03
EQGASW - Agriculture		**5**	NS	0.025	NS	**0.5**	0.0082	NS	**0.0049**	0.008	0.05	0.2	5	0.2	**0.2**	0.003	**0.01**	0.2	NS	0.02	NS	NS	NS	**0.01**	1
CEQG - PFAL		NS	NS	**0.005**	NS	1.5	**0.00033 - 0.0037[4]**	NS	0.0089	**0.001**	NS	**0.004[4]**	**0.3**	**0.007[4]**	0.3 - 0.48[5]	0.000026	0.073	0.15[4]	NS	**0.001**	**0.00025**	NS	**0.0008**	0.015	NA
CEQG - Agriculture		NS	NS	0.025	NS	**0.5**	0.0051	NS	**0.0049**	0.008	0.05	0.2	5	0.1	**0.2**	0.003	**0.01**	0.2	NS	0.02	NS	NS	NS	**0.01**	**1**
Low-Crk 3	29-Jun-21	0.020	<0.001	0.003	0.07	0.11	<0.000016	<0.0005	<0.001	<0.01	<0.0009	<0.0008	<0.1	<0.004	0.130	0.0000061	<0.001	<0.003	0.66	0.0031	<0.00005	32.1	<0.0005	0.002	<0.01
Low-WQ 3	29-Jun-21	0.122	<0.001	0.011	0.15	0.07	<0.000016	0.0005	<0.001	<0.01	<0.0009	0.0010	0.8	<0.0001	0.892	0.000018	0.001	0.004	0.64	0.0041	<0.00005	23.8	<0.0005	0.002	<0.01
Mid-Crk 2	29-Jun-21	0.056	<0.001	0.007	0.09	0.12	0.000030	0.0006	<0.001	<0.01	0.0022	0.0009	1.2	<0.0001	1.34	0.000017	0.002	0.008	0.25	0.0068	<0.00005	26.2	<0.0005	0.003	<0.01
UP-Crk 1	29-Jun-21	0.099	<0.001	0.004	0.10	0.07	<0.000016	<0.0005	<0.001	<0.01	<0.0009	<0.0008	1.0	<0.0001	0.160	0.000017	<0.001	<0.003	0.53	0.0025	<0.00005	18.9	<0.0005	<0.001	<0.01
UP-WQ1	29-Jun-21	0.047	<0.001	0.003	0.11	0.09	<0.000016	<0.0005	<0.001	<0.01	<0.0009	<0.0008	0.6	<0.0001	0.865	0.000020	<0.001	<0.003	1.50	0.0017	<0.00005	27.1	<0.0005	<0.001	<0.01
No Guideline																									
Trip Blank	29-Jun-21	0.007	<0.001	<0.001	<0.05	<0.01	<0.000016	<0.0005	<0.001	<0.01	<0.0009	<0.0008	<0.1	<0.0001	<0.005	<0.0000025	<0.001	<0.003	<0.08	<0.0005	<0.00005	<0.6	<0.0005	<0.001	<0.01

Note: "<" - Below laboratory detection limits; detection limits are less than the applied guideline

NA - Not Available; guideline based on dissolved organic carbon, which was not analyzed.

NS - No Standard

EQGASW - PAL - Environmental Quality Guidelines for Alberta Surface Waters - Table 1. Surface Water Quality Guidelines for the Protection of Freshwater Aquatic Life (Government of Alberta, 2018)

EQGASW - Agriculture - Environmental Quality Guidelines for Alberta Surface Waters - Table 2. Water Quality Guidelines for the Protectuin of Agricultural Water Users (Government of Alberta, 2018)

[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] EQGASW Table 1 - Alert Concentration for Selenium (Government of Alberta, 2018)

[3] EQGASW Table 1 - Guideline Concentration for Selenium (Government of Alberta, 2018)

CEQG - Canadian Environmental Quality Guidelines - Water Quality Guidelines for the Protection of Aquatic Life

CEQG - Canadian Environmental Quality Guidelines - Water Quality Guidelines for the Protection of Agriculture

[4] The CWQG is based on hardness at each sample location. Range represents site-specific minimum and maximum guideline values (Government of Alberta, 2018)

[5] 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

Bold indicates the most stringent guideline

Shading indicates values above the applied guideline

TABLE 3
WATER QUALITY RESULTS - PESTICIDE PARAMETERS

Monitoring Well	Sample Date	Organochlorinated Pesticides																								Triazine Pesticides								
		Aldrin (µg/L)	alpha-BHC (µg/L)	Chlordane (µg/L)	alpha-Chlordane (µg/L)	gamma-Chlordane (µg/L)	DDD (µg/L)	DDT (µg/L)	Dieldrin (µg/L)	Endosulfan (µg/L)	Endosulfan I (µg/L)	Endosulfan II (µg/L)	Endrin (µg/L)	Heptachlor (µg/L)	Heptachlor Epoxide (µg/L)	Heptachlor + Heptachlor Epoxide (µg/L)	Hexachlorobenzene (µg/L)	Methoxychlor (µg/L)	gamma-Hexachlorocyclohexane (µg/L)	op'-DDD (µg/L)	op'-DDE (µg/L)	op'-DDT (µg/L)	pp'-DDD (µg/L)	pp'-DDE (µg/L)	pp'-DDT (µg/L)	Alachlor (µg/L)	Atrazine (µg/L)	Atrazine + N-dealkylated metabolites (µg/L)	Cyanazine (µg/L)	Metolachlor (µg/L)	Metribuzin (µg/L)	Prometryne (µg/L)	Simazine (µg/L)	Trifluralin (µg/L)
EQGASW - PFAL		NS	NS	NS	NS	NS	NS	NS	NS	**0.003**	NS	NS	NS	NS	NS	NS	NS	**0.03**	NS	NS	NS	NS	NS	NS	NS	NS	**1.8**	NS	2	**7.8**	1	NS	10	**0.2**
EQGASW - Agriculture		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**0.52**	NS	NS	NS	NS	NS	NS	NS	NS	NS	5	NS	**0.5**	28	**0.5**	NS	**0.5**	45
CEQG - PFAL		NS	NS	NS	NS	NS	NS	NS	NS	**0.003**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**1.8**	NS	2	**7.8**	1	NS	10	**0.2**
CEQG - Agriculture		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**0.52**	NS	NS	NS	NS	NS	NS	NS	NS	NS	5	NS	**0.5**	28	**0.5**	NS	**0.5**	45
Low-Crk 3	29-Jun-21	<0.01	<0.05	<0.04	<0.1	<0.2	<0.05	<0.04	<0.02	<0.003	<0.05	<0.05	<0.05	<0.01	<0.01	<0.01	<0.01	<0.03	<0.01	<0.05	<0.01	<0.04	<1.5	<0.01	<0.5	<0.5	<0.5	<1	<0.5	<0.11	<0.25	<0.25	<0.5	<0.2
Low-WQ 3	29-Jun-21	<0.01	<0.05	<0.04	<0.1	<0.2	<0.05	<0.04	<0.02	<0.003	<0.05	<0.05	<0.05	<0.01	<0.01	<0.01	<0.01	<0.03	<0.01	<0.05	<0.01	<0.04	<1.5	<0.01	<0.5	<0.5	<0.5	<1	<0.5	<0.11	<0.25	<0.25	<0.5	<0.2
Mid-Crk 2	29-Jun-21	<0.01	<0.05	<0.04	<0.1	<0.2	<0.05	<0.04	<0.02	<0.003	<0.05	<0.05	<0.05	<0.01	<0.01	<0.01	<0.01	<0.03	<0.01	<0.05	<0.01	<0.04	<1.5	<0.01	<0.5	<0.5	<0.5	<1	<0.5	<0.11	<0.25	<0.25	<0.5	<0.2
UP-Crk 1	29-Jun-21	<0.01	<0.05	<0.04	<0.1	<0.2	<0.05	<0.04	<0.02	<0.003	<0.05	<0.05	<0.05	<0.01	<0.01	<0.01	<0.01	<0.03	<0.01	<0.05	<0.01	<0.04	<1.5	<0.01	<0.5	<0.5	<0.5	<1	<0.5	<0.11	<0.25	<0.25	<0.5	<0.2
UP-WQ1	29-Jun-21	<0.01	<0.05	<0.04	<0.1	<0.2	<0.05	<0.04	<0.02	<0.003	<0.05	<0.05	<0.05	<0.01	<0.01	<0.01	<0.01	<0.03	<0.01	<0.05	<0.01	<0.04	<1.5	<0.01	<0.5	<0.5	<0.5	<1	<0.5	<0.11	<0.25	<0.25	<0.5	<0.2
No Guideline																																		
Trip Blank	29-Jun-21	<0.01	<0.05	<0.04	<0.1	<0.2	<0.05	<0.04	<0.02	<0.003	<0.05	<0.05	<0.05	<0.01	<0.01	<0.01	<0.01	<0.03	<0.01	<0.05	<0.01	<0.04	<1.5	<0.01	<0.5	<0.5	<0.5	<1	<0.5	<0.11	<0.25	<0.25	<0.5	<0.2

Note: "<" - Below laboratory detection limits; detection limits are less than the applied guideline

NS - No Standard

EQGASW - PAL - Environmental Quality Guidelines for Alberta Surface Waters - Table 1. Surface Water Quality Guidelines for the Protection of Freshwater Aquatic Life (Government of Alberta, 2018)
EQGASW - Agriculture - Environmental Quality Guidelines for Alberta Surface Waters - Table 2. Water Quality Guidelines for the Protectuin of Agricultural Water Users (Government of Alberta, 2018)
CEQG - Canadian Environmental Quality Guidelines - Water Quality Guidelines for the Protection of Aquatic Life
CEQG - Canadian Environmental Quality Guidelines - Water Quality Guidelines for the Protection of Agriculture

Bold indicates the most stringent guideline


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APPENDIX E
CLIMATE ANALYSIS

E

TECHNICAL NOTE

CLIENT:	Strathcona County
PROJECT:	Astotin Creek Resiliency Study
WSP Ref.:	211-03754-00
SUBJECT:	Climate Change Exposure Assessment for Astotin Creek
DATE:	23 July 2021
RECIPIENT:	Vincent Cormier, Ana Hosseinpour and Kaitlynn Livingstone, WSP Canada Inc.
C.C.:	N/A

1 PROJECT CONTEXT

WSP was commissioned to conduct a Climate Change Exposure Assessment, providing Strathcona County with an analysis of climate trends and an assessment of how climate change may influence flooding. All relevant climate variables and the resulting climate hazards were included in this assessment (e.g. heat waves, droughts and water shortages, wildfires), not just those relating to flooding, in order to give a comprehensive view of future climate change in Astotin Creek.

The watershed has experienced past agricultural and industrial development, clearing riparian habitat along the creek in some areas, and removing wetlands that could moderate run-off conditions. Changing water flow and volume in some parts of the basin have suggested a risk of more frequent flooding and need for adaptive management. The creek has flooded three times in the past decade, affecting agricultural lands, roads and private residences.

The County has responded with emergency mitigation measures such as road closures, pumping and monitoring flood conditions to protect County roads and private homes and property. Pro-active management strategies are required to meet the County's public safety and fiscal management obligations, as well as its environmental management responsibilities for sustainable water quality and quantity, biodiversity, and ecological function.

2 METHODOLOGY

2.1 APPROACH

The general process followed in this note respects Infrastructure Canada's Climate Change Lens[1] principles for climate resilience assessment, which itself is based on ISO 31000 Risk Management standard (Figure 1). The analysis of climate change trends will consist in the first two phases of this process, namely establishing the climate context and identifying the risks. The results of this process are not representative of the impacts of climate hazards affecting the project. An assessment of consequence and resulting risk level would specify how the components would be affected.

[1] https://www.infrastructure.gc.ca/pub/other-autre/cl-occ-eng.html

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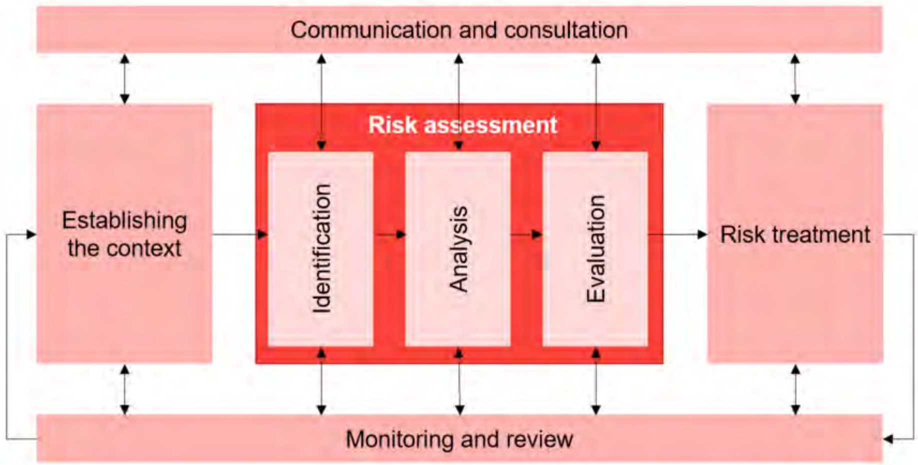

Figure 1 ISO 31000 Risk Management standards

2.2 ANALYSIS OF CLIMATE PROJECTIONS

Globally, climate change will result in a long-term rise in the Earth's average temperature. On a local scale, impacts will vary and include shifts in temperature, precipitation, wind, and other weather patterns, including extreme weather events. Broadly speaking, the local climate projections are divided into different commonly used climate scenarios, or 'Representative Concentration Pathways (RCP)' (Van Vuuren *et al*., 2011). For this assessment, we include projections on the most likely active scenario (RCP4.5) and on the passive scenario (RCP8.5).

The passive scenario is modelled assuming the worst case of the 'business-as-usual' approach without any mitigation measures implemented at global scale and a constant increase in GHG emissions until the depletion of fossil fuel stocks (Figure 2). The passive scenario is the trajectory in which most changes are more significant, especially in higher latitudes such as in Canada, where the effects of climate change are exacerbated. Given the current state of global climate negotiations, the passive scenario remains the most likely at this stage, and thus is the scenario chosen for the exposure assessment. This is a reasonable approach to take considering the level of uncertainty and that the impacts under the more moderate active scenarios have similar outcomes at mid-century. Projections of the active scenario are also presented for comparison.

Climate data was obtained from historical datasets and climate normals from Environment and Climate Change Canada (ECCC, 2020), the Climate Atlas of Canada (PCC, 2019), and the IDF-CC tool (Simonovic *et al*., 2016; Western University, 2018), and scientific and government literature where applicable.

The Climate Atlas of Canada has been developed and published by the Prairie Climate Center (PCC) with the collaboration of Manitoba University. The PCC is a consortium working on climate change impacts and adaptation and has produced global climate simulations for Canada based on 24 global climate models from the CMIP5 exercise (Climate Model Intercomparison Project, phase 5; Taylor, 2012). These data originally obtained from the Pacific Climate Impacts Consortium (PCIC) are reliable and recognized by the academic community, by government agencies and by the engineering community. The user of this platform has access to the evolution of around thirty climate indicators and to graphical data.

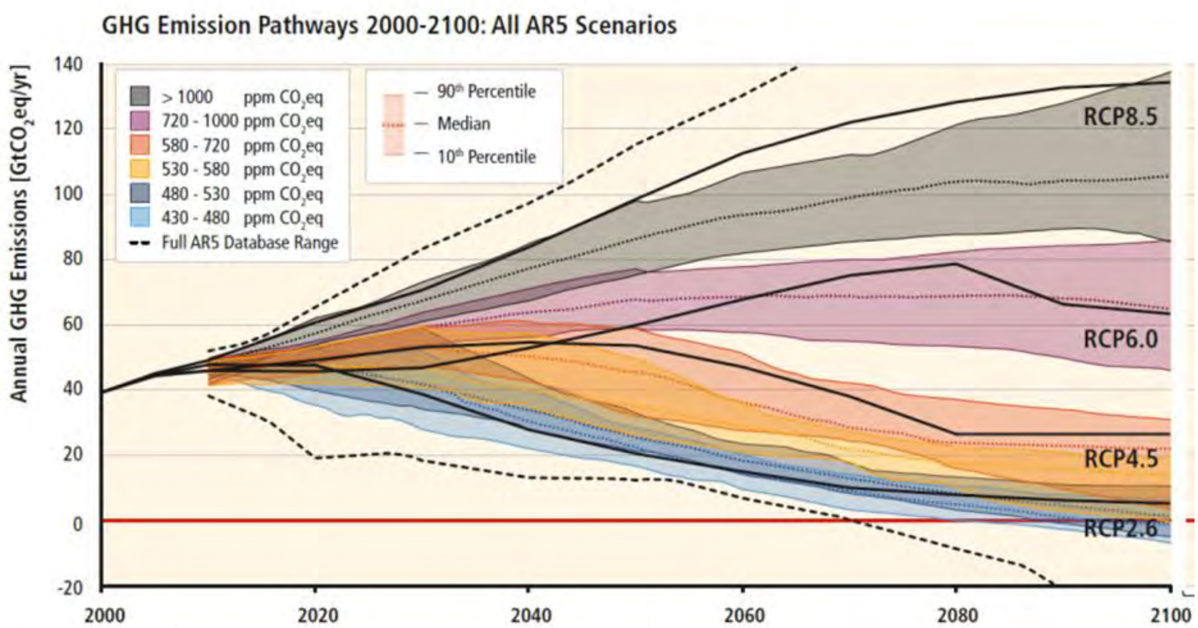

Figure 2 GHG emissions for each RCP scenario until 2100 (Source: IPCC, 2014)

The hydrologic tool developed by Western University (IDF-CC) compiles intensity-duration-frequency (IDF) curve data for various rainfall gauges in Canada. The IDF-CC tool is the result of the use of precipitation data from ECCC stations, spatial interpolations and future statistics based on 24 global climate models and nine regional models (Western University, 2018). Based on historical statistics and different scenarios of greenhouse gas emissions, IDF curves and their uncertainties are generated for different envisaged futures. This tool provides, among other things, the evolution of the maximum hourly or daily cumulative precipitation with different return periods ranging from 2 to 100 years. IDF statistics using a Gumbel distribution are used in this assessment to match with ECCC datasets.

These data sources present climate projections with a recent baseline, a short-term horizon and a long-term horizon (Table 1). For the exposure assessment, the long-term horizon has been selected to capture the greater changes in climate trends and to adopt a conservative approach for the assessment of climate risks. Periods selected correspond to data availability at the weather station, the grid point and in the data source selected for this assessment, and are all representative of the recent past and the time horizons defined for this study.

Table 1 Time periods of data sources on climate change

DATA SOURCE	HISTORICAL BASELINE	NEAR FUTURE	FAR FUTURE
Climate Atlas of Canada	1976-2005	2021-2050	2051-2080
IDF-CC tool	1985-2017	2021-2050	2051-2080

2.3 ANALYSIS OF CLIMATE HAZARDS

Climate trends represent indicators of climatic hazards considered as relevant for the study. The general legend of the levels of likelihood is presented in Table 2. Classes are defined in Infrastructure Canada's Climate Lens guideline. The higher the rating, the greater the increase in the change of climate indicator under the influence of climate change. This score is weighted here by the confidence of climate data, in order to quantify the homogeneity of climate models included in the analysis. This level of confidence enables to assess the importance of climate variability included in the projections, and to consider the false "positives" and the false "negatives" of future climate trends:

- Good confidence (unchanged likelihood);
- Medium confidence (likelihood -0.5);
- Low confidence (likelihood -1).

Table 2 Legend of the climate change exposure assessment

Degree	Exposure	
	Likelihood	**Confidence**
1	**Very low** Projected ranges in future climate are similar to historic ranges and no trend can be identified.	**Low (-1)** - Data source has certain shortcomings and the projections have relatively large uncertainties. - Results come from the scientific literature and the uncertainty ranges are not specified.
2	**Low** Projected ranges in future climate completely or significantly overlap historic baseline means and uncertainty ranges and/or do not exceed historic or design thresholds.	
3	**Moderate** Projected ranges in future climate overlap historic baseline means and lower or upper uncertainty ranges (dependant on if the trends are increasing or decreasing) and/or meet or marginally exceed historic or design thresholds.	**Medium (-0,5)** - Data source is reliable, but the projections have relatively large uncertainties. - Data source has certain shortcomings, but projections have relatively small uncertainties. - Results come directly from the scientific literature.
4	**High** Projected ranges in future climate overlap historic lower or upper uncertainty ranges (dependant on if the trends are increasing or decreasing) and/or exceed historic or design thresholds.	
5	**Very High** Projected ranges in future climate are entirely out of the range of historic baseline means and uncertainty ranges and/or significantly exceed historic or design thresholds.	**High (-0)** - Data source is reliable. - Enough climate models have been used. - Projections have relatively low uncertainties.

3 CLIMATE CHANGE HAZARDS

3.1 IDENTIFICATION OF CLIMATE HAZARDS

A hazard is defined as "a phenomenon, a physical manifestation or a human activity likely to cause loss of life or injury, damage to property, social and economic disturbance or environmental degradation" (MSP, 2009). A climate hazard is therefore a hazard whose origin is at least partly linked to one or more climate variables. Some characteristics such as intensity, probability of occurrence, frequency as well as spatial location allow the identification of hazards likely to have an impact in a given context. Climate hazards considered in this assessment are listed in Table 3.

Table 3 Selection of climate hazards

CLIMATE VARIABLE	RELEVANCE TO THE ASSESSMENT
Spring fluvial flooding due to freshet	Relevant
Summer fluvial flooding due to long extreme precipitation events	Relevant
Extreme precipitation	Relevant
General increase in temperatures	Relevant
Heat waves	Relevant
Droughts and water shortages	Relevant
Wildfires	Relevant
Changes in winter conditions (snow accumulation and freeze-thaw cycles)	Relevant
Strong winds and storm activity	Relevant
Landslides	Not relevant

REJECTED CLIMATE HAZARDS

LANDSLIDES

Landslides, although associated with climatic changes such as precipitation levels, are a geomorphological risk and therefore considered outside of the scope of this study. Furthermore, landslide susceptibility in the study area is classified as very low according to the information that is currently available (GFDRR, n.d.). This means that this area has rainfall patterns, terrain slope, geology, soil, land cover and (potentially) earthquakes that make localized landslides an uncommon hazard phenomenon.

4 RESULTS

The following section presents the different climate trends under RCP4.5 and RCP8.5 for a near- and a long-term horizon (2021-2050 and 2051-2080). Numbers in brackets represent the standard deviation interval of the inter-model spread (climate models do respond differently as a function of their climate sensitivity).

Data extracted from the Climate Atlas of Canada correspond to projections of the Edmonton large grid cell. Projected IDF curves have been extracted from the Elk Island Nat Park station (ID 3012275) on the IDF_CC website. It corresponds to the closest and the most representative weather station for the road asset of the park.

4.1 DETAILED CLIMATE PROFILE & PROJECTIONS

4.1.1 SPRING FLUVIAL FLOODING DUE TO FRESHET

According to the Climate Atlas data, precipitation regimes are likely to change overall, but a great variability remains among the different climate models. Overall, the mean annual change corresponds to an **increase in annual precipitation of 34 to 50 mm over the far future (8% to 11%)**, respectively for low and high carbon emission scenarios. When considering seasonal precipitation, a large increase of 23 mm (28%) is projected during spring for the high carbon emissions scenario.

Mean precipitation is an important hazard to consider as it is a key climate variable in fluvial flood risk on the site is dependent on changes in Astotin Creek flow conditions. However, multiple factors impacted by climate change will influence flow and water levels in Astotin Creek such as freshet events, changes to winter and summer temperature, snowpack, melt rates, rainstorm intensity/frequency, and land cover changes due to forests impacted by wildfires. As such, quantifying the change in flood risk due to climate change is challenging, requiring detailed hydrological/climate modelling, which this study will be used to inform.

Table 4 Historic and projected values and trends of indicators representing the changes to spring fluvial flooding for 2021-2050 and 2051-2080 for RCP4.5 and RCP8.5 (PCC, 2019)

CLIMATE INDICATOR	HISTORIC MEAN (1976-2005) [RANGE]	NEAR FUTURE (2021-2050) [RANGE]		FAR FUTURE (2051-2080) [RANGE]		TREND
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	
Mean annual precipitation (mm)	446 [322 – 576]	479 [346 – 626]	471 [349 – 616]	480 [345 – 635]	496 [356 – 647]	↑
Mean spring precipitation (mm)	83 [42 – 134]	99 [51 – 162]	94 [47 – 148]	99 [53 – 155]	106 [53 – 165]	↑

FRESHET EVENTS

In Alberta, there are two separate snowmelt seasons for snow that has accumulated in the plains and boreal regions or for the snow that has accumulated in the Rocky Mountains. Astotin Creek is situated in the plains and would therefore experience freshet events during early April when air temperatures rise (Government of Alberta, 2018). Freshet flow and timing are contingent on several overlapping factors, namely the amount and timing of winter snowpack and the magnitude of winter and spring temperatures. If a lot of precipitation falls as snow in the winter and does not melt until the spring then the freshet flow will be higher, but if the winter is warmer and more precipitation falls as rain, the freshet flow will be lower. In addition, the amount and timing of spring precipitation will impact the volume of freshet that heads into the water system. Higher temperatures earlier in spring will cause an earlier freshet event, while lower temperatures will cause a later freshet. The climate projections show that under the passive scenario, the date of the last spring frost is projected to change from May 10th to April 20th by the 2080s, indicating that the transition from colder to warmer weather will begin to start earlier in the year.

Projection data for the project site indicates that mean temperatures for the spring months (March, April, and May) are all projected to increase by the 2080s. The annual number of icing days, which indicates how many days in a year without temperatures above 0°C, are projected to decrease by 28%, reducing the amount of time available for snow to accumulate.

Table 5 Historic and projected values and trends of indicators representing the changes to seasonal freshet for 2021-2050 and 2051-2080 for RCP4.5 and RCP8.5 (PCC, 2019)

CLIMATE INDICATOR	HISTORIC MEAN (1976-2005) [RANGE]	NEAR FUTURE (2021-2050) [RANGE]		FAR FUTURE (2051-2080) [RANGE]		TREND
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	
Mean March temperature (°C)	-5.5 [-11.2 – -0.1]	-3.0 [-8.9 – 2.5]	-2.8 [-8.5 – 2.8]	-1.6 [-7.2 – 3.6]	-0.6 [-6.7 – 5.4]	↑
Mean April temperature (°C)	4.0 [-0.1 – 7.5]	6.0 [2.2 – 9.7]	6.0 [2.2 – 9.8]	6.9 [3.0 – 10.5]	7.7 [4.1 – 11.6]	↑
Mean May temperature (°C)	10.6 [8.2 – 13.1]	11.9 [9.2 – 14.8]	12.3 [9.8 – 14.9]	12.8 [10.2 – 15.4]	13.9 [11.0 – 16.7]	↑
Annual number of ice days	95.3 [73.9 – 115.5]	81.7 [60.9 – 103.0]	82.1 [60.0 – 104.7]	74.9 [53.0 – 96.4]	68.9 [45.3 – 93.4]	↓

4.1.2 SUMMER FLUVIAL FLOODING DUE TO LONG EXTREME PRECIPITATION EVENTS

As discussed above, mean precipitation is an important hazard to consider as it is a key climate variable in fluvial flood risk on the site is dependent on changes in Astotin Creek flow conditions. In addition to this, historical trends have shown that summer fluvial flooding events correlated with long 5-day extreme precipitation events and this type of fluvial flooding has been considered separately as a result. Overall, the projections for summer precipitation corresponds to a very slight **increase of 1.3% to 2.2% over the far future** respectively for low and high carbon emission scenarios. When looking at the annual maximum five-day precipitation, an increase of 5.3% to 12.5% over the far future is projected respectively for low and high carbon emission scenarios.

Table 6 Historic and projected values and trends of indicators representing the changes to summer fluvial flooding for 2021-2050 and 2051-2080 for RCP4.5 and RCP8.5 (PCC, 2019)

CLIMATE INDICATOR	HISTORIC MEAN (1976-2005) [RANGE]	NEAR FUTURE (2021-2050) [RANGE]		FAR FUTURE (2051-2080) [RANGE]		TREND
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	
Mean summer precipitation (mm)	224 [129 – 329]	229 [133 – 339]	229 [135 – 346]	227 [125 – 347]	229 [128 – 355]	↑
Annual maximum 5-day precipitation (mm)	56 [32 – 86]	60 [36 – 92]	60 [35 – 93]	59 [34 – 91]	63 [37 – 99]	↑
Maximum 5-day precipitation in a 30-year period (mm)	109 [85 – 151]	114 [89 – 160]	119 [89 – 171]	119 [87 – 167]	123 [92 – 169]	↑

4.1.3 EXTREME PRECIPITATION

Extreme precipitation is an important hazard to consider for this project regarding stormwater management implications and resultant pluvial flooding. IDF (Intensity-Duration-Frequency) projections for the weather station nearest to the study area (Elk Island Nat Park ID# 3012275) indicate an increase in intensity for extreme precipitation events ranging from -8.3% to 29.4%. The projections show variation in the trends over the near future and the far future and the two RCPs, with the projections for RCP4.5 showing an initial increase (11.2% and 13.1% for hourly maximum and daily maximum respectively and -8.3% decrease for 15-min maximum) in the near future and a larger increase (4.9%, 24.1% and 26.4% for 15-min maximum, hourly maximum and daily maximum respectively) in the far future. However, the projections for RCP 8.5 show a contrasting trend, with an initial larger increase in the near future (1.3%, 22.1% and 29.4% for 15-min maximum, hourly maximum and daily maximum respectively) and a smaller percentage increase in the far future (10.0% and 15.2% for hourly maximum and daily maximum respectively) and a 6.0% decrease for 15-min maximum in the far future.

Table 7 Historic and projected values and trends of indicators representing the increase in precipitation intensity for the years 2021-2050 and 2051-2080 for RCP4.5 and RCP8.5 (Western University, 2018)

CLIMATE INDICATOR	HISTORIC MEAN (1985-2017) [RANGE]	NEAR FUTURE (2021-2050) [RANGE]		FAR FUTURE (2051-2080) [RANGE]		TREND
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	
15-min 1:100 year precipitation (mm)	22.1	-8.3% [-21.3% – 8.7%]	1.3% [-18.2% – 13.8%]	4.9% [-16.7% – 10.0%]	-6.0% [-16.8% – 9.5%]	↑
1-hour 1:100 year precipitation (mm)	29.7	11.2% [-7.8% – 44.0%]	22.1% [1.7% – 39.1%]	24.1% [-1.2% – 36.7%]	10.0% [-2.2% – 36.0%]	↑
24-hour 1:100 year precipitation (mm)	90.8	13.1% [-5.6% – 51.2%]	29.4% [3.4% – 46.6%]	26.4% [4.1% – 38.1%]	15.2% [7.4% – 44.6%]	↑

*The range for the IDF_CC tool projections show the 25th and 75th percentiles.

As there is considerable uncertainty surrounding the projections of precipitation as a result of climate change, it is beneficial to consider other sources of projection data. The CSA PLUS 4013:19 standard[2] on the development, interpretation and use of rainfall IDF information states that a 7% increase can be expected for every degree of warming. This has been applied to the historical data from the weather station and the increase in mean annual temperature to provide an alternative set of projections for extreme precipitation, although the projections are the same for each precipitation duration as its based on the same temperature change.

It is recommended to use the most conservative projections data when carrying out flooding modelling or planning exercises to ensure a worst-case scenario is considered. The below percentages from calculations using CSA's proxy should therefore be used.

[2] https://webstore.ansi.org/standards/csa/csaplus40132019

Table 8 Historic and projected values and trends of indicators representing the increase in precipitation intensity for the years 2021-2050 and 2051-2080 for RCP4.5 and RCP8.5 (Western University, 2018; CSA, 2019)

CLIMATE INDICATOR	HISTORIC MEAN (1985-2017) [RANGE]	NEAR FUTURE (2021-2050) [RANGE]		FAR FUTURE (2051-2080) [RANGE]		TREND
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	
15-min 1:100 year maximum precipitation (mm)	22.1	13.7% [0.7% – 27.6%]	15.3% [2.7% – 29.3%]	22.5% [9.2% – 39.3%]	33.8% [16.0% – 53.2%]	↑
1-hour 1:100 year maximum precipitation (mm)	29.7					↑
24-hour 1:100 year maximum precipitation (mm)	90.8					↑

4.1.4 GENERAL INCREASE IN TEMPERATURE

One of the first manifestations of climate change is the general increase in temperatures which is already visible today for all seasons and all types of statistics. Mean annual temperature is expected to rise from 1.9-2.1°C to more than 3.0-4.3°C for the near and far future, respectively. This increase is also visible in maximum summer temperature and minimum winter temperature. During summer, **maximum temperatures may reach 26.4°C (+ 4.4 °C) on average by the end of the century** if no mitigation measures are implemented. Similarly, **minimum average winter temperature may rise by 5.6°C to reach -11.5°C**.

Table 9 Historic and projected values and trends of indicators representing the general increase in temperature for the years 2021-2050 and 2051-2080 for RCP4.5 and RCP8.5 (PCC,2019)

CLIMATE INDICATOR	HISTORIC MEAN (1976-2005) [RANGE]	NEAR FUTURE (2021-2050)		FAR FUTURE (2051-2080)		TREND
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	
Mean annual temperature (°C)	2.6 [1.0 – 4.1]	4.5 [2.7 – 6.2]	4.7 [3.0 – 6.4]	5.6 [3.9 – 7.5]	6.9 [4.8 – 8.9]	↑
Maximum summer temperature (°C)	22.0 [20.1 – 23.9]	23.8 [21.7 – 26.1]	24.1 [21.9 – 26.4]	24.9 [22.6 – 27.4]	26.4 [23.7 – 29.3]	↑
Minimum winter temperature (°C)	-17.1 [-21.2 – -13.1]	-14.6 [-18.7 – -10.5]	-14.3 [-18.9 – -9.9]	-12.9 [-17.2 – -8.8]	-11.5 [-16.0 – -7.2]	↑

4.1.5 HEAT WAVES

Heatwaves are usually defined as a minimum of a three-day period when temperatures exceed 30°C. In addition to being considered human health and safety hazards, they may also contribute to damaging infrastructure, the environment, and impacting operations and costs of a project. The region is projected to experience more than double the number of annual heat waves in the 2080s compared to the historical mean, growing from 0.4 heat waves per year to 3.3 heat waves per year. The average length of heat waves is also projected to increase from 1.2 days to 5.4 days. Table 10 summarizes the historical values and projections of the number of waves, length of heat waves, and longest spell of days over 30°C for the selected climate grid cell using data from Climate Atlas of Canada.

Table 10 Historic and projected values and trends of indicators representing the increase in heatwaves for 2021-2050 and 2051-2080 for RCP4.5 and RCP8.5 (PCC, 2019)

CLIMATE INDICATOR	HISTORIC MEAN (1976-2005) [RANGE]	NEAR FUTURE (2021-2050) [RANGE]		FAR FUTURE (2051-2080) [RANGE]		TREND
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	
Number of heat waves	0.4 [0.0 – 1.5]	1.3 [0.0 – 3.3]	1.5 [0.0 – 3.5]	2.1 [0.2 – 4.7]	3.3 [0.7 – 6.1]	↑
Average length of heat waves (days)	1.2 [0.0 – 4.0]	2.9 [0.1 – 6.1]	3.2 [0.1 – 6.7]	4.1 [0.5 – 7.7]	5.4 [1.9 – 9.3]	↑
Longest spell of days over 30°C	1.2 [0.0 – 3.5]	3.0 [0.2 – 7.4]	3.5 [0.3 – 8.4]	4.8 [0.8 – 10.8]	7.9 [1.8 – 17.0]	↑

4.1.6 DROUGHTS AND WATER SHORTAGES

Projection data shows an increase in precipitation across all seasons and the number of dry days where rainfall is less than 1mm is projected to remain stable over the century (PCC, 2019). However, **the Palmer Drought Severity Index (PDSI) drought index shows a rapid decrease from 0.2 today to -1.5** on the worst-case scenario (Cook *et al.*, 2015). The PDSI uses readily available temperature and precipitation data to estimate relative dryness. It is a standardized index that generally spans -10 (dry) to +10 (wet), but maps of operational agencies typically show a range of -4 to +4, but more extreme values are possible. This change shows that drought conditions will be more likely in the future.

Table 11 Historic and projected values and trends of indicators representing the increase in droughts and water shortages for 2021-2050 and 2051-2080 for RCP4.5 and RCP8.5 (PCC, 2019)

CLIMATE INDICATOR	HISTORIC MEAN (1976-2005) [RANGE]	NEAR FUTURE (2021-2050) [RANGE]		FAR FUTURE (2051-2080) [RANGE]		TREND
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	
Number of dry days (<1mm)	239.7 [221.3 – 258.6]	239.0 [219.9 – 258.3]	239.0 [220.4 – 256.7]	239.2 [220.2 – 259.0]	239.2 [220.7 – 257.9]	-
PDSI Drought Index	0.2	NA	NA	NA	-1.5 [-1.9 – -1.0]	↓

4.1.7 WILDFIRES

Astotin Creek has not historically been exposed to multiple or large forest fires (Figure 3; NRCan, 2020a, 2020b). However, the surrounding area includes forested areas. This high fuel availability may be an indicator of a relatively high future likelihood of wildfires. Most recent results on the future occurrence of fires in Canada show that Western Canada will see a greater than 50% in the number of dry, windy days that let fires start and spread (Wang *et al.*, 2017). Moreover, fires could burn twice as much average area per year in Canada by the end of the century as it has burned in the recent past (Flannigan, 2020). Confidence on climate projections presented in scientific literature remains moderate due to the climate indicators selected to represent the occurrence of fires and to the overall level of uncertainty in climate projections.

Table 12 **Historic and projected values and trends of wildfire indicators for 2021-2050 and 2051-2080 for RCP4.5 and RCP8.5 (PCC, 2019)**

CLIMATE INDICATOR	HISTORIC MEAN (1976-2005) [RANGE]	NEAR FUTURE (2021-2050) [RANGE]		FAR FUTURE (2051-2080) [RANGE]		TREND
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	
Number of dry days (<1mm)	239.7 [221.3 – 258.6]	239.0 [219.9 – 258.3]	239.0 [220.4 – 256.7]	239.2 [220.2 – 259.0]	239.2 [220.7 – 257.9]	-
Average maximum summer temperature (°C)	22.0 [20.1 – 23.9]	23.8 [21.7 – 26.1]	24.1 [21.9 – 26.4]	24.9 [22.6 – 27.4]	26.4 [23.7 – 29.3]	↑

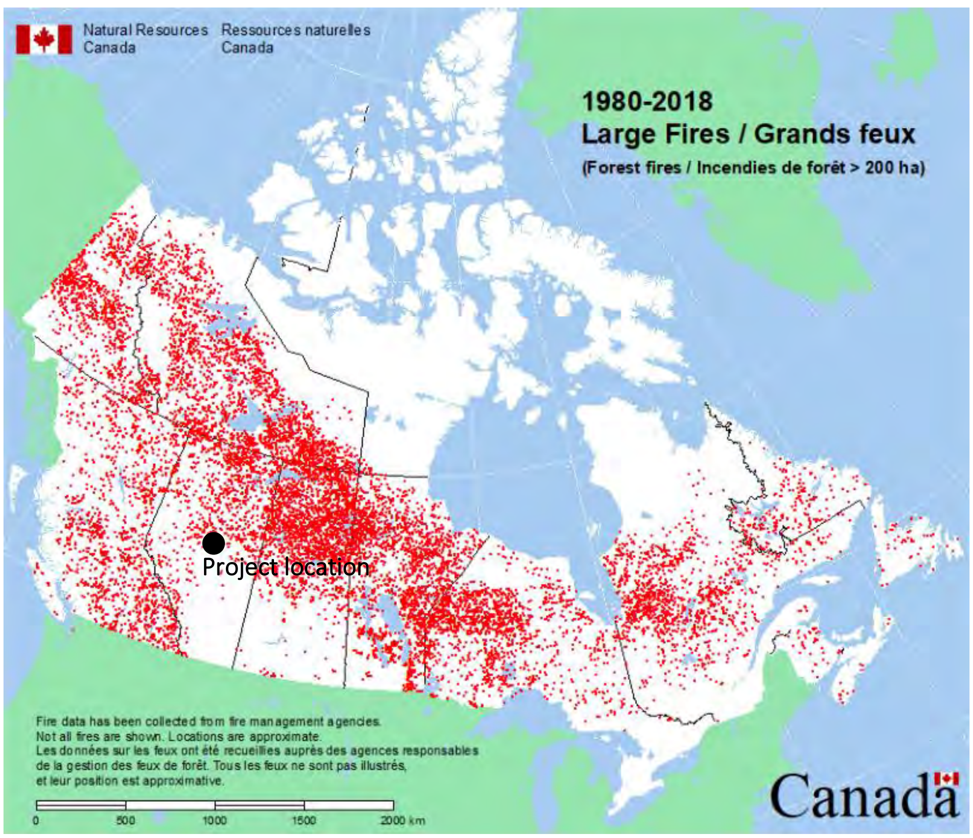

Figure 3 **Forest fires (>200 ha) recorded in Canada for the 1980-2018 period (adapted from NRCAN, 2020b)**

4.1.8 CHANGES IN WINTER CONDITIONS

The increase in winter temperature will lead to **less intense winter conditions**. Snow events will be partly transformed in rain events, which may slightly **increase the risk of landslides**. **Freeze-thaw cycles are likely to be reduced.** Unfortunately, the level of this analysis does not allow to evaluate changes in the seasonality of freeze-thaw cycles. In other northern regions, climate projections suggest a general decrease in the number of annual freeze-thaw cycles, but an increase in the number of winter freeze-thaw cycles. During winter, the ground is generally saturated with water, which will increase the efficiency of frost weathering on geologic material and infrastructures.

Table 13 Historic and projected values and trends in winter conditions for 2021-2050 and 2051-2080 for RCP4.5 and RCP8.5 (PCC, 2019)

CLIMATE INDICATOR	HISTORIC MEAN (1976-2005) [RANGE]	NEAR FUTURE (2021-2050) [RANGE]		FAR FUTURE (2051-2080) [RANGE]		TREND
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	
Number of frost days (<0°C)	196.7 [183.4 – 210.2]	179.1 [159.3 – 198.6]	175.9 [156.7 – 193.8]	168.6 [145.8 – 189.6]	155.0 [131.6 – 178.2]	↓
Number of mild winter days (<-5°C)	137.7 [118.0 – 155.7]	119.5 [97.4 – 140.0]	117.8 [95.0 – 139.1]	109.7 [87.7 – 131.1]	98.0 [71.6 – 122.5]	↓
Number of freeze-thaw cycles	89.2 [71.5 – 107.7]	84.0 [65.0 – 102.8]	80.8 [62.3 – 99.4]	80.0 [61.3 – 99.8]	73.1 [55.2 – 91.5]	↓
Mean winter temperature (°C)	-11.9 [-16.0 – -8.1]	-9.7 [-13.7 – -5.8]	-9.5 [-13.9 – -5.3]	-8.2 [-12.3 – -4.3]	-7.0 [-11.3 – -3.0]	↑

SNOW ACCUMULATION

Historically, the area of the project has received an average of 110.7 cm of snow per year with snow falling between the months of October and May (ECCC, 2020). The greatest snowfall recorded between 1981 and 2010 was 38.8 cm in May of 1997, and the largest extreme snow depth of 62cm occurred in April 1982 following an extreme daily snowfall of 30 cm the day before.

Table 14 Historical snow data for the Elk Island Nat park Station Climate ID 3012275 for the 1981-2010 period (ECCC, 2020)

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	ANNUAL
Mean snowfall (cm)	18.5	11.9	20.6	12.8	5.4	0.0	0.0	0.0	0.1	9.2	15.9	16.4	110.7

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	ANNUAL
Extreme daily snowfall (cm)	11.0	7.0	22.0	30.0	38.8	0.0	0.0	0.0	1.0	18.0	14.7	10.0	NA
Date (yyyy/ dd)	1989/ 30	1984/ 28	1988/ 27	1982/ 14	1997/ 21	1982/ 01	1982/ 01	1982/ 01	1996/ 28	1984/ 17	2003/ 19	1985/ 16	NA
Extreme snow depth (cm)	44	51	59	62	8	0	0	0	0	18	35	43	NA
Date (yyyy/ dd)	1997/ 29	2007/ 23	1982/ 12	1982/ 15	1982/ 06	1982/ 01	1982/ 01	1982/ 01	1982/ 01	2004/ 19	1984/ 14	1996/ 30	NA

While winter and spring precipitations are projected to increase by 15% and 20%, snow formation may be inhibited by the projected increase in mean winter temperatures. Ice days, a measure of days during which the temperature does not exceed 0°C, **are also projected to decrease by two thirds.** Depending on annual variability, a decrease in ice days could result in an increase in rain-on-snow events and associated flooding. Table 15 summarizes the changes in mean winter temperature, mean winter and spring precipitation, and ice days for the project site.

Derksen *et al*. (2019) projected that there would be a decreasing trend in snow water equivalent for the area by 2.5 - 5% per decade for the 2020-2050 time range, which supports a reduction in precipitation falling as snow (Figure 4).

Table 15 Historic and projected values and trends of snow indicators for 2051-2080 and 2071-2100 for RCP4.5 and RCP8.5 (PCC. 2019)

CLIMATE INDICATOR	HISTORIC MEAN (1976-2005) [RANGE]	NEAR FUTURE (2021-2050) [RANGE]		FAR FUTURE (2051-2080) [RANGE]		TREND
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	
Mean winter temperature (°C)	-11.9 [-16.0 – -8.1]	-9.7 [-13.7 – -5.8]	-9.5 [-13.9 – -5.3]	-8.2 [-12.3 – -4.3]	-7.0 [-11.3 – -3.0]	↑
Mean winter precipitation (mm)	62 [37 – 90]	67 [40 – 97]	67 [39 – 100]	69 [42 – 102]	72 [42 – 105]	↑
Mean spring precipitation (mm)	83 [42 – 134]	99 [51 – 162]	94 [47 – 148]	99 [53 – 155]	106 [53 – 165]	↑
Number of icing days	95.2 [73.7 – 115.3]	81.7 [60.9 – 103.0]	82.1 [60.0 – 104.7]	74.9 [53.0 – 96.4]	68.9 [45.3 – 93.4]	↓

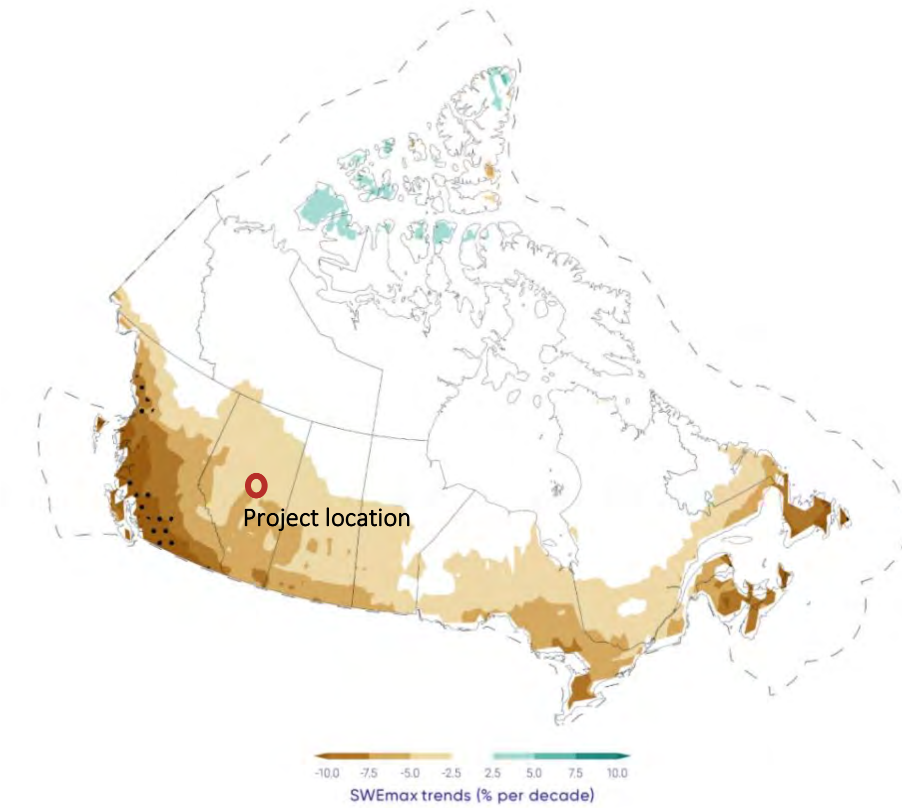

Figure 4 **Projected trends in maximum snow water equivalent, 2020-2050 (adapted from Derksen *et al*., 2019)**

4.1.9 STRONG WINDS AND STORM ACTIVITY

Wind is one of the hardest climate variables to project, both in terms of direction and magnitude. Wind projection is the indirect result of assessing circulation patterns from daily temperature and precipitation outputs from global models. The closest weather station to Astotin Creek for which enough historical wind-related data is available is ECCC's Elk Island Nat Park (ID # 3012275). Table 16 presents some of the values recorded for the 1981-2010 period.

Table 16 **Extreme wind speed values recorded near Astotin Creek for the 1981-2010 period (ECCC, 2020a)**

Indicator	Recorded value (km/h)	Date	Wind direction
Average daily speed	6.4 (mostly to the W)		
Maximum hourly speed	46	2001/05/28	SE

Under the influence of climate change, wind speed is projected to evolve differently depending on the location or the season of interest. Figure 5 represents the evolution of wind speed by the end of the 21st century compared to the most recent period. Changes in the mean wind speeds (top) and wind gusts (bottom) is shown for the 2081-2100 period relative to 1981-2000. No robust trend is found for average wind speed during all seasons and no robust trend is found for extreme winds during winter for the interior of Alberta. Summer extreme winds will decrease in intensity by the end of the century (yellow shade).

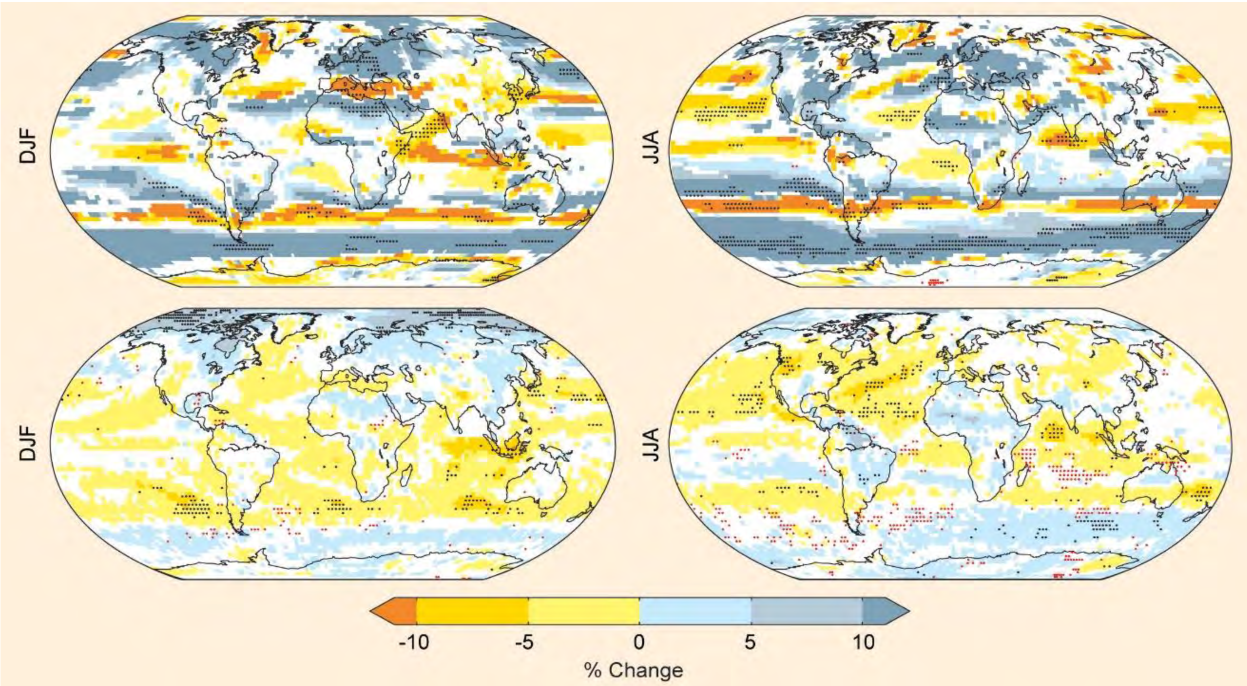

Figure 5 **Changes in the mean of the daily averaged wind speeds (top) and wind gusts (bottom) for the period 2081-2100 relative to 1981-2000 (% change) for December to February (left) and June to August (right) (IPCC, 2012)**

4.2 EXPOSURE ANALYSIS

Exposure is the presence of people, livelihoods, environmental services and resources, infrastructure, or economic, social, and cultural assets in places which could be adversely affected by a changing climate (IPCC, 2014). The aim of this section is to link the climate hazards selected as relevant for the project with the trends in climate indicators presented in the previous sections.

Table 17 presents the likelihood rating for each of these hazards, based on an average of the ratings for the corresponding hazards, using the terminology described in Table 2. **The higher the rating, the greater the increase in the intensity or frequency of the hazards under the influence of climate change.**

Table 17 Likelihood ratings of selected climate hazards for the long-term horizon

CLIMATE HAZARDS		CLIMATE INDICATORS	LIKELIHOOD OF TRENDS (-CONFIDENCE)	MEAN LIKELIHOOD RATINGS
Changes in precipitation	Spring fluvial flooding due to freshet	Mean annual precipitation	2 (-0.5)	**3 – Moderate (*)**
		Mean spring precipitation	2 (-0.5)	
		Mean March temperature	3 (0)	
		Mean April temperature	4 (0)	
		Mean May temperature	4 (0)	
		Annual number of ice days	4 (0)	
		Snow water equivalent	4 (-1)	
	Summer fluvial flooding due to long extreme precipitation events	Mean summer precipitation	1 (-0.5)	**1.2 – Very Low (+)**
		Annual maximum 5-day precipitation	2 (-0.5)	
		Maximum 5-day precipitation in a 30-year period	2 (-0.5)	
	Extreme precipitation	15-min maximum precipitation in 1:100 years	5 (-1)	**4 – High (+)**
		Hourly maximum precipitation in 1:100 years	5 (-1)	
		Daily maximum precipitation in 1:100 years	5 (-1)	
High temperatures	General increase in temperatures	Mean annual temperature	5 (0)	**4.3 – High (+)**
		Maximum summer temperature	4 (0)	
		Minimum winter temperature	4 (0)	
	Heatwaves	Number of heat waves	4 (0)	**4 – High (+)**
		Average length of heat waves (days)	4 (0)	
		Longest spell of days over 30°C	4 (0)	
Droughts	Droughts and water shortages	Number of dry days	1 (0)	**2.5 – Moderate (+)**
		PDSI Drought Index	5 (-1)	
Wildfires	Wildfires	Number of dry days	1 (0)	**3 – Moderate (+)**
		Average maximum summer temperature (°C)	4 (0)	
		Scientific literature	5 (-1)	

CLIMATE HAZARDS		CLIMATE INDICATORS	LIKELIHOOD OF TRENDS (-CONFIDENCE)	MEAN LIKELIHOOD RATINGS
Changes in winter conditions	Low temperature + freeze-thaw cycles	Number of frost days (<0°C)	5 (0)	**4 – High (-)**
		Number of mild winter days (<-5°C)	4 (0)	
		Number of freeze-thaw cycles	3 (0)	
		Mean winter temperature (°C)	4 (0)	
	Snow accumulation	Mean winter temperature (°C)	4 (0)	**2.8 – Moderate (-)**
		Mean winter precipitation (mm)	2 (-0.5)	
		Mean spring precipitation (mm)	2 (-0.5)	
		Number of icing days	4 (0)	
		Snow water equivalent	4 (-1)	
Strong wind and storm activity	Strong wind and storm activity	Global projections	2 (-1)	**1 – Very Low (*)**

* Opposite trends: Final scoring should be considered carefully.
- Exposure decreases with climate change, and thus represents a climate opportunity.
+ Exposure increases with climate change, and thus represents a climate risk.

The exposure assessment concluded that there are strong trends in hazards related to increasing temperatures such as heat waves and changes in winter conditions. Changes in precipitation are less robust but still show a high trend for extreme precipitation indicating an increase in the intensity of storm events and a moderate trend for spring fluvial flooding due to freshet and a decrease during the already-dry summer months. There is a significant data gap for wind and storm related data, but national and global trends point towards an increase in intensity and variability of events.

These probability scores are not representative of the impacts of climate hazards affecting the region. The assessment of consequence and resulting risk level, will specify how infrastructure, services and the population will be affected.

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TECHNICAL NOTE

CLIENT:	Strathcona County		
PROJECT:	Astotin Creek Resiliency Study	**WSP Ref.:**	211-03754-00
SUBJECT:	Preliminary Study on flood occurrence for Astotin Creek	**DATE:**	23 July 2021
RECIPIENT:	Vincent Cormier, Ana Hosseinpour and Kaitlynn Livingstone, WSP Canada Inc.		
C.C.:	N/A		

1 PROJECT CONTEXT

WSP was commissioned to assess how climate change may influence flooding in Astotin Creek, providing Strathcona County with insights on the future occurrence of major weather events that can trigger the degradation of some essential services, infrastructure assets and natural habitats.

The watershed has experienced past agricultural and industrial development, clearing riparian habitat along the creek in some areas, and removing wetlands that could moderate run-off conditions. Changing water flow and volume in some parts of the watershed have suggested a risk of more frequent flooding and need for adaptive management. The creek has flooded three times in the past decade, affecting agricultural lands, roads and private residences.

The County has responded with emergency mitigation measures such as road closures, pumping and monitoring flood conditions to protect County roads and private homes and property. Pro-active management strategies are required to meet the County's public safety and fiscal management obligations, as well as its environmental management responsibilities for sustainable water quality and quantity, biodiversity, and ecological function.

This Technical Note aims at providing preliminary results on what are the drivers of flood events and how these can have a different influence across seasons. A distinction between spring and summer flood events is conducted to identify which mechanisms come into play.

2 TWO TYPES OF FLOOD EVENTS

The cause of a flood can vary depending on the time of year it occurs. Most flood events often happen during the spring and summer months, due to major snowmelt (leading to freshet episodes) and extreme precipitation events (often caused by large depression systems passing through Alberta during summer).

2.1 SPRING EVENTS

By the end of winter, snowpack in plains and mountains reaches its maximum value, while temperatures begin to rise with the onset of spring. Rapid snowmelt can then cause freshet episodes flooding low topographic areas. The Province of Alberta has two separate snowmelt seasons due to its location next to the Rocky Mountains:

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1 Snow accumulates on the plains from November to April with melt typically occurring abruptly over a short period in April;

2 Snow accumulates in the Rocky Mountains from October to April with melt occurring from April to June (i.e. more gradually than in the plains).

Figure 1 shows the evolution of snow cover for both regions illustrating the two different regimes of runoff due to snowmelt in the province.

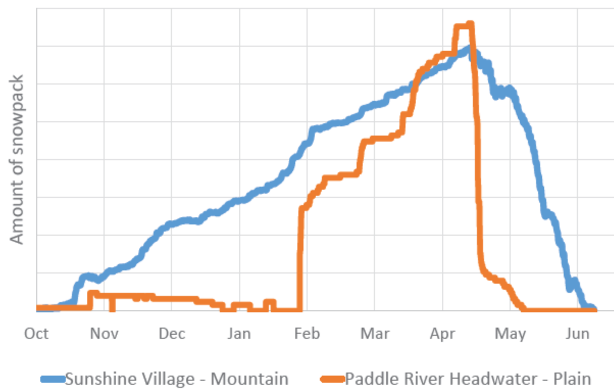

Figure 1 Difference between mountain and plains runoff periods

Source: Government of Alberta (2018)

Astotin Creek is located in the plains, which tends to believe that snowmelt is very abrupt and could cause significant flooding in the Creek's watershed. In general, spring flood events in the plains have the following characteristics:

- It commonly occurs when days are longer, and the surface air temperature rises sufficiently;
- If the rise in temperature is rapid and the water content in snow is high, the risk of flooding from streams is higher;
- In general, the greater the snow in the plains, the greater the risk for localized flooding issues;
- A low gradual change in temperature and night-time temperatures remaining below 0°C can significantly reduce the risk of flooding.

In recent past decades (i.e. since 1980), several episodes with weather conditions leading to flooding have occurred. The four largest events are described in Table 1. The maximum flow values were taken from the historical hydrometric data from ECCC (2021). The closest hydrometric station is the one located at Pointe-aux-Pins (ID 05EB902). Although this station is not directly located in the Astotin Creek watershed, it provides the most representative information for this study (due to its location and the similar topography of both watersheds).

Table 1 Major historical spring events between 1980 and 2020 in Pointe-aux-Pins

Year	Date of occurrence	Annual maximum flow (m^3/s)
1982	April 24	5.88
1997	April 4	4.43

Year	Date of occurrence	Annual maximum flow (m^3/s)
2007	May 5	4.67
2018	April 21	4.63

Source: ECCC (2021)

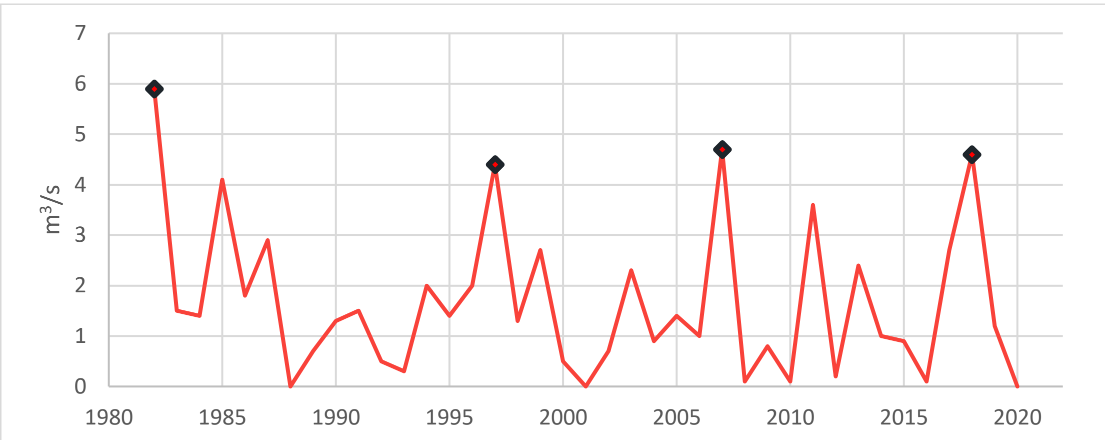

Figure 2 Annual maximum flow in spring in Pointe-aux-Pins

2.2 SUMMER EVENTS

Unlike spring episodes, flood episodes occurring in summer are not due to the melting of snowpack, since the latter has already disappeared with the increase in temperatures during spring months. The increase in river flow is then mainly due to prolonged periods of heavy rainfall. Major events typically occur between June and September, with largest episodes recorded in June in the recent past decades (ECCC, 2021).

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

Year	Date	Maximum flow (m^3/s)
1983	June 26	11.80
1997	June 23	6.76
2011	July 23	6.69

Source: ECCC (2021)

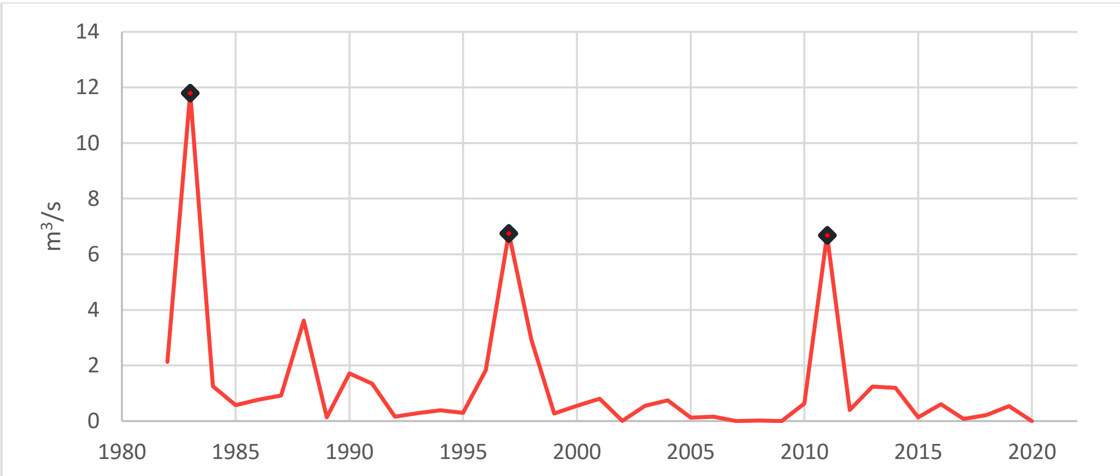

Figure 3 Annual maximum flow in summer in Pointe-aux-Pins

The maximum discharge values are greater in summer than in spring, which suggests that the greatest flooding episodes occur in the summer period and are thus not necessarily due to the melting of the snowpack.

3 METHODOLOGY

The main objective of this preliminary study is twofold:

- To determine which climate parameters have the greatest influence on the occurrence of flood events in spring and in summer;
- To evaluate the likelihood of occurrence of flood events under the influence of climate change.

The approach to meet these objectives here remains at the exploratory stage and only provides preliminary results that should be confirmed by a detailed hydrological modeling assessment of the watershed. The following subsections present the climate datasets selected for the study and the list of climate parameters that can likely be linked to the evolution of water flows (and thus, to the evolution of the occurrence and intensity of flood events).

3.1 CLIMATE DATASETS

The Climate Data portal was developed by the Montreal Computer Science Research Center (CRIM, 2019) in collaboration with Ouranos, PCIC, ECCC, PCC and Habitat Seven. Its goal is to support decision-makers located across Canada and working in a wide range of sectors by providing them with the most up-to-date climate data in user-friendly formats and visualizations. For this study, two different datasets from this portal are considered:

- The portal provides observation data from all meteorological stations in Canada. The Elk Island National Park station is selected for this study as the closest (approx. 30 km) and most representative of Astotin Creek weather conditions (ID: 3012275). Daily data are available from 1982 to 2020 for this station.
- All the results of climate projections come from a set of 24 climate models by interpolation on a 1/12° grid (~ 9 km x 6 km in Astotin Creek) over all of Canada and are bias corrected using historical data of weather stations. Each climate model simulates the climate for the historical period 1950-2005 and for plausible futures over the period 2006-2100. Precipitation projections have been downloaded from the portal for the grid cell centered in Astotin Creek.

3.2 ANALYSIS OF CLIMATE PROJECTIONS

Globally, climate change will result in a long-term rise in the Earth's average temperature. On a local scale, impacts will vary and include shifts in temperature, precipitation, wind, and other weather patterns, including extreme weather events. Broadly speaking, the local climate projections are divided into different commonly used climate scenarios, or 'Representative Concentration Pathways (RCP)' (Van Vuuren *et al*., 2011). For this assessment, we include projections on the most likely active scenario (RCP4.5) and on the passive scenario (RCP8.5).

The passive scenario is modelled assuming the worst case of the 'business-as-usual' approach without any mitigation measures implemented at global scale and a constant increase in GHG emissions until the depletion of fossil fuel stocks (Figure 4). The passive scenario is the trajectory in which most changes are more significant, especially in higher latitudes such as in Canada, where the effects of climate change are exacerbated. Given the current state of global climate negotiations, the passive scenario remains the most likely at this stage, and thus is the scenario chosen for the exposure assessment. This is a reasonable approach to take considering the level of uncertainty and that the impacts under the more moderate active scenarios have similar outcomes at mid-century. Projections of the active scenario are also presented for comparison.

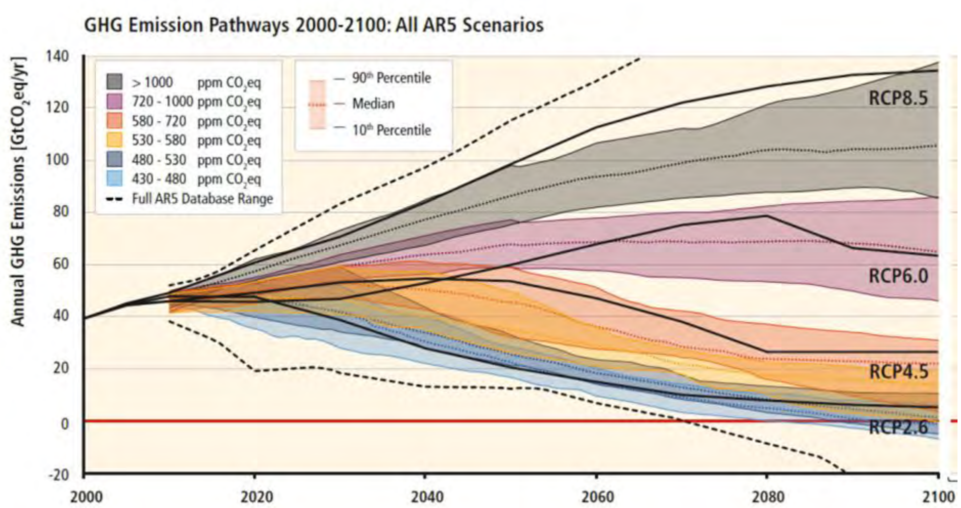

Figure 4 GHG emissions for each RCP scenario until 2100 (Source: IPCC, 2014)

Climate projections are usually presented with a recent baseline, a short-term horizon and a long-term horizon (Table 3).

Table 3 Periods selected for different time horizons

DATA SOURCE	HISTORICAL BASELINE	NEAR FUTURE	FAR FUTURE
Climatedata.ca	1976-2005	2021-2050	2051-2080

3.3 REPRESENTATIVE INDICATORS

As mentioned in previous sections, the occurrence of flood events can be caused by different factors, and most likely a combination of some. A collection of climate indicators is then selected for spring and summer events to investigate possible relationships between maximum flows and timeseries of historical observations.

SPRING EVENTS

The occurrence of freshet episodes can be triggered by rapid snowmelt combined with rising temperatures and high precipitation. A combination of absolute indicators and trends is assessed here to investigate:

- **Absolute indicators**:
  - Mean temperature in April;
  - Minimum temperature in April;
  - Maximum snow depth in March-April;
  - Total liquid precipitation in April;
  - Max 3-day precipitation in April;
- **Trends**:
  - Maximum 48-hour increase rate of temperature in April;
  - Maximum 48-hour decrease rate of snow depth in April;
  - Time interval between maximum snowmelt and maximum spring flow within the same year.

SUMMER EVENTS

The occurrence of summer flood events is mainly caused by heavy precipitation events over a long period of time. Extreme precipitation indicators are then investigated between June and September:

- Maximum 1-day precipitation;
- Maximum 3-day precipitation;
- Maximum 5-day precipitation.

4 PRELIMINARY RESULTS

In this section, Figures illustrate the evolution of key indicators and highlight years when the highest water flows were recorded.

4.1 SPRING EVENTS

TEMPERATURE

As stated in previous sections, statistics of temperature in spring months can play a major role in the occurrence of freshet episodes, since it can influence the pace of snowmelt. Here the evolution of three temperature indicators has been investigated, while considering three assumptions:

1. Freshet episodes often happen when the surface air temperature rises sufficiently;
2. Freshet episodes often happen when the rise in temperature is rapid; and
3. Night-time temperatures remaining below 0°C can significantly reduce the risk of flooding.

Figure 5 shows the evolution of the mean temperature in April. Years when major water flows were recorded do not correspond to periods with significantly high temperatures were observed. **Assumption #1 is then not confirmed for Astotin Creek.**

Figure 6 identifies the annual fastest increase in temperature in a 48-hour period during April. If Fact #2 is valid, then maximum values would occur during years with the highest water flows. Historical data at the Elk Island National Park station does not confirm this relationship, although maximum temperature rise in 1997, 2007 and 2018 are higher than average. **Assumption #2 is then not robustly corroborated for Astotin Creek.**

Figure 7 shows the average daily minimum temperature in April. Low values would reduce the risk of flooding. Historical data does not confirm this hypothesis at the weather station selected. Minimum temperature values during spring with high water flows have even occurred in 1982 and 2018 (years with major water flows in spring). **Assumption #3 is not valid for Astotin Creek.**

In summary, **the evolution of temperature indicators does not explain why high-water flows were recorded in Astotin Creek** between 1982 and 2020.

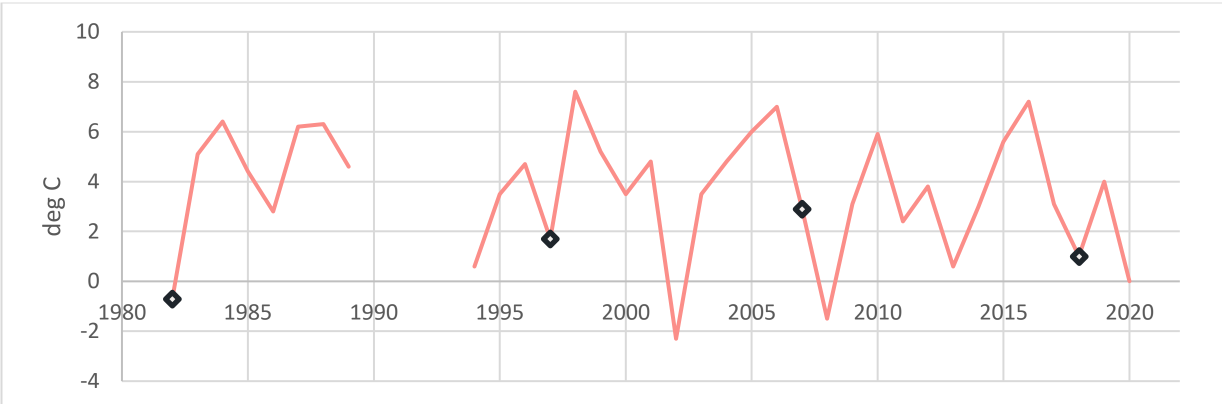

Figure 5 Mean temperature in April at the Elk Island Nat Park station

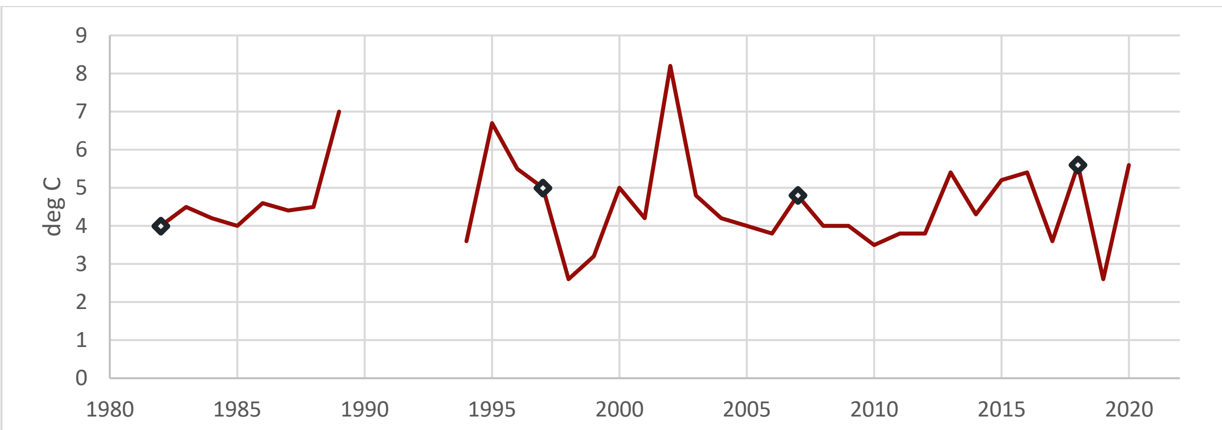

Figure 6 Maximum 48-hour temperature increase in April at the Elk Island Nat Park station

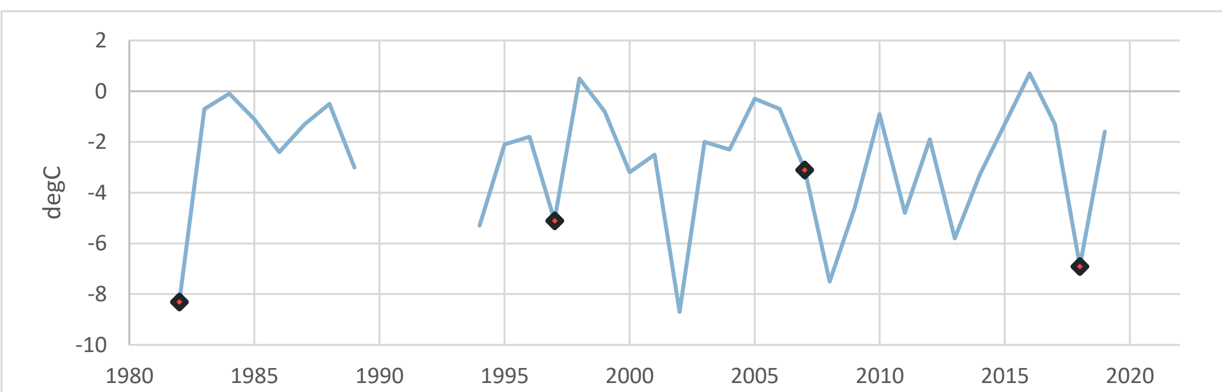

Figure 7 Minimum temperature in April at the Elk Island Nat Park station

LIQUID PRECIPITATION

If snowmelt that could lead to a freshet episode simultaneously comes with heavy liquid precipitation, it could intensify the freshet episode bringing more water (and thus, runoff) in the watershed. Figure 8 and Figure 9 respectively show the total amount of liquid precipitation in April and the maximum amount of liquid precipitation received in three consecutive days. Historical data shows here that heavy precipitation is likely to play a major role in most of major freshet episodes (with at least 30 mm of rain). The major 2018 episode seems to have been generated by other factors. **Heavy precipitation during snowmelt is then likely to play a role in 75% of major events**, according to historical data of the Elk Island National Park station. Note, however, that not all heavy precipitation events resulted in a flood.

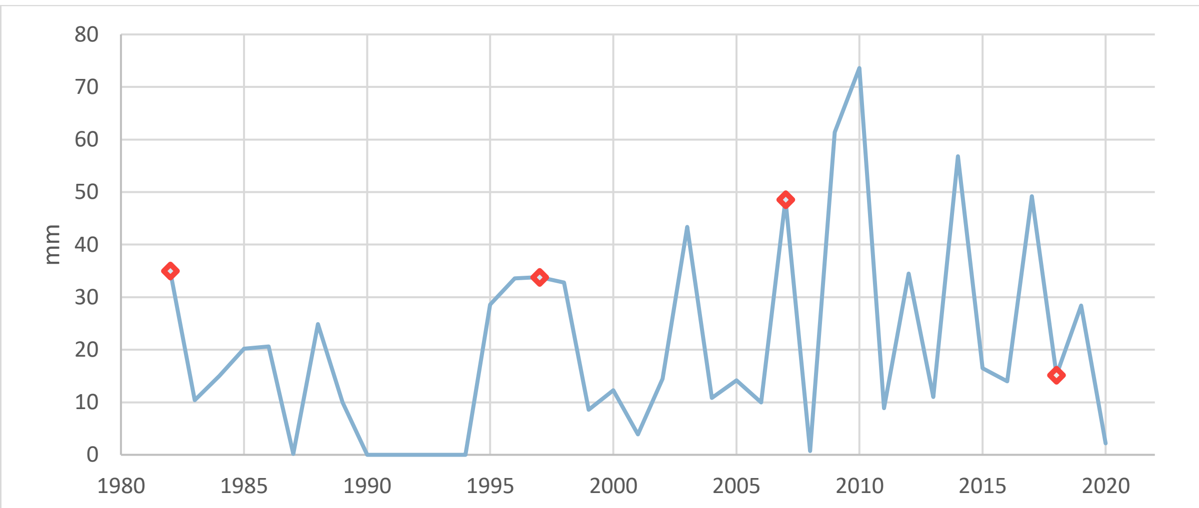

Figure 8 **Total liquid precipitation in April at the Elk Island Nat Park station**

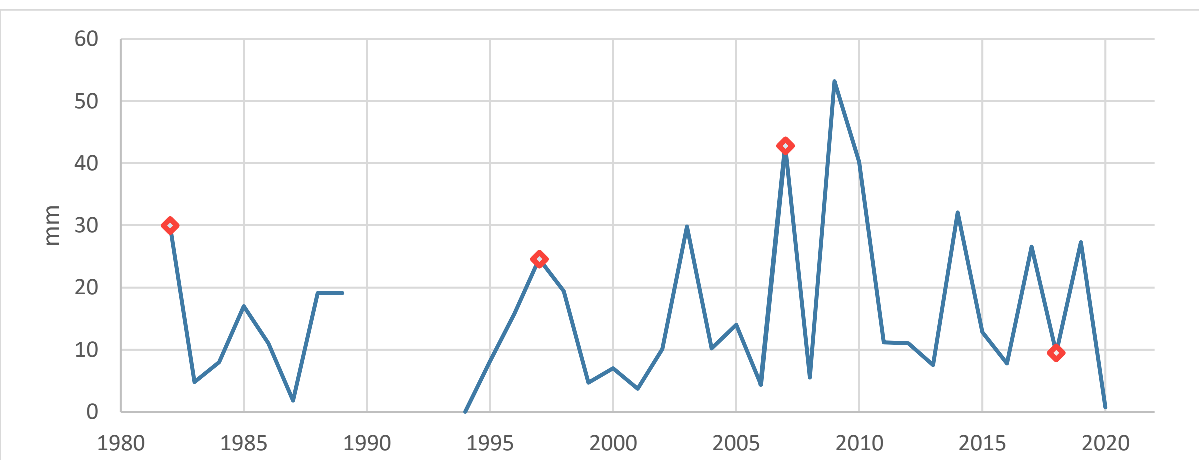

Figure 9 **Maximum 3-day precipitation in April at the Elk Island Nat Park station**

SNOW

As stated in previous sections, snow statistics (accumulation and melting) in spring months is the main contributor in the occurrence of freshet episodes: snow accumulates on the plains from November to March with melt typically occurring abruptly over a short period in April. Large snow accumulation at the end of winter and rapid snowmelt at some point in April is likely to trigger major freshet episodes.

Figure 10 shows that high water flows are observed only when snow accumulation in March and April is significantly higher than the historical average. However, large snow accumulation does not automatically lead to high water flows. Figure 11 illustrates the importance of the maximum pace of snowmelt. The 1982 and 2018 episodes were clearly triggered by a very rapid snowmelt (more than 10 cm in 48 hours). When combined, these two factors were responsible for the largest freshet episodes in historical records. Figure 12 illustrates how the maximum water flows and the maximum pace of snowmelt can be synchronized within a year (less than 10 days), confirming a causal relationship (lower values mean that the maximum water flow and maximum pace of snowmelt occur almost at the same time).

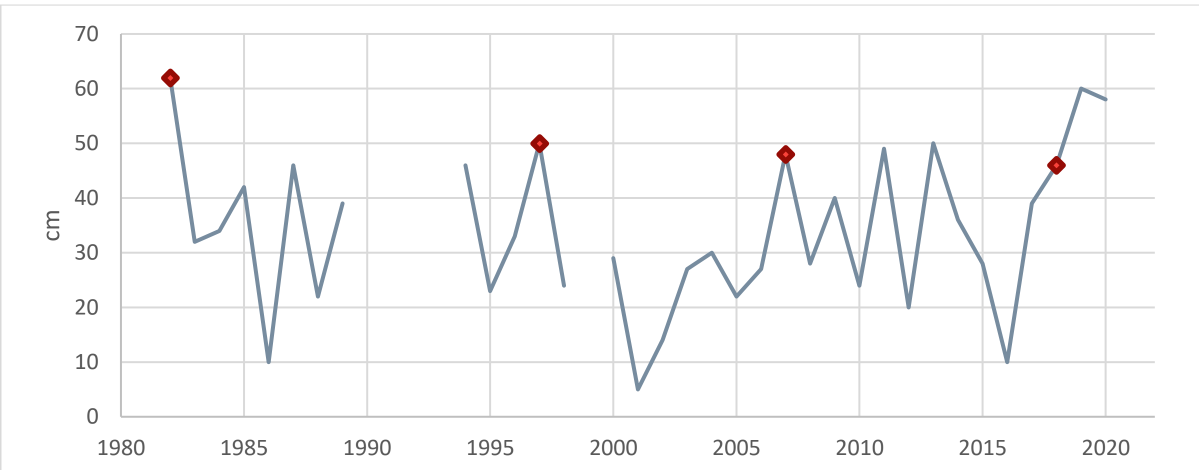

Figure 10 Annual maximum snow depth in March-April at the Elk Island Nat Park station

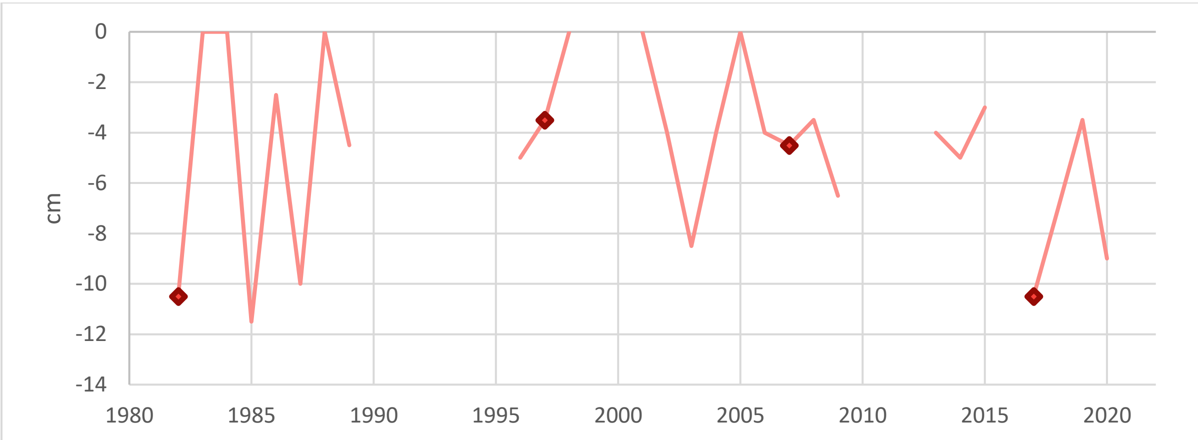

Figure 11 **Maximum 48-hour snowmelt in April at the Elk Island Nat Park station**

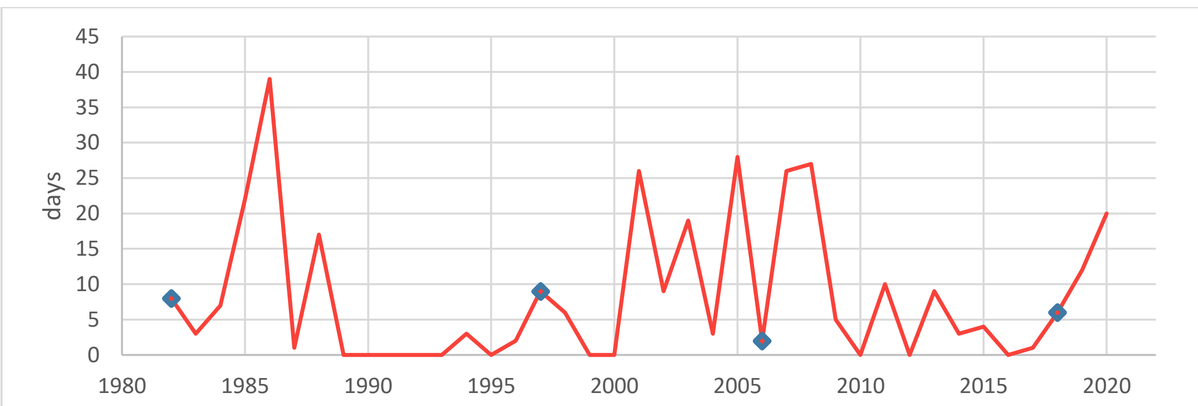

Figure 12 **Time interval between maximum snowmelt and maximum flow within each year at the Elk Island Nat Park station**

The mechanisms causing high flows in the spring are complex and therefore depend on a multitude of factors. Further studies and extensive hydrological modeling would provide a better understanding of the dynamics underlying in Astotin Creek. Yet we can draw the following conclusion from this exploratory analysis.

For a major freshet episode to occur in Astotin Creek, one of the two conditions are necessary (but not always sufficient):

- At least **50 cm of snowpack** should be accumulated by the end of winter; OR
- At least **40 cm with a rapid snowmelt of at least 10 cm** in 48 hours.

An example is given in Figure 13 for the 1982 episode. The maximum snowpack was recorded on April 15th with 62 cm; the maximum snowmelt rate was reached a few days later with 10 cm in 48 hours. The water flow immediately started to increase to reach its maximum value on April 24th.

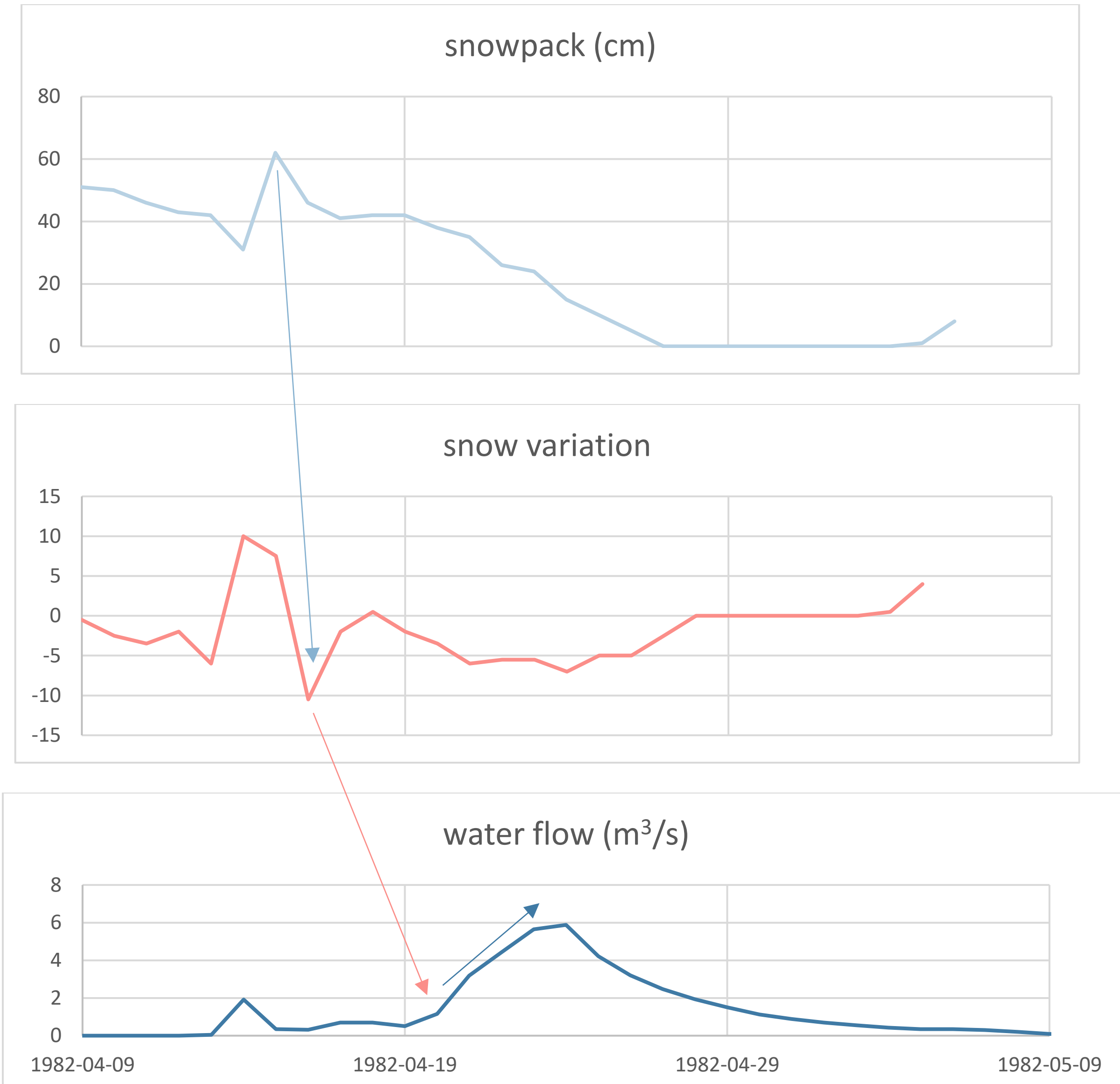

Figure 13 **Evolution of snowpack, snowmelt and water flow in Elk Island National Park / Pointe-aux-Pins in spring 1982**

4.2 SUMMER EVENTS

The occurrence of summer flood events is mainly caused by heavy precipitation events over a long period of time. We are here primarily interested in the one-, three- and five-day extreme precipitation statistics to determine how long the heavy precipitation should last to cause flooding in summer (June to September). After the analysis of historical data, the analysis of climate projections in the medium and long term will show the probability of this type of event in a context of climate change.

HISTORICAL ANALYSIS

Figure 14 shows historical timeseries of precipitations amounts recorded in the rainiest day, period of 3 consecutive days and period of 5 consecutive days during the summer season (June to September). Maximum amounts over a 24-hour period are not correlated with the annual maximum water flows. Maximum 1-day precipitation recorded in 2011 is even below the historical average. However, the three major flood events identified in previous sections occurred when maximum 5-day precipitation statistics were the highest (Table 4). Both indicators show a correlation that would need to be confirmed with a larger dataset.

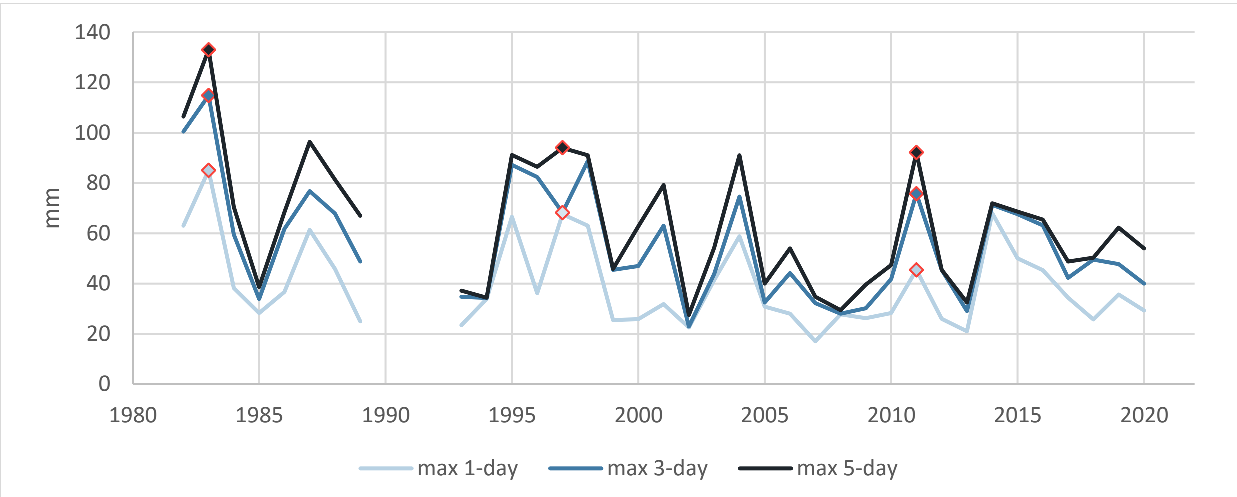

Figure 14 Maximum 1-day, 3-day and 5-day precipitation between June and September at the Elk Island National Park station

Table 4 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 (m^3/s)
1983	133	102	11.80
1997	94	94	6.76
2011	92	61[1]	6.69

According the historical dataset of the Elk Island Nat Park station, the main criteria to trigger a flood event in the summer season is a **maximum 5-day precipitation higher than 90 mm between June and September**. If such an event occurs, **there is approximately a 40% chance of flooding** in Astotin Creek.

CLIMATE PROJECTIONS

Using climate projections of CRIM (2019), the evolution of the likelihood of occurrence of such an event (maximum 5-day precipitation higher than 90 mm) can be assessed with 16 climate models under two emission scenarios.

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

Table 5 shows the return periods of an accumulation of more than 90 mm of rain in five consecutive days between June and September (brackets represent the 10th and 90th percentiles of the inter-model spread). During the historical period, models display a return period of approximately eight years, which is consistent with observation data (Figure 14). In a relatively short-term, both emission scenarios exhibit similar results showing a decrease in the return period, meaning that this type of event will occur more often in the future. On the long term, RCP8.5 shows more pessimistic results with a return period of less than six years. In other words: **by 2051-2080 without any mitigation measures, there would be a 40% chance of major flooding every six years on average due to heavy precipitation episodes during summer months.** Note that confidence in these results remains low (consistently with results of the Climate Change Exposure Assessment) due to high discrepancies across climate models.

Table 5 Return periods of maximum 5-day precipitation higher than 90 mm in Astotin Creek during summer months

[years]	1976-2005	2021-2050	2051-2080
RCP4.5	**8.1** [5.5 – 20.0]	**6.7** [3.8 – 15.0]	**6.4** [3.8 – 15.0]
RCP8.5		**6.8** [3.5 – 20.0]	**5.8** [3.3 – 15.0]

A monthly analysis of the evolution of the maximum 5-day precipitation statistics shows that events with more than 90 mm are very likely occurring during summer months (June to September, Figure 15). Lower monthly values are due to the fact that major episodes do not necessarily occur each year in the same month. Monthly distributions are then flattened compared with annual statistics. The evolution of the summer (June to September) maximum 5-day precipitation is similar to the evolution of the annual maximum 5-day precipitation described in the Technical Note on the Climate Change Exposure Assessment: the annual maximum systematically occurs during summer months.

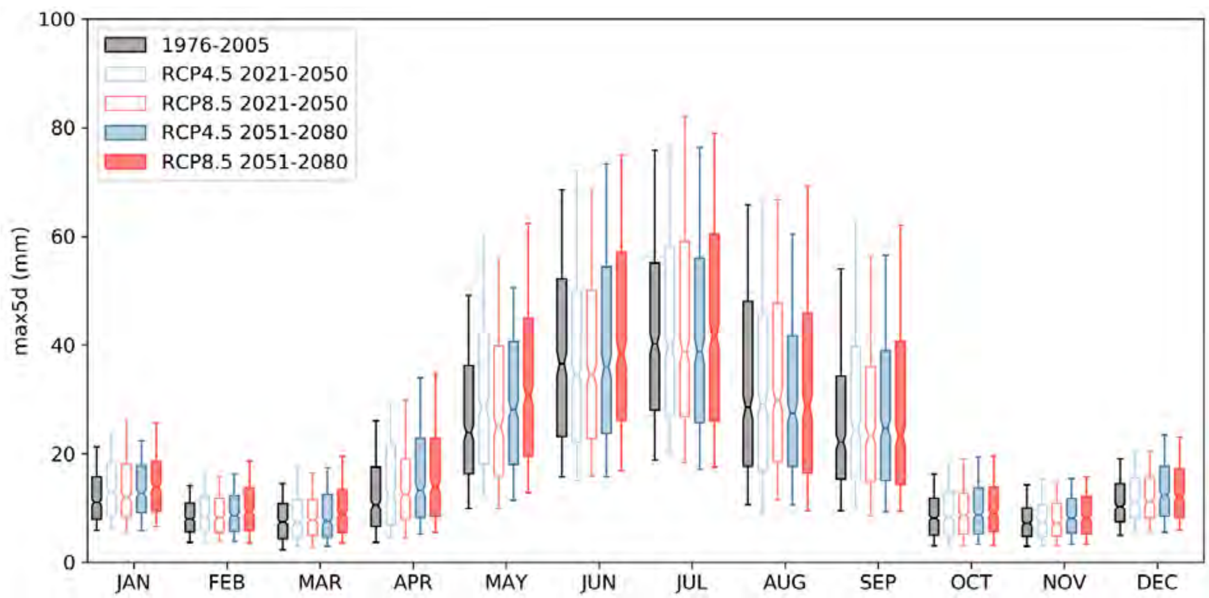

Figure 15 Monthly maximum 5-day precipitation in the historical period and under two emission scenarios in Astotin Creek

Note: Boxes represent the 25th, 50th and 75th percentiles of the inter-model spread, whereas whiskers represent the 10th and 90th percentiles.

In the future, this pattern will likely not be modified for most months. However, given inter-model spread displayed for May values, major precipitation events with more than 90 mm in five days could happen a bit earlier in the year by the end of the century. In the case of a late snowmelt following a large snow accumulation at the end of winter, this could trigger late spring floods that never occurred in the historical period. However, it is important to note that snowpack is very likely to be reduced by a significant increase in temperature for all seasons. A major snowmelt in May with an extreme precipitation event of more 90 mm in five days remain extremely unlikely even under pessimistic circumstances.

5 CONCLUSION

This exploratory analysis allowed us to identify several mechanisms that could be the cause of flooding events. Although the identification of key factors leading to a spring flood remains complex, large snowpack at the end of winter and rapid snowmelt have been shown to be the main drivers of flood severity. To trigger a spring flood, observations show that at least 50 cm of snowpack should be accumulated by the end of winter; or at least 40 cm with a rapid snowmelt of at least 10 cm in 48 hours.

A causal relationship has been clearly identified between the evolution of the maximum 5-day precipitation values and the maximum waterflows during summer months. With an amount higher than 90 mm, there is a 40% chance of flood occurrence in the watershed. During the historical period, a 90 mm event has a return period of eight years. This number is likely to be reduced over the years and reach less than six years by 2051-2080 without any mitigation measures.

The most extreme precipitation events are likely to occur between June and September, and this is the case even under the influence of climate change. A 5-day precipitation event of more than 90 mm may occur in May but will remain extremely rare and will very unlikely happen during a major snowmelt episode.

The results of this technical note are to be considered with caution. Observation data has been recorded by only one weather station located 30 km from Astotin Creek for the 1982-2020 period. Dynamics of spring flood events remain very complex and require further analysis and a hydrological modeling exercise considering as many climate indicators as possible.

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