BOW RIVER WATERSHED

Prioritizing Hydrologically Significant Natural Assets

Project Report

Prepared by Suzanne Marechal, Geo-Libre Inc.
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Disclaimer

Land Stewardship Centre (LSC) is pleased to contribute to the production of this project through the Watershed Stewardship Grant Program, funded by Alberta Environment and Parks. LSC is committed to working with stewardship groups to increase public awareness of the importance of the grassroots initiatives that are having a positive impact on watersheds, water quality and communities across Alberta. Opinions expressed in this publication are those of the core group and not necessarily LSC's.

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The Bow River report and its associated maps were prepared by Suzanne Marechal, Geo-Libre Inc., September 2018.

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- Shannon Frank – Oldman River Watershed Council (OWC)
- Dr. Stefan Kienzle – University of Lethbridge Geography Department
- Oriano Castelli – Alberta Environment and Parks
- Kristi Stebanuk – Cows and Fish
- Kelsey Cartwright – Cows and Fish
- Suzanne Marechal – Geo-Libre Consulting
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1. Executive Summary

Effective conservation and watershed management efforts should be informed by clear, accessible and reliable baseline information about the landscapes they seek to influence. When working at a watershed scale, there is a need to identify areas with natural assets that provide important hydrologic services, like water provision, flow regulation and water purification. Understanding the location of these areas — or hydrologically significant areas (HSA) — can inform decision making on a variety of scales, whether it is a planner drafting a municipal plan or a land trust prioritizing potential project areas.

The HSA conservation planning tool is a unique way to consider the importance of hydrology at a watershed or local scale. It uses a systematic approach that is transparent and repeatable, allowing for future updates or expansion. Partners from across sectors are encouraged to use the maps generated through this project as a decision-support tool to inform conservation, development and stewardship activities.

2. Overview

Watersheds, or regional drainage basins, are complex natural systems influenced by social, economic, cultural and ecological dimensions. When addressing land and water management, it is effective and logical to make decisions using a watershed perspective. The effect of development in one part of the system will impact the quality of the environment, both locally and downstream.

Regional are interested in land-use planning and development that supports socio-economic prosperity and overall watershed health and resilience. Increasingly, partners from across sectors are working to conserve and steward areas that provide multiple benefits, helping to mitigate floods and droughts while enhancing water quality.

When working at a watershed scale, there is a need to identify areas with natural assets that provide important hydrologic services, like water provision, flow regulation and water purification. Understanding the location of these areas — or hydrologically significant areas — can inform decision making on a variety of scales, whether it is a planner drafting a municipal plan or a land trust prioritizing potential project areas.

In recent years, the Government of Alberta has invested in the ability of local landscapes to provide benefits like flood and drought mitigation, through programs like the Watershed Resiliency and Restoration Program (WRRP). In 2017, the WRRP helped fund a project to map hydrologically significant areas in the Oldman River watershed, and this approach has since expanded to the Bow River and Red Deer River watersheds.

In this report, we summarize the methodology and results of a project to map hydrologically significant areas across the Bow watershed, recognizing the importance of these areas for watershed health and resilience. We also present a new online tool to support a variety of stakeholders — municipalities, stewardship groups, land trusts and more — to undertake planning and conservation efforts through a lens of water.

What is a hydrologically significant area?

This report defines hydrologically significant areas (HSAs) as areas with natural assets that, if preserved in a natural state, provide beneficial hydrologic services, like water provision, flow regulation and water purification. An HSA is not a formal designation; instead, it is a term to help understand the importance of landscapes through the lens of water and aligns with watershed resilience thinking.

Why did the Nature Conservancy of Canada undertake this project?

The key objectives of the project were to:

- Evaluate and map natural assets that support healthy hydrologic functions on lands that will potentially be developed.
- Facilitate conservation actions for multiple user groups by identifying priority landscapes in their focal areas.
- Support a shared understanding, participation and partnerships in long-term planning across the watershed.

The Nature Conservancy of Canada (NCC), in collaboration with partners, produced this report and associated map products to support planning and decision making, and to inform conversations within the Bow River watershed at various scales. The partnership was initiated with the realization that both organizations were working toward similar objectives and as an opportunity to leverage expertise and funding.

There was a common understanding between NCC and partners that a publicly available map of HSAs would help facilitate current and future conservation efforts and improve access to information that can support land use planning and decision making. A web portal where HSA maps for the Red Deer, Bow and Oldman River watersheds can be viewed is now available online and can be accessed through the NCC website.

The HSA web portal is an interactive interface that allows users to view hydrologically significant areas in combination with either data that a user wishes to upload, or geo-administrative, value-added or model input layers that are readily available in the platform. Looking at HSAs with other information will aid in regional or local assessments.

When to use hydrologically significant area information?

The principal intended use for the HSA map is as a decision-support tool to inform land use, watershed and conservation planning. The high-resolution map can be used as a reference, in conjunction with other management tools for land evaluation, development planning, stewardship decision support and landowner engagement. Identifying areas that are important hydrologically is a crucial first step in ensuring that a landscape's hydrologic value is considered in land use planning and development.

Examples of how the map output can be used to support decision making include:

- Identifying lands that land trusts may want to target for land conservation.
- Identifying lands that watershed or riparian stewardship groups may want to target for best management practices (for example, grazing and riparian health).
- Supporting municipal planning around watershed and headwaters health by identifying areas that need to be protected or may not be compatible with certain land uses.
- Supporting provincial planning around recreation and industrial activity on public lands.
- Identifying overlapping landscape values by comparing the maps to other datasets (e.g., important watershed features or wildlife habitats, range maps for species at risk, provincially designated Environmentally Significant Areas, Key Wildlife and Biodiversity Zones).

How were hydrologically significant areas created?

The HSA mapping tool was developed using a GIS spatial overlay model that incorporated relevant and representative landscape data. Six landscape inputs (layers) were created to identify areas that substantially contribute to hydrologic health. The inputs were derived from credible, open-source data that covered the extent of the watershed. A map output depicting HSAs was generated by overlaying the six inputs. By using a conservation-minded systematic approach, the intent was to create defensible, objective, repeatable and expandable results that can be modified as new inputs or updates become available.

The remainder of this report will detail the analytical methodology used to identify HSAs, and the results and limitations of the study.

3. Introduction

In response to recent flooding, population growth and climate fluctuations, watershed stakeholders in the Bow River Basin have become more and more interested in maintaining and improving watershed resilience. Actions that help mitigate floods and droughts while enhancing water quality through proactive land management and conservation have become increasingly important.

The purpose of this report is to describe the objectives, methods, results and potential uses of the project, which was developed for the Bow River Watershed using GIS (geographic information systems) to create maps that identify and prioritize areas that can help facilitate stewardship, planning and conservation goals for a variety of potential user groups.

Healthy, natural landscapes are crucial in supporting beneficial hydrologic functions and maintain healthy watersheds. Their natural assets have the capacity to absorb and store excess precipitation, slowing overland flow and releasing water over longer periods. They also have the ability to reduce erosion and filter sediments and contaminants.

To assist watershed stakeholders with decisions around land management and conservation, a spatial model was developed by the core group based on relevant and representative landscape data. Using the results from the model, maps were generated that prioritize hydrologically significant areas. The high-resolution map products created can be used as assessment tools or for reference purposes in land evaluation and landowner engagement.

The key objectives of the project aim to:

- Evaluate, high-grade and map natural assets that support healthy hydrologic functions on lands that are at risk of development;
- Facilitate conservation action for multiple user groups by identifying priority landscapes in their focal areas; and
- Support partnerships where conservation interests overlap.

Examples of how the map outputs might be used include:

- Identifying lands that land trusts may want to target for land conservation;
- Identifying lands that watershed or riparian stewardship groups may want to target for best management practices (for example, grazing and riparian health);
- Supporting municipal planning around watershed and headwaters health by identifying areas that may not be compatible with certain land uses;
- Supporting provincial planning around recreation and industrial activity on public lands; and
- Identifying overlapping landscape values by comparing the maps to other datasets, such as areas that support both watershed health and wildlife habitat, helping to bring more stakeholders to conservation efforts in an area.

Geo-Libre Inc., in collaboration with NAWMP, BRBC, the City of Calgary, NCC, SAIT, SALTS and WSLT, produced this report and associated map products for the Bow River Watershed.

The partnership was initiated with the realization that many of the collaborators were working on projects with similar objectives. In an effort to maximize expertise and minimize costs, the group decided to work collectively.

Finally, there was a common understanding among the collaborating organizations that a publicly available conservation priority map would help facilitate current and future coordinated conservation planning and implementation. Next phases will include stakeholder outreach to gain feedback and support. Maps will also be made available online during the next phase.

4. Methods

The approach used closely follows that developed for SALTS Conservation Priority Mapping Project in the Oldman River Watershed, which was generated by Associated Environmental (Associated Environmental, 2018). This methodology also focuses on identifying hydrologically significant areas for land conservation purposes. The approach was based on work described in Barten and Earnest (2004) and the Source Water Protection Handbook published by the Trust for Public Land the American Water Works Association (2005). Collaborating with SALTS on the methods used for the Oldman River Watershed project ensures that the mapping products that were developed are consistent and transferable across watersheds.

The priority mapping method followed these steps:

- Data rationalization;
- Data collection and verification;
- Attribute classification, scoring and weighting;
- Layer overlay and final score calculation; and
- Map product creation.

The core group of conservation experts and watershed stakeholders were consulted three times during the Bow River project development to discuss design, rationalization, data layers, weighted overlays and mapping products.

Valuable input was also obtained during a workshop held on October 30, 2017, for the Oldman Watershed. Participation included both the technical advisors and stakeholders described in Figure 1.

4.1 Data Rationalization

Six landscape layers were selected for their representation of natural assets. If left undeveloped, these natural assets will provide hydrological benefits to the watershed. The assets identified represent key water quantity and quality functions, which provide resilience during flood and drought conditions, prevent water quality degradation and therefore maintain overall watershed health. Table 1 identifies the data used in the analyses and the rationale behind choosing each input.

Figure 1: Conservation priority mapping collaboration.

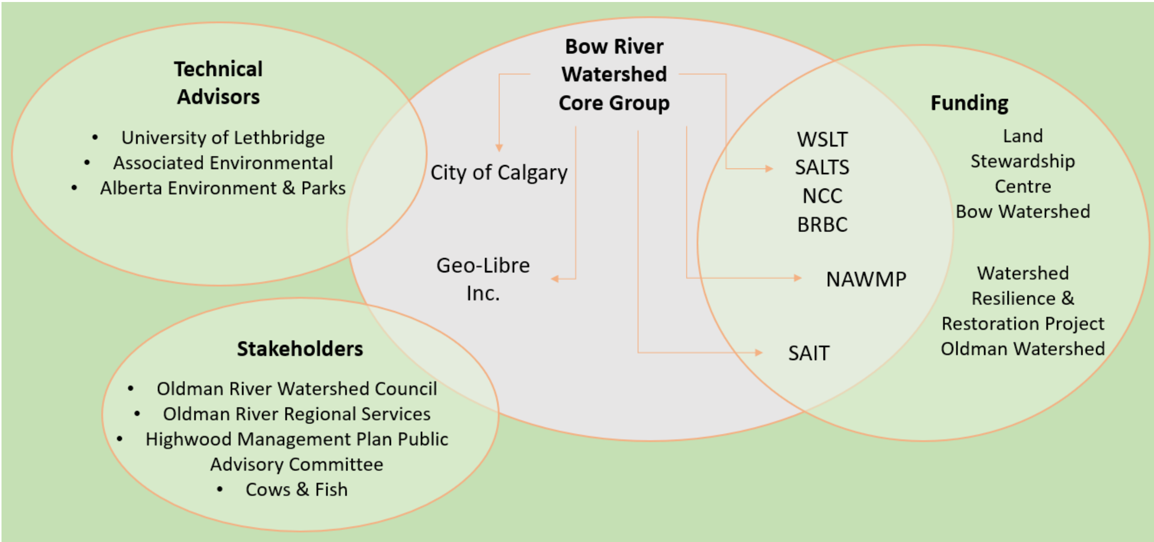


Table 1: Rationale behind the choice of landscape layers.

Layer	Rationale
Precipitation	Areas of higher precipitation increase source water input and replenish groundwater.
Areas proximal to watercourses, lakes and wetlands	These areas, if protected in their natural state, moderate flows (attenuating downstream floods and droughts), promote water quality by filtering water and inhibiting eroded material from entering water systems and stabilize stream banks.
Groundwater vulnerability	Regions with a higher groundwater vulnerability index have coarser textured soils and are more permeable, absorbing water and reducing overland flow after rainfall events.
Land cover	Multiple processes and interactions between water and naturally vegetated zones (for example, interception, absorption, evapotranspiration and infiltration) have the effect of slowing surface flows, storing water and improving water quality.
Slope	Flat areas provide opportunities for pooling and promoting soil infiltration after rainfall events. Developing moderate to steep slopes exacerbates runoff and erosion after rainfall events.
Surficial geology	If developed, areas with erodible surficial material are more vulnerable to erosion.

4.2 Data Collection

4.2.1 Precipitation

Mean annual precipitation (MAP) data for 30-year normals (1961–1990) were downloaded for western North America from Dr. Andreas Hamann's climate data website (Hamann, Andreas Hamann's Website, 2013). The data was developed using the parameter-elevation regressions on independent slopes model (PRISM), which uses physiographic information to better predict climate patterns in mountainous terrain (Hamann, Wang, Spittlehouse, & Murdock, 2013). The one-kilometre resolution point data was extracted for the Bow River Watershed and interpolated using the natural neighbours method.

4.2.2 Areas proximal to watercourses, lakes and wetlands

Below is a description of the development of datasets for watercourses, lakes and wetlands. Once each of these pre-analyses was completed, the layers were merged to make one single layer representing proximity to water.

Watercourses

The following open datasets were used to represent the areas proximal to watercourses:

- *1:20,000 Base Feature Hydro Network,* collected 2004 (AltaLIS, 2017);
- *Lotic Riparian – DEM derived*, collected 2011 (Alberta Government, 2017); and
- *Digital Flood Hazard Mapping*, collected 2015 (Alberta Government, 2015).

Aqueducts, canals, rivers, oxbows and streams were selected from the hydrology network and buffered by 250 metres. These linear hydrological features were then merged with the digital elevation model (DEM)-derived riparian zones associated with streams and rivers and 100-year flood hazard areas (overland flow, floodway and flood fringe zones) to include areas proximal to watercourses.

The prime purpose of creating a vegetated buffer zone, in this case, is to insulate water bodies that are at risk from potentially damaging external influences through nearby development or conversion. The 250-metre buffer used in this study is larger than those currently specified by Alberta's standards and guidelines for development beside watercourses. The rational for this was to ensure that we considered the tremendous variability that exists throughout the watershed and the many localized factors that can influence the effectiveness of a buffer. It is recognized that buffer effectiveness can be affected by variety of factors, such as:

- Land use and types of stressors associated with development;
- Sensitivity of the features and/or functions of concern (that is, position in the landscape, area and shape of the feature); and
- Biophysical factors (hydrologic dynamics, slope, vegetative composition of the buffer, soils) (Beacon Environmental Ltd., 2012).

Also, we wanted buffers to be “wide enough” to potentially include terrestrial protection zones (a riparian area buffer that can help control concentrated erosion flow) (Beacon Environmental Ltd., 2012). These larger buffers were selected as many partners are interested in both riparian and upland habitat, which support the healthy functions of waterbodies.

Wetlands and lakes

To represent the areas proximal to lakes and wetlands, the following datasets were collected:

- *Eastern Irrigation District Wetlands*, collected by Ducks Unlimited Canada in 2017 (Completed 2018);
- *Alberta Merged Wetland Inventory*, collected 1998 to 2016 (Alberta Government, 2017);
- *Foothills and Mountain Wetland Data*, collected 2014 (Morrison, Westbrook, & Bedard-Haughn, 2014); and
- *1:20,000 Base Feature Hydrology Polygons,* collected 2004 (AltaLIS, 2017).

The Eastern Irrigation District of the Alberta Merged Wetland Inventory was updated with the 2018 Ducks Unlimited Canada Wetland Inventory. This updated wetland inventory was merged with the foothills and mountain wetland dataset and the AltaLIS reservoir, lakes and wetland hydrology polygons. It was then buffered by 50 metres to create areas proximal to water bodies. Buffering distances were determined based on *Develop with Care Guidelines* (British Columbia Government, 2014).

4.2.3 Groundwater vulnerability

The Alberta Government *Groundwater Vulnerability* dataset (2002) was used to represent soil infiltration potential. Groundwater vulnerability indices represent how efficiently surface contaminants move into potential shallow aquifers. They are ranked as low, medium, high and very high. In the assessment of groundwater vulnerability, the depth to the aquifer and types of geological materials above them are taken into consideration (Alberta Government, 2011).

4.2.4 Land cover

The Agriculture and Agri-Food Canada *2016 Annual Crop Inventory* dataset (Government of Canada, 2016) was used to characterize natural areas (forest, grassland and shrubland), croplands and other areas (developed, exposed, rock/rubble, snow/ice). Grasslands include both native and tame grasses. Tame grasses are composed of pasture and forage lands.

4.2.5 Slope

Slope surfaces were created using a 25 metre x 25 metre digital elevation model (DEM) supplied by AltaLIS (2017).

4.2.6 Surficial geology

The 2013 *Surficial Geology* open dataset (Alberta Geological Survey, 2016) was included to describe the erosion potential of surface material. Erosional potential classes for the various surficial deposits were adopted from the Mapping and Assessing Terrain Stability Guidebook (British Columbia Government, 1999).

4.3 Dataset Publication Date and Resolution

Open source spatial data available across the Bow River Watershed were used in the mapping model. Certain datasets were not available in Banff National Park, so final mapping did not include results for this region. A priority was to find the most current and highest resolution data available. Table 2 lists the publication date and map scale or resolution of each dataset used in the project.

Table 2: Publication date and resolution of landscape layers.

Layer	Dataset	Map Scale/Resolution	Publication Date
Precipitation	1961-1990 PRISM Interpolated	1 m x 1 m	2013
Proximity to watercourses	Lotic Riparian – DEM derived	1:20,000	2011
	Flood Hazard Mapping	Variable	2015
	AltaLIS Hydrology Polygons	1:20,000	2004
Proximity to wetlands and lakes	Alberta Merged and Ducks Unlimited Canada Wetland Inventory	30 m x 30 m Newly added areas accurate to within 5 m	2016 and 2017
	Hydrology Polygons	1:20,000	2004
	Mountain and Foothills Wetlands	1:30,000	2014
Groundwater vulnerability	Groundwater Vulnerability	1:250,000	2009
Land cover	Annual Crop Inventory 2016	30 m x 30 m	2016
Slope	DEM (AltaLIS)	25 m x 25 m	1996–2002
Surficial Geology	Surficial Geology	1:1,000,000	2013

4.4 Landscape Layer Scores

Scores were assigned to features within a landscape layer based on the rationale established in Table 1. Scores range between 1 and 4, with 4 representing the highest.
Table 3 provides an overview of score and classification divisions for each landscape layer.

Table 3: Scoring and classification of landscape layers.

Layer	Score and Classification Divisions				Natural Asset
	4 Very high	**3 High**	**2 Moderate**	**1 Low**	
Precipitation (mm)	> 762 mm	597–761 mm	432–596 mm	266-431 mm	Provision of clean drinking water.
Proximity to watercourses (m)	≤ 250 m	n/a	n/a	> 250 m	Regulate water quantity and quality by filtering and storing water, buffering water systems and mitigating floods and droughts.
Proximity to wetlands and lakes	≤ 50 m	n/a	n/a	> 50 m	
Groundwater vulnerability	Very high	High	Moderate	Low	Regulate water quantity by retaining water through infiltration, and regulate water quality by reducing overland flow after rainfall events.
Land cover	Forest, grassland (native/tame), shrubland, water	n/a	Cropland	Developed or exposed land	Regulate water quantity by retaining water through infiltration, absorption and evapotranspiration, and regulate water quality by preventing unnecessary runoff and stabilizing shorelines to prevent erosion.
Slope (%)	16–30%	10–15%	0–9%	> 30%	Regulate water quantity by retaining water through infiltration and slowing down overland flow, and regulate water quality by preventing runoff and erosion.
Surficial geology	Lacustrine, glacio-lacustrine, eolian, organic	Glaciofluvial, fluvial	Moraine	Colluvium, bedrock, glaciers	Regulate water quality by preventing exposure and erosion of erodible material.

4.5 Landscape Layer Score Distributions

The following figures show the classification and scoring distribution for the various landscape layers used in the mapping of hydrologically significant areas within the Bow River Watershed.

Precipitation classifications (Figure 2) were delineated by aligning natural sub-regions (Figure 3) with mean annual precipitation (MAP) results to create four precipitation classes. Regions with higher MAP were given higher scores.

Figure 2: Mean annual precipitation value distribution within the Bow River Watershed.

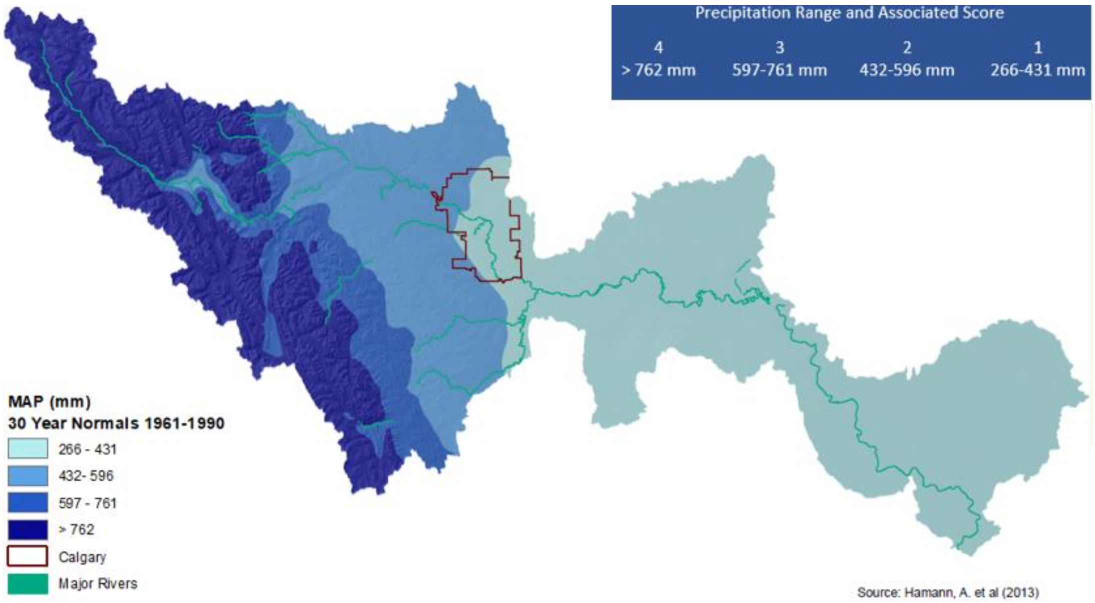
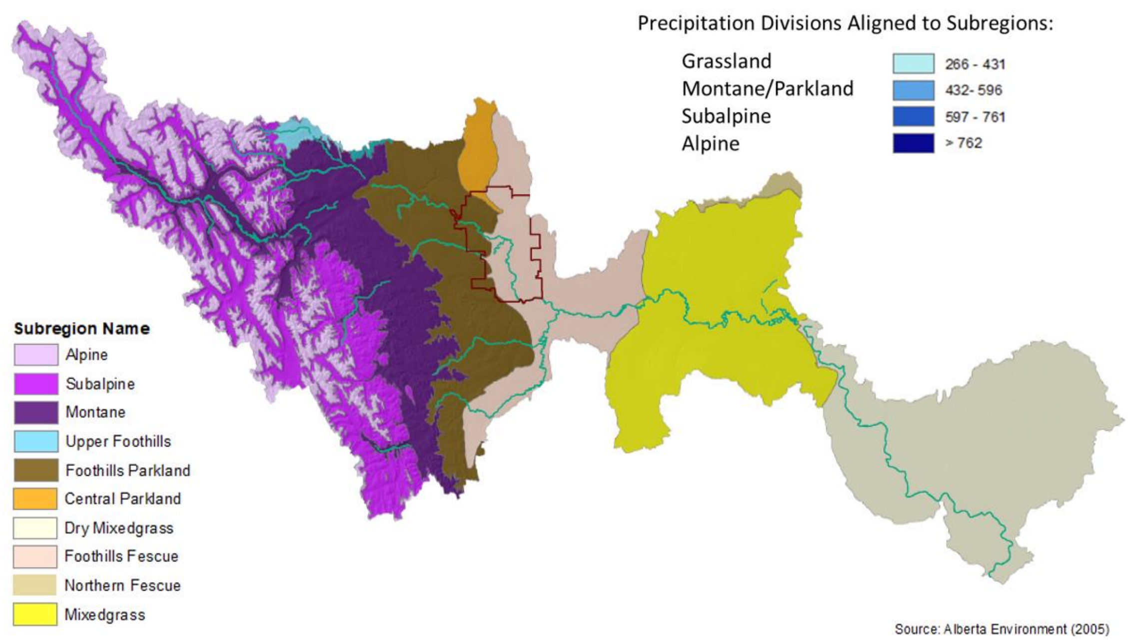
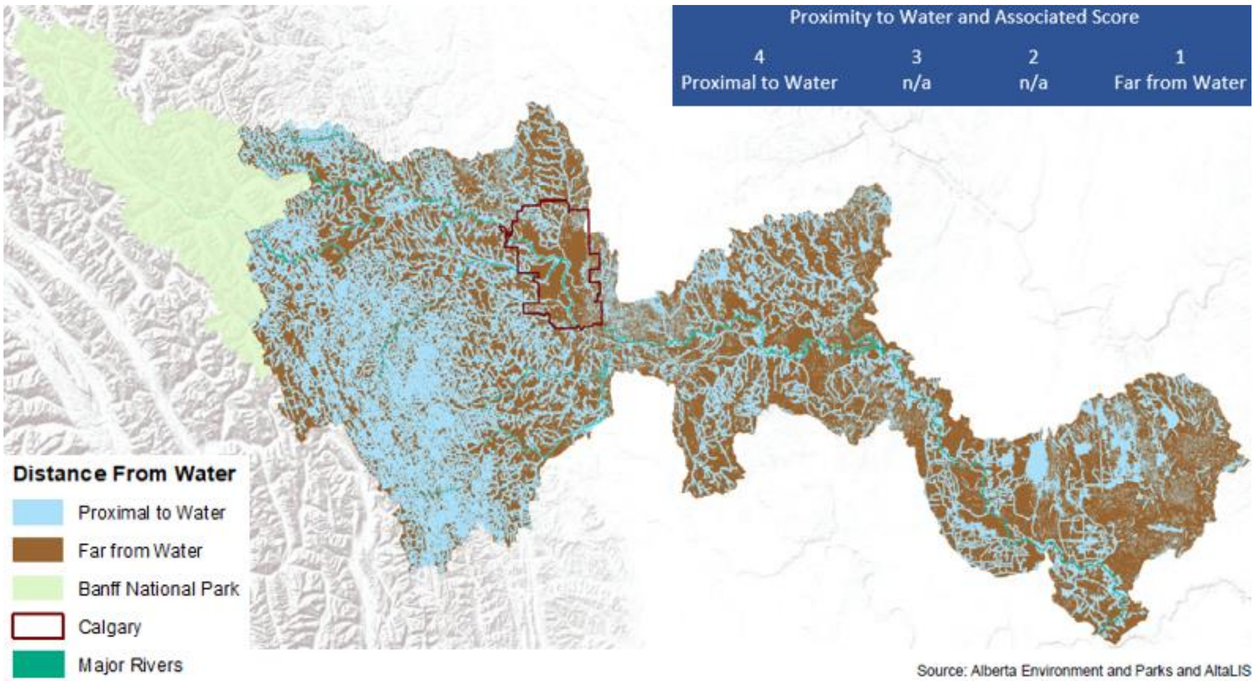


Figure 3: Natural sub-regions of Alberta (Alberta Government, 2005) within the Bow River Watershed.



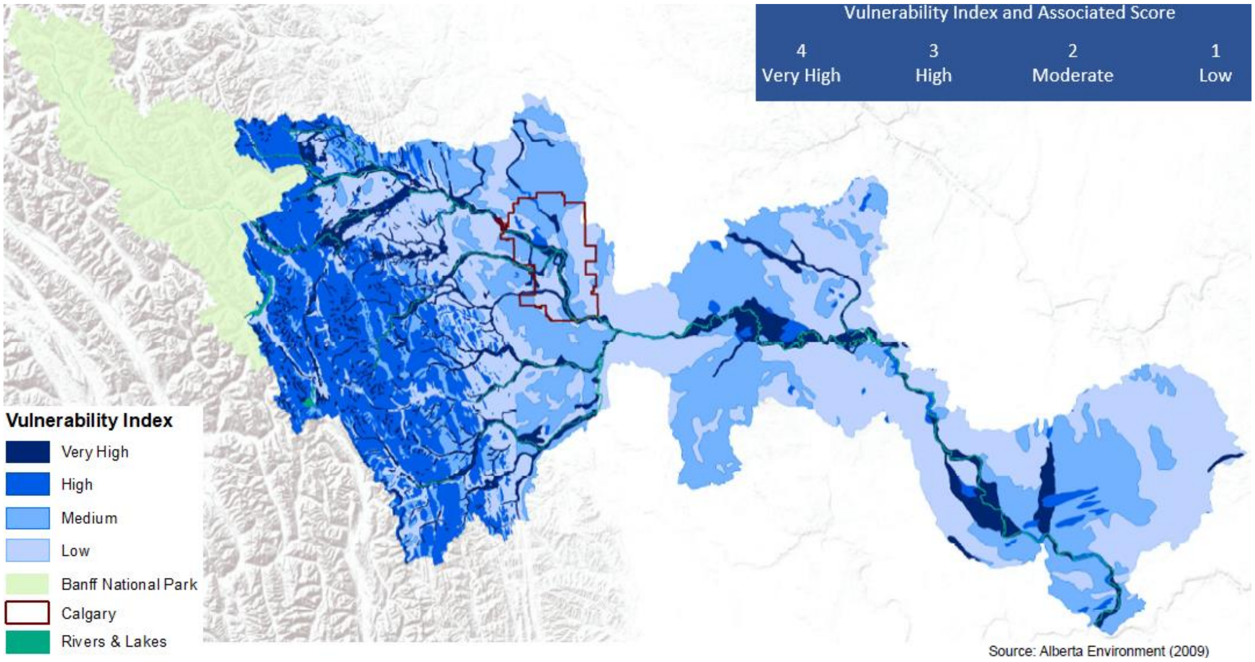
Areas proximal to water (Figure 4) consist of riparian zones, flood hazard areas, streams, rivers and canals buffered by 250 metres, and wetlands, reservoirs and lakes buffered by 50 metres. These areas were given the highest score in the model.

Figure 4: Distribution of areas proximal to water within the Bow River Watershed, excluding Banff National Park.



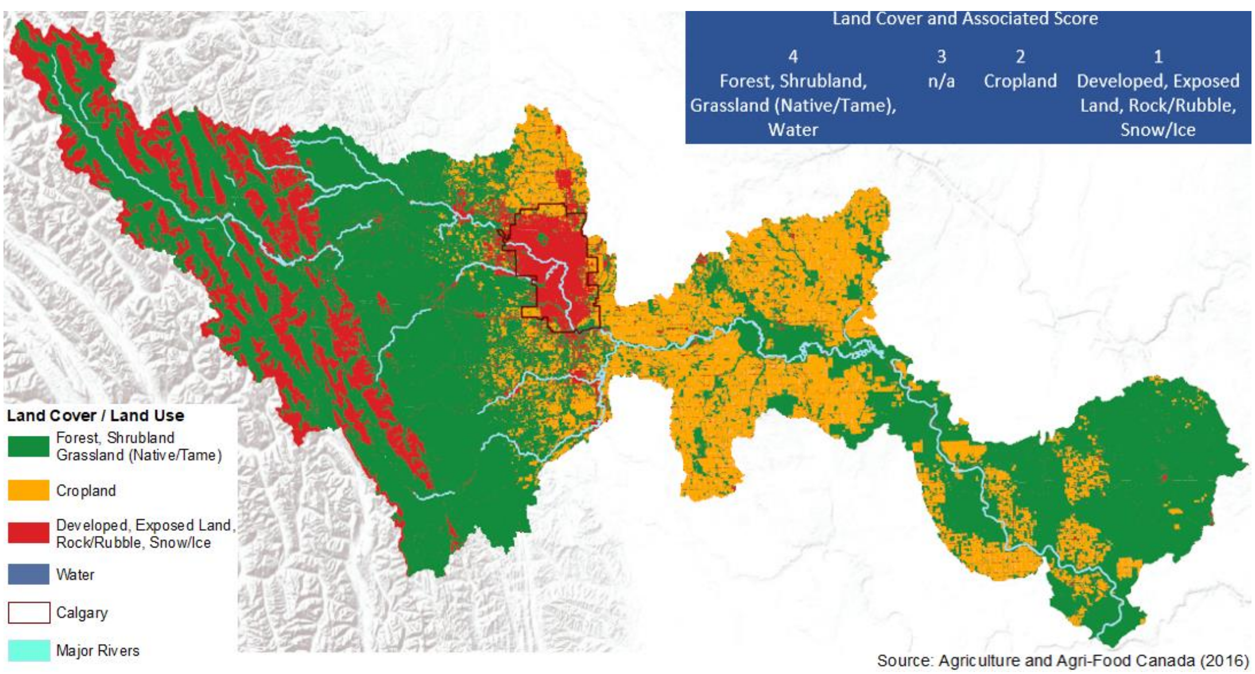
The groundwater vulnerability map in Figure 5 provides a high-level overview of the sensitivity of shallow groundwater to potential surficial impacts (Alberta Government, 2011). Areas with a very high vulnerability index have the highest sensitivity to surface activities due to the coarse-textured deposits at the ground surface. Coarser materials facilitate soil infiltration (vertical and lateral movement of surface water) and were given a higher score.

Figure 5: Groundwater vulnerability index distribution within the Bow River Watershed, excluding Banff National Park.



The ground cover, organic litter and complex root systems integral to natural vegetation play an important role in capturing and slowly releasing water. Natural land cover, such as forest, shrubland and grassland, is therefore given the highest score in this model. The distribution of land cover scores within the Bow River Basin can be seen in Figure 6.

Figure 6: Land cover score distribution within the Bow River Watershed.



Slope classes and scoring (Figure 7) were determined by considering:

- The influence that gentler slopes have on maximizing infiltration and slowing overland flow; and
- The impact that potential development would have on increasing runoff and erosion on moderate and steeper slope gradients.

For scoring purposes, it was decided that the effects of reducing runoff and erosion were more beneficial to water quality than reduced overland flow when considered against the project's objectives. This guided the decision for how scores were ranked.

According to Nassif & Wilson (1975), infiltration capacity decreases and runoff increases significantly beyond slopes of 8%, and runoff amounts peak at between slopes of 16% and 24%, depending on soil and cover. These findings were used to justify slope divisions (Table 4).

Table 4: Justification for slope gradient divisions used in project analysis.

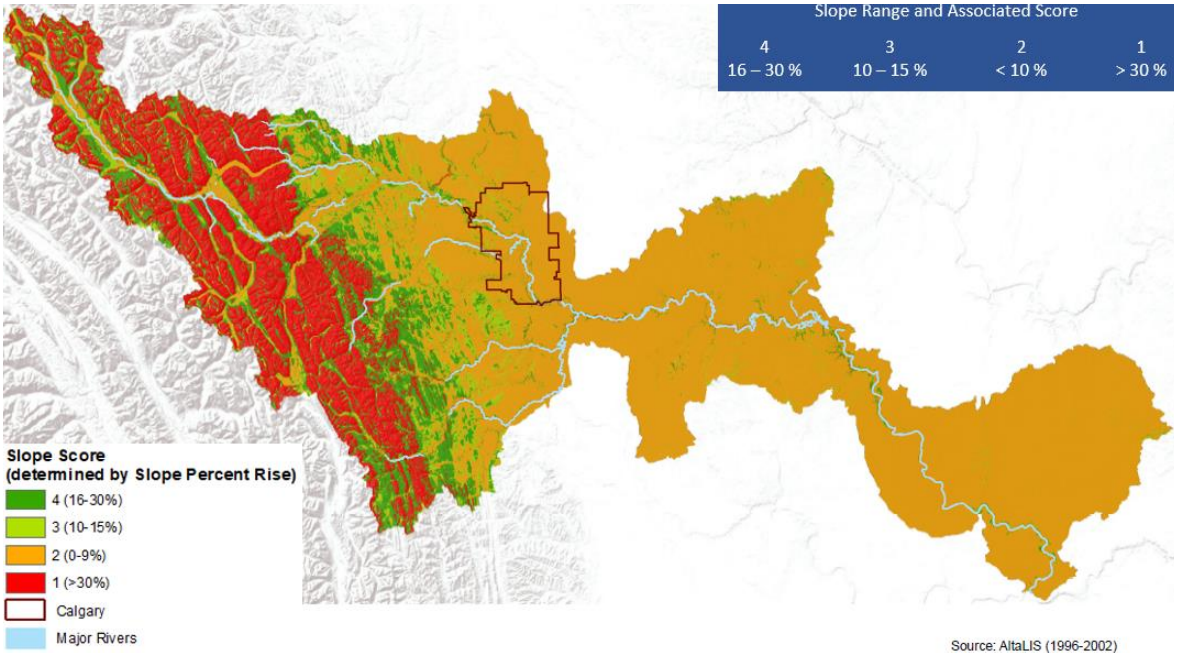
Slope Range	Score	Justification
0–9%	2	Moderate beneficial hydrologic effects — maximum infiltration capacity
10–15%	3	High beneficial hydrologic effects — potential to reduce runoff amounts
16–30%	4	Very high beneficial hydrologic effects — potential to reduce peak runoff amounts
> 30%	1	Considered not developable (City of Nanaimo, 2005) — not an area of interest

Selected slope gradient divisions track nicely with the slope classes defined by Agriculture and Agri-Food Canada (Table 5) (Government of Canada, 2013).

Table 5: Agriculture and Agri-Food Canada slope gradient classes.

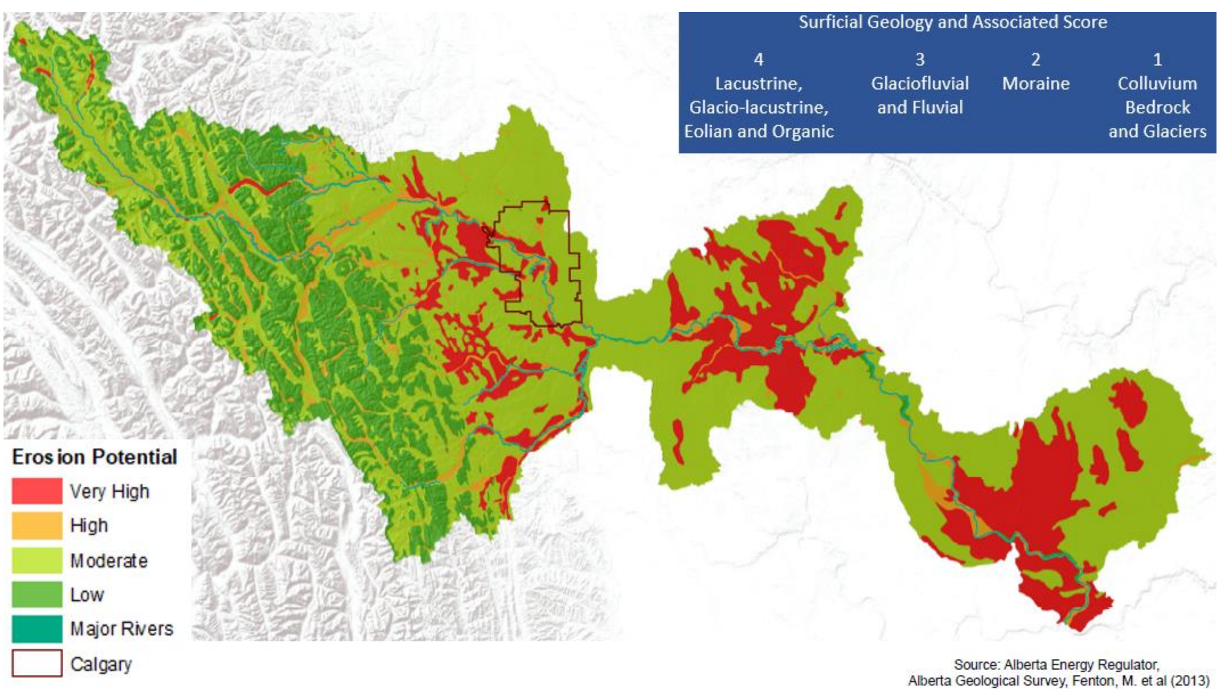
Class	Description
Little or none	Little or no slope: 0–3% gradient
Gentle	Gentle slope: 4–9% gradient
Moderate	Moderate slope: 10–15% gradient
Steep	Steep slope: 16–30% gradient
Extremely steep	Extremely steep slope: 31–60% gradient
Excessively steep	Excessively steep slope: > 60% gradient

Figure 7: Slope score distribution within the Bow River Watershed.



Soil erosion potential is ranked from low to very high based on surficial geology criteria used by the B.C. Ministry of Forests (British Columbia Government, 1999). Figure 8 shows the distribution of regions of very high to low erosion potential, scored high to low, respectively.

Figure 8: Surficial geology erosion potential distribution in the Bow River Watershed.



4.6 Weighting Landscape Layers

Relative weighting was assigned to each landscape layer based on data quality and hydrologic function (Table 6). For each layer, data quality was scored on a scale of 1 to 3, with 3 signifying the higher spatial resolution data. Hydrologic function was scored on a scale from 1 to 5, with 5 representing landscapes with natural assets that have the highest value to hydrologic and water quality functions.

The hydrologic value of a landscape is not easily measured or quantified. Hydrologic services can have ecological, social or economic values, and these are not absolute (what is important to one person may not be important to another). The values assigned for this study were determined during the October 31 Oldman Watershed Conservation Priority Technical Workshop and were based on expert opinion of the relative importance of the layers. Key to the valuation process was establishing the number and type of hydrologic services each landscape layer provided. As well, it was important to qualify the negative effects that could result to both water quality and quantity if the landscape was disturbed and unable to provide its beneficial services.

The relative weights for each layer were determined by summing the data quality and hydrologic function scores and dividing them by the total sum of scores (i.e., 41). Finally, the weights were calculated by assigning a relative weight of 15% to a neutral weight of 1 (Table 6).

Landscape scores were then multiplied by the weighting factor to arrive at a weighted score.

Table 6: Weighting the hydrologic function and spatial quality of each landscape layer.

Layer	Hydrologic Function	Spatial Quality	Sum	Relative Weight	Weighting
Precipitation	3	3	6	15%	1
Proximity to watercourses	5	3	8	20%	1.33
Proximity to wetlands and lakes	5	3	8	20%	1.33
Groundwater vulnerability	2	2	4	10%	0.67
Land cover	3	3	6	15%	1
Slope	3	3	6	15%	1
Surficial geology	2	1	3	7%	0.5
Total			41	≈ 100%	

4.7 Weighted Overlays and Final Scores

All six layers were overlaid and consolidated into one final map. Over 1.1 million discrete polygons with weighted scores for each layer were created during this overlay process. Table 7 is a sampling of the results for four different polygons.

Table 7: Example of final overlay results.

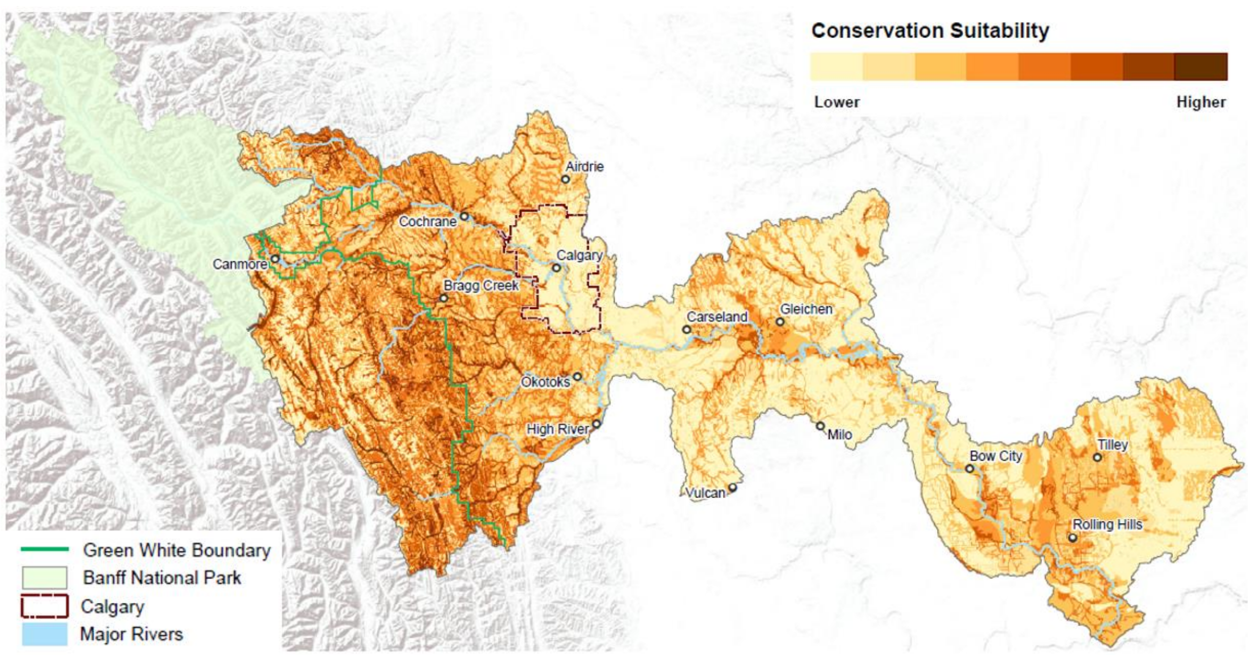
Precipitation_WScore	Land_WScore	Slope_WScore	SurficialGeology_WScore	WaterProximity_WScore	GroundWaterVulnerability_WScore	Add_Score	Mult_Score
4	1	1	0.5	1	2.01	9.51	4.02
4	1	1	0.5	5.32	2.01	13.83	21.3864
4	1	1	0.5	1	2.01	9.51	4.02
4	1	1	0.5	1	2.01	9.51	4.02

To create the final map, we multiplied the scores together and categorized them into eight classes using the geometric interval classification method.

A multiplicative methodology for combining the scores for all the layers was chosen over additive methodology, as it provides a greater range (0.67–1368.73) and a more balanced distribution of scores. The geometric interval classification used to group the scores into eight colour categories was also chosen for similar reasons.

The final scores were mapped for the Bow River Watershed and appear in Figure 9.

Figure 9: Conservation suitability map created by multiplying weighted landscape scores and classifying the end product by geometric interval.



5. Results

5.1 HSA Map Portal

NCC created a map portal where HSA maps for the Red Deer, Bow and Oldman River watersheds can be viewed on the web. It was designed as a tool to help users better understand landscapes from a hydrological perspective, and to support decisions related to land use planning, development and conservation in a user-friendly format.

5.1.1 Optional Layers

Geo-administrative, value-added and model input map layers are also available to be used as a reference or aid in regional or local assessments. All layers have been grouped as boundaries, value-add layers and landscape inputs. All layers can be turned on and off, as needed.

The following geo-administrative boundaries are included in the portal:

- First Nations Communities Reserves
- protected areas
- cities, towns and villages
- rural municipalities
- treaty territories
- land-use framework regions
- Hydrological Unit Code (HUC) boundaries: HUC2 to HUC10 sub-basins
- legal land descriptions for townships and sections
- Alberta green zones

The following value-added layers are included in the portal:

- Environmentally significant areas
- Annual recharge per acre (quantified for southern Alberta)
- Alberta natural sub-regions

Landscape inputs used in the development of the HSA GIS model were also included for the Bow and Red Deer River watersheds; however, NCC does not have access to the input layers from the Oldman River watershed project. The landscape inputs include:

- precipitation
- land cover
- slope
- surficial geology
- groundwater vulnerability
- water proximity

5.1.2 Navigating within the Mapping Portal

a) Widgets are available to:

- Facilitate searches by sub-basin, legal land description, park, reservation or municipal district.
- View symbology of visible layers.
- View a list of layers available to turn on or off.
- Change base maps.
- Print map layouts in various formats.
- Read more about the portal.
- Add your own data (Shape Files, CSV, KML, GPX, Geo JSON) or ArcGIS online maps.

b) Pop-ups containing specific information about a feature appear when a visible feature is clicked on the interactive map.

5.2 GIS Data

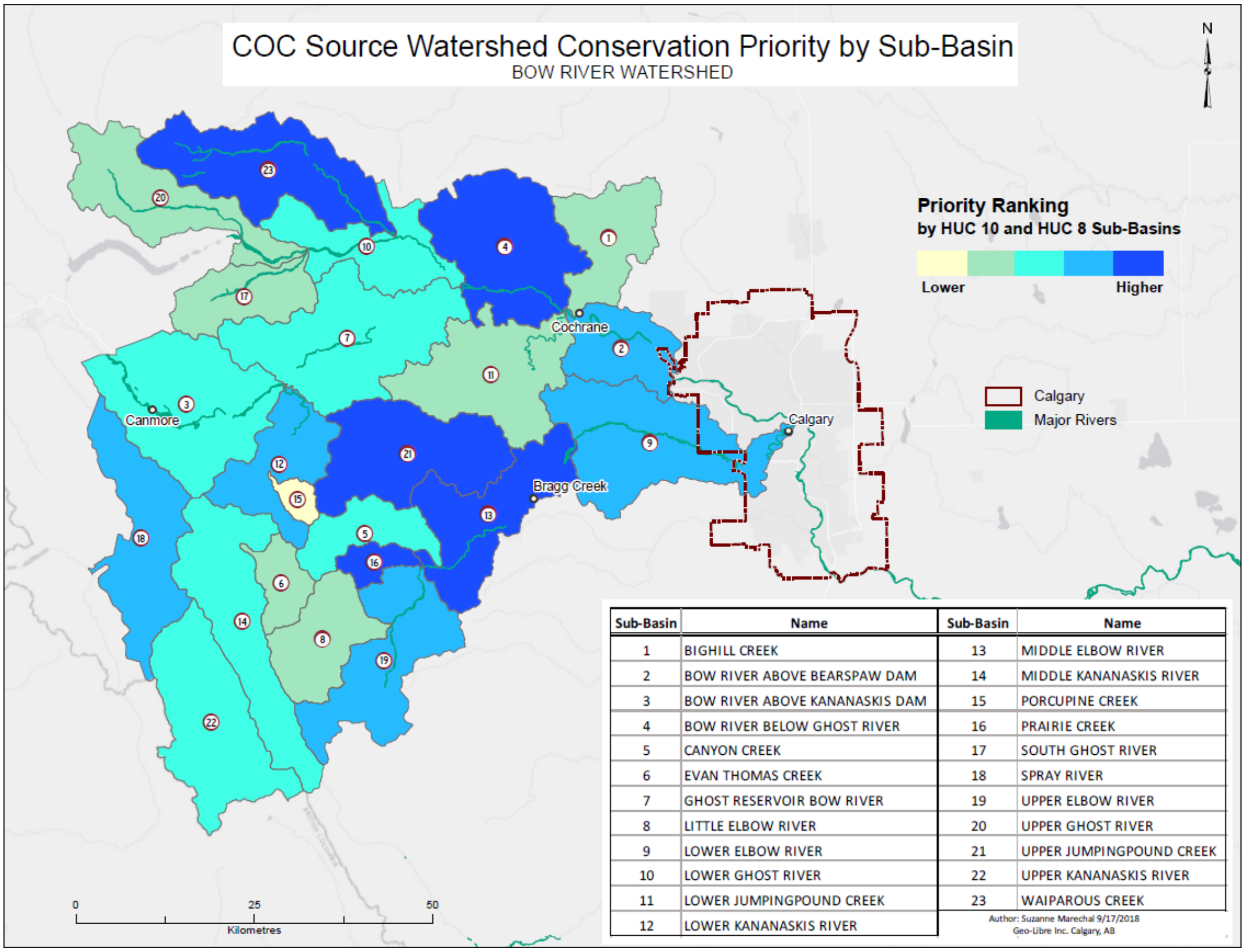
Requests for HSA GIS data (in a layer package format) can be made by contacting NCC's Alberta Region GIS team (alberta@natureconservancy.ca).

GIS data provides final scores calculated by adding weighted and non-weighted input scores or multiplying weighted and non-weighted input scores (Table 7). This allows users to remap results using unweighted inputs, if desired, or to apply additive instead of multiplicative methodology. Users could also work with a subset of the data, dig deeper into specific areas, exclude less relevant inputs or include additional information pertinent to a specific area that is required for planning purposes.

5.3 Source Water Conservation Overview

To help support stewardship within the City of Calgary source watershed, final scores were rolled up at a sub-basin scale for those watersheds upstream of the city. The process highlighted those watersheds that have the highest scores as a percentage of the watershed area. It is important to note that there can still be specific areas of very important hydrological function within a sub-watershed that has a lower priority ranking. The priority sub-basin roll-up map is displayed in Figure 12 as an example of how the data can be used to support the decision making of a specific user group, in this case the City of Calgary.

Figure 10: City of Calgary source watershed conservation priority ranked by sub-basin.



Sub-Basin	Name	Sub-Basin	Name
1	BIGHILL CREEK	13	MIDDLE ELBOW RIVER
2	BOW RIVER ABOVE BEARSPAW DAM	14	MIDDLE KANANASKIS RIVER
3	BOW RIVER ABOVE KANANASKIS DAM	15	PORCUPINE CREEK
4	BOW RIVER BELOW GHOST RIVER	16	PRAIRIE CREEK
5	CANYON CREEK	17	SOUTH GHOST RIVER
6	EVAN THOMAS CREEK	18	SPRAY RIVER
7	GHOST RESERVOIR BOW RIVER	19	UPPER ELBOW RIVER
8	LITTLE ELBOW RIVER	20	UPPER GHOST RIVER
9	LOWER ELBOW RIVER	21	UPPER JUMPINGPOUND CREEK
10	LOWER GHOST RIVER	22	UPPER KANANASKIS RIVER
11	LOWER JUMPINGPOUND CREEK	23	WAIPAROUS CREEK
12	LOWER KANANASKIS RIVER		

The following steps were implemented to roll-up the final scores:

a) Calculate the percentage area of a sub-basin that have high ranking scores — that is, scores in the top half of the range.

b) Classify the percentage areas into five groups and rank.

6. Discussion

Hydrologically significant areas across the Red Deer River watershed were identified based on well-defined inputs. These inputs were selected to represent natural assets that, if preserved in a natural state, provide beneficial hydrologic services, like water provision, flow regulation and water purification.

The HSA conservation planning tool is a unique way to consider the importance of hydrology at a watershed or local scale. It uses a transparent, repeatable systematic approach, allowing for future updates or expansion. Finally, it can and should be used as a decision support tool to complement other land use and conservation planning tools and to increase the probability that hydrologic value is considered in multifunctional landscape decisions. Overall, identifying hydrologically significant areas is a crucial step in creating and maintaining healthy and resilient watersheds.

There are several limitations and assumptions inherent in this model that should be considered when using this product.

1. The HSA map contains finely detailed results but is developed from a variety of coarsely scaled inputs. With that in mind, this should be considered a coarse-scale assessment. HSA boundaries are rough estimates and may need to be ground-truthed and further refined at local scales. Its value is to outline patterns that may not be visible at the surface and should make a user consider the impact of their decision to the local or regional hydrological network.

2. The analysis of HSAs considers the potential hydrologic value of undisturbed natural assets. It considers whether an area has natural vegetation or is developed. It does not consider, however, how nearby disturbances can impact and potentially downgrade the effectiveness of a local hydrologic service. For example, a disturbance such as a road can negatively affect the value a vegetated slope plays in reducing runoff. We did consider including disturbance layers into the project, but recognized the complexity that this would bring to the analysis. Disturbances in a region that potentially compromise hydrologic services should be considered in a planning and decision-making process and can be included as a separate layer if need be.

3. The assessment does not include important wildlife habitats, species locations, landforms, or infrastructure sites such as drinking water intakes. These could also be considered as additional layers in a planning process for a specific project.

4. While it would be valuable to understand which main river stems and tributaries provide clean water and what is driving water quality patterns, the data is not available at this time. In these cases, we used buffered areas surrounding streams, rivers and water bodies as a surrogate measure to identify key areas that contribute to water quality in general. A similar method was used by Fiera Biological Consulting (2010) to identify and define Aquatic Environmentally Significant Areas in Alberta. For simplicity, a similar buffer was used for both streams and rivers rather than using stream classifications or other classification systems to stratify the value of different-sized watercourses.

5. Mean annual precipitation was used as a proxy for where water enters the hydrologic system. This was the best representation we could find. It is important to point out that:

    - Precipitation computations always have a certain level of uncertainty due to the interpolation of precipitation point measurements, which were themselves generated through the PRISM model.

- A base period of 1961–1990 was used, as this was the only period for which we could find PRISM interpolated data. By using this, we are assuming that 30-year normal mean annual precipitation has not significantly changed in the last 30 years.
- Precipitation ranges for scoring purposes were developed by aligning precipitation to Alberta's natural sub-regions as closely as possible. This method was chosen because climate is a key factor in land classification (Alberta Government, 2005). There is room for subjective interpretation in the process.

6. The important interconnectivity between landscapes, groundwater and river systems should not be overlooked; however, understanding all potential ground and surface interactions is very complex. Areas of regional recharge, groundwater springs, alluvial aquifers and prairie potholes are all zones that should be targeted for conservation.

   Unfortunately, we were unable to source watershed-scale regional recharge and local groundwater discharge data. However, by combining annual precipitation amounts with soil infiltration (groundwater vulnerability), we were able to high grade areas where surface-groundwater interactions may take place. As part of the value-added layers in the portal, we did incorporate area-weighted average annual recharge for southern Alberta, scaled up to a HUC8 sub-watershed scale (Klassen, Liggett, Pavlovskii, & Abdrakhimova, 2018).

7. When looking at inputs for the model, we explored the option of incorporating either runoff curve numbers (United States Department of Agriculture - Soil Conservation Service, 1989) or runoff coefficients (Kienzle & Mueller, 2013). In the end, we chose to use neither of these based on feedback from hydrology experts who pointed out various assumptions and generalizations that were made during their computation. Instead, as part of the HSA determination, we identified slope grades that maximized runoff potential (Nassif & Wilson, 1975) as areas that need to be kept intact. There was extended discussion around assignment of scores to slope grades. Ultimately, we decided to look at slope from a land conservation versus development perspective. We gave the lowest score to areas that were not at risk of being developed and applied higher scores to those areas that would cause the most damage to water quality/quantity if they were developed.

8. As new data is continuously being produced and updated, it would be valuable to incorporate these into future iterations of an HSA map. Specifically, the model would benefit from improved wetland inventories, LIDAR-created wet-area mapping, flood hazard areas that extend beyond populated areas, soil permeability data and groundwater recharge and discharge information.

References

Alberta Geological Survey. (2016). *Surficial Geology of Alberta*. Retrieved from Open Data: http://geology-ags-aer.opendata.arcgis.com/datasets/surficial-geology-of-alberta-generalized-digital-mosaic-dig-2013-0002?geometry=-166.812%2C45.024%2C-63.101%2C62.793

Alberta Government. (2005). *Natural Regions and Subregions of Alberta*. Retrieved from GeoDiscover Alberta: https://geodiscover.alberta.ca/geoportal/catalog/search/resource/fullMetadata.page?uuid=%7B130A9885-D79E-4964-B31F-8331506B76D5%7D

Alberta Government. (2011). *South Saskatchewan Regional Plan - Groundwater Vulnerability*. Retrieved from GeoDiscover Alberta: https://geodiscover.alberta.ca/geoportal/catalog/search/resource/fullMetadata.page?uuid=%7B835844A6-7576-48C1-A674-E602B2A54BE1%7D

Alberta Government. (2015). *Digital Flood Hazard Mapping*. Retrieved from GeoDiscover Alberta: https://geodiscover.alberta.ca/geoportal/catalog/search/resource/fullMetadata.page?uuid=%7B41C92445-1244-4985-99F8-CEE0C090B839%7D

Alberta Government. (2017). *Alberta Merged Wetland Inventory*. Retrieved from GeoDiscover Alberta: https://geodiscover.alberta.ca/geoportal/catalog/search/resource/details.page?uuid=%7BA73F5AE1-4677-4731-B3F6-700743A96C97%7D

Alberta Government. (2017). *Lotic Riparian - Digital Elevation Model (DEM) Derived*. Retrieved from GeoDiscover Alberta: https://geodiscover.alberta.ca/geoportal/catalog/search/resource/fullMetadata.page?uuid=%7B14E2B4A7-ACA7-4BA9-B9ED-FBE8B0FFE5B9%7D

AltaLIS. (2017). *20K Base Features*. Retrieved from AltaLIS Products - Base Features: http://www.altalis.com/products/base/20k_base_features.html

AltaLIS. (2017). *DEM*. Retrieved from Products - Terrain: http://www.altalis.com/products/terrain/dem.html

Associated Environmental. (2018, April). *Oldman Watershed Priority Mapping.* Retrieved from Southern Alberta Land Trust Society: https://salts.land/wp-content/uploads/2018/05/Oldman-WS-Priority-Technical-Report.pdf

Barten, P. K., & Ernst, C. (2004). Land Conservation and Watershed Management for Source Protection. *American Water Works Association Journal*, 98: 4.

Beacon Environmental Ltd. (2012). *Ecological Buffer Guideline Review.* Markham, Ontario: Credit Valley Conservation.

British Columbia Government. (1999). *Forest Practices Code Mapping and Assessing Terrain Stability Guidebook.* British Columbia Ministry of Forests.

British Columbia Government. (2014). *Develop with Care 2014: Environmental Guidelines for Urban and Rural Land Developmnet in British Columbia - Section 4*. Retrieved from Government of British Columbia: https://www2.gov.bc.ca/gov/content/environment/natural-resource-

stewardship/natural-resource-standards-and-guidance/best-management-practices/develop-with-care
City of Nanaimo. (2005). *Steep Slope Development Permit Area Guidelines.* Nanaimo: City of Nanaimo.
Fiera Biological Consulting. (2010). *Aquatic Environmentally Significant Areas in Alberta.* Edmonton: Alberta Environment.
Government of Canada. (2013). *Slope Gradient*. Retrieved from Agriculture and Agri-Food Canada: http://sis.agr.gc.ca/cansis/nsdb/slc/v3.2/cmp/slope.html
Government of Canada. (2016). *Annual Crop Inventory*. Retrieved from Open Government: https://open.canada.ca/data/en/dataset/ba2645d5-4458-414d-b196-6303ac06c1c9
Hamann, A. (2013). *Andreas Hamann's Website.* Retrieved from University of Alberta: https://sites.ualberta.ca/~ahamann/data.html
Hamann, A., Wang, T., Spittlehouse, D. L., & Murdock, T. Q. (2013). A Comprehensive High-Resolution database of Historical and Projected Climate Surfaces For Western North America. *American Meteorological Society*, 307-309.
Kienzle, S. W., & Mueller, M. (2013). Mapping Alberta's Surface Water Resources for the Period: 1971 - 2000. *The Canadian Geographer*, 57(4): 506-518.
Klassen, J., Liggett, J. E., Pavlovskii, I., & Abdrakhimova, P. (2018). *First-order groundwater availability assessment for southern Alberta.* Edmonton: Alberta Energy Regulator / Alberta Geological Survey.
Morrison, A., Westbrook, C., & Bedard-Haughn, A. (2014). Distribution of Canadian Rocky Mountain Wetlands Impacted by Beaver. *Wetlands*.
Nassif, S. H., & Wilson, E. M. (1975). The Influence of Slope and Rain Intensity on Runoff and Infiltration. *Hydrological Sciences, XX, 4 12*, 539-553.
Trust for Public Land and the American Water Works Association. (2005). *Source Protection Handbook: Using Land Conservation to Protect Drinking Water Supplies.* Washington D.C.: U.S. Environmental Protection Agency.
United States Department of Agriculture - Soil Conservation Service. (1989). *Runoff Curve Number Computations.* United States Department of Agriculture.