Creation of a Land Cover Dataset for the North Saskatchewan & Battle River Watersheds

FINAL REPORT

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Report Prepared by: Shantel Koenig and Shari Clare

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1.0 Introduction

1.1. Background

The North Saskatchewan Watershed Alliance (NSWA) and Battle River Watershed Alliance (BRWA) engage in many watershed assessment and management projects that require high-resolution spatial datasets. Since 2016, the NSWA has commissioned a number of projects focused on assessing the condition of riparian areas, as well as pressure on riparian system function. Through these projects, a new geospatial method was created to assess riparian intactness at a watershed scale, and this method requires accurate and relatively up to date land cover data. In order to expand the number of watersheds that can be assessed for riparian intactness, a high-resolution land cover is required. While freely available and current land cover layers exist, the resolution of those data (typically 30 m pixel size) are not sufficient for assessing vegetation cover within riparian areas or providing land cover information that can be used for other watershed analysis and management purposes. Thus, the NSWA and BRWA commissioned the creation of a 6-meter pixel resolution land cover dataset that can be used to assess riparian area condition throughout the North Saskatchewan and Battle River watersheds, as well as support other on-going land use assessment and planning initiatives. Using SPOT 6/7 6 m imagery supplied by the Government of Alberta, Fiera Biological Consulting created land cover data products at two scales, and this report describes the methods used to create the classification and assess the accuracy of the final datasets.

1.2. Project Goal

The overall goal of this project was to develop two land cover products, each for a different purpose. The first product is a large-scale, high thematic resolution land cover layer that covers the areas of the North Saskatchewan and Battle River watersheds that are outside the mountain parks, as well as a select number of adjoining municipalities. The second product is a high-resolution, low thematic resolution land cover layer for areas within a 50 m buffer of selected streams and lakes within the North Saskatchewan and Battle River watersheds, which will be used to assess riparian intactness along the shorelines of interest.

2.0 Study Area

The study area covers 111,429 km^2 across Central Alberta, and is expansive, covering approximately 17% of the province. Specifically, the study area included major portions of the North Saskatchewan River watershed located outside of the mountain parks and the full extent of the Battle River watershed (in addition to a number of rural municipalities that intersected each river basin, but also extended beyond the boundaries of the watershed). The study area has an extensive hydrological network that flows across varied landscapes, through the Rocky Mountain, Grassland, Boreal, Parkland, and Grassland Natural Regions.

The large-scale, high thematic resolution land cover (i.e., wall to wall land cover) covers the entire study area, while the high-resolution, low thematic resolution land cover layer is only associated with a 50 m buffer around streams and lakes within the study area that were selected to be assessed for riparian intactness (Figure 1). The buffer land cover is associated with 25,272 km of shoreline and covers an area of 1,246 km^2.

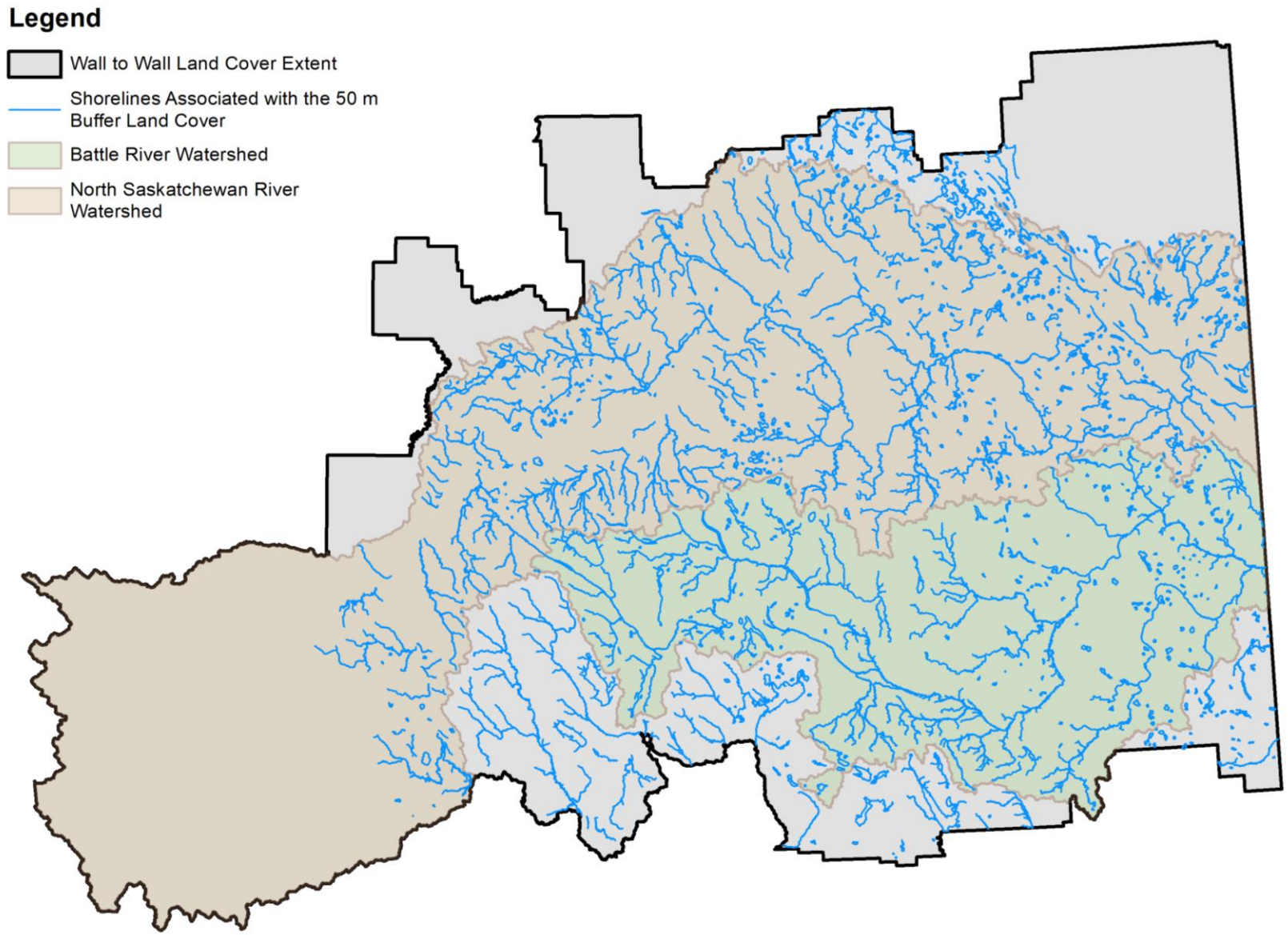


Figure 1. Study area showing the extent of the wall to wall land cover and the 50 m buffer and cover that was created as part of this project.

3.0 Methods

3.1. Image Selection

The land cover classification was created using 6 m resolution multi-band SPOT 6/7 imagery that was provided by the Government of Alberta (GOA). In order to select the best images for classification, imagery was requested from a number of different years (2015 through 2018) and from across different seasons (i.e., spring, summer, fall). Given the massive spatial extent of the study area, the first step in the creation of the land cover was to review and select the most appropriate and consistent set of images for the classification. Images were selected based on quality (e.g., minimal cloud cover), and year/month of acquisition, with the goal of selecting a set of images that balanced the ability to accurately identify the classes of interest with temporal consistency across the entire study area. Specifically, all images were chosen from 2017 or 2018 to ensure the land cover would be as current as possible. We targeted spring images that were obtained during the months of May or June, as imagery from this time of year typically has reliable spectral properties that allow for good differentiation between land cover classes. If a cloud-free spring image from 2018 was not available, then a 2017 spring image was chosen. If a spring image for either year was not available, then a summer or fall (July, August, September, or October) image was chosen from 2018, or from 2017 if a suitable 2018 image was not available. In total, 41 SPOT images were required to cover the study area (Table 1).

Table 1. Year and month of SPOT images used to create the land cover products.

	Total by Month						Total by Year
Year	May	June	July	August	September	October	
2017	4	1	11	7	3	1	27
2018	1	4	2	7	0	0	14

In addition to the 6 m multispectral images that were used to run the land cover classification, we used pan-sharpened 1.5 m SPOT composite mosaic images from the same years and months as the multispectral images to select training and validation data. High-resolution imagery from Google Earth and ArcGIS base maps were also used to assist with the photo-interpretation of the 6 m imagery. The 1.5 m SPOT was also used as a reference image during the quality assurance and quality control (QA/QC) check of the classification outputs.

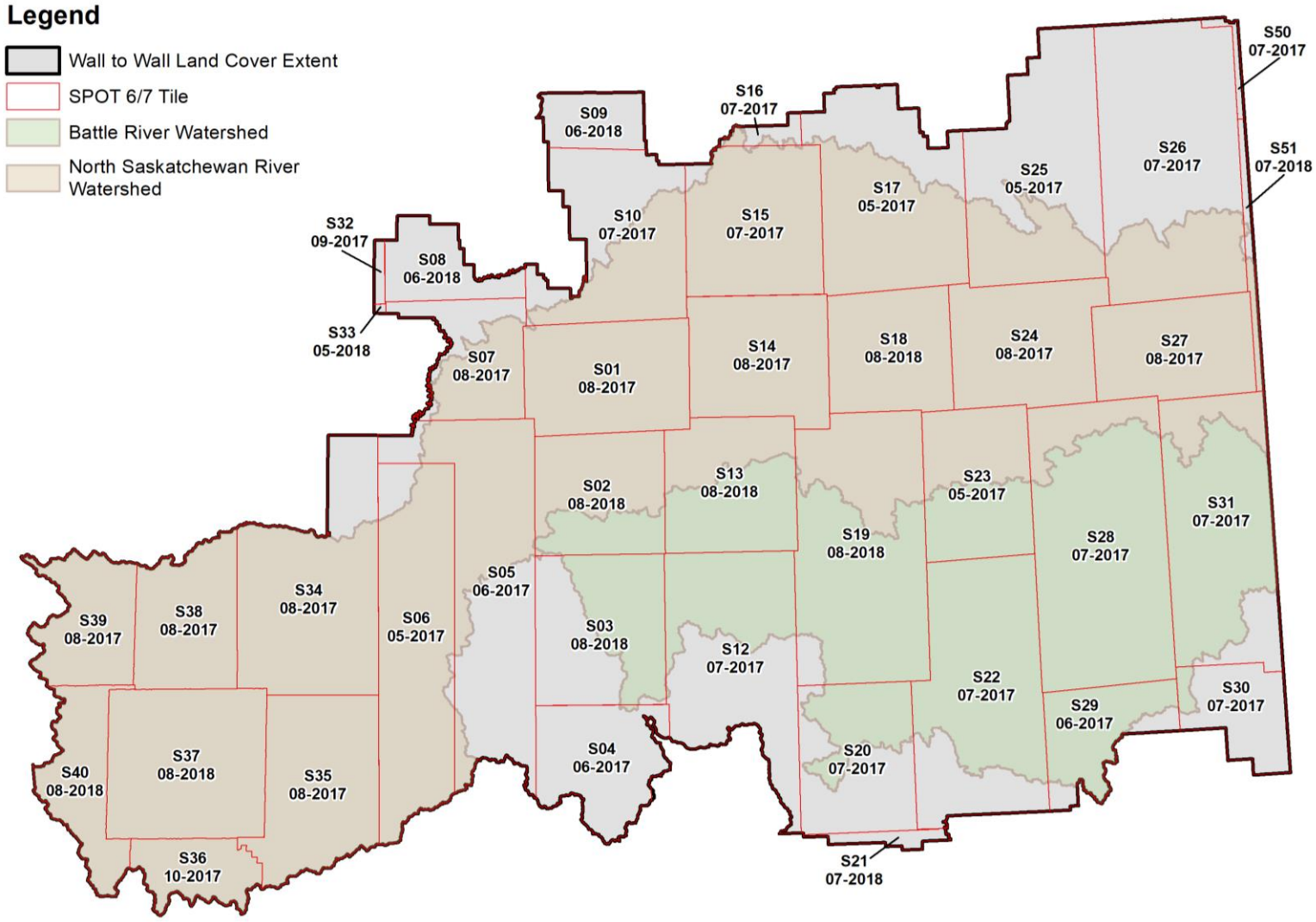


Figure 2. Coverage and vintage (month-year) of the 41 SPOT images used for creating the land cover products.

3.2. Minimum Mapping Unit

The minimum mapping unit (MMU) defines the smallest feature that is resolvable in a land cover classification. The lower limit of MMU size is determined by the pixel size of the imagery used to create the land cover, and for this project, we are working with SPOT imagery with a pixel size of 6 m x 6 m (0.0036 ha). For reference, 0.0036 ha is approximately the size of a single-car garage. The upper limit of MMU is a choice determined by a number of factors, including: purpose of the classification, acceptable detection limits of the smallest landscape features of interest, size of the overall coverage area, and desired smoothness and homogeneity of the features in the land cover map. While a smaller MMU makes it possible to detect and map small features, it often yields a "noisy" classification (i.e., highly speckled) in appearance, and the time and effort required to clean-up and validate a classification at this resolution is extensive and costly, particularly over large geographic areas.

The primary use for this land cover data is a riparian intactness assessment; however, the wall to wall land cover layer for the North Saskatchewan and Battle River watersheds will support a wide range of other secondary planning and mapping objectives. Given this, we created two separate land cover products for the study area, as follows:

MMU 1
Shoreline buffer land cover: 0.0036 ha; 1 pixel
For the purpose of assessing riparian intactness, it is desirable to have a land cover with the highest resolution possible, as this allows for a more accurate assessment of the changes in vegetation, as well as the proportion of different natural or anthropogenic land cover types along the shoreline. Thus, having a high-resolution land cover is critical to derive accurate riparian management area boundaries and riparian intactness scores. This level of spatial accuracy is only required immediately adjacent to the shorelines, and for this reason, a 50 m buffer was created on the left and right banks of each creek, stream, river, and lake shoreline of interest, and a MMU of 0.0036 ha (6 m x 6 m) was maintained within these buffers.

MMU 2
Wall-to-wall land cover: 0.022 ha; 6-pixel aggregation
Outside of the shoreline buffers, maintaining such a small MMU produces a landcover map with an unnecessary amount of speckle and noise. Considering the large size of the project area, and the more generalized land use planning applications, an MMU of 0.022 ha was selected. This mapping unit strikes a reasonable balance between resolution and accuracy. This land cover is hereafter referred to as the wall-to-wall land cover.

3.3. Land Cover Classes

3.3.1. Wall-to-Wall Land Cover

In order to create a wall-to-wall land cover that can serve multiple land use planning purposes, we created a detailed, hierarchical land cover classification with high thematic resolution. Eighteen Level 2 classes were chosen, which nest into ten broader Level 1 classes (Table 2). One of the value-added components of this land cover is the inclusion of an innovative 'Agricultural Depression' class that identifies areas where marsh wetlands may have been impacted by agriculture and are lacking intact emergent vegetation. In croplands, these depressions are typically cultivated and/or drained, and in pasture, these low-lying areas may be drained or utilized for agricultural purposes such as providing water for cattle. This land cover class provides data users with the option to explore areas where wetlands may be impacted by agriculture.

Table 2. Land cover classes that were used to derive the land cover classification for the North Saskatchewan and Battle River watersheds.

Level 1	Level 2	Description
Forest	Coniferous	Coniferous trees (needle-leaf) cover greater than 75% of treed area.
	Deciduous	Broadleaf trees covering greater than 75% of treed area.
	Shrub	Vegetation cover that is at least 1/3 shrub (low/short woody plants), with little or no presence of tress (<10% tree crown closure). Includes upland shrub and riparian shrub (e.g. shrub on gravel bars, shrub around marshes).
Natural Grassland	Natural Grassland	Naturally grassy areas with <1/3 shrub cover and <10% tree cover.
Open Water	Open Water	Any open water (lakes, permanent wetlands, standing water) and flowing water. Includes artificial waterbodies (e.g., dugouts and reservoirs).
Wetland*	Marsh	Low lying areas dominated by emergent or graminoid vegetation and depressional areas adjacent to streams/creeks and lakes.
	Swamp	Depressional areas dominated by deciduous tree or shrub cover.
	Bog	Areas that appear to be dominated by black spruce cover where no water flow is apparent.
	Woody Fen	Depressional areas dominated by woody vegetation cover (trees or shrubs) where surface water flow is apparent.
	Graminoid Fen	Depressional areas dominated by graminoid vegetation cover where surface water flow is apparent.
Agricultural Depression	Agricultural Depression	Human impacted/altered wetland basins in agricultural areas lacking intact emergent vegetation. In croplands these basins are typically cultivated and/or drained, and in pasture these low lying areas may be drained and/or utilized for agricultural purposes such as providing water for cattle.
Natural Bare Ground	Natural Bare Ground	Naturally occurring bare soil, sand, sediment, banks, and beaches.
Agriculture	Pasture	Agricultural areas used primarily as pasture or hayland.
	Cropland	Agricultural areas used primarily as cereal crop. Tilled most years.
Disturbed Vegetation	Disturbed Vegetation	Non-agricultural human-impacted or managed non-woody vegetation.
Built Up/Exposed	Human Built	Human built features and human-caused exposed/bare areas.
	Roads	Paved and unpaved roads.

*NOTE: The wetland class names included in this land cover classification are similar to those used in the Alberta Wetland Classification System; however, this land cover classification should not be considered to be a wetland inventory.

3.3.2. Shoreline Buffer Land Cover

While a land cover with high thematic resolution may be desirable because it can be used for a range of applications or analyses, there is a trade-off between thematic resolution and the associated cost and accuracy (both overall and within-class) of the land cover. Given our experience creating land cover layers for the GIS-based assessment of riparian intactness, combined with what we have learned from a validation exercise that was completed for Alberta Environment and Parks (AEP) (Fiera Biological 2019), we have found that creating a land cover layer with a smaller number of classes that are highly relevant to the quantification of riparian intactness results in more accurate scores. In our recommendations to AEP, we proposed that the following five classes, at a minimum, be included in a land cover layer that is created for the purpose of conducting a riparian assessment (Fiera Biological 2019):

1) Woody cover,
2) Natural open vegetation,
3) Open water,
4) Natural bare ground,
5) Human disturbance/human footprint.

For this project, we created a land cover within the shoreline buffer with five classes, as described in Table 3.

Table 3. Land cover classes that were used to derive the land cover classification for the 100 m shoreline buffers.

Land Cover Class Label	Level 2 Classes Included	Description of Land Cover Class
Woody	Bog, Coniferous, Deciduous, Swamp, Shrub, Woody Fen	Woody upland or woody wetland vegetation.
Natural Open Vegetation	Graminoid Fen, Marsh, Natural Grassland	Areas dominated by graminoid or emergent vegetation and that have not been disturbed or impacted by human activity.
Open Water	Open Water	Any open water (lakes, permanent wetlands, standing water) and flowing water. Includes artificial waterbodies (e.g., dugouts and reservoirs).
Natural Bare Ground	Natural Bare Ground	Naturally occurring bare soil, sand, sediment, banks, and beaches. Includes bedrock, rubble, talus, blockfield, or other natural impervious surfaces.
Disturbed	Agricultural Depression, Cropland, Disturbed Vegetation, Human Built, Pasture, Roads	Areas of human disturbance, including agricultural areas, human-built features, human-caused bare ground, and human-impacted or managed vegetation.

3.4. Land Cover Classification

We created a pixel-based classification using a random forest model. Random forest is a machine learning classification algorithm that is based on a set of decision trees derived by a repeated selection of random subsets of training data (Ho 1995). A standard approach to producing a land cover classification for a large area (i.e. spanning multiple image tiles) is to merge all of the image tiles together into a unified mosaic, select training data across the entire project area, and run a single classification model. This approach is feasible if all of the imagery has been calibrated in a known and standardized way; however, this is not the case with the GOA SPOT data. Instead, our approach was to train and run a unique classification model for each of the 41 SPOT tiles, which increased the overall data management workload, but produced a higher level of overall quality and classification accuracy. Because elevation data was missing for portions of three of the tiles, these areas were classified separately from the rest of the tile, resulting in 44 separate classifications.

For a small number of land cover classes, a semi-automated approach was used to extract training data from existing datasets (e.g., ABMI human footprint; Alberta Base Features) and highly trained photo interpreters quality checked these data, in addition to manually selecting supplemental training data points using the SPOT 6/7 RGB imagery and high resolution orthophotos. Training data were manually selected for each SPOT scene for the following classes: Coniferous; Deciduous; Shrub; Bog; Graminoid Fen; Woody Fen; Marsh; Swamp; Agricultural Depression; Open Water; Pasture; Cropland; Human Built; Natural Bare Ground; Snow/Ice. In total, 31,720 training data points were selected across the study area. For the classification of each SPOT tile, the training data overlapping the tile was extracted and 70% of the training data was used to train the classifier and the remaining 30% of the data was held back to validate the results.

The SPOT imagery was used to generate layers for Normalized Difference Vegetation Index (NDVI), Blue Normalized Difference Vegetation Index (BNDVI), Green Ratio Vegetation Index (GRVI), and Iron Oxide Index (IOI), and a 15 m LiDAR DEM was used to derive terrain layers including Probability of Depression, Cost Distance to Water, and Deviation from Mean Elevation (Table 4). As well, historic image analysis was performed in Google Earth Engine to generate median summer temperature maps from Landsat 8 imagery and mean and standard deviation maps of NDVI from Sentinel 2 imagery. All of these layers were combined together in a stack that was used to run the random forest model for each SPOT tile in R (Version 4.0.3).

Following the first stage of the classification, automated decision rules and manual editing were used to fix general classification errors. During this stage, the Natural Grassland class was added to account for areas of natural, non-woody low cover vegetation, and the Disturbed Vegetation class was added to account for non-agricultural human impacted low vegetation cover and areas with managed or manicured vegetation. The Alberta Base features Roads layer was used to add in a Roads class to complete the Level 2 land cover classification.

The wall-to-wall land cover classification was used as the basis for the creation of the two different land cover products. For the shoreline buffer land cover, the wall-to-wall land cover was clipped to the 50 m shoreline buffer for the lakes and streams of interest. The Level 2 classes were then grouped together into the five land cover classes that were used for the riparian intactness assessment (Table 3). For the wall-to-wall land cover, the Level 2 land cover classes were aggregated to the MMU of 0.022 ha (6 pixels). The two land cover products were then ready for a manual quality assurance and quality control check (QAQC).

Table 4. Description of the spatial data obtained or derived for use in the development of the land cover.

Data Layer	Year	Source	Usage
SPOT 6/7 Satellite Imagery	2017/2018	Government of Alberta	Derivation of land cover classification
15 m LiDAR DEM	n/d	Government of Alberta	Derivation of data products for classification
Normalized Difference Vegetation Index (NDVI)	2017/2018	Fiera Biological. Layer was created using SPOT 6/7 satellite data provided by the Government of Alberta	Derivation of land cover classification
Blue Normalized Difference Vegetation Index (BNDVI)	2017/2018	Fiera Biological. Layer was created using SPOT 6/7 satellite data provided by the Government of Alberta	Derivation of land cover classification
Green Ratio Vegetation Index (GRVI)	2017/2018	Fiera Biological. Layer was created using SPOT 6/7 satellite data provided by the Government of Alberta	Derivation of land cover classification
Iron Oxide Index (IOI)	2017/2018	Fiera Biological. Layer was created using SPOT 6/7 satellite data provided by the Government of Alberta	Derivation of land cover classification
Probability of Depression	n/d	Fiera Biological. Layer was created using LiDAR DEM data provided by the Government of Alberta	Derivation of land cover classification
Cost Distance to Water	n/d	Fiera Biological. Layer was created using LiDAR DEM data provided by the Government of Alberta	Derivation of land cover classification
Deviation from Mean Elevation	n/d	Fiera Biological. Layer was created using LiDAR DEM data provided by the Government of Alberta	Derivation of land cover classification
Roads	2014	Alberta Base Features	Derivation of land cover classification
Median Summer Temperature	2013-2018	Fiera Biological. Layers created using Landsat 8 imagery	Derivation of land cover classification
Mean and Standard Deviation of NDVI	2013-2018	Fiera Biological. Layers created using Sentinel 2 imagery	Derivation of land cover classification
ABMI Human Footprint	2016/2017	Alberta Biodiversity Monitoring Institute	Semi-automated clean up of classification and QA/QC

3.5. Land Cover QAQC

Extensive review and QAQC of the two land cover products was conducted by trained photo interpreters. Details on the QAQC approach for each product are provided below.

3.5.1. Wall-to-Wall Land Cover

The results of the random forest classification produced 44 individual land cover classifications, each of which potentially contained unique classification inconsistencies inherent from unique aspects of the base SPOT imagery (e.g., season of image capture, cloud cover, shadow effects) and differences in the input layers into the imagery stack (e.g., no DEM available). In order to deliver a unified and consistent wall-to-wall land cover, we performed a rigorous review of each classified SPOT tile to assess and correct any systematic classification errors and to ensure consistent adherence to our class definition hierarchy across the entire study area.

The general method for this review and QAQC process was to have trained photo interpreters review each scene using a grid-sweep approach at a pre-defined zoom level in order to ensure that an assessment of classification accuracy was performed thoroughly and at a consistent level of detail. We applied a standardized colour scheme to the land cover results so that the interpreters developed a consistent association between colour, class, and observed image features. Our photo interpreters worked on dual-monitor workstations, where one screen displayed the land cover results at 50% transparency overlain on the original SPOT 6 m or SPOT 1.5 m imagery, and an adjacent screen displayed a synchronized view of high-resolution Google Earth imagery to provide aid in feature interpretation. Any problems observed in the land cover layer were directly corrected by either re-assigning a class label, or cutting/modifying a land cover feature boundary.

Our approach was to perform this QAQC review in three stages. The first stage was performed at a coarse scale, during which reviewers assessed the general ecological accuracy of the distribution of classes within a tile, and identified and manually re-assigned class labels for large features that may have been frequently misclassified in a particular tile (e.g., darker agricultural vegetation frequently misclassified as one of the wooded vegetation classes, freshly cultivated agricultural fields misclassified as human built).

The second stage review was performed at a slightly finer scale with more attention to detail and with more time spent correcting misclassifications that were observed and noted during the first round review. At this stage errors addressed included those caused by patchy cloud cover, dark shadows, and solar glare. Several tiles had substantial areas of cloud cover that required manual digitization of the land cover features. In these areas, features were digitized at a scale of 1:20,000, and ArcGIS base maps were used as reference. We also paid attention to built up areas to ensure that natural low vegetation class labels were not being applied to manicured vegetation such as lawns and golf courses. A priority was placed on ensuring that class assignments were highly accurate at Level 1 of our class hierarchy, and that confusion between natural vs. anthropogenic features that are similar in appearance would be minimized (e.g., Natural Bare Ground areas misclassified as Human Built, Natural Grassland misclassified as Pasture). However, for some classes, there was an unavoidably high level of ambiguity between classes, and thus, it was difficult to differentiate and label these land cover classes with certainty. In particular, in the open grassland areas and valley and coulee areas of the Battle River Watershed, deciding whether the cover should be labelled as Natural Grassland or Pasture was often difficult. In these cases, the ABMI Human Footprint layer was used to help determine whether the cover was natural or agricultural, unless there was an obvious disagreement with the Human Footprint layer. The final stage of review was conducted to ensure classification consistency between a tile and its neighbors, across ecological regions and within HUC6 watersheds.

Once the QAQC was complete, the 44 individual classifications were merged into larger blocks and reviewed for areas where there was missing data due to gaps in the SPOT tile coverage of the study area. These occurred at several places along the study area boundary and at the margins of some neighbouring tiles. Where data were missing, features were manually digitized at a scale of 1:20,000 using ArcGIS base maps as reference. Once the coverage was complete and seamless, the polygon tiles were converted back to a 6 m resolution raster and mosaicked into a complete wall to wall land cover layer of the study area. The final wall to wall land cover is shown in Figure 3.

3.5.2. Shoreline Buffer Land Cover

The QA/QC of the shoreline buffer land cover involved reviewing the five classes within the buffer for every stream and lake included in the riparian assessment (Figure 1; Figure 4). The classification was compared against the 6 m SPOT image, and to assist with the photo-interpretation of the 6 m imagery, analysts referenced 1.5 m SPOT composite RGB images and high-resolution imagery from Google Earth and ArcGIS (where available), as well as the ABMI Human Footprint layer.

The goal in creating the shoreline buffer land cover was to produce a land cover layer that was well-suited to the purpose of riparian assessment. Given the extensive total length of shorelines (~25,271 km), ensuring that each and every pixel was accurate was not possible within the time and budget available. As a result, we prioritized and focused our QA/QC and subsequent editing on changes that would have the greatest impact on the generation of riparian management areas (RMAs) and on the riparian intactness scores. Edits to classes and boundaries were therefore focused on capturing differences between natural and disturbed cover classes, as well as major changes in natural vegetation cover types (i.e., woody vs natural open vegetation). We paid extra attention to editing land cover changes that would result in the generation of a new RMA; for example, we ensured that road breaks across streams were at least three pixels (18 m) wide.

Importantly, there were certain landscape features whose land cover class was ambiguous and challenging to discern, even when referring to higher resolution imagery. Specifically, it was often challenging to distinguish rough pasture that is occasionally grazed and on uncultivated land from natural grassland. In these cases, the ABMI Human Footprint was used to help determine whether the cover was disturbed or natural; where there was disagreement with the ABMI Human Footprint (e.g., obvious signs of grazing impact in an area not covered by the Human Footprint), the photo interpreters used their best judgement to make a decision regarding the class assignment.

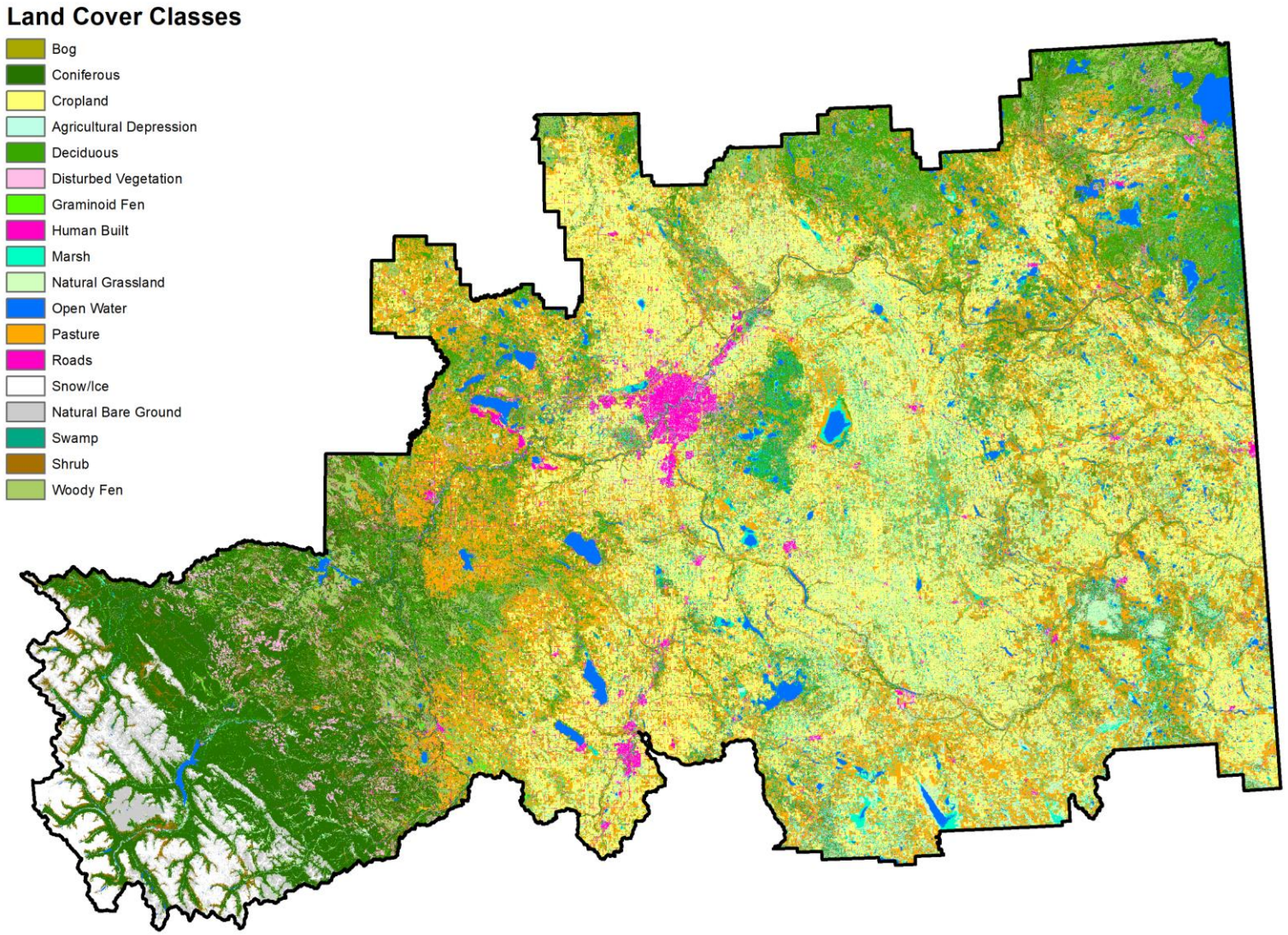


Figure 3. The final 18 class 6 m resolution wall to wall land cover for the study area created using SPOT 6/7 imagery from 2017/2018.

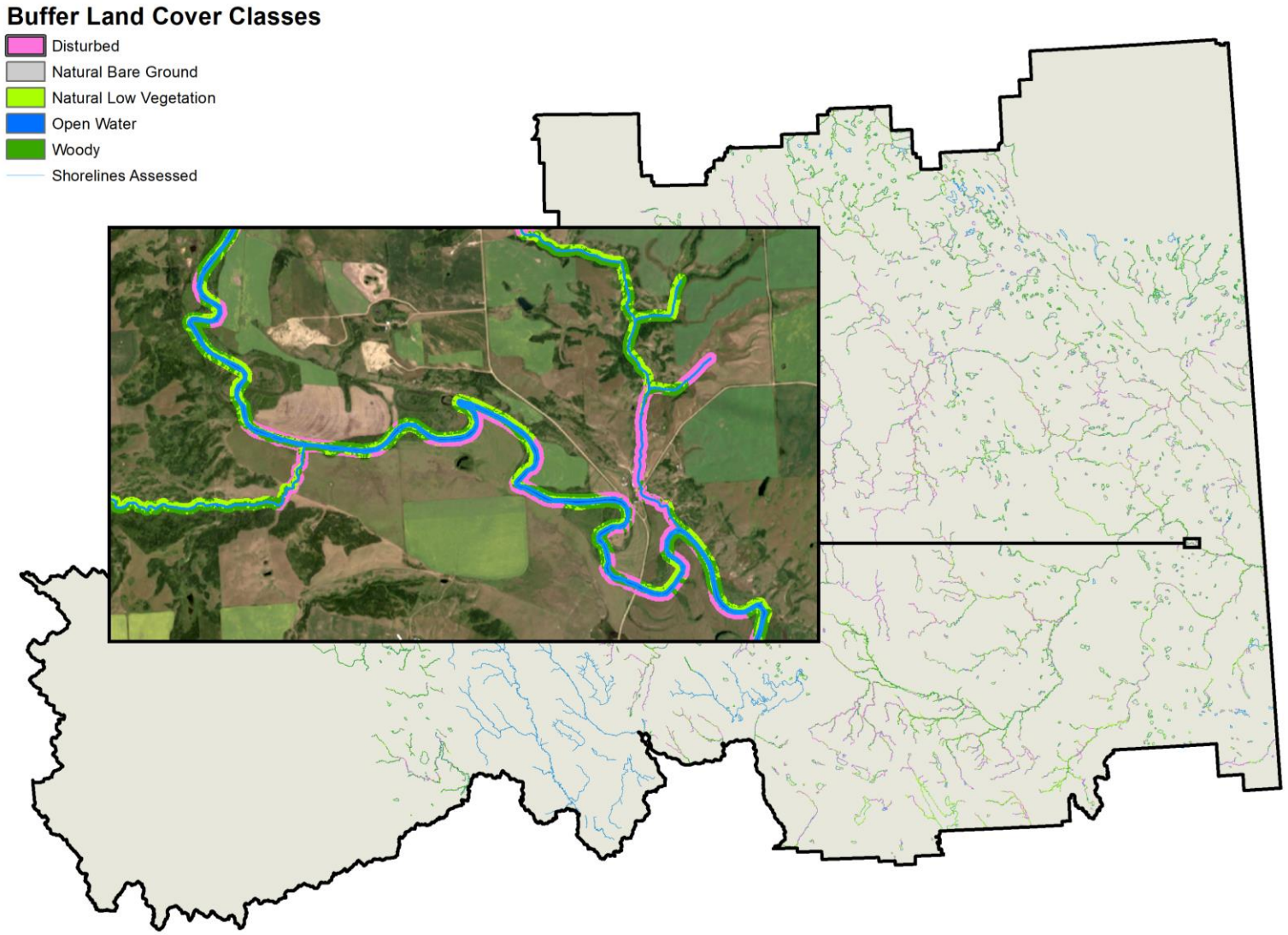


Figure 4. The final five class 6 m resolution buffer land cover for assessing riparian intactness. Inset shows the coverage of the buffer land cover.

4.0 Accuracy Assessment

4.1. Wall to Wall Land Cover

Accuracy of the land cover products was assessed using traditional remote sensing techniques, which provides a measure of accuracy for each land cover class, as well as an overall accuracy for all classes combined. The wall to wall land cover layer accuracy was assessed at Level 1 and Level 2 using a stratified validation dataset that was a combination of held back training data points (samples collected at the same time as training data was selected, but were not used to train the random forest model) and randomly selected points that were validated by a trained photo interpreter. Accuracy was assessed for the land cover in the North Saskatchewan River Watershed and the Battle River Watershed separately.

4.1.1 North Saskatchewan River Watershed

A total of 598 samples were used to assess accuracy for the NSR, with a minimum number of 20 samples for each Level 2 class. Overall accuracy at Level 1 (10 thematic classes) was 92.0% with a Kappa statistic of 0.90 (Table 5). Class accuracies were above 80% for all classes except Agricultural Depression and Natural Grassland. Agricultural Depression tended to be confused with Cropland, Pasture, or Marsh. Natural Grassland is a very rare class, covering ~1% of the watershed, and this class was typically confused with other natural classes, particularly in cases where natural grassland patches exist as small openings in forest dominated regions or in areas where grassland is mixed with other natural land cover classes (e.g., a river valley or wetland margin where there is a mix of grass, wetland, and shrub). Overall accuracy at Level 2 (18 thematic classes) was 87.0% with a Kappa statistic of 0.86 (Table 6). Class accuracies were above 80% for two-thirds of the classes. Lower performing classes were primarily confused with closely related classes within the same Level 1 grouping (e.g., Marsh and Graminoid Fen; Bog and Woody Fen; Shrub and Deciduous).

4.1.2 Battle River Watershed

A total of 588 samples were used to assess accuracy in the BRW, with a minimum of 20 samples for each Level 2 class. The Bog and Graminoid Fen classes were excluded from the accuracy assessment because they were extremely rare (<0.1% of the land cover), and collecting enough independent validation samples for these classes was not feasible. Overall accuracy at Level 1 (9 thematic classes) was 93.0% with a Kappa statistic of 0.89 (Table 7). Class accuracies were above 80% for all classes except for Agricultural Depression, which was confused with related classes (Cropland, Pasture, or Marsh). Overall accuracy at Level 2 (15 thematic classes) was 88.2% with a Kappa statistic of 0.86 (Table 8). Class accuracies were above 80% for the majority of classes. Lower performing classes included Agricultural Depression, Shrub, and Woody Fen. These classes were primarily confused with closely related classes (e.g., Agricultural Depression and Marsh) or classes within the same Level 1 grouping (e.g., Shrub and Deciduous, Woody Fen and Swamp).

Table 5. Accuracy assessment results for the Level 1 land cover classes in the North Saskatchewan Watershed.

	Agriculture	Built Up/ Exposed	Agricultural Depression	Disturbed Vegetation	Forest	Natural Grassland	Open Water	Snow/ Ice	Natural Bare Ground	Wetland	User Accuracy
Agriculture	169	0	4	2	2	1	0	0	1	1	94%
Built Up/Exposed	0	40	0	0	0	0	0	0	1	0	95%
Agricultural Depression	1	0	12	0	0	0	0	0	0	1	86%
Disturbed Vegetation	0	0	0	18	1	0	0	0	0	0	90%
Forest	0	0	0	0	147	3	0	0	0	6	94%
Natural Grassland	0	0	0	0	0	13	0	0	0	0	100%
Open Water	0	0	0	0	1	0	20	0	1	0	91%
Snow/Ice	0	0	0	0	0	0	0	22	0	0	100%
Natural Bare Ground	0	0	0	0	0	0	0	1	16	0	94%
Wetland	0	0	4	0	11	3	0	0	1	95	83%
Producer Accuracy	99%	100%	60%	90%	91%	65%	100%	91%	80%	91%	92%

Table 6. Accuracy assessment results for the Level 2 land cover classes in the North Saskatchewan Watershed.

	Bog	Coniferous	Cropland	Agricultural Depression	Deciduous	Disturbed Vegetation	Graminoid Fen	Human Built	Marsh	Natural Grassland	Open Water	Pasture	Roads	Snow/Ice	Natural Bare Ground	Swamp	Shrub	Woody Fen	User Accuracy
Bog	14	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	88%
Coniferous	0	86	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	5	92%
Cropland	0	0	93	3	0	0	0	0	0	0	0	2	0	0	1	0	2	0	92%
Agricultural Depression	0	0	0	12	0	0	0	0	1	0	0	1	0	0	0	0	0	0	86%
Deciduous	0	1	0	0	38	0	0	0	0	0	0	0	0	0	0	1	1	0	93%
Disturbed Vegetation	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0	1	0	95%
Graminoid Fen	0	0	0	0	0	0	11	0	0	0	0	0	0	0	1	0	1	0	85%
Human Built	0	0	0	0	0	0	0	20	0	0	0	0	0	0	1	0	0	0	95%
Marsh	0	0	0	4	0	0	6	0	21	1	0	0	0	0	0	2	3	0	57%
Natural Grassland	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	100%
Open Water	0	1	0	0	0	0	0	0	0	0	20	0	0	0	1	0	0	0	91%
Pasture	0	0	4	1	0	2	1	0	0	1	0	70	0	0	0	0	0	0	89%
Roads	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	100%
Snow/Ice	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0	100%
Natural Bare Ground	0	0	0	0	0	0	0	0	0	0	0	0	0	1	16	0	0	0	94%
Swamp	1	2	0	0	0	0	1	0	0	1	0	0	0	0	0	15	1	1	68%
Shrub	0	0	0	0	5	0	0	0	0	1	0	0	0	0	0	0	16	0	73%
Woody Fen	5	2	0	0	0	0	1	0	0	1	0	0	0	0	0	2	0	15	58%
Producer Accuracy	70%	91%	96%	60%	88%	90%	55%	100%	95%	65%	100%	96%	100%	96%	80%	75%	64%	71%	87%

NOTE: Producer accuracy measures errors of omission, which is a measure of how well real-world land cover types can be classified. User accuracy measures errors of commission, which represents the likelihood of a classified pixel matching the land cover type of its corresponding real-world location.

Table 7. Accuracy assessment results for the Level 1 land cover classes in the Battle River Watershed.

	Agriculture	Built Up/ Exposed	Agricultural Depression	Disturbed Vegetation	Forest	Natural Grassland	Open Water	Natural Bare Ground	Wetland	User Accuracy
Agriculture	297	0	2	2	4	3	0	0	2	96%
Built Up/Exposed	0	40	0	1	1	0	0	2	0	91%
Agricultural Depression	5	0	20	0	0	0	0	0	0	80%
Disturbed Vegetation	0	0	0	16	0	0	0	0	0	100%
Forest	1	0	0	0	60	0	0	0	3	94%
Natural Grassland	0	0	0	0	0	20	0	1	1	91%
Open Water	0	0	0	0	0	0	20	1	0	95%
Natural Bare Ground	0	0	0	0	0	1	0	16	0	94%
Wetland	1	0	10	1	3	0	0	0	74	83%
Producer Accuracy	98%	100%	63%	80%	88%	83%	100%	80%	93%	93%

Table 8. Accuracy assessment results for the Level 2 land cover classes in the Battle River Watershed.

	Coniferous	Cropland	Agricultural Depression	Deciduous	Disturbed Vegetation	Human Built	Marsh	Natural Grassland	Open Water	Pasture	Roads	Natural Bare Ground	Swamp	Shrub	Woody Fen	User Accuracy
Coniferous	19	0	0	0	0	0	0	0	0	0	0	0	1	1	1	86%
Cropland	0	188	2	0	0	0	1	0	0	5	0	0	0	2	0	95%
Agricultural Depression	0	4	20	0	0	0	0	0	0	1	0	0	0	0	0	80%
Deciduous	0	0	0	17	0	0	0	0	0	0	0	0	0	3	0	85%
Disturbed Vegetation	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	100%
Human Built	0	0	0	1	1	19	0	0	0	0	0	2	0	0	0	83%
Marsh	0	0	10	0	1	0	36	0	0	0	0	0	3	0	0	72%
Natural Grassland	0	0	0	0	0	0	1	20	0	0	0	1	0	0	0	91%
Open Water	0	0	0	0	0	0	0	0	20	0	0	1	0	0	0	95%
Pasture	0	4	0	0	2	0	1	3	0	100	0	0	0	2	0	89%
Roads	0	0	0	0	0	1	0	0	0	0	20	0	0	0	0	95%
Natural Bare Ground	0	0	0	0	0	0	0	1	0	0	0	16	0	0	0	94%
Swamp	0	0	0	1	0	0	1	0	0	1	0	0	16	2	7	57%
Shrub	1	0	0	1	0	0	0	0	0	1	0	0	0	18	1	82%
Woody Fen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	100%
Producer Accuracy	95%	96%	63%	85%	80%	95%	90%	83%	100%	93%	100%	80%	80%	64%	55%	87%

NOTE: Producer accuracy measures errors of omission, which is a measure of how well real-world land cover types can be classified. User accuracy measures errors of commission, which represents the likelihood of a classified pixel matching the land cover type of its corresponding real-world location.

4.2. Shoreline Buffer Land Cover

Accuracy of the land cover layer within the 50 m shoreline buffer was assessed against a stratified validation dataset generated from randomly selected polygons, and validated by trained photo interpreters. Three separate accuracy assessments were performed for the buffer land cover. Accuracy was assessed for the riparian assessment areas within the North Saskatchewan River Watershed, within the Battle River Watershed, and the other areas outside of the NSR and BRW (

Table 9). A minimum of 200 samples were used to assess the accuracy in each group. The accuracy assessment focussed on the three classes used in the calculation of the riparian intactness scores (Disturbed, Natural Low Vegetation, Woody). Open Water and Natural Bare Ground were not included as part of the accuracy assessment because they do not factor into the calculation of Intactness and their presence in the buffer is minimal (less than 5% cover combined).

Table 9. Number of validation samples for the 100 m shoreline buffer, by validation group.

Watershed	HUC6s	Number of Validation Samples
North Saskatchewan River	Beaverhill; Whiteearth; Frog; Vermilion; Monnery; Sturgeon; Strawberry	234
Battle River	Bigstone; Paintearth; Iron Creek; Blackfoot; Ribstone Creek	235
Other Areas	Brazeau; Clearwater; Dowling Lake – Sullivan Lake; Jackfish – Muriel Creeks; Lower Beaver River; Ram; Red Deer River Below Red Deer – Buffalo Lake; Sounding Creek; Tawatinaw River; Upper Beaver River; Wandering River – Lac La Biche	228

4.2.1 North Saskatchewan River Watershed

Overall accuracy for the buffer land cover in the NSR watershed was 90.6% with a Kappa statistic of 0.86 (Table 10). Class accuracies were above 78%.

Table 10. Accuracy assessment results for the buffer land cover in the North Saskatchewan River Watershed.

	Disturbed	Natural Low Vegetation	Woody	User Accuracy
Disturbed	90	1	0	99%
Natural Low Vegetation	8	46	5	78%
Woody	1	7	76	90%
Producer Accuracy	91%	85%	94%	91%

4.2.2 Battle River Watershed

Overall accuracy for the buffer land cover within the BRW was 90.6% with a Kappa statistic of 0.86 (Table 11). Class accuracies were above 80%.

Table 11. Accuracy assessment results for the buffer land cover in the Battle River Watershed.

	Disturbed	Natural Low Vegetation	Woody	User Accuracy
Disturbed	75	4	0	95%
Natural Low Vegetation	8	65	4	84%
Woody	0	6	73	92%
Producer Accuracy	90%	87%	95%	91%

4.2.3 Other Areas

Overall accuracy for the buffer land cover outside the major river basins was 90.8% with a Kappa statistic of 0.86 (Table 12). Class accuracies were above 80%.

Table 12. Accuracy assessment results for the buffer land cover in areas outside of the North Saskatchewan and Battle River Watersheds.

	Disturbed	Natural Low Vegetation	Woody	User Accuracy
Disturbed	46	4	0	92%
Natural Low Vegetation	3	66	3	92%
Woody	1	10	95	90%
Producer Accuracy	92%	83%	97%	91%

4.3. Data Limitations & Considerations

The accuracy assessments provide an assessment of the accuracy of the land cover at a large scale across the study area. However, because the classifications were performed on individual SPOT tiles, and each of these tiles were from different dates and subject to different atmospheric conditions and types of spectral interference, accuracy at a tile scale may be better or worse compared to the accuracy across the study area. Table 13 provides an overview of each SPOT tile and a description of issues and limitations from a remote sensing and classification perspective that users should consider when using the land cover data associated with a particular SPOT tile. Additionally, users of this land cover classification may want to consider that many riparian areas next to streams and rivers are classified as wetland cover classes (e.g., marsh, graminoid fen, treed/shrubby fen) throughout many parts of the watershed.

Table 13. Description of SPOT 6/7 tiles and associated issues with the imagery that impacted the classification results at a tile-scale. Locations for tiles is illustrated in Figure 2.

SPOT Tile	Date	Imagery Issues	Tile Quality
S01	Aug 15, 2017	Several patches of cloud and cloud shadow; moderate haze over east half of tile	Moderate
S02	Aug 01, 2018	Areas in northeast of tile with haze/light cloud and image overexposed compared to rest of tile	Moderate
S03	Aug 06, 2018	Slight haze in northwest of tile	Good
S04	June 08, 2018	Light haze and small patches of cloud and cloud shadow in southwest of tile	Moderate
S05	June 09, 2018	Light haze and small patches of cloud and cloud shadow in south of tile	Moderate
S06	May 08, 2017	Some areas of cloud/haze in northwest of tile; image quality and definition of features poor (forested areas very “bleached” out); balance between bands seems off	Poor
S07	Aug 25, 2017	Cloud and cloud shadow patches throughout, especially at north and south parts of tile	Moderate
S08	June 21, 2018	Areas of thin cloud/cloud haze in south of tile	Moderate
S09	June 20, 2018	Very strong solar glare on the majority of water bodies and some agricultural fields	Moderate
S10	July 26, 2017	Image appears to be overexposed and balance between bands seems off; agricultural fields tend to have glare	Moderate
S12	July 06, 2017	Some solar glare on waterbodies in east half of tile	Good
S13	Aug 06, 2018	Slight haze in northwestern and southeastern quadrants of tile; high solar glare on some water bodies	Moderate
S14	Aug 09, 2017	Very light haze over southwestern quadrant of tile	Good
S15	July 26, 2017	Solar glare on some agricultural fields	Good
S16	July 19, 2017	Heavy haze in southwest of tile and moderate haze in northeast of tile; southeast of tile appears underexposed	Poor
S17	May 28, 2017	Light haze over east half of tile; some agricultural fields overexposed due to time of year; high amounts of standing water in agricultural fields	Moderate
S18	Aug 28, 2018	Patchy cloud and cloud shadow cover throughout; colour/band balance noticeably different from other tiles	Poor
S19	Aug 01, 2018	Heavy atmospheric haze throughout tile	Poor
S20	July 06, 2017	Light haze in east half of tile; very high solar glare off of water bodies throughout tile	Moderate
S21	July 11, 2018	Very high solar glare off of water bodies throughout tile	Moderate
S22	July 13, 2017	Very light haze in central area of tile; very strong solar glare off of waterbodies in south of tile;	Moderate
S23	May 29, 2017	Some agricultural fields overexposed due to time of year; high amounts of standing water in agricultural fields	Moderate
S24	Aug 27, 2017	Light haze in southeast of tile; some overexposed agricultural fields and isolated water bodies with high solar glare	Moderate
S25	May 23, 2017	Cloud/cloud shadow in southwest of tile; many overexposed agricultural fields	Poor

Continued…

Table 13 *continued*. Description of SPOT 6/7 tiles and associated issues with the imagery that impacted the classification results at a tile-scale. Locations for tiles is illustrated in Figure 2.

SPOT Tile	Date	Imagery Issues	Tile Quality
S26	July 15, 2017	Moderate atmospheric haze throughout tile and patchy cloud/cloud shadow in central part of tile; some overexposed agricultural fields	Poor
S27	Aug 28, 2017	Some overexposed agricultural fields	Good
S28	July 07, 2017	Some overexposed agricultural fields and waterbodies with strong solar glare	Moderate
S29	June 25, 2017	Patchy cloud/cloud shadow in east half of tile; many waterbodies with strong solar glare	Moderate
S30	July 28, 2017	Heavy atmospheric haze in south of tile; strong solar glare on some waterbodies	Moderate
S31	July 27, 2017	Heavy cloud/cloud shadow cover in northeast and southeast corners of tile; thin haze and patchy cloud throughout tile; section in bottom southeast corner of tile with no DEM coverage	Poor
S32	Sept 28, 2017	Light haze in some areas; incidence angle at time of capture gives shadow along most treed areas	Moderate
S33	May 05, 2018	Many agricultural fields overexposed due to time of year	Moderate
S34	Aug 16, 2017	Moderate atmospheric haze along central area of tile; light haze throughout rest of tile;	Poor
S35	Aug 16, 2017	Patchy cloud cover and cloud shadow throughout; haze throughout tile	Poor
S36	Oct 03, 2017	Tile underexposed in non-snow covered areas; no DEM coverage for portions of tile	Poor
S37	Aug 19, 2018	Moderate haze throughout tile and patch cloud/cloud shadow cover in northeast quadrant of tile; high glare in snow-covered areas; no DEM coverage for southwest portions of tile	Poor
S38	Aug 27, 2017	Patches of moderate haze/cloud cover in southeast, central, and northwest parts of tile; small patches of cloud/cloud shadow in eastern half of tile; early snow cover at low elevations throughout tile	Poor
S39	Aug 28, 2017	Tile very underexposed and poor contrast throughout; early snow cover at low elevations throughout tile; no DEM coverage for portions of tile	Poor
S40	Aug 19, 2018	Tile underexposed in non-snow covered areas; no DEM coverage for portions of tile	Poor
S50	July 29, 2017	Light haze along west half of tile; strong solar glare on some waterbodies; no DEM coverage for tile	Poor
S51	July 20, 2018	Patches of cloud/cloud shadow throughout; tile very dark/underexposed and with low contrast; no DEM coverage for tile	Poor

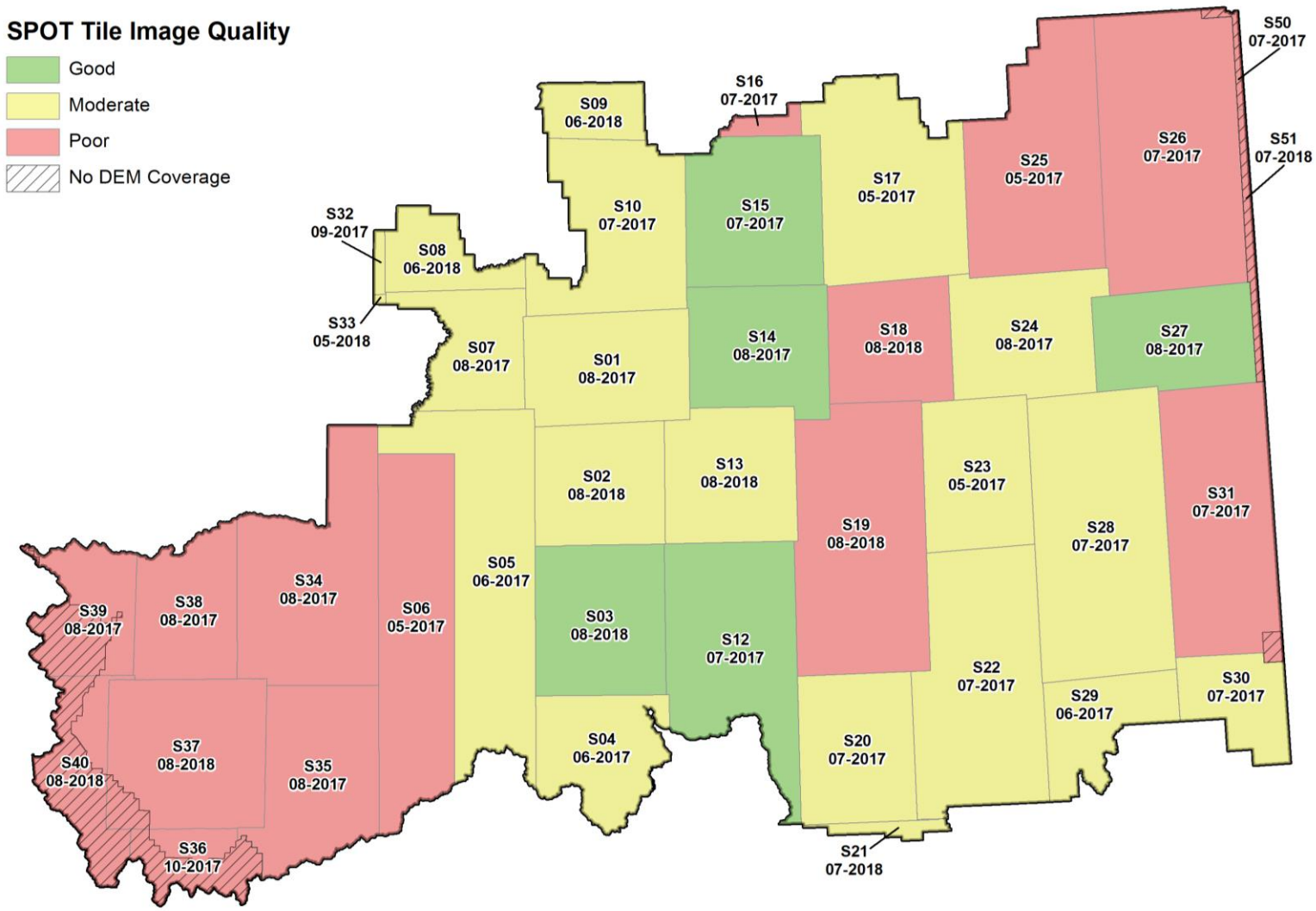


Figure 5. Reference map illustrating SPOT tile quality and areas where no 15 m DEM coverage was available for use in the classifications.

5.0 Data Deliverables

5.1. Wall to Wall Land Cover

The wall to wall land cover is being delivered in two formats:

- A single seamless raster at 6 m resolution in .tif format (*Wall2Wall_LandCover.tif*)
- 41 individual polygon files within a geodatabase. Each file corresponds with the SPOT tile used to perform the classification and the naming is consistent with those presented in this document (e.g., *S01_Final*, *S02_Final*, etc.)

Both formats have fields that describe the classes at Level 1 (*Class_Level1* in polygon files; *Class_L1* in the raster) and Level 2 (*Class_Level2* in polygon files; *Class_L2* in the raster). Metadata is included as part of each spatial data file.

5.2. Buffer Land Cover

The buffer land cover is being delivered in a single format:

- A single seamless raster at 6 m resolution in .tif format (*Buffer50m_LandCover.tif*)

The file has a field that describes the land cover class (*Class*). Metadata is included as part of the spatial data file.

5.3. DEM Mosaic

A 15 m DEM covering the study area is being delivered in a single format:

- A single raster at 15 m resolution in .tif format (*DEM_15m_Mosaic.tif*)

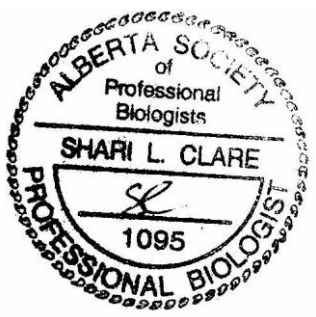
Note that the DEM is not seamless and contains gaps where there was no DEM data available from the GOA. Metadata is included as part of the spatial data file.

5.4. Closure

This report was written by:

Shantel Koenig, MGIS, PhD
Sr. Landscape Ecologist and GIS Specialist

Shari Clare, PhD, PBiol
Director, Sr. Biologist



6.0 Literature Cited

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