PREDICTIVE WETLAND MAPPING OF THE FWCP-PEACE REGION

June 30th , 2018

PREPARED FOR:

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PREPARED WITH FINANCIAL SUPPORT OF THE FISH AND WILDLIFE COMPENSATION PROGRAM ON BEHALF OF ITS PROGRAM PARTNERS: BC HYDRO, THE PROVINCE OF BC, FISHERIES AND OCEANS CANADA, FIRST NATIONS AND PUBLIC STAKEHOLDERS.

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EXECUTIVE SUMMARY

The Ministry of Environment signed a ‘*Letter of Agreement*’ with the Fish and Wildlife Compensation Program to map wetland and riparian areas within the FWCP-Peace Region (FWCP-Peace). Ecosystem mapping products lacked coverage, and were cost prohibitive to map the remainder of the area. Therefore in 2016, a pilot study was conducted to assess the feasibility of machine-learning algorithms to map riparian areas and wetlands in the area. A ‘Random Forest’ model approach was used to map riparian areas and wetlands across the FWCP-Peace at a 25m pixel resolution using 48 mapcodes. The resulting product is superior to publicly available Terrain Resource Information Management (TRIM) wetland polygons as it is more consistent and provides information on wetland and riparian type and distribution. Fieldwork was conducted in the summer of 2017 to support detailed site level inventories and verify model accuracy. The model reliably differentiates wetlands, Terrestrial-uplands (Hereafter denoted “Upland” or ”T”) and water at the scale of the FWCP-Peace and identifies significantly more wetland and riparian area than TRIM. Four classes of wetlands, and three riparian classes were differentiated at a moderate level of reliability. The model output was then used to conduct spatial analysis of wetlands related to biogeoclimatic zones, geology and disturbance.

The project has delivered a 7.2 million hectare wetland-and-riparian mapping product for the FWCP-Peace. Importantly, methods and products were specifically designed for openness and transparency, thereby increasing value through further use and extension opportunities.

Further considerations for extending the product to a wetland management context, as well as data and model improvements as part of continuous improvement cycle are presented herein.

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INTRODUCTION

> ***"You can't manage what you don't know. The first step in wetland protection is to identify, map and classify (i.e., inventory) the wetlands." (Cox & Cullington, 2009)***

BACKGROUND

Fish and Wildlife Compensation Program (FWCP) and Ministry of Environment and Climate Change Strategies (MoECCS) signed a '*Letter of Agreement*' (Dec 2015 - March 31, 2018) to complete mapping of wetland and riparian units representing wetland extent and classification [e.g., fen, bog, marsh, swamp, flooded]. The goal was to create consistent, defensible and repeatable maps with supporting documentation that improves current inventories at a fraction of the traditional inventory mapping costs. The project was designed to address riparian ecosystem goals by determining the distribution, abundance and connectivity of wetland and riparian areas as outlined in the Riparian and Wetlands Action Plan[1] , specifically:

Objective 1*: Improve the understanding of the abundance, distribution, trend and connectivity of riparian and wetland ecosystems.*

> ***Sub-objective 1a****: Improve understanding of the abundance, distribution, trend and connectivity of riparian ecosystems.*

Action 1a-1*: Inventory the distribution, abundance, current function and connectivity of remaining riparian ecosystems.*

Rationale: *Before feasible targets can be established for riparian ecosystem restoration or enhancement, an inventory of existing habitats within the Peace Basin is required to identify potential sites and their current status.*

> ***Sub-objective 1b****: Improve understanding of the abundance, distribution, trend and connectivity of wetland ecosystems.*

Action 1b-1*: Inventory the distribution, abundance, current function and connectivity of remaining wetland ecosystems.*

Rationale*: Before feasible targets can be established for wetland ecosystem restoration or enhancement, an inventory of existing habitats within the Peace Basin is required to identify potential sites and their current status.*

A timeline of activities and deliverables/outcomes is in Appendix A. Trend and current function is beyond the scope of this project.

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[1] "Peace Basin Riparian and Wetlands Action Plan - Fish and Wildlife Compensation Program" http://fwcp.ca/app/uploads/2015/07/fwcp-peace-riparian-and-wetlands-action-plan-march-31-2014.pdf. Accessed 16 Apr. 2018.

STUDY AREA

STUDY AREA OVERVIEW

The wetland project area is confined to the Williston Reservoir Drainage Basin (FWCP-Peace Region) comprised of 7.2 million hectares ranging from the alpine ecosystems of the high mountain ranges to forested lowlands of the Rocky Mountain Trench. Central to the FWCP-Peace is the Williston Reservoir; a 177300 hectare designed water body formed in 1967 by the construction of the WAC Bennett Dam (Golder Associates, 2010). Elevation of the FWCP-Peace ranges from 500 to 3,000 meters and is further described by four basins including the Finlay, Parsnip, Peace and Dinosaur (Figure 1). These cover four physiographic types inclusive of mountains, foothills, plateaus and the Rocky Mountain Trench, and falling within five biogeoclimatic zones. This extent spans the mapping grids 94B-F, 93I, 93J and 93M-O at 1:250,000 scale. At the 1:20,000 scale, the area covers 623 map sheets[2] of which ~150 are partial coverage along the FWCP-Peace project-area boundary.

Factors influencing wetland and riparian ecosystem diversity within the region include topography, substrate (bedrock and soils), climate, hydrology, biota (vegetation, wildlife and other organisms) and disturbance history. These factors ultimately determine the abundance, distribution, current state, function and response rate (trend) of wetland and riparian ecosystems. Of these, topography and substrate are enduring features and are generally unlikely to change over hundreds of years. Conversely, hydrology, natural disturbances and biota change occur more rapidly in response to escalating disturbance due to human activity and a changing climate (Yang *et al*., 2018).

Understanding the interactions and relationships of these factors to wetland and riparian systems is key to improving understanding, prioritizing actions and setting feasible targets (National Research Council, 1995; Euliss *et al*., 2008). Consistent data on wetland extent and type will facilitate analysis to investigate the interrelationships that different environmental factors and disturbance have on ecosystem function, condition and trend.

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[2] Provincial, geometrically corrected aerial photograph that displays ground features in their true ground position with a constant scale throughout the image. https://www2.gov.bc.ca/gov/content/data/geographic-data-services/digital-imagery/orthophotos

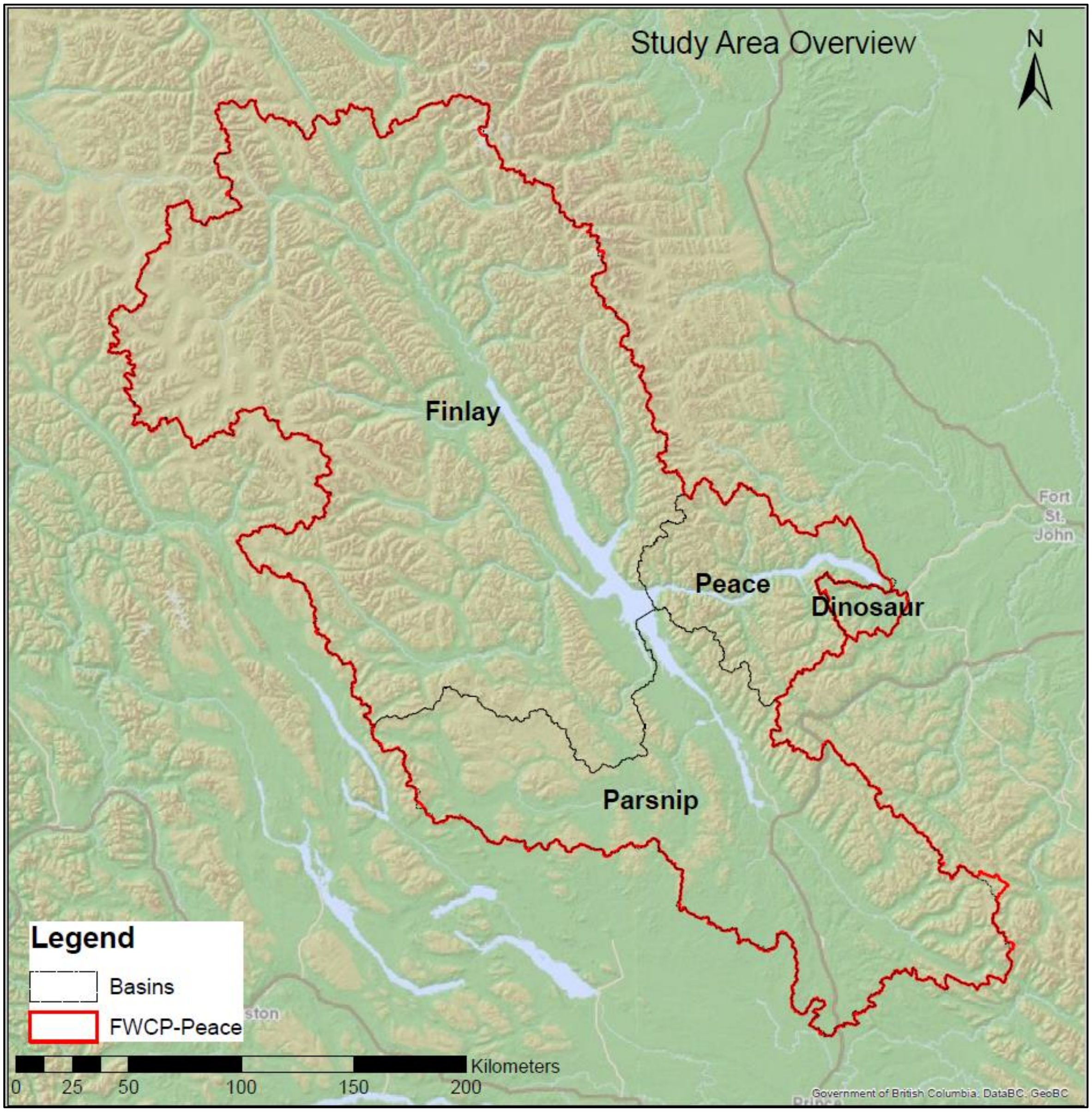


Figure 1. Study area overview map with topography, FWCP-Peace and basin boundaries (FWCP-Peace Region Boundary).

TOPOGRAPHY AND SUBSTRATE

The area consists of nine physiographic regions grouped according to similar landforms of geology and soils which include the: Cassiar Mountains, Interior Plateau, Omineca Mountains, Rocky Mountain Foothills, Rocky Mountain Trench, Rocky Mountains, Skeena Mountains, and Stikine Plateau (Figure 2) (Church & Ryder, 2010).

The FWCP-Peace is within a tectonically active zone resulting in a complex mosaic of rock types and fault lines. Consequently, bedrock geology varies greatly across the study area and within each basin, physiographic area and biogeoclimatic subzone (Figure 2). Surficial materials were deposited by glaciers, water, erosion, wind and organic accumulation. They are abundant, highly variable and very thick (tens of meters) in the major valleys and the Rocky Mountain Trench where “quaternary sediments” are indicated on the map (Figure 2). Surficial materials are key determinants of soils and plant communities that significantly influence wetland and riparian form, function and resilience.

Geology and surficial materials largely influence water chemistry. For example, limestone and calcareous rich sediments of the Rocky Mountains contribute to higher pH while the acidic nutrient poor granitic and intrusive rocks (“Ultramafic”) of the Skeena Mountains result in lower water pH. Ultramafic bedrock has unique chemistry that can be toxic to many plant species but also provide habitat to unique plant communities resilient to these toxins (Alexander *et al*., 2007). Geology and substrate influence water movement as they correlate to infiltration rates, locations of springs, water table levels and drainage patterns. Erosion and drainage occur in weaknesses of bedrock and fault lines. Porous substrates provide groundwater storage and supply to wetland and riparian ecosystems (Warner, 2004).

Wetland soils are typically organic soils, gleysols (saturated mineral soils) and cumulic soils (accumulations of mineral and organic layers from periodic flooding). Cumulic deposits of peat and mineral sediments provide clues to flooding frequency and magnitude. In BC, cumulic sediments preserve a record of the erosion, climate and biotic history of their upslope drainage basins for up to 14,000 years for most wetlands and more than 27,000 years for glacial sediments (Hartman and Clague, 2008). Peaty substrate contributes to water chemistry, filtration, nutrient cycling, and thermal insulation. They are sensitive to subtle changes to the water table and flooding regimes.

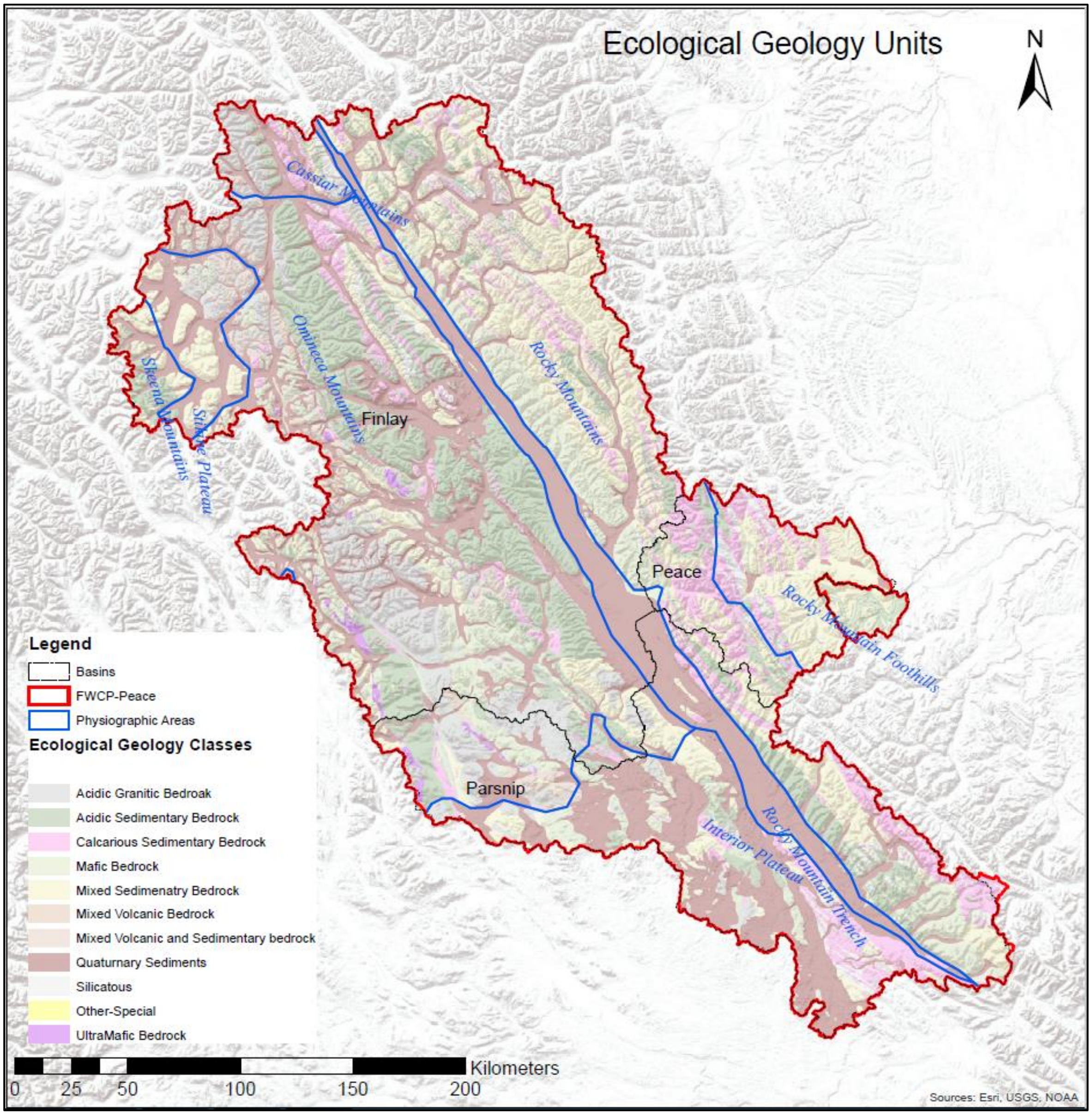


Figure 2. Map of Geology and Physiographic Areas.

Biogeoclimatic zones divide the province in to areas based on climate and vegetation. Biogeoclimatic subzones are areas of relatively uniform regional climate that support a distinct climax plant association on zonal sites. “Variants reflect further distinctions in regional climate and are generally recognized for areas that are slightly drier, wetter, snowier, warmer, or colder than other areas in the subzone.“ (Meidinger & Pojar, 1991). Thus, biogeoclimatic subzones reflect regional climatic conditions that, in combination with edaphic hydrodynamic conditions, can be used to predict climax and successional plant communities in wetland and riparian ecosystems.

The study area for this project spans the following five biogeoclimatic zones: Boreal Altai Fescue Alpine (BAFA), Boreal White and Black Spruce (BWBS), Engelmann Spruce - Subalpine Fir (ESSF), Sub-Boreal Spruce (SBS), and Spruce - Willow - Birch (SWB) (Table 1).

Table 1. Climatic variables within the biogeoclimatic zones in the FWCP-Peace (1961-1990) (Wang *et al.* 2012), and BEC v10 (HectarsBC.org, 2018).

		Mean Annual Temp	Mean Annual Precip (mm)	Mean Snow Precip (mm)	Mean # of Frost Free Days (mm)	Mean Hargreaves Climatic Moisture Deficit (mm)	Mean Annual Heat/Moisture Index	Mean Summer Heat:Moisture Index
BAFA	Boreal Altai Fescue Alpine	-3	1060.5	685.5	81.7	4.4	7	18.5
BWBS	Boreal White and Black Spruce	0.2	541.7	240.1	131.8	169.7	19.2	49.3
ESSF	Engelmann Spruce -- Subalpine Fir	-0.9	925.9	540.6	113.9	47.1	10.6	30.6
SWB	Spruce -- Willow -- Birch	-1.8	759	397.1	102.1	29	11.2	26.2
SBS	Sub-Boreal Spruce	1	770.5	395.1	138	144.8	15.1	45.7

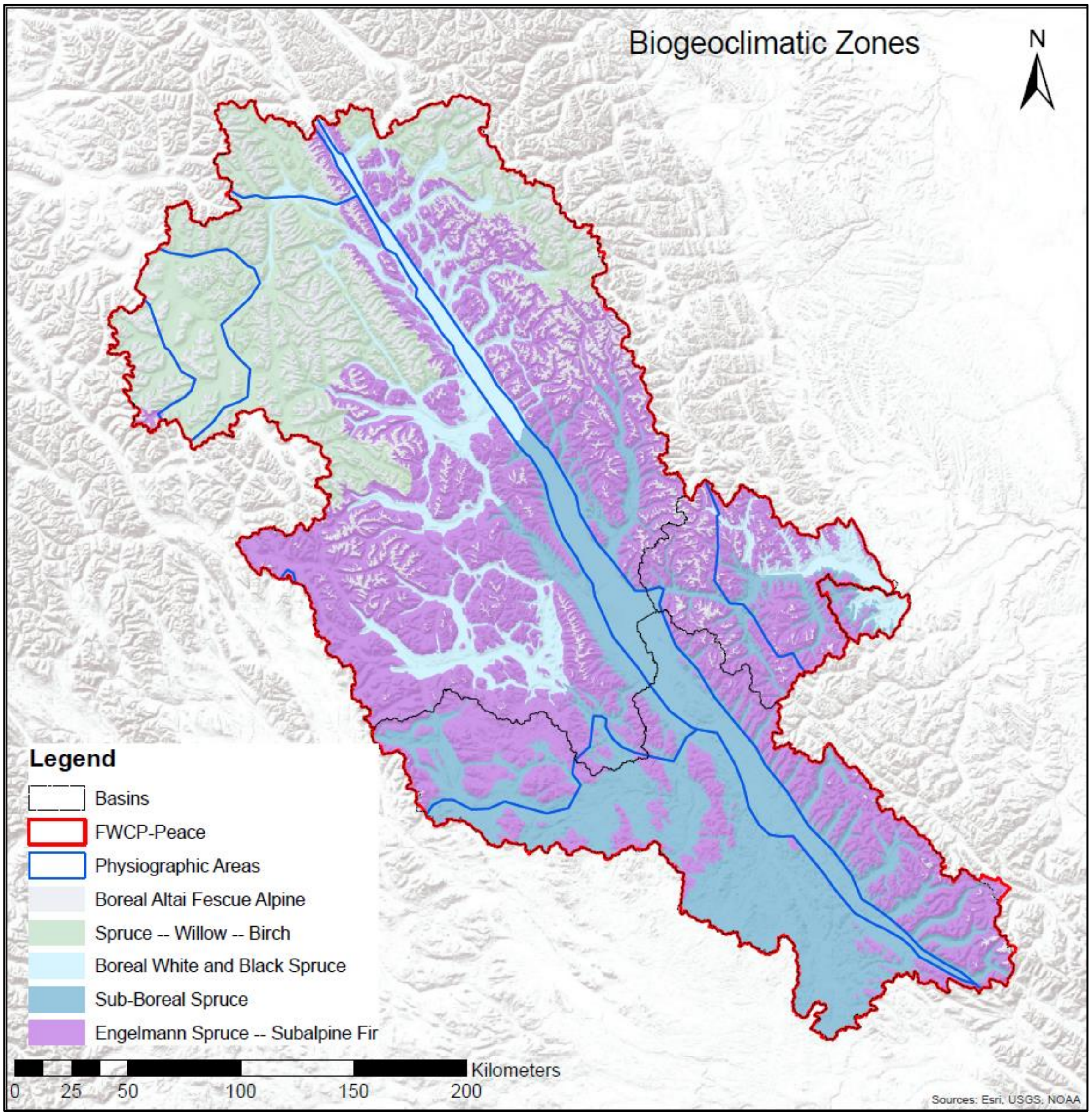


Figure 3. Map of Biogeoclimatic Zones within the FWCP-Peace Region.

HYDROLOGY

Surface flow and groundwater dictate water supply to wetlands and riparian systems. Precipitation and snowmelt are primary sources of surface water. Topography largely controls where surface water accumulates resultiTCang in both isolated wetlands, and connected wetland and riparian systems. Glaciers, icefields, ground ice (in permafrost areas) and persistent snow fields influence the surface water supply to hundreds of kilometers of downstream connected wetland and riparian ecosystems. Changes to temperature, precipitation, and landcover alter water supply, volume and timing from these sources.

Surface water flows can be estimated via hydrometric data. The hydrometric data represents long term trends that may influence wetlands as is influenced by wetland hydrologic functions related to flow moderation (Hanson et al., 2008). Figure 4 shows the hydrometric basins and hydrometric stations present in the area (note that not all areas have stations). Each polygon is labeled with the ten year peak flow in meters cubed per second, and average annual precipitation in millimeters.

Groundwater is another contributor to wetland hydrology. Groundwater aquifers are common in the quaternary deposits of the major valleys in the study area, like the Finlay River Valley, while deep bedrock sources are found along fractures and faults throughout the study area. Some of these groundwater sources give rise to hot springs which are often host to unique ecosystems in the landscape.

The areas immediately surrounding the Williston reservoir are affected by the drawdown associated with the WAC Bennett and Peace Canyon dams. Typically the reservoir has an operating range between 642-673 meters above sea level, and a yearly average drawdown range of 10-12m. Shallow water fringes and associated wetlands can be affected by drawdown fluctuations (Peace Water Use Plan Committee, 2003).

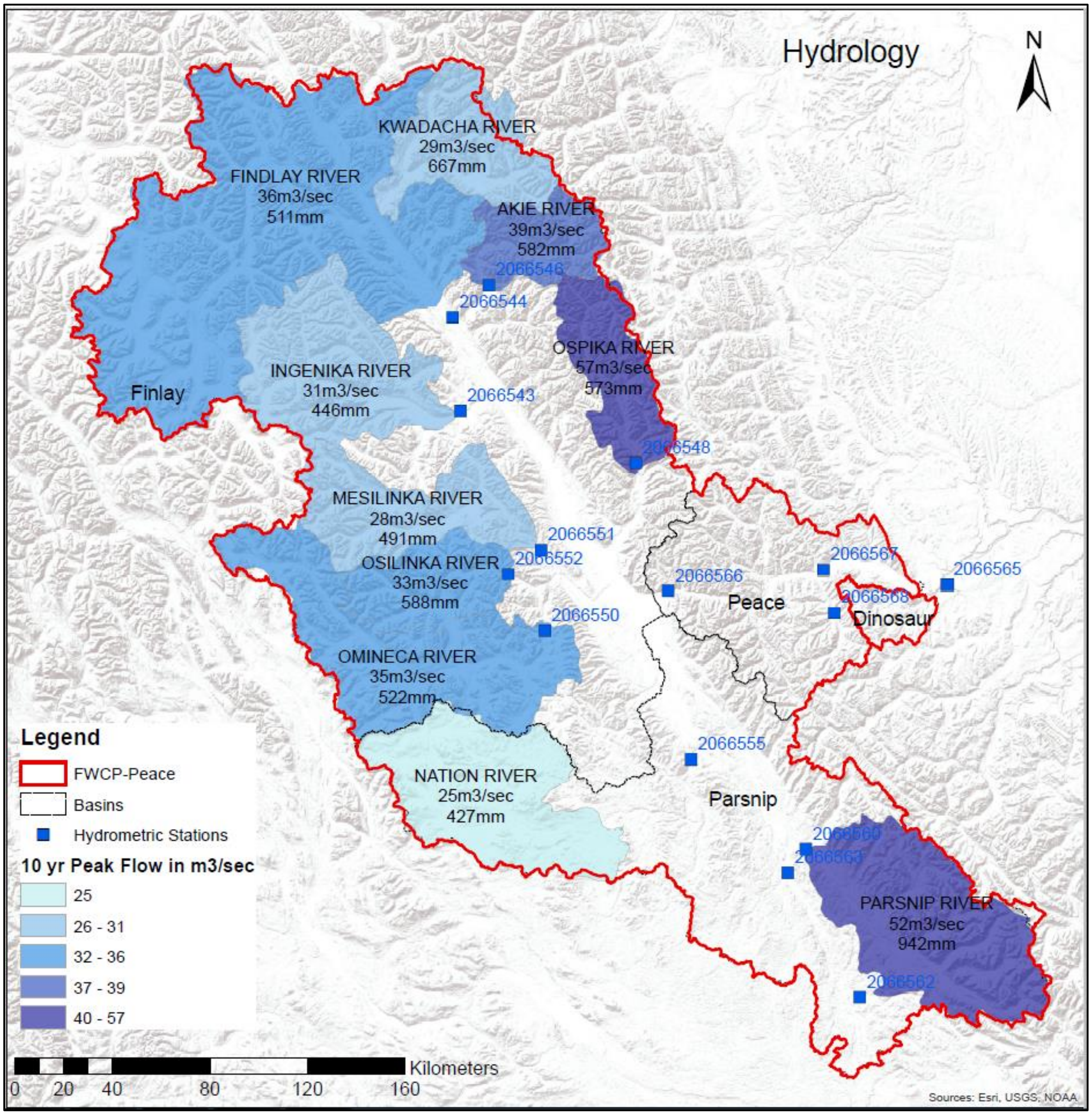


Figure 4. Map of hydrometric basins in the FWCP Finlay, Parsnip, Peace and Dinosaur basins.

DISTURBANCE

Disturbances impact wetlands both directly and indirectly, and these can be cumulative. Direct impacts include immediate physical disturbances to the wetland area. Indirect impacts include factors near wetlands that influence wetland form and function. Since wetlands are connected hydrologically to upland areas, disturbances in the upland catchment areas can also impact downstream wetlands.

Landscape-level disturbances identified in the study area included timber harvest, road density, active mining, and potential future mineral/coal extraction (Figure 5 & 6). While forestry, mining, and road density are not a comprehensive list of disturbance impacts within these basins, they are the predominant anthropogenic disturbances.

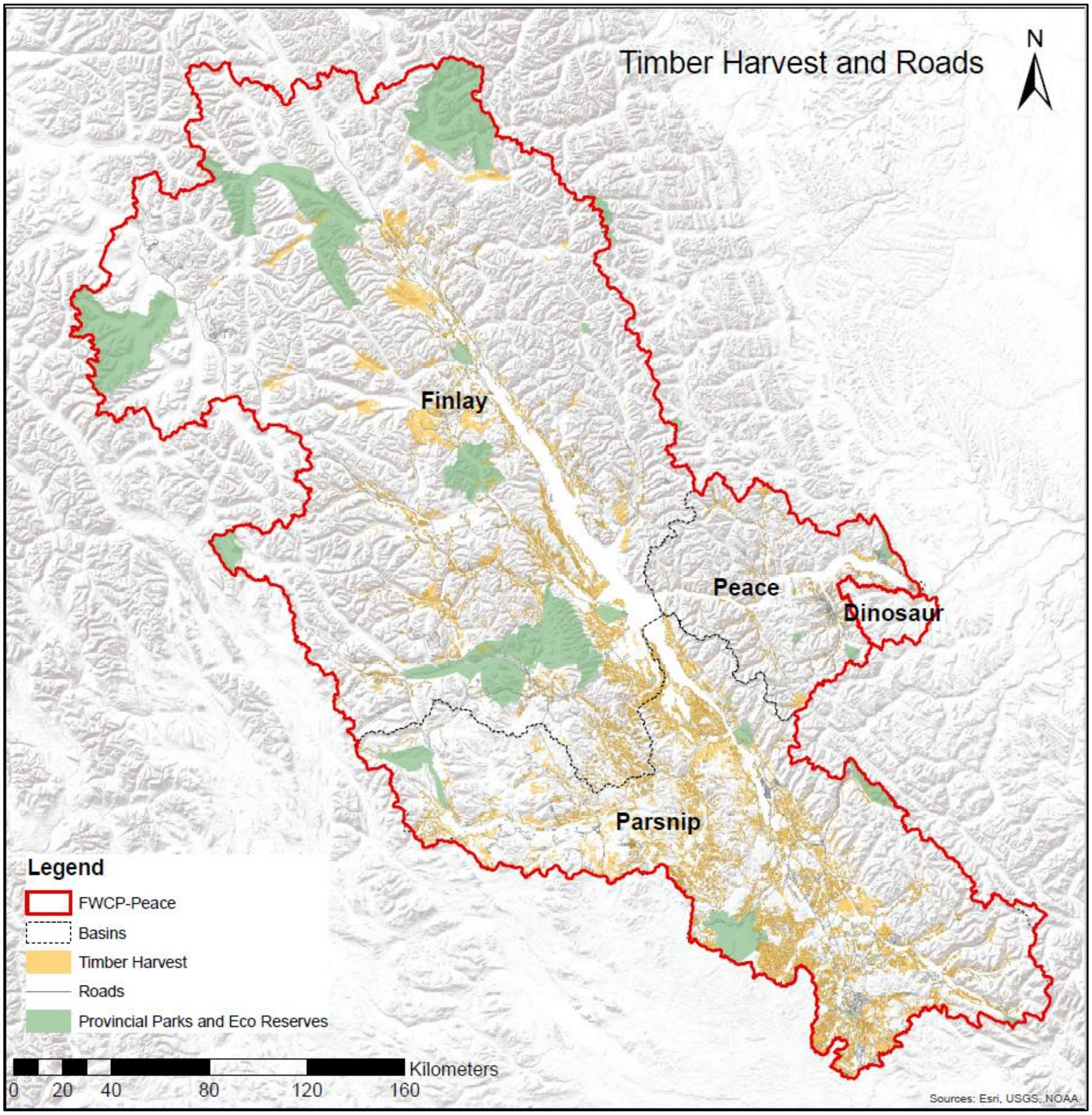
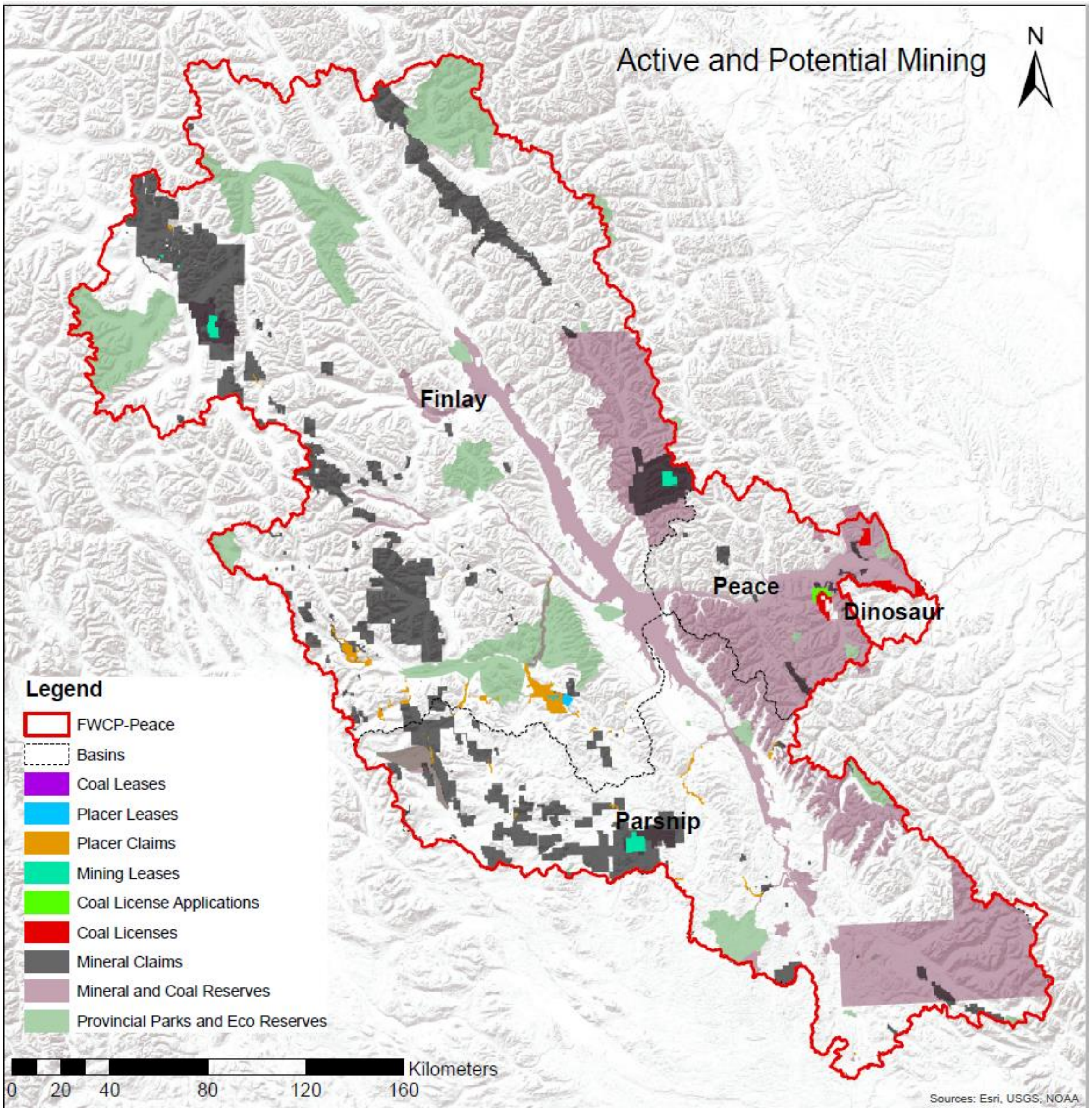


Figure 5. Map of Timber Harvest and Roads.

Although timber harvest is not necessarily a permanent disturbance on the landscape in the same way that conversion to urban land cover is; it often impacts wetlands by altering evapotranspiration, water levels (Dube *et al.*, 1995) and localized ecological function, increasing sedimentation rates (Moore & Wondzel, 2005), and altering hydrologic, thermal, and chemical regimes (Mellina, 2002). Additional work has shown that timber harvest can also negatively impact invertebrate communities (Batzer *et al.,* 2000, Kreutzweiser *et al.,* 2008), change the base of food webs, and affect leaf litter decomposition and nutrient cycling (Kreutzweiser *et al.*, 2008).

Road networks and densities can be used as a proxy for human activity and negative effects on a landscape (Trombulak & Frissell, 2001). Roads contribute to fragmentation and edge effects, can alter hydrology patterns, and increase invasion by exotic species. Furthermore it is demonstrated that overall species richness in wetlands as defined as number of different species represented in an ecological community, decreases with increased road density (Findlay and Houlahan 2003).



Sources: Esri, USGS, NOAA

Figure 6. Map of license, leases, claims and applications for coal and mining activities

Mining activity (coal, placer, mineral leases and claims) changes the landscape through several ways including permanent land conversion, altered hydrology patterns, and fragmentation. These activities can release undesirable contaminants into watersheds, and contribute to siltation. Successful remediation of ecosystems and wetlands after a disturbance may be difficult, as natural wetlands can take several decades to develop complex level of functional interactions. Potential future mining activity can be inferred by placer or mineral claims and reserves.

METHODS

This project was completed in three phases over three years (March 2016 - March 2018). Phase 1 collected background information and evaluated available inventories to support two pilot test methodologies. Phase 2 explored a third pilot to evaluate the application of machine learning (Random Forest Algorithm) and evaluated the output against the existing Freshwater Atlas (FWA) wetland polygons. Phase 3 mapped the wetlands of the FWCP-Peace using machine learning techniques.

PHASE 1: INITIAL PILOT USING EXISTING INVENTORY MAPPING

Phase 1 of the project was completed in March 2016. This phase compiled existing inventories and conducted a pilot project to evaluate the feasibility of using existing provincial wetland polygon data (Tripp *et al*., 2016). The initial data evaluation found that Terrestrial Ecosystem Mapping (TEM) wetland and riparian ecosystem delineation and attribution was of good quality but only covered 7% of the study area.

The Ministry of Environment and Climate Change Strategies (MoECCS) then developed a pilot study to investigate feasible mapping methods. Three map sheets were selected:

- **93O.062** – Southwest of the Williston Reservoir. Contains a very large Freshwater Atlas Wetlands polygon (15 Mile Swamp >2000ha). Available data includes colour imagery, Vegetation Resource Inventory (VRI) and Freshwater Atlas (FWA) wetlands for the entire map sheet.
- **94F.024** – Half of the map sheet covered by Akie Terrestrial Ecosystem Mapping Project. Vegetation Resource Inventory and Freshwater Atlas Wetlands for the entire map sheet. Best available image on government servers appears to be 1999 black and white orthophotos.
- **94C.085** – This map sheet has a higher density (>300 ha/map sheet) of wetland features. It is located near the northwest corner of the FWCP-Peace. Vegetation Resource Inventory, Freshwater Atlas Wetlands and the Ingenika TEM are available.

Two mapping options were evaluated by two contractors using two different mappers each. Time and cost estimates were calculated for the two options. Option 1 used FWA polygons and added attribution. Option 2 allowed mappers to choose linework from any of the available sources and modify as needed before attributing the polygons with the dominant wetland type.

The study concluded that neither method could produce a reliable and consistent system for mapping wetlands to meet the overall objectives within the defined budget and neither method addressed riparian areas. The methods did, however, develop the first draft of practical landscape mapcodes (land cover types to map) and mapping standards (best practices) that informed later phases of the project.

PHASE 2: EVALUATING A MODELLING APPROACH

Starting early 2017, Ministry of Environment and Climate Change Strategies (MoECCS) staff evaluated machine-learning computer algorithms to address the issues of high cost, data gaps and reproducibility identified in Phase 1. The guiding principles of this approach were to:

- Identify appropriate algorithms and mappable wetland and riparian units for the FWCP;
- Provide accurate, repeatable and cost effective predictive maps;
- Use tools that are open source and available to the public at no added cost;
- Use data that are open source and available to the public at no added cost; and
- Use data that are available for the entire Province.

In Phase 2, the following was completed:

a) Initial scoping exercise was completed by MoECCS staff; and
b) An iterative refining process was carried out in conjunction with contracting organizations with expertise in landscape mapping and geographic information systems (GIS).

STEP 1: INITIAL SCOPING

Initial scoping efforts involved selecting a wetland classification system to map, identifying appropriate machine-learning algorithm, sourcing relevant data layers and modelling a single 1:20,000 map sheet.

STEP 2: SELECTING WETLAND CLASSIFICATION SYSTEM

Prior to any modelling, an appropriate wetland classification system needed to be identified for the FWCP-Peace. An initial list of requirements for the classification system included:

- Be relevant to the wetlands occurring within the FWCP-Peace;
- Describe wetland units at a range of appropriate spatial scales; and
- Describe mappable units

Additional requirements of the classification system included compatibility with other classification systems and jurisdictions through shared underlying processes, and that the classification system could be applied at the provincial scale to meet the goals of Phase 2.

Four wetland-specific systems and two non-wetland systems were investigated. The two non-wetland systems are primarily vegetation focused, and included the Vegetation Resource Inventory and the Broad Ecosystem Inventory systems.

The wetland-specific classification systems investigated included:

- Wetland Identification Guide of British Columbia (WIGBC) (Mackenzie & Moran, 2004);
- Non-Forested Biogeoclimatic Ecosystem Classification system (nBEC) (Mackenzie, 2012);
- Canadian Wetland Classification system (CWCS) (National Wetlands Working Group; 1997);
- Cowardin Classification system (Cowardin *et al*., 1979); and
- Alberta Wetland Classification system (AWCS) (Government of Alberta, 2015).

The WIGBC system was selected as the most appropriate for several reasons. First, it is British Columbia specific, and wetland units occurring within the FWCP-Peace Region are likely to be described. Secondly, the system's classification encompasses a range of appropriate spatial scales, and is useful at the site-association (in the field) level to the realm level of description (e.g. upland, water, wetland). Unlike the CWCS and the AWCS systems, the WIGBC key uses site level descriptions of British Columbia focused wetland vegetation communities, hydrogeomorphology and edaphic conditions. The WIGBC system can be related to nBEC (and by extension BEC), the CWCS and AWCS at the wetland class level (Bog, fen, swamp, marsh). The ability of WIGBC to identify wetland class is important as these classification units are most easily interpreted on site by a wide range of users, professionals and stakeholders. They are also more easily interpreted remotely including on poorer quality imagery.

STEP 3: SELECTING APPROPRIATE CLASSIFICATION PROCEDURE TO EVALUATE

Broadly, land cover classification procedures can be grouped into either supervised or unsupervised classifications. Unsupervised classification aggregates data into similar groups based off a defined number of groups and a grouping algorithm. The practical result is a map where each pixel is classified into a group but definition or importance of the group requires interpretation afterwards. Supervised classification requires expert definition of data groups and their associated values. This often requires training an algorithm with a subset of the data, then running on the remainder. In practice this requires an expert to select data (pixels of mapping products) and label accordingly. The result is a map where each pixel is classified into a group, and that these group identities are known.

The goal of Phase 2 was to classify WIGBC wetland units, which can be inferred from air photo imagery, and therefore supervised classification methods were investigated. Of the supervised methods, the Machine Learning Algorithm; Random Forest was selected for evaluation in the initial scoping exercise. Random Forest provides many advantages including: non-parametric nature; a high degree of accuracy; somewhat resistant to outliers, overfitting and missing data; and ability to determine variable importance (Breiman, 2001). It requires the user to provide relevant input spatial information and trained point locations. It then makes use of an ensemble method to grow decision trees and aggregates class votes to make strong predictions. It is widely used in the geospatial community for large scale land cover classifications (Gislason, Benediktsson & Sveinsson, 2006; Belgiu & Draguit, 2016). The Province of British Columbia has used Random Forest to model a range of topographic information (Mike Ryan & Heather Richardson, Forests, Lands, Natural Resource Operations & Rural Development, personal communications, October 2016).

STEP 4: SELECTING INPUT DATA-LAYERS

There were three primary constraints on the selection of input data layers. First, they had to be relevant to wetland processes or identification. Second, the data had to be available at a spatial resolution that could adequately capture wetland features. Third, in accordance with Phase 2 guiding principles, the data layers had to be freely available to the public with a priority for data having coverage of the whole province.

Data layers used in Phase 2 and 3 were derived from three primary sources. The first was the Provincial Digital Elevation Model (DEM) provided at 35 m resolution. From this, a suite of topographic indices were created using the System for Automated Geoscientific Analyses (SAGA). The second source of information was three band composite of Landsat-8 satellite Imagery optimised for vegetation. However, Sentinel-2 13-band multispectral satellite imagery was used in subsequent modelling iterations. The third data source was ClimateBC calculated and modelled layers that were used for information on climatic influences on wetland types. All layers were resampled to 25 m. A complete list of the data layers used in this study is provided in Appendix B.

STEP 5: INITIAL TESTING OF THE RANDOM FOREST MODEL

As part of the supervised classification component of Phase 2, 200 training points were identified on a 1:20,000 orthophoto map sheet (#09C085). The training points were attributed using the WIGBC classes based on airphoto interpretation. Data values were extracted for all input layers at each point location and inputted into a point database. This point database was used as direct input for the Random Forest model, and the model was run to predict wetland units and upland areas.

Initial results of Phase 2 indicated that Random Forest model could be used effectively to map wetlands. These results showed good agreement with the TRIM wetlands layers and followed air photo interpretations of the landscape. The decision therefore was made to pursue, extend, and improve the modelling workflow.

STEP 6: REFINING THE MODELLING PROCESS

In February 2017, Ministry of Environment and Climate Change Strategies (MoECCS) staff worked with contractors to 1). Refine wetland and non-wetland units specific to the FWCP-Peace 2). Assess time requirements and reproducibility of model outputs between mappers, and 3). Develop a standardized landscape unit pick-list and methods for efficient attribution (Appendix C).

Each contractor was provided five 1:20,000 (n=15) orthophoto map sheets, with 500-1,000 randomly generated points. TRIM wetlands layers were used to identify areas within the FWCP-Peace having higher densities of recorded wetlands (Andrew & Green, 2017a). Contractors were asked to attribute WIGBC wetland units, nBEC, hydrogeomorphic systems and subsystems and anthropogenic units where applicable. The contractors worked with MoECCS staff to perform quality assurance (QA) of the wetland units, estimate efforts and assess reproducibility. Based on this QA analysis a 78% match between all mappers at the wetland class level (n=2,544) was achieved. Wetlands of similar structural stages, however, were often difficult to consistently identify from air photos. Key recommendations from this effort included using ancillary updated imagery (Google Earth – DigitalGlobe) along with the MoECCS airphotos when attributing points.

After attribution and QA analysis, work was undertaken to identify a suite of the most appropriate wetland units (Realm/Class/Structure/Association), and nBEC mapcodes for the region (Andrew & Green, 2017a).

The result of the refining process was 48 mapcodes that could be airphoto interpreted, were relevant for the region, and were reproducible between groups (Appendix C). Of these there were 13 wetland specific units, and three flood association riparian units. The remaining mapcodes were for upland ecosystems. There were two principle benefits from the identification of multiple wetland mapcodes; they better characterize the spectrum of wetland conditions in the broader FWCP-Peace landscape, and they give the model a greater choice of units to predict based on input layers. The standardized wetland mapcodes were used to produce Random Forest modelled wetland maps for the 1:20,000 airphoto map sheets. The results are in good agreement with air photo interpretations of wetland land cover. Furthermore, the Random Forest model reporting indicated that spectral imagery (Landsat 3-band) composite was ranked high for variable importance.

The overall result of Phase 2 was a proof of concept of modelling wetlands in the region using Random Forest, a standardized suite of mapcodes, relevant spatial layers, and repeatable methods. Phase 2 also demonstrated that this method could produce cost effective, repeatable, and robust results to the resolution of wetland structure and structural stage.

PHASE 3: MODELLING FWCP-PEACE

Following the expert evaluation and refinement process of Phase 2, it was necessary to extend the methods and model out to the remainder of the FWCP-Peace. Phase 3 (March 2017-December 2017) focused on using lessons learned in the previous work components to further refine the product and produce wetland mapping for the entire area. This component incorporated ground-truthed field work to evaluate overall accuracy of the model outputs.

REFINING INPUT DATA & ATTRIBUTING THE FWCP-PEACE MANAGEMENT AREA

Random Forest outputs from Phase 2 indicated spectral imagery would be important to reduce internal error and effectively predict wetlands. The original Landsat-8 imagery was limited to three spectral bands in the red to shortwave spectrum. A Sentinel-2 composite consisting of 13 spectral bands across the visible and infrared spectrum was sourced and used in conjunction with the Landsat imagery. The increased number and range of bands of the Sentinel-2 imagery provides the model with more physical land cover encoded information. When compared to results using only three bands from Landsat, there was a large decrease in internal estimates of errors.

In total 12,500 points were attributed for the FWCP-Peace using the refined mapcodes and equating to a density of approximately 1 point per 580 hectares (Figure 7).

Three versions of Random Forest were run for the entire 7.26 million hectares in the FWCP-Peace, which included;

- 48 mapcodes;
- An aggregate of all terrestrial-upland units as ‘Upland (T)’, all water units as ‘Water (W)’ and all wetland units to respective wetland class, and;
- All units aggregated to Upland (T), Water (W), and Wetland (WL).

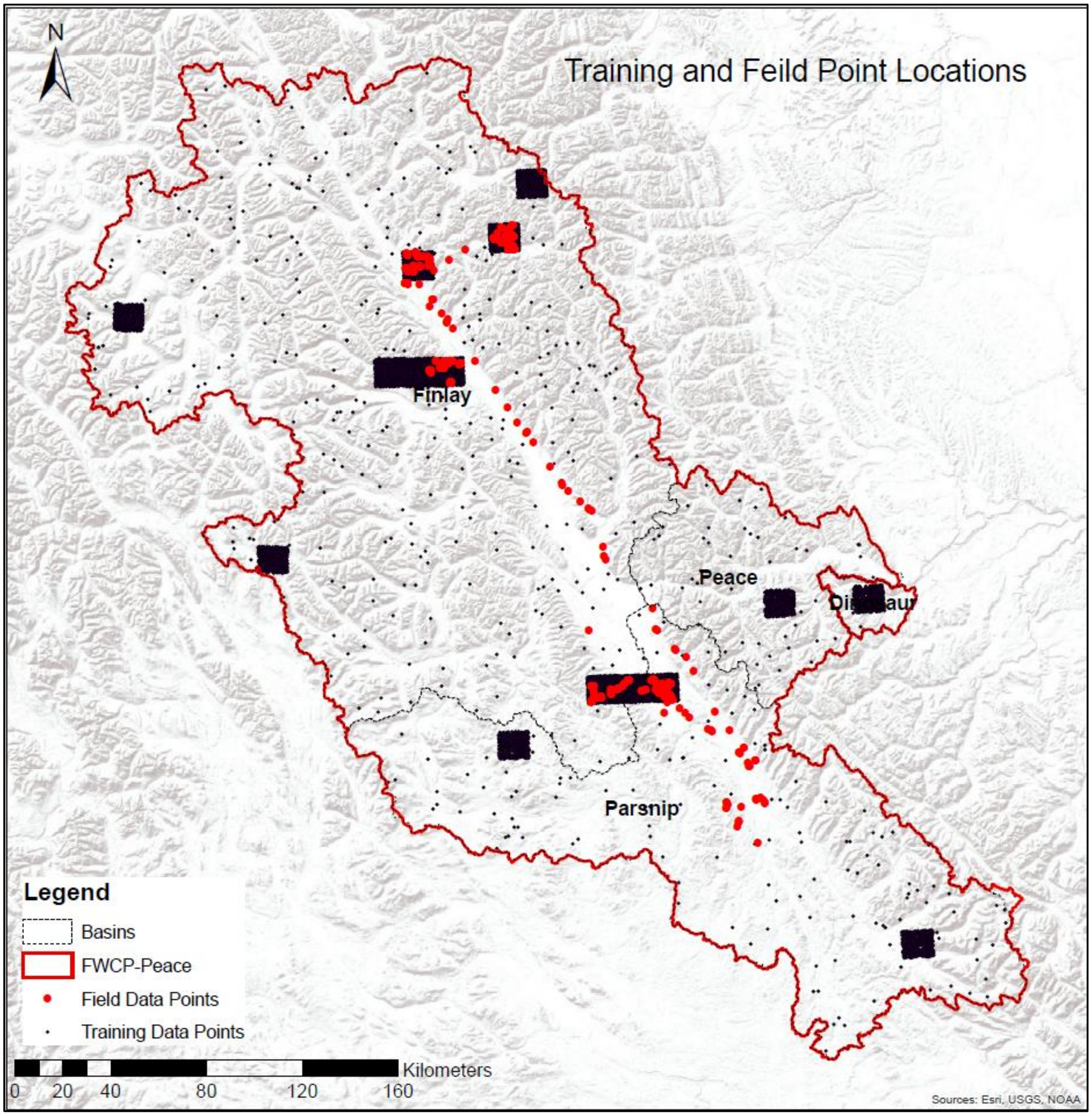


Figure 7. Map of training (Grey) and field (Red) points. The 'squares' represent map sheets that have high density of training points.

FIELDWORK & ACCURACY ASSESSMENT

During August 2017, field work was conducted in the FWCP-Peace to support site level inventories of wetlands as well an accuracy assessment of the predictive model product by comparing field data to model outputs ("match ups"). Prior to this MoECCS staff worked with contractors to develop an appropriate field sampling plan (Andrew & Green, 2017b). The plan identified and prioritized areas within the area having high concentrations of wetlands based on analysis of available TRIM wetlands (Figure 8). Additionally, it divided sampling into two phases; the first was to conduct site visits at 15-25% of the map sheet training points, and the second phase consisted of an inspection density of 1 site per 20-29 ha for all other areas. This corresponds to ~640 inspection points within the FWCP-Peace. In total, there were four days of field sampling, and 276 field sampling points were established (Figure 7 & 8), which corresponds to 43% of recommended sampling intensity. Fens were the most commonly sampled wetland type with 80 inspections, followed by bogs (31 inspections), and marshes (30 inspections); 37 inspections were conducted on upland sites.

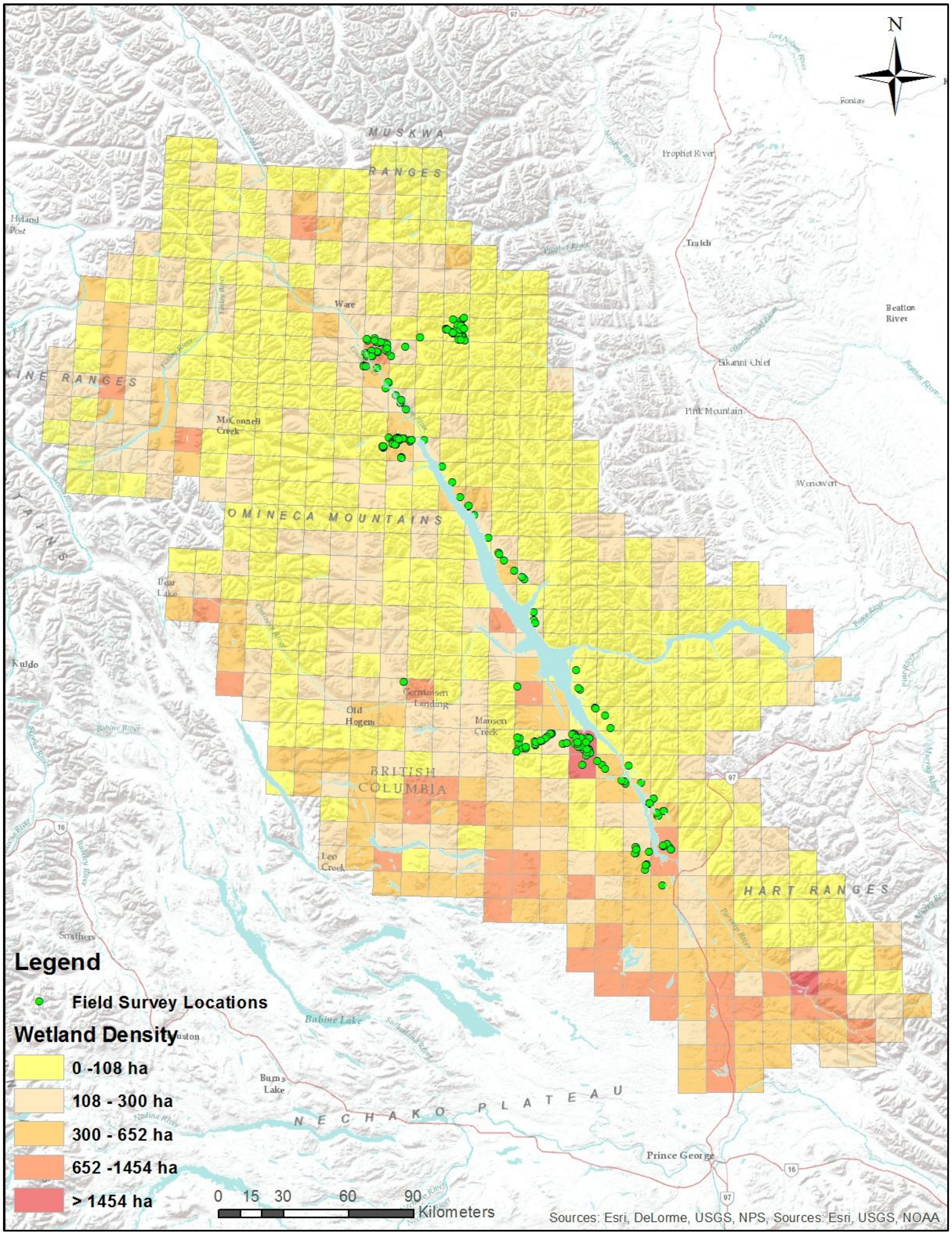


Figure 8. Map of field points and 1:20,000 map sheet wetland densities (hectares) based off TRIM data. These densities were used to identify priority fieldwork areas prior to modelling the entire FWCP-Peace.

Field sampling consisted of a mix of helicopter air calls and detailed site descriptions. Detailed site descriptions included full description of plant communities and soil properties as well as noting hydrogeomorphology, and the broader wetland complexes where possible. Site descriptions were conducted by MoECCS staff with expertise in vegetation ecology and pedology. Data were collected by computer tablet and consolidated after a contractor-led quality assurance process.

Prior to fieldwork, contractors worked with MoECCS staff to identify areas of high wetland concentrations and landscape variability to focus field efforts and maximize sampling efficiency. Through facilitation of the FWCP, MoECCS worked with a Chu Cho Environmental technician whose local area knowledge further aided in field sampling and logistics.

British Columbia experienced a high level of wildfire activity in August 2017, which reduced helicopter availability and restricted helicopter field sampling. Given this constraints, work was conducted to best leverage the assets and time available. As a result, sampling was focused on areas immediately surrounding the Williston Reservoir (Figure 7). Due to the constraints, large areas of the FWCP-Peace are not represented in the field data, including large portions of the outer extents of the Finlay and Parsnip basins.

Key results of the fieldwork were a database of assembled ground points that can verify model accuracy, and this database represents an expert-derived inventory of wetlands in the FWCP-Peace. For example, the fieldwork revealed several calcareous wetlands, which do not currently fit within the provincial classification system. Furthermore, a high level of animal use and flora variety was observed at these sites. Overall the 2017 fieldwork improved knowledge of the wetlands and processes within the FWCP-Peace.

PRELIMINARY ANALYSIS

The mapped product indicates areas of wetlands. However, since wetlands do not occur homogeneously in a landscape it is important to estimate concentration of wetlands per given basin occurring within the FWCP-Peace (Finlay Basin, Peace Basin, Parsnip Basin, Dinosaur Basin). This information is useful in determining areas of high or low wetland concentrations. Both scenarios have implications for management considerations and protection. In certain instances it may be advantageous to protect wetland-dense areas, or conversely protect areas of sparse wetlands, where their relative ecological importance may be greater. To determine the density of modelled wetlands in each of the four basins, the area of predicted wetlands was divided by individual basin area. This enables a comparison of the proportion of wetlands in each basin while controlling for basin size.

As with wetland concentration, it is important to determine the amount of anthropogenic disturbance at the basin level. The FWCP-Peace is resource rich and the landbase values vary significantly across the area. Anthropogenic disturbances are not homogeneously distributed, and are often concentrated in particular areas. To assess overall landscape-level disturbances in the Finlay, Parsnip, Peace, and Dinosaur basins, the data was analyzed from various publically available spatial layers in the Data BC Geographic Warehouse, and summarized at the basin level.

Timber harvest data for the four basins were obtained using the Reporting Silviculture Updates and Land Status Tracking System online application (RESULTS) database[3] (“WHSE_FOREST_VEGETATION.RSLT_OPENING_SVW”). Road length was obtained from the Provincial Digital Road Atlas layer (“WHSE_BASEMAPPING.DRA_DGTL_ROAD_ATLAS_MPAR_SP”). Reserves and active mining activity data was obtained from the Provincial Mineral, Placer, and Coal Tenure layer (“WHSE_MINERAL_TENURE.MTA_ACQUIRED_TENURE_SVW”).

To determine the proportion of area impacted by anthropogenic disturbance in each basin, disturbance area for each area was calculated in ArcGIS and then was divided by the area of each basin.

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[3] https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/silviculture/silviculture-reporting-results

RESULTS & OUTCOMES

DISTRIBUTION OF WETLAND TYPE

Wetlands were modelled to class and these are distributed throughout the FWCP-Peace, varying in abundance and size. The mapping product, however, requires considerations of the caveats and limitations of the model when interpreting results. The mapping product is a function of the quality of input data, model training, and efficiency of the Random Forest Algorithm. The results presented here represent model estimates of wetlands, and these may differ from actuality. They can be viewed as a good tool and starting point to obtain information about distributions of potential wetland areas and types.

The majority of predicted wetlands are located in the flat low lying areas immediately surrounding and south of Williston Reservoir in the Parsnip Basin, as well as valley bottoms in areas with a greater degree of topographic ruggedness (Figure 9).

The prediction results identified 263,688 hectares of wetlands (3.6% of the total area) within the FWCP-Peace (Table 2). Wetlands comprise 54% of the non-upland component, and the remaining 46% is open water. Fen and bog wetland classes are most common, representing 62% and 33% of the total wetland area respectively. Fens cover a greater area than all other classes combined. Marshes and swamps represent a small percentage of wetlands, accounting for< 4.5% and 2 % respectively.

Size and location of wetlands greater than one hectare (Figure 10) indicate a high degree of variability within the landscape. In general, a majority of all wetlands are under 80 hectares in size. These are more evenly dispersed in the landscape when compared to larger features. The larger wetlands (>200 hectares) occur in several discrete locations within the basins, with exception of the Dinosaur Basin which does not contain any larger predicted wetland features. The largest mapped wetland features occur in the Finlay and Parsnip basins. Within the Finlay a majority of larger features are located in the high elevation northwest extents following several large valley bottoms. Within the Parsnip basin there is a cluster of larger features in the western arm of the basin and two distinct areas of larger and connected wetland features that run linearly north to southeast. To a lesser extent, there are also pockets of larger wetland features in the higher elevation regions in the east.

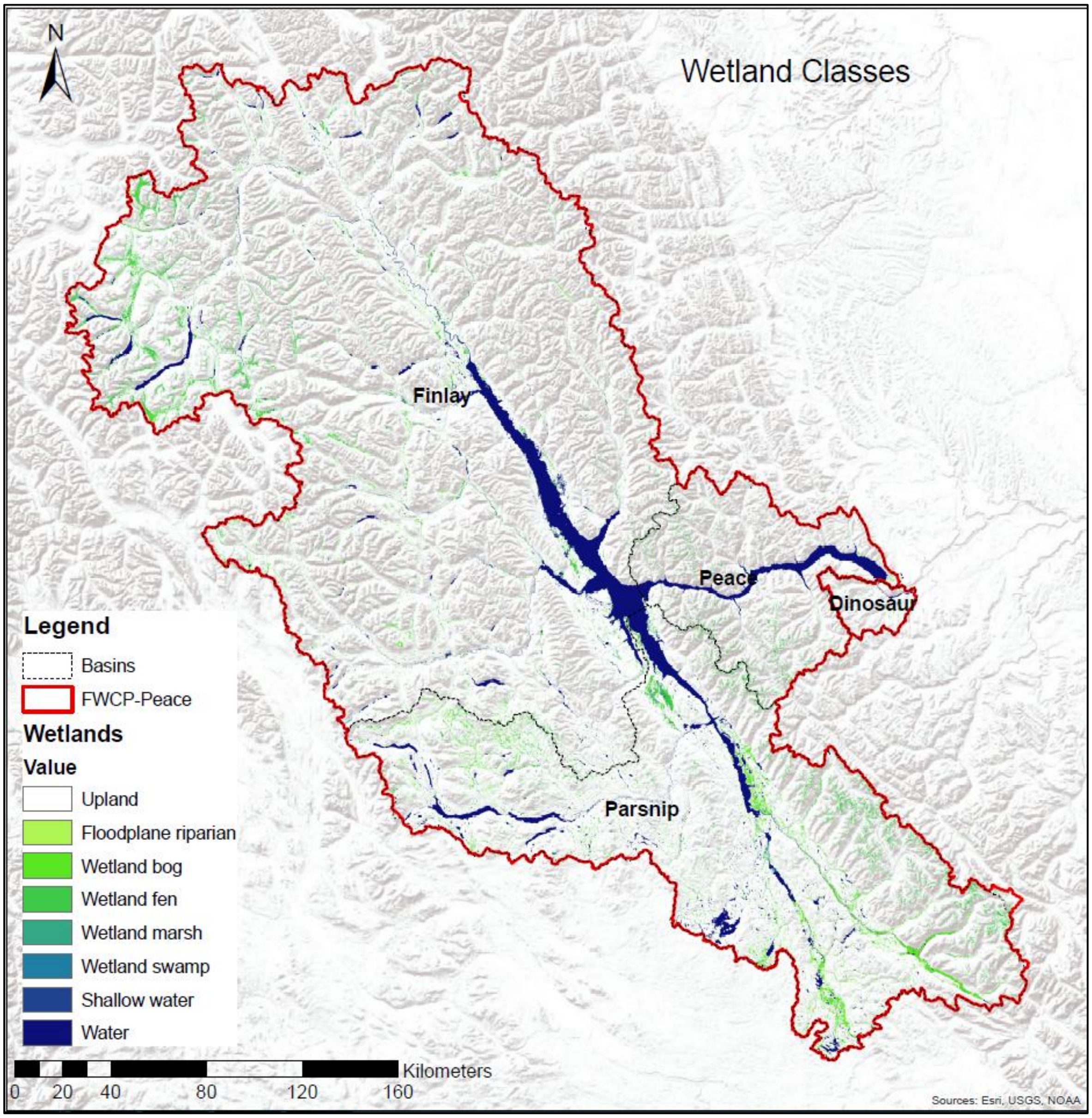


Figure 9. Upland Wetland & Riparian distribution within the four basins of the FWCP-Peace. Individual Basin maps are in Appendix D.

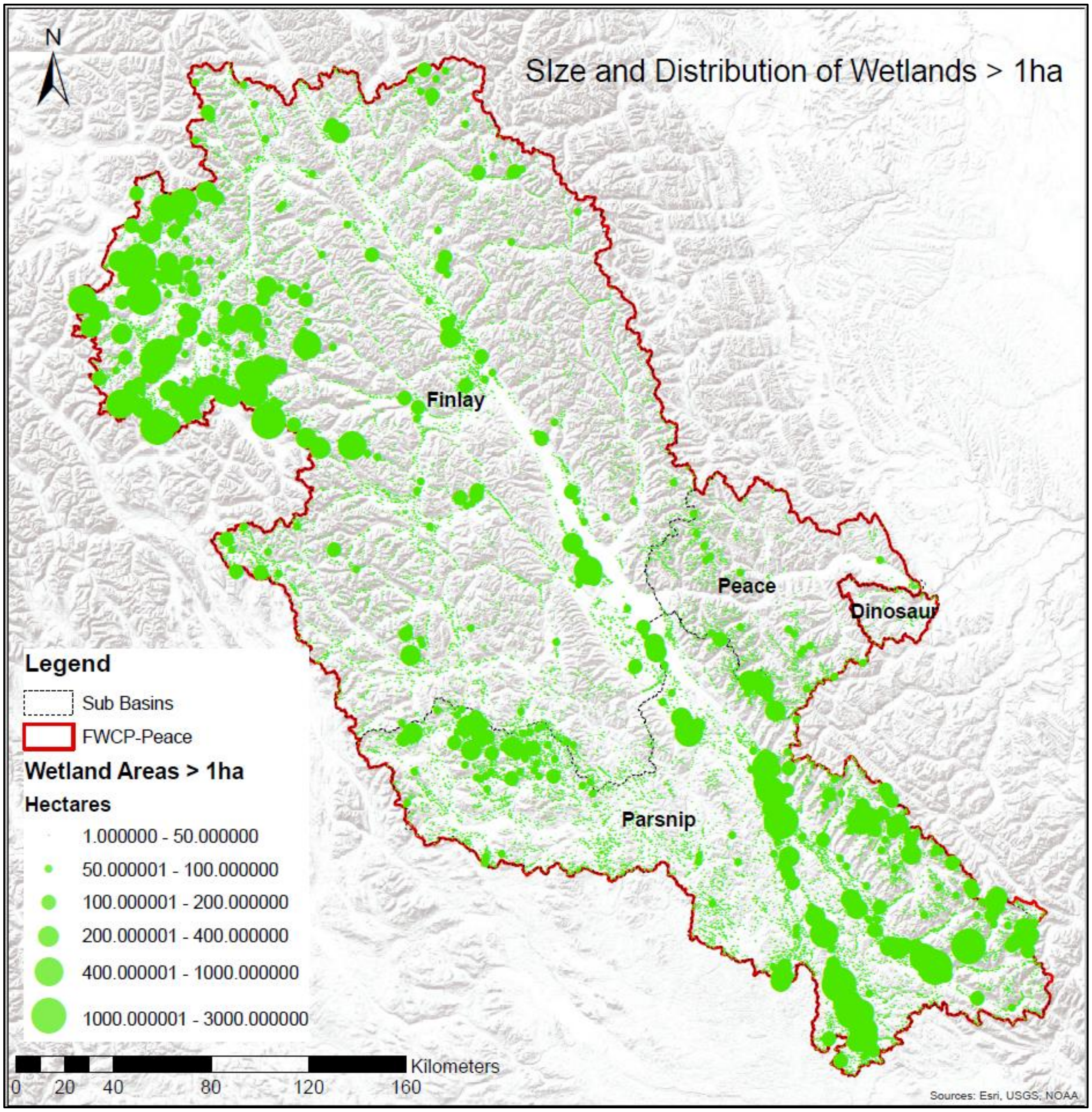


Figure 10. Size and distribution of wetlands greater than 1 hectare within the FWCP-Peace.

Absolute abundance and distribution of wetland types varies throughout all the basins (Table 2). In general, the Peace and Dinosaur basins have the lowest density of wetlands, whereas the Parsnip region is comprised of 6.0% wetlands followed by Finlay at 2.8%. Parsnip has a greater predicted composition of bog wetlands than the remainder of the study area combined. Specifically, this area has the greatest occurrence of swamp and marsh land, representing 55%

and 52% of class totals within the FWCP, respectively. The Finlay region, however, includes 58% of all FWCP-Peace fens and has the second highest occurrences of marshes and swamps.

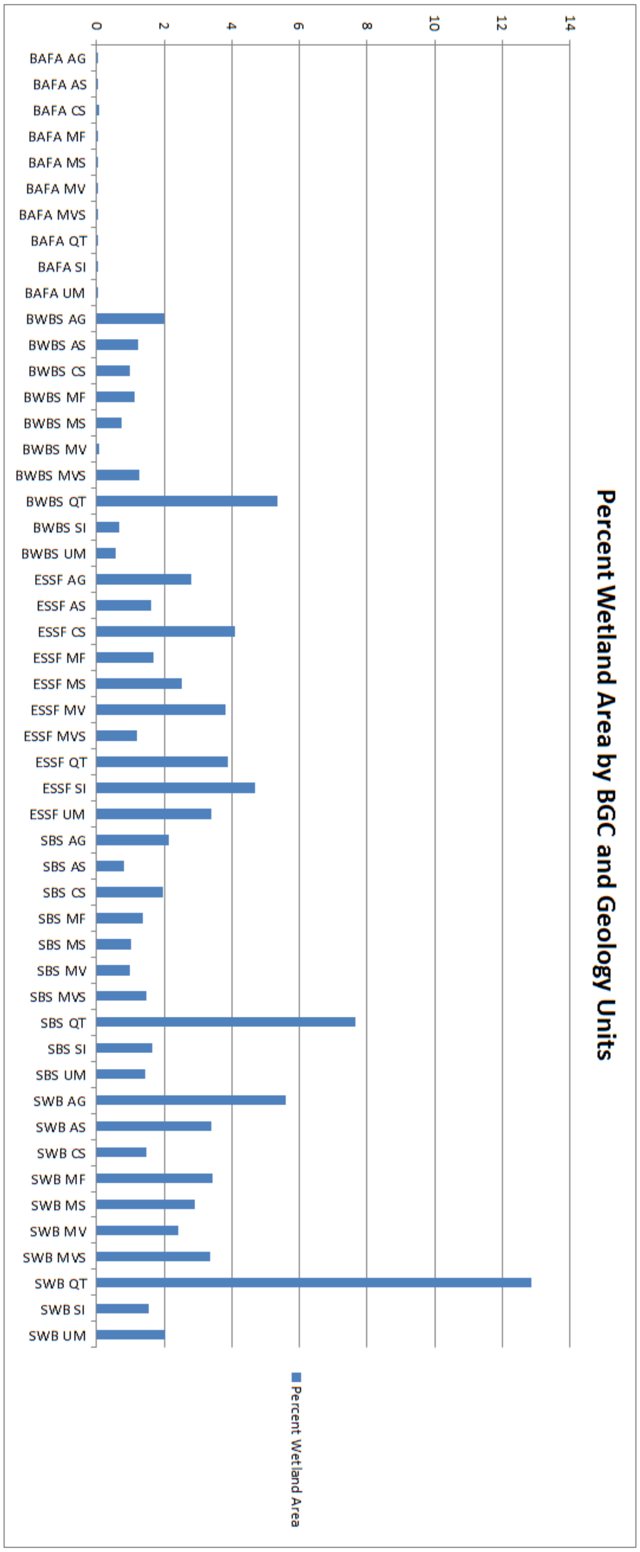
Table 2. Basin wetland coverage and composition of bog (Wb), fen (Wf), marsh (Wm), swamp (Ws), and high-bench (Fh), middle bench (Fm) and low bench (Fl) flooded-riparian units within the FWCP Peace. Bolded values signify greatest occurrence per class.

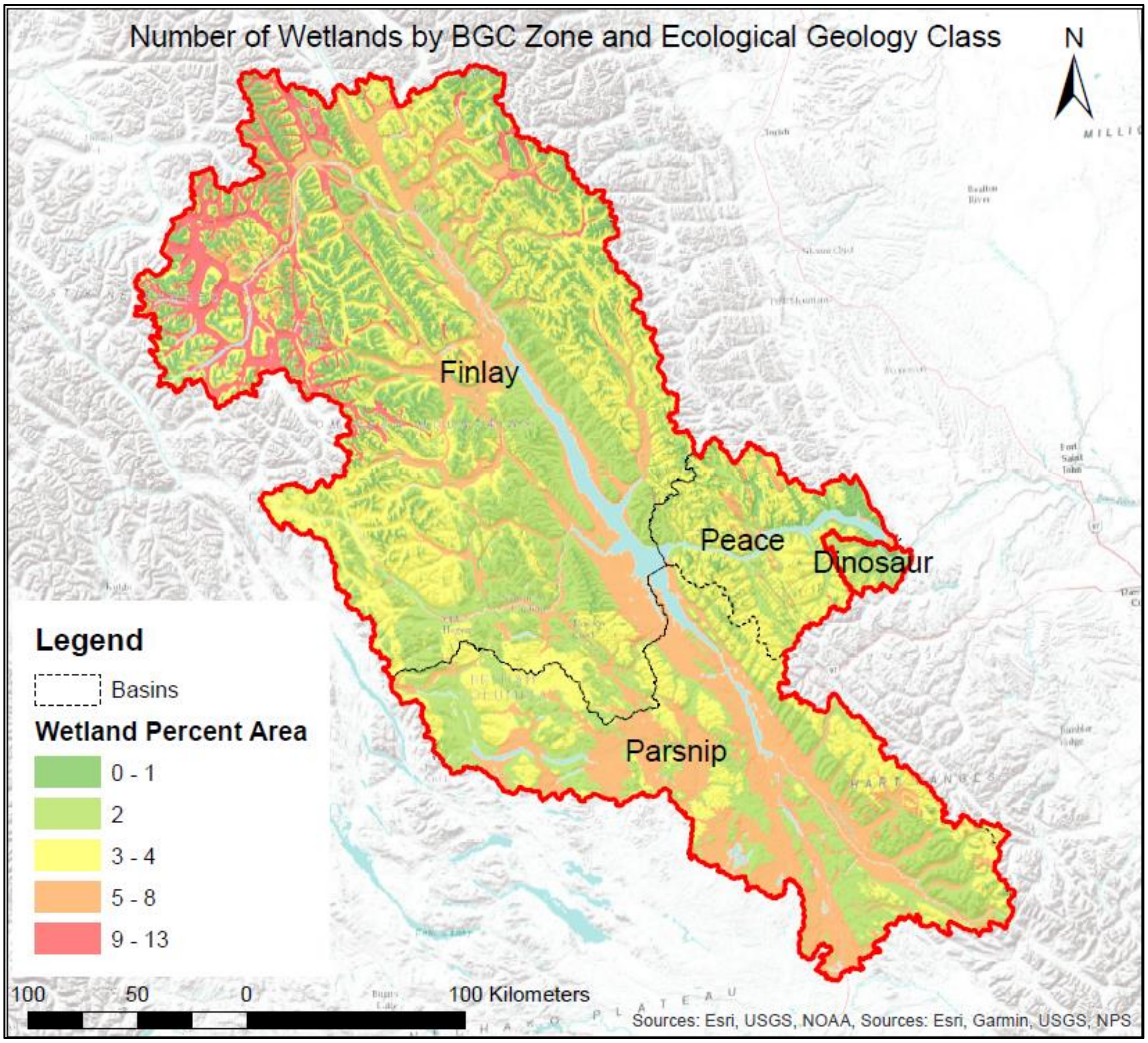
Wetland & Riparian Class Coverage (Ha)											
Basin	Total Basin Area (Ha)	Wetland Area (Ha)	Wetland Density (%)	Wb	Wf	Wm	Ws	Riparian Area (Ha)	Fh	Fm	Fl
Finlay	4,588,888	127,224	2.8	25781	**94001**	5389	2054	2785	**89**	**58**	2638
Parsnip	2,017,227	121,912.3	**6**	**58966**	54461	**5936**	**2550**	**2855**	9	12	**2834**
Peace	588,121.3	13,641.8	2.3	859	12601	152	25	34.3	**0**	0.3	34
Dinosaur	67,838.3	909.1	1.3	573	260	25	21	39.1	0.1	0	39

The Parsnip Basin has the greatest area of wetlands per square kilometer of all four basins, substantially exceeding average area of wetlands (Figure 10, Table 2). The Parsnip has approximately double the area of wetlands as the Finlay basin, which has the second greatest area of wetlands per square kilometer. The Parsnip basin has approximately six times the amount of wetlands per square kilometer as the Dinosaur basin, which has the lowest area of wetlands in the four basins. The Finlay and Peace basins have fairly similar areas of wetlands, and are both close to double the area of wetlands within the Dinosaur basin.

The number, the percent area, shape and size of wetlands vary between BGC zones and Ecological Geology class combinations. By far, the Quaternary sediments have the highest density, frequency, total area, and wetland size (Figure 12, 13 & 14). Quaternary sediments in the Sub-Boreal Spruce (SBS) BGC zone have the highest number of wetlands (116,855), the largest total area (81,657 ha), the second highest percentage of wetland area (7.6%), and contains the largest wetland polygon in the study area (5,004 ha). The quaternary sediments in the Spruce Willow Birch (SWB) BGC zone represents the highest percent wetland area (12.9%), has the second largest total wetland area (47,919 ha), and the second largest maximum wetland area. The quaternary sediments in these two zones contain 50% of the wetlands in the FWCP-Peace.

Figure 11. Percent wetland area by Biogeoclimatic and Ecological Geology units.





Sources: Esri, USGS, NOAA, Sources: Esri, Garmin, USGS, NPS

Figure 12. Percentage area of wetlands by Biogeoclimatic and Ecological Geology units.

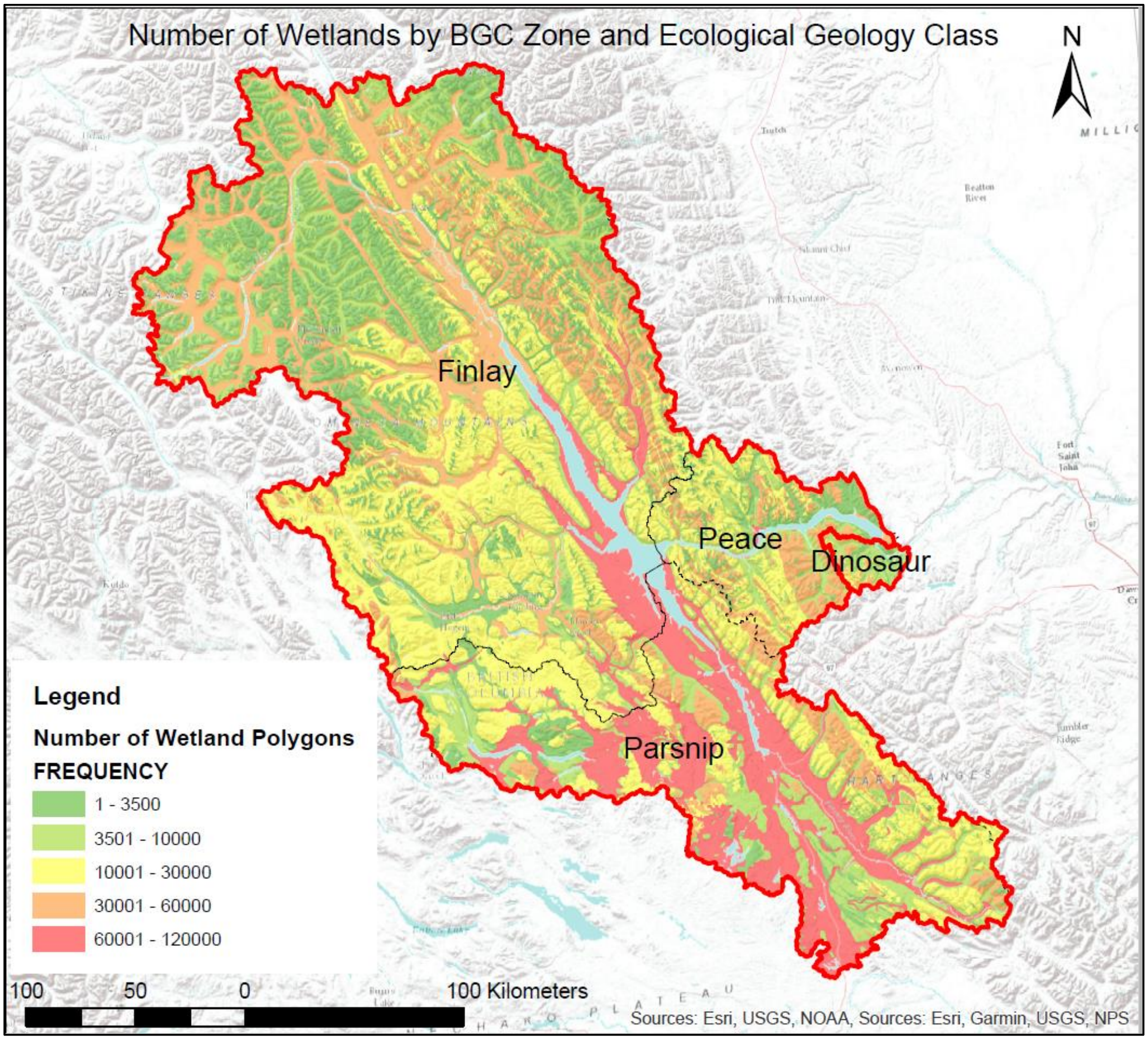


Figure 13. Number of wetlands by Biogeoclimatic and Ecological Geology units.

ACCURACIES

Three versions of wetland maps created using Random Forest modelling were produced and then assessed. At the coarsest level, the model was run to determine areas of Wetland, Water and Upland (3-unit, 'Realm'). Next the model was run for Upland, Water and Wetland/Flooded-riparian classes (9-unit, 'Class'). At the finest level, all 48 mapcodes were used including wetland class, structure, and associations (48-unit, Mapcode & structural association).

While larger sample sizes were collected for fen class and associations (i.e. Wf02), the majority of sampled wetland class associations have less than six plots, or are not present. Therefore, due to a limited number of field sampling points, it was not possible to statistically determine accuracy at the finest level; the wetland class, structure and association level (48 mapcodes product). There are two accuracies reported. First is internal estimates of model prediction error, and second is real world accuracy using an external validation dataset (field data). The internal estimates of error answer the question of how well (consistent) the model performs given new data (a random subset of the training point data). External validation answers the question of how well the model performs when compared to field sample data.

INTERNAL ESTIMATES OF MODEL ERROR

Random Forest models produce 'out-of-bag' estimates of error (OOB) by aggregating bootstrap samples of the model through its run. OOB is a measure of how accurately an algorithm is able to predict outcomes using previously unseen data that match the original prediction (i.e. 3-Unit Realm or 9-Unit Class level predictions). It achieves this by randomly sampling 1/3rd of the input training data (bootstrap) to run the model separately during every decision tree creation, then compares results to the larger dataset and associated decision trees to determine overall differences and error (Breiman, 2001).

OOB relies on just the model training data & input layers, whereas accuracy validation relies on an external validation dataset (field data) to compare with predictions. OOB error estimates tend to be conservative and report slightly lower percent accuracy than external accuracy validations (Mitchell, 2011). OOB error estimates are useful when comparing Random Forest model results with different input parameters (i.e. wetland units), to inform on reproducibility given the training data and spatial layers, and are a useful check against field data validations.

Aside from OOB errors, useful output products of Random Forest reporting is a confusion matrix comparing predicted (bootstrapped) samples to the observed (larger sample). Useful indices of the Random Forest as used here include the individual errors of omission (false negatives) and commission (false positives) between predicted and observed (Tables 3 & 4).

The OOB error estimates show that at the 9-unit 'Class' level there was 89% internal accuracy. The error of omission were highest in flooded units and wetland marsh (Wm), while errors of commission were greatest in the swamp (Ws) and bog (Wb) units (Table 3). This indicates the model had the most difficulty reproducing the predictions for these units (low separability). The highest proportion of omission & commission errors occur between the bog (Wb) and fen (Wf) classes, while the highest number of total errors of commission are in the Upland class. Errors in the Upland class are in part due to the overwhelming proportion of land that is Upland. The errors of commission and omission for bog & fen, as well as Upland indicate classes where the model has relative difficulty in separating from each other (Wb & Wf) and from other units (Upland). This isn't a completely unexpected result given the transitional nature of wetland-upland interfaces, and that a 25 m x 25 m modelled cell may contain a mosaic of upland and wetland units.

In contrast, the 3 unit ‘Realm’ ‘Upland, Water, Wetland’ model returns an OOB accuracy rate of 93%. The confusion matrix shows good separability between the Upland, Water and Wetland units (Table 4). The largest sources of errors of commission and omission are between Upland and Wetland.

Table 3. Random Forest confusion matrix of Upland, Water, and Wetland/Riparian 9-unit ‘Class’ level

observed

		Fh	***Fl***	***Fm***	***T***	***W***	***Wb***	***Wf***	***Wm***	***Ws***	Commission
predicted	***Fh***	1	0	0	0	0	0	0	0	0	0.00
	Fl	0	9	0	2	1	1	1	1	0	0.4
	Fm	0	0	0	0	0	0	0	0	0	NaN
	T	24	25	21	9644	64	162	182	18	207	0.07
	W	2	2	1	8	127	6	16	9	8	0.29
	Wb	2	17	2	34	14	302	114	1	36	0.42
	Wf	0	13	3	36	17	127	347	9	28	0.40
	Wm	0	0	0	0	0	0	0	0	0	NaN
	Ws	0	0	1	12	6	13	8	2	47	0.47
	total	29	66	28	9736	229	611	668	40	326	11733
	Omission	0.97	0.86	1.00	0.01	0.45	0.51	0.48	1.00	0.86	

Table 4. Confusion Matrix of internal predicted and observed units for the Upland (T) -Water-Wetland/Riparian (WL) Realm units.

		observed			
		T	***Water***	***WL***	Commission
predicted	***T***	9675	48	429	0.046986
	Water	11	364	39	0.120773
	WL	202	87	1608	0.152346
	total	9888	499	2076	12463
	Omission	0.021541	0.270541	0.225434	

ACCURACY OF PRODUCT

Overall accuracy validation between modelled product and field data for the 3-unit 'Upland-Water-Wetland/Riparian' (Realm) units was strong at 91%. This indicates that the model is 91% accurate in determining areas of Upland, Water, and Wetlands/Riparian when compared to the field data. This represents good agreement between field assessments and modelled wetlands. A 91% accuracy paired with the OOB internal estimate of accuracy of 93% indicates the model is consistent when using the training data and input layers, and is accurate to field samples at the 3-unit realm level. When the model was verified with field data at the 9-unit wetland class level, there was only a moderate agreement of 54% accuracy. The lower accuracy of the 9 unit wetland class level corresponds to a slightly lower OOB accuracy (89%) as well. These indicate that the model is only slightly worse at making consistent and repeatable predictions at the wetland class (9-unit) level, but has a poorer correlation to real world field data.

In general, the percent error for each of the 9-unit wetland classes generally coincides with the corresponding relative proportion of field samples (match-ups) (Figure 14). This figure gives an indication of the distribution of model error by wetland class (Figure 14). For instance, while bogs comprised only 21% of field points, 26% of the error is attributed to this class. Upland (T) units accounted for 31% of total error, while comprising only 22% of total match up field data. Fens comprise nearly 30% of the match ups, however, they only account for 17% of model error. This suggests modelled error is disproportionately from bog and upland units, whereas in contrast fens perform well when compared to field data.

Overall these results indicate that predicting at the 3-unit 'Upland-Water-Wetland' (realm) level is more reliable than predicting to the 9-unit wetland & riparian class level when compared to field data. Interestingly both produce similar OOB accuracy rates, suggesting that both models can make consistent predictions given the training and input data used, even at the 9-unit wetland class level. However, when compared to field information the 9-unit wetland class product is less accurate.

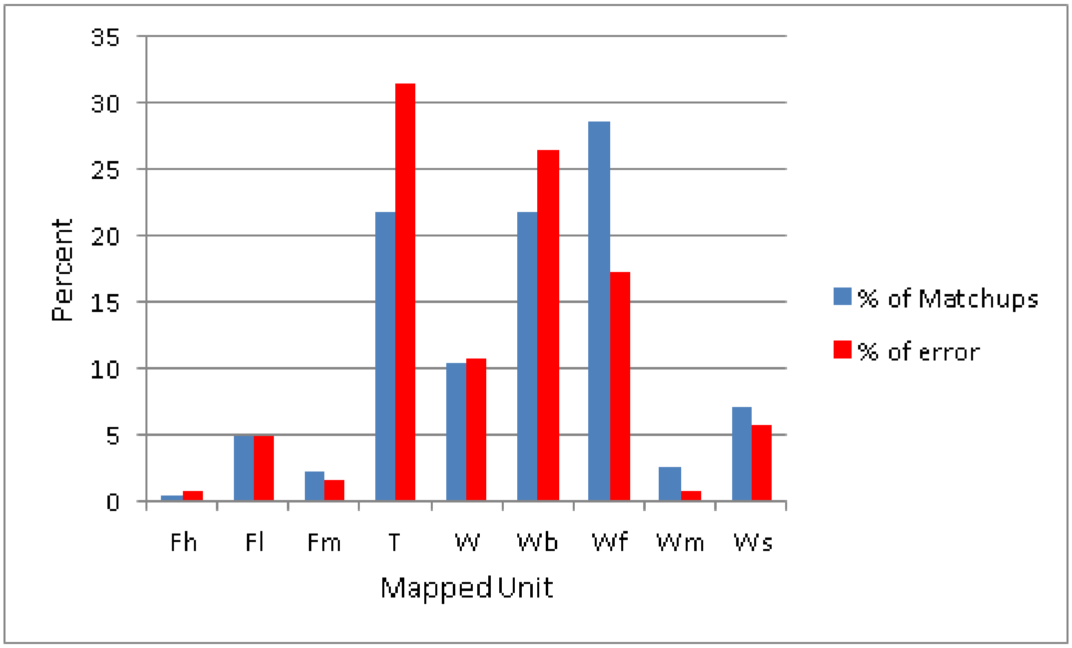


Figure 14. Percent error by wetland unit class.

TRIM WETLANDS COMPARISON

The modelled product represents 263,688 ha of wetlands compared to 107,385 ha from the Provincial Freshwater Atlas Wetlands. Therefore the current FWA layer only captures 43% of the modelled estimates. Visual inspection indicate that while there is good agreement between the modelled product and larger TRIM wetland polygons, the TRIM layer misses many sub-hectare sized wetlands identifiable by air photo interpretation on the landscape. Furthermore, where there is agreement between the two on spatial extent of a wetland complex, the TRIM layer lacks wetland-specific attribution, whereas the modelled product fully describes the composition of the wetland complex. In some cases TRIM may capture wetlands not identified by the model or delineate a wetland edge more accurately (due to 25m pixel size limitation), however these are captured inconsistently within map sheets and across the FWCP-Peace. Additionally, TRIM data does not include the riparian and floodplain units and their class. Given the calculated model accuracy (91%) in determining wetland/water/upland when compared to field data, the modelled product appears to outperform TRIM as a wetland inventory product.

PRELIMINARY DISTURBANCE AND RISK ANALYSIS

Patterns of natural resource extraction and human disturbances also vary between the basins. Available provincial datasets that reflect disturbance patterns and resource extraction pressures were used to analyse potential threats to wetlands at the basin level.

Timber harvesting cutblock area (ha) are high in the Parsnip Basin than in other basins (Figure 5, Table 5). The Parsnip Basin has close to three times the total amount of harvested area than the Finlay Basin, which is the basin with the next greatest area of timber harvest. The Finlay Basin has a slightly greater area of timber harvest than the Peace Basin. The Dinosaur Basin has the least area of timber harvest and is approximately 49 times smaller than the harvested area in the Parsnip Basin.

Road density varies substantially between basins, and is highest in the Parsnip Basin which has approximately double the average across the four basins (Figure 5, Table 5). Road density in the Parsnip is approximately 3900% greater than road density in the Dinosaur, which is the basin with the lowest densities of the four basins.

Area covered by mining claims and tenures also varies by basin. The Finlay has the greatest number of mining claims and tenures per square kilometer of the basins, but is only marginally larger than mining claims and tenures per square kilometer in the Parsnip (Figure 6, Table 5). The Peace Basin has the second lowest proportion of mining claims and tenures per square kilometer, and is close to 3 times smaller than mining tenures in the Finlay. Similar to road density results, the Dinosaur has the least amount of land dedicated to mining tenure and claims and is 54 times smaller than area designated for mining tenure and claims in the Finlay.

Mining reserves cover the most area per square kilometer in the Peace Basin. Reserves in the Peace Basin cover approximately 2.6 times more area than reserves in the Parsnip Basin, which has the second greatest amount of reserves in the four basins. The Peace Basin has 70.5 times more mineral, coal, and placer reserves than the Dinosaur Basin, and approximately 7.3 times more reserves than the Finlay Basin.

Table 5: Proportion of wetlands and various disturbances across the FWCP-Peace basins

	Dinosaur	Finlay	Parsnip	Peace	Average
Wetland Density (%)	1.3	2.8	6	2.3	3.1
Timber Harvest (%)	0.4	6.7	21	5.1	8.3
Road Density (km/km^2)	2.3	2.8	9	4.2	4.0
Mining Claims and Tenures (%)	0.2	11.7	10	4	6.5
Coal, mineral, and placer reserves (%)	1.2	11.8	33	86	33

DATA AND INFORMATION ACCESS

Resulting wetland and riparian maps, indicating location and class, will be made available under the BC Open Data Licensing[4]. This report, supporting data and map data will be made available in a variety of formats to serve a range of users including PDF maps for simple viewing, shapefiles and georeferenced gridded raster data for performing complex GIS analysis and corresponding interactive map viewers.

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[4] https://www2.gov.bc.ca/gov/content/data/open-data/open-government-license-bc

DISCUSSION

Phase 1 of this project was an initial pilot using existing inventory mapping. Efforts to map wetland and riparian areas within the FWCP-Peace clearly demonstrated that ecosystem mapping products lack coverage, and are cost prohibitive to map the FWCP-Peace in its entirety. To address the issues of high cost, data gaps and reproducibility gaps identified in Phase 1, a methodology was developed using expert interpreted training points from remote sensed data, paired with an iterative machine-learning approach. The current approach has produced wetland mapping of the FWCP-Peace area for approximately $0.02 per hectare. This represents a significant savings in cost when compared to traditional TEM method for the same area.

Overall, the approach to the project accomplishes the goals of defining type, distribution and density of wetland features in the FWCP-Peace. The Random Forest modelled product provides consistent, repeatable and defensible predictions of wetland and flood associations ecosystems at the scale of the FWCP-Peace. This product appears to be superior to the TRIM wetland layer in that it identifies riparian floodplain units, and that it classifies wetlands to bog, fen, swamp and marsh categories, which TRIM does not. As an inventory method, the Random Forest modelled wetlands represents a significant improvement over currently available Provincial wetland mapping products for the FWCP-Peace.

This modelled wetland product is appropriate for landscape and regional level display and analysis of wetlands and flood association riparian areas. It reliably captures wetlands larger than one hectare. Heuristically, it does well capturing larger wetland patches and has errors of omissions and false positives where wetland patch size is small and patterns of ecosystems are more complex. The data has been summarized to describe abundance and distribution at the basin level for the FWCP-Peace, but can also be used to create summaries for other landscape level spatial units (e.g. xx). The example analysis using the unique combinations of Biogeoclimatic zone and geological unit yielded interesting preliminary results that indicate wetland distribution, concentration, and type might be in part correlated to and forced by these differences, which warrants further research. The data may also be used for overlap, distance and catchment area analysis related to existing disturbance layers such as flooding, roads, cutblocks, mines, pipelines, transmission lines, or proposed project footprints to expand on the example analysis results relating to roads, timber harvest and mining presented in this report.

THREATS AND TRENDS

THREATS

The FWCP-Peace is resource rich and landbase values vary significantly across the area. These interests, tenures and disturbances are not homogeneously distributed, and are often overlapping wetland concentrations (Figure 6 & 10). Ultimately, understanding threats and trends to specific wetlands requires an understanding of how threats and wetland features covary.

With the exception of mining, timber harvest and road-related disturbances are disproportionately high in the Parsnip Basin. In contrast, the Dinosaur Basin appears to have a relatively small disturbance footprint based on this selection of mapped disturbances. It is possible that differences in disturbance density may be a consequence of proximity of the Parsnip Basin to the resource-industrial hub of Prince George. Inversely, the relative intactness of the Dinosaur Basin may be related to its inaccessibility, mountainous terrain and relatively less timber and mineral resources.

Although mining pressures may be highest in the Finlay Basin when compared to all landscape pressures in the area, the Parsnip Basin is also subject to significant mining-related activities. In addition to current mining pressures, mineral, coal, and placer reserves/claims were used as indications of future mining-related threats in the basins. The Peace basin has the greatest proportion of reserves for future use, but the Parsnip also has substantial reserves. Available reserves coupled with existing infrastructure from current mining effort in the Parsnip may increase the likelihood of continued mining efforts in the Parsnip basin.

Depending on the nature of the disturbance and their proximity and effects on wetlands, a high disturbance load may contribute to trends of decreasing wetland ecological integrity (Dahl, 1990). Impacts from comparatively high road densities, timber harvest, and mining-related activities can be cumulative and contribute to fragmentation, altered hydrology patterns, and increased rates of human intrusion within the Parsnip basin. High disturbance loads and potential decreases in ecological integrity are significant within the context of wetlands because the Parsnip basin also has the highest proportion of modeled wetlands of all the basins.

The significance of the high concentration of both disturbances and modeled wetlands in the Parsnip basin is twofold. If the assumption holds that the modeled wetlands are wetlands on the ground, then the significant disturbance load in the Parsnip basin is a cause for concern as the higher disturbance load may impact a greater number of wetlands. However, the large disturbance footprint in the Parsnip basin could be a source of confusion for the model, where wetlands are overrepresented where disturbance sites are misattributed as wetlands. To add further complication, there are instances where wetlands have been cleared adjacent to harvestable areas, and where other disturbances (i.e. roads) have most likely disturbed areas of historical wetlands. Since the model is predicting areas of and types of wetlands based off all input layers, a higher density of training points coupled with ground validation can help distinguish wetlands from disturbances in these areas.

Field validation of model output in basins with both high disturbance loads and modeled wetland density (Parsnip) and low disturbance loads and modeled wetland density (e.g. Dinosaur) is advantageous in that 1) Both basins are likely to contain outliers as they are at the end of the modeled wetland density spectrum, 2) Model validation would help separate confounding effects of disturbance and 3) A comparison between these two basins could further support wetland identification in disturbed vs. benchmark areas to determine whether identification of wetlands from undisturbed vs. disturbed areas are comparable given that disturbed wetlands may be behaving in transitional ways.

Aside from acute anthropogenic disturbances, the FWCP-Peace hydrology and by association wetlands will continue to be altered by the broader effects of mountain pine beetle kill and a changing climate. Areas that have experienced heavy beetle-kill may have significantly altered hydrology patterns through decreased transpiration and interception, increasing temperatures, and ultimately changes in wetland residence time and biogeochemical processes (Redding *et al*., 2008; Wehner & Stednick, 2017). The effects of climate change are predicted to be diverse and broadly include a trend toward seasonal wetlands, decreases in overall size, increased flooding and siltation, and a loss of biodiversity (Erwin, 2009).

The numerous and large wetlands of the upper western Finlay basin may not currently have substantial human disturbance and pressures, as they are remote and difficult to access. However, this may be a function of market-driven resource pricing, which can be subject to change. More broadly, Finlay wetlands response to climate change may have significant impact to the lower drainage and impact ecosystem services. As such they warrant investigation and further research.

Best practices for assigning conservation status ranks and assessment of trends and threats to wetlands include mapping and describing wetlands at an association level. Before mapping and identifying wetlands at an association level, confidence in properly attributing wetlands as “wetlands” needs to be established. Confidence in correctly attributing wetlands within these basins can largely be accomplished by ground validation of model output and additional mapping in underrepresented basins.

TRENDS

Trend analysis requires a time sequence of two or more measurements/predictions. The data produced from this project represents one snapshot in time; the date of the Sentinel input imagery and, to some degree, the training imagery used for the interpreted points. While this is useful for inventory, it is limited in its ability to identify areas subject to further change. Trend analysis that's useful for management can be accomplished with three approaches.

The first approach is establishing baseline (current) site level monitoring data with a network of long term detailed wetland monitoring sites. This could include identifying sites with relatively little disturbance as well as sites heavily disturbed for comparisons over time. For this, a monitoring plan is needed to establish management objectives and measure baseline information in order to start to monitor change.

The second approach is to source either historical imagery (e.g. LANDSAT) and airphotos to quantify how the landscape has changed in the last 10-20 years. Depending on image source, it may be possible to classify images for wetland type, or investigate wetland proxies (e.g. percent open water or shrubbiness).

The third approach is to use the Random Forests wetland products as part of further inputs to a forecast model of wetland change. In its simplest form this would be altering the current individual climate/topography input layers for future predictions (e.g. 2030 predicted average temperatures), and comparing the two wetland (current vs. future) predictions for change. There are several studies which have adopted this approach to modelling landscape and wetland change (Jeong *et al.*, 2016; Zhao *et al*., 2018). More suitably, however, is the creation of a physical wetland model that considers specific predicted changes in regional topography, climate, and anthropogenic influence and their effect to wetlands present in the FWCP-Peace.

Successful wetland trend analysis and forecasting will more than likely require implementing and leveraging three approaches; site level monitoring for fine scale changes over time, historical image analysis for change detection in the landscape, and a predictive model to determine broad forecasted changes which can be further related to the site level monitoring.

MODEL & DATA

MODEL PERFORMANCE

Overall, Random Forest predicted wetlands produced moderate to good results. When compared to the limited field data, there was a 91% agreement in determining areas of wetland/riparian vs. non-wetland (3-unit 'Realm'). The model provides moderate agreement at the 9-unit class level, however it does not currently work as well at determining individual wetland structural associations (48-unit). While certain wetland class-structure and associations appear to be well defined by the model (e.g. xx), there is uncertainty as there was limited field data collected to verify the model at these levels.

Both the 3-unit and 9-unit indicated similar OOB error, despite differences in real world accuracies. The high internal accuracy of both suggests that the training points and input data layers used were consistently attributed and sufficient for the model to repeat predictions with subsets of the data. The difference to real world accuracy would indicate that there was more agreement with the model and field data when determining if a point was water, upland, wetland/riparian, versus one of the nine wetland/riparian classes. The good internal agreement of the 3-unit realm level can be attributed to the model only needing to predict a pixel as one of three units. Furthermore these units tend to occur within a well-defined niche of topographic parameters (i.e. 0° slope = water), are relatively discreet, and unlikely to change over the FWCP-Peace. The good external accuracy of the 3-unit model can be attributed to the fact it is likely easier to classify an area as upland, water, or wetland both in imagery and in the field. Inaccuracies here are more likely to be from GPS position errors, ephemeral nature of some water & wetlands (in the imagery vs fieldwork), and transitional areas within a 25 m pixel location.

In comparison, the 9-unit model would share the GPS positional errors, feature ephemerality, and mixed pixels & transitional areas. Further to these sources of error, wetland/riparian classes can be more mixed in terms of topographic niches (i.e. fen and bog slopes), and these niches are more likely to change through the FWCP-Peace (i.e. Topographic Position Index of bogs by biogeoclimatic zone) and therefore require representative training points from a range of areas in the FWCP-Peace. External accuracy can also be affected by difficulties of attribution in the field either through miscategorization or in instances of transitional or ‘patchy’ wetland units in a plot. Finally, a large source of external validation error will occur where there is a lack of required input data layer information needed to rectify differences in wetland units. For instance, differences in bog and fen might require information that describes vegetation structural differences rather than other topographic indices. These issues are further described in the following sections.

One of the goals of the project was to produce wetland mapping that was comparable or exceeded existing TRIM wetland inventories, which is currently the only dataset providing province-wide coverage. In general, the Random Forest product more consistently maps wetlands compared to the TRIM dataset (Figure 15 & 16). In particular, the modelled product often captures smaller (sub hectare) wetlands missed by TRIM. Furthermore, the product includes linear riparian areas not included in the TRIM product. However, for larger (several hectare) features, both products show good comparison in spatial extent and defined boundaries. Lastly, there are no wetland type labels associated with TRIM, whereas the modelled product inherently classifies areas by wetland class. As a whole these results indicate that the model is an improvement over the air photo mapping approach that TRIM relies on.

The results do show some current limitations of the modelled product. Currently, the model tends to over capture wetlands in some areas that have landscape disturbance. In particular these tend to occur in low lying areas where cut-blocks or cleared land are present (Figure 16 & 17). These errors are not consistent for all disturbed areas, and represent a minority of cases. Isolating model error occurring on cleared land is difficult from imagery as there are occurrences where wetlands adjacent to upland sites have been cleared. Therefore in some cases, the model can predict wetlands where it occurred pre-disturbance.

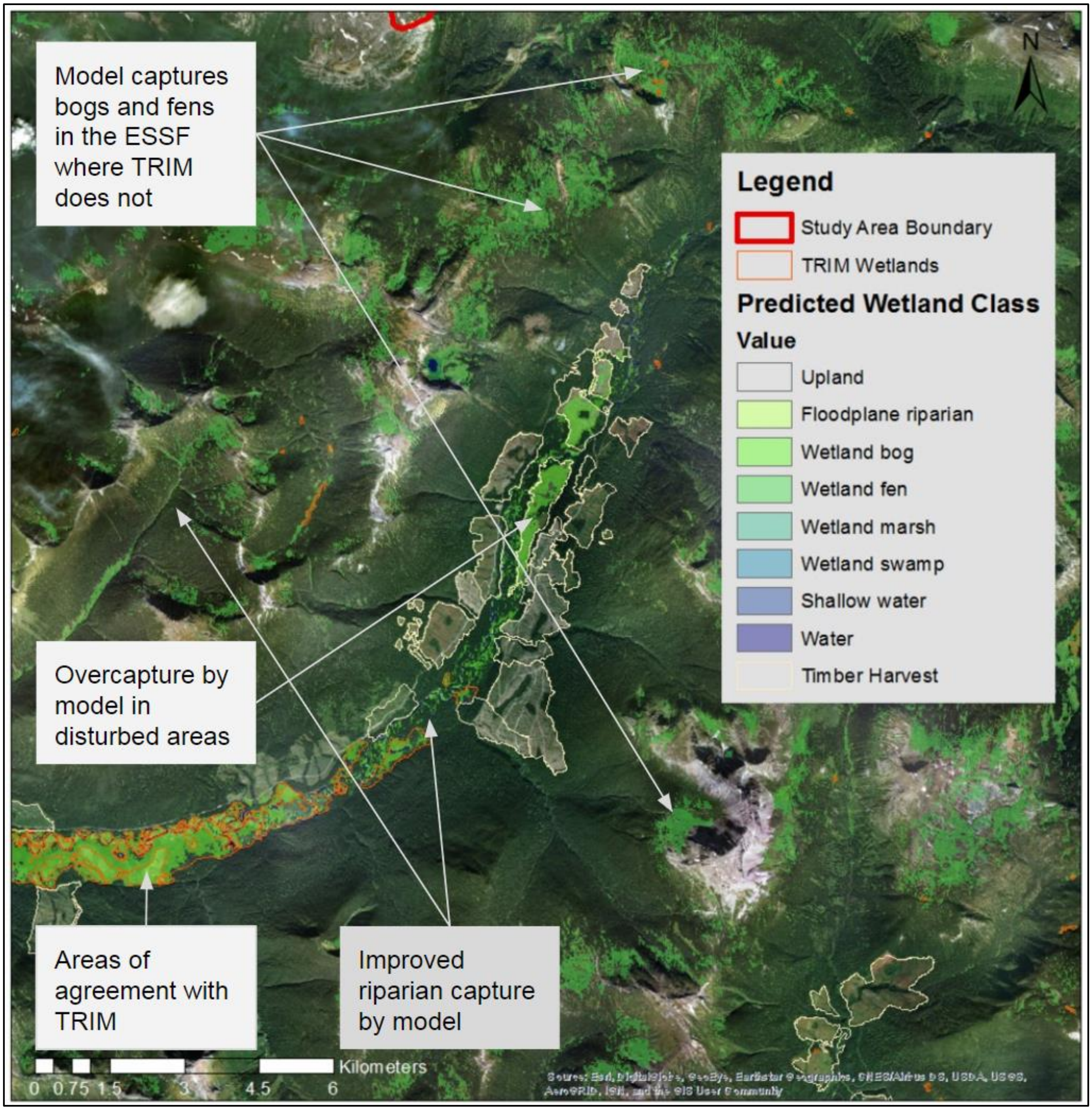

Figure 15. Examples of model results outperforming TRIM wetlands in the ESSF but over-capturing due to cutblocks in an area of low training point density.

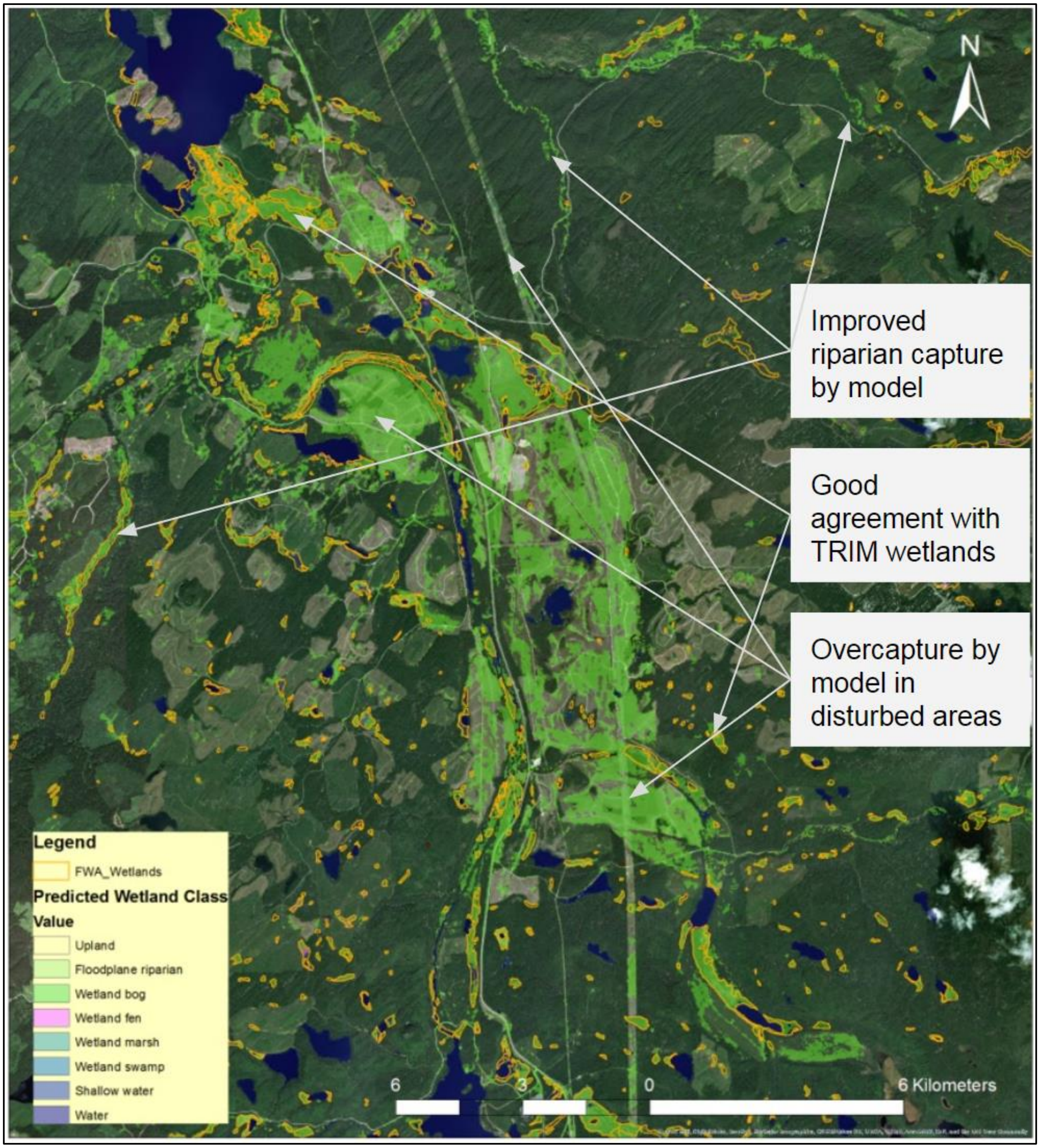

Figure 16. Example of model results in quaternary sediments in the Spruce Willow Birch in the Parsnip basin south of Crooked Lake Park.

While Random Forest has been successfully used in land cover application, it is not inherently designed for mapping of wetlands. Therefore the model and relevant input layers were assembled iteratively with a focus on predicting wetlands within the FWCP-Peace. For supervised models to correctly predict features they require a) Robust model b) Relevant and accurate spatial information c) Correct model training and d) That the wetlands units being predicted are real and predictable.

In general, the Random Forest algorithm was able to give reasonable predictions in areas of missing data (i.e. cloud cover in images), and returned similar results given changes to training points and some input data layers. Therefore the model-algorithm itself is robust, and adequate for the task of determining wetlands within a landscape, at a 25 m scale.

Given a reasonable model, it is critical that relevant and accurate spatial information is used as input data. Phase 2 of this project involved evaluating a modeling approach which necessitated the use of open spatial layers available at no added cost that have full coverage for the FWCP-Peace. These practical constraints meant data were limited to layers available or derived from Provincial datasets, or available in the public domain and ruled out data sets, like orthoimagery, that had gaps in the FWCP-Peace (Appendix B.).

DATA LIMITATIONS

A major limitation of the modelled wetlands accuracy is not the Random Forest model, but rather these input data and their associated limitations. Data limitations for this project can be separated into three categories; spatial inputs, training data, and field data for accuracy assessment. Limitations and inaccuracies in spatial inputs or training data confuse the model and result in poorer overall accuracy. Limitations and inaccuracies in field data for accuracy assessment limit the ability to determine model accuracy.

Spatial layers used for this project present the first data limitation, and were primarily associated with the quality and coarseness of the publicly open and available information used.

All topographic layers used were derived from the Provincial DEM, and incorporate the accuracies and deficiencies of this dataset. The provincial DEM data was originally derived from stereo photo mass points from the 1980s -1998, and values are accurate to 5m vertical, and 10m horizontal accuracy (British Columbia, 2002). Therefore for any given pixel prediction, the underlying information may represent historic (pre-disturbance) elevations at a scale larger than many smaller wetland features. As a consequence the model input layers to spectral imagery may have a temporal mismatch and contributed to errors in prediction results. Small inconsistencies of the DEM in low lying areas were found, that produced instances of artifacts and model confusion. It is possible these are related to the vertical errors of the Provincial DEM.

While the provincial DEM relies on older photogrammetric methods, there exist updated technologies for producing higher resolutions and accurate DEM. These are through remote sensing techniques relying on Interferometric Synthetic RADAR (IFSAR) and LiDAR, which can produce sub meter vertical accuracies and spatial resolutions. Both of these data would produce superior DEM products, and by extension the suit of topographic layers that are derived for model input. Due to the increased cost in data acquisition, storage and analysis, these methods may be cost prohibitive for the entire FWCP-Peace. Currently, there exist LiDAR coverage for specific areas within the area, and analysis should be conducted to determine if LiDAR acquisition for the larger area would be useful.

Satellite imagery reduced overall model confusion, however, there were data quality issues in the Sentinel-2 composite dataset. The inconsistencies generally represent less than 10% of the FWCP-Peace, but include cloud cover obstructing the ground, 'black-holes' where no suitable imagery was available, and minor spectral differences between areas captured at different times. For the most part, the model was able to make reasonable predictions for these areas, but some artifacts remain. A cloud-free composite of the area would produce a more consistent input product and help avoid artifacts resulting from missing data. Perhaps more importantly, the composite should represent early summer conditions where vegetation is near peak phenology. This would give the model improved spectral information to delineate landscape and vegetation differences. While the Sentinel image used was compiled from June imagery, its main drawback are the areas of missing data and present cloud contamination.

Additionally, there exists multispectral imagery from commercial distributors (e.g. GEOEYE) with spatial resolutions less than 2 m. Using these data could increase the ability of the model to differentiate land cover at a finer resolutions. Possible advantages of higher spatial resolutions for model predictions of wetland units is questionable, however, as photo interpreters attributing points would in essence be attributing individual features and vegetation rather than the spectral signature of the wetland complex. Therefore continued use of Sentinel multispectral imagery or similar is appropriate and effective input for the Random Forest model of wetlands.

MODEL TRAINING

Success of the model relies on accurate and consistent training point attribution. As noted in the Wetland Field Sampling and Training Point Comparisons (Andrew & Green, 2017c), there was noticeable matchup differences between Marsh-Fen, Swamp-Bog, and Upland-Swamp. This corresponded to the Training Point Quality Assessment (Andrew & Green 2017b) where mapper confidence in classification of wetland types (in order of increasing confidence) was: flood associations, marshes, swamps, bogs, fens, rivers, and lakes. This points to the difficulty of mappers deciphering wetland units that may appear visually similar in terms of structural stage and composition from air photos, especially when given the transitional and ‘fuzzy’ nature of wetland complexes in the landscape. The pick-list approach (Appendix C.) where mappers have predefined set of upland and wetland/riparian units to choose from, was designed to help minimize inconsistency in classification. In general this approach was effective, however during field sampling areas of wetland and upland classes where discovered that were not in the picklist. In general, inconsistencies were related to wetland class structure, and should be included in future iterations of model training for the area.

WETLAND UNITS

At least some prediction error can be attributed to the wetlands classification system and the units used. Given good input layers and accurate model training, predictions are contingent on the wetland units being discrete, real and observable. While WIGBC provides a comprehensive description of British Columbia wetlands, field sampling clearly showed many instances of wetlands that were difficult to categorize and others that were not present (e.g., calcareous bogs) in the classification. Many field sites surveys required effort in attributing a wetland class and structural stage. This is in part due to the reality that a ‘wetland’ is often a mosaic of small scale features and often represent transitions between the central concepts of defined wetland classes. Future sampling for verification efforts should focus on sampling and recording in areas that are centrally located within typical wetland classes.

Additionally, the 48 mapcodes omitted useful upland classes describing anthropogenic influence that may have confused the predictor (e.g. lack of an Urban or Buildings and Pavement class). In some of these instances, the relative flat surfaces and bright spectral signatures resulted in these areas being incorrectly identified as wetlands. Urban/Pavement can be difficult to identify as they are spectrally similar to rock outcroppings and to each other. A reassessment of current mapcodes and limitations would allow for the refinement of units where these issues occur and thus improve the overall model output.

While WIGBC classification units were used to determine areas of wetlands, there may be other approaches more suitable to specific land management questions. These could include other classification systems, hydrodynamic units, or vegetation qualities (e.g. structure); as long as the units are real and predictable with given input data layers. To leverage the results of any wetland related units, it is important to first establish the management questions and the specific data that would support these before choosing the classification units.

FIELD DATA

While the field sampling plan (Andrew & Green, 2017b) estimated a need to inspect 639 field sites for adequacy, only 43% of this target was achieved. This was a significant barrier for several reasons. Spatially, sampling was constrained in the immediate vicinity of the Williston Reservoir. Analysis indicates that all areas were under sampled. While a majority of samples were taken within the Parsnip and Finlay basins (Figures 7), they were under sampled and these areas have both the greatest total numbers and proportion of wetland area for the FWCP-Peace (Figures 8, 10, 13-14), and high disturbances (Figure 6). As a result there is lower confidence in the modelled wetlands for these areas as well as a lack of information of missed units or unique wetlands that occur here.

In field interpretations and positional accuracy are also likely to account for some of the error in predictions. Many sites were in more transitional areas of a larger wetland complex, therefore were more difficult to interpret as a clearly defined wetland class. In addition, GPS positional accuracy tend to have an accuracy of ± 8 m at the transmitter, and user accuracy (handheld device) ads a further ± 5 m range. Therefore recorded values may not be indicative of the 25 m x 25 m pixel center the plot survey represents, but rather an adjacent pixel. These errors are further exacerbated when sampling in low lying areas with dense vegetation, and at periods of poor satellite coverage or cloud cover (U.S. National Coordination Office for Space-Based Positioning, December 2017). To account for this in the accuracy assessment, each field site recorded location was considered in relation to the site descriptions, and field photos. In instances where there was obvious locational errors, the point was moved to a correct location.

An improved approach would be to make use of real-time kinematic differential GPS (example Trimble) which refines locational estimates through radio signals from ground stations. These are available in either handheld units, or as external receivers to the computer tablet. With these, accuracies can be improved to within half a meter.

RECOMMENDATIONS

USE THIS PROJECT WITHIN A WETLAND MANAGEMENT FRAMEWORK

The work completed in this project should be used in the context of a wetland management framework. The work here addresses section 2.4.1. of the Wetland Ways guidelines (Cox and Cullington 2009). This section relates to Wetland Mapping, Inventory and Assessment by reviewing existing data sources; then identifying, mapping and classifying wetlands at approximately 1:20,000 scale across the entire study area; and making the data available. The limited field work collected satisfies the "preliminary site survey information" at a basin level, as defined by the guide by assessing wetland presence/absence and class in the field.

Currently, the project has delivered a wetland inventory product that provides improved, consistent and FWCP-Peace wide wetland mapping, at a fraction of the cost of other mapping methodologies. It is useful in determining areas of wetland densities, and likely wetland class. Before the product can be leveraged for effective landscape level decision making, there are both technical and model specific limitations that need to be addressed, as well as practical project-level considerations. The following recommendations should be considered in context of a Wetland Management Framework for the FWCP-Peace Region.

> ***"Wetland Ways provides a series of recommended practices to protect and maintain existing wetlands and move towards an increase in wetland area. The guidelines and suggestions in CHAPTER 2 apply to all wetland managers and users. Other chapters provide information for specific groups, professionals or activities." (Cox and Cullington, 2009)***

MAKE DATA AND INFORMATION AVAILABLE AND ACCESSIBLE

A key component of this work and related efforts should be focused on open and transparent data and information access. MoECCS efforts have focused on using open and available data and workflows towards these goals. To this end the FWCP should continue work with the Ministry towards ensuring continuity of the project outputs and publication in formats that intended user groups can access and use.

A comprehensive data and information access strategy should continue to engage stakeholders through eliciting user input to guide the extent and format of information that is required. Furthermore FWCP should support continued extension and outreach activity efforts by working with the Province and partners. Effective information access combined with outreach can help in building stakeholder consensus for project focus and management decisions. Wetland outreach and engagement opportunities through the Wetland Stewardship Partnership (www.bcwetlands.ca) can be leveraged to extend this project and gain user and stakeholder input.

SUPPORT TARGETED FIELD WORK

Across the entire area, more field work is needed. A stratified sampling design by hydrometric watersheds would better capture the wetland diversity at the watershed level and allow for analysis of cumulative impacts on water quality and quantity by potentially leveraging the hydrometric network. As such, additional field work will be needed in many areas of the FWCP-Peace that are grossly under sampled. However, efficient collection of field data can be optimized by prioritizing and focusing in specific basins and types to minimize travel time in such a large area.

Model and analysis results show the Parsnip basin has large, dense and connected wetlands within a heavily fragmented and disturbed landscape. Targeted field work in the Parsnip basin is needed to adequately sample the abundance and varied wetlands of this basin. This is required to better understand complex patterns of wetlands in the basin to both inform mapping and future wetland inventory, monitoring, protection and conservation efforts. In addition, errors of omission and over-capture were observed in the Parsnip which can be reduced with additional training points. Field data will be needed to validate required updates to the model outputs in this basin to reduce observed errors. Areas with unique geology including ultramafic and calcareous should also be targeted to inventory wetland types that may not currently be described in WIGBC.

In addition, establishing minimum requirements for data collection and leveraging other wetland inventory projects can opportunistically raise the survey intensity levels. An FWCP-funded project where wetland assessments and amphibian surveys are being performed (PEA-F18-W-2569-DCA "Amphibian Wetland Connectivity along the Williston Reservoir") offers such an opportunity. Wetland data standards and collection can leverage the Wetland Stewardship Partnership and both utilize and inform their work on the wetland field form. The full FS882 field forms (BC Government 2010) should be used to collect baseline, benchmark wetland and classification level information. While additional work is needed to establish the framework within which benchmarks and monitoring sites for trend analysis will be established, it may be prudent to test field procedures and collect full Ecosystem Field Form FS882[5] sites in the next field season.

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[5] http://www.env.gov.bc.ca/esd/distdata/ecosystems/wis/deif/fieldmanual/forms98.pdf

ESTABLISH A CONTINUOUS IMPROVEMENT CYCLE - MODEL IMPROVEMENT

Wetland inventories and mapping should be managed using a continuous improvement context. Plan for review and improvements on a set time frame and incorporate new data and technologies.

In the short term, there is further capacity to improve the model, and efforts should be focused on refining the input layers, attribution and accuracy analysis. In particular, this project showed the limitations of the Provincial DEM, sources of error in spectral imagery, and the need for more information in the Parsnip and Finlay basins.

A pilot-study in areas where LiDAR is available to determine the cost-benefit of the results compared to the current mapping product should be conducted. This information may be used to further refine the model and should be applied to areas as LiDAR coverage and availability expands in the FWCP-Peace. This will allow Provincial efforts to extend the open data and methodologies produced from this project to superior datasets. The other significant data layer input was spectral imagery. A refined Sentinel composite should be produced to reduce errors. Additionally, in lieu of outdated ortho imagery of the area, current and high resolution imagery for mapping and point attribution should be sourced and incorporated to reduce attribution error.

Furthermore, attribution to training data to inform analysis should be revisited (e.g., hydrogeomorphic systems and subsystems and hydrodynamic index), and informed by the management framework and required information needed for decision making.

Lastly, the model should be improved through the addition of training points to augment areas of known and unknown error. Specifically, the Parsnip lowlands are underrepresented, as are the northwestern reaches of Finlay. Because these basins have the largest proportion of wetlands and mining reserves & activity, they warrant further focus in model improvements. Here increasing training point densities will improve the model for these areas and as a whole, while field sampling will inform model & training accuracy, and get experts on the ground to inventory wetlands. When collecting these data, lessons learned including improved pick-lists and GPS accuracies, should be implemented where possible.

CONTINUE TO LEVERAGE PARTNERSHIPS TO GUIDE MANAGEMENT OBJECTIVES

The project has involved and leveraged expertise from a wide range of government, academic, public, industry and other partners. These include but are not limited to the FWCP, BCWF, First Nations, B.C. Government, and contractors. Much of the success and efficiencies of the project have come from the interdisciplinary, collective efforts of these partners, both through funded and in-kind activities. Continued support, capacity building and further fostering of partnerships is needed to establish specific management objectives related to wetlands "*such as protection of species at risk, maintenance of annual flooding/drying cycles, and repair or re-establishment of riparian areas*" (Cox & Cullington 2009). Specific management objectives are required to support further detailed inventories, analysis, baseline monitoring and change monitoring activities. With improved understanding of the management objectives within a framework for wetland protection and conservation, it will be possible to solidify the information needed to affect potential decisions. Identifying information needed for management purposes will better direct the mapping and analytical products required from the broad group of partners.

SUPPORT RESEARCH AND ANALYSIS

The wetland data set provides opportunity to explore and answer research questions. The MoECCS, FWCP or their partners are encouraged to use this body of work to explore these questions. Sharing research and findings within the partnership is critical and feeding those findings back into the continuous improvement of the inventory and to the Wetland Management framework so that the body of knowledge about wetlands in the FWCP-Peace and the management of wetlands is informed and based on sound science.

ACKNOWLEDGEMENTS

We would like to acknowledge the Fish and Wildlife Compensation Program for the funding and support to further wetland and riparian understanding of the area, and the Province. We would also like to acknowledge the following for their important contributions:

Chelsea Coady, FWCP Peace Region Manager for project support and guidance.

Ecora, EDI, Madrone, Blackwell: For their efforts in assessing data layers and mapping methods to improve the wetland prediction process.

Blackwell Inc.: For the Fieldwork planning, ecosystem mapping, reporting, and continued GIS support Ben Andrew for report editing and review.

Chu Cho Environmental: For the local area knowledge and technical expertise

Field crew: Deepa Filatow, Tyson Carswell, Nyssa Temmel, Emily Cameron, Adrian DeGroot, Kirk Miller

Corey Erwin for original project proposal and ongoing support.

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APPENDIX A. PROJECT TIMELINE

TASKS	TIMELINE	PURPOSE	DELIVERABLE/OUTCOME
Pilot Projects	2015-2017	Evaluate feasibility of existing Ministries data to identify and map FWCP-Peace Wetlands Evaluate feasibility of predictive wetland mapping in FWCP using limited number of map sheets	1. Pilot project to evaluate mapping methods 2. Predicting location and wetland types possible 3. Identified and assembled data required 4. Identified relevant topographic mapping units for the region & prediction 5. Produced 12500 expert-selected site identifications & evaluated consistency
Model Development	2017	Assemble and modify Random Forest modelling product for wetland-specific outputs	1. Source-code assembly 2. Data formatting for input 3. Modifying output parameters to map wetland units
Fieldwork	August 2017	Put experts in the field to collect site-specific information; Identify possible wetlands sites that are not currently represented in Provincial Wetland Guide, with the possibility of these being Red/Blue listed due to rarity; Collect data for model validation and accuracy assessments.	1. Collected ~300 site descriptions and biophysical measurements 2. Worked with regional First Nations professionals 3. Identified unique wetland sites not currently described in the Provincial Wetlands Guide standards 4. Data collected useful towards model accuracies in certain areas 5. Worked with local stakeholders (e.g. BCWF) to use and evaluate new wetland field forms
Predictive Wetland, and riparian mapping	2017	Map the entirety of FWCP-Peace using Random Forest model; Provide the location and probable site wetland types at 25m resolutions	1. Modelled wetland locations for ~70000km^2 2. Approach follows Provincial Wetland Guide
Final Report	March 31st, 2018	Report summarizing work to date; how it addresses Riparian and Wetland Action Plan; and Information gaps and appropriate next steps	1. Mapping and field data in agreed-upon GIS formats (GeoTIFF, geodatabase, others). Data made available for access by stakeholders/interested parties 2. Value-added ancillary summary products

APPENDIX B. LIST OF INPUT LAYERS FOR RANDOM FOREST

Source	Label	Description
ClimateBC (directly calculated)	MAT	mean annual temperature (°C)
	MWMT	mean warmest month temperature (°C)
	MCMT	mean coldest month temperature (°C)
	MAP	mean annual precipitation (mm)
	MSP	mean summer (May to Sept.) precipitation (mm)
	AHM	annual heat: moisture index (MAT+10)/(MAP/1000))
	SHM	summer heat: moisture index ((MWMT)/(MSP/1000))
ClimateBC (derived variables)	DD0	degree-days below 0°C, chilling degree-days
	DD5	degree-days above 5°C, growing degree-days
	DD18	degree-days below 18°C, heating degree-days
	NFFD	the number of frost-free days
	FFP	frost-free period
	BFFP	the Julian date on which FFP begins
	PAS	Precipitation as snow (mm). For an individual year, PAS is calculated for the period between August in previous year and July in current year
	EMT	Extreme minimum temperature over 30 years. For an individual year, the EMT is estimated for a 30-year normal period (one of the nine normal periods included in the package) where the individual year is nearest to the centre of the normal period
	EXT	Extreme maximum temperature over 30 years. For an individual year, the EXT is estimated for a 30-year normal period where the individual year is nearest to the centre of the normal period.
	EREF	Hargreaves reference evaporation.
	CMD	Hargreaves climatic moisture deficit.
BCGW	DEM	25m resolution digital elevation model of the Province.
	Ortho	Mapsheet orthophoto (i.e. 94c085)
Vegetation Resource Inventory	LANDSAT	LandSAT imagery (bands 6,4,3) of the province. A useful measure of vegetative differences
	SENTINEL-2	Sentinel-2 multispectral imagery (13 bands) of the province.
SAGAgis derived products (RSAGA)	TPI	Topographic Position Index. Compares elevation of each cell to the mean in a specific neighbourhood to infer higher and lower positioned cells compared to neighbours.
	Slope	Slope derived from DEM

	TopoWet	Topographic wetness index, but based on catchment area calculation.
	MRVBF	Multiresolution index of valley bottom flatness. Identifies valley bottoms from DEM
	DAH	Diurnal anisotropic heating. Inference of land cover daily heating based on DEM
	cprof	Profile curvature. This is a measure of curvature that's paLANDSATrallel to maximum slope. Negative indicates surface is upward concave, zero is linear slope,
	cplan	Planform curvature. Is perpendicular to direction of maximum slope. Positive values indicate sidewardly concave at cell. Zero indicates linear.
	carea	Catchment area.
	aspect	Aspect of DEM cell

APPENDIX C. LIST OF MAPCODES AND KEY TO MODELLED PRODUCTS

Label	Description	48 Mapcodes (All_LBL)	Wetland Class (T_W_Class)	Realm (T_W_WL)
A	Alpine Ardvaark	1	4	4
Am	Alpine Meadow	2	4	4
BA	Barren Land	3	4	4
F4	Pole Sapling	4	4	4
FCB	Forest Closed- Broadleaf	5	4	4
FCC	Forest Canopy Coniferous - Closed	6	4	4
FCM	Forest Canopy mixed - Closed	7	4	4
Fh	High Bench Floodplain	8	1	4

Fl	Low Bench Floodplain	9	2	4
FLh	Logged Herb	10	4	4
FLs	Logged Shrub	11	4	4
Fm	Flood Midbench	12	3	4
FOB	Forest Open -Broadleaf	13	4	4
FOC	Forest Coniferous - Open	14	4	4
FOM	Forest mixed - Open	15	4	4
GB	Gravel Bar	16	4	4
GL	Ice/Snow/Glacier	17	4	4
LA	Lake	18	5	5

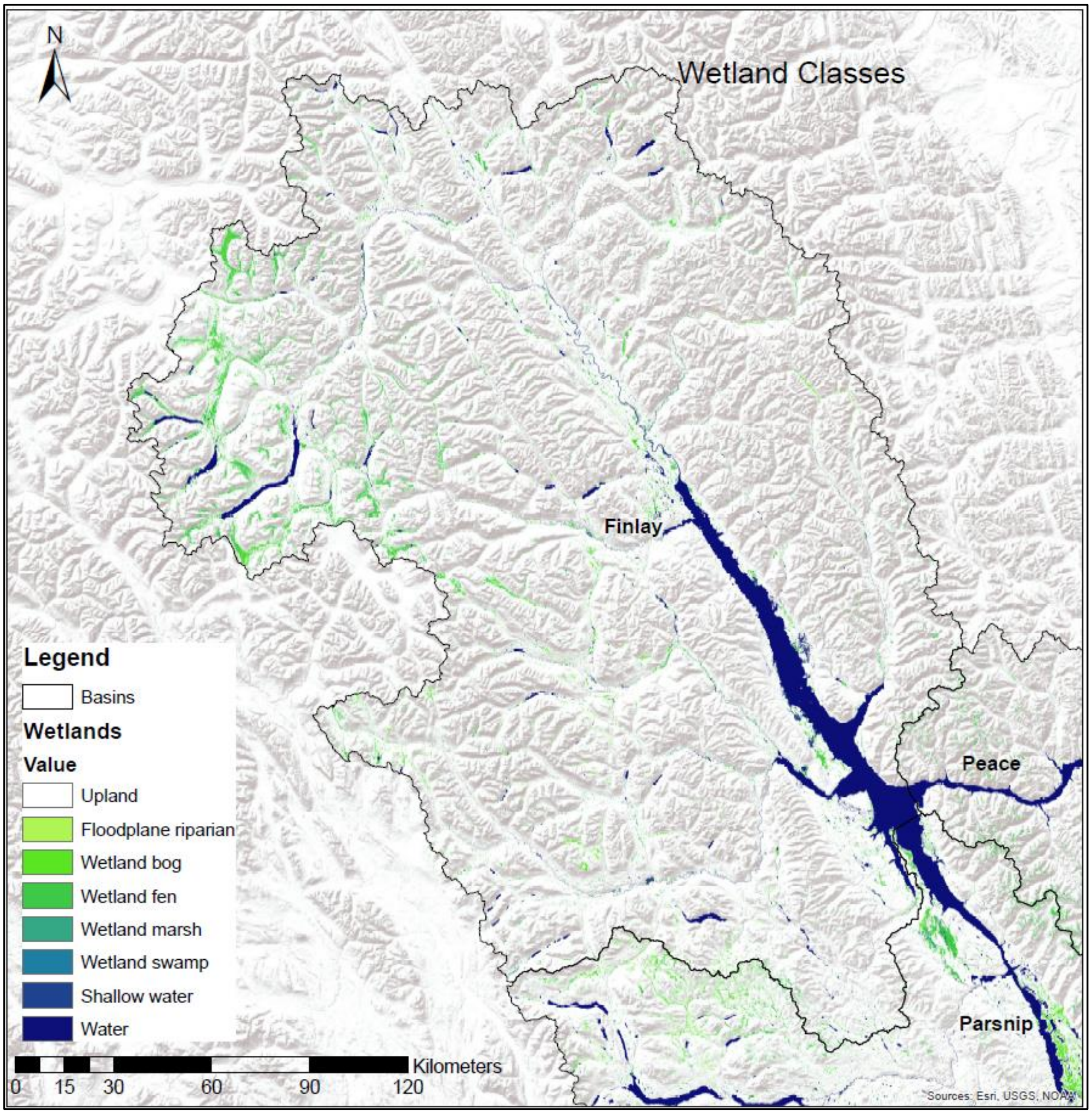
LC	Linear Corridor	19	4	4
Other	Other (in comments)	20	4	4
OW	Open Water (<2ha, no veg)	21	5	5
PD	Pond (2-8ha)	22	5	5
RC	Cliff	23	4	4
RI	River	24	5	5
Ro	Rock Outcrop	25	4	4
Rt	Talus	26	4	4
RZ	Road	27	4	4
Sk	Krummholz	28	4	4

Ss	Subalpine Shrub Seepage	29	4	4
St	Stagnant water	30	5	5
Vh	Avalanch Herb	31	4	4
Vs	Avalanche Shrub	32	4	4
Vt	Avalanceh Treed	33	4	4
Wb2b	Bog - 2b	34	6	6
Wb3a	Bog - 3a	35	6	6
Wb3b	Bog - 3b	36	6	6
Wb7	Bog -7	37	6	6
Wf2b	Fen - 2b	38	7	6

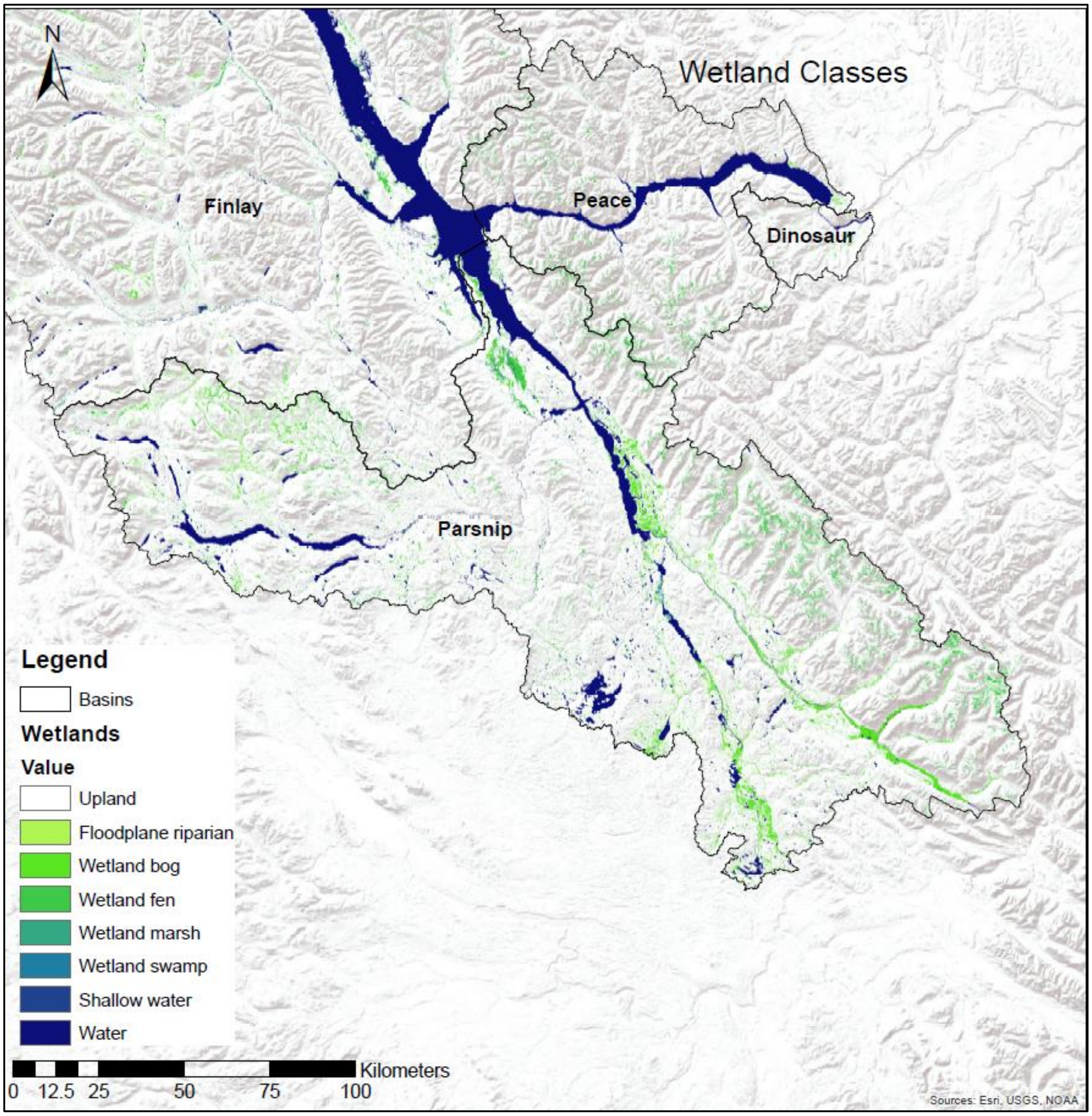
Wf3a	Fen - 3a	39	7	6
Wm2b	Marsh -2b	40	8	6
Ws3a	Swamp - 3a	41	9	6fa
Ws3b	Swamp -3b	42	9	6
Ws5	Swamp - 5	43	9	6
Ws6	Swamp - 6	44	9	6
Ws7	Swamp - 7	45	9	6
Ww2c	Shallow water wetland - 2c	46	5	5
Xh	Disclimax Herb	47	4	4
Xs	Disclimax Shrub	48	4	4

APPENDIX D. BASIN WETLAND COVERAGE MAPS

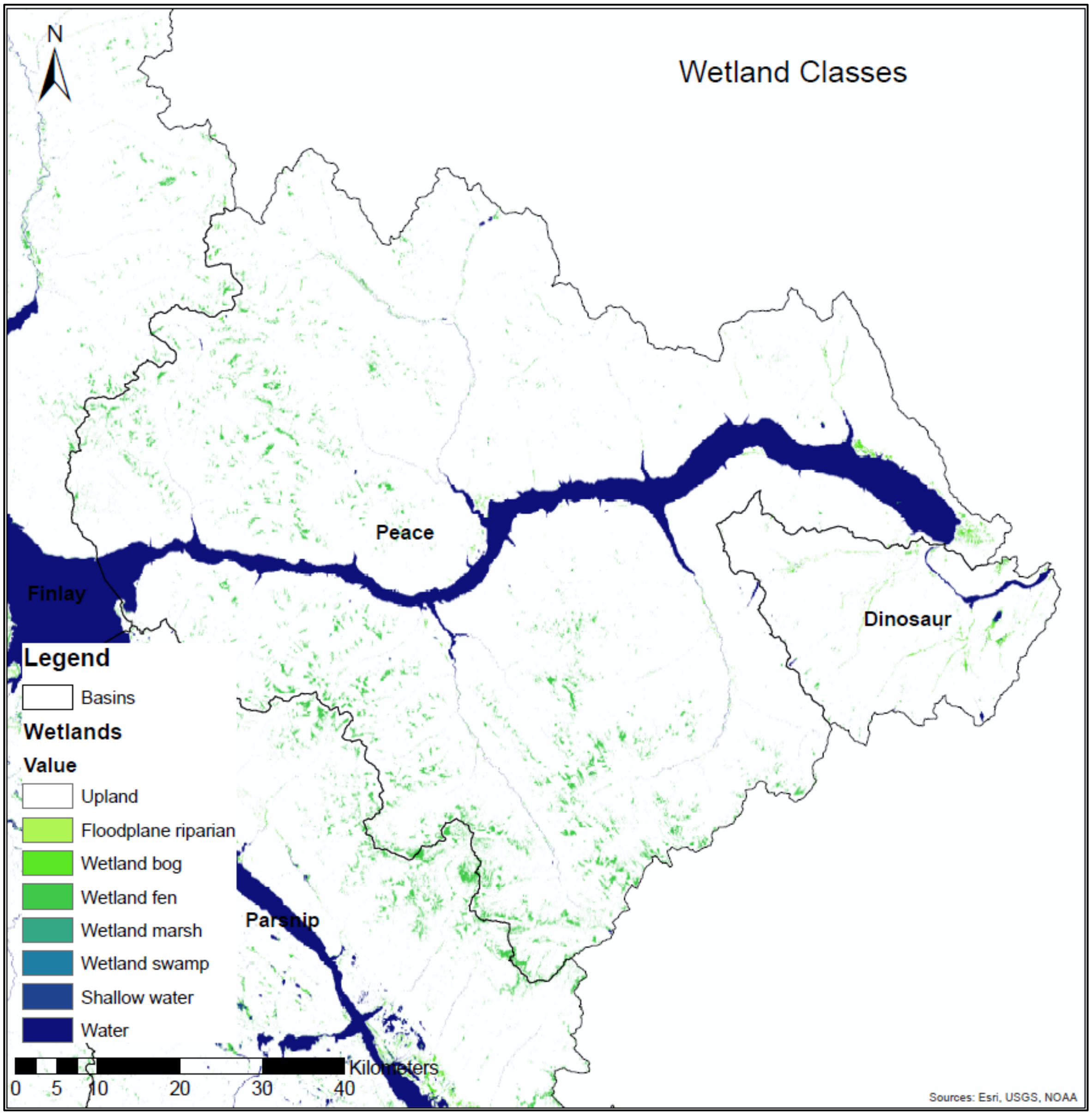
Finlay Basin:



Parsnip Basin:



Peace Basin:


Wetland Classes
N
Peace
Finlay
Dinosaur
Parsnip
Legend
Basins
Wetlands
Value
Upland
Floodplane riparian
Wetland bog
Wetland fen
Wetland marsh
Wetland swamp
Shallow water
Water
0 5 10 20 30 40 Kilometers
Sources: Esri, USGS, NOAA

Dinosaur Basin: