A Review, Enhancement, and Accuracy Assessment of Wetland Features within the eFRI

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A Review, Enhancement, and Accuracy Assessment of Wetland Features within the eFRI*

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Executive Summary

The Ontario forest inventory system identifies wetland areas based on the Ecological Landscape Classification (ELC) system. However, a limitation of the inventory process is that wetlands within waterbodies and small islands are classified as water.

Our project used the ADS40 imagery to identify wetland areas missing from the original forest inventory for Quetico Provincial Park. The review resulted in the addition of 1,886 new wetland polygons classified into six different ecosites for a total area of 2,607.6 hectares. Most of the delineated wetlands were identified as either Organic Shallow Marsh (ecosite 149, 54.3%) or Open Water Marsh: Organic (ecosite 152, 28.2%). Secondary ecosites were applied to 494 polygons (36% of all new polygons) that were formerly classified as water, indicating that these areas consist of more than one ecosite which are too small or interspersed to map independently. Approximately 7% of all areas classified as islands in the original inventory were fully or partial wetland ecosites. Nearly 9% of all waterbodies were found to have contain at least one wetland.

Field validation work was conducted on 167 plots during 2018 and 2019 to allow for an accuracy comparison of the digitization process. Ecosite specific accuracy was low largely due to the inability to determine substrate type (organic vs mineral) from the aerial imagery. Broader categories of classification such as shallow marshes had fairly good agreement with the digitized polygons (71% correct) as did digitized open water marshes in comparison to the field data (77% correct). Of the 116 field sites that were classed as open water, 72 (62%) were in polygons that had open water marsh as either the primary or secondary ecosite. These results illustrate the advantageous use of primary and secondary calls in complex areas.

Ducks Unlimited Canada helps further enhance the utility of wetland classes in the eFRI through the application of a cross-walk of DUC's Enhanced Wetland Classification (EWC).

Lastly, the project investigated the of convolutional neural networks to automate the classification of wetland areas within waterbodies and islands. The model was able to classify the broad classes of water, land and wetlands with accuracies of 95%, 97% and 98% respectively. Model accuracy was lower in specific ecosites (e.g. 135 and 144), but ecosite149 was predicted with good accuracy (90%) as were overall marsh classes (combined ecosite 149 and 152 was 90%).

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1 Project Rationale and Overview

Wetlands provide a wide range of biological, social, and hydrological functions. Accurate wetland inventories and an enhanced understanding of wetland habitat supply is increasingly important in meeting the growing requirements of fish and wildlife management, the Species at Risk and Migratory Birds Acts, and forest certification standards. An accurate wetland inventory for Quetico Provincial Park will also assist in the development of a fisheries and aquatic ecosystem plan, and First Nations have identified wetlands as an important ecosystem component (Brian Jackson, pers. comm.).

While detailed wetland inventories are not available for most areas in Ontario, the eFRI process does classify forest polygons, including most wetland areas, into ecosites based on the Ecological Landscape Classification (ELC) system.

The eFRI system includes 35 potential wetland ecosites, but the inventory process omits most wetlands lying within the boundary of waterbody and island polygons (i.e. small island polygons less than 8 ha are not assigned an ecosite). For example, the Quetico inventory has little area (< 500 ha) in ecosite 147 (shrub shore fen), and no area in either ecosites 149 (organic shallow marsh) or 152 (open water marsh: organic). Field and mapping work by Quetico staff suggests extensive open water wetlands have not been identified in the FRI (Brian Jackson, pers. comm.).

The omission of some wetland ecosites from traditional forest inventories was quantified by the project team during the completion of a wetland inventory project on the adjacent Dog River-Matawin (Dog-Mat) Forest in 2017. While this prior project resulted in the addition of over 5,000 new wetland polygons (over 2,100 hectares) to the inventory on that forest, it was completed solely through photointerpretation with no field verification.

This current project for Quetico expands on our previous methodologies by including field verification as a critical piece of the wetland evaluation process. This project will assess the ability to identify wetland ecosites missing from the eFRI, quantify the amount of wetland area that can be added to the inventory through such a process, and determine the accuracy in doing so using field validation work.

Ducks Unlimited Canada (DUC) helps further enhance the utility of wetland classes in the eFRI through the application of a cross-walk of DUC's Enhanced Wetland Classification (EWC).

Lastly, the project investigates the potential of using deep learning techniques to automate the classification of wetland areas within waterbodies and islands.

2 Field Wetland Identification

2.1 Overview

FRI photo-interpretation calibration and verification plot data are not frequently collected for wetland ecosite types, and thus a significant gap exists in our knowledge of how well our wetland identification system is working in the FRI process. A field accuracy assessment program was conducted in 2018 and 2019 to determine ground-truth ecosite classification and collect additional attributes to help with subsequent aerial photo interpretation.

2.2 Methods

Wetlands for field validation were delineated from eFRI imagery prior to fieldwork. Study areas were chosen based on accessibility from designated canoe routes and proximity to large numbers of wetland polygons.

Vegetation data were collected in accordance with Ontario's Ecological Land Classification standards. Plant species cover was estimated in a 5 m X 5 m quadrat. All vascular plant species and macroalgae (no bryophytes or lichens were observed) occurring in the quadrat were recorded and the percent cover for each species was estimated. Each species was assigned to one of the following physiognomic layers from (species in layers 1 – 5 did not occur in any quadrats) in Table 1.

Table 1. Species layer assignments in field validation qudrats.

Layer	Description
6	Herbs and graminoids
7	Bryophytes and lichens
8	Floating-leaf
9	Submergent

The taxonomic authority was VASCAN (Brouillet et al. 2010+). The total cover of all species in each physiognomic layer was also estimated.

Surface water and substrate pH and conductivity were recorded from three samples at each site using a handheld Oakton multi-meter. Water depth was measured near the centre of each quadrat. The dominant substrate type (humic organic, sand, silt, clay, rock) was recorded. At each plot the ecosite (Banton et al. 2011) and w-type (Harris et al. 1996) were recorded and photographs were taken. Fetch distance (m) and direction (degrees) were estimated following the field work using a Geographical Information System.

2.3 Results and Discussion

In 2018 field verification data were collected from 75 wetland polygons delineated during air photo interpretation. Fieldwork was completed on August 19 to 24 by Allan Harris and Brian Ratcliff. Polygons were accessed by canoe and quadrat locations were recorded with a GPS. An additional 10 sites were sampled by Brian Jackson (Quetico Park Biologist), to bring the total samples to 85 for the 2018 season.

In 2019 field verification data were collected from 82 wetland polygons delineated during air photo interpretation. Fieldwork was completed on August 12 (Al Harris and Seba Belmar) and August 22 to 26 (Al Harris and Brian Ratcliff). Polygons were accessed by canoe and quadrat locations were recorded with a GPS. Figure 1shows the locations of field sites during both seasons.

Site and vegetation data for both seasons are included in Appendices 1 – 4.

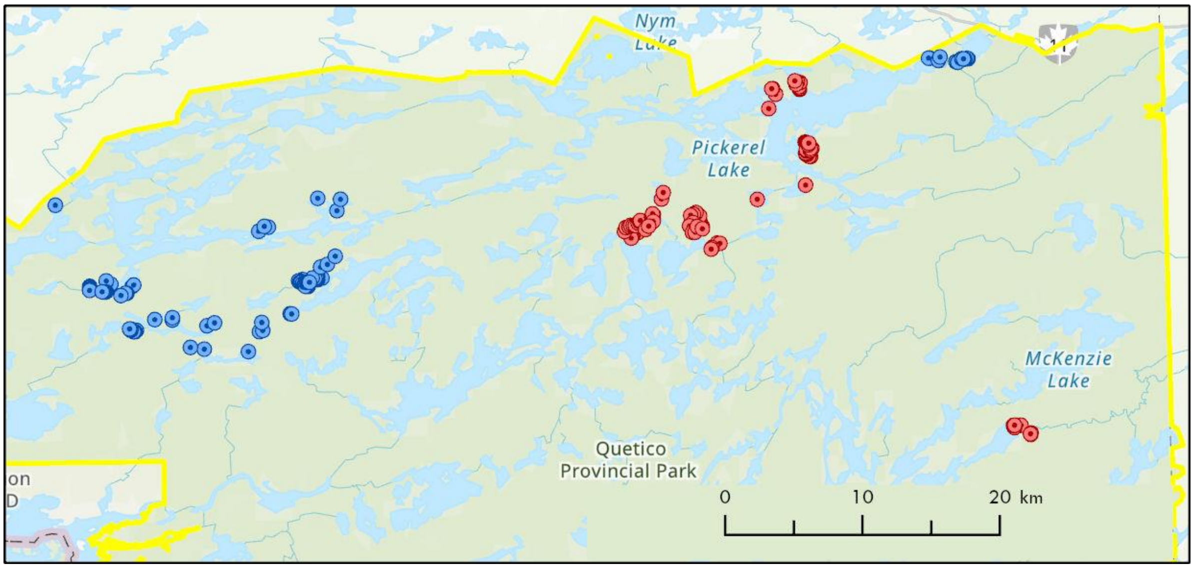

Figure 1. Location of field sample sites in 2018 (Red) and 2019 (Blue).

A full comparison of field data and the ecosites from digitized polygons is discussed in Section 3.

3 Wetland Digitizing

3.1 Overview

The main component of the project was to review all waterbody and islands using digital aerial imagery (ADS40) to identify wetland ecosites omitted during the initial eFRI creation for the entire Quetico Park area. New wetland polygons were digitized and added to the inventory during this process. An accuracy comparison was made between interpreted ecosites and field verification data.

3.2 Methods

Within waterbodies, all wetlands larger than 0.05 ha (500 m^2) and not included in the eFRI dataset were delineated into new polygons. This was considered the minimum practical polygon size given the resolution of the imagery and is also the smallest wetland size delineated in other wetland inventory projects (e.g. Lane and D'Amico 2016). In addition, all island polygons (N = 6,953) were reviewed to evaluate if they were fully or partially wetlands. For the reclassification of island polygons, the minimum size of 500 m^2 was removed as many islands (N = 496) were smaller than this size (Figure 2).

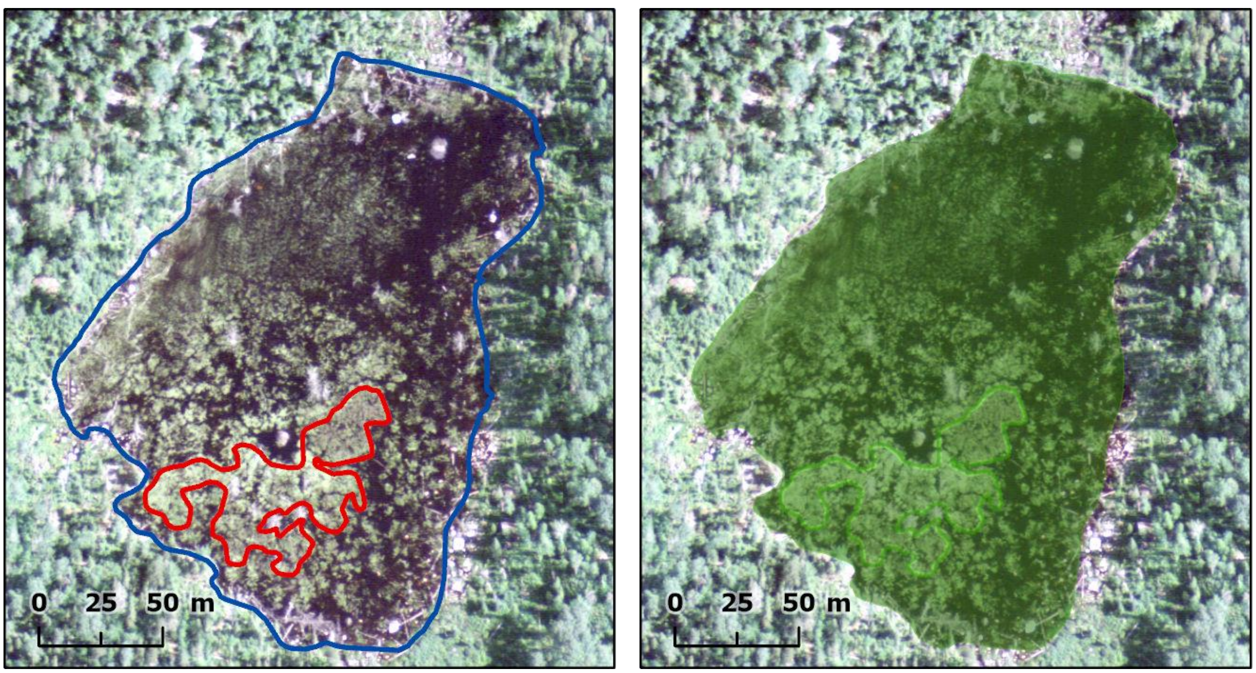

Figure 2. Example of a small island polygon (red outline, left image), within a water polygon (blue outline) in the original inventory. The image on the right shows both original polygons have been reclassified as wetland (Ecosite 144).

Wetlands separated by less than 5 m were delineated as a single polygon, whereas those separated by greater than 5 m were treated as separated polygons (Figure 3). Newly digitized wetlands were identified in areas of waterbody or island polygons in the existing inventory (i.e. forested areas already assigned ecosites were not reviewed). Polygons that were already classified as forest or wetland areas were not altered in shape or existing ecosite class). Where applicable, wetland boundaries were created to share edges of existing polygons to allow for easy incorporation of these polygons into the existing inventory without creating polygon overlap or slivers.

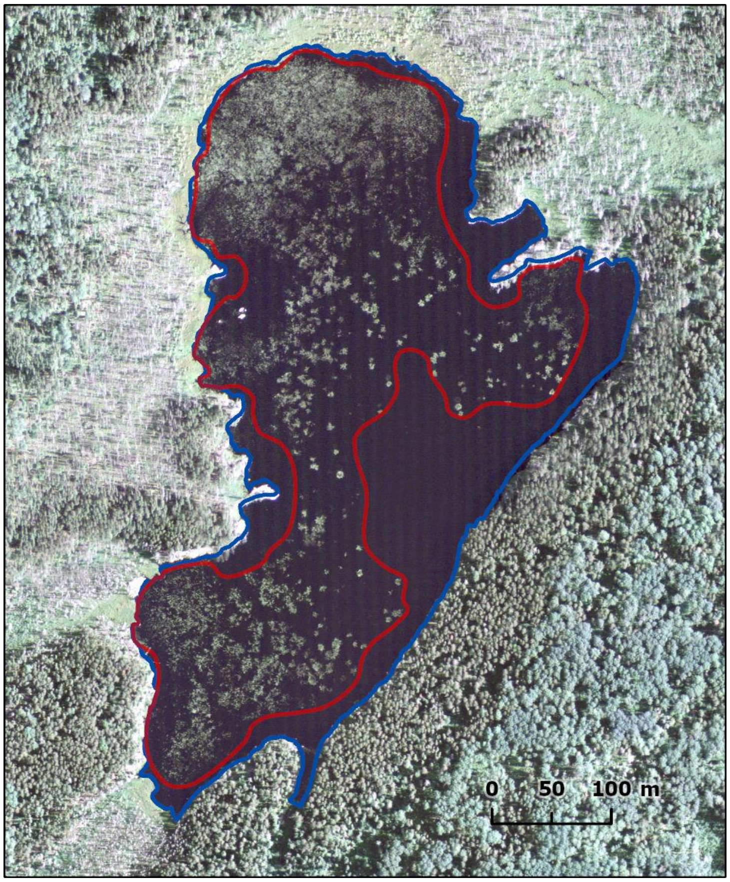

Figure 3. Example Delineation of New Wetland Polygon. blue outline represents original waterbody polygon and red outline illustrates newly delineated wetland area (Ecosite 149).

Digitized wetlands were classified into ecosites following the criteria in Key 10 "Permanently Flooded or Hydric Ecosites" of the ELC guidelines (OMNR 2009). A number of hydric ecosites are defined by whether the substrate is mineral or organic which cannot be assessed using the FRI imagery. In these cases, default decisions were used to assign ecosites to the newly created polygons (Table 2). The defaults were to organic rather than mineral or rock substrate and to open water marsh rather than floating leaved marsh. The difficulty in discerning some of these ecosites from each other using aerial imagery is illustrated in Figure 4 .

Table 2. Default Ecosite Decision Rules.

Wetland	Ecosites	Default Classification
Thicket Swamp	134, 135	135
Meadow Marshes	142, 143, 144	144
Shallow Marshes	148, 149	149
Open Water Marshes	150, 151, 152	152


Figure 4. Field photos from plot 38 (ecosite 148, left image) and plot 57 (ecosite 149, right image) from 2018. The similarity in vegetation appearance and coverage makes the determination of ecosite from aerial imagery very difficult.

The mapping of wetland areas is highly dependent on scale. Wetland vegetation communities often occur in patterns that are highly variable, and thus at times are not independently mappable at a scale useful for most inventory purposes. A primary and secondary ecosite labeling approached was used during delineation to avoid numerous small polygons and produce a more efficient workflow and final inventory product. In situations where more than one wetland ecosite occurred in a complex area, both ecosites were used to label a single polygon where the most common or dominant ecosite is listed first. Common examples include recurring patterns of meadow marsh and thicket swamp on a stream floodplain or a mosaic of emergent vegetation cover percentages along a shoreline (Figure 5). In these cases, we annotated the polygon with both a primary and secondary ecosite, consistent with FRI standards (OMNR 2009; OMNR 2010).

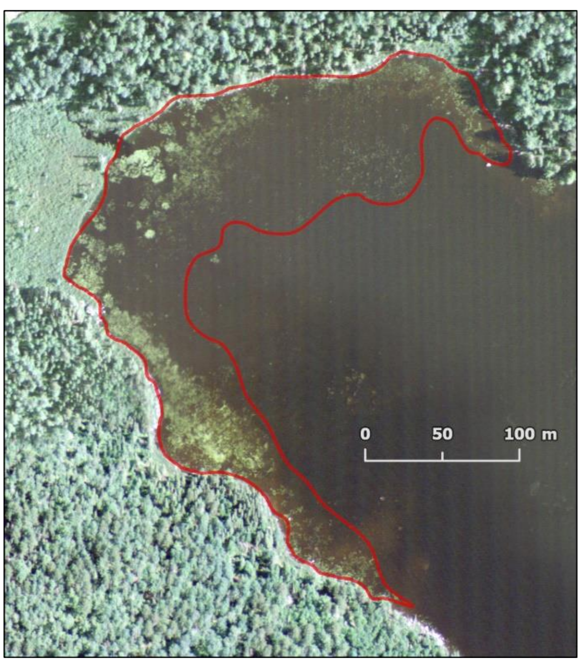

Figure 5. Example of a complex wetland polygon containing a mix shallow marsh (149, primary Ecosite) and open water marsh (152, secondary Ecosite).

Field data from the 2018 and 2019 season was then compared to the newly created wetlands to assess the accuracy of interpreted ecosite labels.

3.3 Results and Discussion

The Quetico forest inventory contains 7,209 water polygons (108,437 ha) and 6,953 island polygons (2,148 ha) which were reviewed for unidentified wetland ecosites. The review resulted in the addition of 1,886 new wetland polygons classified into six different ecosites for a total area of 2,607.6 hectares (Table 3). Most of the delineated wetlands corresponded to two ecosites: Organic Shallow Marsh (149, 54.3%), and Open Water Marsh: Organic (152, 28.2%). Secondary ecosites were applied to 494 (36%) of the polygons that were formerly water, indicating that a these areas have a complex ecosite composition.

The overwhelming majority of wetlands were found within waterbodies (97.6%), whereas only 2.4% of the area was reclassified from island polygons. While the amount of wetland area found within islands is small, it does represent 7.1% of all island polygons being reclassified, at least in part, as wetlands. The 1,390 wetland polygons were found in 645 unique waterbody polygons (i.e. 8.9% of waterbody polygons contained at least one wetland).

Table 3. Summary of Newly Digitized Wetland Areas from Prior Water and Island Polygons.

	Formerly Water		Formerly Island		Grand Total	
Ecosite	**Number of Polygons**	**Area (ha)**	**Number of Polygons**	**Area (ha)**	**Number of Polygons**	**Area (ha)**
127	-	-	8	4.7	8	4.7
135	19	28.4	8	0.4	27	28.8
144	287	365.4	379	52.6	666	418.0
146	4	4.4	-	-	4	4.4
149	627	1,413.1	94	3.9	721	1,417.0
152	453	734.6	7	0.1	460	734.7
Grand Total	1,390	2,545.9	496	61.7	1,886	2,607.6

In 2018, 14 areas were field sampled that did not fall within delineated wetland polygons. This was due to these areas being smaller than the minimum polygon size used. As a result, polygon-field data comparisons were available for 71 sites. For the 2019 field season the new wetland delineation was complete, and field sample areas were pre-selected to ensure the samples were contained within wetland polygons.

Table 4 shows a comparison between ecosite types that were determined in the field and those from the digitization process. The ecosite-to-ecosite comparison illustrates the challenges in making correct ecosite-specific calls as it relates to these wetland types. As mentioned above, default classification rules were applied where ecosites are dependent on substrate type (e.g. 148 vs. 149, 151 vs. 152). In situations where this level of detail is important for habitat or ecosystem evaluation the use of ADS imagery alone may be insufficient. Alternatively, site specific default rules could be constructed based on local knowledge of wetland ecology.

Table 4. Comparison between field and digitized wetland ecosites.

	Digitized Primary Ecosite			
Field Ecosite	144	149	152	**Total**
146	0	1	1	2
148	2	13	6	21
149	0	12	2	14
150	1	55	15	71
151	3	4	8	15
152	1	22	7	30
Total	**7**	**107**	**39**	**153**

Table 5 represents a more generalized comparison between the field and digitization process with ecosites combined into their respective wetland types. Shallow marshes identified in the field had fairly good agreement with the digitized polygons (71% correct) as did digitized open water marshes in comparison to the field data (77% correct). However, results do show substantial differences between areas assessed as open water marshes in the field but labelled as shallow marshes from the imagery (i.e. 81 of 116 sites). This may be in part due plot versus polygon spatial scales and variation across polygons where the relatively small field sample areas are within a larger wetland complex (i.e. the comparisons in Table 4 and Table 5 are only using primary ecosite call). Of the 116 field sites that were classed as open water, 72 (62%) were in polygons that had open water marsh as either the primary or secondary ecosite. This again illustrates the advantageous use of primary and secondary calls in these complex areas (see example in Figure 6).

Table 5. Comparison between field and digitized wetland type.

	Digitized Wetland (Primary Ecosite)				
Field Wetland	Meadow Marsh	Shore Fen	Shallow Marsh	Open Water Marsh	**Total**
Meadow Marsh	0	0	0	0	**0**
Shore Fen	0	0	1	1	**2**
Shallow Marsh	2	0	25	8	**35**
Open Water Marsh	5	0	81	30	**116**
Total	**7**	**0**	**107**	**39**	**153**

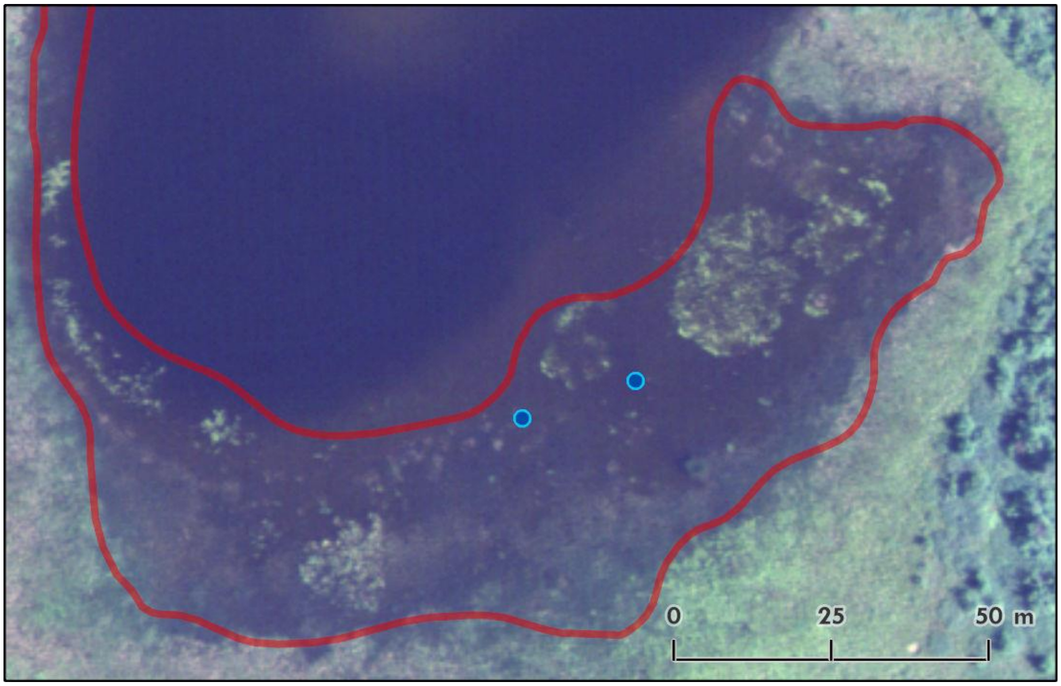

Figure 6. Example of field sites (blue dots) which were classed as open water marsh (152) within a complex wetland polygon (red outline). This polygon had a primary ecosite of shallow marsh (149) with a secondary ecosite of open water marsh (152).

4 Ducks Unlimited Canada Crosswalk

4.1 Overview

To facilitate DUC's interpretation of the wetlands present in Quetico Provincial Park, in addition to developing more concise and user-friendly information for practitioners and forest managers, a crosswalk from OMNR's eFRI permanently flooded/Hydric ecosites to DUC's EWC (Smith et al., 2007; Figure 7) boreal wetland classes was completed.

4.2 Methods

The crosswalk (i.e. translation of classes from one system to another) is detailed in Table 6. 14 EWC classes were identified from this crosswalk exercise. The translation of classes from one classification system to another was completed by analyzing the species composition (i.e. presence), heights, and coverage for each code/class as described in their classification system documentation.

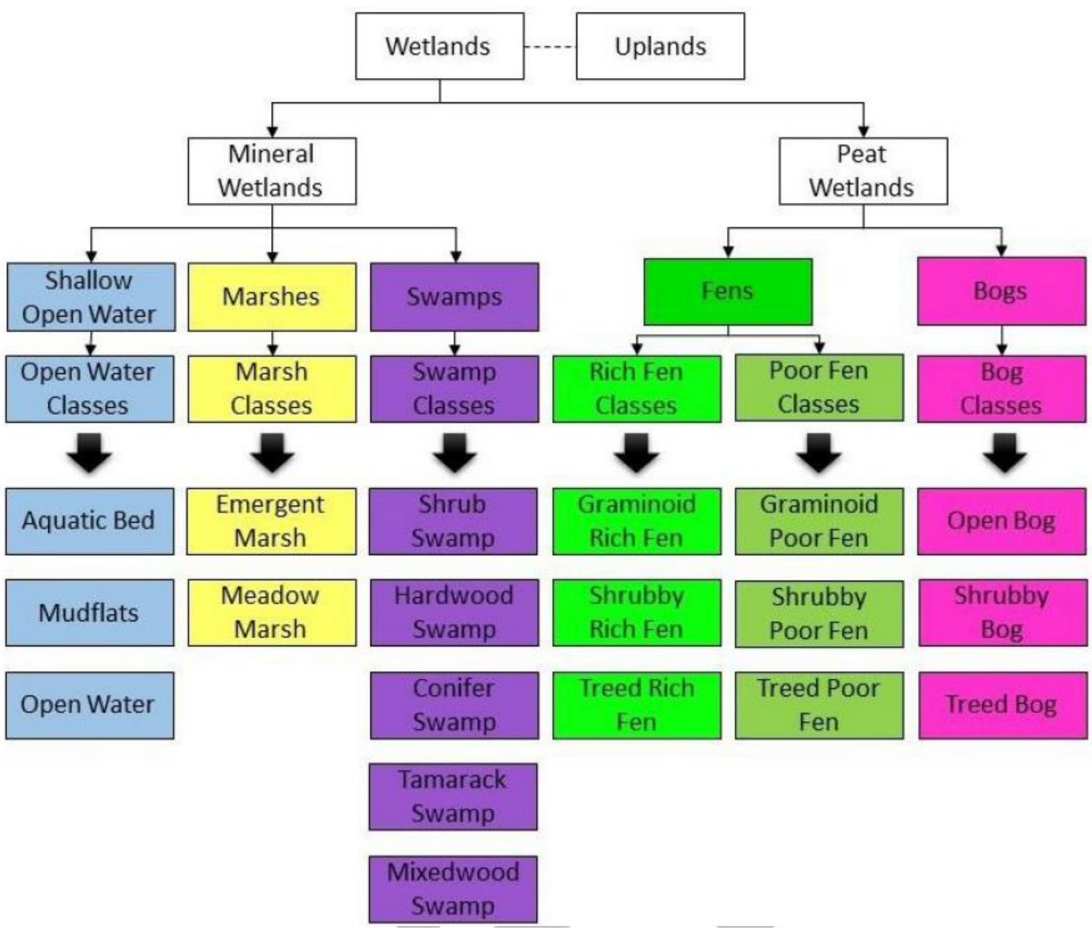

Figure 7. Ducks Unlimited Canada's Enhanced Wetland Classification (EWC) data model, consisting of 19 distinct minor wetland classes that conform to the five major classes of the Canadian Wetland Classification System (CWCS).

Table 6. OMNR ELC ecosite crosswalk (i.e. translation) to CWCS and EWC wetland classes.

ELC Key	ELC Ecosite	CWCS Major Class	EWC Minor Class
B126	Treed Bog	Bog	Treed Bog
B137	Sparse Treed Bog	Bog	Shrubby Bog
B138	Open Bog	Bog	Open Bog
B139	Poor Fen	Fen	Graminoid Poor Fen
B136	Sparse Treed Fen	Fen	Treed Poor Fen
B140	Open Moderately Rich Fen	Fen	Graminoid Rich Fen
B141	Open Extremely Rich Fen	Fen	Graminoid Rich Fen
B146	Open Shore Fen	Fen	Graminoid Rich Fen
B147	Shrub Shore Fen	Fen	Shrubby Rich Fen
B130	Intolerant Hardwood Swamp	Swamp	Hardwood Swamp
B131	Maple Hardwood Swamp	Swamp	Hardwood Swamp
B132	Oak Hardwood Swamp	Swamp	Hardwood Swamp
B133	Hardwood Swamp	Swamp	Hardwood Swamp
B134	Mineral Thicket Swamp	Swamp	Shrub Swamp
B135	Organic Thicket Swamp	Swamp	Shrub Swamp
B127	Poor Conifer Swamp	Swamp	Conifer Swamp
B128	Intermediate Conifer Swamp	Swamp	Conifer Swamp
B129	Rich Conifer Swamp	Swamp	Conifer Swamp
B222	Mineral Poor Conifer Swamp	Swamp	Conifer Swamp
B223	Mineral Intermediate Conifer Swamp	Swamp	Conifer Swamp
B224	Mineral Rich Conifer Swamp	Swamp	Conifer Swamp
B142	Mineral Meadow Marsh	Marsh	Meadow Marsh
B143	Rock Meadow Marsh	Marsh	Meadow Marsh
B144	Organic Meadow Marsh	Marsh	Meadow Marsh
B145	Floating Marsh	Marsh	Emergent Marsh
B148	Mineral Shallow Marsh	Marsh	Emergent Marsh
B149	Organic Shallow Marsh	Marsh	Emergent Marsh
B150	Open Water Marsh: Floating-Leaved	Shallow Open Water	Aquatic Bed
B151	Open Water Marsh: Mineral	Shallow Open Water	Aquatic Bed
B152	Open Water Marsh: Organic	Shallow Open Water	Aquatic Bed
B154	Active Limnetic Rock	Shallow Open Water	Open Water
B155	Active Limnetic Mineral	Shallow Open Water	Open Water
B156	Active Limnetic Organic	Shallow Open Water	Open Water

4.3 Results and Discussion

The eFRI to EWC crosswalk process described in the previous section was spatially applied to the improved Quetico Provincial Park wetland inventory using ArcGIS 10.7 software. This GIS task was applied on the primary ecosite codes assigned in the inventory. Figure 8 displays the final, EWC inventory of Quetico Provincial Park.

A total of 14 EWC classes were identified in Quetico Provincial Park after cross-walking the new eFRI data. Table 7illustrates that the upland class (i.e. non-wetland areas) occupies the largest percentage of the park at 66.67%. Open water (22.02%, which is separate from aquatic bed, and includes both deep and shallow systems) is the most extensive EWC wetland class across the park, followed by conifer swamp (6.35%), meadow marsh (2.06%), and treed poor fen (1.35%). The more rare EWC classes include treed, shrubby and open bogs, and graminoid poor fens (all four classes occupy <1% of the park).

The final EWC inventory of Quetico Provincial Park is made available as a feature class stored in geodatabase (GDB) format. A layer (.lyr) symbology file has also been prepared, according the EWC color scheme (as seen in Figure 7) developed by Ducks Unlimited Canada (Smith et al., 2007).

The EWC is a user friendly classification system that profiles the wetland types existing on the landscape, however there are several value added inferred products that can be derived from the EWC classes. Wetlands develop in response to numerous variables such as geology, hydrology, and climate, which dictate wetland vegetation, species diversity and underlying characteristics. Ducks Unlimited Canada has inferred several of these underlying characteristics from our EWC including water flow, soil moisture content, and relative nutrient status (Ducks Unlimited Canada, 2011;Table 8). These inferred products, which allow the mapping of these variables across the landscape, enhance the knowledge of wetland functions and provide useful recommendations to help conserve the boreal. Further, value added information can aid in the development and implementation of best management practices (BMP) around activities associated with development, such as road building, and can also help assist in meeting various provincial/federal regulatory requirements, including Species at Risk and Migratory birds Convention Acts, and forest certification standards (e.g. SFI, FSC, CSA).

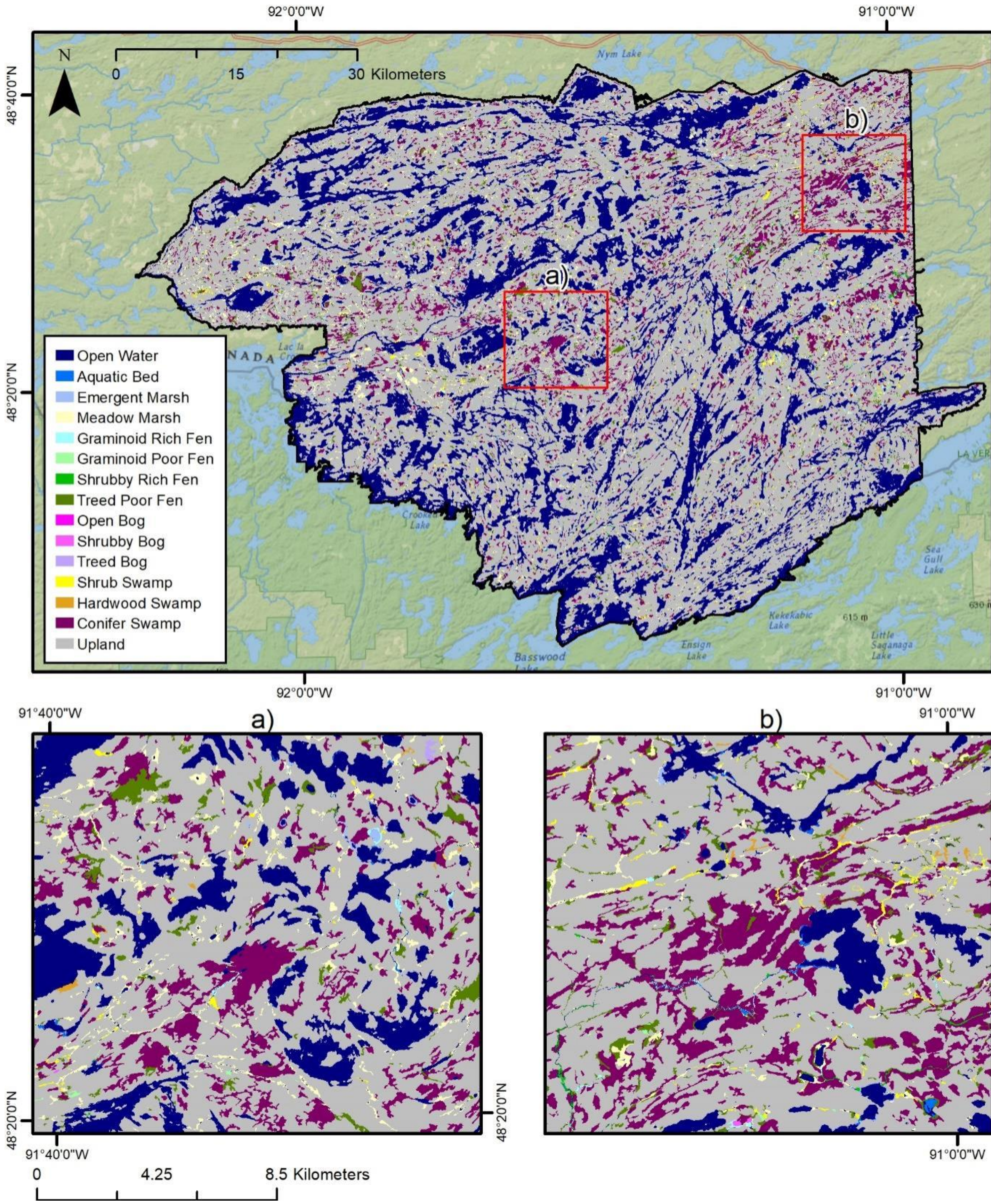

Figure 8. EWC map of Quetico Provincial Park. Image subsets are of high-density wetland regions.

Table 7. Total park area by EWC wetland class.

EWC Class	Area (ha)	Percent
Upland	320,419.7	66.7
Open Water	105,892.7	22.0
Conifer Swamp	30,538.4	6.4
Meadow Marsh	9,905.4	2.1
Treed Poor Fen	6,488.3	1.4
Shrub Swamp	2,702.6	0.6
Emergent Marsh	1,413.1	0.3
Graminoid Rich Fen	998.1	0.2
Aquatic Bed	734.6	0.2
Hardwood Swamp	457.5	0.1
Shrubby Rich Fen	436.9	0.1
Graminoid Poor Fen	421.4	0.1
Shrubby Bog	167.3	0.0
Treed Bog	48.8	0.0
Open Bog	12.4	0.0
Total	480,636.9	100.0

Table 8. EWC wetland classes and their associated inferred classifications according to Ducks Unlimited Canada.

EWC Class	Hydrodynamic Regime	Nutrient Regime	Moisture Regime
Open Water	Dynamic	Open Water	Very Hydric
Aquatic Bed	Dynamic	Open Water	Very Hydric
Emergent Marsh	Very Dynamic	Very Rich	Very Hydric
Meadow Marsh	Very Dynamic	Very Rich	Hydric
Graminoid Poor Fen	Slow Moving	Poor	Hydric
Graminoid Rich Fen	Moving	Rich	Hydric
Shrubby Rich Fen	Moving	Rich	Sub Hydric
Treed Poor Fen	Slow Moving	Poor	Hygric
Open Bog	Stagnant	Very Poor	Sub Hygric
Shrubby Bog	Stagnant	Very Poor	Sub Hygric
Treed Bog	Stagnant	Very Poor	Sub Hygric
Shrub Swamp	Dynamic	Rich	Hydric
Hardwood Swamp	Dynamic	Rich	Hydric
Conifer Swamp	Stagnant	Medium	Sub Hygric

Figure 9 displays the inferred products derived from the EWC for Quetico Provincial Park. This inferred information is contained within the attribute table of the EWC feature class, and each inferred product has an accompanied layer (.lyr) symbology file as a deliverable with this project.

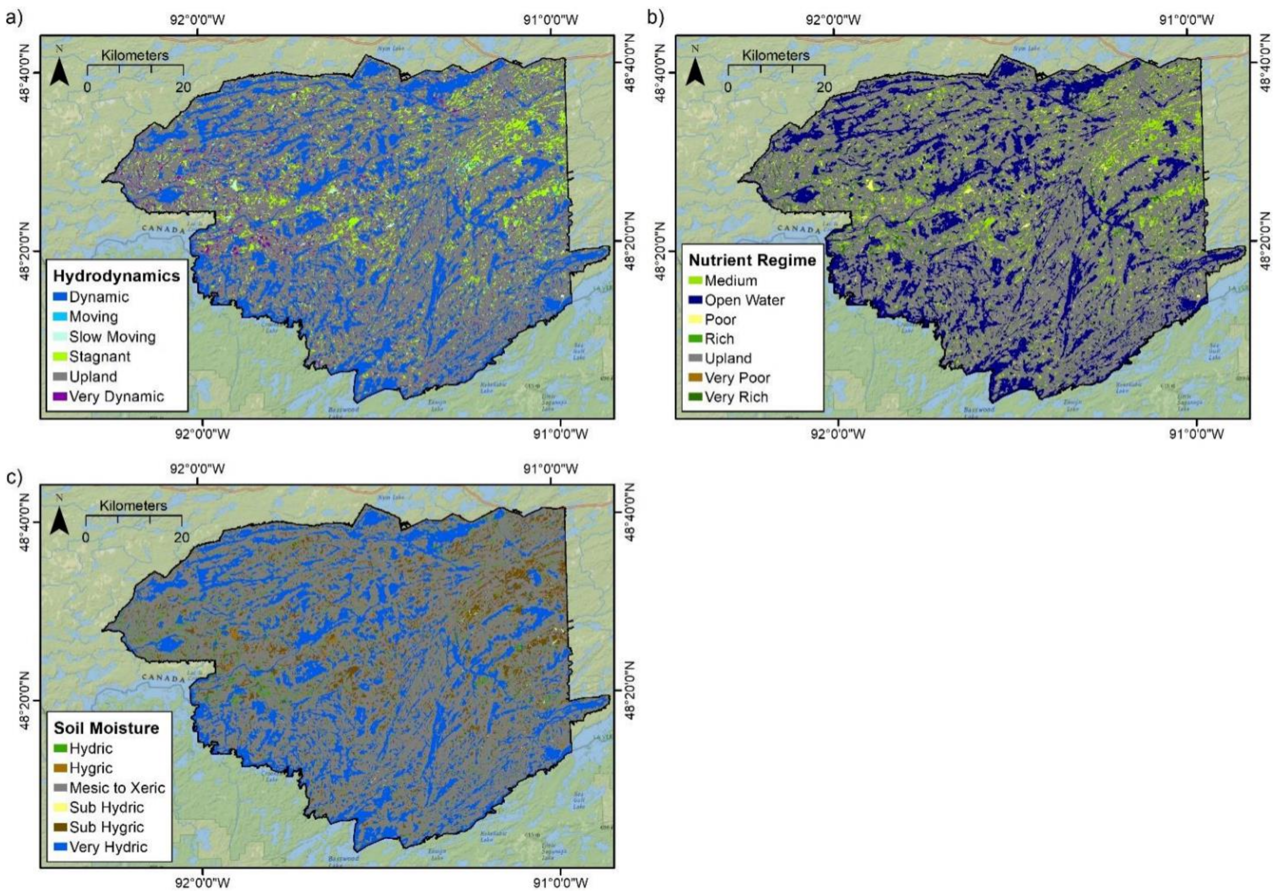

Figure 9. Inferred products derived from the Quetico Provincial Park EWC. a) hydrodynamics, b) nutrient regime, and c) soil moisture.

5 Wetland Deep Learning Identification

5.1 Overview

The original project proposal did not include a deep learning (convolutional neural network) component, however the authors wished to quickly examine the possibility of using the created wetland polygons in this manner. Thus, it is important to note that this investigation was not intended to be a complete analysis of what is possible, but rather a brief exploration as a 'value added' part of the project. As the previous sections of the report illustrate, the manual identification and delineation of wetland ecosites within waterbodies is feasible. However, the exercise is labour intensive and methods to automate the task should be investigated. Studies suggest deep learning methods may outperform other methods of classification (e.g. random forest) (Amani et. al. 2018, Mahdianpari, et. al. 2018). A number of studies have investigated the use of convolutional neural networks and satellite imagery to identify wetlands in Canada at large spatial scales (Amani et. al. 2019, Pouliot et. al. 2019), but, to our knowledge, few studies have leveraged fine resolution imagery (Du et. al. 2020) and scales as described below.

5.2 Methods

Image chips of 32 x 32 pixels were extracted from each of six different classes: water, terrestrial island (i.e. true island), ecosite 135, ecosite 144, ecosite 149 and ecosite 152. Wetland ecosite 146 was not included in the deep learning exercise as there were only two polygons in this class within the study area. This image size was selected as it represented a reasonably fine level of feature identification (e.g. ~13m length, or ~164m^2) and is an image size used in other deep learning training sets (e.g. CIFAR) which would allow some advantage if transfer learning were to be investigated.

Image chip locations were manually selected within areas to ensure the sample area represented the class and were not overlapping boundaries of other classes. Preliminary random chip extraction within polygons illustrated this to be a problem. For example, a number of wetland polygons frequently encompassed areas of open water and it would create a false training set to have labelled images from these locations (see Figure 10). In addition, care was taken to include a diversity of conditions for water (i.e. deep, shallow, waves, and turbulent outfalls of river)s and land (i.e. variety of tree cover conditions, rocky outcrops, etc.).

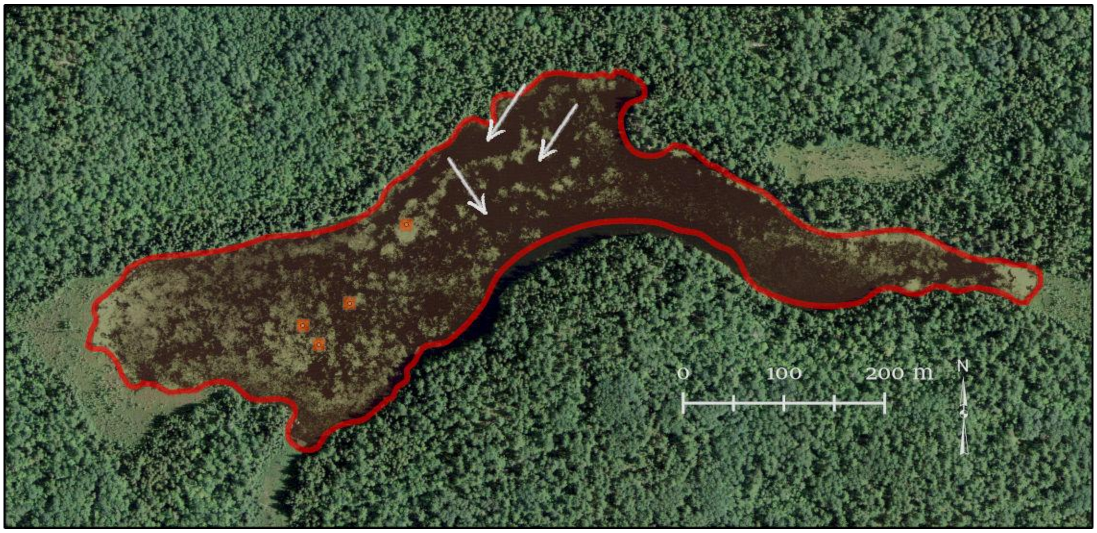

Figure 10. Example of image chip locations (orange squares) extracted from a wetland feature. White arrows indicate areas of intermixed open water which were avoided.

Image chips were created for both 3 band RGB and a 3 band false-colour combination of NIR, red and green as these wavelengths are known to have strong predictive value for wetlands (Amani et. al. 2018). The two training sets (true colour and NIR) allowed deep learning models to be tested against each set to evaluate if different band combinations had an impact on model performance.

For testing and validation, one thousand image chips were created per category for a total of 6,000 images in both the true colour and NIR training sets. While more image samples could be easily collected from some of classes (e.g. water and common ecosites like 149), it was important to keep the number of samples even between classes to provide a better deep learning environment. An additional 600 samples (100 per class) were created for independent testing so the models could be evaluated against an image set not previously seen. To facilitate this, the north-west corner of the park was selected as the area for testing image locations as it has a relatively high density of wetlands as well as field sample data from 2019 (Figure 11).

All models were created in Tensorflow 2.1.0 (www.tensorflow.org).

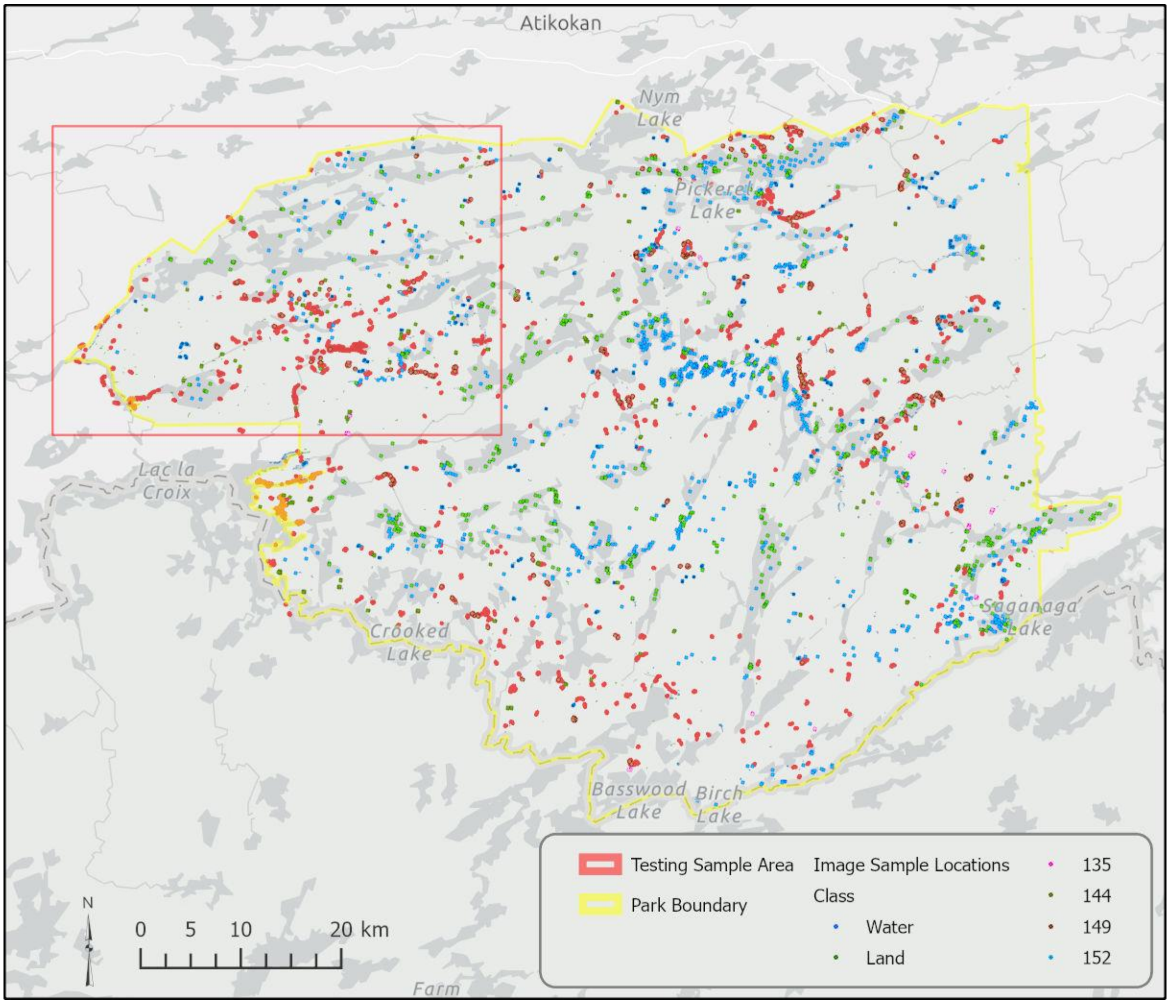

Figure 11. Image sample locations.

5.3 Results and Discussion

Preliminary models (convolutional neural networks) were created to test for the differences between optimizers (stochastic gradient descent and 'adam'), impacts of drop-out and regularization to prevent overfitting, the differences between true colour and NIR datasets in their predictive ability, and to find model(s) that had a structure suitable for further investigation.

Nine preliminary models were run using a training/validation split of 80/20 (i.e. 4,800 images for testing and 1,200 images for validation) and run for 100 epochs.

Given the relatively few training images (1,000 per class), many models commonly showed signs of overfitting (i.e. increases in validation loss and no improvement in validation accuracy compared to training data) within 20 epochs (Figure 12). Increasing the split between training and validation typically resulted in unstable and poor overall model performance.

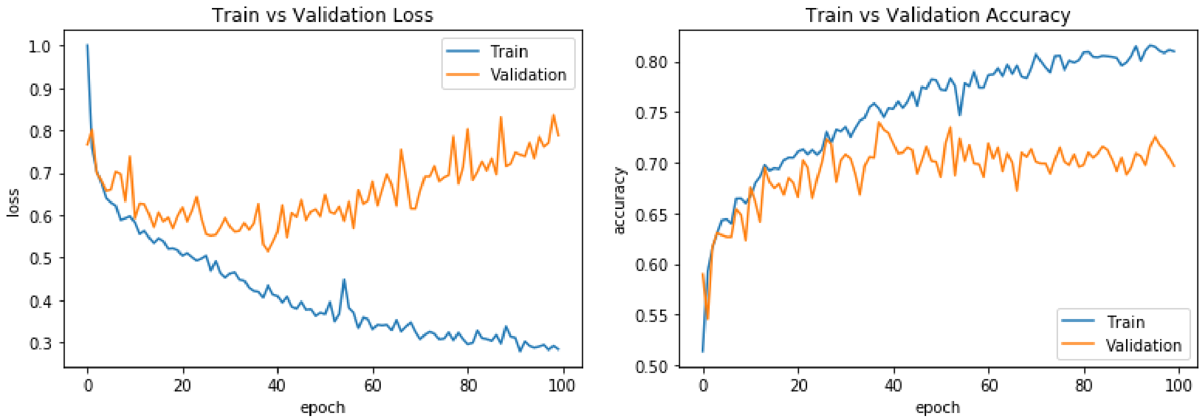

Figure 12. Example training and validation loss and accuracy (model 3, NIR)

The final training and validation accuracy for the nine preliminary models is shown in Table 9, and highlight that a number of models had developed overfitting by 50 epochs with generally poor validation accuracy. It is noteworthy that the RGB data was more susceptible to overfitting than the NIR data. This suggests that, for the model configurations reviewed here, the NIR data was more appropriate to identify general wetland features.

Table 9. Training and Validation Results for Preliminary Models Using RGB and NIR Datasets at 50 Epochs.

	RGB (Training Accuracy/Validation Accuracy)	NIR (Training Accuracy/Validation Accuracy)
Model 1	94.0/65.4	90.9 / 69.8
Model 2	84.6/64.1	88.6 / 72.3
Model 3	79.3/59.5	82.2 / 73.7
Model 4	64.2/61.2	74.2 / 73.3
Model 5	78.2/60.3	82.2 / 72.8
Model 6	65.7/65.3	72.6/ 70.8
Model 7	76.8/64.3	84.9 / 70.9
Model 8	85.4/66.5	84.8 / 73.6
Model 9	91.4/65.9	87.2 / 71.0

While Model 4 and 6 in the above table had relatively low training accuracies at 50 epochs, the models did not show signs of overfitting. These models were then further investigated with changes to improve accuracy and run for more epochs. The final model was also only investigated with the NIR dataset as preliminary results showed slightly better performance than with the true colour images.

The final model architecture is shown in Figure 13. The model was run with a training/validation split of 80/20, a batch size of 32, and run for 125 epochs. The optimizer was stochastic gradient decent with a set learning rate of 0.01.

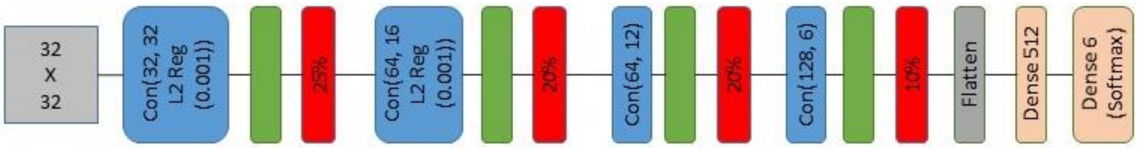

Figure 13. Model Architecture. Blue = convolution layers with same padding, Green = MaxPooling, Red = Dropout. All activations are ReLu except the final Softmax layer.

The model produced a training and validation accuracy of 90.7% and 82.7% respectively at the end of 125 epochs.

The model was then used to predict the 600 test images that were held back from both training and validation. The confusion matrix for these results is in Figure 14. The model was able to classify the broad classes of water (label = 99), land (label = 100) and wetlands with accuracies of 95%, 97% and 98% (391 of 400 images) respectively.

The model was able to predict specific ecosites with less accuracy. It performed well on ecosite 149 (90%), but most frequently misclassified ecosites 135 (30% accuracy) and 144 (29% accuracy). With respect to ecosite 135, this may be in part due to the limited number of polygons from which to choose from for the training set. A substantial amount of overlap between image chips was required to achieve 1,000 training samples, and the model therefore had limited information from which to create generalized predictions.

If ecosite 152 (open water) was combined with 149 (shallow water), the model had a 90% accuracy in classifying these marsh types within the test data.

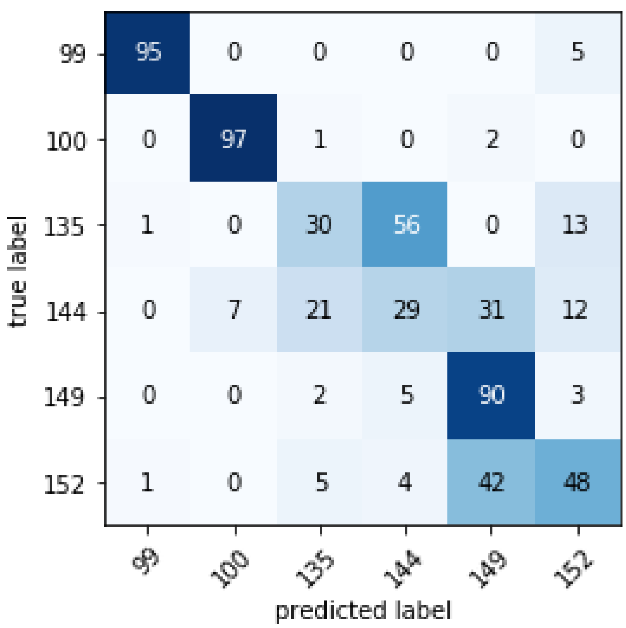

Figure 14. Confusion matrix for test images [99 = water, 100 = land, and all other labels are wetland ecosites].

Given the diversity of how a single ecosite may look across an area, it may be that additional samples are required to create a more accurate model. Wetland polygons delineated in this study often contained a mix of vegetation conditions and it may be that the fine scale image size is too focused to provide the context need to properly identify the overall feature (e.g. the proximity to shores, broken nature of flakes or strings). It would be worthwhile to investigate the performance of larger initial chip sizes with multi-scale cropping (e.g. Pouliot et. al. 2019).

6 Conclusions

This project has demonstrated that the eFRI dataset with enhancements to refine island and waterbody polygons can be effectively used to produce high-resolution wetland inventories, and that they are comparable to inventories generated using alternative methods of classification, such as the DUC Enhanced Wetland Classification System. While the overall wetland area added to the inventory (~2,600 ha) is small compared to the overall park size, it is important to note that much of this area is in ecosites that were completely omitted from the original inventory. These areas can therefore aid in fish and wildlife habitat planning as well as broader ecosystem plans.

Interpretation of wetlands from the imagery had accuracies of 62 – 77% to field data depending on wetland class. These results show that there is a reasonable ability to identify wetland classes from the ADS imagery, but that some caution is needed as ecosite-specific determination remains difficult. Depending on the end use of the wetland inventory (i.e. if specific ecosites are required, or if broader classifications are sufficient), this may or may not be a problem. The use of both primary and secondary ecosite labels in complex wetland areas is one way to improve the accuracy of delineated areas. It is possible that the new imagery with increased spatial resolution may also aid in accurate identification.

One limitation of the use of eFRI imagery for the development of wetland inventories is that the time when the images were captured does not necessarily represent the time of maximum vegetation growth. This can potentially lead to underestimating the total area of a wetland ecosite and/or to errors in the ecosite classification. Wetland vegetation is at its maximum cover from about late June to mid-September. Year to year variation in wetland vegetation cover due to water level fluctuations is another potential source of error. If eFRI imagery was acquired outside of this period, alternate data sources, such as Google Earth and Bing imageries, can be used to assist the delineation and classification process. High temporal resolution image sources such as Planet would also provide a high level of accuracy on the timing of vegetation emergence and may aid in ecosite assessment.

The results from modelling using convolution neural networks and imagery with the near-infrared band illustrates a promising area of investigation into automated wetland classification. The model was able to classify the broad classes of water, land and wetlands with accuracies of 95%, 97% and 98% respectively. Model accuracy was lower in specific ecosites, but some such as ecosite149 were predicted with good accuracy (90%) as were overall marsh classes (ecosite 149 and 152). An increase in sample sizes for training these models, investigating the use of other image chip sizes, and the higher resolution from new ADS imagery may help produce higher accuracy results.

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Appendix 1. Quetico wetland site data (2018)

Site No.	Lake	Fetch direction (degrees)	Fetch Distance (m)	Substrate	Depth (m)	Zone	Easting	Northing	Date	W-type	Ecosite	Water pH	Water Cond.	Substrate pH	Substrate Cond.
1	Pickerel	90	173	sand	0.20	15	623971	5385145	8/19/2018	12	149	7.18	36.33	6.85	149.70
2	Pickerel	90	112	humic	0.70	15	624031	5385094	8/19/2018	4	150	7.73	38.20		
3	Pickerel	135	159	humic	1.10	15	624098	5385038	8/19/2018	4	150	7.00	38.25		
4	Pickerel	45	113	humic	1.00	15	624127	5384954	8/19/2018	4	150	6.82	37.70	5.55	146.80
5	Pickerel	0	391	humic	0.60	15	624096	5384934	8/19/2018	4	150	6.67	37.23	5.78	171.80
6	Pickerel	0	521	humic	0.45	15	624129	5384729	8/20/2018	3	152	6.60	39.35	5.55	157.20
7	Pickerel	225	546	humic	0.40	15	624472	5384679	8/20/2018	4	150	6.09	27.23	5.78	93.10
8	Pickerel	0	576	sand	0.40	15	624367	5384094	8/20/2018	6	148	6.44	26.93	5.88	34.05
9	Pickerel	23	631	sand	0.80	15	624257	5384118	8/20/2018	5	150	6.49	27.70	6.13	27.35
10	Pickerel	45	514	boulders	0.30	15	624123	5384260	8/20/2018	6	148	6.44	26.23	6.02	51.15
11	Pickerel	45	572	humic	0.50	15	624043	5384262	8/20/2018	4	150	6.53	27.23	5.93	81.90
12	Pickerel	45	523	humic	0.50	15	624006	5384357	8/20/2018	4	150	6.44	26.73	5.88	140.15
13	Pickerel	135	525	sand	0.35	15	624059	5384507	8/20/2018	5	148	6.45	27.47	5.67	74.20

Site No.	Lake	Fetch direction (degrees)	Fetch Distance (m)	Substrate	Depth (m)	Zone	Easting	Northing	Date	W-type	Ecosite	Water pH	Water Cond.	Substrate pH	Substrate Cond.
14	Pickerel	135	585	humic	0.75	15	624055	5384587	8/20/2018	4	150	6.48	27.50	5.46	99.70
15	Pickerel	180	485	humic	0.65	15	624352	5384558	8/20/2018	4	150	6.39	26.90	5.91	142.10
16	Pickerel	180	578	humic	0.40	15	624361	5384683	8/20/2018	4	150	6.41	29.33	5.87	109.75
17	Pickerel	315	231	humic	0.90	15	624204	5384940	8/20/2018	4	150	6.54	38.63		
18	Pickerel	270	247	humic	0.35	15	624235	5385066	8/20/2018	10	149	6.12	36.67	5.67	131.50
19	Bisk	260	1478	humic	0.35	15	624007	5382019	8/20/2018	4	150	6.52	39.07	5.69	115.90
20	Beg	335	684	sand	0.30	15	620492	5380983	8/20/2018	1	151	7.28	42.20	6.64	149.45
21	unnamed	315	1150	humic	0.80	15	616496	5378953	8/21/2018	4	150	6.45	31.37		
22	unnamed	315	1213	sand	0.75	15	616470	5379054	8/21/2018	4	150	6.23	24.70		
23	unnamed	250	857	sand	0.65	15	616363	5379218	8/21/2018	4	150	6.11	24.37	6.09	40.80
24	unnamed	225	1114	sand	0.35	15	616314	5379409	8/21/2018	6	148	6.23	24.07	6.29	49.30
25	unnamed	225	1183	sand	0.45	15	616280	5379543	8/21/2018	6	148	6.14	24.13	5.83	54.10
26	unnamed	225	1401	sand	0.75	15	616287	5379783	8/21/2018	4	150	6.36	23.70	6.06	26.60
27	unnamed	200	1611	humic	1.30	15	616028	5380027	8/21/2018	4	150	6.24	28.30		
28	unnamed	160	1279	sand	0.60	15	615844	5379906	8/21/2018	4	150	6.21	24.20	6.07	25.00

Site No.	Lake	Fetch direction (degrees)	Fetch Distance (m)	Substrate	Depth (m)	Zone	Easting	Northing	Date	W-type	Ecosite	Water pH	Water Cond.	Substrate pH	Substrate Cond.
29	unnamed	135	1169	humic	0.80	15	615641	5379824	8/21/2018	4	150	6.22	24.53		
30	unnamed	180	857	sand	0.55	15	615802	5379286	8/21/2018	4	150	6.32	24.70	5.62	61.60
31	unnamed	45	902	silt	0.50	15	615558	5379058	8/21/2018	4	150	6.54	23.60	5.70	59.30
32	unnamed	10	1493	humic	1.50	15	615768	5378588	8/21/2018	4	150	6.35	24.63		
33	unnamed	350	711	humic	0.85	15	615962	5378594	8/21/2018	4	150	6.44	24.13	5.85	43.80
34	unnamed	0	1046	sand	0.45	15	616120	5379010	8/21/2018	4	150	6.54	26.60	5.95	56.10
35	unnamed	270	176	humic	0.65	15	616492	5378845	8/21/2018	4	150	6.35	23.13	5.83	62.10
36	Pickerel R.	225	107	sand	0.15	15	617575	5377809	8/21/2018	5	148	6.76	35.40	5.94	91.80
37	Pickerel R.	0	298	silt	0.55	15	617772	5377785	8/21/2018	4	150	6.45	23.70	5.90	58.50
38	Pickerel R.	180	182	silt	0.35	15	617200	5377479	8/21/2018	6	148	7.22	38.97	5.91	75.50
39	Pickerel R.	270	134	silt	0.45	15	617136	5377369	8/21/2018	6	148	7.21	36.60	6.19	93.40
40	Sturgeon	315	882	silt	1.50	15	611685	5378583	8/22/2018	1	151	7.40	37.90		
41	Sturgeon	315	897	silt	1.40	15	611807	5378576	8/22/2018	7	148	7.33	38.73		
42	Sturgeon	315	812	silt	1.50	15	611452	5378423	8/22/2018	1	151	7.26	44.67		
43	Sturgeon	45	1263	silt	1.50	15	611368	5378233	8/22/2018	1	151	7.40	37.67		

Site No.	Lake	Fetch direction (degrees)	Fetch Distance (m)	Substrate	Depth (m)	Zone	Easting	Northing	Date	W-type	Ecosite	Water pH	Water Cond.	Substrate pH	Substrate Cond.
44	Sturgeon	0	939	clay	0.60	15	611311	5378166	8/22/2018	6	148	7.25	37.23	6.30	91.20
45	Sturgeon	70	1547	humic	0.60	15	610824	5378650	8/22/2018	10	149	6.48	31.10	6.16	123.90
46	Sturgeon	180	585	silty clay	1.10	15	610936	5378936	8/22/2018	4	150	7.29	39.27	6.77	53.15
47	Sturgeon	180	708	clay	1.20	15	611148	5379009	8/22/2018	4	150	7.39	39.40		
48	Sturgeon	225	860	silty clay	0.45	15	611277	5379093	8/22/2018	7	148	6.98	33.87	6.06	111.55
49	Sturgeon	225	945	silt	0.65	15	611464	5379092	8/22/2018	7	148	7.24	37.53	6.01	77.70
50	Sturgeon	225	986	silty clay	1.20	15	611611	5379088	8/22/2018	7	148	7.18	37.27		
51	Sturgeon	180	778	silty clay	1.00	15	611819	5379266	8/22/2018	4	150	7.23	36.87	6.45	97.40
52	Sturgeon	225	1313	silt	0.40	15	611929	5379362	8/22/2018	6	148	7.24	36.77	5.97	76.90
53	Sturgeon	45	1141	silt	0.65	15	611977	5379445	8/22/2018	2	151	7.34	40.70	5.83	58.50
54	Sturgeon	245	1085	silt	0.70	15	612795	5379700	8/22/2018	1	151	7.46	37.67	5.71	137.35
55	Sturgeon	260	981	silt	0.75	15	612915	5379620	8/22/2018	7	148	7.10	35.87	6.58	117.25
56	Deux Rivieres	90	114	silt	0.70	15	612839	5379827	8/22/2018	9	149	6.94	60.00	5.78	205.95
57	Deux Rivieres	270	71	humic	0.15	15	612922	5379887	8/22/2018	9	149	6.91	71.10	5.83	110.05
58	Deux Rivieres	315	87	humic	0.35	15	612885	5379872	8/22/2018	9	149	6.90	69.03	5.87	126.80

Site No.	Lake	Fetch direction (degrees)	Fetch Distanc e (m)	Substrate	Depth (m)	Zon e	Easting	Northing	Date	W-type	Ecosite	Water pH	Water Cond.	Substrate pH	Substrate Cond.
59	Deux Rivieres	270	36	humic	0.30	15	612867	5379937	8/22/2018	9	149	6.93	68.50	5.81	99.65
60	Sturgeon	315	700	silt	0.65	15	612913	5379384	8/22/2018	7	148	7.30	35.27	5.78	78.30
61	Sturgeon	290	1410	silt	0.80	15	612355	5378796	8/23/2018	7	148	6.84	44.77	6.15	163.00
62	Sturgeon	0	761	silt	0.40	15	612582	5379037	8/23/2018	7	148	6.63	37.53	6.21	165.70
63	Deux Rivieres	315	129	silt	0.90	15	613517	5381007	8/23/2018	4	150	6.33	27.97	5.91	185.90
64	Twin	220	255	silt	1.10	15	613648	5381476	8/23/2018	1	151	6.65	27.73	5.94	101.30
65	Pickerel	0	705	silty sand	0.30	15	621325	5387583	8/23/2018	6	148	7.70	57.40		
66	Pickerel	290	1395	humic	0.40	15	621824	5388620	8/24/2018	10	149	6.05	51.33	5.48	150.35
67	Pickerel	255	905	humic	0.55	15	621601	5389032	8/24/2018	4	150	6.16	37.20	5.79	137.50
68	Pickerel	255	862	clay	0.10	15	621540	5389017	8/24/2018	10	149	6.33	41.37	6.05	131.40
69	Pickerel	10	291	clay	0.80	15	623567	5388972	8/24/2018	6	148	6.72	36.50		
70	Pickerel	20	215	clay	1.00	15	623554	5389050	8/24/2018	4	150	6.63	35.57	5.59	72.70
71	Pickerel	20	193	clay	0.70	15	623525	5389168	8/24/2018	4	150	6.48	34.40	5.72	124.90
72	Pickerel	270	329	humic	0.60	15	623602	5389470	8/24/2018	4	150	5.92	30.77	5.67	174.10
73	Pickerel	180	169	humic	0.35	15	623402	5389527	8/24/2018	4	150	6.34	32.90	5.62	139.60

Site No.	Lake	Fetch direction (degrees)	Fetch Distance (m)	Substrate	Depth (m)	Zone	Easting	Northing	Date	W-type	Ecosite	Water pH	Water Cond.	Substrate pH	Substrate Cond.
74	Pickerel	0	203	humic	0.70	15	623312	5389345	8/24/2018	4	150	6.34	32.37	5.77	170.85
75	Pickerel	340	114	clay	0.55	15	623227	5389594	8/24/2018	4	150	6.59	32.57	5.85	105.00

Appendix 2. Quetico wetland vegetation data (2018)

Site number	Scientific Name	Layer	Cover	Notes
1	*Carex lasiocarpa*	6	45	
1	*Equisetum fluviatile*	6	5	
1	*Acorus americanus*	6	0.1	
1	*Sparganium fluctuans*	8	40	
1	*Sagittaria latifolia*	9	25	
1	*Myriophyllum sibericum*	9	4	
1	*Urticularia vulgaris*	9	1	
1	*Urticularia minor*	9	0.1	
1	*Potamogeton spirillus*	9	0.1	
1	*Myriophyllum verticillatum*	9	1	
1	*Potamogeton epihydrus*	9	1	
2	*Sparganium fluctuans*	8	80	
2	*Nuphar variegata*	8	0.1	
3	*Sparganium fluctuans*	8	30	
4	*Sparganium fluctuans*	8	55	
5	*Sparganium fluctuans*	8	40	
6	*Carex lasiocarpa*	6	5	
6	*Schoenoplectus acutus*	6	0.1	
6	*Sparganium angustifolium*	8	1	

Site number	Scientific Name	Layer	Cover	Notes
6	*Brasenia schreberi*	8	0.1	
6	*Sagittaria sp.*	9	30	
6	*Potamogeton gramineus*	9	0.1	
7	*Sparganium fluctuans*	8	80	
7	*Potamogeton pusillus*	9	10	?
7	*Myriophyllum verticillatum*	9	0.1	
7	*Schoenoplectus subterminalis*	9	0.1	
8	*Eleocharis palustris*	6	40	
8	*Glyceria borealis*	6	0.1	
8	*Equisetum fluviatile*	6	0.1	
8	*Sparganium fluctuans*	8	4	
8	*Glyceria borealis*	8	1	
8	*Nuphar variegata*	8	0.1	
8	*Isoetes sp.*	9	5	
9	*Sparganium fluctuans*	8	50	
9	*Nuphar variegata*	8	10	
10	*Eleocharis palustris*	6	20	
10	*Carex utriculata*	6	5	
10	*Glyceria borealis*	6	5	
10	*Sparganium fluctuans*	8	30	

Site number	Scientific Name	Layer	Cover	Notes
10	*Nuphar variegata*	8	10	
10	*Isoetes echinospora*	9	0.1	
11	*Sparganium fluctuans*	8	55	
11	*Nuphar variegata*	8	5	
11	*Schoenoplectus subterminalis*	9	30	
11	*Urticularia minor*	9	0.1	
12	*Sparganium fluctuans*	8	60	
12	*Nuphar variegata*	8	0.1	
12	*Schoenoplectus subterminalis*	9	40	
13	*Eleocharis palustris*	6	20	
13	*Dulichium arundinaceum*	6	10	
13	*Carex lasiocarpa*	6	10	
13	*Sparganium fluctuans*	8	40	
13	*Nuphar variegata*	8	30	
13	*Urticularia vulgaris*	9	0.1	
14	*Sparganium fluctuans*	8	70	
14	*Potamogeton natans*	8	10	
14	*Sagittaria sp.*	8	0.1	
14	*Nuphar variegata*	8	0.1	
14	*Potamogeton pusillus*	9	0.1	?

Site number	Scientific Name	Layer	Cover	Notes
15	*Eleocharis palustris*	6	3	
15	*Sparganium fluctuans*	8	30	
15	*Nuphar variegata*	8	0.1	
15	*Potamogeton natans*	8	0.1	
15	*Schoenoplectus subterminalis*	9	1	
15	*Urticularia minor*	9	5	
16	*Eleocharis palustris*	6	20	
16	*Sagittaria latifolia*	6	0.1	
16	*Sparganium fluctuans*	8	60	
16	*Nuphar variegata*	8	10	
16	*Urticularia vulgaris*	9	2	
16	*Schoenoplectus subterminalis*	9	0.1	
17	*Sparganium fluctuans*	40	8	
18	*Acorus americanus*	6	55	
18	*Sagittaria latifolia*	6	5	
18	*Sparganium fluctuans*	8	80	
18	*Nuphar variegata*	8	0.1	
18	*Potamogeton natans*	8	0.1	
19	*Schoenoplectus subterminalis*	6	10	
19	*Nymphaea odorata*	8	15	

Site number	Scientific Name	Layer	Cover	Notes
19	*Brasenia schreberi*	8	5	
19	*Sparganium fluctuans*	8	30	
19	*Schoenoplectus subterminalis*	9	80	
19	*Potamogeton sp.*	9	5	narrow leaf
20	*Eleocharis palustris*	6	10	
20	*Lobelia dortmanna*	6	0.1	
20	*Sparganium angustifolium*	8	40	
20	*Potamogeton spirillus*	9	30	
20	*Isoetes echinospora*	9	10	
20	*Sagittaria sp.*	9	10	
20	*Eriocaulon aquaticum*	9	0.1	
20	*Potamogeton sp.*	9	T	narrow leaf
21	*Sparganium fluctuans*	8	60	
21	*Nymphaea odorata*	8	20	
21	*Brasenia schreberi*	8	0.1	
22	*Sparganium fluctuans*	8	30	
22	*Nuphar variegata*	8	10	
22	*Brasenia schreberi*	8	0.1	
22	*Potamogeton epihydrus*	9	0.1	
23	*Eleocharis palustris*	6	1	

Site number	Scientific Name	Layer	Cover	Notes
23	*Sparganium fluctuans*	8	50	
23	*Nuphar variegata*	8	10	
23	*Brasenia schreberi*	8	0.1	
23	*Nymphaea odorata*	8	0.1	
24	*Eleocharis palustris*	6	45	
24	*Phragmites australis*	6	15	
24	*Brasenia schreberi*	8	0.1	
24	*Urticularia vulgaris*	9	0.1	
24	*Potamogeton epihydrus*	9	0.1	
25	*Eleocharis palustris*	6	60	
25	*Schoenoplectus tabernaemontani*	6	0.1	
25	*Nymphaea odorata*	8	0.1	
25	*Brasenia schreberi*	8	0.1	
25	*Potamogeton epihydrus*	9	0.1	
26	*Eleocharis palustris*	6	0.1	
26	*Glyceria borealis*	6	0.1	
26	*Sparganium fluctuans*	8	80	
26	*Nuphar variegata*	8	5	
26	*Brasenia schreberi*	8	5	
27	*Sparganium fluctuans*	8	50	

Site number	Scientific Name	Layer	Cover	Notes
27	*Brasenia schreberi*	8	30	
27	*Nymphaea odorata*	8	0.1	
28	*Eleocharis palustris*	6	20	
28	*Nymphaea odorata*	8	30	
28	*Sparganium fluctuans*	8	25	
28	*Brasenia schreberi*	8	5	
28	*Potamogeton epihydrus*	9	0.1	
29	*Sparganium fluctuans*	8	60	
29	*Brasenia schreberi*	8	15	
29	*Nymphaea odorata*	8	10	
30	*Eleocharis palustris*	6	15	
30	*Glyceria borealis*	6	5	
30	*Brasenia schreberi*	8	20	
30	*Nymphaea odorata*	8	10	
30	*Sparganium fluctuans*	8	30	
31	*Eleocharis palustris*	6	5	
31	*Sparganium fluctuans*	8	65	
31	*Nymphaea odorata*	8	10	
31	*Brasenia schreberi*	8	10	
32	*Sparganium fluctuans*	8	20	

Site number	Scientific Name	Layer	Cover	Notes
32	*Nymphaea odorata*	8	10	
32	*Brasenia schreberi*	8	0.1	
33	*Sparganium fluctuans*	8	65	
33	*Brasenia schreberi*	8	5	
33	*Nymphaea odorata*	8	0.1	
33	*Potamogeton epihydrus*	9	0.1	
34	*Eleocharis palustris*	6	4	
34	*Glyceria borealis*	6	1	
34	*Sparganium fluctuans*	8	50	
34	*Nymphaea odorata*	8	40	
34	*Potamogeton sp.*	9	0.1	
35	*Sparganium fluctuans*	8	80	
35	*Nymphaea odorata*	8	15	
35	*Potamogeton natans*	8	t	
35	*Callitriche palustre*	9	t	
36	*Acorus americanus*	6	60	
36	*Equisetum fluviatile*	6	25	
36	*Eleocharis palustris*	6	10	
36	*Schoenoplectus acutus*	6	1	
36	*Nuphar variegata*	8	1	

Site number	Scientific Name	Layer	Cover	Notes
36	*Sparganium eurycarpum*	6	T	
37	*Sagittaria rigida*	6	4	
37	*Equisetum fluviatile*	6	1	
37	*Sparganium fluctuans*	8	90	
37	*Nuphar variegata*	8	5	
38	*Eleocharis palustris*	6	60	
38	*Equisetum fluviatile*	6	15	
38	*Nymphaea odorata*	8	75	
38	*Potamogeton natans*	8	5	
38	*Eleocharis acicularis*	9	T	
38	*Eriocaulon aquaticum*	9	T	
39	*Eleocharis palustris*	6	80	
39	*Potamogeton natans*	8	20	
39	*Brasenia schreberi*	8	20	
39	*Nymphaea odorata*	8	5	
39	*Eriocaulon aquaticum*	9	20	
39	*Potamogeton gramineus*	9	T	
40	*Nymphaea odorata*	8	10	
40	*Potamogeton amplifolius*	9	5	
40	*Vallisneria americana*	9	40	

Site number	Scientific Name	Layer	Cover	Notes
41	*Schoenoplectus acutus*	6	30	
41	*Nymphaea odorata*	8	T	
41	*Persicaria amphibia*	8	2	
41	*Najas flexilis*	9	T	
42	*Potamogeton gramineus*	9	45	
42	*Najas flexilis*	9	T	
43	*Schoenoplectus acutus*	6	20	
43	*Nymphaea odorata*	8	15	
43	*Vallisneria americana*	9	20	
43	*Potamogeton richardsonii*	9	20	
44	*Eleocharis palustris*	6	30	
44	*Schoenoplectus acutus*	6	15	
44	*Equisetum fluviatile*	6	10	
44	*Nuphar variegata*	8	25	
44	*Nymphaea odorata*	8	5	
44	*Brasenia schreberi*	8	5	
44	*Potamogeton natans*	8	T	
44	*Lobelia dortmanna*	9	3	
44	*Isoetes echinospora*	9	T	
44	*Eriocaulon aquaticum*	9	T	

Site number	Scientific Name	Layer	Cover	Notes
45	*Schoenoplectus subterminalis*	6	40	
45	*Brasenia schreberi*	8	15	
45	*Nymphaea odorata*	8	5	
45	*Urticularia intermedia*	9	T	
45	*Schoenoplectus subterminalis*	9	80	
45	*Urticularia vulgaris*	9	T	
46	*Brasenia schreberi*	8	30	
46	*Sparganium fluctuans*	8	10	
46	*Najas flexilis*	9	T	
46	*Vallisneria americana*	9	T	
47	*Sparganium fluctuans*	8	15	
47	*Nymphaea odorata*	8	10	
47	*Brasenia schreberi*	8	10	
47	*Potamogeton richardsonii*	9	T	
48	*Schoenoplectus acutus*	6	50	
48	*Eleocharis palustris*	6	10	
48	*Sagittaria rigida*	6	T	
48	*Nuphar variegata*	8	10	
48	*Nymphaea odorata*	8	20	
48	*Schoenoplectus subterminalis*	9	30	

Site number	Scientific Name	Layer	Cover	Notes
48	*Najas flexilis*	9	T	
48	*Potamogeton spirillus*	9	T	
48	*Sagittaria sp.*	9	T	
48	*Isoetes echinospora*	9	T	
49	*Schoenoplectus acutus*	6	50	
49	*Phragmites australis*	6	10	
49	*Schoenoplectus americanus*	6	T	
49	*Brasenia schreberi*	8	15	
49	*Nymphaea odorata*	8	15	
49	*Isoetes echinospora*	9	10	
49	*Potamogeton gramineus*	9	10	
49	*Potamogeton zosteriformis*	9	T	
49	*Eriocaulon aquaticum*	9	T	
49	*Najas flexilis*	9	T	
50	*Schoenoplectus acutus*	6	30	
50	*Nymphaea odorata*	8	2	
50	*Potamogeton amplifolius*	8	T	
50	*Najas flexilis*	9	T	
50	*Chara sp.*	9	T	
51	*Schoenoplectus acutus*	6	5	

Site number	Scientific Name	Layer	Cover	Notes
51	*Brasenia schreberi*	8	30	
51	*Nymphaea odorata*	8	15	
51	*Potamogeton richardsonii*	9	1	
51	*Ranunculus longirostris*	9	5	
51	*Eleocharis acicularis*	9	T	
52	*Eleocharis palustris*	6	55	
52	*Schoenoplectus acutus*	6	5	
52	*Nymphaea odorata*	8	5	
52	*Potamogeton natans*	8	T	
52	*Eriocaulon aquaticum*	9	T	
53	*Eleocharis palustris*	6	15	
53	*Schoenoplectus acutus*	6	T	
53	*Nymphaea odorata*	8	35	
53	*Potamogeton natans*	8	5	
53	*Potamogeton gramineus*	9	1	
53	*Lobelia dortmanna*	9	30	
53	*Eriocaulon aquaticum*	9	15	
53	*Eleocharis acicularis*	9	T	
54	*Zizania palustris*	6	2	
54	*Sparganium fluctuans*	8	10	

Site number	Scientific Name	Layer	Cover	Notes
54	*Nymphaea odorata*	8	5	
54	*Schoenoplectus subterminalis*	9	75	
54	*Potamogeton spirillus*	9	T	
54	*Urticularia vulgaris*	9	T	
54	*Najas flexilis*	9	T	
55	*Phragmites australis*	6	20	
55	*Schoenoplectus acutus*	6	30	
55	*Equisetum fluviatile*	6	5	
55	*Nymphaea odorata*	8	2	
55	*Lobelia dortmanna*	9	30	
55	*Isoetes echinospora*	9	5	
55	*Juncus pelocarpus*	9	T	
56	*Zizania palustris*	6	70	
56	*Schoenoplectus subterminalis*	6	10	
56	*Nuphar variegata*	8	10	
56	*Sparganium fluctuans*	8	5	
56	*Potamogeton natans*	8	T	
56	*Schoenoplectus subterminalis*	9	60	
57	*Zizania palustris*	6	80	
57	*Nymphaea odorata*	8	35	

Site number	Scientific Name	Layer	Cover	Notes
57	*Sagittaria sp.*	9	5	
57	*Schoenoplectus subterminalis*	9	T	
58	*Zizania palustris*	6	90	
58	*Nymphaea odorata*	8	15	
58	*Potamogeton natans*	8	T	
58	*Schoenoplectus subterminalis*	9	8	
58	*Urticularia vulgaris*	9	T	
59	*Zizania palustris*	6	70	
59	*Nuphar variegata*	8	60	
59	*Schoenoplectus subterminalis*	9	20	
59	*Urticularia vulgaris*	9	T	
60	*Schoenoplectus acutus*	6	30	
60	*Potamogeton natans*	8	35	
60	*Lobelia dortmanna*	9	40	
61	*Schoenoplectus acutus*	6	40	
61	*Equisetum fluviatile*	6	T	
61	*Brasenia schreberi*	8	20	
61	*Sparganium fluctuans*	8	20	
61	*Nymphaea odorata*	8	5	
61	*Sagittaria sp.*	9	4	

Site number	Scientific Name	Layer	Cover	Notes
61	*Najas flexilis*	9	1	
61	*Isoetes echinospora*	9	T	
62	*Schoenoplectus acutus*	6	50	
62	*Eleocharis palustris*	6	5	
62	*Equisetum fluviatile*	6	T	
62	*Nuphar variegata*	8	5	
62	*Brasenia schreberi*	8	5	
62	*Sagittaria sp.*	9	4	
62	*Urticularia minor*	9	1	
62	*Schoenoplectus subterminalis*	9	T	
62	*Eriocaulon aquaticum*	9	T	
62	*Najas flexilis*	9	T	
63	*Eleocharis palustris*	6	T	
63	*Nymphaea odorata*	8	75	
63	*Sparganium fluctuans*	8	T	
63	*Schoenoplectus subterminalis*	9	60	
63	*Potamogeton epihydrus*	9	T	
63	*Myriophyllum verticillatum*	9	T	
63	*Urticularia minor*	9	T	
64	*Brasenia schreberi*	8	10	

Site number	Scientific Name	Layer	Cover	Notes
64	*Nuphar variegata*	8	5	
64	*Sparganium fluctuans*	8	T	
64	*Schoenoplectus subterminalis*	9	5	
64	*Najas flexilis*	9	T	
64	*Myriophyllum verticillatum*	9	T	
65	*Eleocharis palustris*	6	50	
65	*Equisetum fluviatile*	6	3	
65	*Glyceria borealis*	6	2	
65	*Eleocharis acicularis*	9	30	
65	*Lobelia dortmanna*	9	15	
66	*Acorus americanus*	6	30	
66	*Equisetum fluviatile*	6	T	
66	*Eleocharis palustris*	6	T	
66	*Nuphar variegata*	8	60	
66	*Sparganium fluctuans*	8	5	
66	*Potamogeton natans*	8	T	
66	*Potamogeton sp.*	9	1	narrow leaf
66	*Schoenoplectus subterminalis*	9	4	
66	*Potamogeton epihydrus*	9	T	
67	*Eleocharis palustris*	6	25	

Site number	Scientific Name	Layer	Cover	Notes
67	*Sparganium fluctuans*	8	70	
67	*Sagittaria sp.*	9	1	
67	*Potamogeton sp.*	9	T	
68	*Eleocharis palustris*	6	35	
68	*Sagittaria latifolia*	6	T	
68	*Dulichium arundinaceum*	6	T	
68	*Carex utriculata*	6	T	
68	*Equisetum fluviatile*	6	T	
68	*Sparganium fluctuans*	8	60	
68	*Nymphaea odorata*	8	T	
68	*Eriocaulon aquaticum*	9	30	
68	*Potamogeton spirillus*	9	T	
68	*Sagittaria sp.*	9	T	
68	*Juncus pelocarpus*	9	30	
69	*Eleocharis palustris*	6	60	
69	*Sparganium fluctuans*	8	2	
69	*Isoetes echinospora*	9	10	
70	*Brasenia schreberi*	8	70	
70	*Sparganium fluctuans*	8	5	
70	*Isoetes echinospora*	9	10	

Site number	Scientific Name	Layer	Cover	Notes
71	*Brasenia schreberi*	8	35	
71	*Nuphar variegata*	8	10	
71	*Sparganium fluctuans*	8	5	
71	*Nymphaea odorata*	8	10	
71	*Potamogeton epihydrus*	9	T	
72	*Sagittaria rigida*	6	T	
72	*Nymphaea odorata*	8	50	
72	*Sparganium fluctuans*	8	10	
72	*Brasenia schreberi*	8	10	
72	*Schoenoplectus subterminalis*	9	10	
72	*Urticularia minor*	9	T	
72	*Bidens beckii*	9	T	
73	*Acorus americanus*	6	5	
73	*Eleocharis palustris*	6	T	
73	*Nymphaea odorata*	8	70	
73	*Brasenia schreberi*	8	2	
73	*Sparganium fluctuans*	8	3	
73	*Schoenoplectus subterminalis*	9	5	
73	*Bidens beckii*	9	T	
74	*Sparganium fluctuans*	8	35	

Site number	Scientific Name	Layer	Cover	Notes
74	*Nymphaea odorata*	8	2	
74	*Sagittaria cuneata*	8	3	
74	*Nuphar variegata*	8	T	
75	*Equisetum fluviatile*	6	10	
75	*Sparganium fluctuans*	8	30	
75	*Nymphaea odorata*	8	15	
75	*Isoetes echinospora*	9	3	
75	*Sagittaria sp.*	9	2	

Appendix 3 Quetico wetland site data (2019)

Site No.	Lake	Substrate Type	Depth	Zone	Easting	Northing	Date	W-type	Ecosite	Water pH	Water Cond.	Substrate pH	Substrate Cond.
1	French	sand	0.94	15	635829	5391206	Aug 12 2019	6	151	7.07	35		
2	French	sand	0.67	15	635749	5391225	Aug 12 2019		151	6.99	33		
3	French	sand	0.83	15	635593	5391180	Aug 12 2019		151	6.93	34		
4	Pickerel	org	1.06	15	633016	5391257	Aug 12 2019		150	7.24	34		
5	Pickerel	org	0.89	15	633005	5391237	Aug 12 2019		150	7.30	34		
6	Pickerel	org	0.72	15	632957	5391245	Aug 12 2019		150	6.56	24		
7	Pickerel	org	0.91	15	633675	5391076	Aug 12 2019		150	6.91	29		
8	Pickerel	org	0.95	15	633666	5391086	Aug 12 2019		150	6.91	29		
9	Pickerel	org	0.71	15	633791	5391328	Aug 12 2019		152	6.69	30		
10	French	org	0.67	15	634945	5390987	Aug 12 2019		150	7.17	34		
11	French	org	0.68	15	635069	5390939	Aug 12 2019		152	7.24	35		
12	French	org	0.85	15	635087	5390945	Aug 12 2019		152	7.29	34		
13	French	sand	0.68	15	635375	5391212	Aug 12 2019		151	7.34	34		
14	French	sand	0.72	15	635500	5391194	Aug 12 2019		151	7.32	34		
15	Quetico	org	0.67	15	573436	5374822	Aug 22 2019	4	150	7.73	21	6.54	135
16	Quetico	org	0.47	15	573099	5375057	Aug 22 2019	3	152	7.50	19	6.27	136
17	Quetico	org	0.90	15	571896	5374665	Aug 22 2019	3	152	7.22	23		
18	Quetico	org	1.03	15	571895	5374566	Aug 22 2019	3	152	7.14	24	6.56	89
19	Quetico	org	0.92	15	571895	5374461	Aug 22 2019	4	150	7.16	24	6.57	96
20	Quetico	org	0.67	15	571892	5374364	Aug 22 2019	3	152	7.41	24	6.51	191
21	Quetico	org	0.71	15	573096	5374261	Aug 23 2019	4	150	7.08	22	6.53	86
22	Quetico	org	1.22	15	572995	5374261	Aug 23 2019	4	150	7.07	22	6.61	140
23	Quetico	org	0.76	15	572894	5374261	Aug 23 2019	4	150	7.10	22	6.26	82
24	Quetico	org	0.37	15	572802	5374265	Aug 23 2019	10	149	6.49	17	6.24	118

Site No.	Lake	Substrate Type	Depth	Zone	Easting	Northing	Date	W-type	Ecosite	Water pH	Water Cond.	Substrate pH	Substrate Cond.
25	Quetico	org	0.54	15	574992	5374658	Aug 23 2019	3	152	7.04	20	6.38	63
26	Quetico	org	0.40	15	575101	5374760	Aug 23 2019	3	152	7.05	20	6.39	30
27	Quetico	sand	0.53	15	574599	5374155	Aug 23 2019	2	151	7.13	21	6.28	
28	Quetico	org	0.54	15	574496	5374158	Aug 23 2019	3	152	7.11	21	6.62	135
29	Quetico	sand	0.47	15	574169	5373993	Aug 23 2019	2	151	7.17	21	5.87	69
30	Badwater	org	1.19	15	575296	5371463	Aug 23 2019	3	152	6.75	14	6.19	83
31	Badwater	org	0.72	15	575198	5371366	Aug 23 2019	4	150	6.67	13	6.19	38
32	Badwater	org	0.93	15	575092	5371368	Aug 23 2019	4	150	6.66	13	6.43	108
33	Badwater	org	0.94	15	574896	5371462	Aug 23 2019	4	150	6.46	14		
34	Badwater	org	0.96	15	574898	5371556	Aug 23 2019	13	149	6.37	13	6.17	40
35	Badwater	org. ?	> 1.75	15	574797	5371566	Aug 23 2019	4	150	6.27	13		
36	Bee	org	0.66	15	576634	5372246	Aug 23 2019	4	150	7.09	12	6.40	79
37	Bee	org	0.15	15	577906	5372214	Aug 23 2019	3	149	6.52	11	5.99	35
38	Stream	org	0.74	15	577917	5372386	Aug 24 2019	4	150	6.47	12	6.08	49
39	Pelee	sand	0.78	15	580434	5371799	Aug 24 2019	4	150	6.75	14		
40	Pelee	sand?	> 1.75	15	580984	5372010	Aug 24 2019	11	151	6.78	14		
41	Fair	org	> 1.75	15	580234	5370098	Aug 24 2019	4	150	6.94	15		
42	Fair	org	> 1.75	15	579229	5370225	Aug 24 2019	3	152	7.04	15		
43	Your	org	0.52	15	583445	5369922	Aug 24 2019	3	152	6.96	15	6.00	
44	Boulder	org	0.68	15	584253	5371371	Aug 24 2019	4	150	6.89	15	6.38	68
45	Boulder	org	0.65	15	584491	5371457	Aug 24 2019	3	152	7.05	13	6.31	72
46	Unnamed	org	1.22	15	584421	5372034	Aug 24 2019	3	152	7.05	15	6.56	70
47	Creek	org	0.53	15	586493	5372670	Aug 24 2019	4	150	6.17	14		
48	Creek	org	1.17	15	586599	5372658	Aug 24 2019	3	152	6.36	14		
49	S. Of Conk L	org	0.76	15	588798	5375262	Aug 25 2019	4	150	6.76	11	6.46	222
50	S. Of Conk L	org	> 1.75	15	588494	5375154	Aug 25 2019	3	152	6.79	11	6.48	118
51	S. Of Conk L	org	1.05	15	588398	5375159	2019-08-25	3	152	6.77	11	6.45	126

Site No.	Lake	Substrate Type	Depth	Zone	Easting	Northing	Date	W-type	Ecosite	Water pH	Water Cond.	Substrate pH	Substrate Cond.
52	S. Of Conk L	org	0.96	15	588397	5375256	2019-08-25	3	152	6.74	11	6.38	108
53	S. Of Conk L	org	0.94	15	588493	5375362	2019-08-25	4	150	6.73	11	6.46	124
54	S. Of Conk L	org	0.53	15	588396	5375356	2019-08-25	4	150	6.62	11	5.98	105
55	S. Of Conk L	org	0.48	15	588292	5375258	2019-08-25	3	152	6.58	11	6.32	166
56	S. Of Conk L	org	0.67	15	588097	5375260	2019-08-25	4	150	6.67	11	6.42	140
57	S. Of Conk L	org	0.85	15	587392	5375156	2019-08-25	3	152	6.82	11	6.58	127
58	S. Of Conk L	org	0.89	15	587193	5375057	2019-08-25	4	150	6.45	11		
59	S. Of Conk L	org	0.54	15	587097	5375060	2019-08-25	4	150	5.90	12	5.71	74
60	S. Of Conk L	org	0.81	15	587195	5374963	2019-08-25	4	150	6.06	10		
61	S. Of Conk L	org	1.07	15	587295	5374962	2019-08-25	3	152	6.31	12	6.21	125
62	S. Of Conk L	org	1.20	15	587395	5374864	2019-08-25	3	152	6.41	11	6.36	128
63	S. Of Conk L	sand	0.79	15	587493	5374754	2019-08-25	4	150	6.56	11		
64	S. Of Conk L	org	1.28	15	587598	5374756	2019-08-25	3	152	6.54	11	6.45	128
65	S. Of Conk L	org	0.96	15	587688	5374764	2019-08-25	3	152	6.54	12	6.42	123
66	S. Of Conk L	org	0.51	15	587802	5374655	2019-08-25	4	150	6.52	11	6.21	179
67	S. Of Conk L	org	0.67	15	587695	5374658	2019-08-25	4	150	6.55	11	6.06	127
68	S. Of Conk L	org	0.35	15	587601	5374663	2019-08-25	4	150	6.51	11	6.09	86
69	S. Of Conk L	org	0.71	15	587589	5374958	2019-08-25	1	151	6.63	11		
70	S. Of Conk L	org	0.68	15	587700	5374959	2019-08-25	3	152	6.69	11	6.49	139
71	S. Of Conk L	org	0.91	15	587792	5374962	2019-08-25	3	152	6.67	11	6.55	260
72	S. Of Conk L	org	0.88	15	587893	5374958	2019-08-25	3	152	6.89	11	6.39	212
73	Conk	org	1.03	15	588697	5376063	2019-08-25	4	150	6.70	14	6.16	53
74	Conk	org	0.30	15	589194	5376260	2019-08-25	4	150	6.50	13	5.97	64
75	Conk	rock	0.96	15	589773	5376849	2019-08-25	2	151	6.88	15		
76	Quetico	org,sand	0.63	15	589894	5380159	2019-08-26	4	150	6.91	16		
77	Quetico	org	0.80	15	590151	5380993	2019-08-26	4	150	6.82	16		
78	Quetico	org	0.70	15	588493	5381058	2019-08-26	4	150	6.48	15		

Site No.	Lake	Substrate Type	Depth	Zone	Easting	Northing	Date	W-type	Ecosite	Water pH	Water Cond.	Substrate pH	Substrate Cond.
79	Quetico	org	0.28	15	584896	5378961	2019-08-26	4	150	6.53	15		
80	Quetico	org	0.49	15	584199	5378665	2019-08-26		152	6.93	15		
81	Beaverhouse	sand	0.36	15	569394	5380554	2019-08-26		148	6.97	15		
82	Beaverhouse	org	0.29	15	584605	5379021	2019-08-26	9	149	6.25	20		

Appendix 4. Quetico wetland vegetation data (2019)

Site number	Scientific Name	Layer	Cover
1	Eleocharis smallii	Herb	70
1	Nuphar variegata	Floating	0.1
1	Brasenia schreberi	Floating	0.1
1	Potamogeton gramineus	Floating	0.1
1	Lobelia dortmanna	Submergent	0.1
1	Isoetes echinospora	Submergent	0.1
2	Equisetum fluviatile	Herb	60
2	Eleocharis smallii	Herb	10
2	Typha latifolia	Herb	0.1
2	Glyceria borealis	Herb	0.1
2	Brasenia schreberi	Floating	20
2	Scirpus subterminalis	Submergent	60
2	Potamogeton gramineus	Submergent	1
3	Eleocharis smallii	Herb	40
3	Sagittaria rigida	Herb	25
3	Nuphar variegata	Floating	10
3	Brasenia schreberi	Floating	5
3	Sparganium angustifolium	Floating	0.1
4	Sagittaria rigida	Herb	2
4	Sparganium fluviatile	Floating	65
4	Nuphar variegata	Floating	3
4	Brasenia schreberi	Floating	2
4	Myriophyllum verticillatum	Submergent	10
4	Megalodonta beckii	Submergent	5
4	Elodea canadensis	Submergent	10
4	Utricularia vulgaris	Submergent	0.1
5	Sparganium fluviatile	Floating	60

Site number	Scientific Name	Layer	Cover
5	Nuphar variegata	Floating	5
5	Potamogeton amplifolius	Floating	0.1
5	Myriophyllum verticillatum	Submergent	2
5	Utricularia vulgaris	Submergent	2
6	Sagittaria rigida	Herb	15
6	Sparganium fluviatile	Floating	60
6	Nuphar variegata	Floating	0.1
6	Potamogeton gramineus	Floating	0.1
7	Zizania palustris	Herb	1
7	Sparganium fluviatile	Floating	74
7	Brasenia schreberi	Floating	1
7	Myriophyllum verticillatum	Submergent	1
8	Sparganium fluviatile	Floating	70
8	Brasenia schreberi	Floating	3
8	Nuphar variegata	Floating	2
8	Potamogeton sp.	Submergent	30
9	Zizania palustris	Herb	75
9	Sagittaria rigida	Herb	0.1
9	Sparganium fluviatile	Floating	40
9	Potamogeton sp.	Submergent	5
10	Eleocharis smallii	Herb	30
10	Equisetum fluviatile	Herb	0.1
10	Glyceria borealis	Herb	0.1
10	Brasenia schreberi	Floating	65
10	Potamogeton sp.	Submergent	0.1
10	Isoetes echinospora	Submergent	10
11	Eleocharis smallii	Herb	15
11	Equisetum fluviatile	Herb	5
11	Brasenia schreberi	Floating	25

Site number	Scientific Name	Layer	Cover
11	Eriocaulon septangulare	Submergent	20
11	Potamogeton spirillis	Submergent	15
11	Potamogeton sp	Submergent	20
11	Sagittaria sp.	Submergent	5
12	Glyceria borealis	Herb	0.1
12	Brasenia schreberi	Floating	20
12	Sparganium fluviatile	Floating	25
12	Glyceria borealis	Floating	0.1
12	Elodea canadensis	Submergent	0.1
12	Isoetes echinospora	Submergent	40
12	Potamogeton sp.	Submergent	10
13	Eleocharis smallii	Herb	25
13	Isoetes echinospora	Submergent	2
13	Lobelia dortmanna	Submergent	1
14	Eleocharis smallii	Herb	80
14	Brasenia schreberi	Floating	10
14	Juncus pelocarpa	Submergent	0.1
14	Sagittaria sp.	Submergent	0.1
15	Sparganium fluviatile	Floating	40
15	Nymphaea odorata	Floating	10
15	Nuphar variegata	Floating	10
15	Vallisneria americana	Submergent	20
15	Isoetes echinospora	Submergent	10
15	Potamogeton sp.	Submergent	0.1
16	Sagittaria rigida	Herb	25
16	Sparganium fluviatile	Floating	5
16	Nymphaea odorata	Floating	5
16	Sparganium sp.	Submergent	65
16	Potamogeton vaseyi	Submergent	20

Site number	Scientific Name	Layer	Cover
16	Utricularia vulgaris	Submergent	5
16	Utricularia vulgaris	Submergent	5
16	Megalodonta beckii	Submergent	1
16	Najas flexilis	Submergent	0.1
16	Potamogeton robbinsii	Submergent	0.1
16	Potamogeton pusillus	Submergent	0.1
16	Ranunculus longifolius	Submergent	0.1
17	Sparganium fluviatile	Floating	30
17	Nymphaea odorata	Floating	0.1
17	Sparganium angustifolium	Floating	0.1
17	Potamogeton pusillus	Submergent	0.1
17	Utricularia minor	Submergent	0.1
18	Nymphaea odorata	Floating	0.1
18	Sparganium angustifolium	Floating	0.1
19	Sparganium fluviatile	Floating	40
19	Nuphar variegata	Floating	20
19	Utricularia vulgaris	Submergent	0.1
20	Sagittaria rigida	Herb	0.1
20	Nymphaea odorata	Floating	2
20	Sparganium fluviatile	Floating	0.1
20	Megalodonta beckii	Submergent	90
20	Utricularia vulgaris	Submergent	10
20	Potamogeton pusillus	Submergent	0.1
20	Potamogeton robbinsii	Submergent	0.1
20	Myriophyllum verticillatum	Submergent	0.1
21	Nymphaea odorata	Floating	75
21	Sparganium fluviatile	Floating	5
22	Sparganium fluviatile	Submergent	60
23	Myriophyllum verticillatum	Submergent	0.1

Site number	Scientific Name	Layer	Cover
23	Nymphaea odorata	Floating	60
23	Sparganium fluviatile	Floating	25
24	Sagittaria latifolia	Herb	30
24	Eleocharis smallii	Herb	10
24	Nymphaea odorata	Floating	85
24	Myriophyllum farwellii	Submergent	35
24	Potamogeton pusillus	Submergent	25
24	Potamogeton spirillis	Submergent	0.1
24	Potamogeton epihydrus	Submergent	0.1
25	Nuphar variegata	Floating	35
25	Sparganium angustifolium	Floating	0.1
25	Sparganium sp.	Submergent	60
26	Nymphaea odorata	Floating	20
26	Sparganium fluviatile	Floating	20
26	Utricularia minor	Submergent	40
27	Sagittaria latifolia	Herb	2
27	Sparganium eurycarpum	Herb	2
27	Bolboschoenus fluviatilis	Herb	2
27	Sparganium angustifolium	Floating	0.1
27	Elatine minima	Submergent	0.1
27	Lobelia dortmanna	Submergent	10
27	Isoetes echinospora	Submergent	10
27	Eleocharis acicularis	Submergent	50
27	Sparganium sp.	Submergent	0.1
28	Sagittaria rigida	Herb	0.1
28	Sparganium fluviatile	Floating	30
28	Nymphaea odorata	Floating	25
28	Sparganium angustifolium	Floating	0.1
28	Isoetes echinospora	Submergent	40

Site number	Scientific Name	Layer	Cover
28	Potamogeton spirillis	Submergent	0.1
28	Myriophyllum sp.	Submergent	0.1
28	Potamogeton robbinsii	Submergent	0.1
28	Elodea canadensis	Submergent	0.1
28	Potamogeton pusillus	Submergent	0.1
29	Potamogeton epihydrus	Submergent	0.1
29	Eleocharis acicularis	Submergent	97
29	Isoetes echinospora	Submergent	3
29	Utricularia vulgaris	Submergent	0.1
29	Myriophyllum verticillatum	Submergent	0.1
29	Potamogeton spirillis	Submergent	0.1
30	Brasenia schreberi	Floating	0.1
30	Nymphaea odorata	Floating	1
30	Sparganium fluviatile	Floating	0.1
30	Scirpus subterminalis	Submergent	75
31	Pontederia cordata	Herb	13
31	Sagittaria rigida	Herb	2
31	Brasenia schreberi	Floating	40
31	Nymphaea odorata	Floating	30
31	Scirpus subterminalis	Submergent	0.1
31	Sagittaria sp.	Submergent	20
31	Utricularia minor	Submergent	0.1
32	Pontederia cordata	Herb	10
32	Brasenia schreberi	Floating	50
32	Nymphaea odorata	Floating	25
32	Nuphar variegata	Floating	0.1
32	Sparganium fluviatile	Floating	0.1
32	Utricularia minor	Submergent	0.1
32	Scirpus subterminalis	Submergent	15

Site number	Scientific Name	Layer	Cover
33	Carex lacustris	Herb	8
33	Dulichium arundinaceum	Herb	2
33	Glyceria grandis	Herb	0.1
33	Nymphaea odorata	Floating	50
33	Utricularia vulgaris	Submergent	5
34	Calamagrostis canadensis	Herb	25
34	Carex lacustris	Herb	5
34	Dulichium arundinaceum	Herb	0.1
34	Nymphaea odorata	Floating	3
34	Brasenia schreberi	Floating	2
34	Utricularia vulgaris	Submergent	0.1
35	Calamagrostis canadensis	Herb	2
35	Pontederia cordata	Herb	0.1
35	Brasenia schreberi	Floating	73
35	Nuphar variegata	Floating	2
35	Utricularia vulgaris	Submergent	0.1
36	Nymphaea odorata	Floating	50
36	Sparganium fluviatile	Floating	5
36	Brasenia schreberi	Floating	15
36	Sparganium sp.	Submergent	20
36	Scirpus subterminalis	Submergent	5
36	Isoetes echinospora	Submergent	0.1
37	Pontederia cordata	Herb	40
37	Scirpus subterminalis	Herb	30
37	Dulichium arundinaceum	Herb	0.1
37	Brasenia schreberi	Floating	0.1
37	Utricularia intermedia	Submergent	2
38	Pontederia cordata	Herb	15
38	Equisetum fluviatile	Herb	0.1

Site number	Scientific Name	Layer	Cover
38	Sparganium eurycarpum	Herb	0.1
38	Brasenia schreberi	Floating	64
38	Nymphaea odorata	Floating	1
38	Scirpus subterminalis	Submergent	1
38	Potamogeton spirillis	Submergent	0.1
38	Utricularia intermedia	Submergent	0.1
39	Brasenia schreberi	Floating	75
39	Isoetes echinospora	Submergent	0.1
40	Brasenia schreberi	Floating	10
40	Sparganium fluviatile	Floating	10
40	Potamogeton amplifolius	Floating	0.1
41	Brasenia schreberi	Floating	40
41	Sparganium fluviatile	Floating	10
41	Utricularia minor	Submergent	0.1
41	Utricularia vulgaris	Submergent	0.1
42	Sparganium fluviatile	Floating	25
42	Nuphar variegata	Floating	0.1
43	Equisetum fluviatile	Herb	0.1
43	Sparganium eurycarpum	Herb	10
43	Nymphaea odorata	Floating	30
43	Brasenia schreberi	Floating	5
43	Sparganium fluviatile	Floating	0.1
43	Potamogeton spirillis	Submergent	30
43	Utricularia vulgaris	Submergent	20
43	Potamogeton vaseyi	Submergent	30
43	Ranunculus longifolius	Submergent	10
43	Eleocharis acicularis	Submergent	0.1
44	Brasenia schreberi	Floating	60
44	Sparganium fluviatile	Floating	10

Site number	Scientific Name	Layer	Cover
45	Nymphaea odorata	Floating	2
45	Brasenia schreberi	Floating	13
45	Potamogeton vaseyi	Submergent	0.1
45	Potamogeton epihydrus	Submergent	5
45	Utricularia vulgaris	Submergent	5
45	Sparganium sp.	Submergent	0.1
45	Potamogeton pusillus	Submergent	0.1
46	Nymphaea odorata	Floating	5
46	Myriophyllum farwellii	Submergent	80
46	Potamogeton amplifolius	Submergent	5
47	Sagittaria latifolia	Herb	0.1
47	Nymphaea odorata	Floating	63
47	Sparganium fluviatile	Floating	2
47	Utricularia vulgaris	Submergent	10
47	Scirpus subterminalis	Submergent	20
47	Potamogeton epihydrus	Submergent	0.1
47	Sagittaria sp.	Submergent	0.1
48	Sparganium fluviatile	Floating	5
48	Potamogeton amplifolius	Floating	20
48	Scirpus subterminalis	Submergent	84
48	Utricularia vulgaris	Submergent	1
49	Brasenia schreberi	Floating	55
49	Potamogeton amplifolius	Floating	0.1
49	Sagittaria sp.	Submergent	2
50	Brasenia schreberi	Floating	2
51	Brasenia schreberi	Floating	30
51	Nymphaea odorata	Floating	0.1
51	Isoetes echinospora	Submergent	0.1
52	Potamogeton natans	Floating	25

Site number	Scientific Name	Layer	Cover
52	Brasenia schreberi	Floating	5
52	Nymphaea odorata	Floating	0.1
52	Utricularia minor	Submergent	0.1
52	Utricularia vulgaris	Submergent	0.1
53	Potamogeton natans	Floating	45
53	Nymphaea odorata	Floating	3
53	Brasenia schreberi	Floating	5
54	Nymphaea odorata	Floating	65
54	Sparganium fluviatile	Floating	0.1
54	Utricularia vulgaris	Submergent	1
55	Sparganium fluviatile	Floating	25
55	Brasenia schreberi	Floating	5
55	Utricularia vulgaris	Submergent	2
56	Brasenia schreberi	Floating	10
57	Nuphar variegata	Floating	35
57	Sparganium fluviatile	Floating	20
58	Brasenia schreberi	Floating	93
58	Nuphar variegata	Floating	2
58	Myriophyllum sp	Submergent	1
58	Utricularia vulgaris	Submergent	1
59	Nuphar variegata	Floating	80
59	Nymphaea odorata	Floating	0.1
59	Utricularia vulgaris	Submergent	0.1
59	Scirpus subterminalis	Submergent	2
59	Potamogeton obtusifolius	Submergent	0.1
60	Brasenia schreberi	Floating	90
60	Nuphar variegata	Floating	5
60	Utricularia vulgaris	Submergent	0.1
61	Sparganium fluviatile	Floating	0.1

Site number	Scientific Name	Layer	Cover
61	Brasenia schreberi	Floating	30
61	Myriophyllum farwellii	Submergent	65
61	Utricularia vulgaris	Submergent	10
61	Najas flexilis	Submergent	0.1
61	Ranunculus longifolius	Submergent	0.1
62	Brasenia schreberi	Floating	30
62	Nymphaea odorata	Floating	0.1
63	Brasenia schreberi	Floating	60
63	Sparganium fluviatile	Floating	0.1
63	Myriophyllum sp	Submergent	0.1
63	Najas flexilis	Submergent	0.1
64	Brasenia schreberi	Floating	45
64	Myriophyllum sp	Submergent	0.1
64	Utricularia vulgaris	Submergent	0.1
65	Nuphar variegata	Floating	20
65	Nymphaea odorata	Floating	5
65	Brasenia schreberi	Floating	0.1
66	Nymphaea odorata	Floating	25
66	Sparganium fluviatile	Floating	25
66	Brasenia schreberi	Floating	5
66	Nuphar variegata	Floating	20
66	Utricularia vulgaris	Submergent	15
66	Sagittaria sp.	Submergent	0.1
66	Myriophyllum sp	Submergent	25
67	Nuphar variegata	Floating	80
67	Nymphaea odorata	Floating	5
67	Sparganium fluviatile	Floating	5
67	Utricularia vulgaris	Submergent	3
68	Sparganium eurycarpum	Herb	5

Site number	Scientific Name	Layer	Cover
68	Sparganium fluviatile	Floating	40
68	Brasenia schreberi	Floating	15
68	Nuphar variegata	Floating	10
68	Utricularia vulgaris	Submergent	10
68	Sagittaria sp.	Submergent	10
68	Potamogeton epihydrus	Submergent	0.1
69	Brasenia schreberi	Floating	40
69	Sparganium fluviatile	Floating	5
69	Utricularia vulgaris	Submergent	15
69	Ranunculus longifolius	Submergent	15
69	Eriocaulon septangulare	Submergent	0.1
69	Najas flexilis	Submergent	0.1
70	Sparganium fluviatile	Floating	20
70	Sparganium angustifolium	Floating	0.1
70	Sagittaria sp.	Submergent	3
71	Brasenia schreberi	Floating	30
71	Sparganium fluviatile	Floating	5
72	Brasenia schreberi	Floating	30
72	Potamogeton natans	Floating	0.1
73	Sparganium fluviatile	Floating	75
73	Nuphar variegata	Floating	5
73	Utricularia vulgaris	Submergent	0.1
74	Sparganium eurycarpum	Herb	20
74	Brasenia schreberi	Floating	80
75	Brasenia schreberi	Floating	10
75	Sparganium fluviatile	Floating	25
75	Myriophyllum sp	Submergent	0.1
76	Sparganium fluviatile	Floating	35
76	Nymphaea odorata	Floating	20

Site number	Scientific Name	Layer	Cover
76	Brasenia schreberi	Floating	10
76	Eleocharis acicularis	Submergent	80
76	Potamogeton sp.	Submergent	0.1
77	Sparganium fluviatile	Floating	75
77	Brasenia schreberi	Floating	10
77	Nymphaea odorata	Floating	5
78	Sparganium fluviatile	Floating	70
78	Nuphar variegata	Floating	5
78	Nymphaea odorata	Floating	0.1
78	Scirpus subterminalis	Submergent	85
78	Potamogeton sp.	Submergent	0.1
79	Sagittaria rigida	Herb	3
79	Schoenoplectus torreyi	Herb	0.1
79	Nymphaea odorata	Floating	60
79	Brasenia schreberi	Floating	10
79	Sparganium fluviatile	Floating	5
79	Potamogeton natans	Floating	10
79	Najas flexilis	Submergent	55
79	Utricularia vulgaris	Submergent	2
79	Potamogeton epihydrus	Submergent	3
80	Potamogeton natans	Floating	30
80	Sparganium fluviatile	Floating	10
80	Eleocharis acicularis	Submergent	35
80	Ranunculus longifolius	Submergent	35
81	Equisetum fluviatile	Herb	40
81	Eleocharis acicularis	Submergent	0.1
82	Zizania palustris	Herb	85
82	Sagittaria latifolia	Herb	0.1
82	Leersia oryzoides	Herb	0.1

Site number	Scientific Name	Layer	Cover
82	Nymphaea odorata	Floating	60
82	Potamogeton natans	Floating	10
82	Potamogeton sp.	Submergent	0.1
82	Potamogeton epihydrus	Submergent	3
82	Utricularia minor	Submergent	0.1