Whatshan Project Water Use Plan

Whatshan Reservoir Vegetation Monitoring

Implementation Year 10

Reference: WGSMON-2

Whatshan Water Use Plan Monitoring Program: Reservoir Vegetation Monitoring – Technical Report

Study Period: 2015

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Whatshan Reservoir Vegetation Monitoring

2016 Technical Report

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EXECUTIVE SUMMARY

G3 Consulting Ltd. (G3) was retained by BC Hydro to assess macrophyte communities in the Whatshan Reservoir. A Water Use Planning Process was initiated for Whatshan Reservoir in 2002 and resulted in development of changes to water use at Whatshan Reservoir to promote recreational use of the waters. A three phase vegetation monitoring study (Baseline, 2006; 5-Year Post Changes, 2011; and, 10-Year Post Changes, 2016) was implemented to assess potential effects associated with changes to the operations which included the following:

- an increase in the minimum year-round water elevations to 636.5 m (previously 634 m); and,
- annual increases in minimum reservoir elevation occurring earlier in the year (i.e., minimum of 639 m by May 15th and a minimum of 640.35 m between June 15th and October 1st of each year).

Objectives and management questions were established prior to commissioning the Whatshan Reservoir Vegetation Monitoring Program. Study design and applied methodologies were developed to address study-specific objectives and management questions. The main objective of the Whatshan Reservoir macrophyte survey was to reduce uncertainty related to effects of reservoir operations on Whatshan Lake Reservoir by:

- monitoring key aquatic vegetation sites (Bennett et al. 2002); and,
- examining vegetation community boundary shifts.

The key management question identified in the WGSMON-2 Terms of Reference (BC Hydro, 2005) examines whether reservoir vegetation is affected by changes in the operation of the Whatshan Lake Reservoir.

Table ES-1: BC Hydro Status of Objectives Table

Objectives	Management Question	Management Hypotheses	Year Six (2011) Status	Year Ten (2015) Status
Reduce uncertainty related to the effects of reservoir operations on reservoir vegetation in the Whatshan Lake Reservoir. Monitoring will focus on key locations where aquatic vegetation is present (Bennett et al. 2002), and primarily examine large-scale changes in the boundaries of vegetation communities.	Do changes in the operation of the Whatshan Lake Reservoir affect reservoir vegetation?	H1: The area of emergent vegetation will decrease as a consequence of extended inundation.	Tentatively Supported, to be confirmed in 2015	Rejected
		H1a: The species composition of emergent vegetation will change as a consequence of extended inundation.	Not as yet addressed, to be assessed in 2015	Accepted
		H2: The area of submerged vegetation will increase as a consequence of extended inundation.	Tentatively Supported, to be confirmed in 2015	Rejected
		H2a: The species composition of submerged vegetation will change as a consequence of extended inundation.	Not as yet addressed, to be assessed in 2015	Accepted

Note: Emergent and submergent species composition changes may have been due, at least in part, to additional, unidentified climate variables.

Macrophyte assessments included satellite image acquisition and prediction of macrophyte size and location using algorithm-based index modeling accompanied by ground-truthing and model calibration (September 2011 and 2015). Due to unavailability of detailed results from Phase 1 (2006), Phase 2 (2011) was used to establish baseline conditions to which Phase 3 (2015) assessments were compared to address management questions posed by BC Hydro.

H1: The area of emergent vegetation will decrease as a consequence of extended inundation.

Mean areas of emergent macrophyte vegetation from eight (8) sites showed a slight decrease from 2011 to 2015; however, there was no statistically notable difference in emergent macrophyte area between 2011 and 2015. As a result, the hypothesis H1 was rejected.

H1a: The species composition of emergent vegetation will change as a consequence of extended inundation.

Nine (9) emergent species were recorded only in 2011 and six (6) emergent species only recorded in 2015, and differences in macrophyte composition were noted between 2011 and 2015 at each site. As a result, the hypothesis H1a was accepted, even though species composition data were not available for Phase 1 (2006).

H2: The area of submerged vegetation will increase as a consequence of extended inundation.

Mean areas of submerged vegetation from eight (8) sites slightly decreased from 2011 to 2015; however, there was no statistically notable difference in submerged macrophyte area between the two years. As a result, the hypothesis H2 was rejected.

H2a: The species composition of submerged vegetation will change as a consequence of extended inundation.

Six (6) submerged species were recorded only in 2011 and one (1) submerged species only recorded in 2015. Submerged macrophyte community structure was significantly different between the 2011 and 2015. As a result, the hypothesis was accepted, even though species composition data were not available for Phase 1 (2006).

1.0 INTRODUCTION

On behalf of the British Columbia Hydro and Power Authority (BC Hydro), G3 Consulting Ltd. (G3) was retained to complete a vegetation monitoring program on Whatshan Reservoir in southeastern BC. The program was to evaluate potential effects of changes to water management practices, as outlined in the BC Hydro Water Use Plan (WUP) on aquatic vegetation, as a proxy for fish and wildlife habitat. The overall program is comprised of three phases of assessment. Phase One was a baseline investigation conducted in 2006, prior to the changes in operations outlined in the WUP. Changes to operations which had the capacity to affect vegetative communities in Whatshan Reservoir came into effect in 2007 and included:

- an increase in the minimum year-round water elevations to 636.5 m (previously 634 m); and,
- annual increases in minimum reservoir elevation occurring earlier in the year (i.e., minimum of 639 m by May 15th and a minimum of 640.35 m between June 15th and October 1st of each year).

Phase 2 field surveys were conducted in September, 2011 and constitute a follow-up to the 2006 baseline assessment (Moody, 2007). Phase 3 was completed during a similar time period in mid to late August of 2015. Due to the unavailability of data derived from the 2006 study, data from the 2011 field study were also considered as a baseline assessment for comparison to 2015 data.

The assessment outlined in this report was developed as part of a hypothesis-driven, Multiple Before-After, Control-Impact-Paired (MBACIP) statistical design, which accounts for confounding influences posed by the dynamic and heterogeneous nature of the reservoir and natural spatial and temporal variability posed by both natural phenomena and anthropogenic activities. This comparative investigation examines current and past conditions of the reservoir and associated macrophyte communities in an effort to map and compare surface area, composition and spatial location using high-resolution satellite imagery (Section 2.5) and ground-truthing (Section 2.3). Polygons generated from 2011 spectral data (baseline) were compared directly with 2015 spectral data to assess changes in size and distribution of macrophyte communities. Whole-reservoir modeled spectral data was also compared between years to assess changes in community composition as outlined in the management questions and objectives (Section 1.1).

This report provides interpretive text and tables (Chapters 1 through 4), references and appendices. This chapter (Chapter 1) briefly outlines study objectives for the Vegetation Monitoring Program and summarizes important information on Whatshan Dam, general reservoir characteristics and ecology and the general study area. Chapter 2 provides an overview of the study design and methodology for field and laboratory work. Chapter 3 provides general study results and Chapter 4 a discussion of results. A summary and recommendations are provided in Chapter 5 with references and literature cited in Chapter 6.

Appendices provide figures (Appendix 1), photographs (Appendix 2), summary charts (Appendix 3), summary tables (Appendix 4), ecological characteristics of observed macrophytes (Appendix 5), the Safety Management Plan (Appendix 6) and a sample of field forms used (Appendix 7). Photographic meta data and excel spreadsheet of field data were provided as an Annex to this report.

1.1 Study Objectives

To ensure that provincial water management decisions reflect changing public values and environmental priorities a water use planning process was initiated for Whatshan Reservoir in March, 2002. The Consultative Committee for the Whatshan Water Use Plan (WUP) agreed upon a water management strategy so as to improve and protect the recreational use of Whatshan Reservoir through improved access and improving fisheries habitat quality. As part of these changes BC Hydro would fill the reservoir earlier in the year (May 15) to enable use of the boat ramp earlier in the season, improving access and use of the reservoir.

The agreed upon strategy resulted in operational constraints to the minimum year round reservoir elevation (previously 634 m) and the spring filling dates (previously mid-May through early June). Due to a lack of information regarding potential effects of spring and winter reservoir elevation on vegetative communities and fisheries and wildlife resources and habitat, as well as a general concern expressed during the consultative process, a pre- (Phase 1), mid (Phase 2) and post-project (Phase 3) assessment of vegetative communities was recommended, and subsequently approved, to verify predictions on changes to vegetative communities. This report (post project) provides an interpretive analysis of assessment results from each Phase.

Objectives and management questions were established prior to commissioning the Whatshan Reservoir Vegetation Monitoring Program. Study design and field methodologies were specifically designed to address study-specific objectives and answer management questions. The Objective of the Whatshan Reservoir macrophyte survey was to:

> *Reduce uncertainty related to the effects of reservoir operations on reservoir vegetation in the Whatshan Lake Reservoir. Monitoring will focus on key locations where aquatic vegetation is present (Bennett et al. 2002), and primarily examine large-scale changes in the boundaries of vegetation communities.*

A key management question was:

> *Do changes in the operation of the Whatshan Lake Reservoir affect reservoir vegetation?*

1.2 Background & Project Rationale

The Whatshan Reservoir hydroelectric project was designed and constructed by the British Columbia Power Commission and completed in 1951. Whatshan Dam is a 12 m high and 82 m long concrete dam with 91 m of earth filled embankments. The Dam is located at the southern end of Whatshan Reservoir and fed primarily by Whatshan River at the north end (Figure A1-1, Appendix 1). Whatshan Reservoir has a storage capacity of 122,000,000 m^3 at maximum operating elevation (641.3 m). The penstock intake at the southeast side of Whatshan Lake is a 3.4 km tunnel that directs water to the powerhouse on the west side of the Arrow Lakes Reservoir. The Whatshan Powerhouse generates 121 GWh annually through a single Francis-type Turbine (50 MW, 33 m^3/s).

The three interconnected basins of Whatsh.an Reservoir flow north to south. The upper basin is the largest at 1,255 hectares (ha) with a maximum depth of 116 m. The middle basin is characterized by “The Narrows” and resembles a lentic riverine system. The maximum depth of the middle basin is 15.2 m and occupies only 99 ha. The lower basin has a surface area of 338 ha and has a maximum depth of 33 m. Water residency time is estimated at four months (Consultative Committee, 2003).

Whatshan Reservoir maintains a year-round alarm threshold level of 640.9 m elevation providing a 0.4 m buffer to maximum operating level. At the threshold level, power generation occurs at maximum capacity. The year round operating minimum is 636.5 m.

Monthly turbine flow and Whatshan Reservoir water elevation (minimum, maximum and average), from January 2000 to November 2015, are provided in Chart A3-1 (Appendix 3). During recreational use (May – Oct) minimum reservoir levels are established at -1.5 m of the maximum elevation (641.3 m). Between October 1 and May 15 the minimum operating level is 636.5 m.

1.2.1 Reservoir Characteristics

Reservoirs are typically described as occupying intermediate positions between rivers and natural lakes on a continuum of aquatic ecosystems (Kimmel and Groeger, 1984). River-flooded reservoirs, such as Whatshan Reservoir undergo fluctuation of water levels associated with drawdown of water for hydroelectric power generation. Water levels in Whatshan reservoir remain relatively constant during summer months (fluctuation between 640.3 m and 641 m; Chart A3-1, Appendix 3).

Compared with natural systems reservoirs are, in general, characterized by a large shore development ratio (SDR), dendritic shorelines (many-branched and convoluted), V-shaped bottom profiles, short retention times, large barren and unstable drawdown zones, high spatial and temporal heterogeneity, unidirectional flow and serial zonation, shorter lifespan and high allochthonous sediment loading due to high watershed-to-lake area ratio (Lind *et al*., 1993; Straskraba et al., 1993; Straškrábová et al., 2005). The euphotic zone in reservoirs is usually only a few metres deep (Morris and Jiahua, 1998). Sediment inflow and re-suspension of bottom sediments by wave action can increase water turbidity, most notably up reservoir.

Reservoirs are influenced by climatological, hydrological and anthropogenic parameters, with the degree of response depending on the size and volume of reservoirs and varying proportionately to the magnitude of environmental parameters. The different uses of reservoirs and associated watersheds may have an impact on water quality, and consequently on aquatic life.

Reservoirs can typically be divided into three regions:

- **Riverine Zone:** the region of a reservoir where the types of processes (e.g., bank erosion, water flow, sedimentation) occurring are more comparable to a river than a lake. This zone is characterized by narrow geometry, shallow waters, significant flow velocities and the transport of silts and clays (Morris and Jiahua, 1998). Allochthonous (i.e., external) organic material predominates in this zone; however, water remains well-oxygenated due to low depths. Water transparency can be reduced by high sediments loading from rivers or high primary productivity (e.g., algae blooms caused by high nutrient inputs from rivers). Many of the original riverine invertebrate and fish species persist. Excessive silting may influence bottom living invertebrates that rely on clean, sediment-free conditions;
- **Transition Zone:** headwaters are often dominated or influenced by the riverine inputs to the region. If inflows have a density greater than lacustrine zone surface waters, the inflows will tend to plunge beneath the lacustrine zone surface. Often a “trash line” of floating debris will indicate such a plunge point. If the inflow water is less dense, it will flow over the lacustrine zone surface. If inflow density is greater than the lacustrine zone surface, but less dense than that of the lacustrine zone bottom waters, these flows may extend into the lacustrine zone or perhaps throughout the lacustrine zone. Such interflows are common where plunging inflows attain depths similar to the penstock opening depth on the dam impounding the lacustrine zone. Substantial inflows (e.g., high flows from occasional precipitation events) can greatly influence the lacustrine zone thermal structure. For example, inflows with high (or low) temperatures have the potential to change the thermocline depth and, thus, may be a primary factor influencing the thermal structure of the lacustrine zone; and,
- **Lacustrine Zone:** the deepest region, typically downstream from the transition area, where strictly limnetic processes dominate. This zone extends to the dam and has characteristics similar to lakes (e.g., clearer water, lower sediments loading, stratified water column, organic matter mostly produced by reservoir plankton, primary production limited by nutrients loading rather than lack of light; Morris and Jiahua, 1998). True lacustrine phyto- and zooplankton develop in this zone. Floating vegetation, such as the water fern and the water hyacinth, may form extensive mats covering large areas of the reservoir. Lacustrine insects, such as lake flies (chironomids and chaoborids), also colonize this zone.

The region in which the lake gradually changes from riverine to limnetic dominance is aptly termed the transition area. This ecotone (i.e., ecological transition) is usually rich and diverse in biota, and dynamic and complex in hydrology. Mixing of riverine and lacustrine waters, when combined with reservoir drawdown cycles and seasonal influences (e.g., winds and related currents, winter freeze-up), result in complicated horizontal and vertical hydrological movements in the transition area. Changing seasonally, these forces produce differences in current and density between riverine and lacustrine waters.

The theoretical retention time of a reservoir is the ratio of reservoir volume to inflow rate. Short retention times prevent significant settling of suspended particles (Cooke *et al*., 2005). Phytoplanktonic and macrophytic production depends greatly on reservoir retention time, specifically with regards to the settling of organic and inorganic suspended particles present in the water column. When retention time is low (e.g., a few days) and the reservoir is shallow, benthic algae dominate autotrophic production (Hargrave, 1969). In reservoirs with greater retention times, colonization by typical lake flora is favoured.

Whatshan Reservoir is dissimilar to typical reservoir zonation in that there are three distinct basins (Upper Basin, Middle Basin, Lower Basin) which each exhibit typical reservoir zonation on a localized scale (Figure A1-1, Appendix 1). Retention times of each basin vary with the level of hydroelectric power generation activity at a given time of year.

1.2.2 Reservoirs & Macrophyte Ecology

Macrophyte (i.e., emergent, submerged or floating-type plants) communities play an important role in fish and wildlife habitat. Macrophyte communities provide spawning, nesting, nursery and feeding habitat for a variety of organisms (i.e., fish, waterfowl, raptors, ungulates and other large herbivorous mammals, large carnivorous mammals, and small mammals, reptiles and amphibians). Upstream influx of nutrients can generate abundant levels of macrophyte growth which may cover fish habitat, causing decreased dissolved oxygen (DO) levels thereby reducing the quantity and quality of fish habitat (i.e., eutrophication). Macrophytes provide a number of ecosystem services (i.e., water purification, nutrient cycling, etc.) and are of critical importance to supporting fish, zooplankton and invertebrate populations (Cowx and Welcomme, 1998). Aquatic macrophytes are also a source of food for waterfowl, muskrats, beavers and moose (Mitchell and Prepas, 1990). Growth of macrophytes in reservoirs depends on several environmental parameters (e.g., light energy and nutrient availability, water temperature, water level fluctuations, water velocity.

The type of substrate and reservoir slope can also have an impact (positive or negative) on macrophytes growth (Cooke et al., 2005). Nearshore areas (i.e., littoral vs. limnetic, profundal and benthic) are characterized by better light availability and higher risk of desiccation while deeper zones are characterized by lower light availability and higher flow velocity. The highest macrophyte biomass is typically observed in the littoral zone of reservoirs, especially during periods when water levels are constant (Wetzel, 2001).

Biophysical changes in the littoral zone of reservoirs associated with periodic drawdown and inundation typically have significant effects (positive or negative) on macrophyte development (Wetzel, 1983; Baxter, 1985; Kimmel and Groeger, 1986; Northcote and Atagi, 1997). Macrophyte mobility is very limited with their development depending on environmental parameters in both reservoir water and sediments. Macrophyte species are sensitive to physical and chemical changes in the surrounding environment and are, thus, good indicators of both current environmental conditions and long-term environmental changes.

Water level fluctuations within a reservoir constitute a periodic disturbance regime to the littoral environment. Studies in Canada (Hill *et al.,* 1998) and northern Europe (Rørslett, 1991; Hellsten, 2001) demonstrated that macrophyte diversity was, in general, lower in reservoirs than in non-regulated lakes.

1.3 Study Area

The Whatshan dam is located approximately at UTM coordinates 419800 E 5530000 N 11U; 100 km southeast of Vernon, BC. The Whatshan River drainage basin has an area of 390 km^2 and lies within the eastern range of the Monashee Mountains, just west of the Arrow Valley in south central British Columbia. The reservoir is primarily located in the Columbia-Shuswap Moist Interior Cedar-Hemlock (ICHmw2) Biogeoclimatic Zone with northern portions of the reservoir and headwaters located in the Selkirk Wet Cold Engelmann Spruce-Subalpine Fir (ESSFwc4) biogeoclimatic subzone (Bennett *et al.,* 2002). The upper basin of Whatshan Reservoir is bounded by Whatshan Peak to the west and Mount Ingersoll to the east.

Large snow pack accumulations occur through the winter which account for the majority of runoff during warming conditions from April to June, with annual runoff typically starting in May. Following spring freshet, water is stored in the reservoir to maximum elevation and held relatively consistent throughout the summer. During fall and winter, stored water is used to generate electricity (BC Hydro, 2005).

1.3.1 Fisheries

Whatshan Reservoir supports a healthy fish community dominated by salmonids and cyprinidae (Table A4-1, Appendix 4). Wetland habitats consist of *Typha sp*. dominated marshes, reed and sedge dominated marshes, sedge and shrub dominated wet meadows (fen), riparian vegetation and various transitional communities.

1.3.2 Wildlife

Extensive wetlands around Whatshan Reservoir support a diverse and abundant wildlife community. Species observed during field assessments are noted in Table 1-2 (Appendix 4). Elk (three cows and two calves) were observed in the Upper Basin at Site 1-17 in 2011 (Figure A1-1a, Appendix 1). A muskrat lodge was identified at Site 6-3 in the Lower Basin in 2011 (no lodges were observed in 2015) and likely muskrat habitat was observed at Sites 3-7, 3-8, 2-13, 1-17 and 1-18.

1.4 Study Sites

1.4.1 Phase 1 (2006)

The 2006 Phase 1 baseline study conducted by AIM Ecological Consultants Ltd. Moody (2007) used colour infrared aerial photography and ground truthing to delineate vegetation polygons within Whatshan Reservoir. Moody (2007) designed the 2006 baseline study based on vegetation studies of similar nearby reservoirs. It was discovered upon arrival that Whatshan Reservoir was unlike other reservoirs in which other vegetation studies had been conducted. The elevation range of emergent vegetation was found to be very restricted as most emergent vegetation had developed on accumulations of woody debris along gently sloped shores.

Species distributions within sites were not published and not available during Phase 2 (2011) or Phase 3 (2015) assessments with which to compare community structure and distribution. In addition, no GPS data was available from BC Hydro to enable sampling along comparable transects and/or quadrats. As a result, Phase 2 (2011) was considered as the new baseline study.

1.4.2 Phase 2 (2011) & Phase 3 (2015)

The study area for Phase 2 (Year 5) and Phase 3 (Year 10) of the Whatshan Reservoir Vegetation Monitoring Program included eight previously identified long-term monitoring sites as defined in Bennett *et al.* (2002; Figure A1-1 a & b, Appendix 1).

Two of the long-term monitoring Sites 1-17 and 1-18 were situated at the north end of the upper basin on the west and east sites of the Whatshan River outlet, respectively (Figures A1-2a and A1-2b, Appendix 1). Site 2-13 was located at the southern end of the upper basin, near the outlet of White Grouse Creek. Sites 3-7 and 3-8 were located immediately south of "The Narrows", separating the middle and lower basins. Sites 3-7 and 3-8 (Figures A1-2e and A1-2f, Appendix 1) were situated on the west and east sides of the reservoir, respectively, with Site 3-7 (also bounding Site 3-6), locally referred to as "Robin's Lagoon" (Figure A1-2d, Appendix 1). Site 4-4, locally referred to as "David's Lagoon," was near the middle of the lower basin and bounded by the eastern shore of Whatshan Reservoir (Figure A1-2g, Appendix 1). Site 6-3 was located at the southern end of the Reservoir near the Penstock intake (Figure A1-2h, Appendix 1). Detailed site descriptions are provided in Section 3.2.1.

1.5 Phase 1 & 2 Summaries

1.5.1 Phase 1 Summary

Phase 1 assessments were conducted September 7-12, 2006 (Moody, 2007). During the 2006 baseline survey, reservoir elevation was 640.6 m. Emergent vegetation was found to be restricted to a range approximately equal to the summer operating level (640.9 m). Moody (2007) noted that submerged macrophyte communities appeared to be primarily associated with inflowing water sources (e.g., creek mouths). Moody (2007) also noted that the upper 1-2 m of the drawdown zone supported almost no macrophyte vegetation except along shallow grades and near water inputs. The maximum depth of macrophyte vegetation was found to be 633 m which corresponded to the maximum depth of the euphotic zone (Moody, 2007). Vegetative growth was noted to be generally sparse and of reduced quality at depths exceeding 635 m. Peak growth was noted in the 636 m to 638 m elevation range.

Moody (2007) identified 82 polygons of aquatic vegetation (submerged and emergent) occupying a total of 1,107,489.1 m^2. In total, 53 plant species were identified in various habitat types. The baseline study located 111.3 ha of wetland habitat with 26.8 ha of emergent and 84.5 ha of submerged vegetation. Moody (2007) identified 17 species of submerged macrophytes.

1.5.2 Phase 2 Summary

G3 Conducted *in situ* vegetative community assessments and ground truthing (Phase 2) September 27 to 30, 2011. Macrophyte distribution was estimated from 72 quadrats distributed along transects through 8 study sites. Samples were collected from each transect and distribution apportioned by biomass and percent cover. Voucher specimens were identified to species level upon return from the field. Based on field data and ground truthing, an algorithm was then created from which to identify and delineate habitat for the entire reservoir.

In total, 42 taxa were identified during the 2011 Whatshan Reservoir Vegetation Monitoring Program. Twenty-six taxa were associated with emergent vegetation (i.e., aquatic vegetation partially or fully above the waterline but below the HHWM [i.e., full pool]), 20 were submerged taxa (i.e., at or below the waterline) and 4 taxa were observed in quadrats above and below the waterline. Spectral analysis of satellite imagery was successful at classifying wetland habitats at all sites. Over 4.0 million m^2 of aquatic vegetation were identified and classified using spectral imaging techniques.

Due to unavailability of detailed results from Phase 1 (2006), Phase 2 (2011) was used to establish baseline conditions to which Phase 3 (2015) assessments were compared to answer the management questions posed by BC Hydro. Detailed and final assessments addressing the specific management questions were conducted in the fall of 2015 (Phase 3).

2.0 STUDY DESIGN & METHODS

The Whatshan Reservoir Vegetation Monitoring Program (VMP) adopted an MBACIP (Multiple Before-After, Control-Impact-Paired) statistical design from which to assess potential spatial and temporal effects on heterogeneous reservoir macrophyte communities associated with changes to the Water Use Plan (WUP). MBACIP designs use multiple impact and control sites, assessed over time (Downes *et al*., 2002).

Phase 1 (2006) of this VMP was the first of three phases in a 10 year (2006 – 2016) program in which baseline data was to be established for comparison with subsequent field assessments (Phases 2 and 3). The original Phase 1 baseline data (species distributions) was not available, requiring the Phase 2 program to become the baseline study which Phase 3 could be compared.

Pre-field tasks for Phase 2 and Phase 3 included summarizing existing information, developing a site-specific *Environmental and Safety Plan*, tasking satellites and obtaining required imagery and preparing base maps. On September 18, 2015, Pleiades 2 m multispectral imagery was collected for Phase 3 work and featured Red, Green, Blue, and Near-Infrared bands. Phase 2 satellite imagery was collected on August 1, 2011 using RapidEye 5 m resolution multispectral (Red, Green, Blue, Red-Edge, Near-Infrared).

Satellite data were subsequently used to generate spectral classification and False Colour Composite (FCC) base maps to assist in field assessments (Appendix 1). A main objective of the Whatshan Reservoir Macrophyte Assessment Program was pre- (Phase 1) and post-assessment (Phase 2 and 3) of macrophytes potentially affected by changes to the Water Use Plan. Remote satellite sensing was used as a means to identify the size and presence of aquatic vegetation communities over time (i.e., compare satellite data collected at different times to track changes in macrophyte community size and presence over time). To this end, *in situ* vegetative community assessments and ground truthing were conducted from September 24 to 27, 2015 to verify satellite map accuracy in Phase 3. Results of these assessments were then used to attenuate NDVI classification ranges in which macrophytes were found throughout the reservoir and produce a predictive macrophyte algorithm for the reservoir. Macrophyte communities observed on Phase 2 (2011) and Phase 3 (2015) satellite maps were then compared and assessed for potential changes between Phases.

Methodologies employed during office and baseline assessments followed those developed by G3 on other similar environmental and macrophyte assessment programs, those specified in the original Request for Proposal (RFP) and those of the provincial Resource Inventory Committee (RIC, 1997).

2.1 Start-up Meeting & Communications

Prior to commencement of office and field activities, a project start-up meeting was convened by telephone (May 5, 2011). This meeting finalized the scope of work (e.g., project objectives, budget, timing, methods/approach), discussed environmental and safety planning and introduced project participants and responsibilities.

2.2 Pre-Field

Pre-field assessments were completed to reacquaint personnel with the subject area and develop a *Workplan* for Phase 3 assessments. Pre-field assessments included:

- summary of existing information;
- review of current and historical air photos, satellite imagery, and site maps;
- acquiring multi-spectral satellite imagery (Pleiades)
- development of classification algorithms and False Colour Composite (FCC) imagery (Section 2.5);
- development and approval by BC Hydro of the *Workplan*; and,

- development and acceptance by BC Hydro of a site-specific Whatshan Reservoir *Site Specific Safety Management Plan* in accordance with criteria stipulated (i.e., *BC Hydro Water License Requirement Safety Requirements*).

2.2.1 Summary of Existing Information

Relevant available information on macrophytes in Whatshan Reservoir (e.g., species list, relative abundance, contributing factors, distribution, etc.) was collected and summarized. In addition, historic reports on similar reservoirs in the area, such as the Arrow Lakes and Revelstoke reservoirs were reviewed. Information was obtained from grey and peer reviewed literature, queries to agencies (i.e., BC Hydro, BC Ministry of Environment) and consultant reports.

Aerial photographs and assessments (where available) produced by Moody (2007) were collected and reviewed to identify potential locations and types of macrophyte species thought to be currently present in Whatshan Reservoir. Meta-analysis synthesized data from various sources and developed a historical background profile and current trend analysis. A comprehensive evaluation of various terrestrial and aquatic vegetation indices was completed with an iterative feedback and review cycle.

A priori False-Colour-Composite (FCC) and spectral classification vegetative survey maps were created to establish thresholds for calibrating algorithms and distinguish between emergent, submerged, riparian and algal vegetative communities.

2.3 Field Work

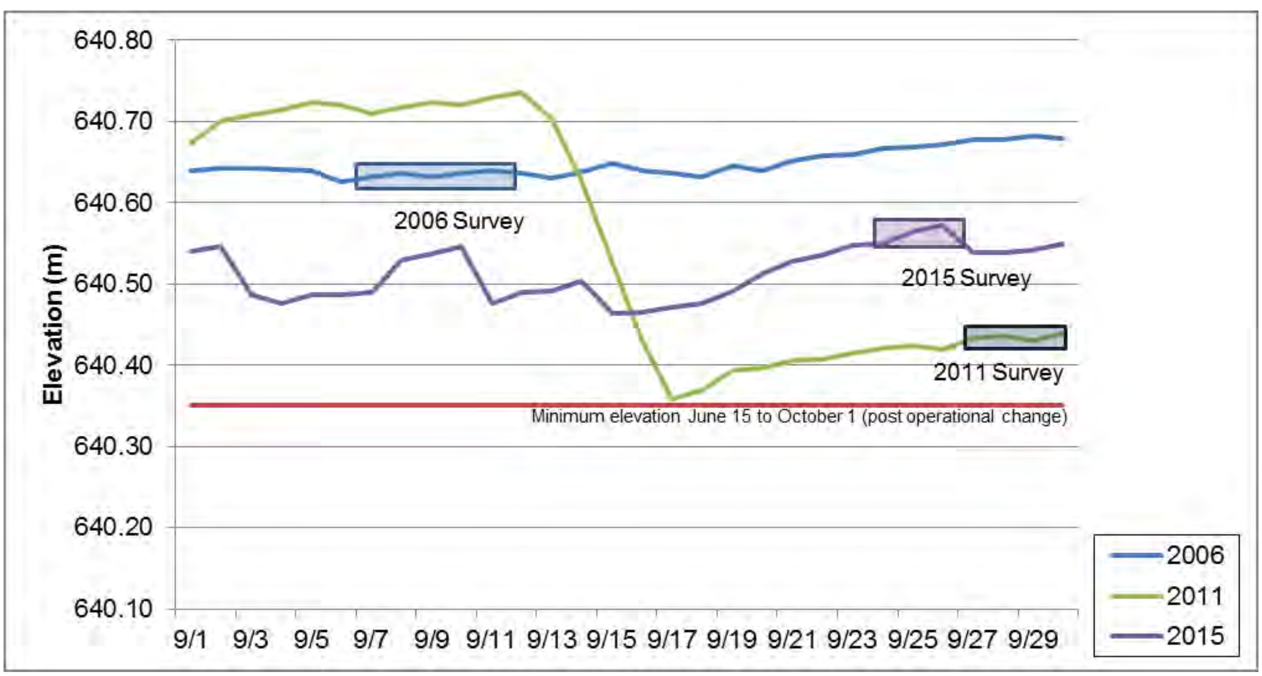
Field assessments of submerged and emergent vegetation at Whatshan Reservoir were conducted in three phases:

Phase 1: Year 1 (2006) Baseline Assessment (Moody, 2007);

Phase 2: Year 5 (2011) Vegetation Monitoring, Baseline Re-Evaluation; and,

Phase 3: Year 10 (2015) Final Vegetation Assessment (Current).

Figure 2-1: Whatshan Lake Reservoir Elevation (m) September 1 - September 30 (2006 & 2011)



Year 1 (2006) field activities were conducted by AIM Ecological Consultants Ltd. between September 7 and September 12, 2006 and are described in detail in Moody (2007) and summarized in Section 1.5.1 of the present report.

Year 5 (2011) field activities at Whatshan Reservoir were conducted from September 26 to September 30, 2011 with detailed methodology described in the Phase 2 Report (G3, 2012).

Year 10 (2015) field activities at Whatshan Reservoir were conducted September 24 to September 27, 2015 with detailed methodology described herein. Field activities were conducted in accordance with the *2011 Operational Workplan* provided to BC Hydro in advance to enable review and comment on project planning activities and objectives prior to start-up of field and assessment activities.

2.3.1 Research Vessel

A 6.7 m aluminum boat powered by a 340 HP inboard jet drive engine (Photo 2-1, Appendix 2) was used to conduct field studies. The boat was launched at or near the Inonoaklin Recreational Site boat launch, along the western shoreline, in the southern basin of the reservoir each day. The vessel was transported using a single axle EZ-load trailer, rated for highway transport and compliant with Transport Canada regulations. The boat was equipped with an emergency kit that included six (6) life jackets, a survival kit, flashlights, a bail bucket, two oars, a rope, a life ring, flares, a VHF radio, cellular phone and satellite phone.

2.3.2 Whatshan Reservoir Environmental & Safety Plan

Prior to conducting baseline assessments, G3 developed a project-specific *Safety Management Plan* in accordance with BC Hydro safety protocols. The *Safety Management Plan* included detailed protocols on:

- radio and communication;
- job hazards;
- field emergencies;
- Emergency Action Plans;
- water rescue;
- field mobility and activities (i.e., boat safety);
- field check-in procedures; and,
- emergency and program contacts (e.g., local fire, SAR, police, medical, BC Hydro, G3, etc.).

The *Safety Management Plan* was submitted to, and subsequently accepted by BC Hydro prior to field crew deployment and followed BC Hydro Standard Operating Procedures (SOPs) and Occupational Safety and Health (OSH) guidelines.

2.3.3 Study Sites

Eight (8) study sites were selected based on sites identified in the 2002 *Whatshan Water Use Plan Wildlife Overview* (Bennett et al., 2002). In Phase 2, approximate site locations were first established using maps published in Bennett *et al.* (2002), Moody (2007) and through use of multispectral imagery collected during Phase 2. In the field, study sites were further delineated using GPS coordinates estimated from previously published imagery with locations ultimately confirmed by verifying site descriptions from Bennett *et al.* (2002). Original site transect markers (from 2006) could not be identified at any site and GPS coordinates for transects or sample quadrats from those Year 1 field assessments were unavailable for comparison. GPS coordinates and site transect markers created during Phase 2 (2011) were subsequently used for Phase 3 assessments.

2.3.4 Site Layout

In Phase 2, study sites were established using available map data (Bennett *et al,* 2002; Moody, 2007) and confirmed using site descriptions (Bennett *et al.*, 2002). Northern, southern and furthest from shore boundaries of the macrophyte community were then delineated using a Garmin GPSmap60Cx (Garmin GPS) and through strategic site survey and bottom viewing and assessment. Nearshore emergent macrophyte community boundaries were delineated using GPS operated from the research vessel. Boundaries were determined through observation of distinct changes in vegetation or soil composition, by field technicians. The high-high water mark (HHWM) boundary was defined through visual cues and differences observed in vegetation communities by on-shore personnel.

Site boundaries and transect points of commencement (POCs) were permanently marked with wooden stakes (0.05 m x 0.05 m x 1.20 m), metal ID tags affixed to the nearest permanent structure and/or other permanent on-shore markers (e.g., tree, boulder, stump). Stakes and permanent markers were tagged with coded location identifiers and flagged with orange marking ribbon and paint. Locations of all boundaries and markers were recorded using the Garmin GPS. Permanent markers and GPS points established in Phase 2 were subsequently used for Phase 3 assessments.

POCs were situated at the HHWM. The centre transect POC of each site was positioned equidistant from the northern and southern (or eastern and western) extents and measured using the Garmin GPS. Outer transect POCs were placed equidistant from the Centre POC and the corresponding site boundary (i.e., northern extent for north transect). Transects at each site were run parallel to each other (along established compass bearings) to prevent crossover and ensure comparability of communities obtained from quadrat sampling. In some instances sites deviated from the prescribed sampling plan (e.g., transects at Site 2-13 were placed at obtuse angles to one another to accommodate an unusual and challenging orientation of the shoreline [Figure A1-2c, Appendix 1] and transects at Site 6-3 were placed at right angles (90°) to better reflect the macrophyte community of an island [Figure A1-2h, Appendix 1]). Transect orientations are discussed in further detail in subsections below.

Three 1 m^2 quadrats were established along each transect representing three separate ecological zones, associated with distance from the high-high water mark, visual observation of plant communities and depth. Ecological zones sampled at each study site were:

1. Near High-High-Water-Mark (HHWM; Zone A);
2. Mid-Distance from HHWM (Zone B); and,
3. Far from HHWM (Zone C).

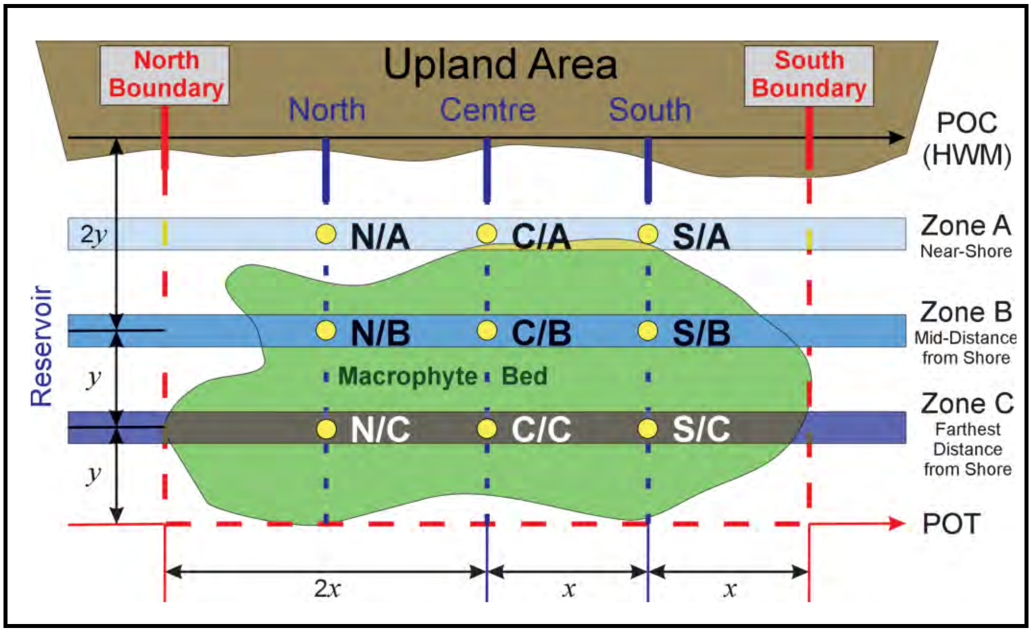
Sites were divided into quartiles as follows and illustrated in Figure 2-2. Zone B was established at the mid-point between the HHWM (i.e., POC) and the farthest point from shore where macrophytes were observed (i.e., Point of Termination [POT]. To provide consistency between transects at sites with expansive marshland (i.e., Sites 1-17, 1-18, 3-7 and 3-8) Zone B was positioned at the edge of marsh-grass communities. Zone A was set equidistant between B and the HHWM, and Zone C was equidistant between B and POT. There were nine sample quadrats per site.

Table 2-1: Quadrat Distribution

	north (or west)	Centre	south (or east)
Near HHWM (Zone A)	N(W)-Near	C-Near	S(E)-Near
Mid-Distance from HHWM (Zone B)	N(W)-Mid	C-Mid	S(E)-Mid
Far from HHWM (Zone C)	N(W)-Far	C-Far	S(E)-Far

UTM coordinates for each sample plot were recorded using GPS and waypoint numbers recorded into field notes. Full descriptions of each site are provided in Section 3.2.1.

Figure 2-2: Example Layout Schematic for Macrophyte Site Surveys



2.3.5 Study Sites

Detailed site descriptions are provided in Section 3.2.1. Phase 2 and Phase 3 involved the same sampling methodology.

Site 6-3

As the macrophyte vegetation on and around the island could not be accurately described using parallel transect assessment techniques, the three transects at this site were radially-oriented. The Centre Transect POC was positioned on the west side of the island and extended southwest to the eastern bank of Whatshan Reservoir (POT). North and south transect POCs were positioned at the northern and southern-most HHWMs and extended along the axis of the island (NW to SE) to the distal extent of macrophyte communities (Figure A1-2h, Appendix 1).

Site 4-4

Transects for this site were oriented north-south, perpendicular to the lagoon mouth. A fourth quadrat was established along each transect at this site, midway between the deepest part of the transect and the POT.

Sites 3-6, 3-7 & 3-8

Transects were established north-south and the sampling plan did not require modification to accurately describe the macrophyte community.

Site 2-13

The shoreline of Site 2-13 was contoured such that parallel transects were deemed inappropriate in the representation of the vegetative communities. Consequently, transects were oriented in a radial pattern to better represent the terrain and vegetative features of the monitoring location (Figure A1-2c, Appendix 1).

Sites 1-17 & 1-18

Transects were established north-south at Site 1-17 and east-west at Site 1-18 and the sampling plan did not require modification to accurately describe the macrophyte community.

2.3.6 Collection of Biological & Physical Data

The main biophysical components assessed at each monitoring site were:

- macrophyte communities (i.e., community distribution, diversity and abundance, delineation of community types, and estimated percent (%) cover);
- *in situ* water quality; and,
- general sediment characteristics.

Distribution and size of macrophyte communities detected at the eight long-term monitoring sites identified in the *Whatshan Water Use Plan Wildlife Overview* (Bennett *et al.*, 2002) were predicted using several multispectral analysis techniques including False Colour Composite (FCC) imagery and a comprehensive vegetation algorithm applying thirteen (13) vegetative indices (Section 2.4.4).

Predictions were assessed in comparison with Phase 2 *in situ* observations and used to aid in identifying macrophyte communities in Phase 3 field work. Each site was traversed by boat along transects running from shore to the site boundary from the northern most to southernmost extent of the site (as previously mapped in Phase 2), and a drop camera used to identify macrophyte communities. Observation continued until the end of the macrophyte community was observed. Community locations were recorded with GPS waypoints and used for post field comparison and NDVI calibration.

2.3.6.1 Macrophyte Collection

Physical collection of macrophytes from quadrats employed two different methods. Depending on whether communities were submerged or emergent:

1. *Macrophyte Sampling Rake:* used in submerged and partially submerged quadrats (typically zones ‘B’ and ‘C’). The macrophyte sampling rake consisted of two standard 0.5 m wide metal garden rakes bolted back to back with tines facing outwards and weighted at the collection end (Photo 2-2, Appendix 2). Braided nylon rope was fastened to the handle for easy deployment and retrieval; and,
2. *Direct Observation and Removal:* used for emergent and very shallow quadrats; field personnel used trowels, and handheld garden rakes to remove macrophytes and root structures from quadrats for preservation and identification.

Over deeper sample plots, a drop camera with attached quadrat (Photo 2-6, Appendix 2) was used as an initial check to determine if submerged macrophytes were present at that location. If observed macrophytes were not immediately identifiable, samples were collected using the macrophyte rake. The rake was lowered onto the sampling plot and dragged for one linear meter. This procedure was repeated three times within each quadrat regardless of whether macrophytes were collected. The sampling rake was effective in collecting all types of submerged macrophytes and used in most Zone B and all Zone C collections.

Once successfully collected, macrophyte specimens were brought to the surface, removed from the sampling device and placed in pre-labeled sample containers (specific to transect point) for processing. A small amount of site water accompanied each sample to prevent desiccation of macrophytes. Preliminary identification was completed *in situ* to establish relative densities within each quadrat and to ensure that at least one specimen of each species was retained from each study site.

Representative plant specimens from each plot were labeled and placed in a project-specific plant press and dried. Specimens included stem, leaves and reproductive structures (when present). Specimens were labeled according to site, transect, quadrat, and date. Photos were taken of each new species collected at a site and of each specimen prior to pressing. Observations were recorded in G3-developed biophysical field forms, including site locations, quadrat depths, transect distances, dominant and subdominant substrate and vegetation and site layout. A collection of voucher specimens was laminated, bound and submitted to BC Hydro after Phase 2 sampling (*2011 Macrophyte Reference Collection*). The collection was supplemented with new macrophytes identified in Phase 3 (2015).

2.3.6.2 Estimation of Percent (%) Macrophyte Cover

Estimates of per cent (%) vegetation coverage were made for each 1x1 m quadrat. Assessments were made through:

1. visual observation from the research vessel;
2. visual observations from the drop camera; and,
3. visual observations from shore-based field technicians.

The drop camera was deployed at each sampling quadrat where macrophyte community percent cover could not be estimated from visual observations. A 1 m^2 sampling quadrat frame was to assist with percent cover estimates at both shore-based and vessel based stations. Through use of each method above, assessments were made with two field technicians separately estimating the extent of reservoir bottom covered by aquatic plants. Values were then averaged to yield the estimated per cent (%) coverage of a macrophyte community within a given quadrat. Estimates were recorded in field notebooks and on biophysical observation forms, photos were taken of each quadrat, where possible. Estimation methods were based on those defined in Terry and Chilingar (1955).

In Phase 2 estimations of percent (%) macrophyte cover were based on macrophyte sampling rake fullness and rate of success (when visual observations were not possible). In Phase 2, visual estimates of macrophyte coverage were possible at most sample plots. A depth sounder was also used to help delineate macrophyte communities located in deeper areas which were present, though not visually observed from the boat or via satellite.

During Phase 3, a drop camera and macrophyte sampling rake were used and two field technicians independently estimated macrophyte coverage. Macrophyte coverage estimates generally fell into three macrophyte coverage ranges regardless of the technique used (sparse [0-20% coverage], moderate [40-60% coverage], abundant [80-100% coverage]). Overall, there was no significant difference in abundance identified between years (2011 and 2015) and potential differences between techniques did not appear to import notable bias on macrophyte coverage results.

2.3.6.3 Emergent Vegetation Perimeter Mapping

The delineations of different vegetative communities within a study site were conducted using a Garmin GPSmap 60Cx (DGPS <5 m, typical). A field technician traversed the high-high water mark (HHWM) between the north and south (or east and west, as applicable) extents of each study site and identified and delineated any distinctive vegetative zones within the emergent and shallower-submerged portions of the study area. GPS waypoints were recorded with descriptions of emergent vegetation and photographs and were used in post-field analysis to ground truth the spectral classification.

2.3.6.4 Drop Camera Vegetation Perimeter Mapping

In Phase 2 submerged vegetation community perimeters were defined through visual observations, strategic sampling along transects, satellite spectral imagery and bathymetric data. At the end of Phase 2 it was recommended that a drop camera be used to reduce error in deeper and/or more turbid water where macrophyte communities could not always be distinguished visually from the surface. The drop camera helped provide a continuous view of the macrophyte bed and allowed for a more accurate assessment of macrophyte community boundaries and estimate of per cent (%) macrophyte cover. Boundaries of the macrophyte communities were delineated using strategic underwater viewing with a drop camera, digital Lowrance LCX-15MT depth sounder and a Garmin GPSmap 60Cx (Garmin GPS; DGPS <5m, typical).

The drop camera was connected to a video monitor and lowered to the reservoir bottom for a real time video feed of substrate and any associated macrophyte communities. The research vessel then slowly traversed the study site in a grid formation. Several passes were made perpendicular to the shore until macrophytes were no longer detected, became very patchy and reservoir depth increased beyond suitable macrophyte growth range (depth in metres based on light penetration). Subsequent passes were made parallel to shore at several locations across the site. Location of observed macrophyte communities and corresponding depth and distance to shore were recorded in project specific notebooks and macrophyte communities boundaries marked with a Garmin GPSmap 60Cx.

2.3.6.5 In Situ Water Quality

A YSI 6600 Sonde was used to assess *in situ* water quality. Readings were taken along the centre transects of each study site at each submerged quadrat. In total, 17 samples (including all assessed parameters) were collected over all sites. Water quality parameters assessed included temperature, conductivity, depth, pH, ORP, turbidity and dissolved oxygen (DO). Measurements were saved directly to the Sonde, backed up each night, then to the G3 server upon return from the field. Data is presented in Tables A4-17 to A4-22, Appendix 4-2 and discussed in Section 3.3.1.

A Secchi disk was used to measure water transparency at the centre of each study site in cases where the bottom could not be visually observed. In such cases, Secchi disk measurements were completed in the centre transect within zone ‘C’ using a calibrated chain on the shaded side of the boat. Secchi depth was recorded independently by two observers and results averaged. Recordings were documented in field notebooks and on project specific forms.

2.3.6.6 Sediment

A stainless steel 15 cm Ponar was used to collect sediment samples from each study area (Photo 2-4, Appendix 2). Samples were collected within each zone of the centre transect for visual assessment and photographic documentation.

Qualitative assessments of each sample were made *in situ* with descriptions documented according to criteria defined in sediment field forms developed by G3 specifically for this study (Appendix 4). In addition, qualitative nearshore evaluations were completed based on visual assessments. Gross sediment characteristics assessed, based on the Environmental Effects Monitoring (EEM) Working Group (EWG) and USEPA National Benthic Workshop (PTI, 1993), included:

- overall sediment characteristics (i.e., texture, colour, consistency, odour, presence of debris, and presence of fauna);
- vertical profile characteristics (i.e., homogeneity, layering, oily sheen, varves); and,

- other distinguishing features.

2.3.7 Bathymetry

Concomitant with drop camera surveys, a digital Lowrance LCX-15MT depth sounder, interfacing directly to an Omnistar differentially corrected DGPS receiver (measured in UTM coordinates, NAD83, Zone 11U), was used to record bathymetry of each site. The sounder was used to record depth, assess the presence of submerged macrophytes and determine relative substrate condition and bottom slope. Information was stored in real-time and correlated with real-time collection of differentially-corrected GPS data. Raster bathymetric images of long-term monitoring sites were produced from sonar log data to enable comparative analysis at each site. Depth intervals were assigned unique colour values and were repeated across all sites.

2.3.8 Site Photos, Data & Observations

Photographs were taken of each study site (Appendix 2) using a 10-megapixel Olympus Stylus Tough waterproof camera. Photos captured images from a number of monitoring site vantage points including cardinal directions and site specific vantage points.

Photographic documentation was maintained for each new macrophyte species, emergent vegetation quadrats and methodologies employed. Photographs were catalogued in a database as described in Section 2.4.3.

2.4 Post Field

2.4.1 Taxonomy

Following field surveys, macrophyte samples were checked against field forms and identifications confirmed by examining corresponding site photographs from Phases 1, 2 and 3. Pressed and dried samples were then individually identified through examination of morphological structures and comparison with diagnostic characterizations in appropriate published keys (See Section 6.0, Taxonomy References).

Morphological structures were examined under a Nikon SMZ1000 dissecting microscope. Specimens were identified to the lowest possible taxonomic level and stored in a secure, cool, dry environment until all were identified. Quality assurance procedures during the identification of macrophytes involved a comparison of specimens with other confirmed verified specimens.

2.4.2 Reference Collection

In Phase 2 macrophyte specimens best preserved and most representative of a given species were compiled into a reference collection. Samples were pressed into 21.6 cm x 55.9 cm cardstock and laminated to preserve sample integrity. Each reference sample includes a site ID card listing the following:

- Latin name (*Genus species var.*);
- family name;
- date; and,
- collection site.

The reference collection was submitted to BC Hydro as an annex to the Phase 2 report (*2011 Macrophyte Reference Collection*). The collection will be supplemented with new macrophytes identified in Phase 3 (2015).

2.4.3 Photographic Database

All G3 project photos were uploaded and entered into the 2015 Whatshan Reservoir Vegetation Assessment Photo Database. *Photo Collector Professional* was used to create the database and chosen based on a number of beneficial traits including: ease of use; compatibility; and, functionality. Key information about each photograph was attached as a tag and can be searched using a query tool. The information attached to each photo includes, but is not limited to:

- site name;
- photo date and time;
- photographer;
- photo caption;
- file details (format, file size, resolution and colour);
- camera details (type, flash, zoom, focal length and aperture); and,
- additional notes.

Photographs and meta database were submitted to BC Hydro on included DVD-ROM media. All photographs were included in both their native resolution and as lower resolution 800 x 600 versions.

2.5 Satellite Analyses

Satellite Imagery was assessed visually to evaluate the effectiveness of each spectral band and established vegetative indices to differentiate between vegetated classes identified during the field study. The classification was based on minute differences in chlorophyll a:b ratios, carotenoids and individual plant characteristics detectable through spectral differences. Imagery was atmospherically corrected to remove cloud and haze and to minimize sun reflectance on water surfaces due to wave action.

2.5.1 Vegetation Classification & Satellite Model Refinement

Orthorectified multispectral satellite imagery obtained from Pleiades (GeoTIFF format) was imported into ArcGIS. Pleiades imagery was selected given that its wavelength encompassed those of past surveys (e.g., Rapid Eye and Ikonos satellites), enabling comparison through spectral analysis between years. Satellite imagery was provided in Blue, Green, Red, and Near-Infrared (NIR) bands. The NIR channel (750 – 950 nm) cannot penetrate water and was used to create an outline of the current water level of Whatshan Reservoir. Spectral bands were then corrected for “top-of-atmosphere” reflectance using manufacturer (Pleiades) provided constants and formulae and data separated into emergent and submerged domains based on the established clipping boundaries. Thirteen (13) spectral indices were calculated from the Pleiades multispectral data to broaden the feature input for the vegetation classification process (Table 2-2, below). Established clipping boundaries were also used to clip macrophyte polygons assessed in Phase 1 to allow for direct comparison of macrophyte community areas between all Phases; however due to the differences in methodology used in Phase 1, only Phase 2 and Phase 3 area estimates were used for statistical analysis.

Table 2-2: Spectral Bands Considered in Analysis

Spectral Bands and Indices Considered	Submerged	Emergent
Blue (430 – 550 nm)	NA	NA
Green (490 – 610 nm)	Green (520 – 590 nm)	Green (520 – 590 nm)
Red (600 – 720 nm)	Red (630 – 685 nm)	NA
Near Infra-Red (NIR; 750 - 950 nm)	Near Infra-Red (NIR; 760 – 850 nm)	NA
Green / Blue	Green / Blue	Green / Blue
Green – Blue	Green - Blue	Green – Blue
Red – Green	Red – Green	Red – Green
Red / Blue	Red / Blue	Red / Blue
(NIR – Red) / (NIR + Red)	(NIR – Red) / (NIR + Red)	NA
Red / Green	Red / Green	NA
Red – Blue	Red – Blue	NA
(Red * Blue) – NIR	(Red * Blue) – NIR	NA
NIR - Red	NA	NA
NIR / Green	NA	NA
NIR / Blue	NA	NA
NIR / Red	NA	NA
NIR – Blue	NA	NA
NIR – Green	NA	NA

NA: Not Applicable, therefore removed from classification

Each spectral index was assessed for interference (confounding data) and contrast of submerged and emergent vegetation types. Preliminary results were conducted via an iterative feedback process including field and technical personnel. Spectral classification proceeded using an applied forced trial and error approach resulting in the final selection of bands listed in Table 2-2 (above). Selected bands for each vegetation domain were composited into multi-channel GeoTIFF files (submerged and emergent).

Composited multi-channel data was classified using the *spectral classification isocluster tool within the ESRI ArcGIS software package.* Ground truthing was undertaken on known vegetation areas derived from site visits to “train” the processor and aid in classification. ArcGIS generated a colour coded vegetation classification by grouping pixels with like spectral characteristics. Colour patterns were then recorded in the model surrounding each field-marked quadrat. Quadrats with like-colours and like-vegetative characteristics were grouped into classes as per the *Canadian Wetland Classification System* (National Wetlands Working Group, 1997). ArcGIS was used to obtain areas of each class within the respective boundaries of each long-term study site.

GPS tracks and waypoints collected during field surveys were overlaid on geo-referenced satellite maps. Any offset between field and satellite data was rectified manually, based on field notes, photographs and consensus between field personnel.

Dominant and sub-dominant taxa within a quadrat (i.e., ≥ 20 % cover of quadrat) were correlated with the presence/absence of colour. In Phase 2 and Phase 3, colours were assigned habitat types based on dominant vegetation, though several species were found to overlap within submerged groups. A table with submerged macrophyte community classes is located in Section 3.2.4.

Satellite studies of submerged macrophyte communities rely on light penetration to depth and accurate resolution of plant communities. Short wavelengths (400 – 450 nm) have the deepest water column penetration and are readily absorbed by chlorophyll a (peak absorption 430 nm and 662 nm in diethyl ether). The smallest spectral band of the Pleiades satellite encompassed 430 – 550 nm enabling good water column penetration and detection of substrate at depth.

2.6 Macrophyte Community Data Analysis

Univariate parameters (i.e., relative abundance and species richness) were used to characterize the macrophyte community. As species richness was very low in some samples, diversity indices (e.g., Shannon-Wiener Diversity Index, Pielou's Evenness Index, Simpson's Diversity Index, etc.) were not calculated in this report.

A two-way ANOVA (analysis of variance) was employed to test differences in univariate parameters between years and among sites or distance groups. A paired t-test ($p<0.05$) was used to test differences in relative abundance and species richness between 2011 and 2015 at each site and in macrophyte coverage area between the two years.

Multivariate methods were employed to determine differences in macrophyte community structure, using the software PRIMER 6 (Plymouth Routines in Multivariate Ecological Research).

Similarities between macrophyte samples were calculated using the Bray–Curtis coefficient (Bray and Curtis, 1957):

$$S_{jk} = 100 * \left(1 - \frac{\sum_{i=1}^{p} |y_{ij} - y_{ik}|}{\sum_{i=1}^{p} (y_{ij} + y_{ik})}\right)$$

where S_{jk} = Bray–Curtis similarity between the j^{th} and k^{th} samples, y_{ij} = the % coverage for i^{th} species in j^{th} sample ($i = 1,2,\ldots,p$; $j = 1,2,\ldots,n$).

The coefficient ranges between 0 and 100%. S = 100 means that species compositions in the two samples were identical, while S = 0 means no common species in the two samples. Abundance data were square-root transformed before computing the coefficient.

Analysis of similarities (ANOSIM) was carried out to test the null hypothesis that there were no differences in community structure between sample groups. ANOSIM was measured using the global test (R) (Clarke and Warwick, 2001):

$$R = (r_B - r_W) / (M/2)$$

where r_B = the average of rank similarities from all pairs of replicates between different groups, r_W = the average of all rank similarities among replicates within groups, $M = n*(n - 1)/2$ and n = the total number of samples under consideration.

R varies between 0 and 1, indicating some degree of discrimination between groups. R = 1 means all replicates within groups are more similar to each other than any replicates from different groups; R is approximately zero if similarities between and within groups are on average the same.

2.7 QA/QC & Data management

A set of *Quality Assurance and Quality Control* (QA/QC) procedures and practices were implemented throughout this Phase 3 (Year 10) assessment to ensure program integrity at every level. QA/QC objectives were incorporated into *workplan*s, established in the management strategy, and included protocols for handling and recording information (in the field and office) and criteria used to confirm accuracy and precision of that information. QA/QC objectives included established protocols for literature management to ensure accurate citations and relevance based on date and source of publication.

Sampling was undertaken using both replication (i.e., multiple samples in each quadrat) and duplication (i.e., multiple representative individuals of each species identified in the laboratory, multiple water quality readings collected at each site) for measures taken in the field. Further, instrumentation was calibrated daily to ensure accurate performance.

Transcription or entry errors were checked through cross-referencing and review of original field notes and forms by alternate staff members on 20-25% of entered data. If an error greater than five percent (%) was encountered the entire dataset was scrutinized. Macrophyte taxonomy QA involved comparison of specimens with verified specimens.

In accordance with BC Hydro protocol, a quality assurance and safety field audit was conducted by a BC Hydro representative (September 25, 2015). The field audit evaluated a number of study elements which included, but not limited to:

- project organization (e.g., schedule, field crew competency);
- study design (e.g., clearly stated objectives in project plan, field crew familiarity with study design and respective responsibilities);
- sampling methodology (e.g., sampling protocols consistent with regulatory standards, adherence to sampling protocols, appropriate field forms); and,
- data management (e.g., specific procedures for data entry and management, data storage compatible with BC Hydro).

Evaluation of study elements, safety and QA/QC procedures addressed BC Hydro requirements as defined by the *Operational Work Plan* and *Safety Management Plan* defined in the original RFP.

3.0 RESULTS

The study was designed to assess macrophyte ecology within Whatshan Reservoir and identify any changes to aquatic vegetation community structure or coverage that may have occurred as a result of the changes to the WUP. The following section provides comparative results for Phase 2 (2011) and Phase 3 (2015) of the Whatshan Reservoir Vegetation Monitoring Program using multispectral image analysis ground truthing.

A primary task of the Whatshan Reservoir Macrophyte Assessment Program was to test and compare satellite map multispectral imaging produced in Phase 2 and Phase 3 to identify the size and presence of emergent and submerged vegetation communities and track any changes in community size composition and presence over time. Basemaps were produced in both Phase 2 and Phase 3 using comparable methodologies. Basemaps were produced in Phase 1 using colour infrared aerial photography and orthorectified polygons. Phases 2 and 3 were compared to estimated aquatic vegetation community size over time for the entire reservoir as Phase 1 data were not comparable. Full reservoir comparative results are discussed in Section 3.2.2.

To attenuate and verify algorithm accuracy in Phase 2 and Phase 3, *in situ* vegetative community assessments and ground truthing were conducted. The type (e.g., species) and extent of macrophyte distribution (i.e., location, depth, relative abundance, biodiversity, etc.) within Whatshan Reservoir was assessed at each of the eight long-term study sites in Phase 2 and Phase 3 following changes to the Whatshan WUP in 2006. Results from the Phase 1 (2006) assessment were not available to enable comparison of substrate, water quality and vegetative community compositions between years. Limited physical (i.e., water quality and sediment) and biological (i.e., macrophyte species identification and coverage) data were collected to aid in the understanding of macrophyte ecology within Whatshan Reservoir. Both Phase 2 and Phase 3 data from each of the eight long-term sites were assessed and compared to identify any long term trends in the reservoir.

3.1 Reservoir Elevation

The changes to the WUP are outlined in Section 1.0 and entailed filling of the reservoir earlier in spring each year (639 m minimum elevation by May 15) and higher overall minimum elevations (636.5 m; previously 634 m). On 14 July 2005, BC Hydro was ordered to implement the conditions proposed in the Whatshan WUP and prepare the monitoring programs and physical works terms of reference (TOR).

Chart A3-1 shows reservoir elevations from 2000 to 2015. All years subsequent to WUP implementation had water elevations at or above the minimum elevation by May 15 (639 m) with the exception of 2012. In 2012, mid- to late-May water levels were 3 to 4 m below the norm. In 2006, water elevations appeared higher than the average mid- to late-May.

Phase 1 assessments were conducted on September 7 to 12, 2006 (Moody, 2007). During the 2006 baseline survey, reservoir elevation averaged 640.6 m. Phase 2 assessments were conducted September 27 to 30, 2011 at an average reservoir elevation of 640.4 m. Phase 3 assessments were conducted September 24 to 27, 2015 at an average reservoir elevation of 640.6 m.

3.2 Macrophyte Observations

3.2.1 Study Sites

Eight (8) assessed macrophyte study sites were distributed through the three (3) distinct basins of Whatshan Reservoir (Section 1.2; Figure A1-1, Appendix 1). Individual site layout and habitat descriptions for each site are provided below. Most emergent vegetation was identified in the mid and southern (lower) basins (Figure A1-1, Appendix 1). The northern (upper) basin featured extensive submerged aquatic vegetation at the northern-most locations surrounding the Whatshan River outlet into the reservoir. Most other areas of the northern basin did not appear to support appreciable macrophyte communities with the exception of Site 2-13 which also resides at a creek outlet (Figures A1-2a through A1-2h, Appendix 1).

Extensive marsh communities, noted at Sites 1-17, 1-18, 3-7 and 3-8 (Figures A1-2[a,b,e,f]), tended to be associated with residual log debris that overtime has started to breakdown and become in-filled and facilitate ecological succession through plant development.

Changes to noted emergent plant types at sites between Phase 2 and 3 (2011 and 2015; Tables 3-1) appeared to reflect this ongoing community succession (i.e., shrubbery growth in marsh habitat, etc.). Potential succession in plant communities between Phase 1 (2006) and Phase 2 and 3 (2011 and 2015) could not be evaluated fully due to limited results from Phase 1 (2006) field assessments.

Site 6-3

Site 6-3 was located in the Lower Basin of Whatshan Reservoir and was a small island (approximately 30 m x 150 m) made up of Low Marsh, Marsh and Fen with an additional Transitional Fen/Marsh habitat (Figure A1-2h, Appendix 1). Emergent vegetation was characterized by *Typha sp.* and *Carex sp*. Submerged vegetation was typical of most sites in Whatshan Reservoir. A muskrat lodge was observed on the south-eastern edge of the island in 2011.

The western side of the island had extensive macrophyte coverage and was uniform to the western shore of Whatshan Reservoir. The eastern side of the island featured little aquatic vegetation with no observed macrophyte growth due to steep bottom profiles. Submerged macrophyte growth was prevalent between the western side of the island and the western shore of Whatshan Reservoir. Dominant vegetation included *Chara sp*. and *Potamogeton sp.* On the western side of the island, water depth did not exceed the depth of the euphotic zone with macrophyte growth being extensive and uniform to the western shore of Whatshan Reservoir. The eastern side of the island featured little aquatic vegetation with no observed macrophyte growth due to a steep drop off and substrate that appeared more gravelly.

Site 4-4

Site 4-4, locally referred to as David's Lagoon, was bounded by the eastern shore of Whatshan Reservoir and located in the southern basin (Figure A1-2g, Appendix 1). Site 4-4 had two small and distinct sedge (*Carex sp.*) dominated marsh communities along the northern shore of the lagoon and submerged macrophytes were ubiquitous within the confines of the lagoon (i.e., substrates within the lagoon were completely covered in low-lying macrophyte growth). Two large nest-trees were present in the centre of the lagoon, although no wildlife was observed. There were four private docks within the lagoon and one private residence was visible from the water. These features were well established and appeared to have little to no effect on macrophyte communities between Phase 2 and Phase 3.

Site 3-6

Site 3-6, locally referred to as Robin's Lagoon, was located on the eastern shore of Whatshan Lake and confined by a small peninsula making up adjacent Site 3-7 (Figure A1-2d, Appendix 1). Along the northern edge of the lagoon were cattail (*Typha sp.*) and sedge (*Carex sp.*) marshes in a narrow strip adjacent to the shoreline. Lagoon waters appeared dark due to bottom substrate colour and high dissolved organic materials in the water; however, Secchi disk readings were visible to bottom. Submerged macrophytes were dominated by *Potamogeton sp.* and *Chara sp.* in both Phase 2 and Phase 3. Submerged macrophytes at deeper quadrats were not identifiable from the boat and required sampling and use of the drop camera to confirm presence. Artificial bird nesting platforms had been previously deployed at the site though no current nest activity was observed.

Site 3-7 & 3-8

Sites 3-7 and 3-8 were primarily cattail (*Typha sp.*) dominated marshlands following the west and east shorelines of Whatshan Reservoir (Figures A1-2e and A1-2f, Appendix 1). Submerged macrophyte communities at these sites were dominated by *Chara sp.*, *Isoetes sp.* and *Najas sp.* at Site 3-7. At Site 3-8, submerged communities were dominated by *Potamogeton sp. Crassula sp.* and *Isoetes sp.* in Phase 2 and *Potamogeton sp., Isoetes sp., Chara sp. and Crassula sp.* in Phase 3. Sites were separated by the deeper, narrow, original river channel in which macrophytes were not present. Emergent vegetation (i.e., *Typha sp.* marshes) appeared to rely on extensive log debris which facilitated formation of existing marsh communities and associated habitat use. No direct wildlife observations were noted at either site; however, Cattails (*Typha sp.*) appeared compacted in many areas indicated ongoing and current use by wildlife.

Site 2-13

Site 2-13 contained macrophytes along the north and south sides of White Grouse Creek (BC Watershed Code 300-680400-36400) in the Upper Basin of Whatshan Reservoir (Figure A1-2c, Appendix 1). Vegetation at this site consisted primarily of submerged macrophytes (*Potamogeton sp., Isoetes sp*. and *Chara sp*.) in both Phase 2 and Phase 3 and wet meadow habitat (Marsh, Fen and Fen/Marsh Transitional) dominated by *Isoetes sp.* and *Carex sp.* south of the creek mouth. Vegetation tended to become patchy in cover as depth increased. No wildlife was observed at Site 2-13 during field assessments; however, due to proximity to White Grouse Creek, and wetland coverage, potential use of habitat by wildlife is likely to be extensive.

Sites 1-17 & 1-18

Low sloping areas of Sites 1-17, 1-18, which had substantial accumulated log debris, tended to have extensive marsh (*Typha sp., Eleocharis sp., Juncus sp. and Carex sp.* and) communities.

Sites 1-17 and 1-18 featured diverse marsh communities each with distinctive sedge (*Carex sp.*), rush (*Juncus sp.*), cattail (*Typha sp.*) and macrophyte (*Potamogeton sp* and *Isoetes sp.*) communities. Sites were separated by the mouth of Whatshan River (5th Order; BC Watershed Code 300-680400). Marshland vegetation at both sites had historical log debris which was now overgrown. At these sites, successive wetland zones extended from the HHWM to wetted shorelines. At 1-18, there was little submerged macrophyte cover surrounding the site.

At Site 1-17 transect points of termination (POTs) there was submerged macrophyte growth which extended to 200 m from shore (Figure A1-2a). Emergent growth (*Carex sp.* dominated) was very dense and habitat appeared delta-like with multiple rivulets and small islands extending from the outlet into the reservoir. Expansive Fen habitat at upland areas was reliant on log debris in-filled with river sediment.

In Phase 2, elk were observed at Site 1-17 during field activities and wildlife use of the area appeared extensive.

3.2.2 Macrophyte Community Coverage

Total coverage areas of macrophyte vegetation at each site during Phase 2 and Phase 3 are presented in Table 3-1. Macrophyte community area determinations were not directly comparable between all program years (i.e., Phase 1 compared to Phase 2 and Phase 3) given differences in methodology; therefore, site boundaries established in Phase 2 were used to provide a more comparable assessment of polygon areas, and only macrophyte coverage areas in Phases 2 and 3 were compared as the methodology used in Phases 2 and 3 was not comparable to that used in Phase 1.

3.2.2.1 Emergent Areas

For emergent macrophyte vegetation, mean areas showed a slight decrease from 19,847 m^2/site in 2011 to 19,477 m^2/site in 2015. There were no clear patterns in emergent macrophyte areas at each site, and overall emergent macrophyte area was not notably different between 2011 and 2015.

Table 3-1: Long-term Monitoring Site Emergent Macrophyte Areas

Site	2011 Area (m^2)	2015 Area (m^2)
6-3	2,425	2,404
4-4	2,125	952
3-6	1,850	1,752
3-7	44,150	44,440
3-8	62,275	63,732
2-13	11,500	9,500
1-17	24,750	25,728
1-18	9,700	7,308

A breakdown of specific vegetation classes determined in Phase 2 and Phase 3 are included in Tables A4-4 to A4-19, Appendix 4.

Site 6-3 was located in the Lower Basin of Whatshan Reservoir and was a small island (approximately 30 m x 150 m). Phase 1 field studies classified the island as 100% marsh habitat; however, Phase 2 and Phase 3 field assessments and subsequent satellite analysis found the island to be partially dominated by fen and mature forest habitat. Well established trees were present in the centre of the island and the fen and mature (non-aquatic) communities appeared to be separated by a distinctive HHWM. There was no significant change in emergent macrophyte area between Phase 2 (2011) and Phase 3 (2015).

Accurate measures of emergent vegetation boundaries were difficult at **Site 4-4** due to dense forested areas overhanging the edges of the site. In Phase 2, total area of emergent vegetation was 2,125 m^2. Site 4-4 had two small and distinct sedge (*Carex sp.*) dominated marsh communities (900 m^2 Low Marsh and 400 m^2 Marsh). In Phase 3, the marsh communities were still present (280 m^2 Low Marsh and 444 m^2 Marsh); however, the total estimated area of emergent vegetation was lower (952 m^2). Lower area estimates of emergent vegetation in Phase 3, were more likely a result of difficulty classifying imagery due to forest overhanging the edges of the site. Visual comparisons of emergent vegetation area between Phase 2 and Phase 3 showed little difference. Anthropogenic effects at Site 4-4 included several private docks and a boat launch to the northeast. These features were well established and appeared to have little to no effect on macrophyte communities between Phase 2 and Phase 3.

At **Site 3-6**, emergent areas between Phase 2 and Phase 3 were similar (1,850 m^2 and 1,752 m^2, respectively). In Phase 1, emergent vegetation was classified as 100% fen habitat; however, Phase 2 and Phase 3 field assessments and analysis found mostly Marsh classifications (1,700 m^2 [2011] and 1,468 m^2 [2015]).

Sites **3-7** and **3-8** were primarily cattail (*Typha sp.*) dominated marshlands following the west and east shorelines of Whatshan Reservoir. Each site had similar emergent macrophyte areas between years. At **Site 3-7** and **Site 3-8** overall emergent vegetation slightly increased from Phase 2 (44,150 m^2 and 62,275 m^2, respectively) to Phase 3 (44,440 m^2 and 63,732 m^2, respectively).

Sites **3-7 and 3-8** featured a clear and distinct zonation of Marsh and Fen habitats in Phase 1 and 2 with high habitat complexity resulting from large woody debris. Zonation of emergent communities was noted in Phase 3, though less distinct than Phase 2 between Marsh and Fen communities.

At **Site 2-13**, emergent areas slightly decreased from Phase 2 (11,500 m^2) to Phase 3 (9,500 m^2). The largest segment of emergent vegetation was classified as Marsh, Low Marsh or Marsh Transitional in all three Phases dominated by *Isoetes sp.* and *Carex sp.* south of the creek-mouth.

At **Site 1-17**, emergent area estimates slightly increased from Phase 2 (24,750 m^2) to Phase 3 (25,728 m^2). At **Site 1-18**, emergent area decreased from 2011 (9,700 m^2) 2015 (7,308 m^2). Specific habitat classes were similar between Phase 2 and Phase 3.

3.2.2.2 Submerged Areas

Mean areas of submerged macrophyte vegetation slightly decreased from 2011 (47,502 m^2/site) to 2015 (46,087 m^2/site). There was no statistically notable difference in submerged vegetation area between 2011 and 2015.

Table 3-2: Long-term Monitoring Site Submergent Macrophyte Areas

Site	2011 Area (m^2)	2015 Area (m^2)
6-3	37,200	33,924
4-4	5,075	5,984
3-6	53,475	55,136
3-7	18,675	23,276
3-8	51,100	38,152
2-13	89,479	88,580
1-17	109,921	107,744
1-18	15,091	15,896

A breakdown of specific vegetation classes determined in Phase 2 and Phase 3 for each site are included in Tables A4-4 to A4-19, Appendix 4.

Between Phase 2 and Phase 3, there was no obvious trend in submerged macrophyte area. At Site 6-3, 3-8, 2-13 and 1-17 submerged macrophyte areas decreased slightly between Phase 2 and Phase 3 while submerged macrophyte areas increased slightly at Site 4-4, 3-6, 3-7 and 1-18.

3.2.2.3 Overall Macrophyte Area & Spectral Class Breakdown

Polygons generated from 2011 spectral data were compared directly with 2015 spectral data to assess changes in macrophyte communities over the whole reservoir. Total submerged macrophyte area increased in Phase 3 (3,114,688 m^2) compared to Phase 2 (2,856,724 m^2).

ArcGIS generated a colour coded vegetation classifications by grouping pixels with like spectral characteristics (Figure A1-2). Dominant and sub-dominant taxa within a quadrat (i.e., ≥ 20 % cover of quadrat) were correlated with the presence/absence of colour. In Phase 2 and Phase 3, colours were assigned habitat types based on dominant vegetation. Class 4 was the dominant submerged macrophyte class in 2011 (1,612,753 m^2) while Class 2 was the dominant submerged macrophyte class in 2015 (1,845,448 m^2). Total emergent macrophyte area decreased slightly from Phase 2 (581,325 m^2) to Phase 3 (565,272 m^2). Fen/Marsh Transitional Class was the dominant class in Phase 2 (150,275 m^2) while Marsh Class was the dominant class in Phase 3 (302,880 m^2).

Table 3-3: Overall Macrophyte Area Estimates		
Classification	**Phase 2 (2011)**	**Phase 3 (2015)**
Submerged Macrophyte Classes		
Class 1	270,313 m^2	290,304 m^2
Class 2	664,002 m^2	1,845,448 m^2
Class 3	309,656 m^2	206,372 m^2
Class 4	1,612,753 m^2	772,564 m^2
Total Submerged Area	**2,856,724 m^2**	**3,114,688 m^2**
Emergent Macrophyte Classes		
Low Marsh	121,300 m^2	125,008 m^2
Marsh	250,100 m^2	302,880 m^2
Fen/Marsh Transitional	150,275 m^2	66,332 m^2
Fen	59,650 m^2	71,052 m^2
Total Emergent Area	**581,325 m^2**	**565,272 m^2**

Note: Submerged Class 5 (no macrophytes) was removed from total macrophyte area estimates

3.2.3 Macrophyte Community Structure

Potential succession in plant communities could only be evaluated between Phases 2 and 3 (2011 and 2015) due to lack of detailed Phase 1 (2006) macrophyte community assessments. Community succession between Phase 2 and Phase 3 is discussed below.

3.2.3.1 Univariate Parameters

Highest mean value of macrophyte relative abundance (% coverage) was 92.22%/sample at Site 3-8 in 2011 and at Site 1-17 in 2015, while lowest mean values were 54.44%/sample at Site 6-3 in 2011 and 30.00% at Site 2-13 in 2015 (Chart A3-5, Appendix 3). Relative abundance of the macrophyte community was significantly higher in 2015 compared to 2011 at Site 1-17 ($p<0.05$, paired t-test) and significantly lower in 2015 compared to 2011 at Site 2-13 ($p<0.01$), and showed no significant differences between the two (2) years at other sites. Overall, relative abundance of macrophyte communities showed statistically significant differences among sites ($p<0.0001$, 2-way ANOVA); however, there was no significant difference between the two years.

Total species richness decreased from 37 species in 2011 to 29 species in 2015 (Macrophyte Raw Data, Appendix 6). Total species richness for emergent and submerged macrophyte decreased from 2011 (22 and 15 species, respectively) to 2015 (19 and 10 species, respectively).

Highest mean values of macrophyte species richness were 5.50 species/sample at Site 4-4 in 2011 and 3.67 species/sample at Site 3-7 in 2015, while lowest mean values were 3.22 species/sample at Site 3-6 in 2011 and 1.67 species/sample at Site 2-13 in 2015 (Chart A3-6, Appendix 3). Species richness was significantly higher in 2011 compared to 2015 ($p<0.05$ to <0.01) at all site except Site 3-7. Overall, mean species richness of transect data showed statistically significant differences among sites and was significantly higher in 2011 (9.3 species/transect) compared to 2015 (6.4 species/transect) ($p<0.0001$, 2-way ANOVA).

Macrophyte sample data were also grouped based on distance from shore (i.e., near, mid, far, and far-far [at Site 4-4 only]) at each site. Highest mean values of relative abundance were 91.67% at Site 4-4 in the nearshore statistical grouping, 100.00% at Site 3-8 in the mid-distance group, and 93.33% at Site 3-8 in the far-shore group; while lowest mean values was 65.83% at Site 6-3 in the nearshore group, 33.33% at Site 3-6 in the mid-distance group, and 26.67% at Site 2-13 in the far-shore group (Chart A3-7, Appendix 3). There was no clear pattern in relative abundance for distance groups; however, overall mean abundance showed a slight decrease from the nearshore group (77.81%) to the far-shore group (65.21%). However, there were no notable differences in relative abundance among distance groups or between years (two-way ANOVA).

Highest mean values of species richness was 5.17 species/sample at Site 1-18 in the nearshore group(nearshore group), 5.00 species/sample at Site 3-7 in the mid-distance group, and 5.17 species/sample at Site 4-4 in the far-shore group. Lowest mean values were 1.67 species/sample at Site 1-17 in the nearshore group, 0.67 species/sample at Site 3-6 in the mid-distance group, and 2.17 species/sample at Site 2-13 4 in the far-shore group (Chart A3-8, Appendix 3). Overall, there were no notable differences in species richness among distance groups (two-way ANOVA).

3.2.3.2 Species Composition & Community Structure

In total 44 macrophyte species were recorded over both Phase 2 and Phase 3 surveys. The top five (5) dominant species were *Typha angustifolia*, *Carex* sp., *Chara* sp., *Juncus* sp. and *Isoetes* sp. in 2011, and *Typha angustifolia*, *Isoetes* sp., *Najas flexilis*, *Crassula aquatica* and *Carex* sp. in 2015 (Table A4-3, Appendix 4; Macrophyte Raw Data, Appendix 6).

Nine (9) emergent species (i.e., *Carex exsiccata*, *Eleocharis palustris?*, *Schoenoplectus tabernaemontani, Equisetum fluviatile, Equisetum pratense, Rhododendron groenlandicum, Fragaria virginiana, Viola orbiculata,* and *Betula* sp.) and six (6) submerged species (i.e., *Tolypella* sp*., Potamogeton natans, Myriophyllum verticillatum/sibiricum, Utricularia macrorhiza, Utricularia minor, Nuphar* sp.*)* were recorded only in 2011, while six (6) emergent species (i.e., *Carex rossii, Carex rostrata, Cryptogramma stelleri, Galium trifidum, Urtica dioica,* and *Verbascum thapsus*) and one (1) submerged species (*Potamogeton perfoliatus*) were recorded only in 2015. All were perennial species except for *V. thapsus* (biennial) and *Tolypella* sp.

For multivariate analyses, data was pooled by transect or distance (i.e., nearshore, mid-distance and far-shore groups) at each site since macrophyte species richness was low and no macrophytes were found in some samples (i.e., Site 3-6 in 2015).

Non-metric multidimensional scaling (MDS) plot based on transect data displays differences in community structure among the eight (8) sites and between 2011 and 2015 (Chart A3-9, Appendix 3). Two-way crossed ANOSIM showed significant differences in macrophyte community structure among sites ($R=0.458$, $p<0.001$) and between 2011 and 2015 ($R=0.148$, $p<0.05$).

Non-metric MDS plot based on distance data shows points (samples) gradually moving from the nearshore group on the left site to the far-shore statistical group on the right site (Chart A3-10, Appendix 3), suggesting differences in community structure between nearshore and mid/far-shore zones. Two-way ANOSIM confirmed significant differences in community structure between nearshore group and the far-shore group ($R=0.559$, $p<0.001$) or the mid-distance group ($R=0.328$, $p<0.01$), yet showed no significant difference between the mid-distance and far-shore groups ($R=0.106$). Based on distance data, no significant differences in community structure were noted between 2011 and 2015 ($R=0.072$).

Macrophyte species were divided into two categories (submerged and emergent) using the *Ministry of Environment Key to the Aquatic Plants of BC* (MOE, 2001). This key initially separates species based on ecology with herbaceous floating fresh water plants, fully submersed, rooted plants with finely dissected leaves and fully submersed, herbaceous plants without finely dissected leaves falling into the submerged category. Emergent species include herbaceous fresh water plants which are rooted and emerge above the surface of the water with either opposite, whorled, clustered, cauline or alternate leaves and fully emergent plants that have basal clusters of leaves. Each species identified in sample quadrats were categorized based on these definitions and the data was compared between years.

Emergent macrophyte community structure showed no significant difference between 2011 (blue) and 2015 (red; Chart A3-11, Appendix 3). Submerged macrophyte community structure was significantly different between the two (2) years (Chart A3-12, Appendix 3; R=0.408, $p<0.01$, ANOSIM).

3.2.4 Macrophyte Community Spectral Classes

Using the spectral bands in Table 2-2 and the methods provided, the model was successful at identifying submerged macrophyte community area. To group spectral responses for submerged species to form the defined classes required additional ground truthing using currently available technology. Ground truthing was undertaken on known vegetation areas derived from site visits to attenuate the processor and aid in classification. ArcGIS generated a colour coded vegetation classification by grouping pixels with like spectral characteristics.

Select dominant submerged species were then used to help determine community spectral classes in Phase 2 and Phase 3. Several species were found to overlap between classes. Chara sp. and Najas flexilis were often found in similar habitats/ quadrats and were observed most frequently in Class 1. Isoetes sp. and Crassula aquatica were often found in similar habitats/ quadrats and were found most frequently in Class 2. Based on growth form and habitat, species observed commonly in Class 1 and Class 2 were often species that grow rooted or anchored in the sediment with all vegetative parts beneath the surface of the water at the start of growing season and may grow partially out of water when water levels drop. No strong associations were observed for dominant species in Class 3 or Class 4; however, many of the dominant species observed in Class 1 and Class 2 and potamogeton sp. were also observed in Class 4.

Table 3-4: Submerged Macrophyte Community Classes

Submerged Class	Macrophyte Community
1	*Chara sp.* (algae) and *Najas flexilis* were dominant
2	*Isoetes sp.* and *Crassula aquatica* were dominant
3	No obvious species trends; *potamogeton sp.* and *Isoetes sp.* observed in several quadrats
4	No obvious species trends; *potamogeton sp.* observed; *Chara sp.* and *Najas flexilis* observed in few quadrats

Dominant emergent species include *Carex sp.* which was associated with Marsh and Fen habitat classes and *Typha angustifolia* which was strongly associated with Marsh habitat.

3.2.5 Macrophyte Bed Elevations

Mean elevations of submerged macrophyte community boundaries were similar between Phase 2 (637.4 m to 640.0 m) and Phase 3 (637.8 m to 640.6 m) and submerged macrophyte elevations were similar at the same sites between years. No obvious trend was observed over time or within zones of the reservoir. High Water Mark boundary elevations were similar at all sites (approximately 643 m).

Table 3-5: Submerged Macrophyte Elevations

Site	2011		2015	
	Nearshore (m)	Far-shore (m)	Nearshore (m)	Far-shore (m)
6-3	639.6	636.9	640.5	637.5
4-4	639.7	N/A	640.5	N/A
3-6	639.8	N/A	640.5	N/A
3-7	640.1	637.5	640.6	637.0
3-8	640.0	635.3	640.5	636.2
2-13	640.1	637.5	640.6	638.1
1-17	640.4	638.3	640.6	638.4
1-18	640.3	639.1	640.6	639.3
Mean	640.0	637.4	640.6	637.8

N/A: Not Applicable as these sites are lagoon shaped and contain macrophytes at all depths

3.3 Biophysical Observations

Data provided below is from *in situ* profiling of long term monitoring site quadrat locations. Data may not be representative of general reservoir conditions.

3.3.1 Water Quality

Water quality profiles, as assessed in September 2015 at Whatshan Reservoir for temperature, conductivity, pH, redox (ORP), turbidity and dissolved oxygen (DO), are discussed below and depicted in Table A4-20 to Table A4-25 (Appendix 4). Mean water quality values are discussed below for Phase 3 and compared to the same sites in Phase 2.

This study examined water quality at a single event only and should not be considered representative of annual conditions. General trends between regions of the reservoir and among study year are discussed below.

Temperature

Whatshan Reservoir water temperatures were relatively consistent between sites with no discernible patterns noted within the reservoir. Assessments were conducted in September, 2015 and mean temperatures ranged from 14.07°C to 15.60°C. In 2011 (September) temperatures ranged from 14.44°C to 16.65°C. In 2011, lowest temperatures were measured at Site 2-13 in the southern portion of the upper basin where temperatures ranged from 14.07°C to 14.63°C. Lower temperatures at Site 2-13 may have been influenced by input from White Grouse Creek, located within the study site or time of day as that station was measured in the early morning. In 2015, lowest temperatures were noted at Site 1-17 (14.07°C).

Water temperature is an important variable that can affect the suitability of an ecosystem to support aquatic organisms. Factors which can influence water temperature include seasonal and daily changes in sunlight energy, shade, air temperature, stream flow, water depth, inflow of groundwater or surface water, and the colour and turbidity of the water. Optimal water temperatures for aquatic life (i.e., salmonids) are typically below 15°C (EPA, 1998). Water temperatures consistently outside of this range (i.e., 20+°C) may negative effect sensitive species. High water temperatures (up to an organism-specific limit) generally increase biological activity for many organisms (Fidler and Oliver, 2001; Haidekker, 2005). Temperature also affects biological activity by influencing water chemistry. Warm waters contain less dissolved oxygen (DO) than cooler waters, as solubility of oxygen in water is temperature-dependent (Mel'nichenko *et al.*, 2008). Such reduced DO levels may be insufficient to support development of macrophyte communities.

Dissolved Oxygen (DO)

Dissolved oxygen levels were relatively consistent between sites and between years with no discernible patterns noted with respect to specific long term monitoring site location within the reservoir. In 2015, dissolved oxygen means ranged from 9.33 mg/L (Site 6-3) to 10.07 mg/L (Site 2-13). In 2011, DO site means ranged from 9.39 mg/L (Site 6-3) to 10.04 mg/L (Site 2-13).

Dissolved oxygen (DO) analysis is a measure of the amount of gaseous oxygen (O_2) dissolved in an aqueous solution. Oxygen dissolves into water by diffusion from the surrounding air, by aeration (rapid movement) and as a by-product of photosynthesis (Poppe, 1987). Riverine waters are usually more oxygenated than lacustrine waters, given that water movement tends to cause more oxygen to be introduced. Water temperatures in creeks from glacial, melting or upland sources may be lower than temperatures in receiving lacustrine environments. These effects may be why Site 2-13 waters, near the outlet of White Grouse Creek, were most oxygenated in both Phase 2 and Phase 3. Oxygen concentrations of water did not appear to be correlated with reservoir basins or position within the Whatshan Reservoir.

Conductivity

Conductivity assessments during the 2011 field surveys ranged from 50 µS/cm (Site 4-4) to 57 µS/cm (Site 1-18). Conductivity was generally higher at reservoir sites in the Upper Basin (i.e., Sites 1-17, 1-18 and 2-13, 55-57 µS/cm) compared to Mid Basin (3-6, 3-7 and 3-8, 51-52 µS/cm) and Lower Basin sites (4-4 and 6-3, 50-51 µS/cm). During 2015 field surveys, mean conductivity ranged from 98 µS/cm (Site 4-4) to 109 µS/cm (Site 1-17 and 1-18). A similar trend was observed with conductivity values higher at Upper Basin Sites (106 µS/cm to 109 µS/cm) than Mid Basin (104 µS/cm) and Lower Basin Sites (98 µS/cm to 101 µS/cm).

Conductivity measurements remained comparatively low throughout the reservoir during field surveys. Conductivity was generally consistent between sites in 2011 and 2015 and does not appear to affect macrophyte distribution or community structure in Whatshan Reservoir. Conductivity provides an estimate of the amount of total dissolved ions in water. Many factors influence the conductivity of freshwater, including geology, watershed size, input from point and non-point sources of nutrients and minerals, atmospheric fallout, evaporation rates, precipitation and bacterial metabolism (McNeil and Cox, 2000).

pH

In Phase 2 assessments (September 2011), mean pH values ranged from 7.43 pH units (Site 3-6) to 7.75 pH units (Site 2-13 and 1-18). In Phase 3 (September 2015), mean pH values ranged from 7.54 (Site 3-6) to 7.96 (Site 2-13). There did not appear to be a relationship between reservoir location and water pH values (i.e., no apparent basin zonation, and not attributed to stream output nor log debris).

If water becomes either too alkaline or acidic, it can be inhospitable to many species of macrophytes. pH is a measure of the hydrogen ion concentration (or acidity) in water. A pH of 7 is considered neutral. Values lower than 7 are considered acidic, while values higher than 7 are basic. Many important chemical and biological reactions are strongly affected by pH. In turn, chemical reactions and biological processes (e.g., photosynthesis, respiration) can influence pH (CCME, 2016). The Canadian Council of Ministers of the Environment (CCME, 2016) states the optimum range of pH for the protection of aquatic life to be 6.5 to 9.0 pH units. Water profiles within the Whatshan Reservoir were noted to be within this ideal range.

Redox (ORP)

During Phase 2 field assessments (September 2011), ORP in water ranged from 135 mV (Site 3-7) to 200 mV (Site 1-17). In phase 3 (September 2015), ORP ranged from 215 mV (Site 1-18) to 246 mV (Site 4-4). Redox potential was similar between sites with no apparent relationships between proximity within Whatshan Reservoir and ORP values. Redox values in freshwater ecosystems tend to rely on the type of rocks present in the watershed (Schüring et al., 2000). Reductive agents (e.g., organic compounds) are a contributing factor in the decrease of oxygen in water. Reductive agents also decrease the redox potential, indicating the deterioration of water quality.

The decomposition of organic matter proceeds in a succession of redox reactions oxidizing an organic substance to yield carbon dioxide and water. Oxidation-reduction (i.e., redox) reactions are characterized by the flow of electrons between oxidized and reduced states toward equilibrium (Wetzel, 2001). When oxygen is dissolved in water, a redox potential (Eh) is generated. Dissolved organic compounds effectively lower redox potential in sediment and reduce the depth to the redox discontinuity (RPD) layer, a zone of rapid change from positive to negative Eh values (transition between oxic, oxidizing and anoxic reducing layers; Sampou and Oviatt, 1991; Levington, 1995). High rates of organic matter loading eventually create anoxic sediments with Eh levels of less than 0 mV and surface RPD (Hargrave *et al.*, 1997). In freshwater redox can range between +500 mV in the oxic zone to approximately -200 mV in the sulfidic- and methane-based zones (Mackie, 2004). The dimensions of these zones vary depending on the concentration of decomposed organic substances in sediment and turnover rates of those sediments. Redox values can often fluctuate in the range of ±50 mV (Schüring et al., 2000).

Turbidity

In September 2011, Whatshan Reservoir turbidity ranged from 0.7 NTU (Site 1-18) to 2.1 NTU (Site 1-17). Due to turbidity probe malfunction, turbidity readings at Sites 2-13, 3-6, 3-7, 3-8, and 6-3 were considered unreliable and Secchi disk readings were used for inter-site comparisons (see below). In Phase 3 (September 2015), turbidity ranged from 0.1 NTU (Site 1-17) to 3.1 NTU (Site 3-8) with no apparent relationship between reservoir location and turbidity values in Phase 3.

Turbidity typically ranges from 0 to 1,000 NTU in freshwater ecosystems (i.e., lakes and rivers), with values exceeding 10 NTU considered turbid (Gradall and Swenson, 1982). Turbidity is a measure of water clarity. Turbidity in water is caused by suspended matter (e.g., clay, silt, organic matter, plankton, other microscopic organisms) that interferes with the passage of light through water (APHA, 1998). Very clear water, however, is not necessarily a sign of good water quality, as suspended particles can be induced to fall (decreasing turbidity readings) by high acid or salt conditions. Turbidity of natural waters tends to increase during runoff events due to increased overland flow, stream flow and erosion. Increased turbidity reduces light penetration, thereby decreasing the growth of aquatic plants and organisms (Gradall and Swenson, 1982). Very turbid waters will reduce the diversity and coverage of macrophyte communities.

Transparency

Water transparency (clarity) was based on *in situ* visual observations and Secchi disk readings, and was high in the reservoir. Macrophyte communities present at most sites were small and restricted to waters immediately above bottom substrates (~20 cm). As such, visual detection of macrophytes was not always possible even at sites where bottom substrates were visible. Secchi depths were measured at each site. In Phase 2 (September 2011), light was visible to the bottom at all sites with the exception of Site 3-7 (4.4 m), 3-8 (4.4 m) and 2-13 (8.5 m). In Phase 3, light was visible to the bottom at all sites with the exception of Site 3-6 (5.79 m).

Water bodies with medium and dense macrophyte cover are characterized by a low concentration of suspended sediments and, thus, high water transparency. Such high water transparency enables light to penetrate deeper into the water column and decreases attenuation of photosynthetically active radiation (PAR) with depth, thereby facilitating colonization of macrophyte communities (usually adapted to low irradiances) in deeper areas (O’Sullivan and Reynolds, 2004). Conversely, water transparency decreases where coverage and density of aquatic macrophytes are reduced, such as in cases of eutrophication (Hargeby *et al*., 1994). In freshwater ecosystems, where macrophytes reappear after a period of absence, water transparency gradually improves with increasing vegetation cover.

3.3.2 Substrate Characteristics

Qualitative substrate observations were made at the near-shore, mid-distance and farthest from shore zones of the Centre Transect (i.e., C/A, C/B, C/C) for each site and are tabulated in Table A4-26 (Appendix 4).

Consistency and texture of substrates observed during baseline assessments varied throughout the reservoir ranging from ‘gritty’ and ‘gravelly’ to ‘silky’ and from ‘thick’, ‘pudding-like’ consistency to substrate that falls apart into pellets. No trends between qualitative sediment observations and zonation within the reservoir were reliably identified in Phase 2 (2011) or Phase 3 (2015). Variation in sediment quality was more consistent within a site than within a given reservoir zone.

Near-shore transect locations in the Lower Basin had gritty substrate in comparison with quadrats in the Middle and Upper Basins which were largely dominated by woody debris. Near-shore quadrats tended to have odourless substrates with substrate consistency being homogenous throughout. Near-shore sediment qualities were more attributed to site-specific factors than overall reservoir characteristics. Mid-distance from shore quadrats tended to have gritty substrates and were generally odourless and thick like pudding. Sites from the Middle Basin had a hydrogen sulphide (H_2S) odour at mid distance quadrats. Quadrats further from shore tended to reflect sediments with variable texture and consistency and with a distinct H_2S odour throughout the reservoir.

Near-shore quadrats, in general, were found to be dark brown colour while mid distance tended to be grey-green to brown-green colour and furthest from shore substrates were grey-green. Sediment colouration did not appear to vary with reservoir proximity in the reservoir and were likely a function of water depth.

Hydrogen sulphide (H_2S) imparts sediments with a distinctive smell (i.e., odour reminiscent of rotten eggs), and usually indicates anoxic sediments (i.e., lack of oxygen). Anthropogenic activities are usually an important source of organic matter in reservoirs and can cause anoxic sediments. Sites 3-6 and 3-8 in the middle basin of Whatshan Reservoir had distinct H_2S odours and were however not visibly impacted by anthropogenic activities.

During both Phase 2 (2011) and Phase 3 (2015) assessments in Whatshan Reservoir, there was no obvious trend in sediment characteristics with reservoir zonation. Observed differences were attributed to site-specific factors (i.e., accumulation of woody debris) rather than specific reservoir characteristics or location (i.e., north to south flow).

3.4 Anthropogenic Activities

Upland areas surrounding Whatshan Reservoir showed considerable evidence of current and historic logging activities. Primary access to forestry sites was via a network of visible logging roads. Little forestry activity was evident in areas immediately adjacent to Whatshan Reservoir with the exception of a clearing for BC Hydro High Voltage right-of-way near Whatshan Dam in the Lower Basin.

No permanent point or non-point waste discharges were observed along Whatshan Reservoir foreshore. Campgrounds in the Upper Basin (Stevens Creek and Richy Park) were not observed during field assessments.

Recreational activities in and around Whatshan Lake are generally concentrated during summer months with the peak period occurring between May and October. There are reportedly three boat launches in Whatshan Reservoir, one (Inonoaklin beach) was located and used during Phase 2 and Phase 3 field assessments. Boat launches and campgrounds at Steven’s Creek and Richy Park were not observed and may have been decommissioned or were not visible from the water. The area surrounding the site locations appeared otherwise undisturbed.

4.0 SUMMARY & DISCUSSION

BC Hydro's Management Objective to reduce the uncertainty of the effects of reservoir operations on reservoir vegetation in the Whatshan Lake Reservoir was addressed. Given the absence of detailed results from Phase 1 (2006), Phase 2 was used to establish a baseline for Phase 3 (2016) comparisons and as a framework for addressing management hypotheses, as defined in Table 4-1, below.

Whatshan Reservoir was impounded in 1951 by the British Columbia Power Commission and currently generates 121 GWh annually. A Water Use Planning Process was initiated for Whatshan Reservoir in 2002 and resulted in recommendations that included:

- an increase in the minimum year-round water elevations to 636.5 m (previously 634 m); and,
- annual increases in minimum reservoir elevation occurring earlier in the year (i.e., minimum of 639 m by May 15th and a minimum of 640.35 m between June 15th and October 1st of each year).

A proposed earlier rise of water in spring was hypothesized to be potentially beneficial to submergent communities while potentially detrimental to emergent vegetation. Macrophyte (i.e., emergent and submerged) communities play an important role in fish and wildlife habitat. Biophysical changes in the littoral zone of reservoirs, associated with periodic drawdown and inundation (including frequency and duration), typically have notable effects (positive or negative) on macrophyte development. Macrophyte species are sensitive to physical and chemical changes in the surrounding environment and macrophyte mobility is limited with development dependant on environmental parameters in both reservoir water and sediments.

Due to a lack of information regarding potential effects of spring and winter reservoir elevation on vegetative communities and fisheries and wildlife resources and habitat, as well as a general concern expressed during the consultative process, a pre- (Phase 1), mid (Phase 2) and post-project (Phase 3) assessment of vegetative communities was recommended, and subsequently approved, to verify predictions on changes to vegetative communities.

Objectives and management questions were established prior to commissioning a Whatshan Reservoir Vegetation Monitoring Program. As part of this program study design and field methodologies were designed to address study-specific objectives and address these management questions. The Objective of the Whatshan Reservoir macrophyte survey was to:

Reduce uncertainty related to the effects of reservoir operations on reservoir vegetation in the Whatshan Lake Reservoir. Monitoring will focus on key locations where aquatic vegetation is present (Bennett et al. 2002), and primarily examine large-scale changes in the boundaries of vegetation communities.

Key management questions included:

Do changes in the operation of the Whatshan Lake Reservoir affect reservoir vegetation?

Table 4-1: BC Hydro Status of Objectives Table

Objectives	Management Questions	Management Hypotheses	Year Six (2011) Status	Year Ten (2016) Status
Reduce uncertainty related to the effects of reservoir operations on reservoir vegetation in the Whatshan Lake Reservoir. Monitoring will focus on key locations where aquatic vegetation is present (Bennett et al. 2002), and primarily examine large-scale changes in the boundaries of vegetation communities.	Do changes in the operation of the Whatshan Lake Reservoir affect reservoir vegetation?	H1: The area of emergent vegetation will decrease as a consequence of extended inundation.	Tentatively Supported, to be confirmed in 2016	Rejected
		H1a: The species composition of emergent vegetation will change as a consequence of extended inundation.	Not as yet addressed, to be assessed in 2016	Accepted
		H2: The area of submerged vegetation will increase as a consequence of extended inundation.	Tentatively Supported, to be confirmed in 2016	Rejected
		H2a: The species composition of submerged vegetation will change as a consequence of extended inundation.	Not as yet addressed, to be assessed in 2016	Accepted

Note: Emergent and submergent species composition change may have been due, at least in part, to additional climate variables.

Satellite map multispectral imaging produced in Phase 2 and Phase 3 were created and attenuated using field results then used to identify size and presence of emergent and submergent vegetation communities and track changes in communities over time. Eight long-term study sites were selected for Phase 2 and Phase 3 assessments to verify algorithm accuracy and assess macrophyte community distribution and composition (i.e., location, depth, relative abundance, biodiversity, etc.) following changes to the Whatshan WUP in 2006. Detailed results from the Phase 1 (2006) baseline assessment were not available to enable comparison of vegetative community compositions or macrophyte coverage between years (Phase 1, 2 and 3).

Outcomes for each of the four Management Hypotheses are discussed below:

H1: Area of emergent vegetation will decrease as a consequence of extended inundation

An earlier increase in reservoir elevation in the spring (i.e., minimum of 639 m by May 15th of each year) and a resulting extension in the inundation period was hypothesized to potentially decrease the area of emergent macrophyte vegetation in Whatshan reservoir.

Emergent macrophyte areas as assessed at the eight long-term monitoring sites showed a slight decrease from 2011 to 2015; however, there was no statistically notable difference in emergent macrophyte area between 2011 and 2015. As a result, Hypothesis H1 was rejected.

During all three Phases of the monitoring program, emergent vegetation was observed to be constrained to a small elevation band (estimated between 640 m and 643 m in Phase 2 and Phase 3) and primarily observed on gently sloping shores. As described in the Phase 1 report (Moody, 2007), emergent vegetation tends to occur at elevations near the summer operating level (minimum of 640.35 m between June 15th and October 1st of each year). Elevation changes occurring during the growing season in Whatshan Reservoir may be more typical of natural wetlands rather than other BC reservoirs, acting to mitigate impacts to emergent vegetation communities.

H1a: Species composition of emergent vegetation will change as a consequence of extended inundation

Although the area of emergent vegetation did not appear to change as a consequence of extended inundation, species composition data indicated overall changes. Nine (9) emergent species were recorded only in 2011 and six (6) emergent species recorded only in 2015. Differences in macrophyte composition were noted between 2011 and 2015 at each site (Chart A3-11, Appendix 3). Results for Phase 2 and Phase 3 suggested that Hypothesis H1a be accepted; however, it should be noted that it remains unclear if changes in emergent species composition were a consequence of extended inundation or due at least in part to climate variables (e.g., precipitation amount and frequency, temperature), without detailed Phase 1 species composition data.

Extensive marsh communities, noted at Sites 1-17, 1-18, 3-7 and 3-8, tended to be associated with residual log debris that overtime has started to decompose and become in-filled, facilitating ecological succession through plant development. Several streams were also noted to discharge at or near sites with extensive emergent communities (with the exception of Site 3-7). These water sources may also provide moisture and nutrients to sustain emergent communities during lower drawdown periods and may contribute to emergent community success. Additional biophysical observations (water quality and substrate characteristics) at each of the eight (8) long-term monitoring sites showed no discernable trends between Phase 2 (2011) and Phase 3 (2015).

H2: Area of submerged vegetation will increase as a consequence of extended inundation

An earlier increase in reservoir elevation in the spring and resulting extended inundation period was hypothesized to potentially increase the area of submerged macrophyte vegetation in Whatshan Reservoir. Long-term monitoring sites were used to establish standardized boundaries for macrophyte community comparisons over time within the reservoir in Phase 2 and Phase 3.

Submerged macrophytes were observed on average between 637.4 m to 640.0 m (Phase 2) and 637.8 m to 640.6 m in (Phase 3). Mean areas of submerged vegetation from the eight established long-term monitoring sites decreased slightly from 2011 to 2015; however, there was no statistically notable difference in submerged macrophyte area between the two years. As a result, Hypothesis H2 was rejected.

Elevation ranges occupied by submerged macrophyte communities are dewatered in the winter months each year. The earlier rise of water levels in the spring is likely to enhance submerged development and growth earlier in the season.

H2a: Species composition of submerged vegetation will change as a consequence of extended inundation

Long-term site survey results in Phase 2 and Phase 3 indicated that submerged macrophyte composition was significantly different between the two years (Chart A3-12, Appendix 3; $p<0.01$, ANOSIM). As a result, Hypothesis H2a was accepted, though species composition data were not collected in 2006. Factors other than water level may affect growth and composition of submerged macrophyte species. Annual variability may also be dependent on climatic factors such as water quality, and sediment conditions.

Dominant submerged species included *Chara* sp. and *Isoetes* sp. in 2011, and *Isoetes* sp., *Najas flexilis* and *Crassula aquatica* in 2015; however, there were no apparent trends in the quadrat frequency of dominant species between the two phases. Overall submerged vegetation classes were substantially different between Phase 2 and Phase 3. *Crassula aquatica* and *Isoetes sp.* were observed frequently in nearshore communities (Class 2). *Najas flexilis* and *Chara sp.* were associated with community Class 1. *Chara* sp. (algae), *Isoetes* sp. *Najas flexilis* and *Crassula aquatica* are submerged species that are rooted or anchored in the sediment and often considered marginal plants, located in shallow water that may grow partially or completely out of the water in late summer when water levels drop. Isoetes sp. and *Najas flexilis* are perennial species while *Crassula aquatica* is an annual species. In general, most aquatic species observed in all three phases were perennial. Though annual species are likely more susceptible to environmental disturbances, no obvious trends were observed.

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Appendices

Appendix 1

Figures

Appendix 1-1

Figures – Whatshan Reservoir

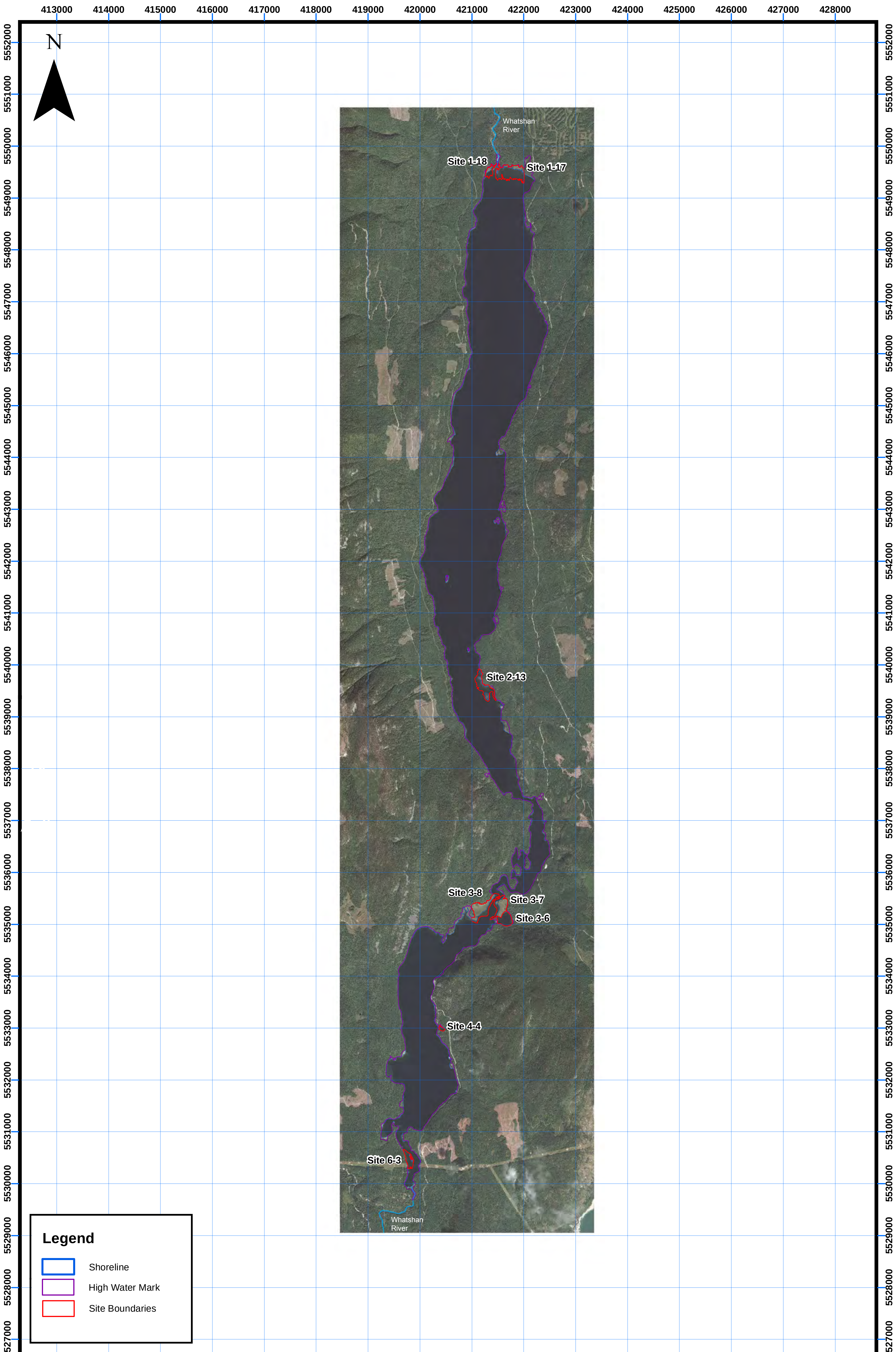

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Figure A1-1a: Whole Reservoir True Colour

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:65,000

0 750 1,500 3,000 Meters

1 centimeter = 650 meters

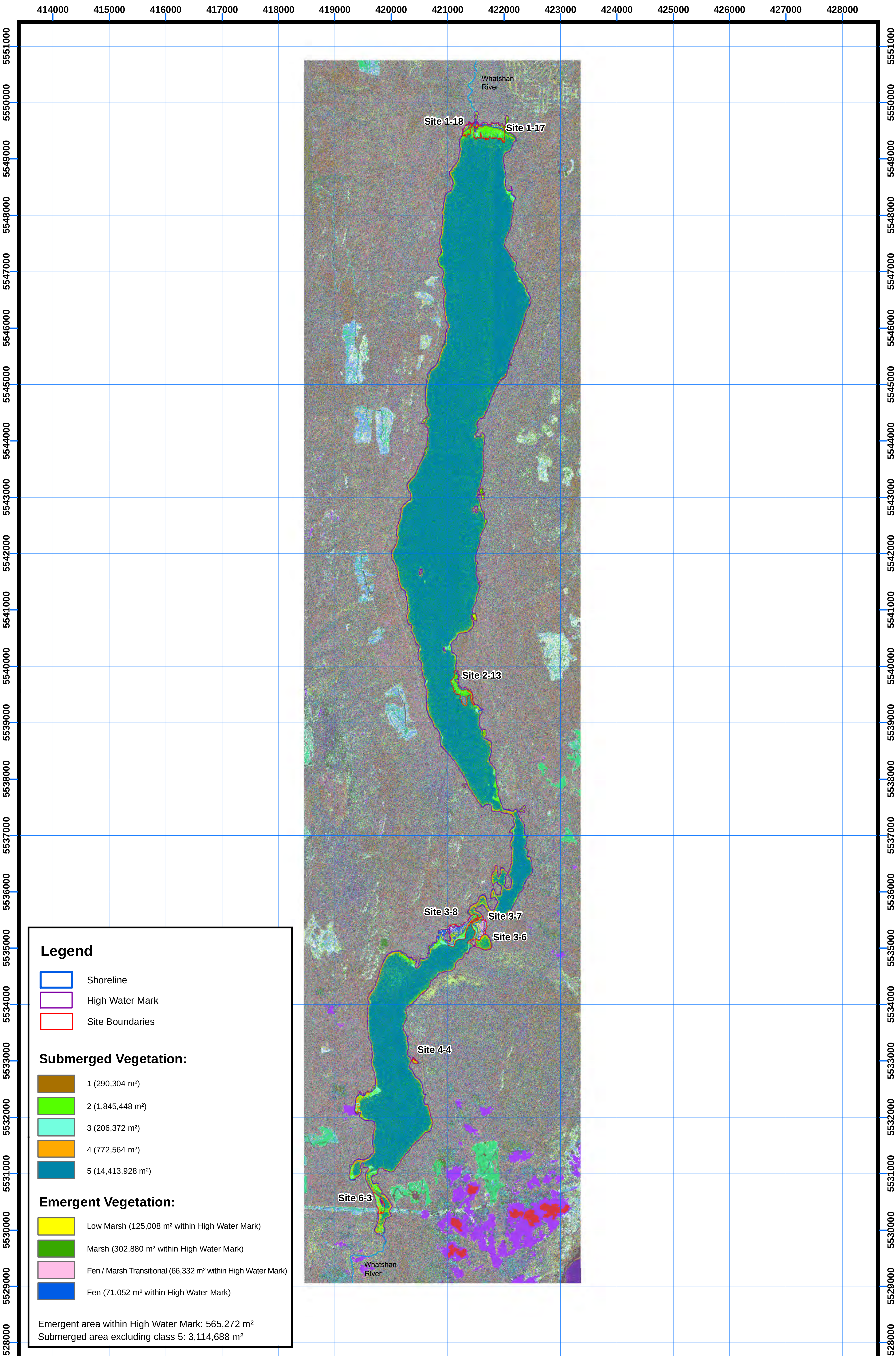

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Figure A1-1b: Whole Reservoir Spectral Classification

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:60,000

0 0.5 1 2 Kilometers

1 centimeter = 600 meters

Appendix 1-2

Figures – Site Spectral Vegetation

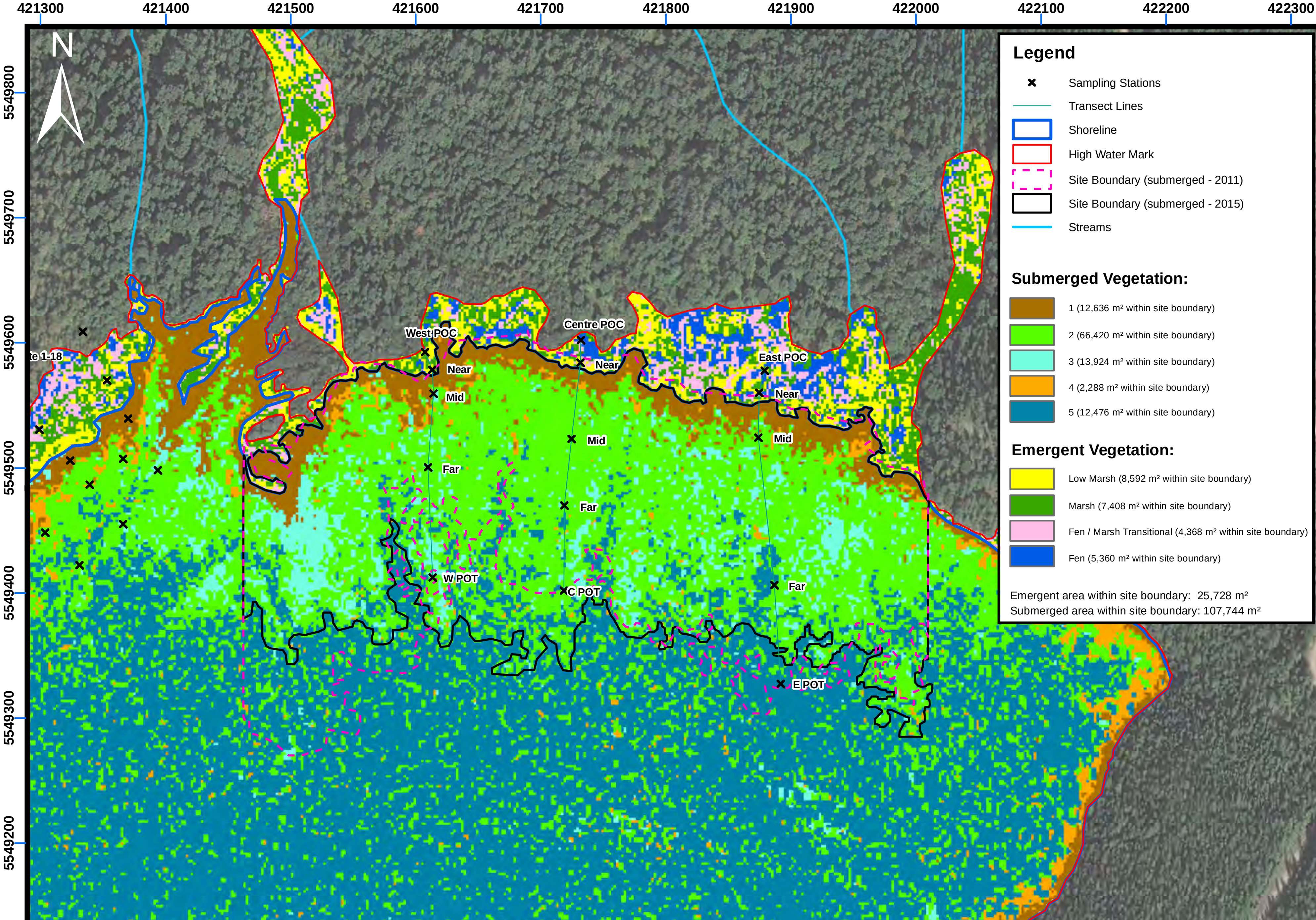

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Figure A1-2a: Site 1-17 Spectral Vegetation Classifications

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:4,000

0 50 100 200 Meters

1 centimeter = 40 meters

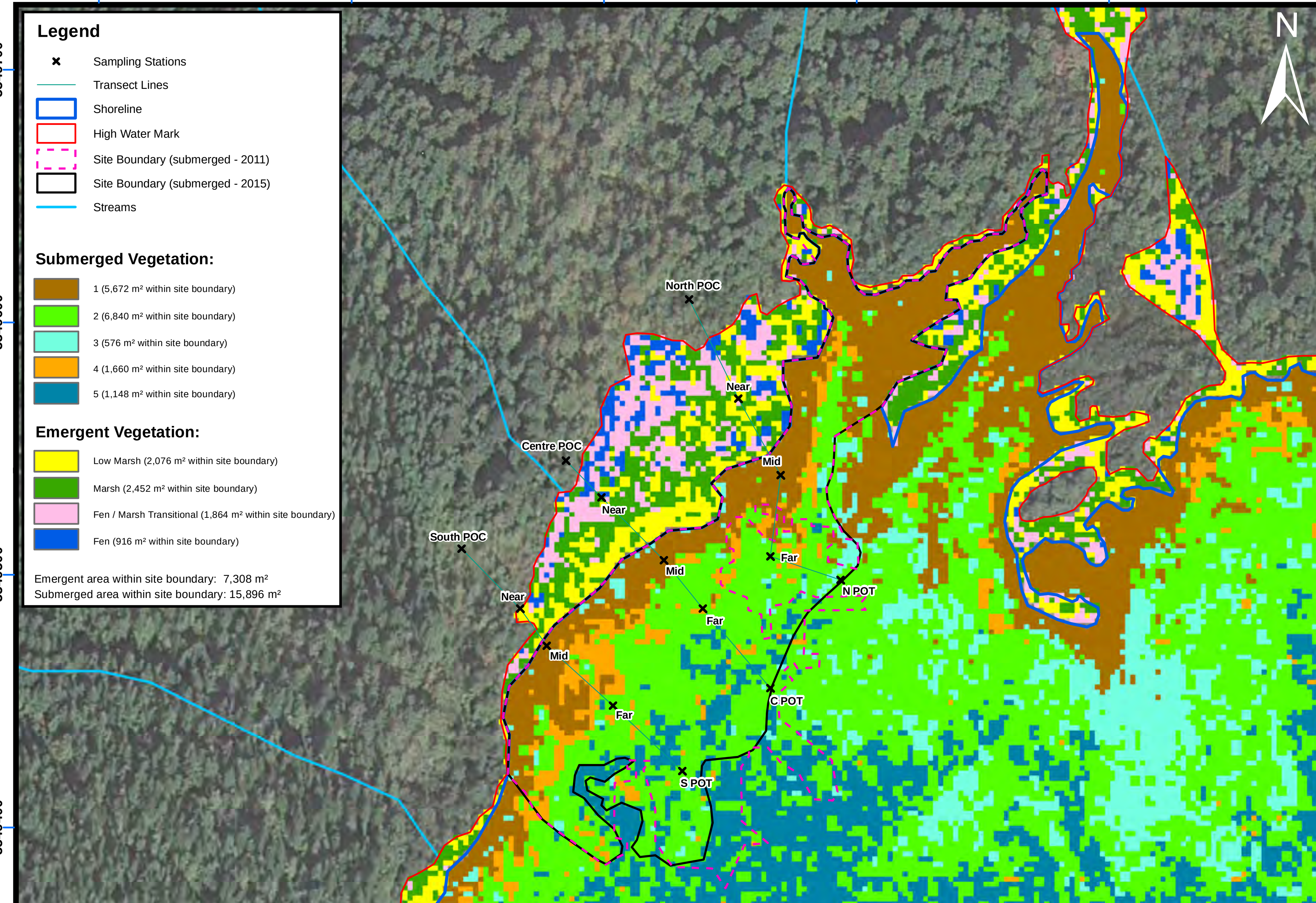

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Figure A1-2b: Site 1-18 Spectral Vegetation Classifications

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:2,000

0 25 50 100 Meters

1 centimeter = 20 meters

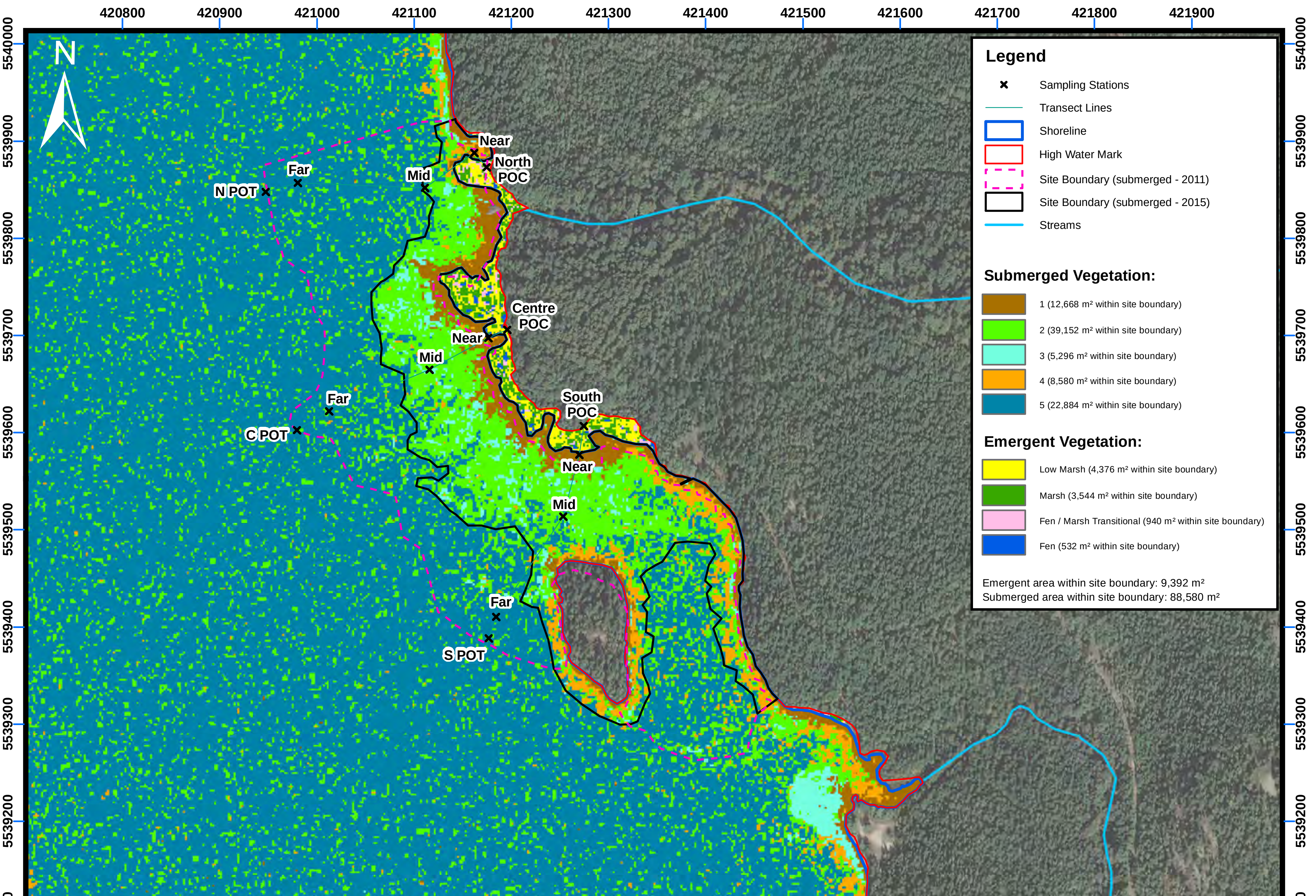

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Figure A1-2c: Site 2-13 Spectral Vegetation Classifications

Date/Author: 11/05/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:5,000

0 25 50 100 150 200 Meters

1 centimeter = 50 meters

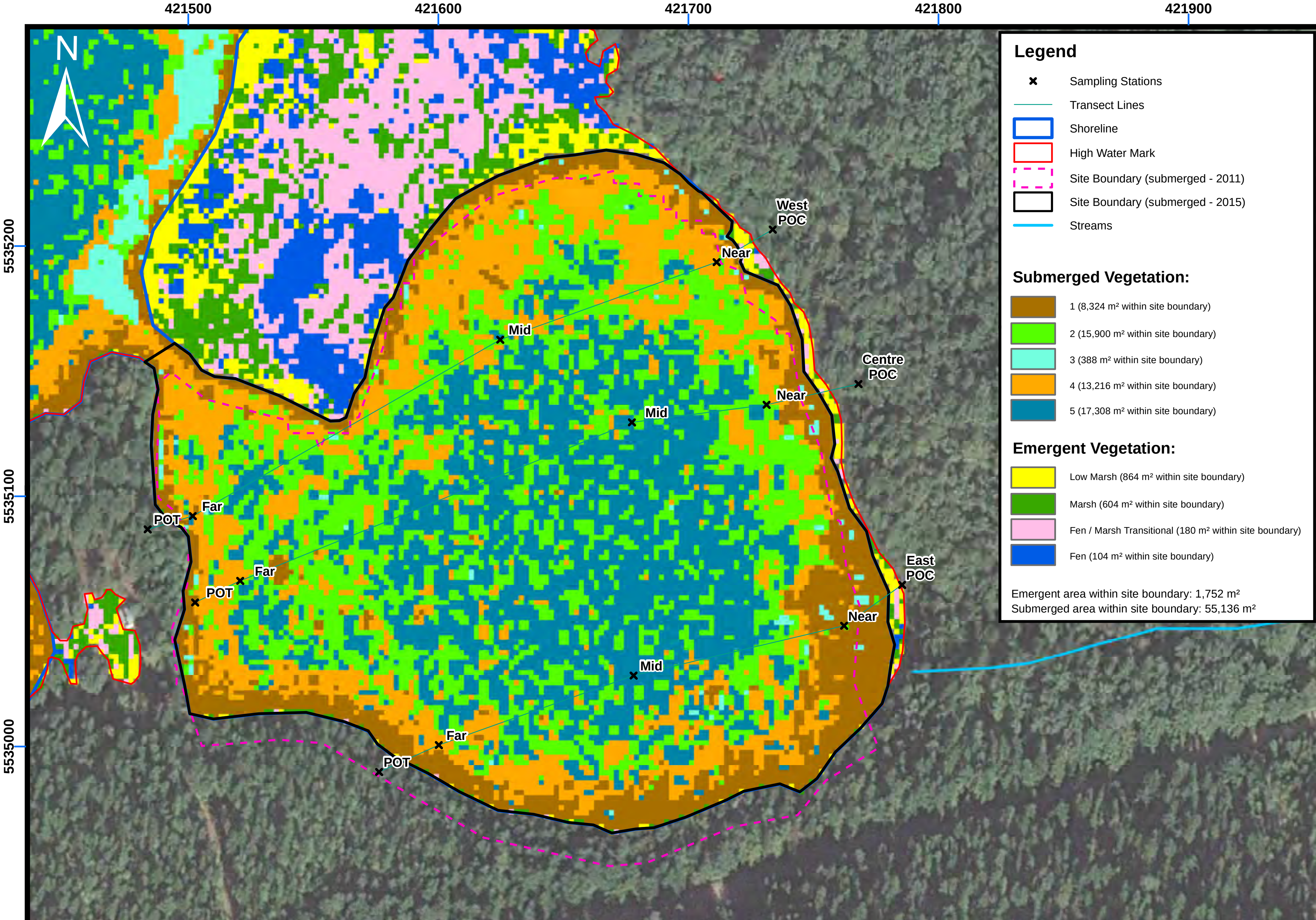

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Figure A1-2d: Site 3-6 Spectral Vegetation Classifications

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:2,000

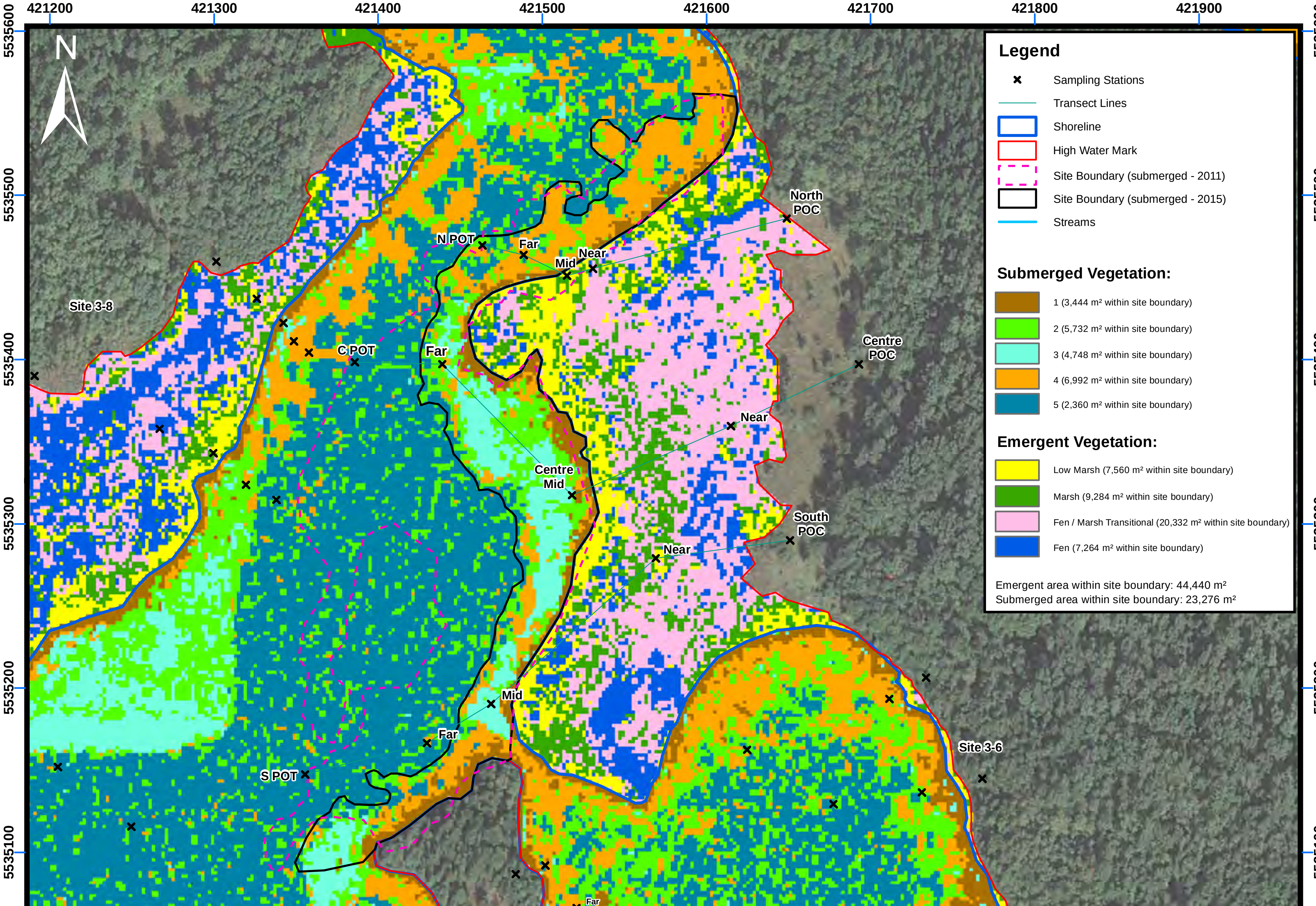

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Figure A1-2e: Site 3-7 Spectral Vegetation Classifications

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:3,000

0 37.5 75 150 Meters

1 centimeter = 30 meters

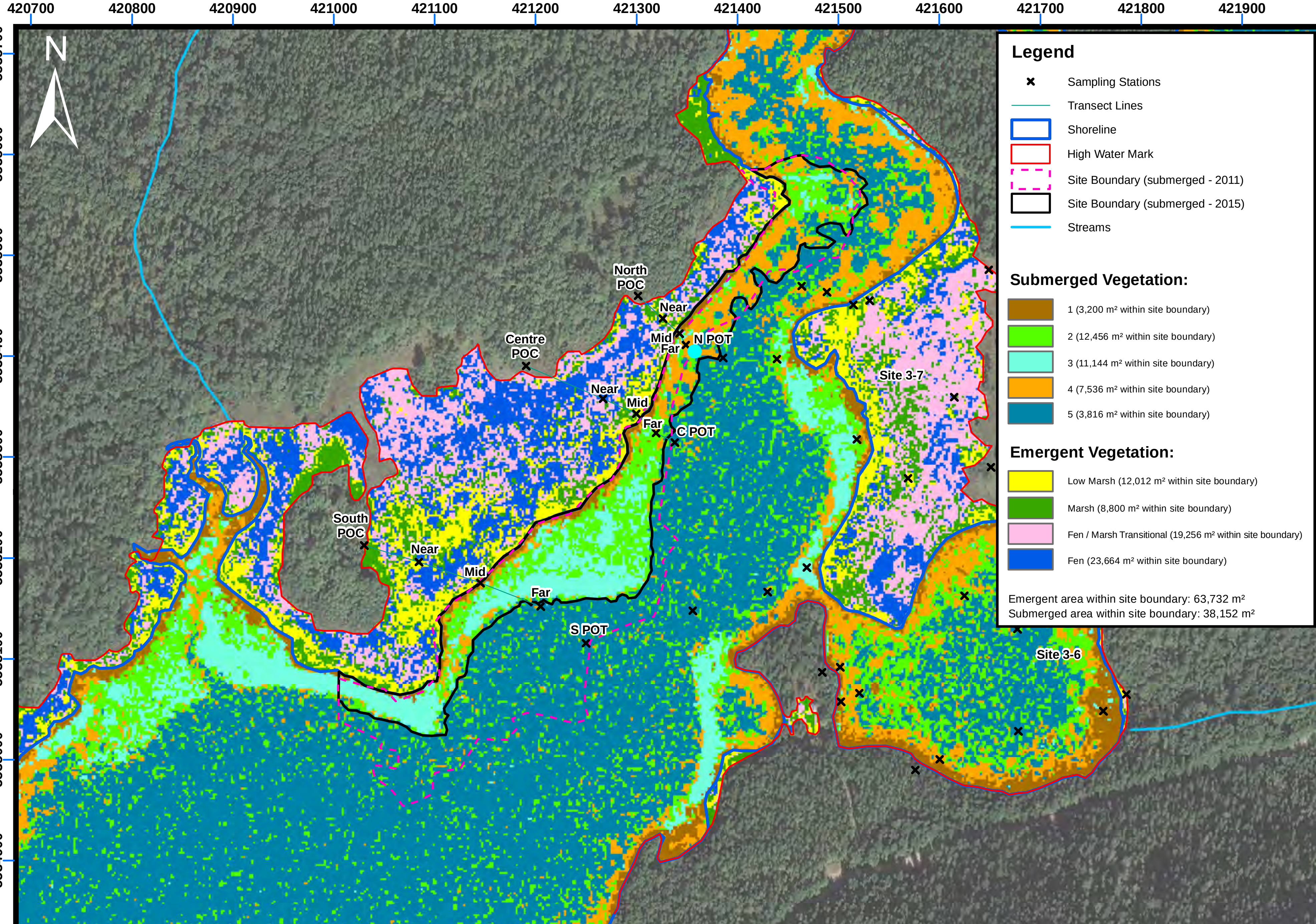

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Figure A1-2f: Site 3-8 Spectral Vegetation Classifications

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:5,000

0 62.5 125 250 Meters

1 centimeter = 50 meters

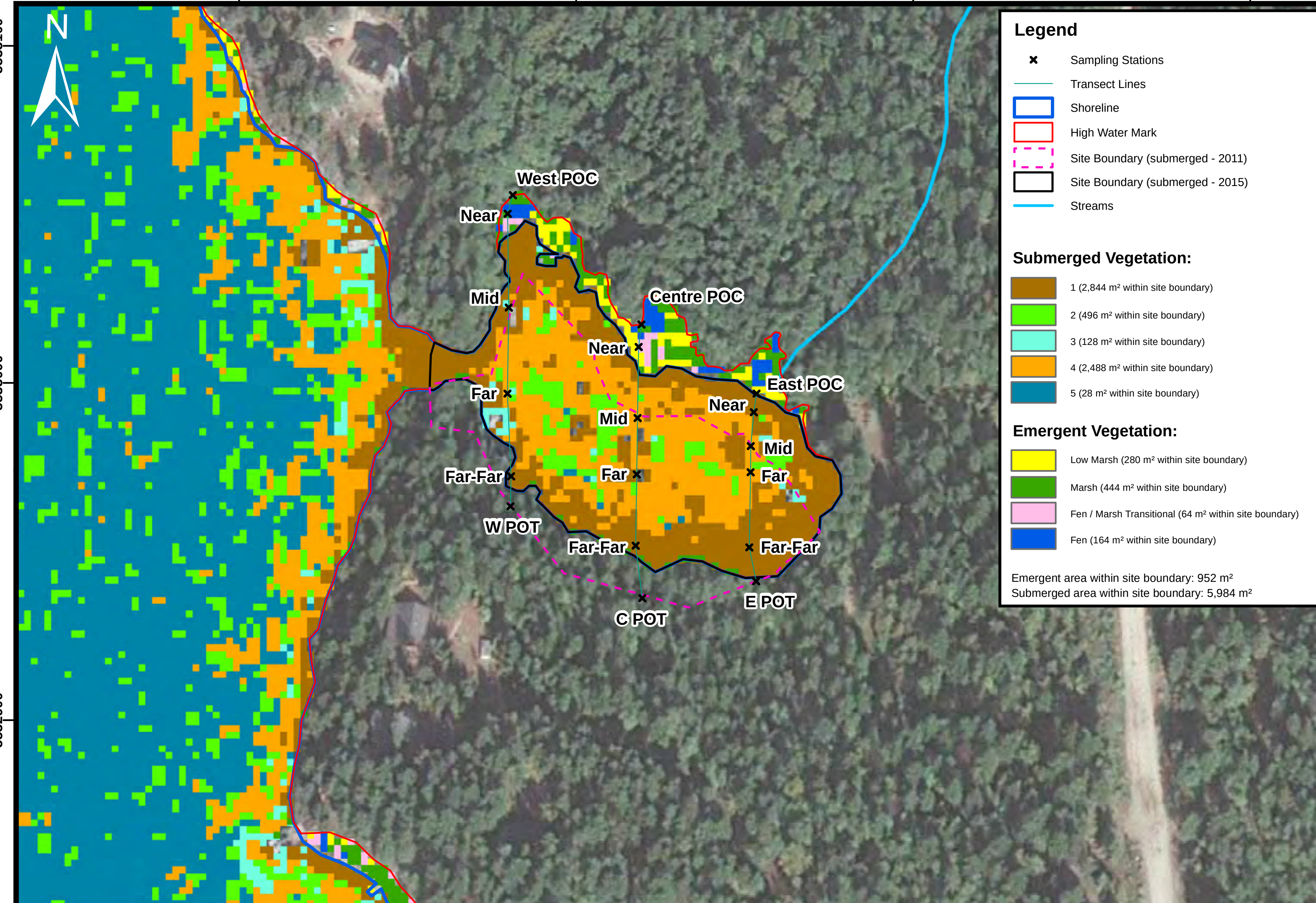

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Figure A1-2g: Site 4-4 Spectral Vegetation Classifications

Date/Author: 11/05/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:1,500

0 25 50 Meters

1 centimeter = 15 meters

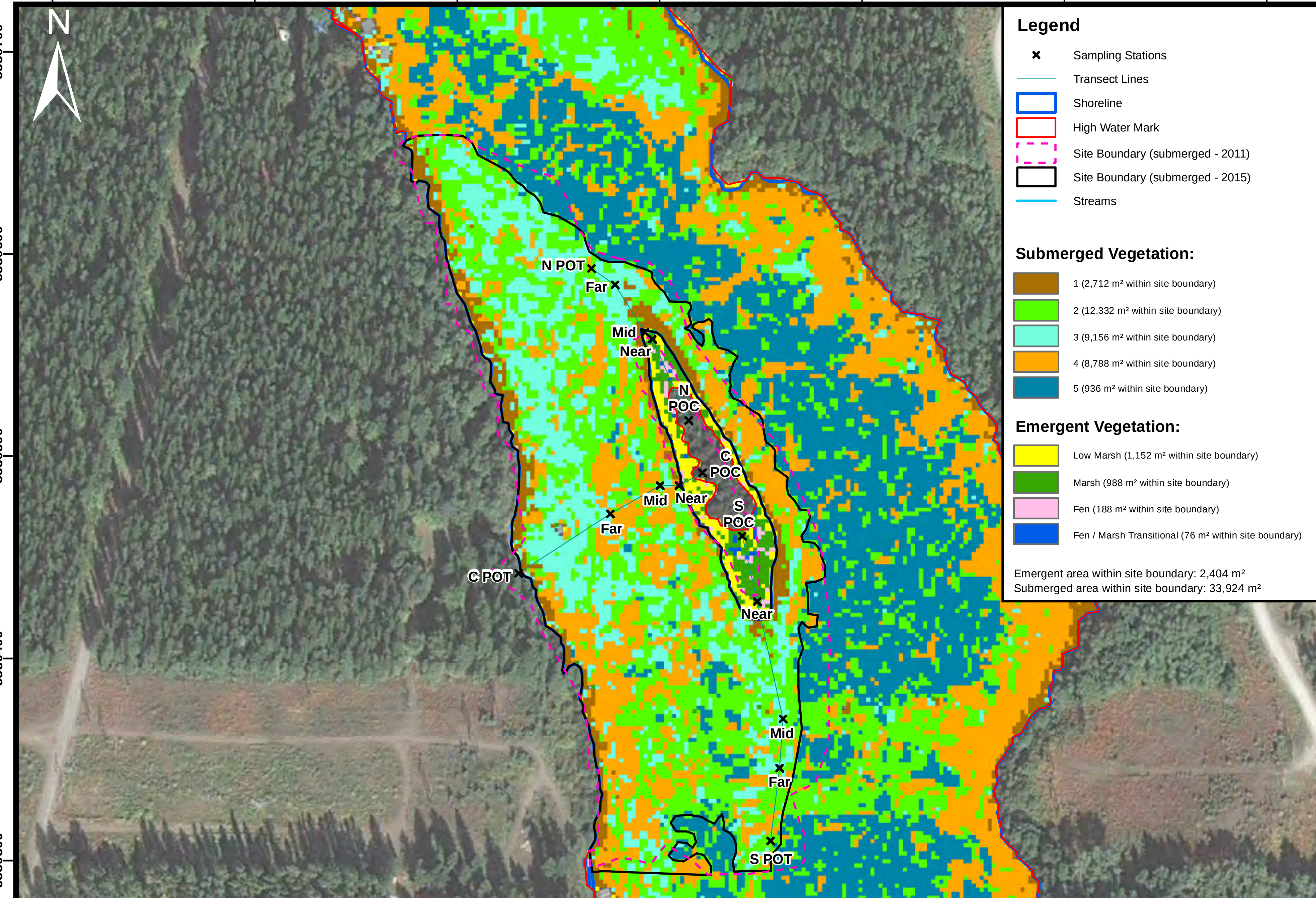

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Figure A1-2h: Site 6-3 Spectral Vegetation Classifications

Date: 15/10/2015
Coordinate System: NAD83 UTM Zone 11
Scale: 1:2,500

0 25 50 100 Meters

1 centimeter = 25 meters

Appendix 1-3

Figures – Site Bathymetry

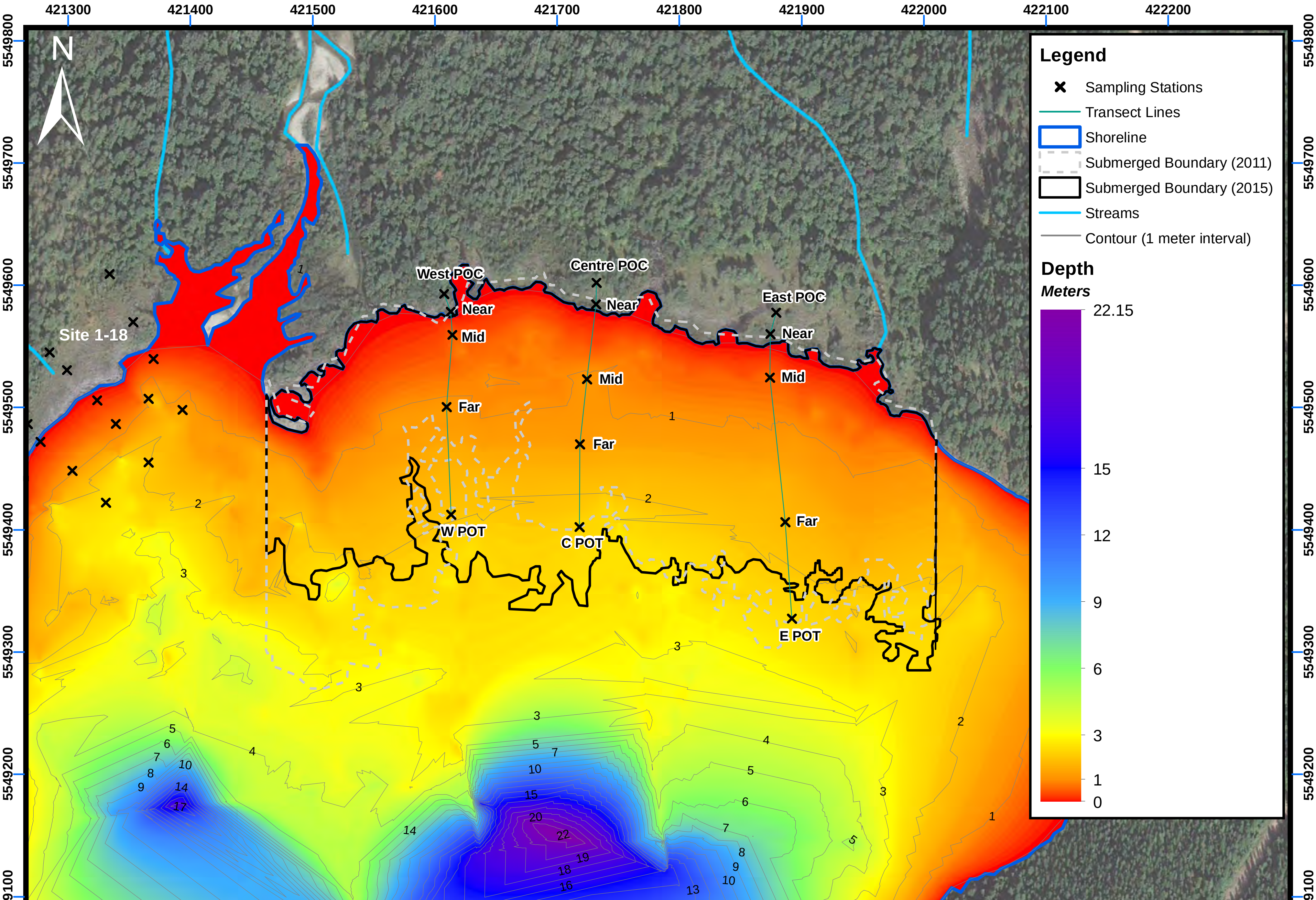

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Figure A1-3a: Site 1-17 Bathymetry

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:4,000

0 50 100 200 Meters

1 centimeter = 40 meters

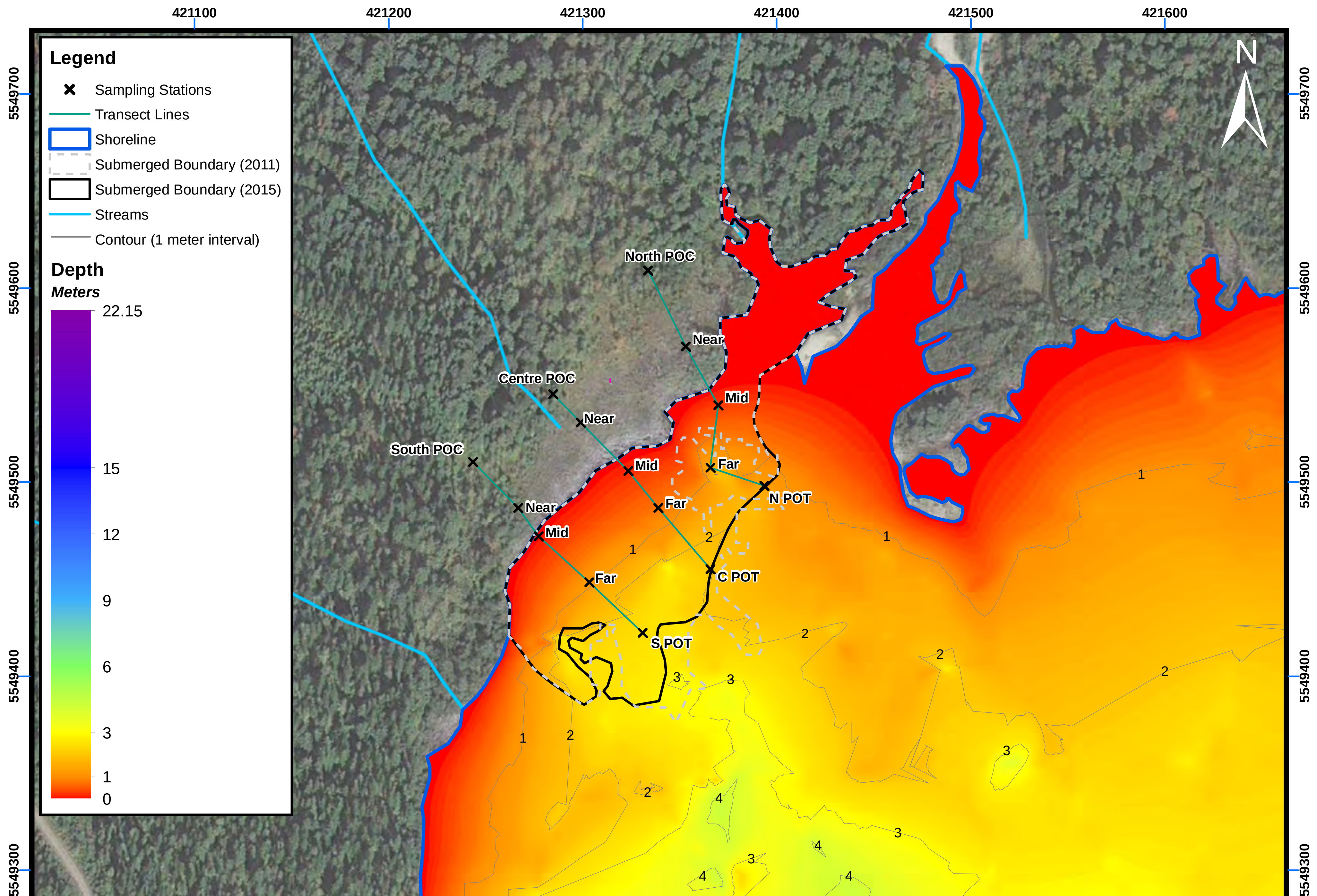

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Figure A1-3b: Site 1-18 Bathymetry

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:2,500

0 30 60 120 Meters

1 centimeter = 25 meters

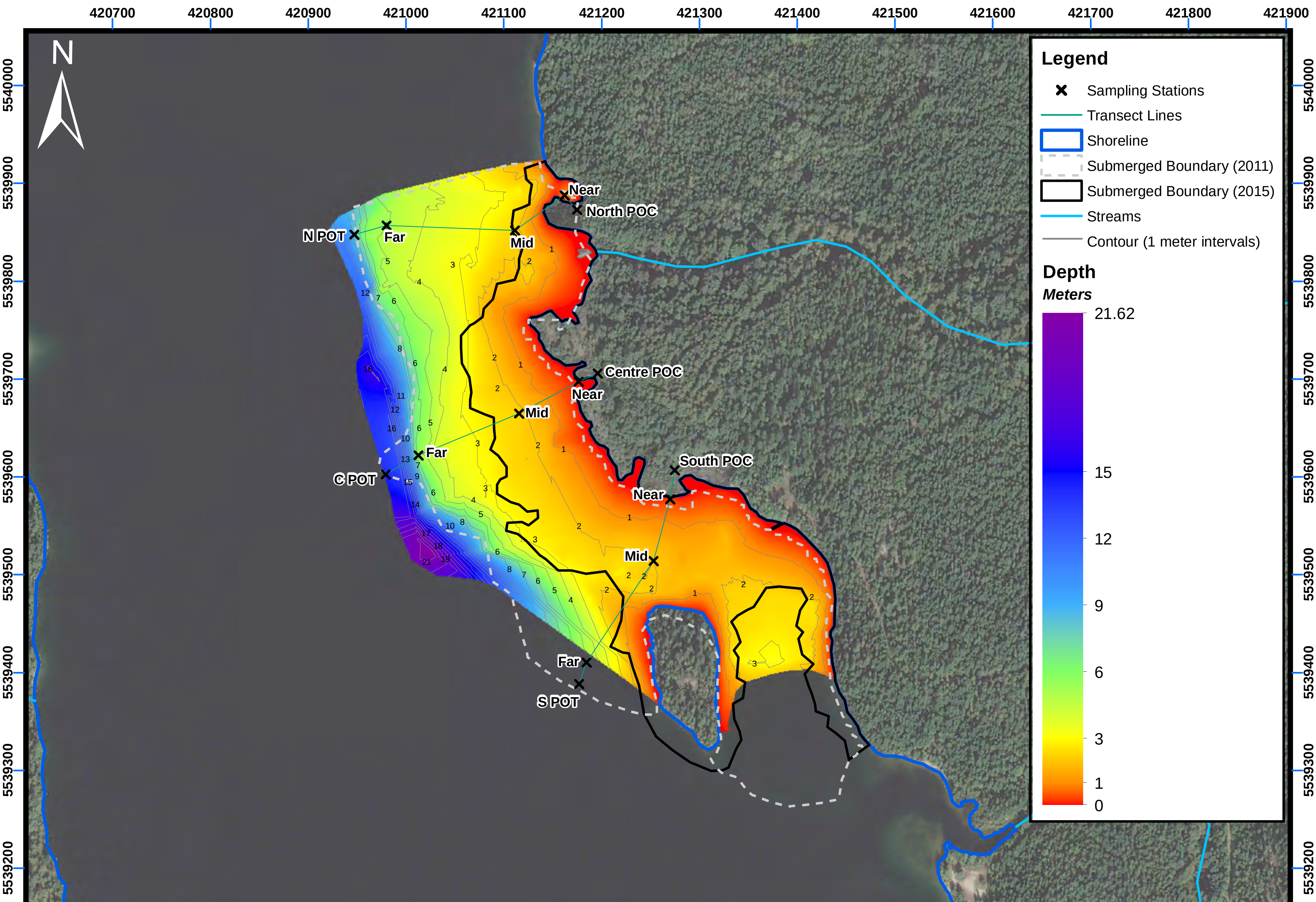

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Figure A1-3c: Site 2-13 Bathymetry

Date/Author: 11/05/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:5,000

0 25 50 100 150 200 Meters

1 centimeter = 50 meters

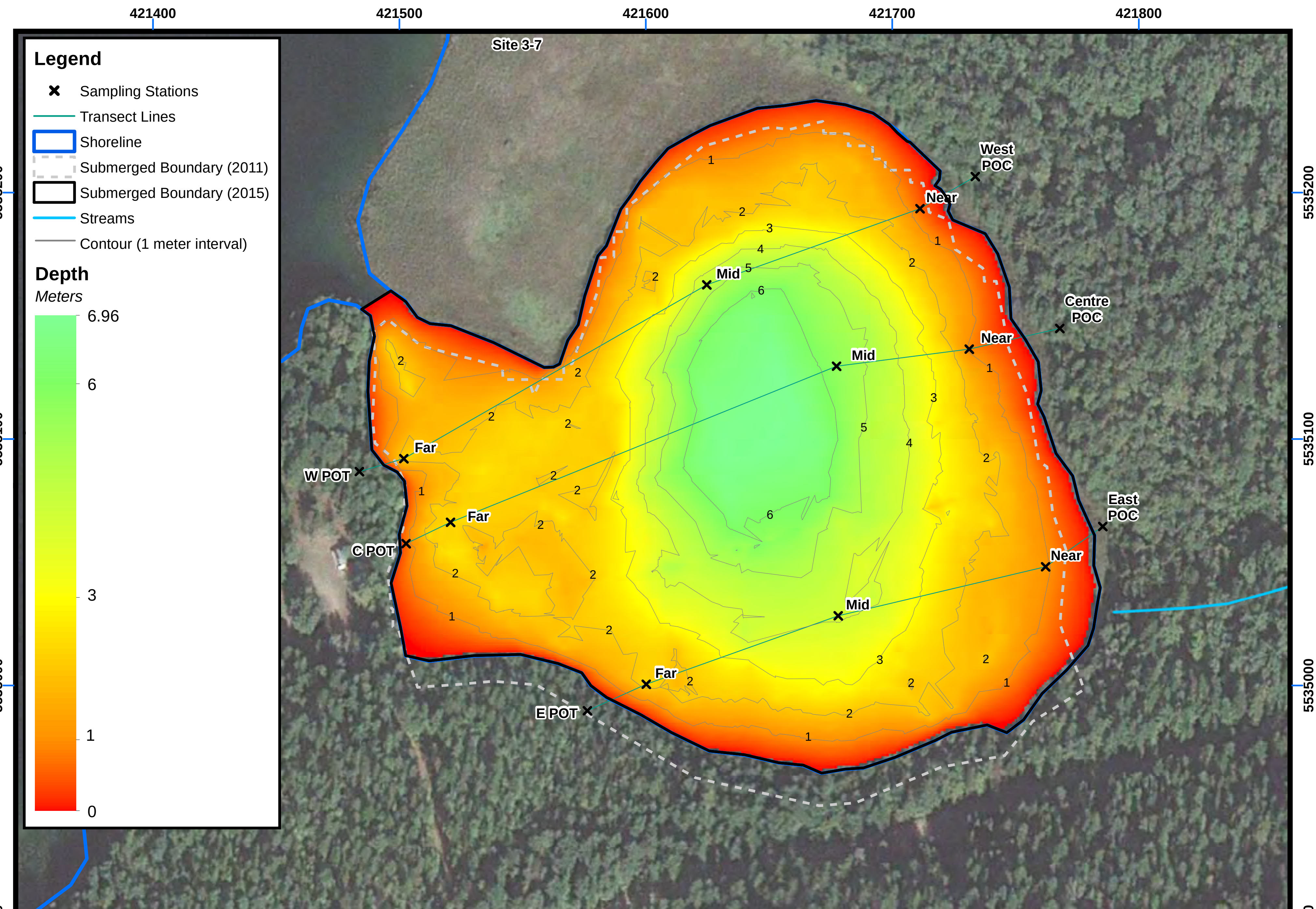

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Figure A1-3d: Site 3-6 Bathymetry

Date/Author: 11/05/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:2,000

0 50 100 Meters

1 centimeter = 20 meters

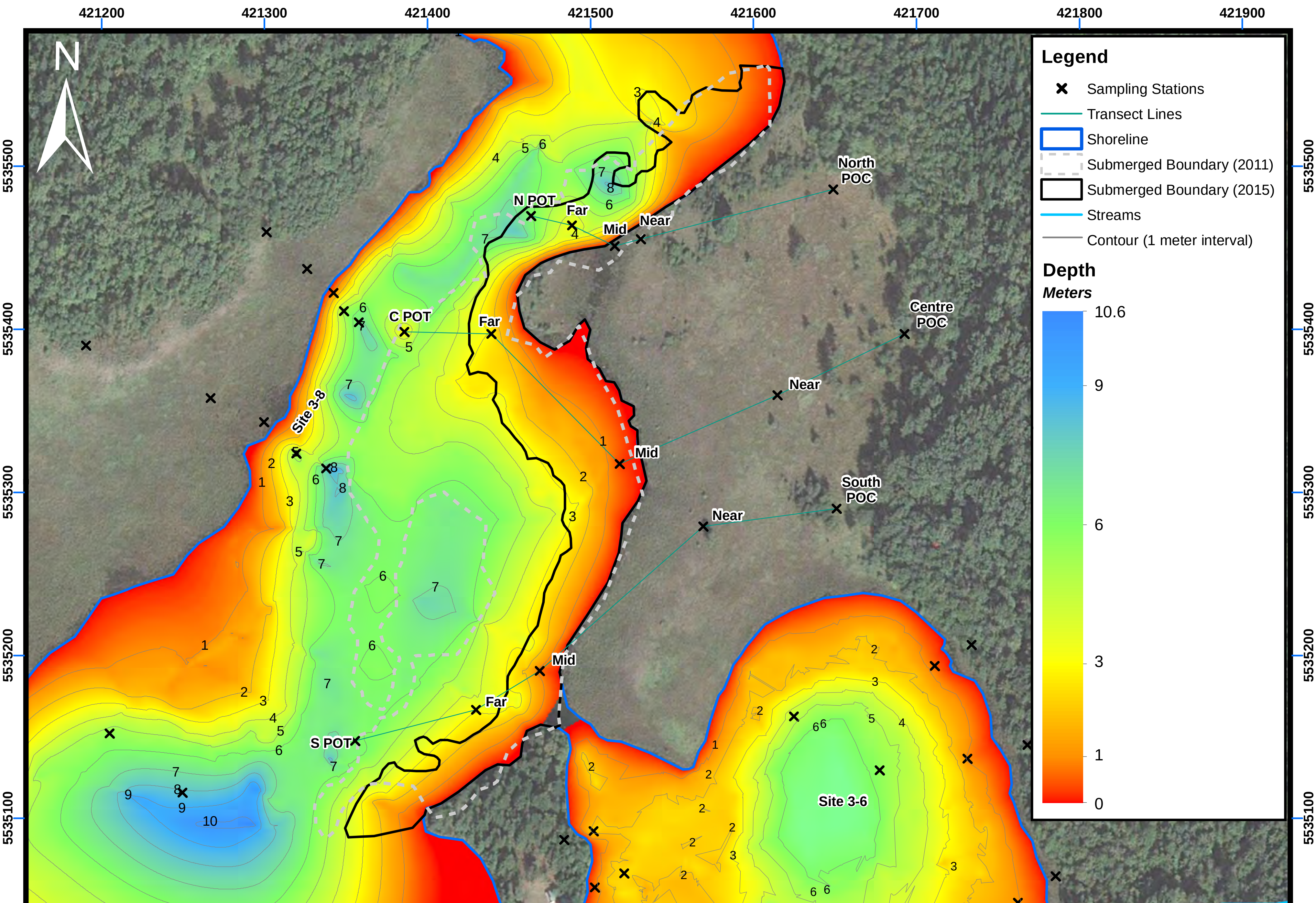

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Figure A1-3e: Site 3-7 Bathymetry

Date/Author: 11/05/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:3,000

0 50 100 200 Meters

1 centimeter = 30 meters

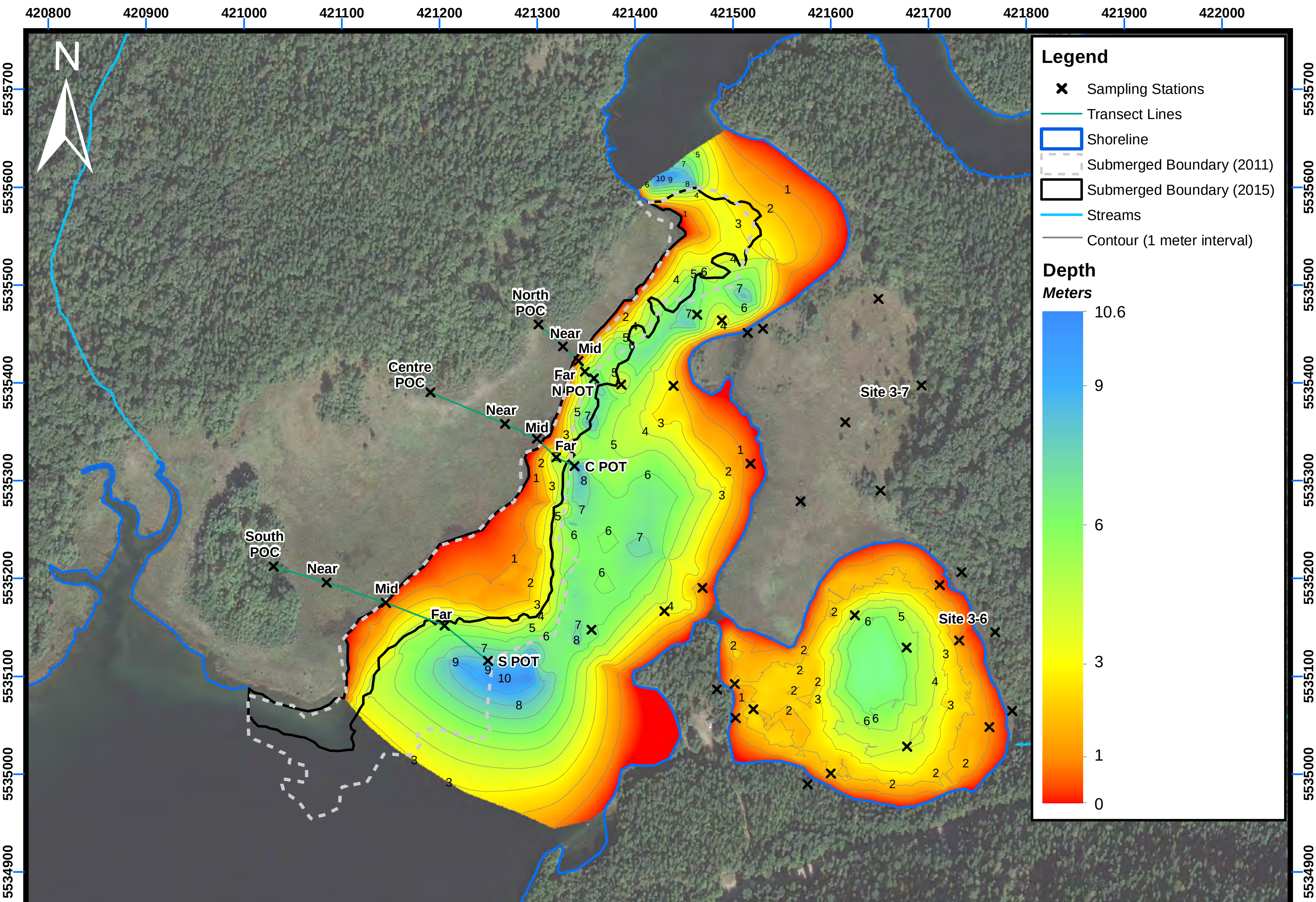

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Figure A1-3f: Site 3-8 Bathymetry

Date/Author: 11/05/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:5,000

0 87.5 175 350 Meters

1 centimeter = 50 meters

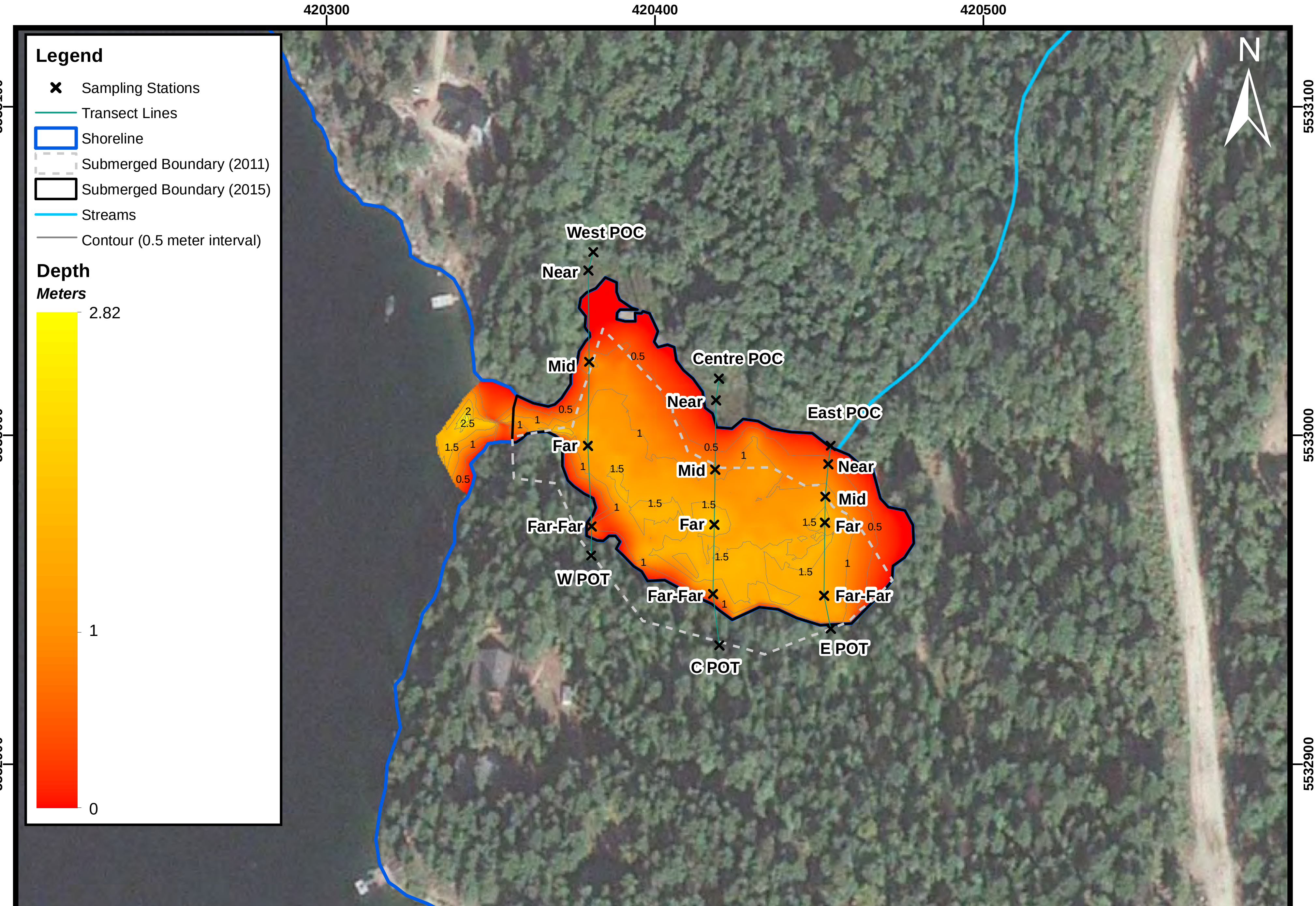

Figure A1-3g: Site 4-4 Bathymetry

Date/Author: 11/05/2015, C. Adamson

Coordinate System: NAD83 UTM Zone 11

Scale: 1:1,500

0 25 50

Meters

1 centimeter = 15 meters

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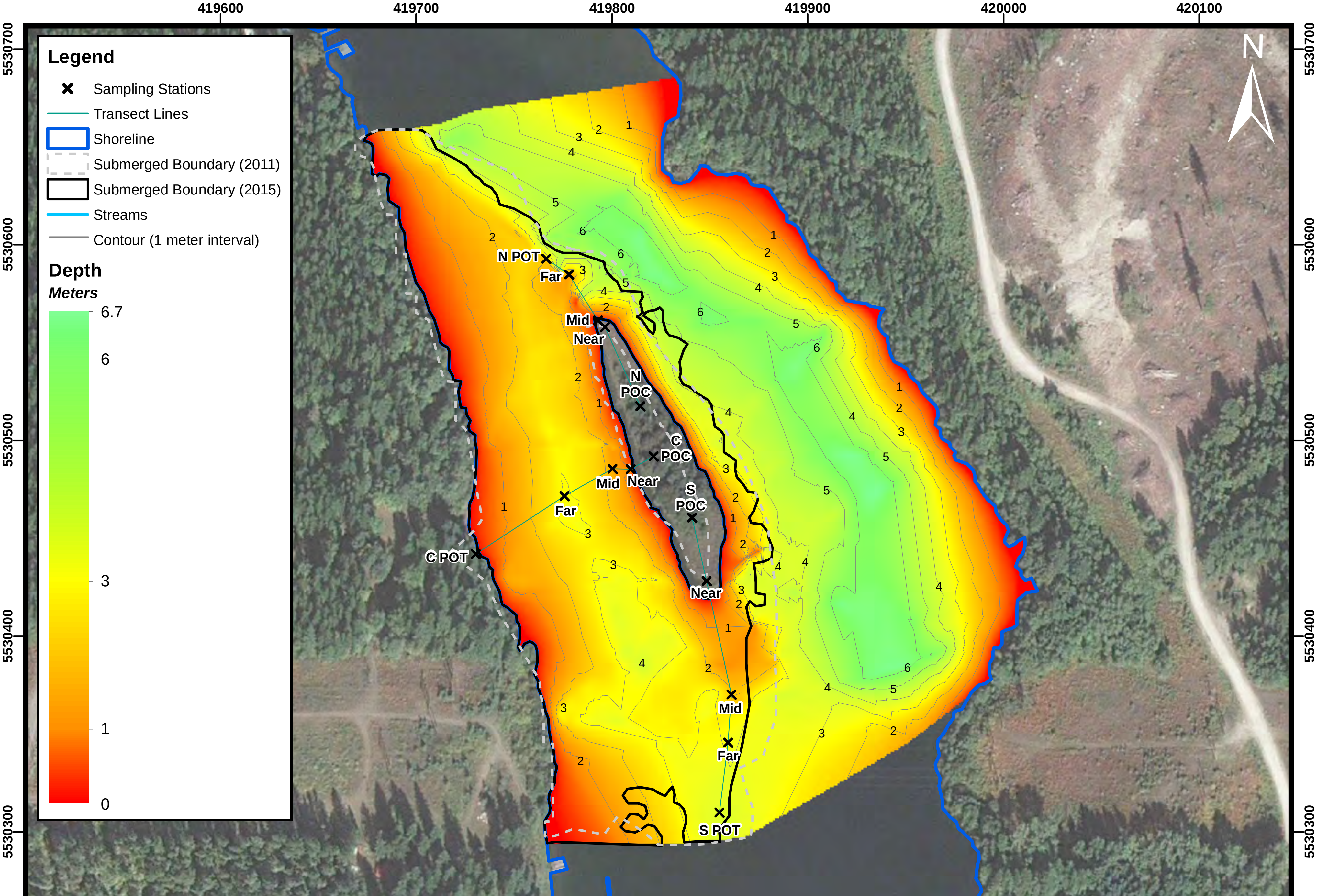

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Figure A1-3h: Site 6-3 Bathymetry

Date: 15/10/2015
Coordinate System: NAD83 UTM Zone 11
Scale: 1:2,500

0 25 50 100 Meters

1 centimeter = 25 meters

Appendix 2

Photos

2-1 Site Overview
2-2 Methodology

Appendix 2-1

Photos – Site Overview

Appendix 2-1: Site Description 6-3

Photo 1-1: Looking northwest at macrophytes on south side of Site 6-3 (September 30, 2011)

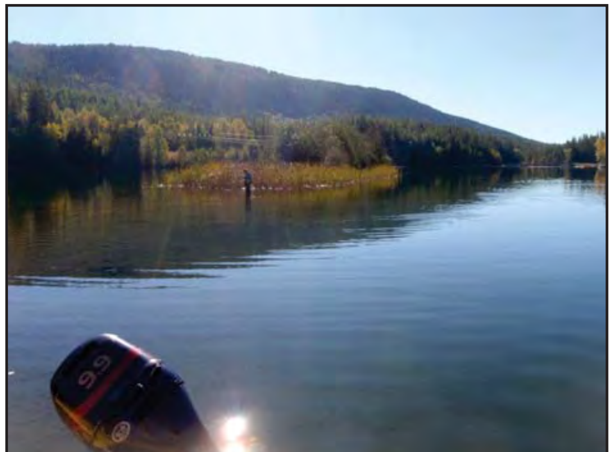


Photo 1-2: Looking northwest at macrophytes on south side of Site 6-3 (September 27, 2015)

Photo 1-3: Looking south from Site 6-3 nearshore centre quadrat location (September 30, 2011)

Photo 1-4: Looking south from Site 6-3 nearshore centre quadrat location (September 27, 2015)

Photo 1-5: Looking north from Site 6-3 south nearshore quadrat (September 27, 2015)

Photo 1-6: Looking at macrophytes present at Site 6-3 north farshore quadrat (September 27, 2015)

Appendix 2-1: Site Description 4-4

Photo 1-7: Looking east from Site 4-4 east POC (September 27, 2011)

Photo 1-8: Looking east from Site 4-4 east (September 24, 2015)

Photo 1-9: Looking south at macrophytes observed near the centre of Site 4-4 (September 27, 2011)

Photo 1-10: Looking south at macrophytes observed near the centre of Site 4-4 (September 24, 2015)

Photo 1-11: Example nearshore quadrat with visible macrophytes (September 24, 2015)

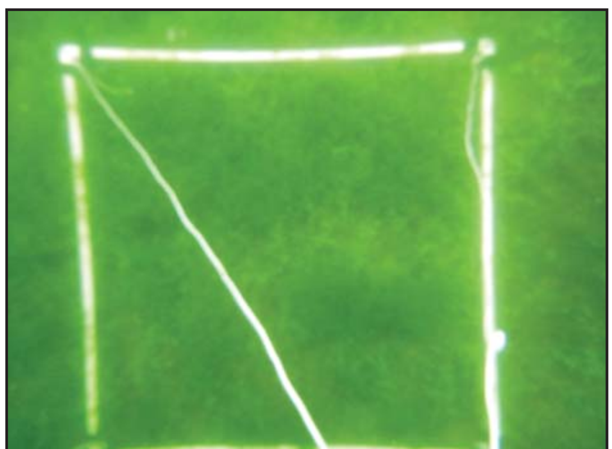


Photo 1-12: Example of a far-shore quadrat with visible macrophytes (September 24, 2015)

Appendix 2-1: Site Description 3-6

Photo 1-13: Looking east from Site 3-6 centre POC (September 29, 2011)

Photo 1-14: Looking east at Site 3-6 (September 24, 2015)

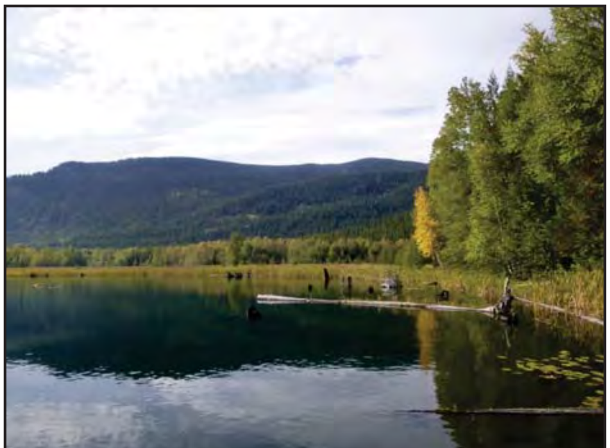


Photo 1-15: Looking west from 3-6 east POC (September 24, 2015)

Photo 1-16: Looking south from 3-6 center POC (September 24, 2015)

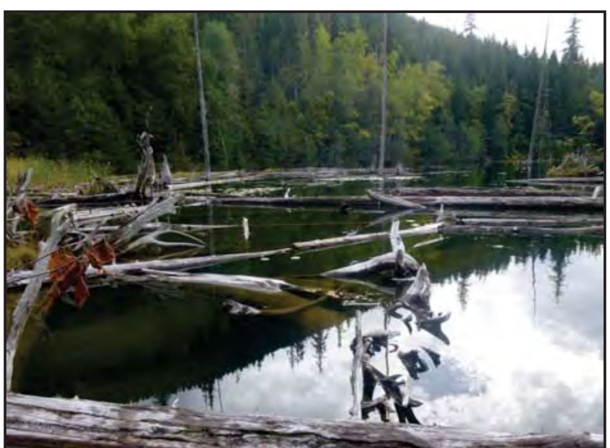


Photo 1-17: Looking east at large woody debris along the shoreline (September 24, 2015)

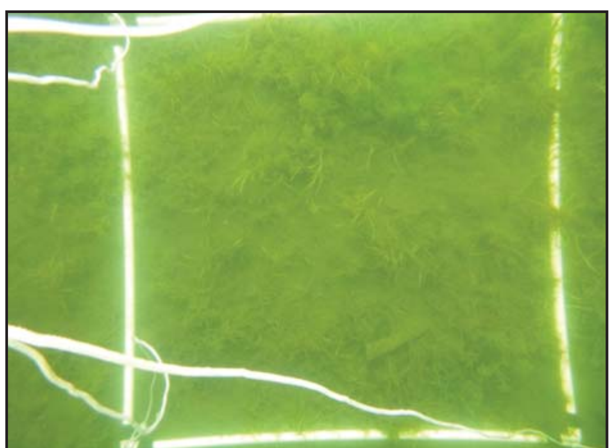


Photo 1-18: Example of submerged quadrat with visible macrophytes (September 24, 2015)

Appendix 2-1: Site Description 3-7

Photo 1-19: Looking west from Site 3-7 south nearshore quadrat (September 29, 2011)

Photo 1-20: Looking west from Site 3-7 south (September 25, 2015)

Photo 1-21: Looking at large woody debris within emergent macrophytes (September 25, 2015)

Photo 1-22: Looking west from the north end of the site (September 25, 2015)

Photo 1-23: Example of nearshore quadrat with visible macrophytes (September 25, 2015)

Photo 1-24: Looking at visible macrophytes within Site 3-7 north mid-distance quadrat (September 25, 2015)

Appendix 2-1: Site Description 3-8

Photo 1-25: Looking south from Site 3-8 centre POC (September 30, 2011)

Photo 1-26: Looking north from Site 3-8 centre POC (September 25, 2015)

Photo 1-27: Looking at macrophytes within Site 3-8 north nearshore quadrat (September 30, 2011)

Photo 1-28: Looking at macrophytes within Site 3-8 north nearshore quadrat (September 25, 2015)

Photo 1-29: Looking south from edge of emergent macrophyte community (September 25, 2015)

Photo 1-30: Looking at macrophytes within mid-distance quadrat (September 25, 2015)

Appendix 2-1: Site Description 2-13

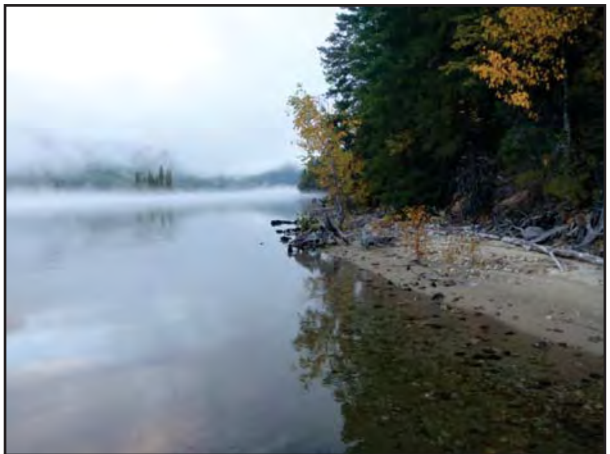


Photo 1-31: Looking north from Site 2-13 north POC (September 30, 2011)

Photo 1-32: Looking north from Site 2-13 north POC (September 36, 2015)

Photo 1-33: Looking north from Site 2-13 south nearshore quadrat (September 30, 2011)

Photo 1-34: Looking north from Site 2-13 south nearshore quadrat (September 26, 2015)

Photo 1-35: Looking at Macrophytes at centre transect nearshore quadrat (September 26, 2015)

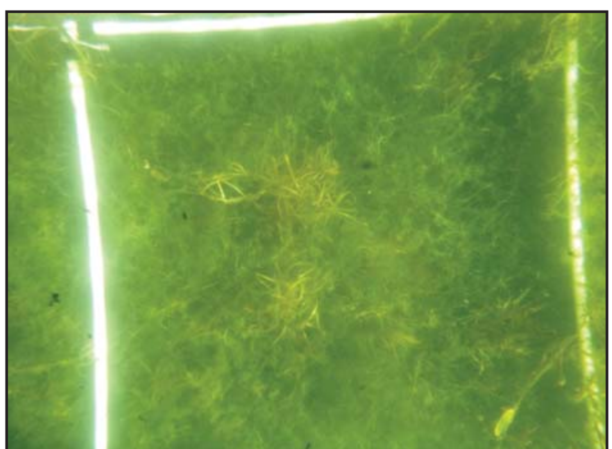


Photo 1-36: Looking at macrophytes with north transect nearshore quadrat (September 26, 2015)

Appendix 2-1: Site Description 1-18

Photo 1-37: Looking northwest at Site 1-18 (September 28, 2011)

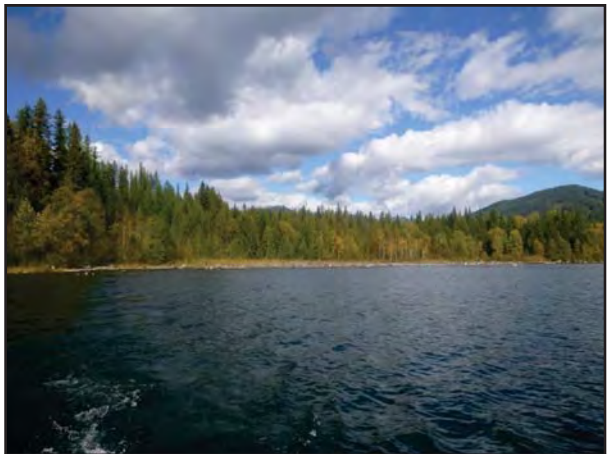


Photo 1-38: Looking northwest at Site 1-18 (September 26, 2015)

Photo 1-39: Looking south from Site 1-18 (September 25, 2015)

Photo 1-40: Looking east from Site 1-18 northern extent (September 25, 2015)

Photo 1-41: Looking southwest from Site 1-18 (September 25, 2015)

Photo 1-42: Looking at submerged macrophytes at centre transect farshore quadrat (September 25, 2015)

Appendix 2-1: Site Description 1-17

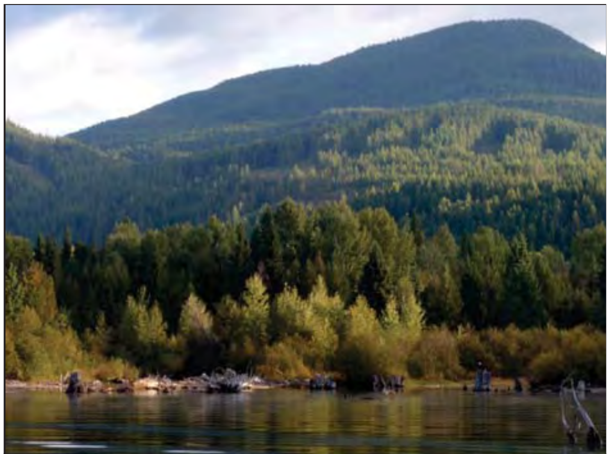


Photo 1-43: Looking north at the mouth of Watshan River (September 28, 2011)

Photo 1-44: Looking south from Site 1-17 (September 26, 2015)

Photo 1-45: Looking at Site 1-17 centre nearshore quadrat (September 28, 2011)

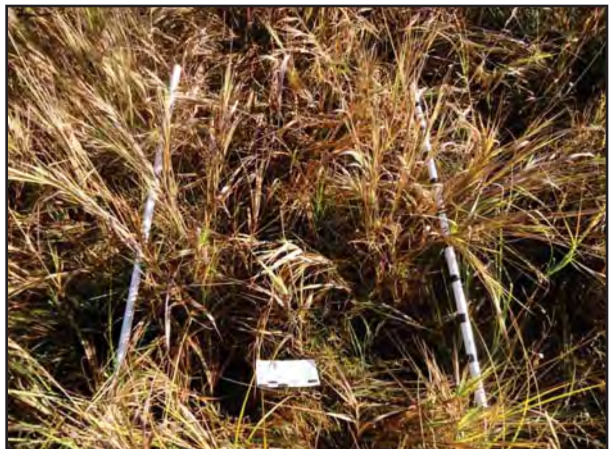


Photo 1-46: Looking at Site 1-17 east nearshore quadrat (September 26, 2015)

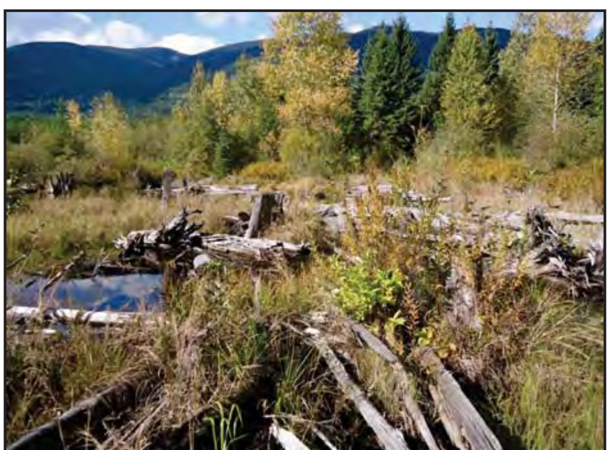


Photo 1-47: Looking west at Site 1-17 emergent macrophyte communities (September 26, 2015)

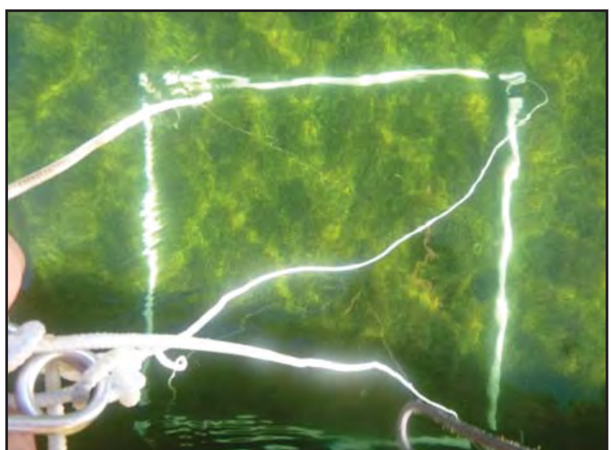


Photo 1-48: Looking at Site 1-17 west transect farshore quadrat (September 26, 2015)

Appendix 2-2

Photos – Methodology

Appendix 2-2: Methodology

Photo 2-1: Looking at the 6.7 m aluminum field vessel powered by a 340 HP inboard jet drive engine

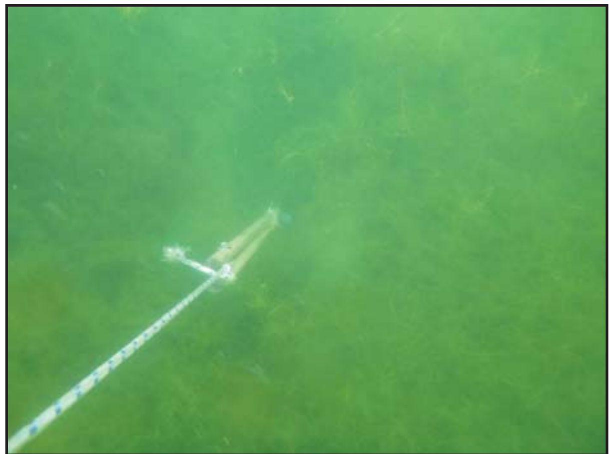


Photo 2-2: Macrophyte sampling rake used to collect macrophyte samples from deeper areas

Photo 2-3: Digital Lowrance LCX-15MT depth sounder interfacing directly to an omnistar DGPS receiver used to view and record bathymetry data

Photo 2-4: Petit ponar used to collect sediment samples

Photo 2-5: Preparing representative macrophytes for pressing

Photo 2-6: Quadrat used for shallow water and drop camera assessments

Appendix 3

Charts

3-1 Reservoir Elevation
3-2 Macrophyte Results

Appendix 3-1

Reservoir Elevation Charts

A3-1: Whatshan Lake Reservior Elevation March 1 to July 31 (2000 to 2015)
A3-2: Whatshan Lake Reservior Elevation January 1, 2000 - November 9, 2015
A3-3: Whatshan Lake Reservior Elevation January 1 - December 31 (2006, 2011 & 2015)
A3-4: Whatshan Lake Reservior Elevation September 1 - September 30 (2006 & 2011)

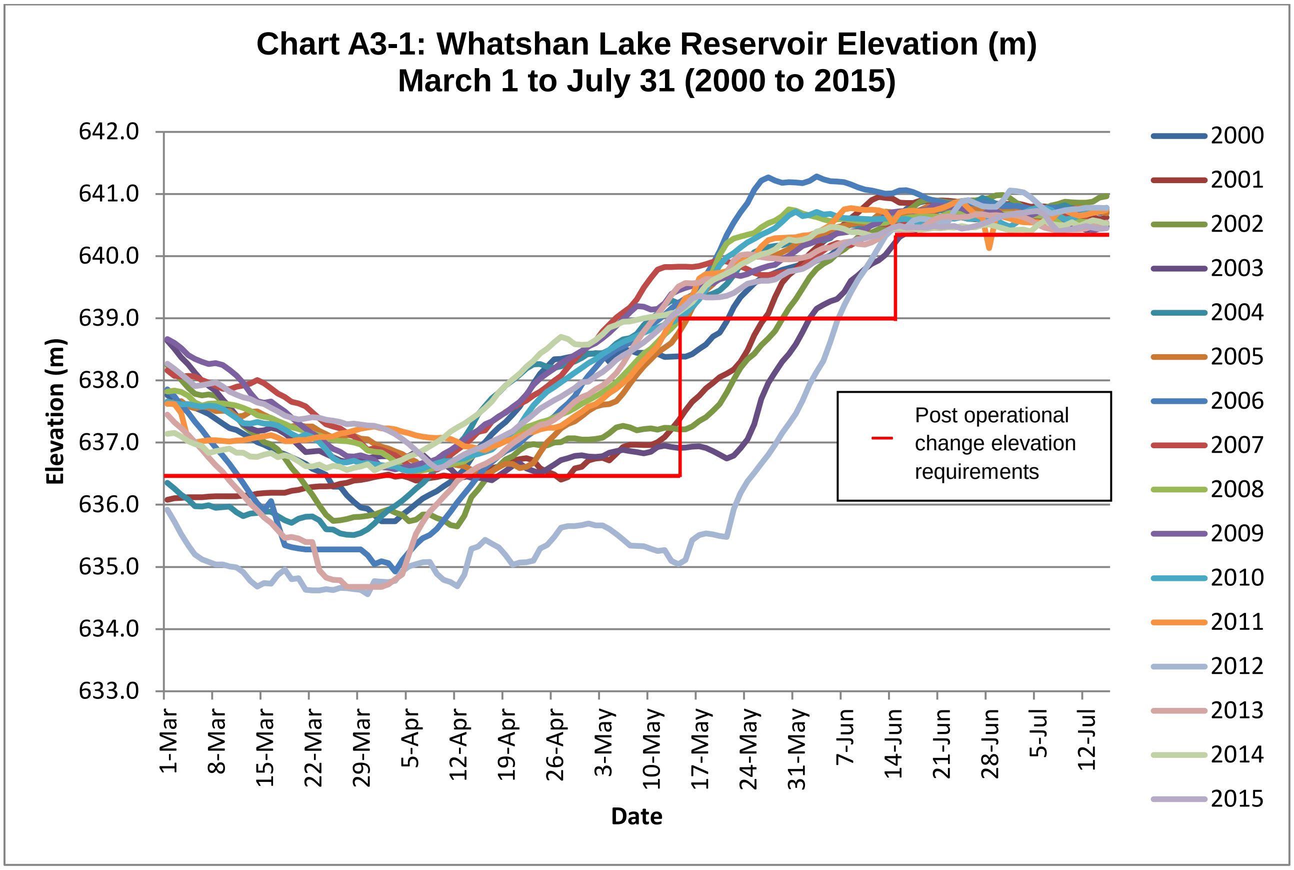


Chart A3-1: Whatshan Lake Reservoir Elevation (m)
March 1 to July 31 (2000 to 2015)
Elevation (m)
642.0
641.0
640.0
639.0
638.0
637.0
636.0
635.0
634.0
633.0
1-Mar
8-Mar
15-Mar
22-Mar
29-Mar
5-Apr
12-Apr
19-Apr
26-Apr
3-May
10-May
17-May
24-May
31-May
7-Jun
14-Jun
21-Jun
28-Jun
5-Jul
12-Jul
Date
Post operational change elevation requirements
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015

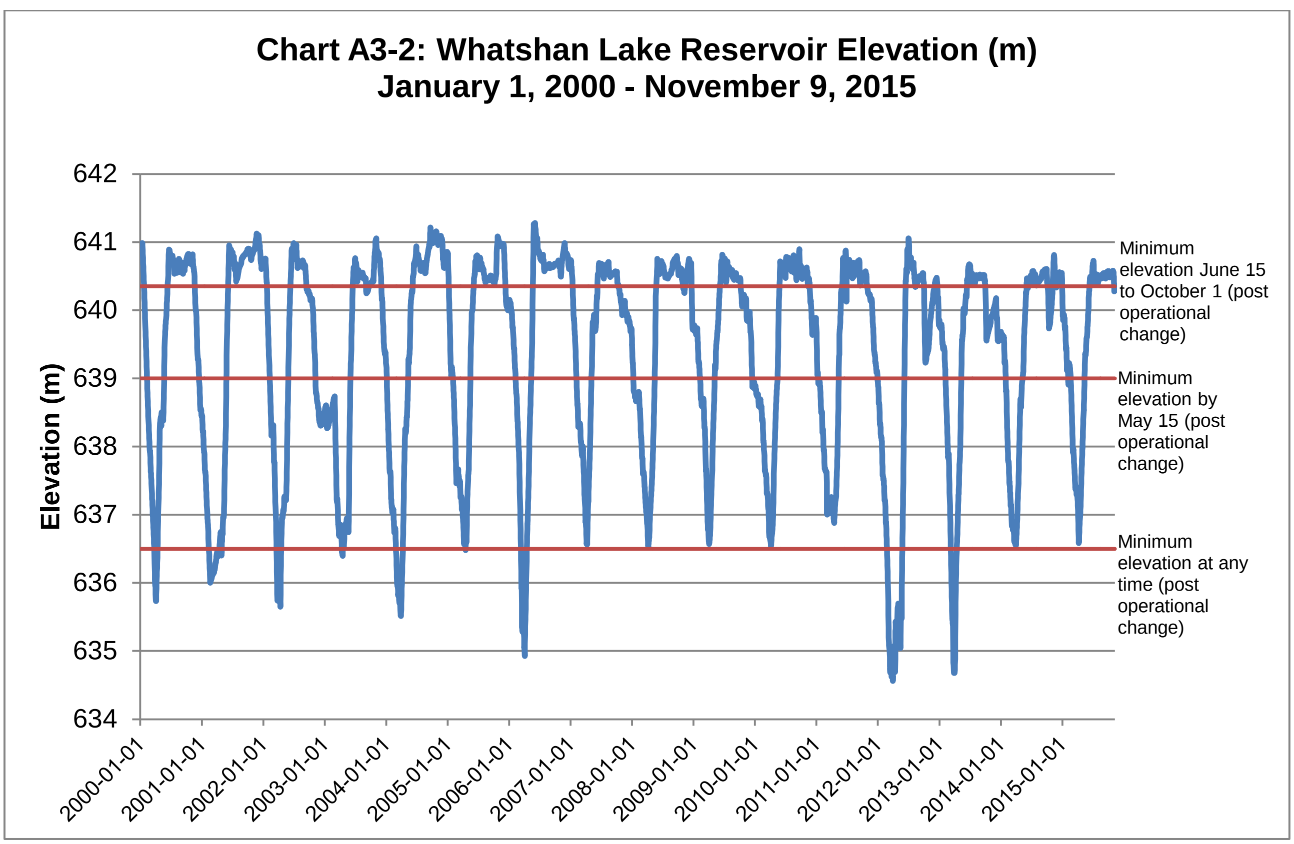


Chart A3-2: Whatshan Lake Reservoir Elevation (m)
January 1, 2000 - November 9, 2015
Elevation (m)
642
641
640
639
638
637
636
635
634
2000-01-01
2001-01-01
2002-01-01
2003-01-01
2004-01-01
2005-01-01
2006-01-01
2007-01-01
2008-01-01
2009-01-01
2010-01-01
2011-01-01
2012-01-01
2013-01-01
2014-01-01
2015-01-01
Minimum elevation June 15 to October 1 (post operational change)
Minimum elevation by May 15 (post operational change)
Minimum elevation at any time (post operational change)

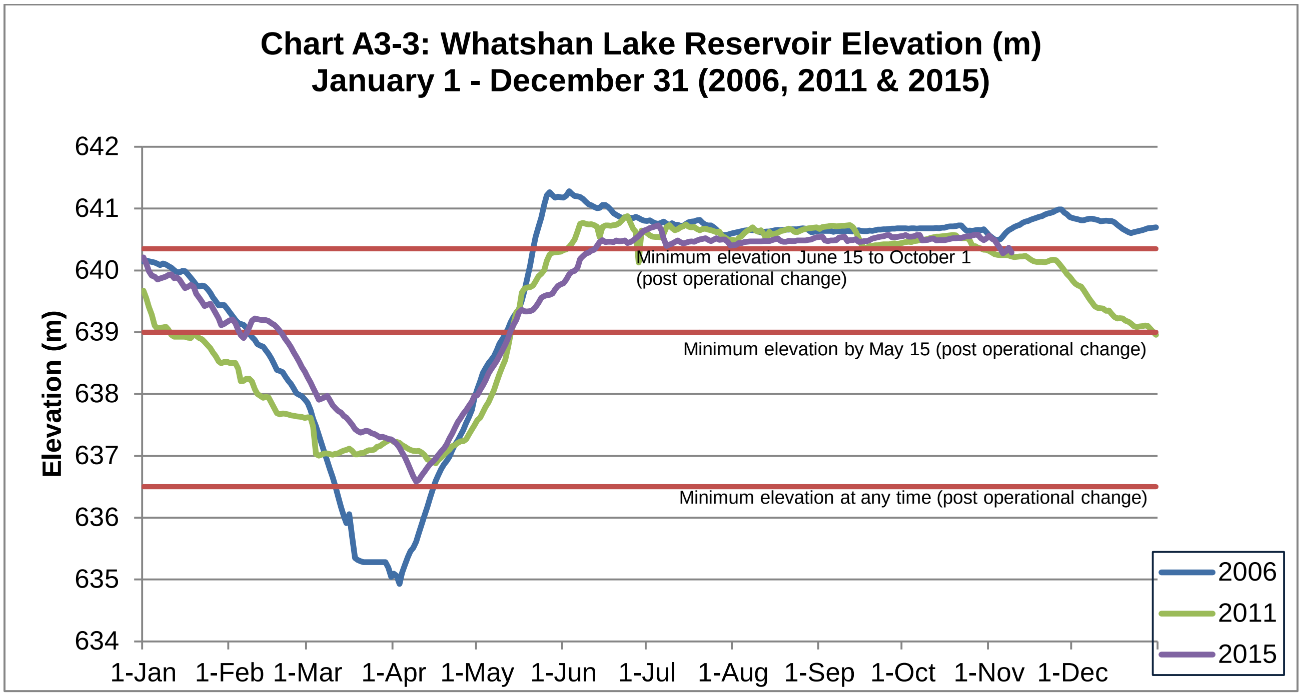


Chart A3-3: Whatshan Lake Reservoir Elevation (m)
January 1 - December 31 (2006, 2011 & 2015)
Elevation (m)
642
641
640
639
638
637
636
635
634
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
Minimum elevation June 15 to October 1
(post operational change)
Minimum elevation by May 15 (post operational change)
Minimum elevation at any time (post operational change)
2006
2011
2015

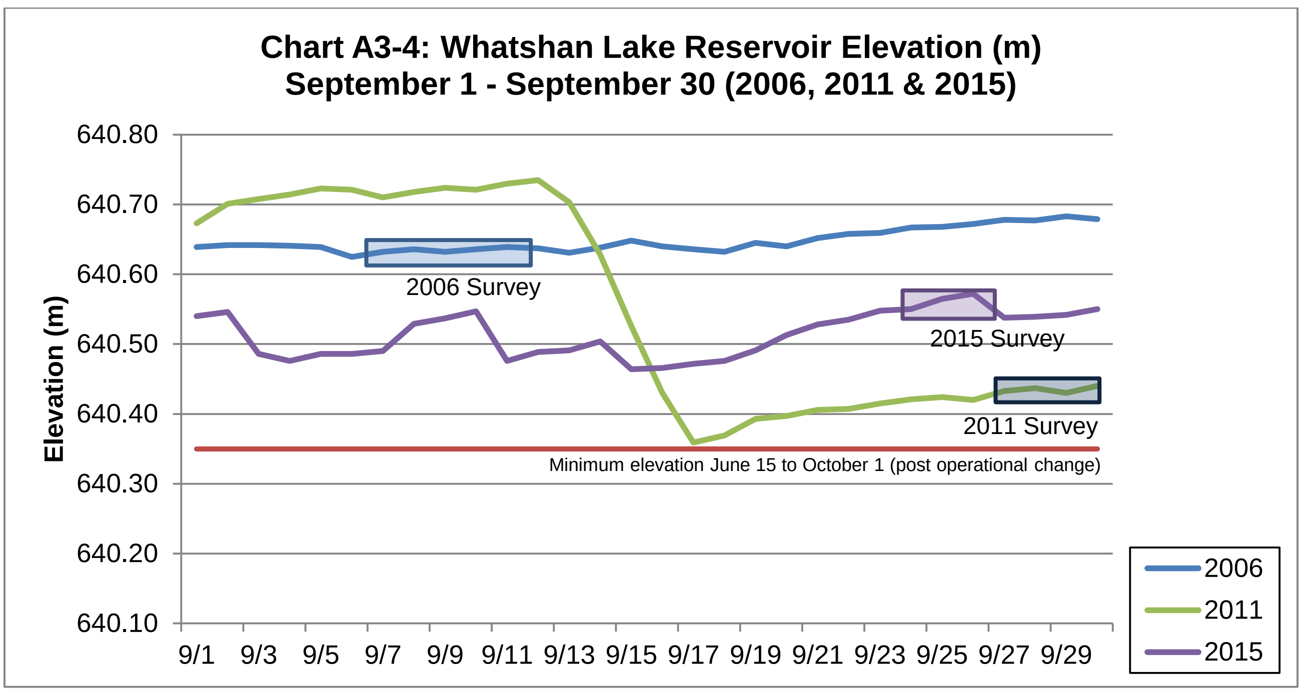
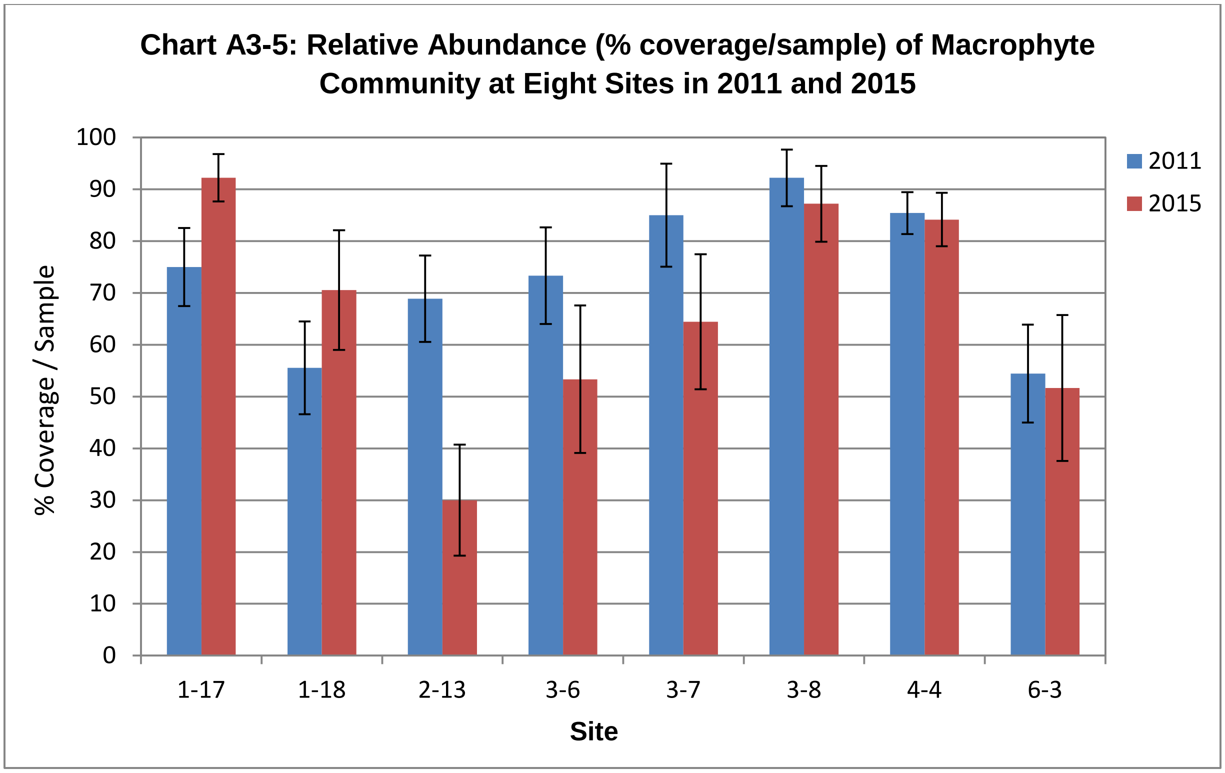


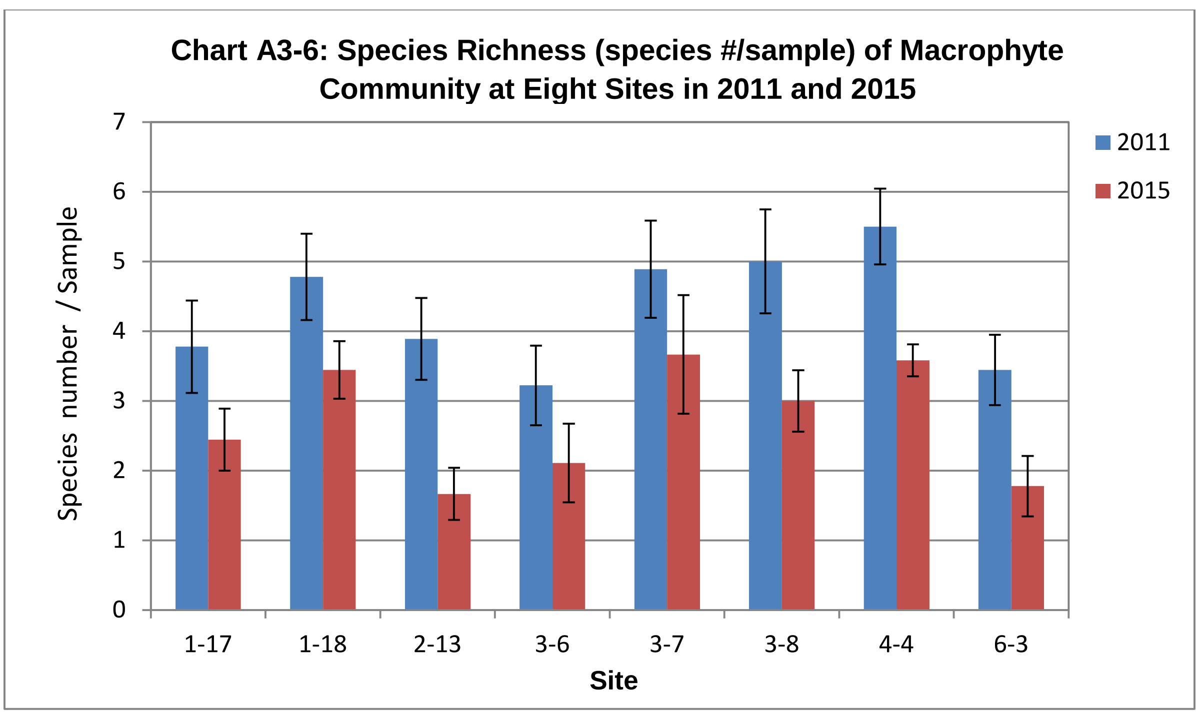
Chart A3-4: Whatshan Lake Reservoir Elevation (m)
September 1 - September 30 (2006, 2011 & 2015)
Elevation (m)
640.80
640.70
640.60
640.50
640.40
640.30
640.20
640.10
9/1
9/3
9/5
9/7
9/9
9/11
9/13
9/15
9/17
9/19
9/21
9/23
9/25
9/27
9/29
2006 Survey
2015 Survey
2011 Survey
Minimum elevation June 15 to October 1 (post operational change)
2006
2011
2015

Appendix 3-2

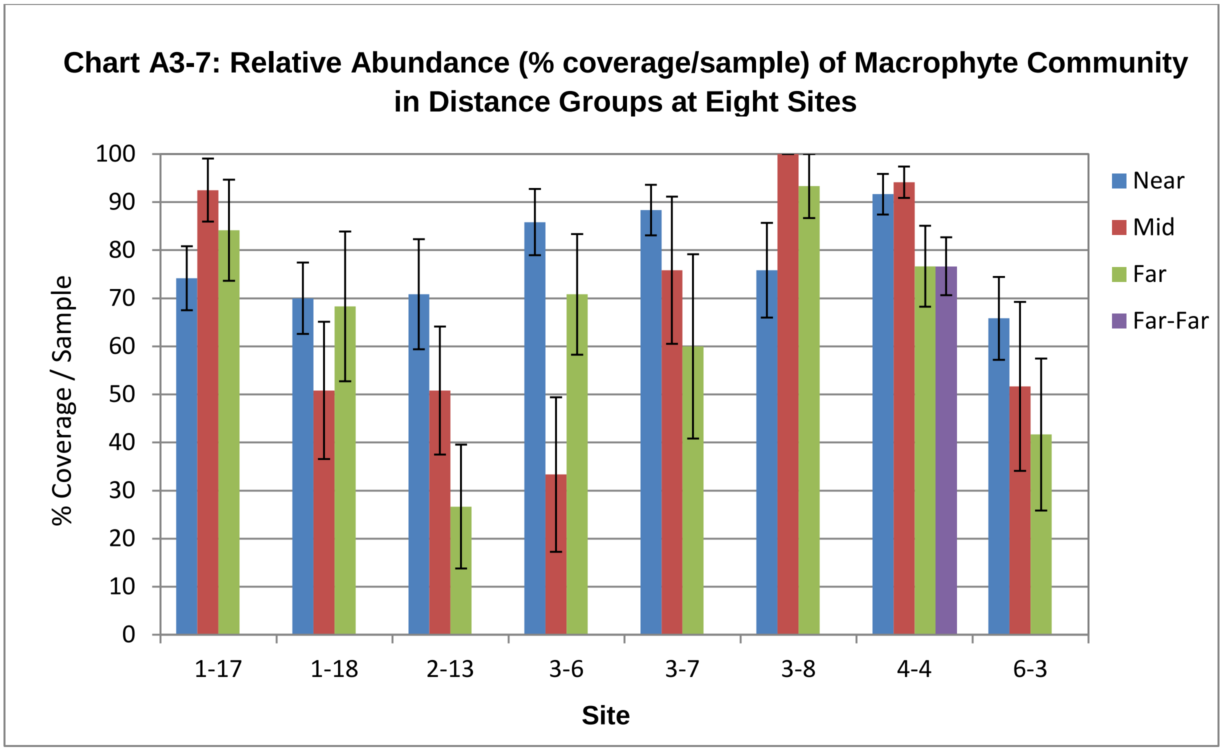
Macrophyte Results Charts



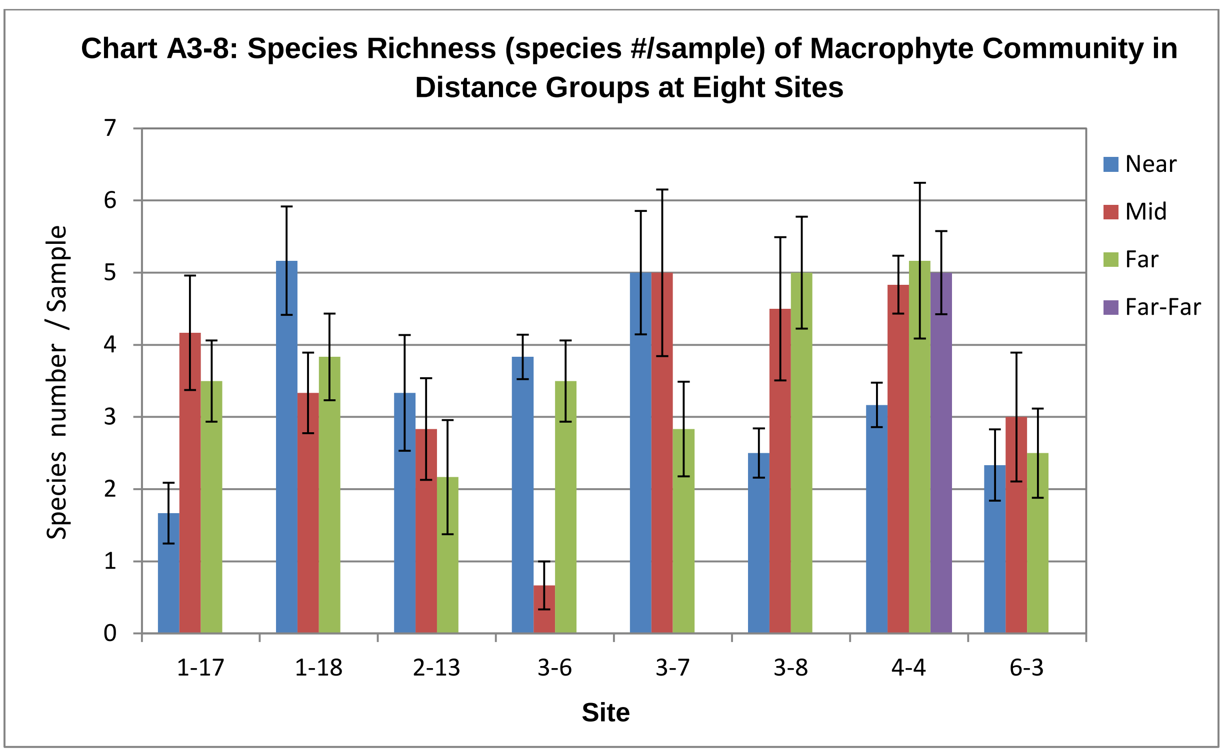
Note: Data are presented as mean (n = 9 or 12 [Site 4-4 only]) ± SE (standard error).



Note: Data are presented as mean (n = 9 or 12 [Site 4-4 only]) ± SE (standard error).



Note: Data are presented as mean (n = 6) ± SE (standard error).



Note: Data are presented as mean (n = 6) ± SE (standard error).

Chart A3-9: MDS Plot of Macrophyte Transect Samples at Eight Sites in 2011 and 2015

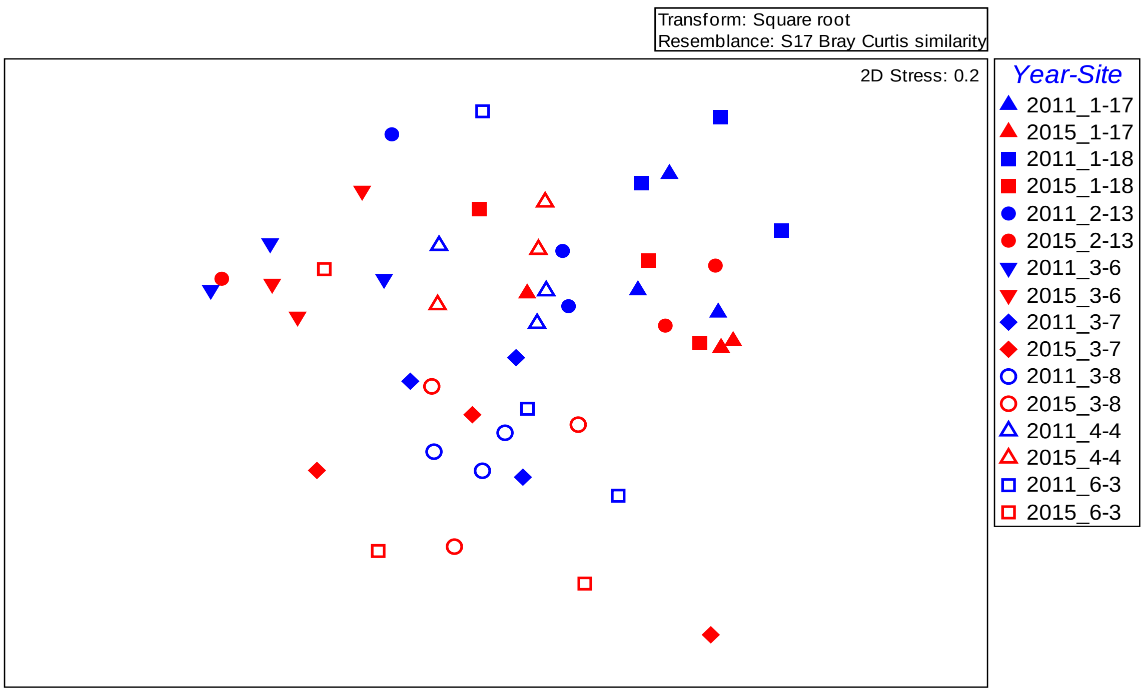


Chart A3-10: MDS Plot of Macrophyte Distance Samples in 2011 and 2015

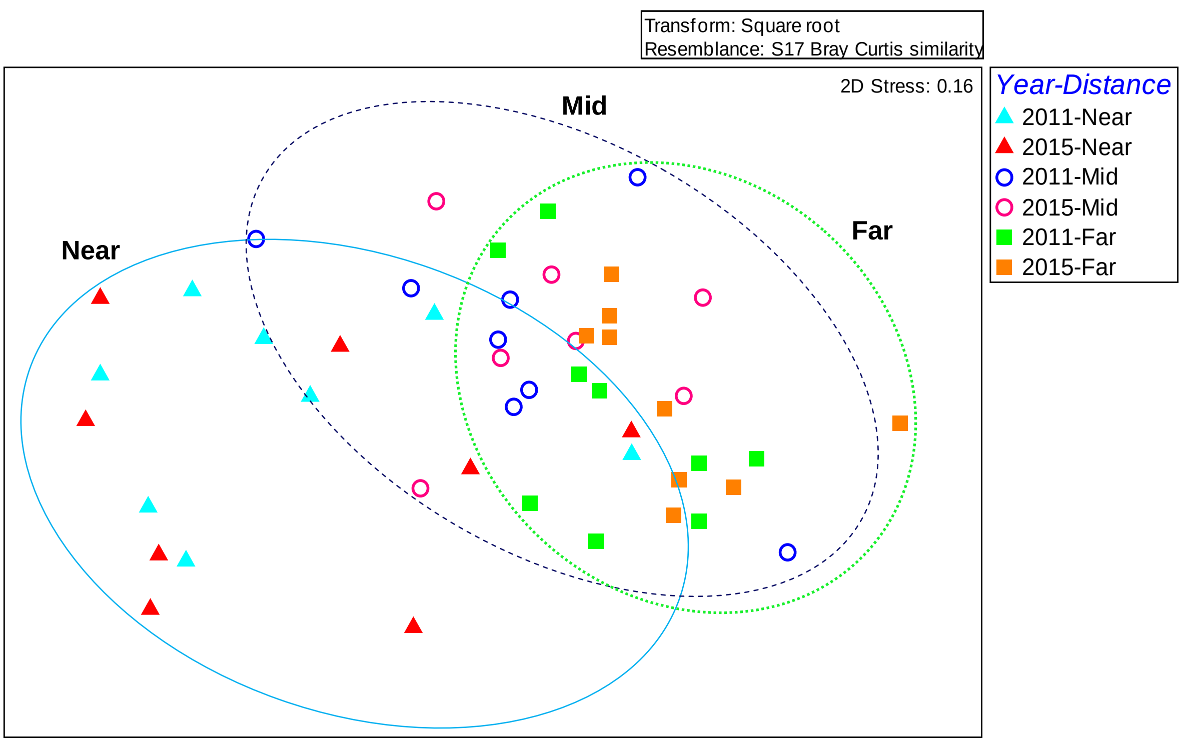


Chart A3-11: MDS Plot for Emergent Macrophyte Community in 2011 and 2015

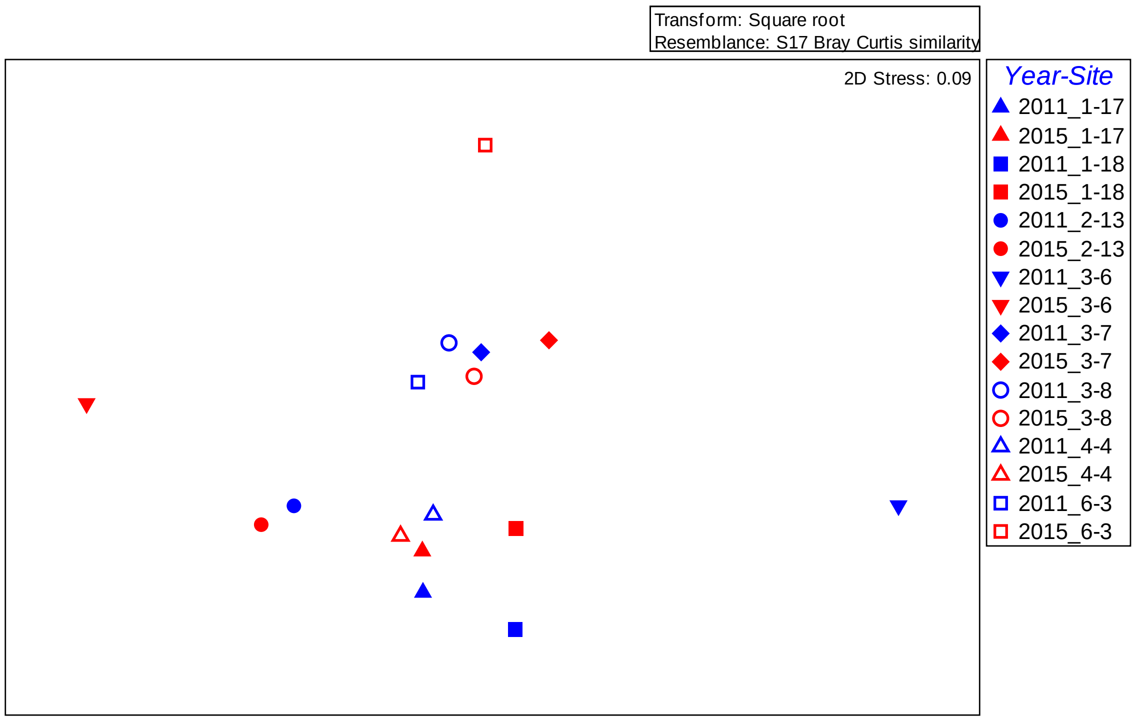
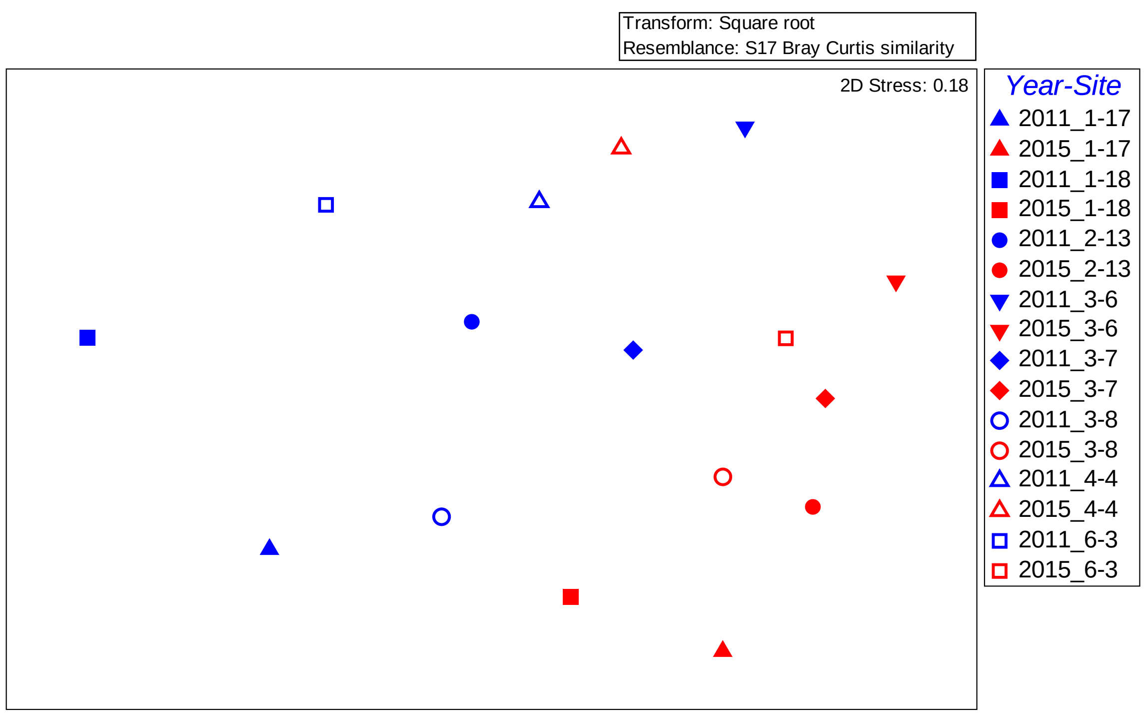


Chart A3-12: MDS Plot for Submerged Macrophyte Community in 2011 and 2015



Appendix 4

Tables

4-1 Spectral Vegetation Classes
4-2 Water Quality
4-3 Sediment Quality

Appendix 4-1

Spectral Vegetation Class Tables

Table A4-1: Whatshan Reservoir Fisheries Resources (2015)		
Common Name	**Latin Name**	**BC Conservation Status[1]**
Sport Fish		
Kokanee	*Oncorhynchus nerka*	No Status
Rainbow Trout	*Oncorhynchus mykiss*	Yellow Listed
Bull Trout	*Salvelinus confluentus*	Blue Listed
Mountain Whitefish	*Prosopium williamsoni*	Yellow Listed
Non-Sport Fish		
Northern Pikeminnow	*Ptychocheilus oregonensis*	Yellow Listed
Largescale Sucker	*Catostomus macrocheilus*	Yellow Listed
Peamouth Chub	*Mylocheilus caurinus*	Yellow Listed
Longnose Sucker	*Catostomus catostomus*	Yellow Listed
Longnose Dace	*Rhinichthys cataractae*	Yellow Listed
Slimy Sculpin	*Cottus cognatus*	Yellow Listed
Redside Shiner	*Richardsonius balteatus*	Yellow Listed

Note: [1]BC CDC (2016)

Table A4-2: Potential Wildlife at Whatshan Reservoir			
Common Name	**Latin Name**	**BC Conservation Status[1]**	**Local Status**
Amphibians (*Amphibia*) & Reptiles (*Reptilia*)			
Columbia Spotted Frog	*Rana luteiventris*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Northern Pacific Treefrog	*Pseudacris regilla*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Western Toad	*Anaxyrus boreas*	Blue Listed	Confirmed (Bennett *et al.* 2002)
Common Garter Snake	*Thamnophis sirtalis*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Terrestrial Garter Snake	*Thamnophis elegans*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Northern Leopard Frog	*Lithobates pipiens*	Red Listed	Potential (BC CDC, 2016)
Mammals (*Mammalia*)			
Moose	*Alces americanus*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
White-tailed deer	*Odocoileus virginianus*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Mule deer	*Odocoileus hemionus*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Elk	*Cervus canadensis*	Yellow Listed	Observed (2011)
Red squirrel	*Tamiasciurus hudsonicus*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Yellow-Pine chipmunk	*Tamias amoenus*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Yellow-bellied marmot	*Marmota flaviventris*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Beaver	*Castor canadensis*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Muskrat	*Ondatra zibethicus*	Yellow Listed	Confirmed (2011)
River otter	*Lontra canadensis*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Grey wolf	*Canis lupus*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)

Table A4-2: Potential Wildlife at Whatshan Reservoir Con'd			
Common Name	**Latin Name**	**BC Conservation Status[1]**	**Local Status**
Mammals (*Mammalia)* Con'd			
Black Bear	*Ursus americanus*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Grizzly Bear	*Ursus arctos horribilis*	Blue Listed	Potential (BC CDC, 2016)
Fisher	*Martes pennanti*	Blue Listed	Potential (BC CDC, 2016)
Avians (*Aves)*			
Common Loon	*Gavia immer*	Yellow Listed	Observed (2011)
Red-necked grebe	*Podiceps grisegena*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Great Blue Heron; *Herodias* subspecies	*Ardea Herodias herodias*	Blue Listed	Observed (2011)
Canada goose	*Branta canadensis*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Common merganser	*Mergus merganser*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Mallard	*Anas platyrhynchos*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Bufflehead	*Bucephala albeola*	Yellow Listed	Confirmed (Knopp 2002)
Ruddy duck	*Oxyura jamaicensis*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Green-winged teal	*Anas crecca*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Blue-winged teal	*Anas discors*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Northern shoveler	*Anas clypeata*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Wood duck	*Aix sponsa*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Bald eagle	*Haliaeetus leucocephalus*	Yellow Listed	Observed (2011)
Osprey	*Pandion haliaetus*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Northern goshawk	*Accipiter gentilis*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Northern harrier	*Circus cyaneus*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Peregrine falcon	*Falco peregrinus*	No Status	Confirmed (Knopp 2002)
Turkey vulture	*Cathartes aura*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Spruce grouse	*Falcipennis canadensis*	Yellow Listed	Confirmed (Knopp 2002)
Ruffed grouse	*Bonasa umbellus*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Sora	*Porzana carolina*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Spotted sandpiper	*Actitis macularius*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Killdeer	*Charadrius vociferus*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Wilson's snipe	*Gallinago delicata*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
California gull	*Larus californicus*	Blue Listed	Confirmed (van Oort & Kellner, 2006)
Mourning dove	*Zenaida macroura*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Barred owl	*Strix varia*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Rufous hummingbird	*Selasphorus rufus*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Belted kingfisher	*Megaceryle alcyon*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Red-naped sapsucker	*Sphyrapicus nuchalis*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Northern flicker	*Colaptes auratus*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Downy woodpecker	*Picoides pubescens*	Yellow Listed	Confirmed (Bennett *et al.* 2002)

Table A4-2: Potential Wildlife at Whatshan Reservoir Con'd			
Common Name	**Latin Name**	**BC Conservation Status[1]**	**Local Status**
Avians (*Aves*) Con'd			
Pileated woodpecker	*Dryocopus pileatus*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Hammond's flycatcher	*Empidonax hammondii*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Willow flycatcher	*Empidonax traillii*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Pacific-slope flycatcher	*Empidonax difficilis*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Warbling vireo	*Vireo gilvus*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Cassin's vireo	*Vireo cassinii*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Red-eyed vireo	*Vireo olivaceus*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
American Crow	*Corvus brachyrhynchos*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Common raven	*Corvus corax*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Tree swallow	*Tachycineta bicolor*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Northern rough-winged swallow	*Stelgidopteryx serripennis*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Violet-green swallow	*Tachycineta thalassina*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Bank swallow	*Riparia riparia*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Barn Swallow	*Hirundo rustica*	Blue Listed	Confirmed (van Oort & Kellner, 2006)
Black-capped chickadee	*Poecile atricapillus*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Chestnut-backed chickadee	*Poecile rufescens*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Red-breasted nuthatch	*Sitta canadensis*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Brown creeper	*Certhia americana*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
American dipper	*Cinclus mexicanus*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Winter wren	*Troglodytes hiemalis*	Blue Listed	Confirmed (van Oort & Kellner, 2006)
Golden-crowned kinglet	*Regulus satrapa*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
American robin	*Turdus migratorius*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Varied thrush	*Ixoreus naevius*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Hermit thrush	*Catharus guttatus*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Swainson's thrush	*Catharus ustulatus*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Cedar waxwing	*Bombycilla cedrorum*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Yellow warbler	*Setophaga petechia*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
Yellow-rumped warbler	*Setophaga coronata*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Townsend's warbler	*Setophaga townsendi*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Common yellowthroat	*Geothlypis trichas*	Yellow Listed	Confirmed (Bennett *et al.* 2002)
American redstart	*Setophaga ruticilla*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Orange-crowned warbler	*Oreothlypis celata*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Northern waterthrush	*Parkesia noveboracensis*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Western tanager	*Piranga ludoviciana*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Dark-eyed Junco	*Junco hyemalis*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Song Sparrow	*Melospiza melodia*	Yellow Listed	Confirmed (Bennett *et al.* 2002)

Table A4-2: Potential Wildlife at Whatshan Reservoir Con'd			
Common Name	**Latin Name**	**BC Conservation Status[1]**	**Local Status**
Avians (*Aves*) Con'd			
Savannah Sparrow	*Passerculus sandwichensis*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Lincoln's sparrow	*Melospiza lincolnii*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Brown-headed cowbird	*Molothrus ater*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Pine siskin	*Spinus pinus*	Yellow Listed	Confirmed (Knopp 2002)
Purple finch	*Haemorhous purpureus*	Yellow Listed	Confirmed (van Oort & Kellner, 2006)
Prairie Falcon	*Falco mexicanus*	Red Listed	Confirmed (Bennett *et al.* 2002)
Lewis's Woodpecker	*Melanerpes lewis*	Blue Listed	Suspected (Bennett *et al.* 2002)
Peregrine Falcon; *anatum* subspecies	*Falco peregrines anatum*	Red Listed	Suspected (Bennett *et al.* 2002)
Western Screech-Owl; *macfarlanei* subspecies	*Megascops kennicottii macfarlanei*	Red Listed	Suspected (Bennett *et al.* 2002)
White-throated swift	*Aeronautes saxatalis*	Blue Listed	Suspected (Bennett *et al.* 2002)
American Bittern	*Botaurus lentiginosus*	Blue Listed	Suspected (Bennett *et al.* 2002)
Swainson's Hawk	*Buteo swainsoni*	Red Listed	Suspected (Bennett *et al.* 2002)

Note: [1]BC CDC (2016)

Table A4-3: Species Identified in Whatshan Reservoir Phase 1 (2006), Phase 2 (2011) and Phase 3 (2015) Vegetation Monitoring Studies								
Family	**Species**	**2006**	**2011**	**2015**	**BC Conservation Status**	**Habitat**	**Habit**	**Emergent/ Submergent**
Athyriaceae	*Athyrium filix-femina*	-	+	+	Yellow Listed	Terrestrial	Perennial	Emergent
Betulaceae	*Betula papyrifera*	+	-	-	Yellow Listed	Terrestrial	Tree	Emergent
Betulaceae	*Betula* sp.	-	+	-	N/A	Terrestrial	Shrub	N/A
Betulaceae	Corylus cornuta Marsh.	+	-	-	Yellow Listed	Terrestrial	Shrub	N/A
Characeae	*Chara* sp.	+	+	+	Not Listed	Aquatic	Green Algae	Submergent
Characeae	*Tolypella* sp.	-	+	-	Not Listed	Aquatic	Green Algae	Submergent
Climaciaceae	*Climacium dendroides*	-	+	+	Yellow Listed	Terrestrial	Moss	Emergent
Cornaceae	*Cornus sericea*	+	-	-	Yellow Listed	Wetland	Shrub	Emergent
Crassulaceae	*Crassula aquatica* (L.) Schoenl.	+	+	+	Yellow Listed	Aquatic	Annual	Emergent
Cupressaceae	*Thuja plicata*	+	-	-	Yellow Listed	Terrestrial	Tree	N/A
Cyperaceae	*Carex bebbii* (Bailey) Fern.	+	-	-	Yellow Listed	Wetland	Perennial	Emergent
Cyperaceae	*Carex exsiccata* Bailey	+	+	-	Yellow Listed	Wetland	Perennial	Emergent
Cyperaceae	*Carex lasiocarpa* Ehrh.	+	-	-	Yellow Listed	Wetland	Perennial	Emergent
Cyperaceae	*Carex lenticularis* Michx.	+	-	-	Yellow Listed	Wetland	Perennial	Emergent
Cyperaceae	*Carex rossii*	-	-	+	Yellow Listed	Terrestrial	Perennial	Emergent
Cyperaceae	*Carex rostrata*	+	-	+	Yellow Listed	Wetland	Perennial	Emergent
Cyperaceae	*Carex scoparia* .Schkur ex Willd	+	-	-	Yellow Listed	Wetland	Perennial	Emergent
Cyperaceae	*Carex* sp.	-	+	+	N/A	Wetland	Perennial	Emergent
Cyperaceae	*Carex stipata* Muhl. ex Willd.	+	-	-	Yellow Listed	Wetland	Perennial	Emergent
Cyperaceae	*Carex utriculata* Boott	+	-	-	Yellow Listed	Wetland	Perennial	Emergent
Cyperaceae	*Carex vesicaria* L	+	-	-	Yellow Listed	Wetland	Perennial	Emergent
Cyperaceae	*Carex vulpinoidea* Michx.	+	-	-	Yellow Listed	Wetland	Perennial	Emergent
Cyperaceae	*Eleocharis palustris* (L.)	+	+	+	Yellow Listed	Wetland	Perennial	Emergent
Cyperaceae	*Eleocharis* sp.	-	+	-	N/A	Aquatic	N/A	Emergent
Cyperaceae	*Schoenoplectus lacustris*	+	-	-	Not Listed	Wetland	Perennial	Emergent
Cyperaceae	*Schoenoplectus tabernaemontani* (K.C. Gmel.)	+	+	-	Yellow Listed	Wetland	Perennial	Emergent
Cyperaceae	*Scirpus atrocinctus* Fern.	+	-	-	Invasive	Wetland	Perennial	Emergent
Dennstaedtiacea	*Pteridium aquilinum*	+	-	-	Yellow Listed	Terrestrial	Perennial	N/A
Equisetaceae	*Equisetum fluviatile* L.	+	+	-	Yellow Listed	Wetland	Perennial	Emergent
Equisetaceae	*Equisetum pratense* Ehrh.	-	+	-	Yellow Listed	Wetland	Perennial	Emergent
Equisetaceae	*Equisetum* sp.	-	+	+	N/A	Wetland	Perennial	Emergent
Ericaceae	*Chimaphila umbellata*	+	-	-	Yellow Listed	Terrestrial	Perennial	N/A
Ericaceae	*Rhododendron groenlandicum* (Oeder)	-	+	-	Yellow Listed	Terrestrial	Shrub	Emergent
Fontinalaceae	*Fontinalis antipyretica*	+	-	-	Yellow Listed	Aquatic	Moss	Submergent
Haloragaceae	*Myriophyllum* sp.	-	+	-	Yellow Listed	Aquatic	Perennial	Submergent
Haloragaceae	*Myriophyllum spicatum*	+	-	-	Exotic	Aquatic	Perennial	Submergent
Isoetaceae	*Isoetes* sp.	-	+	+	N/A	Aquatic	Perennial	Submergent
Juncaceae	*Juncus* sp.	-	+	+	N/A	Wetland	N/A	Emergent
Lamiaceae	*Mentha arvensis* L.	-	+	+	Yellow Listed	Terrestrial	Perennial	Emergent
Lentibulariaceae	*Utricularia macrorhiza* Leconte	-	+	-	Yellow Listed	Aquatic	Perennial	Submergent
Lentibulariaceae	*Utricularia minor* L.	-	+	-	Yellow Listed	Aquatic	Perennial	Submergent
N/A	Fibrous Decomposing Organics	-	-	+	N/A	N/A	N/A	Submergent
N/A	Other Moss	-	+	+	N/A	Terrestrial	Moss	Emergent
Najadaceae	*Najas flexilis* (Willd.)	+	+	+	Yellow Listed	Aquatic	Perennial	Submergent
Nymphaeaceae	*Nuphar lutea* (L.) Sm.	-	+	-	Yellow Listed	Aquatic	Perennial	Submergent
Pinaceae	*Picea glauca*	+	-	-	Yellow Listed	Terrestrial	Tree	N/A
Poaceae	*Calamagrostis canadensis*	+	-	-	Yellow Listed	Wetland	Perennial	Emergent
Poaceae	*Glyceria borealis*	+	-	-	Yellow Listed	Wetland	Perennial	Emergent
Poaceae	*Juncus arcticus*	+	-	-	Yellow Listed	Wetland	Perennial	Emergent
Poaceae	*Juncus ensifolius* Wikstr.	+	-	-	Yellow Listed	Wetland	Perennial	Emergent
Poaceae	*Phalaris arundinacea* L.	+	-	-	Exotic	Wetland	Perennial	Emergent
Poaceae	Poaceae	-	+	+	N/A	N/A	N/A	Emergent
Poaceae	*Sporobolus airoides* (Torr.) Torr	+	-	-	Red Listed	Terrestrial	Perennial	N/A
Polygonaceae	*Persicaria amphibia* var. *emersa* (Michx.)	+	+	+	Yellow Listed	Aquatic	Perennial	Emergent
Potamogetonaceae	*Potamogeton alpinus subellipticus*	+	-	-	Yellow Listed	Aquatic	Perennial	Submergent
Potamogetonaceae	*Potamogeton amplifolius* Tucker	+	-	-	Yellow Listed	Aquatic	Perennial	Submergent
Potamogetonaceae	*Potamogeton friesii*	+	-	-	Yellow Listed	Aquatic	Perennial	Submergent
Potamogetonaceae	*Potamogeton epihydrus* Raf.	+	+	+	Yellow Listed	Aquatic	Perennial	Submergent
Potamogetonaceae	*Potamogeton foliosus* Raf.	+	+	+	Yellow Listed	Aquatic	Perennial	Submergent
Potamogetonaceae	*Potamogeton gramineus* L.	+	+	+	Yellow Listed	Aquatic	Perennial	Submergent
Potamogetonaceae	*Potamogeton natans* L.	-	+	-	Yellow Listed	Aquatic	Perennial	Submergent
Potamogetonaceae	*Potamogeton perfoliatus* L.	+	-	+	Blue Listed	Aquatic	Perennial	Submergent
Potamogetonaceae	*Potamogeton pusillus* L.	+	+	+	Yellow Listed	Aquatic	Perennial	Submergent
Potamogetonaceae	*Potamogeton robbinsii*	+	-	-	Yellow Listed	Aquatic	Perennial	Submergent
Potamogetonaceae	*Potamogeton* sp.	-	+	+	N/A	Aquatic	N/A	Submergent
Potamogetonaceae	*Stuckenia filiformis*	+	-	-	Yellow Listed	Aquatic	Perennial	Submergent
Pteridaceae	*Cryptogramma stelleri*	-	-	+	Yellow Listed	Terrestrial	Perennial	Emergent
Ranunculaceae	*Ranunculus aquatilis* var. *diffusus*	+	+	+	Yellow Listed	Aquatic	Perennial	Submergent
Ranunculaceae	*Ranunculus flammula*	+	-	-	Yellow Listed	Amphibious	Perennial	Emergent
Rosaceae	*Comarum palustre* L.	+	+	+	Yellow Listed	Wetland	Perennial	Emergent
Rosaceae	*Fragaria virginiana* Duchesne	-	+	-	Yellow Listed	Terrestrial	Perennial	Emergent
Rosaceae	*Geum macrophyllum*	+	-	-	Yellow Listed	Terrestrial	Perennial	Emergent
Rosaceae	*Spiraea douglasii* Hook.	+	-	-	Yellow Listed	Wetland	Shrub	Emergent
Rubiaceae	*Galium trifidum*	-	-	+	Yellow Listed	Terrestrial	Perennial	Emergent
Scrophulariaceae	*Verbascum thapsus*	-	-	+	Exotic	Terrestrial	Biennial	Emergent
Typhaceae	*Sparganium* sp.	+	-	-	N/A	Wetland	Perennial	Emergent
Typhaceae	*Typha angustifolia* L.	-	+	+	Exotic	Wetland	Perennial	Emergent
Typhaceae	*Typha latifolia* L.	+	-	-	Yellow Listed	Wetland	Perennial	Emergent
Urticaceae	*Urtica dioica*	-	-	+	Yellow Listed	Terrestrial	Perennial	Emergent
Violaceae	*Viola orbiculata* Geyer ex Holz.	-	+	-	Yellow Listed	Terrestrial	Perennial	Emergent

+: present
-: absent

Table A4-4: Site 6-3 Submerged Classified Vegetation Areas			
Vegetation Type	2006 Area (m^2)	2011 Area (m^2)	2015 Area (m^2)
Sum of Submerged Macrophytes	32,531.70	37,200	33,924
Class 1	NA	2150	2,712
Class 2	NA	4150	12,332
Class 3	NA	3050	9,156
Class 4	NA	6400	8,788
Class 5	NA	21,450	936

NA: Not Applicable

Table A4-5: Site 6-3 Emergent Classified Vegetation Areas			
Vegetation Type	2006 Area (m^2)	2011 Area (m^2)	2015 Area (m^2)
Low Marsh	NA	900	1,152
Marsh	2,886.01	400	988
Fen	NA	375	76
Fen/Marsh Transitional	NA	750	188
Sum of Emergent Macrophytes	2,886.01	2,425	2,404

NA: Not Applicable

Table A4-6: Site 4-4 Submerged Classified Vegetation Areas			
Vegetation Type	2006 Area (m^2)	2011 Area (m^2)	2015 Area (m^2)
Sum of Submerged Macrophytes	3,386.90	5,075	5,984
Class 1	NA	1,150	2,844
Class 2	NA	2,050	496
Class 3	NA	150	128
Class 4	NA	1,000	2,488
Class 5	NA	725	28

NA: Not Applicable

Table A4-7: Site 4-4 Emergent Classified Vegetation Areas			
Vegetation Type	2006 Area (m^2)	2011 Area (m^2)	2015 Area (m^2)
Low Marsh	NA	200	280
Marsh	210.47	475	444
Fen	NA	700	164
Fen/Marsh Transitional	NA	750	64
Sum of Emergent Macrophytes	210.47	2,125	952

NA: Not Applicable

Table A4-8: Site 3-6 Submerged Classified Vegetation Areas			
Vegetation Type	2006 Area (m^2)	2011 Area (m^2)	2015 Area (m^2)
Sum of Submerged Macrophytes	50,986	53,475	55,136
Class 1	NA	4,725	8,324
Class 2	NA	7,950	15,900
Class 3	NA	400	388
Class 4	NA	4,700	13,216
Class 5	NA	35,700	17,308

NA: Not Applicable

Table A4-9: Site 3-6 Emergent Classified Vegetation Areas			
Vegetation Type	2006 Area (m^2)	2011 Area (m^2)	2015 Area (m^2)
Low Marsh	NA	725	864
Marsh	NA	975	604
Fen	3,616.14	75	104
Fen/Marsh Transitional	NA	75	180
Sum of Emergent Macrophytes	3,616.14	1,850	1,752

NA: Not Applicable

Table A4-10: Site 3-7 Submerged Classified Vegetation Areas			
Vegetation Type	2006 Area (m^2)	2011 Area (m^2)	2015 Area (m^2)
Sum of Submerged Macrophytes	12,851	44,850	23,276
Class 1	NA	2,875	3,444
Class 2	NA	5,025	5,732
Class 3	NA	3,200	4,748
Class 4	NA	7,575	6,992
Class 5	NA	26,175	2,360

NA: Not Applicable

Note: Site 3-7 Class 5 (2011) was not included during area assessments due to over estimation of site boundary

Table A4-11: Site 3-7 Emergent Classified Vegetation Areas			
Vegetation Type	2006 Area (m^2)	2011 Area (m^2)	2015 Area (m^2)
Low Marsh	NA	4,100	7,560
Marsh	28,271.46	11,400	9,284
Fen	22,175.10	13,925	7,264
Fen/Marsh Transitional	NA	14,725	20,332
Sum of Emergent Macrophytes	50,446.56	44,150	44,440

NA: Not Applicable

Table A4-12: Site 3-8 Submerged Classified Vegetation Areas			
Vegetation Type	2006 Area (m^2)	2011 Area (m^2)	2015 Area (m^2)
Sum of Submerged Macrophytes	28,894	60,700	38,152
Class 1	NA	3,250	3,200
Class 2	NA	9,875	12,456
Class 3	NA	12,700	11,144
Class 4	NA	25,275	7,536
Class 5	NA	9,600	3,816

NA: Not Applicable

Table A4-13: Site 3-8 Emergent Classified Vegetation Areas			
Vegetation Type	2006 Area (m^2)	2011 Area (m^2)	2015 Area (m^2)
Low Marsh	NA	11,375	12,012
Marsh	39,431.42	21,725	8,800
Fen	20,000.75	19,100	23,664
Fen/Marsh Transitional	NA	10,075	19,256
Sum of Emergent Macrophytes	59,432.17	62,275	63,732

NA: Not Applicable

Note: Sit e3-8 Class 5 (2011) was not included during area assessments due to over estimation of site boundary

Table A4-14: Site 2-13 Submerged Classified Vegetation Areas			
Vegetation Type	2006 Area (m^2)	2011 Area (m^2)	2015 Area (m^2)
Sum of Submerged Macrophytes	85,738.60	133,593	88,580
Class 1	NA	3,485	12,668
Class 2	NA	15,059	39,152
Class 3	NA	20,983	5,296
Class 4	NA	49,952	8,580
Class 5	NA	44,114	22,884

NA: Not Applicable

Note: Site 2-13 Class 5 (2011) was not included during area assessments due to over estimation of site boundary

Table A4-15: Site 2-13 Emergent Classified Vegetation Areas			
Vegetation Type	2006 Area (m^2)	2011 Area (m^2)	2015 Area (m^2)
Low Marsh	NA	3,300	4,432
Marsh	9,394.53	2,925	3,580
Fen	NA	1,350	956
Fen/Marsh Transitional	NA	3,925	532
Sum of Emergent Macrophytes	9,394.53	11,500	9,500

NA: Not Applicable

Table A4-16: Site 1-17 Submerged Classified Vegetation Areas			
Vegetation Type	2006 Area (m^2)	2011 Area (m^2)	2015 Area (m^2)
Sum of Submerged Macrophytes	150,716	109,921	107,744
Class 1	NA	11,440	12,636
Class 2	NA	39,465	66,420
Class 3	NA	55,625	13,924
Class 4	NA	3,391	2,288
Class 5	NA	0	12,476

NA: Not Applicable

Table A4-17: Site 1-17 Emergent Classified Vegetation Areas			
Vegetation Type	2006 Area (m^2)	2011 Area (m^2)	2015 Area (m^2)
Low Marsh	15,722.81	4,850	8,592
Marsh	NA	5,475	7,408
Fen	18,713.09	7,400	5,360
Fen/Marsh Transitional	NA	7,025	4,368
Sum of Emergent Macrophytes	34,435.90	24,750	25,728

NA: Not Applicable

Table A4-18: Site 1-18 Submerged Classified Vegetation Areas			
Vegetation Type	2006 Area (m^2)	2011 Area (m^2)	2015 Area (m^2)
Sum of Submerged Macrophytes	5,231	15,091	15,896
Class 1	NA	3871	5672
Class 2	NA	9308	6840
Class 3	NA	1770	576
Class 4	NA	142	1660
Class 5	NA	0	1148

NA: Not Applicable

Table A4-19: Site 1-18 Emergent Classified Vegetation Areas			
Vegetation Type	2006 Area (m^2)	2011 Area (m^2)	2015 Area (m^2)
Low Marsh	151.57	4,200	2,076
Marsh	8,693.65	1,675	2,452
Fen	NA	1,775	916
Fen/Marsh Transitional	NA	2,050	1,864
Sum of Emergent Macrophytes	8,845.22	9,700	7,308

NA: Not Applicable

Appendix 4-2

Water Quality Tables

Table A4-20: pH
Table A4-21: Temperature (°C)
Table A4-22: DO (mg/L)
Table A4-23: Conductivity (uS/cm)
Table A4-24: Redox (mV)
Table A4-25: Turbidity (NTU)

Table A4-20: pH

Site	2011			2015		
	Mean	Min	Max	Mean	Min	Max
Site 4-4	7.70	7.68	7.77	7.74	7.66	7.85
Site 3-8	7.61	7.55	7.67	7.80	7.79	7.80
Site 3-7	7.51	7.50	7.53	7.75	7.74	7.77
Site 3-6	7.43	7.18	7.51	7.54	7.49	7.61
Site 2-13	7.75	7.64	7.79	7.96	7.89	8.05
Site 1-18	7.75	7.73	7.76	7.92	7.86	7.94
Site 1-17	7.72	7.65	7.73	7.75	7.75	7.76
Site 6-3	7.73	7.65	7.90	7.83	7.76	7.86

Table A4-21: Temperature (°C)

Site	2011			2015		
	Mean	Min	Max	Mean	Min	Max
Site 4-4	16.3	16.1	16.4	15.6	15.4	15.9
Site 3-8	15.9	15.6	16.2	15.4	15.3	15.4
Site 3-7	16.5	16.3	16.6	15.3	15.3	15.3
Site 3-6	15.7	15.0	16.5	14.9	14.0	15.0
Site 2-13	14.4	14.1	14.6	15.0	14.7	15.4
Site 1-18	16.2	16.2	16.2	14.9	14.8	15.1
Site 1-17	16.5	16.4	17.1	14.1	14.1	14.1
Site 6-3	16.7	16.3	16.9	15.0	15.0	15.0

Table A4-22: DO (mg/L)

Site	2011			2015		
	Mean	Min	Max	Mean	Min	Max
Site 4-4	9.67	9.61	9.76	9.81	9.55	9.90
Site 3-8	9.64	9.56	9.79	9.60	9.55	9.68
Site 3-7	9.42	9.40	9.43	9.46	9.41	9.60
Site 3-6	9.40	8.55	10.05	9.49	9.37	9.82
Site 2-13	10.04	10.00	10.09	10.07	9.82	10.30
Site 1-18	9.62	9.44	9.80	9.91	9.67	10.15
Site 1-17	9.89	9.79	9.94	9.83	9.55	9.86
Site 6-3	9.39	9.28	9.59	9.33	9.23	9.52

Table A4-23: Conductivity (uS/cm)						
Site	2011			2015		
	Mean	Min	Max	Mean	Min	Max
Site 4-4	50	50	50	98	97	99
Site 3-8	52	51	53	104	104	104
Site 3-7	51	51	52	104	103	104
Site 3-6	52	52	54	104	103	133
Site 2-13	55	55	56	106	105	107
Site 1-18	57	56	57	109	108	109
Site 1-17	56	56	57	109	109	109
Site 6-3	51	50	51	101	101	102

Table A4-24: Redox (mV)						
Site	2011			2015		
	Mean	Min	Max	Mean	Min	Max
Site 4-4	189	187	190	246	245	247
Site 3-8	170	166	172	228	227	229
Site 3-7	135	134	136	242	240	245
Site 3-6	185	132	196	221	194	237
Site 2-13	185	179	189	223	198	242
Site 1-18	169	155	182	215	213	221
Site 1-17	200	169	205	222	222	223
Site 6-3	178	168	183	224	218	228

Table A4-25: Turbidity (NTU)						
Site	2011			2015		
	Mean	Min	Max	Mean	Min	Max
Site 4-4	1.1	0.5	1.5	0.5	0.2	1.3
Site 3-8	NA	NA	NA	3.1	0.2	8.6
Site 3-7	NA	NA	NA	0.5	0.3	1.4
Site 3-6	NA	NA	NA	1.5	0.4	4.0
Site 2-13	NA	NA	NA	0.3	0.1	0.6
Site 1-18	0.7	0.0	1.4	0.3	0.2	0.7
Site 1-17	2.1	0.8	4.2	0.1	0.1	0.2
Site 6-3	NA	NA	NA	0.5	0.4	0.6

Appendix 4-3

Sediment Quality Tables

Table A4-26: Sediment Characteristics

Table A4-26: Sediment Characteristics

Site #	Year	Depth (m)	Colour	Texture	Smell	Consistency	Homogeneous throughout	Description of Debris Present
1-18C Mid	2011	1.0	dark brown	Woody debris	odourless	Loose, woody debris	yes	Wood Chips; a few long sticks; organic detritus; fine woody debris
	2015	1.2	dark brown	Woody debris	odourless	Woody debris	yes	Fine organics, woody debris with macros at surface (Isoetes).
1-18C Far	2011	1.5	gray-green	Gritty	H_2S	Thick like pudding	yes	Fine organic detritus on surface layer; Macrophytes; small woody debris; Brown surface Layer
	2015	1.7	brown-green	Gritty	H_2S	Thick like pudding	yes	Fine organic detritus on surface layer; Macrophytes
1-17C Near	2011	emergent	dark brown	Woody debris	odourless	Thick like pudding	yes	Organic debris/detritus, roots throughout; surface covered in macrophytes (small sedges)
	2015	0.2	grey	Silty with some sand	odourless	Thick like pudding	yes	Organic debris/detritus, roots throughout
1-17C Mid	2011	0.8	brown-green	Gritty	odourless	Thick like pudding	yes	Fine gravel; surface plant layer; aquatic macrophytes
	2015	1.0	brown-green	Silky	odourless	Thick like pudding	yes	Living macrophytes and organic roots throughout sample. 100% cover.
1-17C Far	2011	2.4	gray-green	Gritty	odourless	Thick like pudding	no	Macrophytes; small organic debris; very few woodchips
	2015	2.5	brown-green	Gritty	odourless	Thick like pudding	no	Macrophytes; small organic debris
3-6C Near	2011	0.5	dark brown	Woody debris	Wood Chips	Loose	yes	Wood Chips; macrophytes
	2015	0.7	dark brown	Woody debris	odourless	Loose	yes	Wood Chips; macrophytes
3-6C Mid	2011	6.0	brown-green	Silky	H_2S, algae	Falls apart into fluffy pellets	yes	Few sticks
	2015	6.2	dark brown	Silky	rotten egg	Falls apart into fluffy pellets	yes	Very fine organic debris
3-6C Far	2011	2.0	gray-green	Woody debris	H_2S	Falls apart into fluffy pellets	no	Lots of wood chips; some macrophytes; macrophyte layer followed by fluffy Layer followed by woodchip Layer
	2015	2.3	gray-green	Woody debris	H_2S	Falls apart into fluffy pellets	no	Lots of wood chips
3-7C Near	2011	emergent	dark brown	Rooty	Soil	Thick like pudding	yes	Lots of organic debris, roots + detritus
	2015	emergent	brown	Fibrous	Soil	Thick like pudding	yes	Poorly decomposed humic material
3-7C Mid	2011	0.2	brown-green	Gritty	odourless	Thick like pudding	yes	Organic debris/detritus, roots throughout; some wood chunks; surface covered in macrophytes (small sedges)
	2015	0.4	black to gray-green	Gritty	odourless	Thick like pudding	no	Organics, living isoetes sp.

Table A4-26: Sediment Characteristics (Con’d)

Site #	Year	Depth (m)	Colour	Texture	Smell	Consistency	Homogeneous throughout	Description of Debris Present
3-7C Far	2011	3.0	gray-green	Gravelly	H_2S	Loose	yes	Some macrophytes; small woodchips
	2015	3.2	brown-green	Gravelly	H_2S	Loose	yes	Some macrophytes
3-8C Near	2011	emergent, but wet	dark brown	Woody debris	odourless	Woody debis	yes	Almost entirely roots & woody debris; some moss on surface
	2015	emergent, but wet	dark brown	Woody debris	odourless	Woody debis	yes	Organic matter, undifferentiated vegetation and roots
3-8C Mid	2011	0.5	gray-green	Gritty	H_2S	Thick like pudding, debris laden	no	Many macrophytes on surface-subsurface decaying macrophytes; wood & large sticks; very thick macrophyte layer.
	2015	0.7	brown-green	Gritty	odourless	Thick like pudding	yes	Organics
3-8C Far	2011	5.5	gray-green	Gritty	H_2S	Thick like pudding	yes	Sticks (small); macrophytes.
	2015	5.7	brown-green	Gritty	H_2S	Thick like pudding	yes	Organics
4-4C Mid	2011	0.5	dark brown	Silky	odourless	Thick like pudding	yes	Macrophytes; woody debris; grey/white sediments (inclusion) streaked throughout
	2015	0.7	dark brown	Silky	odourless	Loose, mostly organics	yes	Macrophytes (isoetes), organics
6-3C Near	2011	0.2	dark brown	Gritty	odourless	Thick like pudding	yes	Large pebbles in surface ~5mm to 30mm; below surface layer consists of brown mud; some woody debris present
	2015	0.4	dark brown	gravelly	odourless	Loose	no	Cobbles an d gravels
6-3C Mid	2011	2.0	brown-green	Gritty	odourless	Thick like pudding	yes	Macrophytes in surface layer; fluffy subsurface layer then gravelly
	2015	2.2	brown-green	Gritty	odourless	Thick like pudding	yes	Macrophytes in surface layer; fluffy subsurface layer then gravelly
6-3C Far	2011	3.0	gray-green	Gritty	H_2S	Falls apart into fluffy pellets	yes	Some organic debris; some parts of the profile are thicker (globular masses)
	2015	3.2	gray-green	Gritty	H_2S	Thick like pudding	yes	Some organic debris
2-13C Near	2011	0.2	gray-green	Silky, some grit	odourless	Falls apart into fluffy pellets	yes	Dense macrophytes and roots; some white inclusions throughout sediment
	2015	0.4	brown-grey	Gritty	odourless	Thick like pudding	yes	Organics; rush
2-13C Mid	2011	2.1	gray-green	Gravelly	odourless	Thick like pudding	yes	Macrophytes; black organic flecking throughout
	2015	2.3	NA	Gravelly	NA	NA	NA	Too rocky for grab, substrate gravel and cobble
2-13C Far	2011	5.8	dark brown	Woody debris	odourless	Loose	no	Woodchips and small sticks; fish in sample; brown-green subsurface; gravelly
	2015	6.0	dark brown	Woody debris	odourless	Loose	yes	Woodchips and small sticks

Appendix 5

Macrophyte Ecology

Potamageton natans — Floating-leaved Pondweed

General Description

Classification

Kingdom *Plantae* – Plants
Subkingdom *Tracheobionta* – Vascular plants
Superdivision *Spermatophyta* – Seed plants
Division *Magnoliophyta* – Flowering plants
Class *Liliopsida* – Monocotyledons
Subclass *Alismatidae*
Order *Najadales*
Family *Potamogetonaceae* – Pondweeds
Genus *Potamogeton L.* – pondweed

Native Status

Native in Canada, Alaska, and Continental USA

Duration

Perennial

Threatened & Endangered Information

Not threatened

Habitat

Shallow lentic waters up to 3 m deep in fresh or brackish water, circumboreal

Growth Habit

Unknown

Morphology / Physiology

Active Growth Period

Summer

Growth Rate

Rapid

Growth Form

Rhizomatous

Growth Form

Long slender stems up to 2 mm thick and 1.5 m long extend from extensive submerged rhizomes.

Nitrogen Fixation

None

Foliage

Foliage is coppery-green. Floating Leaves are long and elliptical with a waxy – leathery texture. Submerged leaves are 1 - 2 mm wide and 5 - 20 cm long. Spirally arranged. Foliage is porous year-round.

Fruit/Seed Colour

Seeds are inconspicuous, semi-fleshy sessile Achenes; greenish brown in colour with a single diploid seed (2n = 52). Seeds are non-toxic.

Flowers

Produces inconspicuous green flowers which are tiny, stalkless, and whorled with 4 segments. There are 4 ovaries and 4 stamens present.

Growth Requirements

Soil Requirements

Rhizomous roots require 0 cm soil depth and are not adapted to a particular soil type. Requires submerged soils with medium fertility and medium C:N Ratios.

Hardiness

Minimum temperature tolerance of -38.9 °C; acceptable pH range of 5.8 – 7.0. High tolerance for anaerobic conditions. Requires 90 frost free days per annum and is shade intolerant. Found in regions with 30 – 140 cm of annual precipitation.

Reproduction

Bloom Period

Blooms in mid-summer and produces seeds from summer – fall.

Propagation Vectors

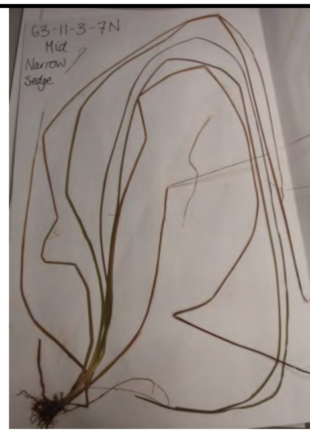
Can be propagated by bare roots, sprigs or seeds.
Forms extensive rhizomes that produce overwintering tubers.

Propagation Rate

Spread by seeds is slow due to low seed production and low seedling vigour. Vegetative spread is rapid.

Carex essicata, L.H. Bailey — Inflated Sedge

General Description



Classification

Kingdom *Plantae* – Plants
Subkingdom *Tracheobionta* – Vascular plants
Superdivision *Spermatophyta* – Seed plants
Division *Magnoliophyta* – Flowering plants
Class *Liliopsida* – Monocotyledons
Subclass *Commelinidae*
Order *Cyperales*
Family *Cyperaceae* – Sedge family
Genus *Carex* L. – sedge

Native Status

Native to BC

Duration

Perennial

Threatened & Endangered Information

Not Threatened

Habitat

Found along shores of lakes, rivers, also in marshes, fens and wet meadows from 100 – 1890 m elevation. Typically within lowland and montane zones.

Synonyms

Synonymous with *Carex vesicaria* var. *major* Boott

Morphology / Physiology

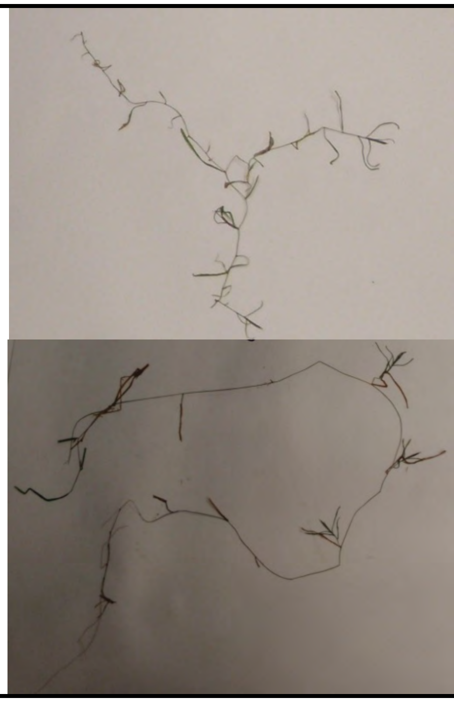
Foliage Texture	Inflorescence	Fruit/Seed Colour
Leaves are basal and cauline. Blades are flat and V shaped with a distinct midvein. **Shape and Orientation** Tufted herb with creeping rhizomes.	Stems protrude 30 – 100 cm from the base and are taller than leaves. Inflorescence are terminal with have 4 - 7 spikes.	Perigynia lanceolate, 7 - 10 mm long, 1.5 - 3 mm wide. Yellow-green to reddish-brown in colour Produces seeds from June – September.

Growth Requirements

Soil Texture (Coarse – Fine)	Cold Stratification Required	Temperature Tolerance (°C)
Not available	Not available	Not available
Anaerobic Tolerance	**Soil Fertility**	**pH Tolerance**
Not available	Rich	Not available
Precipitation, Min – Max	**Shade Tolerance**	**Submergence Tolerance**
Not available	Not available	Can persist in up to 0.50 m water

Potamogeton, Foliosus — Leafy Pondweed

General Description



Classification

Kingdom *Plantae* – Plants
Subkingdom *Tracheobionta* – Vascular plants
Superdivision *Spermatophyta* – Seed plants
Division *Magnoliophyta* – Flowering plants
Class *Liliopsida* – Monocotyledons
Subclass *Alismatidae*
Order *Najadales*
Family *Potamogetonaceae* – Pondweeds
Genus *Potamogeton L.* – pondweed

Native Status

Native to BC, Canada and the US including Hawaii and Puerto Rico

Duration

Perennial

Threatened & Endangered Information

Endangered in Maryland and New Hampshire

Habitat

Submerged macrophyte existing in shallow water up to 1.2 m deep with soft sediments.

Growth Habit

Forb/Herb

Morphology / Physiology

Active Growth Period	**Flower Colour**	**Fruit/Seed Colour**
Spring and Summer	Green	Brown
Growth Rate	**Flower Conspicuous**	**Fruit/Seed Conspicuous**
Moderate	No	No
Growth Form	**Foliage Texture**	**Toxicity**
Single Crown	Fine	None
Shape and Orientation	**Foliage Colour**	**Fall Conspicuous**
Prostate	Green	No
C:N Ratio	**Foliage Porosity Summer**	**Known Allelopath**
Medium	Porous	No
Nitrogen Fixation	**Foliage Porosity Winter**	
None	Porous	

Growth Requirements

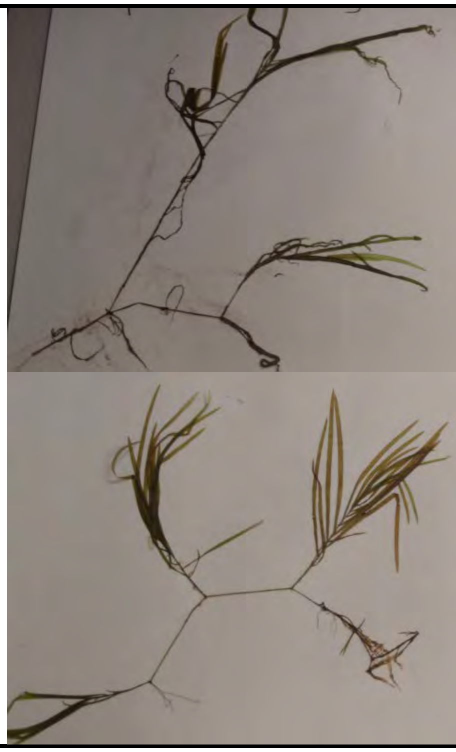
Soil Requirements	**Hardiness**
Rhizomous roots require 0 cm soil depth and are not adapted to a particular soil type. Requires submerged soils with medium fertility and medium C:N Ratios.	Minimum temperature tolerance of -38.9 °C; acceptable pH range of 5.5 – 7.0. High tolerance for anaerobic conditions. Requires 100 frost free days per annum and is shade intolerant. Found in regions with 30 – 140 cm of annual precipitation.

Reproduction

Bloom Period	**Propagated by Bare Root**	**Seed Spread Rate**
Late Spring	Yes	Moderate
Fruit/Seed Abundance	**Propagated by Sprigs**	**Seeding Vigor**
Medium	Yes	Medium
Fruit/Seed Period	**Propagated by Seed**	**Vegetative Spread Rate**
Summer	Yes	Slow
Fruit/Seed Persistence	**Propagated by Tubers**	
No	No	

Potamogeton epihydrous — Ribbonleaf pondweed

General Description



Classification

Kingdom *Plantae* – Plants
Subkingdom *Tracheobionta* – Vascular plants
Superdivision *Spermatophyta* – Seed plants
Division *Magnoliophyta* – Flowering plants
Class *Liliopsida* – Monocotyledons
Subclass *Alismatidae*
Order *Najadales*
Family *Potamogetonaceae* – Pondweeds
Genus *Potamogeton L.* – pondweed

Native Status

Native to BC, Canada and the US including Hawaii and Puerto Rico

Duration

Perennial

Threatened & Endangered Information

BC Yellow listed, Endangered in parts of SE USA.

Habitat

Found in lakes, ponds, ditches in lowland to subalpine zones.

Growth Habit

Monocot Forb/Herb

Morphology / Physiology

Active Growth Period	Flower Colour	Foliage Texture
Summer and Fall	Inconspicuous and green. Inflorescence is spike-like with spikes 2 - 4 cm long containing 5 - 12 whorls.	Foliage is fine, green and remains porous in Winter and Summer. Leaves are ribbon-like, between 3 - 7 mm wide and 1 - 20 cm long. Broad translucent bands run along mid-veins.
Growth Rate		
Rapid, from a single crown.		
Shape and Orientation	**C:N Ratio**	
Prostrate	Medium	
Fruit/Seed Colour	**Fall Conspicuous**	
Globe shaped, brown achenes	No	

Growth Requirements

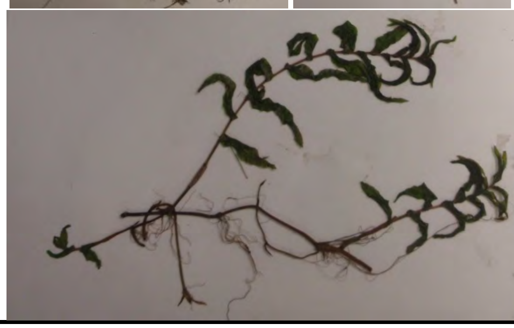
Soil Requirements	Hardiness
Rhizomous roots require 0 cm soil depth and are not adapted to a particular soil type. Requires submerged soils with medium fertility and medium C:N Ratios.	Minimum temperature tolerance of -33.0 °C; acceptable pH range of 5.4 – 7.0. High tolerance for anaerobic conditions. Requires 100 frost free days per annum and is shade intolerant. Found in regions with 35 – 140 cm of annual precipitation.

Reproduction

Bloom Period	Propagated by Bare Root	Seed Spread Rate
Mid Summer	Yes	Moderate
Fruit/Seed Abundance	**Propagated by Sprigs**	**Seeding Vigor**
Medium	Yes	Medium
Fruit/Seed Period	**Propagated by Seed**	**Vegetative Spread Rate**
Summer - Fall	Yes	Slow
Fruit/Seed Persistence	**Propagated by Tubers**	
No	No	

Potamogeton gramineus — Variable-leaf Pondweed

General Description

Classification

Kingdom *Plantae* – Plants
Subkingdom *Tracheobionta* – Vascular plants
Superdivision *Spermatophyta* – Seed plants
Division *Magnoliophyta* – Flowering plants
Class *Liliopsida* – Monocotyledons
Subclass *Alismatidae*
Order *Najadales*
Family *Potamogetonaceae* – Pondweeds
Genus *Potamogeton L.* – pondweed

Native Status

Native to BC and most of North America

Duration

Perennial

Threatened & Endangered Information

Not Threatened

Habitat

Lakes and lake margins, bogs and lentic water systems in all but the alpine zone. Primarily Interior Douglas Fir Biogeoclimatic zone.

Growth Habit

unknown

Morphology / Physiology

Active Growth Period	Flower Colour	Fruit/Seed Colour
Spring and Summer	Inflorescence are spike-like 2 - 4 cm long with 5 - 10 whorls	Globe shapes achenes with short beaks and sharp prominent keels.
Shape and Orientation	**Foliage Texture**	**Growth Rate**
Aquatic or semi-terrestrial herbaceous plant with strong rhizomes. Stems can extend up to 150 cm and are approximately circular. Prostrate.	Submerged leaves are lanceolate, thin, flat and green.	Rapid growth from a single crown.
		C:N Ratio
		Medium

Growth Requirements

Soil Requirements	Hardiness
Rhizomous roots require 0 cm soil depth and are not adapted to a particular soil types. Requires submerged soils with medium fertility and medium C:N Ratios.	Minimum temperature tolerance of -38.9 °C; acceptable pH range of 5.5 – 7.0. High tolerance for anaerobic conditions. Requires 90 frost free days per annum and is shade intolerant. Found in regions with 30 – 140 cm of annual precipitation.

Reproduction

Bloom Period	Propagated by Bare Root	Seed Spread Rate
Late Spring	Yes	Moderate
Fruit/Seed Abundance	**Propagated by Sprigs**	**Seeding Vigor**
Low	Yes	Low
Fruit/Seed Period	**Propagated by Seed**	**Vegetative Spread Rate**
Summer	Yes	Slow
Fruit/Seed Persistence	**Propagated by Tubers**	
No	No	

Eleocharis palustris (L.) Roem & J.A. Schoenl — Common Spikerush

General Description


Classification

Kingdom *Plantae* – Plants
Subkingdom *Tracheobionta* – Vascular plants
Superdivision *Spermatophyta* – Seed plants
Division *Magnoliophyta* – Flowering plants
Class *Liliopsida* – Monocotyledons
Subclass *Commelinidae*
Order *Cyperales*
Family *Cyperaceae* – Sedge family
Genus *Eleocharis* R. Br. - Spikerush

Native Status

Native throughout North America

Duration

Perennial Monocot

Threatened & Endangered Information

Not Threatened

Habitat

Obligate wetland species, thrives in water up to 1 m deep and up to 30 cm above water table (seasonally). Found up to 3000 m elevation.

Growth Habit

Graminoid

Morphology / Physiology

Shape and Orientation	Flower Colour	Fruit/Seed Colour
Strongly rhizomatous, develops thick root mass resistant to erosion.	Stems 10 – 70 cm tall, topped with terminal spikelet with multiple inconspicuous brown flowers.	Yellow – Brown bristled achene, 1.5 – 2.5 mm long
Active Growth Period	**C:N Ratio**	**Foliage Colour**
Spring	High	Dark green fine foliage porous in winter and moderately porous in summer.

Growth Requirements

Soil Requirements	Hardiness
Suited to moisture saturated fine-textured soils. High tolerance for anaerobic conditions.	Tolerates temperatures down to -38.9 °C and is found in areas with 40 – 152 cm of annual precipitation. Tolerates pH ranges from 4.0 – 8.0

Reproduction

Bloom Period	Propagated by Bare Root	Seed Spread Rate
Late Spring	No	Moderate
Fruit/Seed Abundance	**Propagated by Sprigs**	**Seeding Vigor**
Medium	Yes	Medium
Fruit/Seed Period	**Propagated by Seed**	**Vegetative Spread Rate**
Fall	Yes	Moderate
Fruit/Seed Persistence	**Propagated by Tubers**	
No	No	

Typha angustifolia L. — Narrowleaf Cattail

General Description

Classification

Kingdom *Plantae* – Plants
Subkingdom *Tracheobionta* – Vascular plants
Superdivision *Spermatophyta* – Seed plants
Division *Magnoliophyta* – Flowering plants
Class *Liliopsida* – Monocotyledons
Subclass *Commelinidae*
Order *Typhales*
Family *Typhaceae* – Cat-tail family
Genus *Typha L.* - Cattail

Native Status

Native to BC, MN, SK, ON, QC and maritime provinces.
Introduced in US.
May also be *Typha latifolia*

Duration

Perennial, Monocot

Threatened & Endangered Information

Not Threatened

Habitat

Brackish - subsaline waters through 0 – 1900 m elevation

Growth Habit

Forb / Herb

Morphology / Physiology

Foliage Texture	Flower Colour	Fruit/Seed Colour
Foliage is green, coarse and porous year round.	Flowering shoots 5 – 12 mm thick, reduced to 2 – 3 mm thick in inflorescence. Flowers are brown and inconspicuous	Seeds/fruits are brown and conspicuous, 2n = 30.
Active Growth Period	**Growth Form**	**Toxicity**
Spring and Summer	Rhizomatous	None
Shape and Orientation	**C:N Ratio**	
Erect shoots, 150 – 300 cm.	High	

Growth Requirements

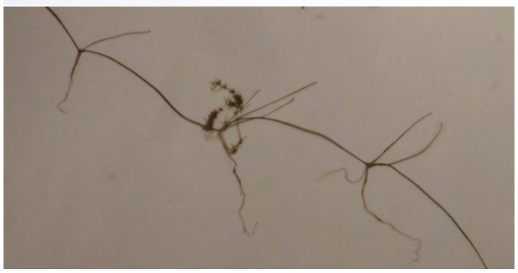
Soil Requirements	Hardiness
Adapted to coarse – fine sediment types. In soils with medium fertility. Roots require a minimum of 45 cm depth.	Requires 100 frost free days per annum and can tolerate temperatures to -37 °C. pHs of 5.5 – 8.7 are tolerated.
Anaerobic Tolerance	**Shade Tolerance**
High	Intermediate

Reproduction

Bloom Period	Propagated by Bare Root	Seed Spread Rate
Late Spring	Yes	Moderate
Fruit/Seed Abundance	**Propagated by Sprigs**	**Seeding Vigor**
High	Yes	Medium
Fruit/Seed Period	**Propagated by Seed**	**Vegetative Spread Rate**
Fall	Yes	Rapid
Fruit/Seed Persistence	**Propagated by Tubers**	
Yes	No	

Isoetes sp. Quillworts

General Description



Classification

Kingdom *Plantae* – Plants
Subkingdom *Tracheobionta* – Vascular plants
Division *Lycopodiophyta* – Lycopods
Class *Lycopodiopsida* – Monocotyledons
Order *Isoetales*
Family *Isoetaceae* – Quillwort family
Isoetes L. – quillwort
Most Likely Species: *I. occidentalis* or *I. howelli,*
Also possibilities: *I. minima, I. xpseudotruncata, I. tenella.*
In area, but not ID'd: *I. nuttallii, I. maratima*

Native Status

Several Native species in BC

Duration

Perennial

Threatened & Endangered Information

Most species not threatened
Isoetes nuttallii is listed as sensitive in Washington.
Other threatened/endangered taxa are not present in BC.

Habitat

Lakes in lowland to subalpine zones, lacustrine or lentic waters. Habitat is used to delineate taxa. Mostly submerged individuals in Whatshan Reservoir.

Growth Habit

Graminoid, fern allies

Morphology / Physiology

Shape and Orientation	Fruit/Seed Colour	Flower Colour
Small and upright with short-lobed rootstock.	Spores stored within rootstock. Sporangia ovoid to ellipsoid. Spores cristulate with distinctive tri-lateral ridge	n/a
Growth Form	**Foliage Colour**	**Foliage Texture**
Propagated by spores	Green	Fine

Crassula aquatic (L.) Schoenl — Water Pygmyweed

General Description

Classification

Kingdom *Plantae* – Plants
Subkingdom *Tracheobionta* – Vascular plants
Superdivision *Spermatophyta* – Seed plants
Division *Magnoliophyta* – Flowering plants
Class *Magnoliopsida* – Dicotyledons
Subclass *Rosidae*
Order *Rosales*
Family *Crassulaceae* – Stonecrop family
Genus *Crassula L.* - pygmyweed

Native Status

Native to North America, widespread in southern BC.

Duration

Annual, usually co-dominant

Threatened & Endangered Information

Not threatened in Canada
Endangered/extirpated in Connecticut, Maryland, New York, New Hampshire and Pennsylvania.
Threatened in Massachusetts and Minnesota.

Habitat

Brackish mudflats, pools, margins of ponds, coastal marshes and stream sides. 0 – 3000 m elevation.

Growth Habit

Weak annual herb, nodal roots.

Morphology / Physiology

Shape and Orientation	Foliage Texture	Fruit/Seed Colour
Roots at basal nodes, branching at the base.	Succulent opposite leaves, Oblancoleate leaf blades 2 - 6 mm	Oblong ellipsoid seeds (2n=42) from follicles (6-12 seeds per follicle).
Bloom Period	**Foliage Colour**	**Fruit/Seed Conspicuous**
Late Spring - Summer	Green	No

Ranunculus aquatilis L. White Water-crowsfoot

General Description

Classification

Kingdom *Plantae* – Plants
Subkingdom *Tracheobionta* – Vascular plants
Superdivision *Spermatophyta* – Seed plants
Division *Magnoliophyta* – Flowering plants
Class *Magnoliopsida* – Dicotyledons
Subclass *Magnolidae*
Order *Ranunculales*
Family *Ranunculaceae* – Buttercup family
Genus *Ranunculus L.* - Buttercup

Native Status

Native to Canada, Alaska and the continental US.

Duration

Perennial

Threatened & Endangered Information

Not threatened

Habitat

Ponds, lakes, streams, ditches and river edges form 0 – 3,200 m.

Growth Habit

Forb/Herb

Morphology / Physiology

Shape and Orientation	Foliage Texture	Toxicity
Rooting from nodes of lower stems. Stems are weak with few branches, creeping and mat forming.	Filiform dissected, connate leaves. Leaves are all alternate stemmed, typically kidney shaped with three parts (5 – 8 mm long).	All parts of plant are poisonous when fresh. Leaves of *R. aquatilis capillaceous* are used to treat fevers and asthma in India.
Known Allelopath	**Flower Colour**	**Fruit/Seed Colour**
Inhibits growth of nearby plants, particularly legumes	White , self compatible, hermaphroditic flowers	Fruiting pedicles recurved, producing hemispheric achenes. Taxonomy unclear.

Growth Requirements

Soil Texture (Coarse – Fine)	Shade Tolerance	pH Tolerance
Suited to sandy, loamy and clay soils. Requires moist soils or submergence.	Semi-shade to full sun	Wide tolerance
Bloom Period		
Late Spring - Summer		

Najas flexilis — Nodding Waternymph

General Description

Classification

Kingdom Plantae – Plants
Subkingdom Tracheobionta – Vascular plants
Superdivision Spermatophyta – Seed plants
Division Magnoliophyta – Flowering plants
Class Liliopsida – Monocotyledons
Subclass Alismatidae
Order Najadales
Family Najadaceae – Water-Nymphs
Genus *Najas* L. - waternymph

Native Status

Native to Canada, Alaska, and parts of the USA

Duration

Annual Monocot

Threatened & Endangered Information

Not Threatened

Habitat

Shallow fresh or brackish waters, Lakes and Rivers 0 – 1,500 m. Obligate wetland species.

Growth Habit

Forb/Herb

Morphology / Physiology

Active Growth Period	**Flower Colour**	**Fruit/Seed Colour**
Spring, Summer, Fall	Solitary or paired inflorescence with unstalked axilary green flowers (monoecious). Male flowers have single-chambered anthers.	Spindle-shaped achenes, 3 mm, long green.
Growth Rate		**Foliage Porosity Summer**
Rapid		Porous
Growth Form	**Flower Conspicuous**	**Foliage Porosity Winter**
Colonizing	No	Porous
C:N Ratio	**Foliage Texture**	**Foliage Colour**
Low	Fine	Green

Growth Requireme

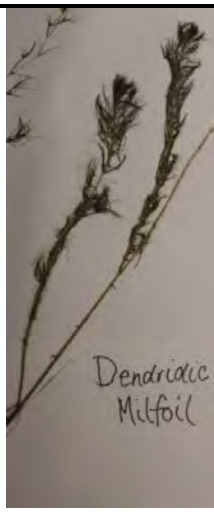
Soil Texture (Coarse – Fine)	**Cold Stratification Required**	**Temperature Tolerance (°C)**
Very tolerant of soil texture	Yes	Min -40°C
Anaerobic Tolerance	**Soil Fertility**	**pH Tolerance**
High	Medium	6.5 – 7.5
Precipitation, Min – Max	**Shade Tolerance**	
Unknown	Intermediate	

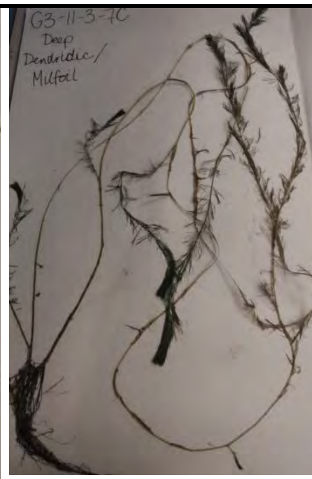
Reproduction

Bloom Period	**Propagated by Bare Root**	**Seed Spread Rate**
Late Summer	No	Moderate
Fruit/Seed Abundance	**Propagated by Sprigs**	**Seeding Vigor**
Medium	Yes	Medium
Fruit/Seed Period	**Propagated by Seed**	**Vegetative Spread Rate**
Summer to Fall	Yes	Slow
Fruit/Seed Persistence	**Propagated by Tubers**	
No	No	

Myriophyllum, sibiricum — Water milfoil

General Description





Classification

Kingdom *Plantae* – Plants
Subkingdom *Tracheobionta* – Vascular plants
Superdivision *Spermatophyta* – Seed plants
Division *Magnoliophyta* – Flowering plants
Class *Magnoliopsida* – Dicotyledons
Subclass *Rosidae*
Order *Haloragales*
Family *Haloragaceae* – Water milfoil
Genus *Myriophyllum L.* - watermilfoil

Native Status

Native to BC and North America
Indistinguishable from M. Verticillatum

Duration

Perennial

Threatened & Endangered Information

Endangered in New Jersey, Pennsylvania
Threatened in Ohio

Habitat

Lakes, ponds and sloughs in the lowland and montane zones. Frequent throughout BC

Growth Period

Forb/Herb

Morphology / Physiology

Shape and Orientation	Flower Colour	Foliage Texture
Short rhizomes producing stems 10 – 150 cm long.	Spikes emergent, 15 cm long. Male flowers pink-red in *sibiricum*, yellow in *M. verticillatum.*	Foliage in whorls of 3 – 4. Leaves pinnate with 4 - 14 segments.
Growth Form	**Flower Conspicuous**	**Foliage Colour**
Herbaceous	Yes	Green
Fruit/Seed Colour	**Fruit/Seed Conspicuous**	
4 brown Mericarps, wrinkled	No	

Growth Requirements

Soil Texture (Coarse – Fine)	Soil Fertility	Temperature Tolerance (°C)
Sandy to loamy soils	Unknown	Suspected -40 °C
Anaerobic Tolerance	**Shade Tolerance**	**pH Tolerance**
Unknown	Intolerant	High alkaline tolerance

Reproduction

Bloom Period	Propagated by Bare Root	Propagated by Seed
Monoescious flowers, wind pollinated. Blooms July - August	unknown	Yes
Fruit/Seed Period	**Propagated by Sprigs**	**Propagated by Tubers**
Seeds present Fall	unknown	Unknown
Fruit/Seed Persistence		
Sessile until following spring.		

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E-Flora BC: Electronic Atlas of the Plants of British Columbia

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Plants For a Future

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http://www.efloras.org/florataxon.aspx?flora_id=1&taxon_id=233501119

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http://www.efloras.org/florataxon.aspx?flora_id=1&taxon_id=200024696
http://plants.usda.gov/java/profile?symbol=PONA4&mapType=nativity&photoID=pona4_002_ahp.tif

http://www.rook.org/earl/bwca/nature/aquatics/myriophyllumver.html

Appendix 6

Macrophyte Raw Data

Year	2011	2011	2011	2011	2011	2011	2011	2011	2011	2015	2015	2015	2015	2015	2015	2015	2015	2015
Site	2011_1-17aN	2011_1-17bN	2011_1-17cN	2011_1-17aM	2011_1-17bM	2011_1-17cM	2011_1-17aF	2011_1-17bF	2011_1-17cF	2015_1-17aN	2015_1-17bN	2015_1-17cN	2015_1-17aM	2015_1-17bM	2015_1-17cM	2015_1-17aF	2015_1-17bF	2015_1-17cF
Location	Near	Near	Near	Mid	Mid	Mid	Far	Far	Far	Near	Near	Near	Mid	Mid	Mid	Far	Far	Far
Transect	E	C	W	E	C	W	E	C	W	E	C	W	E	C	W	E	C	W
Total Cover (%)	80	80	50	60	100	100	40	65	100	95	80	60	95	100	100	100	100	100
Chara sp.								5.85					19			60		
Tolypella sp.				6														
Crassula aquatica				0.6	31	25	1.2	6.5	30				28.5	20	60		20	10
Carex exsiccata																		
Carex sp.		80	50	24						47.5	80	60						
Carex rossii																		
Carex rostrata																		
Eleocharis sp.																		
Eleocharis palustris (L.)	56			24	21	15												
Schoenoplectus tabernaemontani																		
Equisetum sp.																		
Equisetum fluviatile L.																		
Equisetum pretense Ehrh.																		
Isoetes sp.	4			0.6	31	25	10	52	50				38	80	40		80	90
Najas flexilis (Willd.)				4.2	11		0.8						9.5			20		
Persicaria amphibia var. emersa (Michx.)																		
Potamogeton sp.																		
Potamogeton epihydrus Raf.							4											
Potamogeton foliosus Raf.																		
Potamogeton gramineus L.						10	24	0.65										
Potamogeton natans L.																		
Potamogeton pusillus L.																1		
Potamogeton perfoliatus																9		
Ranunculus aquatilis var. diffusus With. p.p.				0.6												10		
Comarum palustre L.																		
Typha angustifolia L.																		
Poaceae																		
Juncus sp.										38								
Myriophyllum verticillatum or M. sibiricum																		
Utricularia macrorhiza Leconte					6													
Utricularia minor L.																		
Nuphar lutea (L.) Sm.																		
Climacium dendroidies																		
Other Moss	20					25			20	9.5								
Mentha arvensis L.																		
Athyrium felix-femina																		
Rhododendron groenlandicum (Oeder)																		
Fragaria virginiana Duchesne																		
Viola orbiculata Geyer ex Holz.																		
Beluta sp.																		
Cryptogramma stelleri																		
Galium trifidum																		
Urtica dioica																		
Verbascum thapsus																		
Fibrous Decomposing Organics																		
Total (%)	80	80	50	60	100	100	40	65	100	95	80	60	95	100	100	100	100	100

Year	2011	2011	2011	2011	2011	2011	2011	2011	2011	2015	2015	2015	2015	2015	2015	2015	2015	2015
Site	2011_1-18aN	2011_1-18bN	2011_1-18cN	2011_1-18aM	2011_1-18bM	2011_1-18cM	2011_1-18aF	2011_1-18bF	2011_1-18cF	2015_1-18aN	2015_1-18bN	2015_1-18cN	2015_1-18aM	2015_1-18bM	2015_1-18cM	2015_1-18aF	2015_1-18bF	2015_1-18cF
Location	Near	Near	Near	Mid	Mid	Mid	Far	Far	Far	Near	Near	Near	Mid	Mid	Mid	Far	Far	Far
Transect	N	C	S	N	C	S	N	C	S	N	C	S	N	C	S	N	C	S
Total Cover (%)	70	85	60	80	25	60	20	80	20	40	75	90	100	30	10	90	100	100
Chara sp.								2							6.9		5	
Tolypella sp.								2										
Crassula aquatica				1.6			0.2						50			4.5		
Carex exsiccata																		
Carex sp.	62.3	68	42	68						22	41.25	18	25					
Carex rossii																		
Carex rostrata																		
Eleocharis sp.																		
Eleocharis palustris (L.)						54												
Schoenoplectus tabernaemontani																		
Equisetum sp.	0.7																	
Equisetum fluviatile L.																		
Equisetum pretense Ehrh.																		
Isoetes sp.							7.6	32	0.2				20			81	80	20
Najas flexilis (Willd.)						3		4									5	70
Persicaria amphibia var. emersa (Michx.)																		
Potamogeton sp.															2.5			
Potamogeton epihydrus Raf.								8										
Potamogeton foliosus Raf.																		
Potamogeton gramineus L.				1.6	1.25	3	12	32						30				10
Potamogeton natans L.					22.5				19.8									
Potamogeton pusillus L.																		
Potamogeton perfoliatus															0.5	4.5	5	
Ranunculus aquatilis var. diffusus With. p.p.				0.8									5		0.1		5	
Comarum palustre L.	1.4	1.7	0.6															
Typha angustifolia L.			6									4.5						
Poaceae		8.5								2	3.75	27						
Juncus sp.																		
Myriophyllum verticillatum or M. sibiricum																		
Utricularia macrorhiza Leconte																		
Utricularia minor L.																		
Nuphar lutea (L.) Sm.																		
Climacium dendroidies		1.7	4.2								30							
Other Moss	3.5	2.55	4.8				0.2			16								
Mentha arvensis L.												13.5						
Athyrium felix-femina			1.2									27						
Rhododendron groenlandicum (Oeder)	0.7																	
Fragaria virginiana Duchesne	0.7			8	1.25													
Viola orbiculata Geyer ex Holz.	0.7	2.55																
Beluta sp.			1.2															
Cryptogramma stelleri																		
Galium trifidum																		
Urtica dioica																		
Verbascum thapsus																		
Fibrous Decomposing Organics																		
Total (%)	70	85	60	80	25	60	20	80	20	40	75	90	100	30	10	90	100	100

Year	2011	2011	2011	2011	2011	2011	2011	2011	2011	2015	2015	2015	2015	2015	2015	2015	2015	2015
Site	2011_2-13aN	2011_2-13bN	2011_2-13cN	2011_2-13aM	2011_2-13bM	2011_2-13cM	2011_2-13aF	2011_2-13bF	2011_2-13cF	2015_2-13aN	2015_2-13bN	2015_2-13cN	2015_2-13aM	2015_2-13bM	2015_2-13cM	2015_2-13aF	2015_2-13bF	2015_2-13cF
Location	Near	Near	Near	Mid	Mid	Mid	Far	Far	Far	Near	Near	Near	Mid	Mid	Mid	Far	Far	Far
Transect	N	C	S	N	C	S	N	C	S	N	C	S	N	C	S	N	C	S
Total Cover (%)	80	90	80	60	65	100	30	85	30	100	50	25	10	20	50	15	0	0
Chara sp.	8					1	25.5	80.75	21					8	5	4.5		
Tolypella sp.	0.8			3	0.65	1	1.5		0.3									
Crassula aquatica		27									10							
Carex exsiccata																		
Carex sp.	0.8	27	40								30	15						
Carex rossii																		
Carex rostrata																		
Eleocharis sp.		9																
Eleocharis palustris (L.)												10						
Schoenoplectus tabernaemontani																		
Equisetum sp.																		
Equisetum fluviatile L.																		
Equisetum pretense Ehrh.																		
Isoetes sp.	5.6	27	40		42.25	15					10			12	45			
Najas flexilis (Willd.)	8				1.3	3			6	50								
Persicaria amphibia var. emersa (Michx.)																		
Potamogeton sp.	0.8						3	4.25	1.2	50			10			7.5		
Potamogeton epihydrus Raf.				57	19.5				1.5									
Potamogeton foliosus Raf.																		
Potamogeton gramineus L.																		
Potamogeton natans L.	56																	
Potamogeton pusillus L.																		
Potamogeton perfoliatus																3		
Ranunculus aquatilis var. diffusus With. p.p.					1.3	80												
Comarum palustre L.																		
Typha angustifolia L.																		
Poaceae																		
Juncus sp.																		
Myriophyllum verticillatum or M. sibiricum																		
Utricularia macrorhiza Leconte																		
Utricularia minor L.																		
Nuphar lutea (L.) Sm.																		
Climacium dendroidies																		
Other Moss																		
Mentha arvensis L.																		
Athyrium felix-femina																		
Rhododendron groenlandicum (Oeder)																		
Fragaria virginiana Duchesne																		
Viola orbiculata Geyer ex Holz.																		
Beluta sp.																		
Cryptogramma stelleri																		
Galium trifidum																		
Urtica dioica																		
Verbascum thapsus																		
Fibrous Decomposing Organics																		
Total (%)	80	90	80	60	65	100	30	85	30	100	50	25	10	20	50	15	0	0

Year	2011	2011	2011	2011	2011	2011	2011	2011	2011	2015	2015	2015	2015	2015	2015	2015	2015	2015
Site	2011_3-6aN	2011_3-6bN	2011_3-6cN	2011_3-6aM	2011_3-6bM	2011_3-6cM	2011_3-6aF	2011_3-6bF	2011_3-6cF	2015_3-6aN	2015_3-6bN	2015_3-6cN	2015_3-6aM	2015_3-6bM	2015_3-6cM	2015_3-6aF	2015_3-6bF	2015_3-6cF
Location	Near	Near	Near	Mid	Mid	Mid	Far	Far	Far	Near	Near	Near	Mid	Mid	Mid	Far	Far	Far
Transect	E	C	W	E	C	W	E	C	W	E	C	W	E	C	W	E	C	W
Total Cover (%)	60	95	100	85	75	40	20	85	100	100	90	70	0	0	0	60	60	100
Chara sp.	3	28.5	60		45	40		51	70		36	14				3		15
Tolypella sp.									10									
Crassula aquatica											9							
Carex exsiccata																		
Carex sp.																		
Carex rossii																		
Carex rostrata																		
Eleocharis sp.																		
Eleocharis palustris (L.)																		
Schoenoplectus tabernaemontani																		
Equisetum sp.																		
Equisetum fluviatile L.																		
Equisetum pretense Ehrh.																		
Isoetes sp.			30							20								1
Najas flexilis (Willd.)	18	4.75	4				12	25.5	10	60	18	7				54	30	50
Persicaria amphibia var. emersa (Michx.)																		
Potamogeton sp.	36	4.75	1	85	30		8	2.55	5		27	49					30	34
Potamogeton epihydrus Raf.		57						4.25										
Potamogeton foliosus Raf.																		
Potamogeton gramineus L.									5									
Potamogeton natans L.																		
Potamogeton pusillus L.																		
Potamogeton perfoliatus																		
Ranunculus aquatilis var. diffusus With. p.p.								1.7		20						3		
Comarum palustre L.																		
Typha angustifolia L.																		
Poaceae																		
Juncus sp.																		
Myriophyllum verticillatum or M. sibiricum																		
Utricularia macrorhiza Leconte																		
Utricularia minor L.																		
Nuphar lutea (L.) Sm.			5															
Climacium dendroidies																		
Other Moss	3																	
Mentha arvensis L.																		
Athyrium felix-femina																		
Rhododendron groenlandicum (Oeder)																		
Fragaria virginiana Duchesne																		
Viola orbiculata Geyer ex Holz.																		
Beluta sp.																		
Cryptogramma stelleri																		
Galium trifidum																		
Urtica dioica																		
Verbascum thapsus																		
Fibrous Decomposing Organics																		
Total (%)	60	95	100	85	75	40	20	85	100	100	90	70	0	0	0	60	60	100

Year	2011	2011	2011	2011	2011	2011	2011	2011	2011	2015	2015	2015	2015	2015	2015	2015	2015	2015
Site	2011_3-7aN	2011_3-7bN	2011_3-7cN	2011_3-7aM	2011_3-7bM	2011_3-7cM	2011_3-7aF	2011_3-7bF	2011_3-7cF	2015_3-7aN	2015_3-7bN	2015_3-7cN	2015_3-7aM	2015_3-7bM	2015_3-7cM	2015_3-7aF	2015_3-7bF	2015_3-7cF
Location	Near	Near	Near	Mid	Mid	Mid	Far	Far	Far	Near	Near	Near	Mid	Mid	Mid	Far	Far	Far
Transect	N	C	S	N	C	S	N	C	S	N	C	S	N	C	S	N	C	S
Total Cover (%)	70	95	90	100	100	100	10	100	100	75	100	100	30	100	25	0	50	100
Chara sp.				20		10	2.5	60	40						17.5		10	70
Tolypella sp.				10		5			35									
Crassula aquatica				3	5	20								70				
Carex exsiccata																		
Carex sp.	28	1.9	36							7.5								
Carex rossii												15						
Carex rostrata										7.5								
Eleocharis sp.																		
Eleocharis palustris (L.)																		
Schoenoplectus tabernaemontani																		
Equisetum sp.	7									3.75	1		18					
Equisetum fluviatile L.					3													
Equisetum pretense Ehrh.																		
Isoetes sp.					15	62								30				
Najas flexilis (Willd.)				3	48				15						2.5		35	
Persicaria amphibia var. emersa (Michx.)																		
Potamogeton sp.							1.5	30	10						2.5		2.5	30
Potamogeton epihydrus Raf.																		
Potamogeton foliosus Raf.																		
Potamogeton gramineus L.					2	1	6	1							2.5			
Potamogeton natans L.																		
Potamogeton pusillus L.					1													
Potamogeton perfoliatus																	2.5	
Ranunculus aquatilis var. diffusus With. p.p.				4	5													
Comarum palustre L.										0.75								
Typha angustifolia L.	35	85.5	45	20	20	2				32.25	74	67	12					
Poaceae		4.75								8.25								
Juncus sp.				40														
Myriophyllum verticillatum or M. sibiricum					1			9										
Utricularia macrorhiza Leconte																		
Utricularia minor L.																		
Nuphar lutea (L.) Sm.																		
Climacium dendroidies										15		5						
Other Moss		0.95										5						
Mentha arvensis L.		1.9	9								20	1						
Athyrium felix-femina																		
Rhododendron groenlandicum (Oeder)																		
Fragaria virginiana Duchesne																		
Viola orbiculata Geyer ex Holz.																		
Beluta sp.																		
Cryptogramma stelleri												5						
Galium trifidum												1						
Urtica dioica											5							
Verbascum thapsus												1						
Fibrous Decomposing Organics																		
Total (%)	70	95	90	100	100	100	10	100	100	75	100	100	30	100	25	0	50	100

Year	2011	2011	2011	2011	2011	2011	2011	2011	2011	2015	2015	2015	2015	2015	2015	2015	2015	2015
Site	2011_3-8aN	2011_3-8bN	2011_3-8cN	2011_3-8aM	2011_3-8bM	2011_3-8cM	2011_3-8aF	2011_3-8bF	2011_3-8cF	2015_3-8aN	2015_3-8bN	2015_3-8cN	2015_3-8aM	2015_3-8bM	2015_3-8cM	2015_3-8aF	2015_3-8bF	2015_3-8cF
Location	Near	Near	Near	Mid	Mid	Mid	Far	Far	Far	Near	Near	Near	Mid	Mid	Mid	Far	Far	Far
Transect	N	C	S	N	C	S	N	C	S	N	C	S	N	C	S	N	C	S
Total Cover (%)	90	90	50	100	100	100	100	100	100	90	95	40	100	100	100	60	100	100
Chara sp.				5	4	4	5	30								54	33	15
Tolypella sp.					1	1			5									
Crassula aquatica				30	5	5	30						45		90		1	
Carex exsiccata	22.5																	
Carex sp.		22.5								9								
Carex rossii																		
Carex rostrata																		
Eleocharis sp.																		
Eleocharis palustris (L.)																		
Schoenoplectus tabernaemontani					10													
Equisetum sp.																		
Equisetum fluviatile L.																		
Equisetum pretense Ehrh.																		
Isoetes sp.				30		90	5						45	80		6		
Najas flexilis (Willd.)				7				1									32	5
Persicaria amphibia var. emersa (Michx.)																		
Potamogeton sp.				3			5	25	75								33	
Potamogeton epihydrus Raf.																		
Potamogeton foliosus Raf.																		
Potamogeton gramineus L.				15	30		10	30	5									
Potamogeton natans L.																		
Potamogeton pusillus L.																		
Potamogeton perfoliatus														5				15
Ranunculus aquatilis var. diffusus With. p.p.				5	10		5	14	5								1	5
Comarum palustre L.																		
Typha angustifolia L.	63	63	47.5		40		30			72	71.25	40	10	15	10			
Poaceae										9	9.5							
Juncus sp.																		
Myriophyllum verticillatum or M. sibiricum									10									
Utricularia macrorhiza Leconte																		
Utricularia minor L.			2.5	5			10											
Nuphar lutea (L.) Sm.																		
Climacium dendroidies																		
Other Moss	4.5	4.5									14.25							
Mentha arvensis L.																		
Athyrium felix-femina																		
Rhododendron groenlandicum (Oeder)																		
Fragaria virginiana Duchesne																		
Viola orbiculata Geyer ex Holz.																		
Beluta sp.																		
Cryptogramma stelleri																		
Galium trifidum																		
Urtica dioica																		
Verbascum thapsus																		
Fibrous Decomposing Organics																		60
Total (%)	90	90	50	100	100	100	100	100	100	90	95	40	100	100	100	60	100	100

Year	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015
Site	2011_4-4aN	2011_4-4bN	2011_4-4cN	2011_4-4aM	2011_4-4bM	2011_4-4cM	2011_4-4aF	2011_4-4bF	2011_4-4cF	2011_4-4aFF	2011_4-4bFF	2011_4-4cFF	2015_4-4aN	2015_4-4bN	2015_4-4cN	2015_4-4aM	2015_4-4bM	2015_4-4cM	2015_4-4aF	2015_4-4bF	2015_4-4cF	2015_4-4aFF	2015_4-4bFF	2015_4-4cFF
Location	Near	Near	Near	Mid	Mid	Mid	Far	Far	Far	Far-Far	Far-Far	Far-Far	Near	Near	Near	Mid	Mid	Mid	Far	Far	Far	Far-Far	Far-Far	Far-Far
Transect	E	C	W	E	C	W	E	C	W	E	C	W	E	C	W	E	C	W	E	C	W	E	C	W
Total Cover (%)	100	85	75	95	100	80	100	60	80	85	100	65	90	100	100	100	90	100	100	50	70	80	70	60
Chara sp.				6.65		3.2	10	1.8	44	28.9	60	22.75	4.5			10		20	40	0.5	0.7	16	7	0.6
Tolypella sp.				14.25	1	4	1	9	8	29.75	20	3.25												
Crassula aquatica	90			61.75	55	64	5	18				9.75	72			30	27	5	50				28	10.8
Carex exsiccata																								
Carex sp.		63.75	67.5											80	90									
Carex rossii																								
Carex rostrata																								
Eleocharis sp.																								
Eleocharis palustris (L.)	5						1																	
Schoenoplectus tabernaemontani																								
Equisetum sp.																								
Equisetum fluviatile L.																								
Equisetum pretense Ehrh.			2.25																					
Isoetes sp.	3			9.5	4	4	1	18	4	8.5	3	27.3	9				4.5	5			30.1	16	7	9
Najas flexilis (Willd.)				1.9	15	4	58	9	24	17	10	0.65				10	13.5	70	10	14.5	14	48	28	39
Persicaria amphibia var. emersa (Michx.)		0.85												5										
Potamogeton sp.													4.5											
Potamogeton epihydrus Raf.								1.2									45			35				
Potamogeton foliosus Raf.										0.85											25.2			
Potamogeton gramineus L.											5					50								
Potamogeton natans L.							20				1													
Potamogeton pusillus L.																								
Potamogeton perfoliatus																								0.6
Ranunculus aquatilis var. diffusus With. p.p.								1.2			1													
Comarum palustre L.			5.25																					
Typha angustifolia L.		20.4																						
Poaceae														15	10									
Juncus sp.																								
Myriophyllum verticillatum or M. sibiricum							1																	
Utricularia macrorhiza Leconte																								
Utricularia minor L.																								
Nuphar lutea (L.) Sm.																								
Climacium dendroidies																								
Other Moss	2			0.95	25	0.8	3	1.8				1.3												
Mentha arvensis L.																								
Athyrium felix-femina																								
Rhododendron groenlandicum (Oeder)																								
Fragaria virginiana Duchesne																								
Viola orbiculata Geyer ex Holz.																								
Beluta sp.																								
Cryptogramma stelleri																								
Galium trifidum																								
Urtica dioica																								
Verbascum thapsus																								
Fibrous Decomposing Organics																								
Total (%)	100	85	75	95	100	80	100	60	80	85	100	65	90	100	100	100	90	100	100	50	70	80	70	60

Year	2011	2011	2011	2011	2011	2011	2011	2011	2011	2015	2015	2015	2015	2015	2015	2015	2015	2015
Site	2011_6-3aN	2011_6-3bN	2011_6-3cN	2011_6-3aM	2011_6-3bM	2011_6-3cM	2011_6-3aF	2011_6-3bF	2011_6-3cF	2015_6-3aN	2015_6-3bN	2015_6-3cN	2015_6-3aM	2015_6-3bM	2015_6-3cM	2015_6-3aF	2015_6-3bF	2015_6-3cF
Location	Near	Near	Near	Mid	Mid	Mid	Far	Far	Far	Near	Near	Near	Mid	Mid	Mid	Far	Far	Far
Transect	N	C	S	N	C	S	N	C	S	N	C	S	N	C	S	N	C	S
Total Cover (%)	60	50	70	60	100	40	10	80	20	100	40	75	0	100	10	30	100	10
Chara sp.						1.6					12			40	10		40	5
Tolypella sp.					60	0.4		12										
Crassula aquatica	18		21	6		2												
Carex exsiccata																		
Carex sp.		40																
Carex rossii																		
Carex rostrata																		
Eleocharis sp.																		
Eleocharis palustris (L.)																		
Schoenoplectus tabernaemontani																		
Equisetum sp.																		
Equisetum fluviatile L.																		
Equisetum pretense Ehrh.																		
Isoetes sp.	6		7	12	5	36	10							10		30		
Najas flexilis (Willd.)					15			12	16		4			50			40	5
Persicaria amphibia var. emersa (Michx.)																		
Potamogeton sp.					5			24	2								20	
Potamogeton epihydrus Raf.					10			16										
Potamogeton foliosus Raf.																		
Potamogeton gramineus L.				24	5													
Potamogeton natans L.		10																
Potamogeton pusillus L.											12							
Potamogeton perfoliatus																		
Ranunculus aquatilis var. diffusus With. p.p.											12							
Comarum palustre L.																		
Typha angustifolia L.	36		42	18						100		75						
Poaceae																		
Juncus sp.																		
Myriophyllum verticillatum or M. sibiricum								16										
Utricularia macrorhiza Leconte																		
Utricularia minor L.																		
Nuphar lutea (L.) Sm.																		
Climacium dendroidies																		
Other Moss									2									
Mentha arvensis L.																		
Athyrium felix-femina																		
Rhododendron groenlandicum (Oeder)																		
Fragaria virginiana Duchesne																		
Viola orbiculata Geyer ex Holz.																		
Beluta sp.																		
Cryptogramma stelleri																		
Galium trifidum																		
Urtica dioica																		
Verbascum thapsus																		
Fibrous Decomposing Organics																		
Total (%)	60	50	70	60	100	40	10	80	20	100	40	75	0	100	10	30	100	10

Appendix 7

Base maps

B1:	**Emergent Vegetation FCC Field Map**
B2:	**Submerged Vegetation FCC Field Map**
B3-1a:	**Field Map Sites 1-17 1-18 - Submerged**
B3-1b:	**Field Map Sites 1-17 1-18 – Emergent**
B3-2a:	**Field Map Site 2-13 – Submerged**
B3-2b:	**Field Map Site 2-13 – Emergent**
B3-3a:	**Field Map Sites 3-6 3-7 3-8 – Submerged**
B3-3b:	**Field Map Sites 3-6 3-7 3-8 – Emergent**
B3-4a:	**Field Map Site 4-4 – Submerged**
B3-4b:	**Field Map Site 4-4 – Emergent**
B3-5a:	**Field Map Site 6-3 – Submerged**
B3-5b:	**Field Map Site 6-3 – Emergent**
B4:	**NDVI**

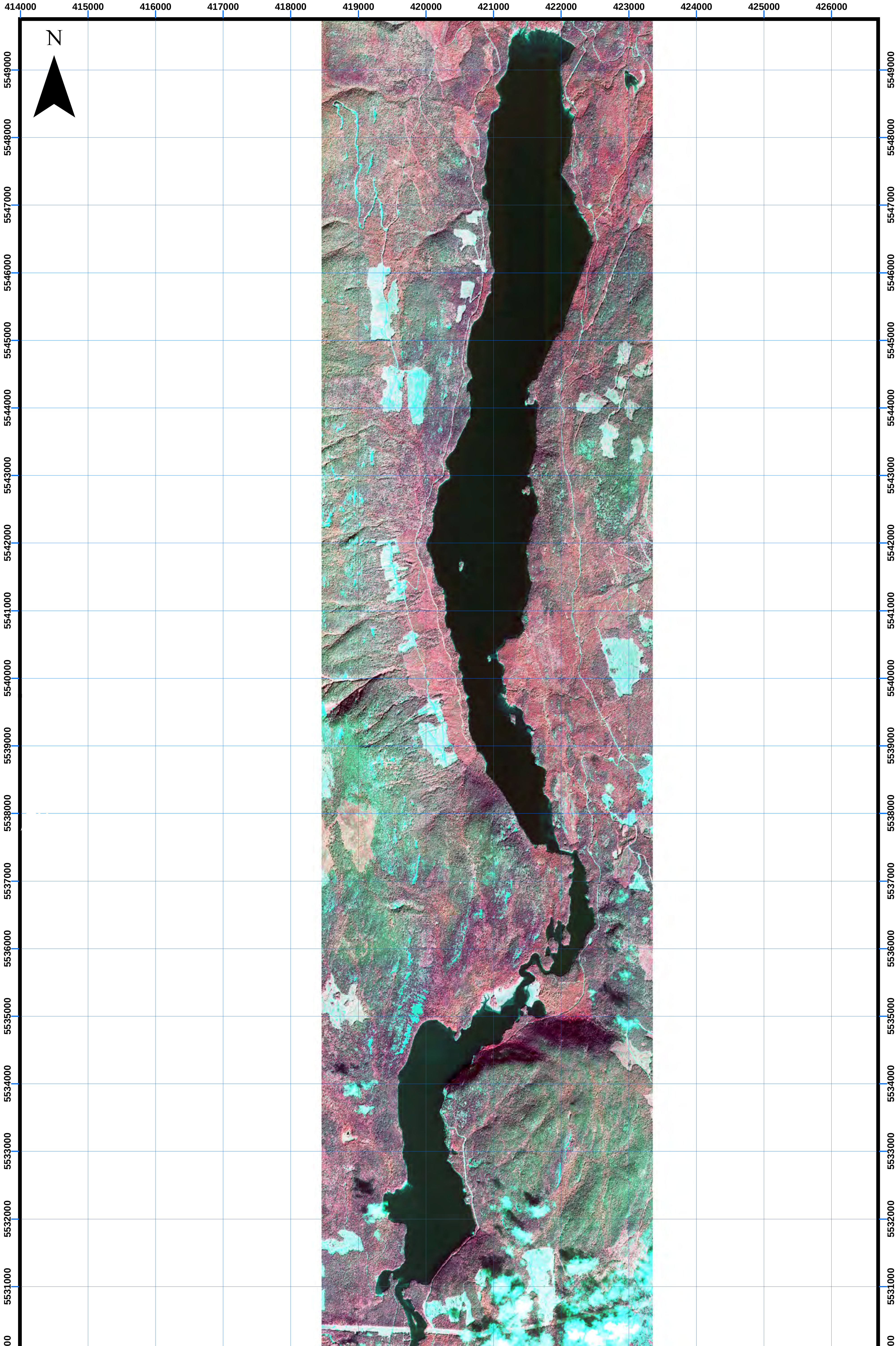

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Figure B1: Whole Reservoir Emergent Vegetation FCC Field Map

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:50,000

0 625 1,250 2,500
Meters

1 centimeter = 500 meters

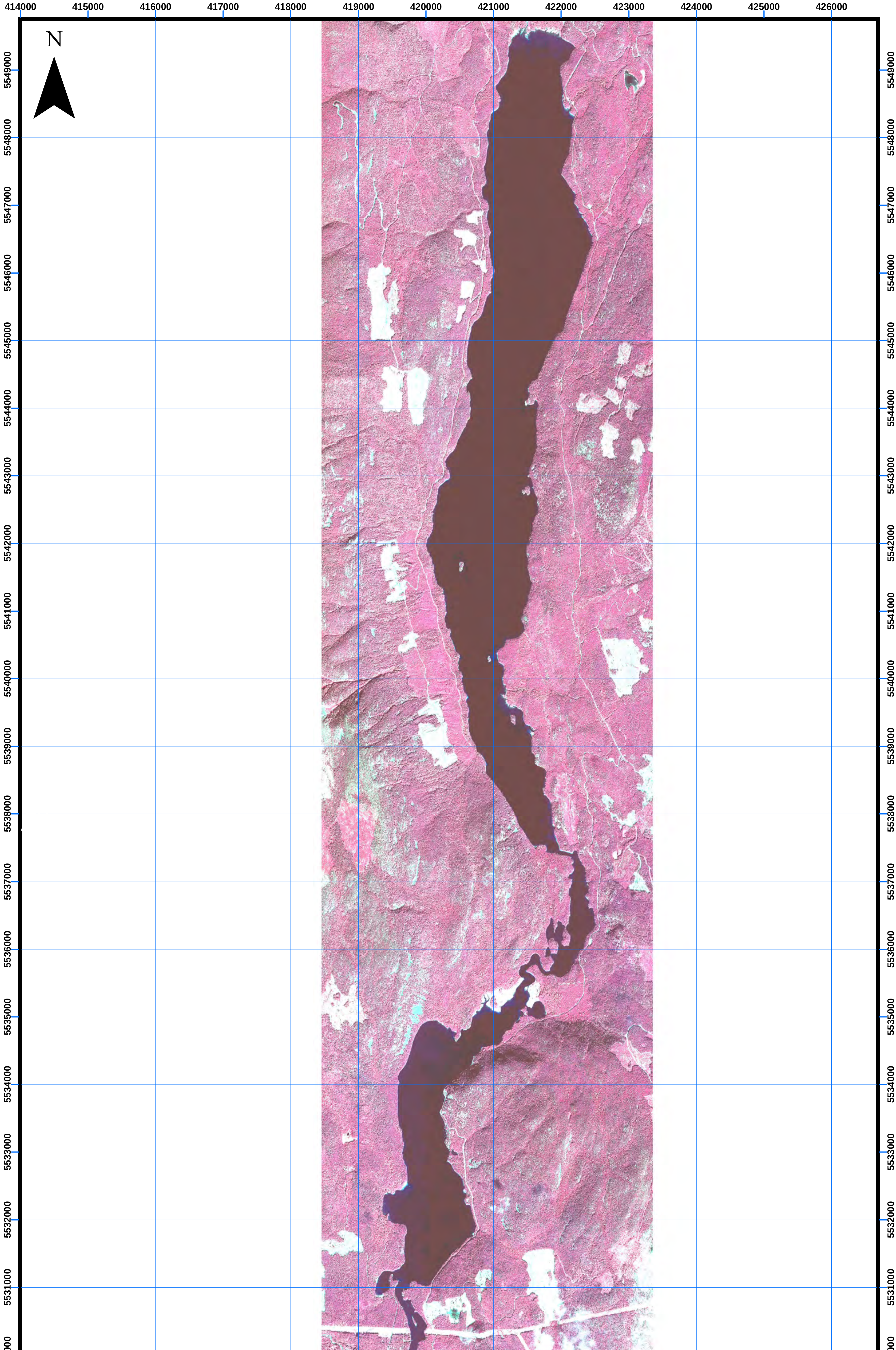

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Figure B2: Whole Reservoir Submerged Vegetation FCC Field Map

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:50,000

0 625 1,250 2,500
Meters

1 centimeter = 500 meters

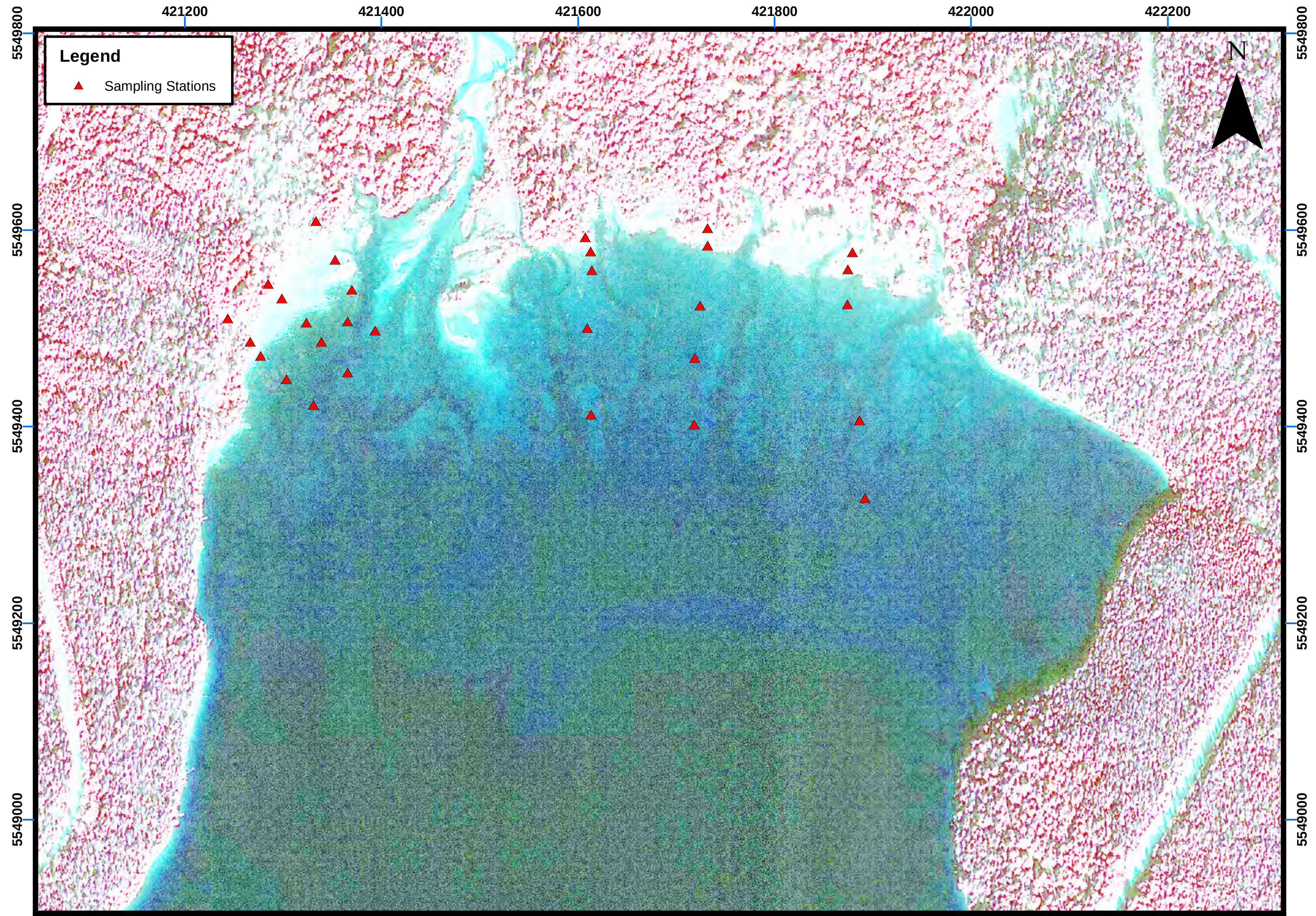

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Figure B3-1a: Field Map - Sites 1-17 & 1-18 - Submerged Vegetation

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:5,000

0 62.5 125 250 Meters

1 centimeter = 50 meters

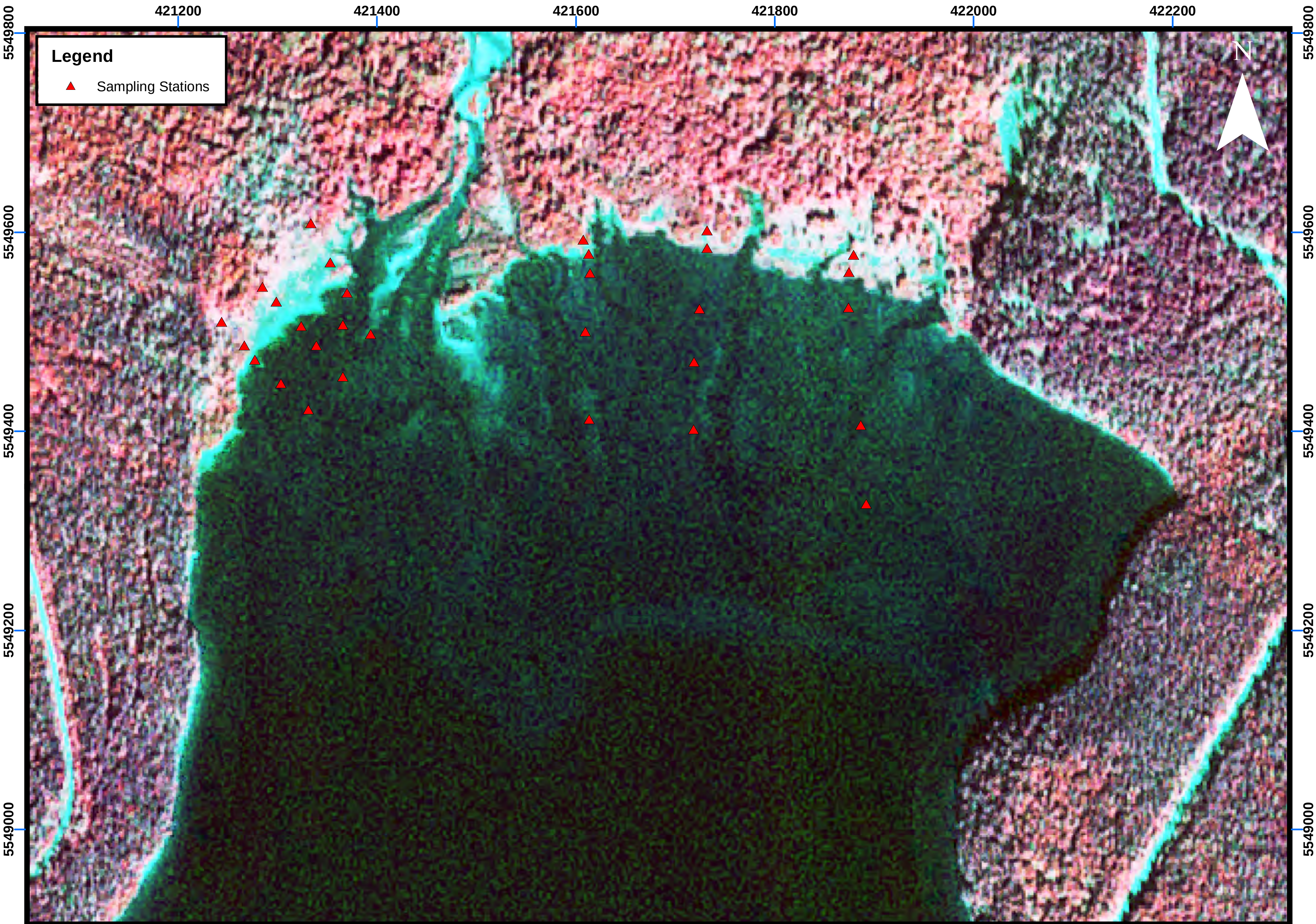

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Figure B3-1b: Field Map - Sites 1-17 & 1-18 - Emergent Vegetation

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:5,000

0 62.5 125 250 Meters

1 centimeter = 50 meters

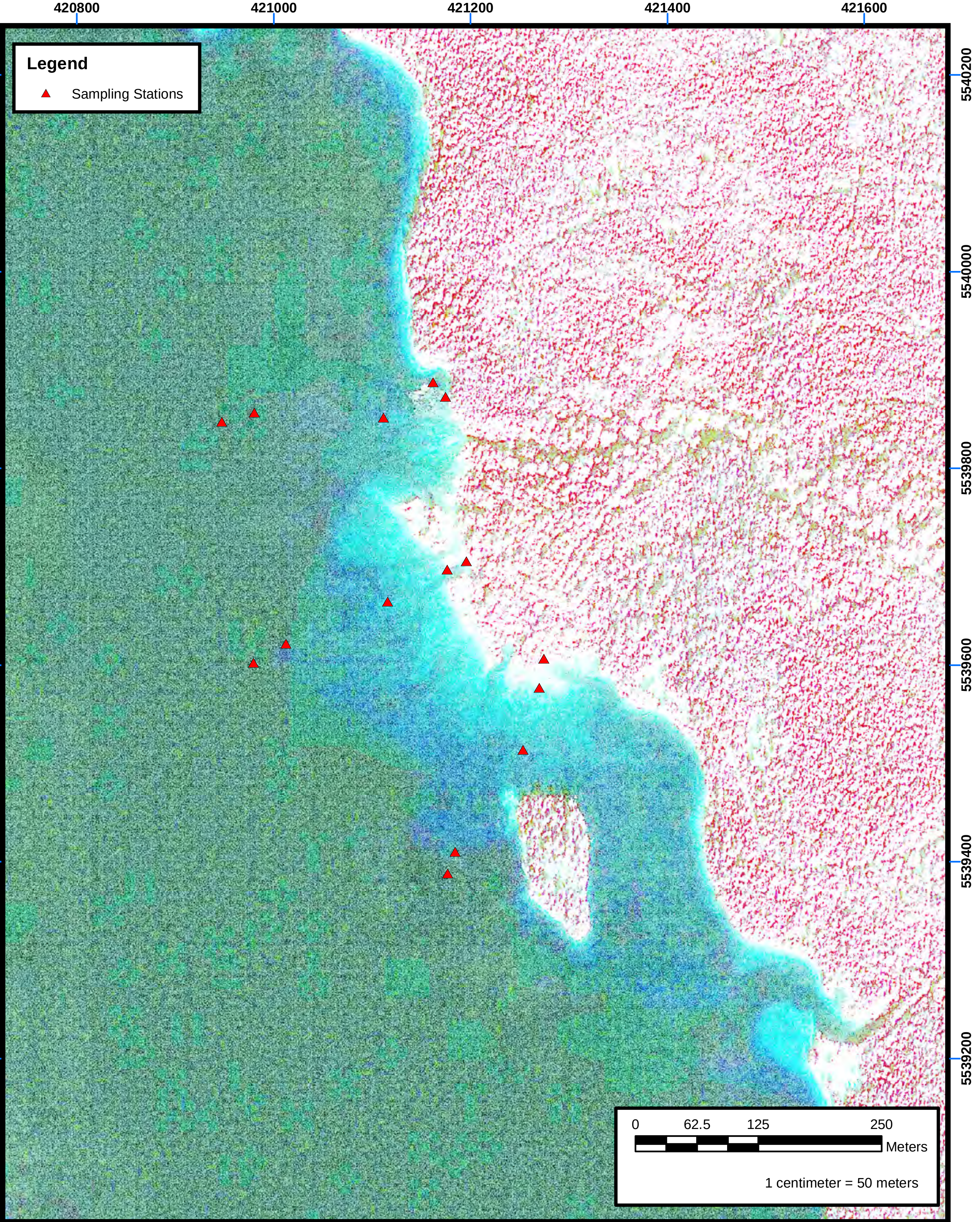

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Figure B3-2a: Field Map - Site 2-13 - Submerged Vegetation

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:5,000

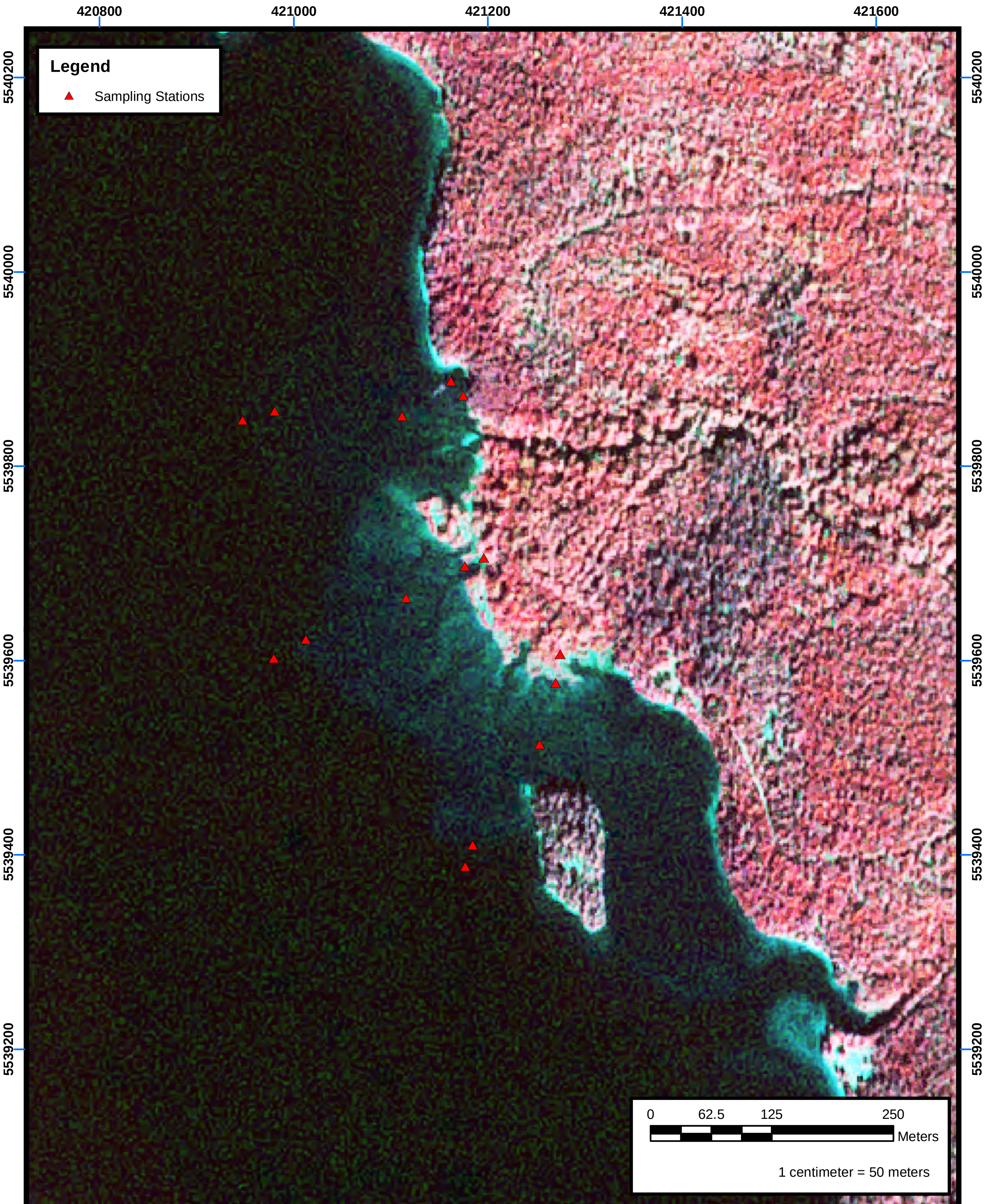

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Figure B3-2b: Field Map - Site 2-13 - Emergent Vegetation

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:5,000

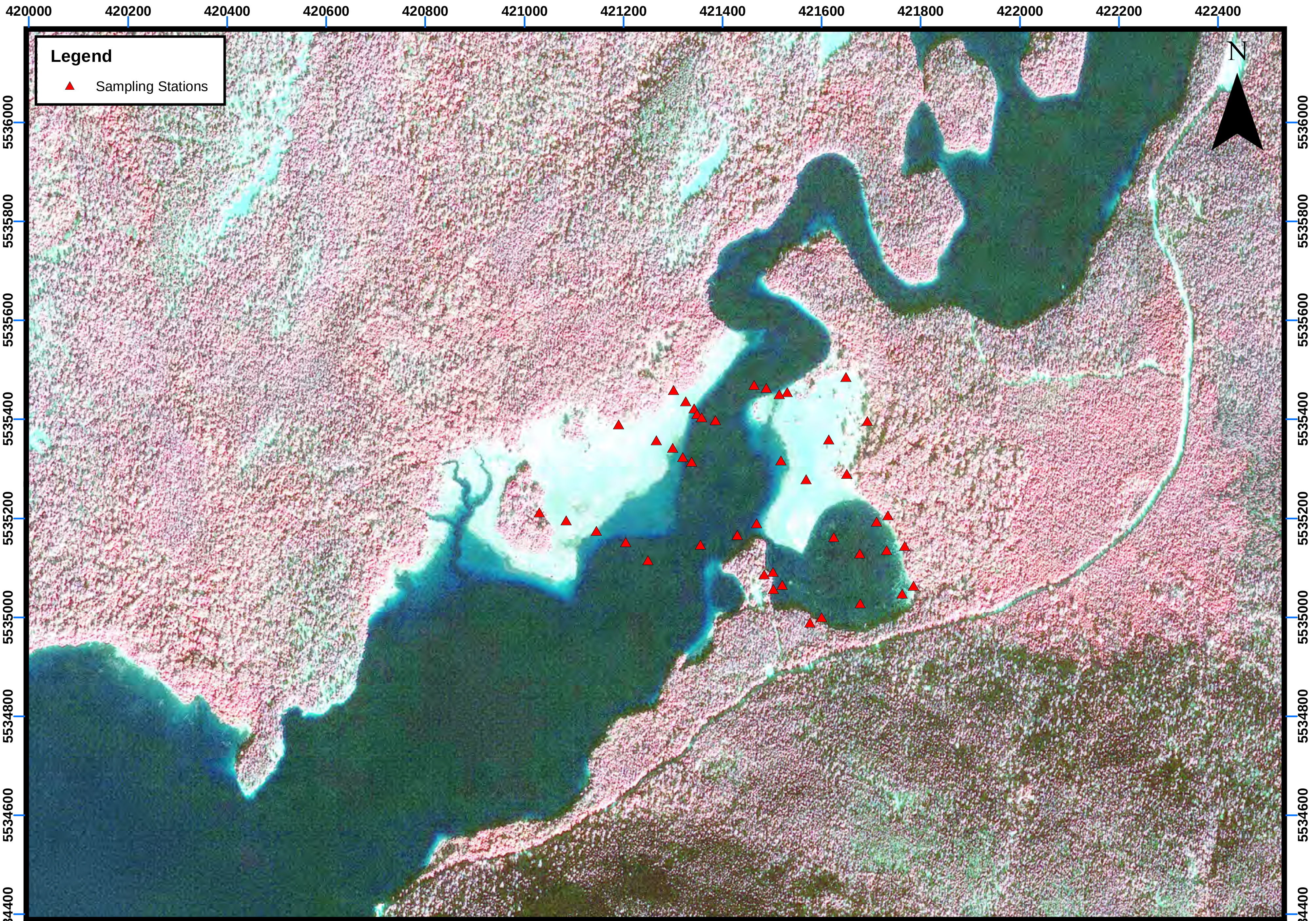

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Figure B3-3a: Field Map - Sites 3-6, 3-7 & 3-8 - Submerged Vegetation

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:10,000

0 125 250 500 Meters

1 centimeter = 100 meters

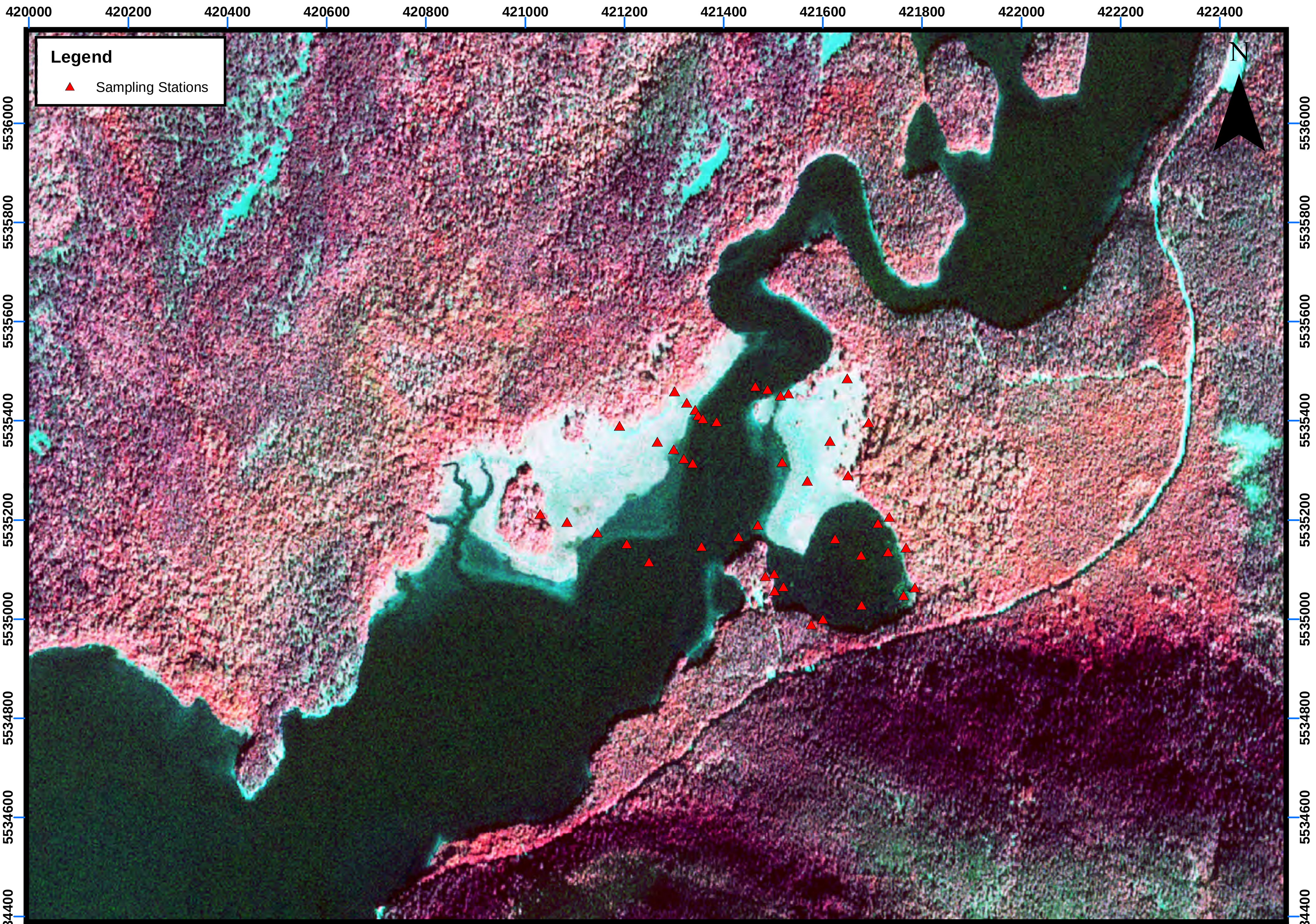

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Figure B3-3b: Field Map - Sites 3-6, 3-7 & 3-8 - Emergent Vegetation

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:10,000

0 125 250 500 Meters

1 centimeter = 100 meters

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Figure B3-4a: Field Map - Site 4-4 - Submerged Vegetation

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:5,000

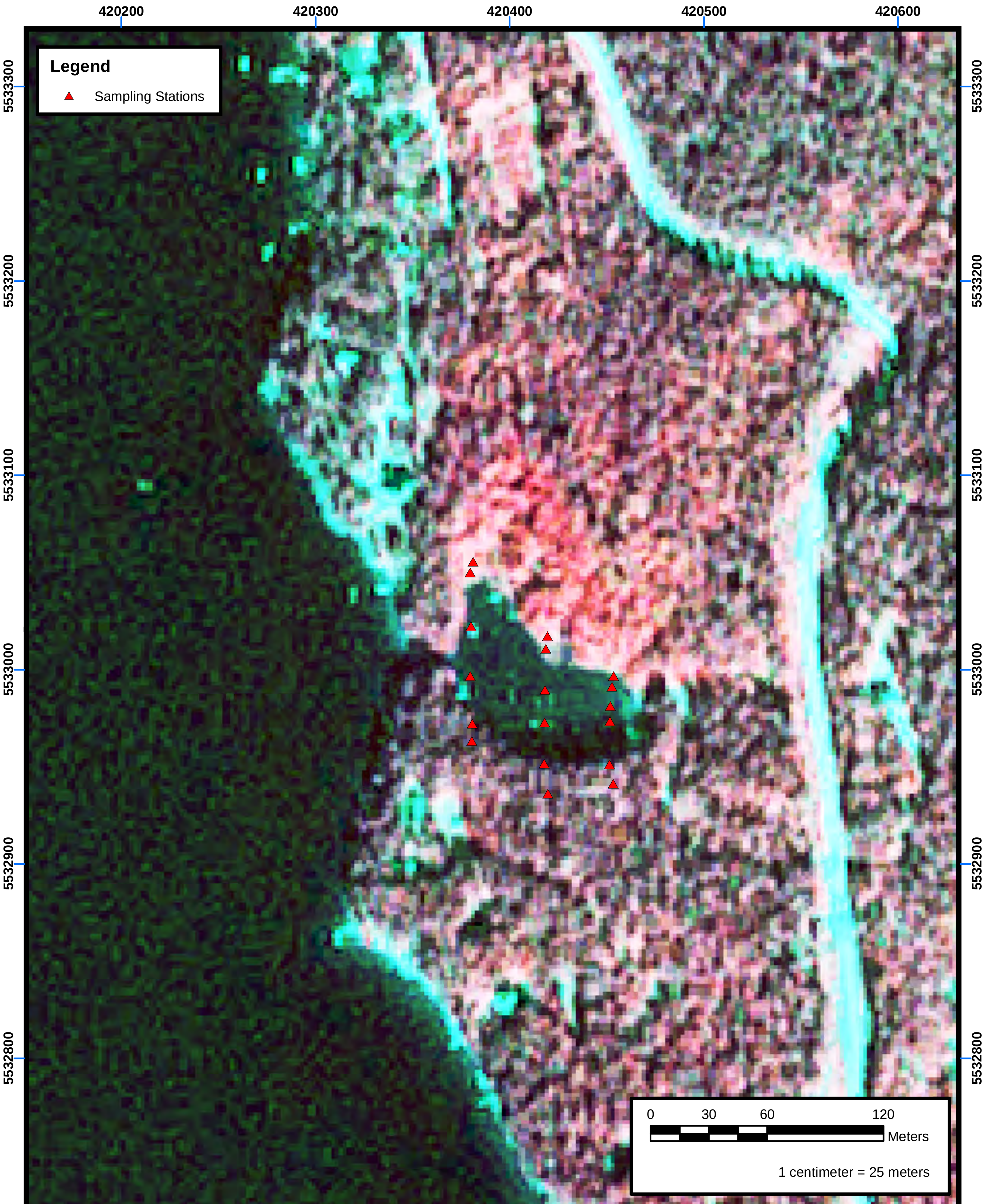

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Figure B3-4b: Field Map - Site 4-4 - Emergent Vegetation

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:2,500

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Figure B3-5a: Field Map - Site 6-3 - Submerged Vegetation

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:5,000

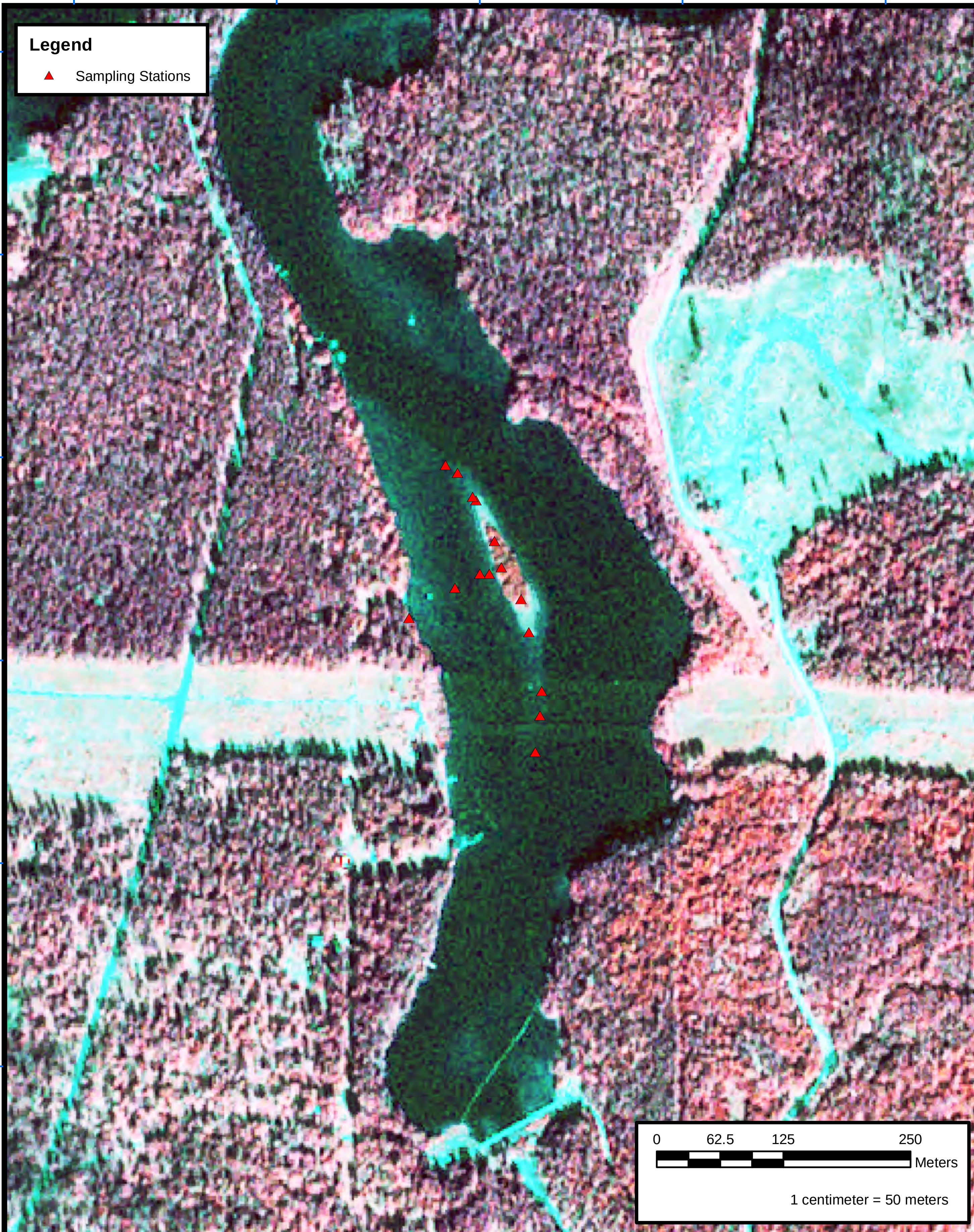

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Figure B3-5b: Field Map - Site 6-3 - Emergent Vegetation
Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:5,000

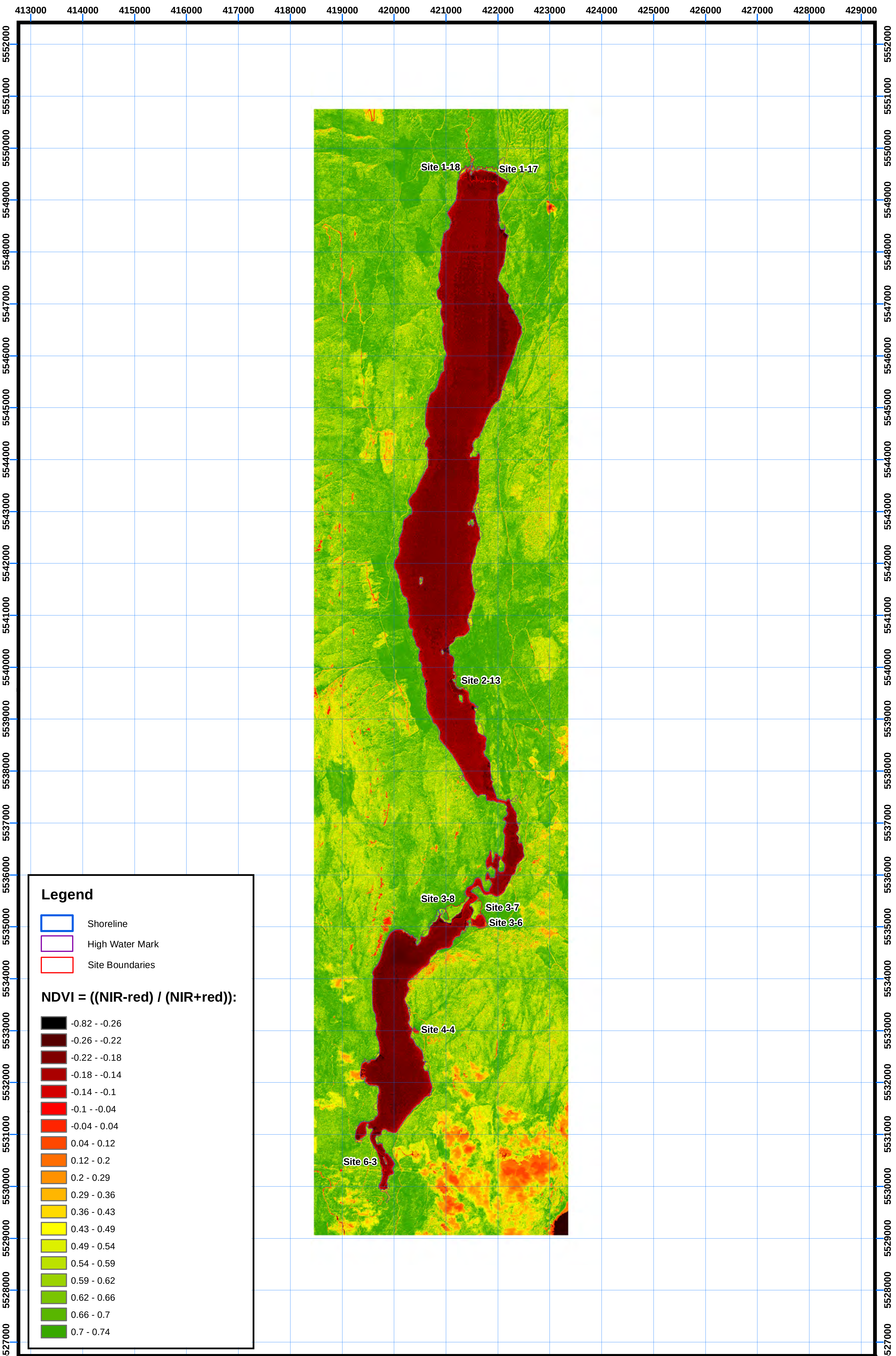

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Figure B4: Whole Reservoir NDVI

Date/Author: 14/10/2015, C. Adamson
Coordinate System: NAD83 UTM Zone 11
Scale: 1:60,000

0 500 1,000 2,000 3,000 Meters

1 centimeter = 650 meters