Bridge River Project Water Use Plan

Bridge-Seton Metals and Contaminant Monitoring Program

Implementation Year 2

Reference: BRGMON-12

Possible Effects of WORKS1 Vegetation Program on Mercury Concentrations in Carpenter Reservoir

Study Period: 2014/2015

Prepared by:
Azimuth Consulting Group Partnership
218-2902 West Broadway
Vancouver

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BRGMON-12: Possible Effects of WORKS1 Vegetation Program on Mercury Concentrations in Carpenter Reservoir

Prepared for

St'at'imc Eco-Resources
Box 2218 Lillooet BC
V0K 1V0

March 2015

Azimuth Consulting Group Partnership
218-2902 West Broadway
Vancouver, BC
V6K 2G8

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1. INTRODUCTION

Carpenter Reservoir is the largest reservoir on the Bridge River system. The principal recipient of discharge from the reservoir is Seton Lake, via two tunnels for the purposes of hydroelectric generation. A small amount of water (presently 6 m^3/sec) is also discharged over the Terzaghi Dam to the lower Bridge River. Carpenter Reservoir is 50 km in length, with a surface area of about 50 km^2.

Carpenter Reservoir is characterized as having a 'high drawdown', usually defined as a reservoir with a >3 m annual fluctuation in water level elevation. The typical annual hydraulic pattern is characterized by a gradual filling from low volume / elevation in spring, using runoff and freshet water from the mountains to reach high elevation/full capacity during fall. After reaching full supply, the reservoir is gradually drained over the winter, diminishing back to low elevation in spring. The reservoir typically ranges in elevation between an average low pool elevation of 622.5 m above sea level (asl) in late winter to an average high water elevation of 646.25 m asl in fall, just over 20 m. However, the licensed difference between low (606 m asl) and high water elevation (651 m asl) is about 45 m, although these extremes are seldom reached. . Under the present Water Use Plan, the reservoir is operated to decrease the drawdown relative to historical practices.

One of the consequences of this drawdown pattern is that extensive portions of the reservoir are left exposed at lower water levels, drying the terrain and resulting in dust generation, lowered aesthetic appeal and unrealized habitat potential. One of the programs sponsored by BC Hydro in the Bridge River region is WORKS-1, which targets the planting of perennial native vegetation species in an un-vegetated portion of the drawdown zone of Carpenter Reservoir to help stabilize exposed sediments. However, while WORKS-1 may improve the above situation, there are concerns that it may lead to exacerbating fish mercury concentrations in the reservoir due to generation of methylmercury in sediments and mobilization of methylmercury from sediment to the food web; this report addresses this concern.

1.1. Background

The main objective of the BRMON12 contaminants program has been to determine whether regulation of the Bridge River system under the N2-2P regime has mobilized and caused an increase in metals (in particular, mercury) into the food web of the Bridge River system. This has been addressed via the analysis of collections of water, sediment and fish tissue at roughly five year intervals from Downton and Carpenter reservoirs, lower Bridge River and Seton Lake (Baker and Mann 2001, Azimuth 2008, 2012, 2014).

Carpenter Reservoir was created more than 60 years ago, well beyond the maximum time that fish mercury concentrations increase and decrease, following initial flooding and reservoir creation (Bodaly et al. 2007, Schetagne et al. 2003). The most recent Azimuth (2014) investigation has determined that mercury concentrations within the Bridge River system have been relatively stable over the monitoring period of nearly 15 years. However, mercury concentrations in Carpenter Reservoir fish are elevated, about 2 – 3x higher for the same species located downstream, in lower Bridge River and in Seton Lake. In fact, mercury concentrations in Carpenter Reservoir bull trout (*Salvelinus confluentus*) are among the highest in the province (Baker 2002).

Determining the specific cause(s) of the elevated bull trout tissue mercury concentrations in Carpenter Reservoir has not been within the scope of the historic investigations. However, we speculate that it may be due, at least in part, to the drawdown pattern resulting from reservoir operations. Reservoirs with large annual or seasonal drawdown patterns expose large areas of sediment, formerly inundated under a water cover. Being exposed to oxygen, changing chemical conditions and growth of algae and plants have been implicated as drivers for maintaining and exacerbating an elevated rate of methylmercury generation and accumulation in sediments and biota, after re-flooding. While alternate wetting and drying of sediments have been implicated in sustaining elevated rates of methylmercury generation (Ullrich et al. 2001, Hall et al. 2008, Windham-Myers et al. 2009), there has been little research into this phenomenon. In addition, the Bridge River watershed is highly mineralized and has elevated background concentrations of some metals (Baker and Mann 2001). In particular the Tyaughton Creek watershed is elevated in some metals (arsenic) and mercury.

This region was subjected to lode and placer mining for gold and mercury more than a century, some of which may have used mercury-amalgamation as an extraction technique. Mercury mineralization is also known to naturally occur in the Carpenter Reservoir watershed, as reflected in the names of two streams; North and South Cinnabar creeks (i.e., cinnabar is the mineralized form of mercury as mercury sulfide). Furthermore, this area encompasses at least five former mines including two large gold producers, Bralorne and Pioneer; three small producers, Wayside, Minto and Congress and more than 60 surrounding mineral prospects. Historically, operation of the Bralorne and Pioneer mines released heavy metals into the Bridge River system via Cadwallader Creek (http://www.gunlake.bc.ca/mining01.htm). In addition, the Silverquick Mine mined mercury north of Carpenter Reservoir, suggesting potential natural and anthropogenic sources of mercury may be directly entering the system. Thus, the combination of high drawdown and ongoing natural and/or anthropogenic additions of mercury to Carpenter Reservoir may be responsible for sustaining elevated mercury concentrations in fish.

During the annual hydraulic cycle, a significant proportion of the surface area of the reservoir is drained, leaving extensive substrate exposed. The extent and duration of the exposure period depends on elevation, annual hydraulics and magnitude of drawdown depending on energy demand. Depending on the magnitude of drawdown and the geographic position within Carpenter Reservoir, the duration or amount of time that the sediments are exposed will vary from a short period of time (days – weeks) in the lower part of the reservoir, to a longer period (weeks to months) in the upper part of the reservoir. During this time, algae and vegetation will begin to colonize and grow. Thus, the main 'ingredients' for the manufacture of methylmercury (see **Section 2.3** below) within Carpenter Reservoir appear to be present. That is, a source of labile organic carbon, available mercury and an abundant sulfate reducing bacterial community residing in the sediment (Benoit et al. 2003, Gilmour et al. 1992 and others).

1.2. Objective of 2015 Study

One of the programs sponsored by BC Hydro in the Bridge River region is WORKS-1. The goal of this program is to plant perennial native vegetation species in an un-vegetated portion of the drawdown zone Carpenter Reservoir. The objective is to stabilize exposed sediment preventing mobilization of dust during the drawdown period, improve aesthetic appeal, increase recreation activities, improve wildlife habitat and enhance aquatic habitat (Splitrock Environmental 2015).

During a meeting between project team members, BC Hydro and St'at'imc Eco-resources in spring 2014, Azimuth identified that an unintended consequence of the revegetation effort may be to provide a key 'raw material' that could fuel mercury methylation in the reservoir. Given the already elevated mercury concentrations in fish within the reservoir, there is the potential that concentrations could be increased further, potentially posing incrementally higher risks to wildlife (and people) from methylmercury exposure.

To help address this question, Splitrock Environmental was hired by Azimuth to answer the following questions:

- What is the relative proportion, or the aerial extent that Carpenter Reservoir becomes exposed each year, and what proportion of this area naturally re-vegetates each year? and;
- What is the predicted incremental change in vegetation aerial extent and biomass between current 'baseline conditions' and what is being proposed by the WORKS-1 vegetation plan?

Establishing the magnitude of difference between baseline and predicted conditions in Carpenter Reservoir will determine the relative change in vegetation biomass and spatial coverage post-WORKS-1. The magnitude of change will provide insights as to the likelihood of whether a significant or detectable increase in fish mercury concentrations may occur in future, after implementation of the program. For example, a 2-3% increase in biomass above baseline will unlikely be detectable in higher organisms, like fish; however a 50% increase has a high probability of causing mercury concentrations in the reservoir to increase further. Using the information provided by Splitrock, this report has the following objectives:

1. What are the physical and chemical factors that contribute to mercury methylation in high drawdown reservoirs? This is achieved principally via a literature survey to review/summarize recent science that investigates mercury methylation dynamics of high

drawdown reservoirs. We also consulted with external experts to determine grey literature sources, information and expertise.

2. Are the re-vegetation efforts of WORKS1 likely to cause an increase in methylmercury generation in Carpenter Reservoir? Based on the outcome of our first objective and in concert with findings of the Splitrock investigation (assuming that the vegetation plan is completely successful) we predict the extent to which currently mercury methylation rates may change within Carpenter Reservoir. Note that the biochemical processes that control methylmercury generation in sediment are extremely complex. Many physical, chemical and biological factors combine to affect this process and ultimately, bioaccumulation of methylmercury by biota. In the absence of site-specific, empirical baseline data from Carpenter Reservoir, it is beyond the scope of this program to categorically or quantitatively determine the degree to which detectable changes in mercury in sediment or biota (e.g., invertebrates, fish) concentrations may occur.

Ultimately, as part of the long-term objectives of the BRGMON-12 program, a change in conditions, should the magnitude of change be considered large enough, may influence the outcome of the initial hypotheses for the Bridge River system. Thus, the null hypothesis of this work is:

> H_0: Implementation of the WORKS1 vegetation program will not result in an increase in methylmercury concentrations in Carpenter Reservoir water, sediment or fish.

Finally, this program will determine whether further experimental investigation of mercury in environmental media within Carpenter Reservoir is warranted upon implementation of WORKS-1 and to determine if changes in methylmercury concentrations can be measured in sediment or biota, through routine environmental monitoring under the BRGMON-12 program.

1.3. Report Structure

The report is structured as a serious of posed questions. Each question is posed and then answered, to provide the reader with a logically progressive, structured means by which we attempt to answer the essential questions posed above. The report begins with an explanation of ‘what is mercury’, including its various chemical forms, how it’s transformed in the environment to become methylmercury and an examination of the key physical / chemical conditions that influence mercury methylation (e.g., redox, sulfate), ultimately leading to answering the question ‘will re-vegetation of a portion of Carpenter Reservoir cause fish mercury concentrations to increase?’

The questions posed by this report are as follows:

- Where is mercury found in the environment
- How is methylmercury created and what processes affect this?
- What environmental factors influence methylation (and demethylation)?

- How does reservoir creation increase mercury methylation?
- How do high drawdown reservoirs affect this pattern?
- What are mercury concentrations in Carpenter Reservoir fish?
- What are current vegetation conditions in Carpenter Reservoir?
- What are the predicted changes under WORKS-1?
- How do changes in vegetation and alternate flooding affect mercury methylation? – A literature review
- How will current vegetation conditions change under WORKS-1?

Finally, a qualitative assessment of the influence of the WORKS-1 re-vegetation program on mercury concentrations in Carpenter Reservoir will be made.

2. KEY QUESTIONS

2.1. Where is mercury found in the environment?

Mercury (Hg) is present in small quantities in all environmental media including air, water, soil, sediment and all living creatures. Mercury is unique among metals in that it is the only metal that can exist as a solid, a liquid and a gas at room temperature, at the same time. The most abundant form of mercury in the atmosphere is elemental gaseous mercury (Hg^o). Vast quantities of mercury are discharged to the atmosphere daily, from burning of fossil fuels (especially coal), forest fires, volcano's, natural degassing from the earth, industrial losses and from mercury and gold mining by artisanal miners in about 60 countries around the world. Mercury is deposited to the landscape as dry or wet (i.e., in rain or snow) forms. Atmospheric mercury is also accumulated by the leaves and needles of plants during respiration. Over many hundreds of years, as leaves and needles fall to the ground, mercury is accumulated in small quantities in organic soils, especially in organic rich soils, wetlands and in peat. Mercury is also present in small quantities in all mineral soils and enters aquatic environments during the erosional process.

There are two main forms of mercury in the environment – the elemental, inorganic form (Hg) described above and the organic form of which methylmercury ($HgCH_3$) is the most common. Methylmercury (MeHg) is the more toxic form of mercury and is the form that is accumulated by animals in concentrations greater than found in the environment. Methylmercury is the main form of mercury found in fish, which is why there are sometimes advisories for fish, but not for other animals.

The global cycle of mercury is largely controlled by oxidation – reduction reactions that occur in the atmosphere and in water (Morel et al. 1998, Mason et al. 1994). During this process, a small portion of the inorganic, atmospheric elemental mercury (Hg^o) is oxidized (i.e., loses electrons) and is converted to ionic mercury (Hg+2). In this form, ionic mercury is highly soluble in water and is readily available to be adsorbed or bound to other elements in the water (Morel et al. 1998). Similarly, Hg+2 can be oxidized and converted back to Hg^o and lost back to the atmosphere, in a continuous cycle. The major inorganic forms of mercury in water are ionic mercury, which is commonly bound to many other compounds including hydroxide (Hg(OH)+, Hg(OH)2, Hg(OH)3−), and chloride ions (HgCl+, HgClOH, $HgCl_2$ and other ionic forms), depending on pH, hardness and water column chloride concentration. In addition, a large (perhaps up to 95%; Mielli 1997) but variable fraction of Hg+2 is bound to humic acids, the assemblage of poorly defined organic compounds that constitute 50% – 90% of dissolved organic carbon (DOC) in natural waters.

Once in water and bound to particulates or other elements, mercury accumulates in sediment. Based on sediment records (Swain et al. 1992), it is estimated that the atmospheric inputs of mercury have tripled over the past 150 years (Mason et al. 1994). This indicates that two thirds of the mercury now in the atmosphere, and hence in surface water, is of anthropogenic origin, and one third is from natural sources.

2.2. How is methylmercury created?

As discussed above, a small portion of the gaseous elemental mercury (Hg^o) in the atmosphere is oxidized to the mercuric ion (as Hg+2), captured by rain and snow and deposited as ‘wet deposition’ on land and water (Mason et al. 1994). Mercury also adheres via ‘dry deposition’ to particles that accumulate on vegetation and in soil. Mercury is continually cycling in the environment, alternating between the oxidized Hg+2 form and reduced back to Hg^0. Ultimately, a portion of the pool of atmospheric mercury deposited to the earth accumulates in soils and wetlands, eventually entering the sediment pool of mercury in freshwater and marine systems.

There is an immense quantity of literature on mercury methylation, demethylation and cycling in the environment. It is not within the scope of work of this report to review most of the literature. Rather, some essential facts are provided, intended to assist the reader in understanding how methylmercury is created and the conditions that favor this process. The chemical basis for this is also important to understand – as this may relate to processes that occur in Carpenter Reservoir.

Methylation of the mercuric ion (Hg+2) refers to the combination of Hg with a methyl group (CH3-). This process occurs principally, but not exclusively, in aquatic sediments (Compeau and Bartha 1984, Compeau and Bartha 1985, Regnell 1990), especially in wetlands, marshes and bogs. Methylation of mercury is a by-product of the breakdown of organic material by ‘sulfate reducing bacteria’.

Oxidation – Reduction

One of the key elements to understanding the dynamics of mercury methylation is understanding changes in oxidation – reduction (i.e., ‘redox’) conditions within soils or sediments. Changing redox conditions are a key driver of methylation. Redox refers to the alternating processes of a gain (reduction) or loss (oxidation) of electrons by molecules. These include all chemical reactions where atoms have their oxidation state (i.e., balance of electrons and protons or electronic charge) changed. Oxidation occurs when there is an *increase* in oxidation state (*loss* of electrons) by a molecule, atom, or ion, typically in the presence of oxygen. An example is ferrous iron Fe^{+2} is oxidized to form ferric iron Fe^{+3}. Reduction is the opposite reaction where there is a *decrease* in oxidation state (i.e., *gain* of electrons) by a molecule, atom, or ion. A relevant example of a reduction reaction is when sulfate SO_4^{-2}, is reduced to form sulfide (Hs^{-1}) or hydrogen sulfide (H_2S) under anoxic conditions. Most oxidation reactions are commonly associated with the formation of oxides when exposed to oxygen molecules. Oxygen is by far the most important oxidizing agent.

Sulfate Reduction

The redox concept is particularly important to understand sulfate reduction, a key driver in the manufacture of methylmercury. Sulfate reduction is the process by which sulfate (SO_4^{-2}) gains electrons (i.e., is reduced) to form sulfide (HS^{-1}) and hydrogen sulfide (H_2S) as metabolic by-products of respiration by sulfate reducing bacteria. Sulfate reducing bacteria (SRB) are a variety of very ancient bacteria that acquire energy by oxidizing organic compounds or molecular hydrogen (H_2) while reducing sulfate (SO_2^{-1}) to hydrogen sulphide. Essentially, sulfate reducing bacteria 'breath' sulfate rather than oxygen, in a form of anaerobic respiration, because this process takes place in the absence of oxygen.

Sulfate reducing bacteria reduce large amounts of sulfate to obtain energy, generating sulfide as a waste product. As noted above, sulfate reduction principally occurs under low or anoxic conditions in sediments of lakes, wetlands, bogs and marsh habitat. While most of these bacteria are strictly anaerobic, some sulfate reducing bacteria are tolerant of oxygen. Under oxygenated conditions these bacteria switch to aerobic respiration before reducing sulfate.

Although most of the evidence has shown that sulfate reducing bacteria play a dominant role in the production of methylmercury, in freshwater systems containing limited amounts of sulfate, it has been suggested that other anaerobic bacteria, including iron reducing bacteria and methanogens, may also be involved in mercury methylation (Warner et al. 2003; Kerin et al. 2006; Fleming et al. 2006).

Methylmercury can also be degraded or demethylated in aquatic systems, again via microbial processes, (Pak and Bartha 1998; Korthals and Winfrey 1987; Miskimmin et al. 1992) mainly in lake sediments and also in the water column. Demethylation is also carried out by sulfate reducing and methanogenic bacteria (Pak and Bartha 1998) as well as abiotically in surface waters from radiation in sunlight (Sellers et al. 1996). Concentrations of methylmercury in sediments and water are a reflection of the balance between methylation and demethylation rates. The net rate of methylation is very complex and is dependent upon a number of factors interacting together including temperature, oxygen, pH, availability of labile inorganic mercury, organic carbon and sulfate as nutrient sources.

2.3. What environmental conditions favor methylation?

The rate and magnitude of methylmercury production is affected by many factors. These include the bioavailability of Hg+2 mercury (Orihel et al. 2007, Munthe et al. 2007), temperature (Korthals and Winfrey 1987), pH (Miskimmin et al. 1992), sulfate availability (Gilmour and Henry 1991), oxygen (Gilmour and Henry 1991), and dissolved organic carbon (DOC) concentration (Barkay et al. 1997, Miskimmin et al. 1992). Microbial metabolic rates are also influenced by the availability of organic carbon, fueling bacterial growth and mercury methylation (Furutani and Rudd 1980, Pak and Bartha 1998). These factors all influence net mercury methylation, but their effects will vary depending on site specific conditions. In general, the factors that favor mercury methylation are poor in BC, which explains why fish mercury concentrations in this province are low relative to other parts of Canada (DePew et al. 2013).

High temperature favors methylation: Korthals and Winfrey (1987) report that methylation increases with increasing temperatures, with highest methylation rates during summer. However, this relationship is not a strong one. Although Carpenter Reservoir water is generally cold, the extensive areas of shallow water present during spring and summer as the reservoir refills may create localized areas of higher temperatures that favor methylation.

Low pH favors methylation: It is well understood that there is a significant inverse correlation between methylation and pH in lake water and sediment. In lake sediments, acidity stimulates methylation while depressing demethylation only as low as pH 5, at which point methylmercury production and sulfate reduction rates are both decreased (Gilmour and Henry 1991, Miskimmin et al. 1992). Another study showed that sulfuric acid acidification of a lake basin resulted in higher sediment and water methylation rates than in ambient pH basin (Winfrey and Rudd 1990). Water body pH below 6.5 has definitively been associated with higher methylation rates. The pH of Carpenter Reservoir averages 7.5 for water and ranges from 7.0 – 8.2 for sediment (Azimuth 2009, 2012), which suggests that this factor is a minor driver of fish mercury concentrations in this reservoir.

High sulfate availability favors methylation: Sulfate reducing bacteria are abundant in sediments of lakes and wetlands and are responsible for metabolizing a large fraction of the particulate organic matter entering freshwater sediments (Smith and Klug 1981). This is particularly true in shallow lakes where organic substrates are abundant and sediment temperatures are relatively high in summer. This may also occur beneath the sediment interface in exposed, de-watered areas. Experimental addition of organic carbon and sulfate stimulate sulfate-reduction and methylmercury generation in sediments. Sulfate concentration in upper Carpenter Reservoir water was 24 mg/L and 9 mg/L in the lower reservoir, similar to Seton Lake; so sulfate is somewhat elevated in the Tyaughton Creek area.

Low oxygen favors methylation: As discussed above, methylation is favored in low oxygen or anoxic sediment or the anoxic hypolimnion of lakes (Compeau and Bartha 1984, 1985). In Carpenter Reservoir, water column oxygen concentration is high at all times of the year; however, depending on the amount of organic carbon in the sediment and the resulting oxygen demand, sediments may be anoxic at shallow depths beneath the sediment-water interface. The degree to which sediments become anoxic is dependent on the biomass of organic or vegetative cover (including algae) that forms over the exposed mudflats, prior to becoming re-inundated. Organic carbon concentrations in Carpenter Reservoir and Seton Lake are low (~1%) and similar.

Dissolved organic carbon has mixed effects: In the water column, increased levels of dissolved organic carbon (DOC) can reduce the rate of mercury methylation, despite an increase in overall bacterial activity (Winfrey and Rudd 1990). Presumably, ligand formation between dissolved mercury and DOC in the water column binds up the mercury making it less available for methylation by bacteria. Higher labile organic carbon concentration in sediments generally has the opposite effect, enhancing both methylation rate and bacterial activity (Furutani and Rudd 1980, Kelly et al. 1997, Hall et al. 2004). The extent to which flooded carbon is mineralized in reservoirs and the amount of methylmercury produced depends on the amount and type of organic carbon that is flooded (Kelly et al. 1997). In general, the more labile or available the carbon is, the more prone to methylation it tends to be. Generally 'new' or freshly deposited organic carbon is more labile.

These factors will influence mercury dynamics in Carpenter Reservoir. The amount of time that sediments are exposed, sediment pH, redox conditions, oxygen concentration, sediment organic composition and available mercury (Hg^{+2}) are the most important factors to consider.

2.4. How does reservoir creation affect mercury concentrations?

The inundation of organic soils and to a much lesser extent, standing vegetation, to create reservoirs during hydroelectric development introduces the main raw ingredients for methylation – inorganic mercury and nutrients. Increased generation and bioaccumulation of methylmercury by aquatic organisms in new reservoirs has been extensively studied in Canada (Bodaly et al. 1984, Kelly et al. 1997, Bodaly et al. 2004, 2007, Schetagne et al. 2003 and many others). Following inundation, sulfate reducing bacteria generate methylmercury during the decomposition process. Methylmercury is now incorporated within bacterial tissue and is available to be consumed and accumulated at progressively higher concentrations moving up through the food web. Note that this process is independent of ongoing, local atmospheric loading of inorganic mercury (Munthe et al. 2007) that occurs all watersheds, or inputs of mercury via erosion or from mercury contaminated sources.

In the early life of all new hydroelectric reservoirs, the rate of methylation is much greater than the rate of demethylation because of the large quantity of 'new' decomposing organic matter that drives bacterial activity, which in turn increases methylation (Bodaly et al. 1984). Some of the methylmercury generated in sediment is dissolved into the overlying surface water column and is quickly absorbed by microscopic plankton. The concentration of mercury in water is very small, measured as parts per trillion or nanograms per litre (ng/L). Methylmercury comprises only between 1 – 5% of this total (i.e., ~0.05 ng/L). By contrast, the concentration of mercury in fish is measured in parts per million (mg/kg), typically between 0.1 and 1.0 mg/kg on a wet weight basis. This is nearly a billion times greater than in water. Thus, to yield high concentrations in fish, mercury must not only be taken up efficiently by the microorganisms that are at the bottom of the food chain, but it must also be retained by these organisms and passed on (i.e., bioaccumulated) to their predators.

Methylmercury is one of the very few compounds to be accumulated, concentrated and biomagnify up the food chain. Once incorporated into the tissues of phyto- and zooplankton, or benthic invertebrate tissues, methylmercury is bioaccumulated at a greater rate than it can be metabolized or depurated. This is especially true in new reservoirs. Methylmercury has very high affinity for sulfur containing anions, and particularly certain sulfur-based amino acids, which are the building blocks of protein. As a result, the average proportion of total (i.e., all forms of mercury) that is comprised of methylmercury increases within increasing steps up the food chain. That is, the percent methylmercury in phytoplankton is about 15%, increasing to 30% in zooplankton, 40 – 50% in predatory benthic invertebrates and >90% in fish (Bloom 1992).

Fish acquire virtually all of their methylmercury from food (Hall et al. 1997; Harris and Bodaly 1997, 2004). The main factors influencing bioaccumulation rates of mercury are mercury concentration in prey, age and size of the fish, growth rate and reproduction. Furthermore, a shift in diet from invertebrates to fish or from small fish to larger fish as a fish gets older and larger will further increase accumulation of mercury by the predator.

Canadian studies on the evolution of fish mercury concentrations after reservoir creation come mainly from Québec (Schetagne et al. 2003; Schetagne and Verdon 1999) and Manitoba (Bodaly et al. 2007). Following a sharp increase in methylmercury generation during the first few years, the rate and amount of methylmercury generation slowly declines over time. This has been observed in all reservoirs. Using data from fish populations, mercury in fish parallels but lags the bacterial production cycle. The increase in fish is initially moderate, with peak concentrations three to eight years after reservoir impoundment. Beyond this, fish tissue mercury levels decrease rather slowly, returning to reach a new equilibrium or baseline concentration between 20 and 30 years after reservoir creation (Schetagne et al. 2003, Munthe et al. 2007, Bodaly et al. 2007).

It is important to note that when fish mercury concentrations return to a ‘stable’ concentration after 25 – 30 years, that concentration may be higher than pre-impoundment concentrations or nearby lakes that were not affected by hydroelectric development. This is obviously likely the case for Carpenter Reservoir. The Bridge River system, including the creation of Carpenter Reservoir was accomplished in the late 1940s, more than 70 years ago. Thus, based on our current understanding of the dynamics of mercury concentrations in fish, it is to be expected that fish mercury concentrations have stabilized. As Azimuth's 2013 fish mercury survey confirmed, mercury concentrations in bull trout, rainbow trout and mountain whitefish have not substantially changed since monitoring first began in 2000 (Azimuth 2014).

Nevertheless, mercury concentrations in Carpenter Reservoir fish are elevated – about three times higher than mercury concentrations in the same species from Bridge River and Seton Lake These data suggest that there is something unique happening in Carpenter Reservoir that is sustaining elevated fish mercury concentrations.

2.5. What are mercury concentrations in Carpenter Reservoir fish?

The most recent investigation of fish mercury concentrations by Azimuth (2014; BRGMON-12) was in 2013, with earlier investigations in 2008 (Azimuth 2009) and 2000 (Baker and Mann 2001). Consistent with the early surveys, the three key species studied were bull trout (*Salvelinus confluentus*), mountain whitefish (*Prosopium williamsoni*) and rainbow trout (*Oncorhynchus mykiss*). Results from 2013 study concluded that mercury concentrations in these three species were not statistically different in 2000, when concentrations first measured and 2013. Mercury concentrations in bull trout were statistically lower in 2008 than in 2000 or 2013 however, suggesting that conditions affecting mercury tissue accumulation may be more dynamic than expected (e.g., due to the effects of high drawdown) or that the events were somehow biased by small sample size or were more characteristic of a particular tributary than the reservoir as a whole. Regardless, these results confirmed that mercury concentrations of Carpenter Reservoir fish are consistently much higher than fish from connected waterbodies Bridge River and Seton Lake, as well as from nearly all other BC lakes and reservoirs (Rieberger 1992, Baker 2002, DePew et al. 2013).

In 2013, arithmetic mean mercury concentrations in bull trout from Carpenter Reservoir (0.71 ppm) were more than 3x higher than from Seton Lake (0.22 ppm) and >8x higher than in Lower Bridge River (0.08 ppm). Some of this difference however, was due to smaller fish size in Lower Bridge River. Similarly, mean mercury concentration of Carpenter Reservoir rainbow trout (0.21 ppm) was higher than in Seton Lake (0.11 ppm) and Lower Bridge River (0.08 ppm).

Interestingly, the mercury concentrations of rainbow trout in Downton Reservoir (the only fish species in this reservoir) was 0.16 ppm, double that of Seton Lake and similar to Carpenter Reservoir. Fish size of Downton rainbow trout was smaller (315 mm, 288 g) than from Carpenter Reservoir (346 mm, 395 g), so on a size-adjusted basis it's likely that the concentrations would be equivalent. Given that Downton Reservoir is also a high drawdown reservoir (> 20 m annually), this corroborates the relationship between high drawdown and elevated mercury concentrations in fish.

Mean mercury concentration of Carpenter Reservoir mountain whitefish (0.32 ppm) was also 3x higher than in Seton Lake (0.11 ppm); no whitefish were captured from Lower Bridge River in 2013 or in 2008. These data confirm that mercury concentrations in Carpenter Reservoir fish are elevated relative to Seton Lake, as well as other BC lakes and reservoirs (Baker 2002), based on

15 years of data. Given that Carpenter Reservoir was created at least 60 y ago, it is somewhat surprising that fish tissue mercury concentrations remain so high.

The reasons behind this, however, are not well understood. Although the amount of literature dealing with high-drawdown reservoirs is sparse, the phenomenon observed here is consistent with what has been suggested for other such reservoirs and seasonally flooded wetlands, which is explored below. Until now, the reason why fish from high drawdown reservoirs tend to have higher mercury concentrations than nearby lakes or reservoirs with lower drawdown is not known and has not been the objective of any previous study. As noted above, Carpenter Reservoir is relatively old (>60 y) and well past the time period where methylmercury generation was due to flooding of organic soils during reservoir creation (Schetagne et al. 1999, Bodaly et al. 2007). Thus, it has been speculated that changing redox conditions and re-vegetation associated with alternating wetting and drying periods in reservoirs and wetlands may be responsible for enhanced net methylation activity.

Another factor that needs to be considered is that Carpenter Reservoir is situated within an area of naturally high mercury mineralization. It is noteworthy that local features are named after the mercury bearing ore, cinnabar, such as 'North and South Cinnabar creeks' and 'Cinnabar Ridge', running northwest of the reservoir. There are numerous old mines in the area, at least two of which were mercury mines. The Silverquick Mine, (MINFILE No. 0920 017) operated for a brief time and ore was processed near Mowson Pond, upgradient from Carpenter Reservoir (SNC Lavalin, Azimuth and Wilson Scientific 2013). Tyaughton Creek which flows into Carpenter Reservoir, was identified by Azimuth (2009) in 2008 as having elevated inorganic mercury in stream sediments and in the delta or fan offshore into the reservoir. The degree to which these mercury sources contribute to the observed fish tissue mercury concentrations in the reservoir is not known.

2.6. How changes in vegetation and alternate flooding affect mercury methylation – A Literature Review

As discussed above, the rate and magnitude of methylmercury production is affected by many factors, in sometimes complex mechanisms and interactions. In a large drawdown reservoir, a vast area is alternately (and potentially frequently) wetted and dried. Each time the reservoir area is flooded, there is a potential for re-introduction of new organic material (algae, deciduous shrubs, introduction from upstream and tributaries) and deposition of fresh inorganic mercury via dry and wet deposition, similar to the creation of a new reservoir. The nature of the bacterial community and methylmercury generation in the submerged part of the reservoir and exposed wetlands is undoubtedly very important, along with the abundance and 'availability' of labile organic carbon and reducible mercury (Hg+2) and other abiotic conditions such as redox conditions (sulfate, iron), pH, oxygen, temperature and other more subtle factors.

This section reviews the relevant literature related to reservoirs, seasonally flooded wetlands and other intermittently wetted and dried environments as it relates to mercury methylation. There is a great paucity in studies or literature relating to high-drawdown reservoirs – much of the literature found relates to mercury methylation in seasonally or intermittently flooded environments like rice paddies, agricultural land, wetlands, and estuaries.

We realize that this section is long and complex – rather than relegate it to an appendix, we have left it here, although the reader may wish to skim this section, as the level of detail may be too complex for most readers.

2.6.1. Studies of Rice Growing

Recently, a series of papers were published that examine mercury dynamics in soils of intermittently flooded soils to grow rice (*Oryza sativa*) in paddies in China (e.g., Meng et al. 2011, Zhang et al. 2010a, 2010b, Qui et al. 2008, Li et al. 2010). Rice paddies are ephemeral, seasonally flooded wetland environments, alternately inundated and dried during the course of planting and harvest. It was proven many years ago that sulfur reducing bacteria also actively occur in rice paddy soil (Wind and Conrad 1995) and are responsible for methylmercury generation. The characteristics or rice paddies are quite similar to other submerged wetland environments that have been demonstrated to be relatively large producers of methylmercury (e.g., St Louis et al. 1994). Recently however, several studies have shown (e.g., Feng 2008, Rothenberg and Feng 2012), that alternately flooded and drained rice paddies providing optimal physiochemical conditions for sulfate reducing bacteria and methylmercury production.

These papers shed some light on the influence of intermittent flooding, effects on vegetation growth and decomposition and the influence on mercury methylation dynamics within inundated soils. In China, there is also the additional issue of pollution of agricultural soils with inorganic mercury. This occurs in areas that are situated near mercury mines and/or near sites where artisanal gold mining with mercury amalgamation takes place. Burning of mercury-gold amalgams volatilizes elemental mercury, resulting wet and dry deposition of $Hg+2$ to nearby rice paddies. Coincidentally, the Carpenter Reservoir watershed is also in a naturally merciferous area, with naturally inputs of mercury from the Tyaughton Creek watershed as well as undocumented, but potentially meaningful, inputs historically and/or currently from sources up the Cadwallader River.

The abundance of available mercury, combined with conditions favorable for mercury methylation in paddies have caused rice to accumulate methylmercury within the grain at rates that are 10 – 100 times greater than any other plant. For example, Zhang et al. (2010a, b) has determined that on average, rice can bioaccumulate methylmercury 800 x more than inorganic mercury. Inorganic mercury is typically not absorbed via the root system of vascular plants (Schwesig and Krebs 2003), even in mercury contaminated areas (Ericksen and Gustin 2004, Dombaiova 2005).

Meng et al. (2011) studied methylmercury generation and uptake by rice (*Oryza sativa*) in experimental plantations distributed among artisanal mercury producing areas of rural China and at a regional background control site. Results showed that the newly deposited mercury is more readily transformed to methylmercury and accumulated in rice than did ‘old’ mercury with an extended residence time in soil and sediment. This has also been documented in studies elsewhere in the world. In this study, as in other studies of rice, methylmercury was absorbed by roots and then translocated to the above-ground parts (leaf and stalk), but later, the majority of methylmercury was transferred to seed during the ripening period.

Zhang et al. (2010a) also determined that rice plants accumulated methylmercury from paddy soils in contaminated and uncontaminated soils near mercury mining areas. Interestingly, despite two order of magnitude differences in inorganic mercury concentrations in soil between contaminated and uncontaminated paddy soils, methylmercury concentration in rice grains were only twice as high from contaminated paddies as controls. This suggests that a source of inorganic mercury is not the major rate limiting step to methylmercury production.

Rothenberg and Feng (2012) also examined mercury cycling within a flooded rice paddy environment in a mercury contaminated area of China in 2008 and 2009. A series of rice paddies were flooded, planted with rice and allowed to progress through the various life stages, with final ripening occurring after the rice paddies were drained. During the approximately 120 day growing cycle, a wide variety of parameters were measured in soil/sediment, vertical cores and in extracted pore waters at 2 cm intervals through the cores. Soils were continuously or periodically monitored for temperature, pH, extractable sulfate/sulfide and iron species, redox conditions, wet and dry organic matter and inorganic and methylmercury concentration and flux. One of the paddies was left fallow (i.e., not planted) and maintained fallow during the entire experiment to determine the difference between rice planted and a fallow section of earth. This research provide us with some insight as to the effects on mercury methylation from periodic flooding of un-vegetated and vegetated soils and sheds light on two questions: 1) what is the effect of seasonal flooding on soils with newly planted vegetation? and 2) how does intermittent wetting and drying of un-vegetated soils affect dynamics of methylmercury? The first question speaks to possible effects of WORKS-1 and the second question speaks to the issue of elevated methylmercury in high-drawdown reservoir sediments.

In sediment cores, the concentrations of methylmercury and pore water sulfate peaked at levels between 2.5 and 4.6 standard deviations above the mean, respectively, while the same parameters were 0.72 and 0.73 standard deviations from the mean in rice planted section. While methylmercury concentrations were elevated in both vegetated and fallow (un-vegetated) plots, the fallow plots exhibited the highest concentrations. Rothenberg and Feng (2012) speculated that flooding of the dried paddy soil in the fallow section caused a pulse in mercury methylation following stimulation of sulfate reducing bacteria, with methylmercury being quickly resorbed back to the sediment.

From our perspective, results from Rothenberg and Feng (2012) indicate that mercury methylation is increased when soils with and without vegetation are allowed to completely dry and are then re-wetted. This partly helps to explain results of studies of cultivated rice paddies where there is a positive correlation between methylmercury concentration in sediment and rice (Meng et al. 2011, Zhang et al. 2010a, 2010b, Qui et al. 2008, Li et al. 2010). Another much more recent study of a high drawdown by Eckley et al. (2015) corroborates this, as discussed later.

2.6.2. Experimental removal of vegetation

For mercury methylation to occur, the 'raw' ingredients must be present, in particular an abundant sulfate reducing bacterial community and availability of Hg+2 (Benoit et al. 2003, Gilmour et al. 1992). As well, there are a number of pysico-chemical parameters that are positively correlated with mercury methylation rates, all of which have been well studied. As discussed above, these principally include slightly acidic pH (5.5 – 6.5), anoxic conditions, availability of reducing agents as nutrients (sulfate, iron), chloride, and labile organic carbon.

At the landscape level, seasonally and tidally flooded wetlands that undergo periodic wetting and drying have been implicated with leading to enhanced methylmercury production (Ullrich et al. 2001, Hall et al. 2008). This is purportedly achieved by stimulating microbial activity by re-oxidizing reduced sulfur species, thus making Hg+2 more available to microbes. At the local scale, at the interface between the sediment/soil and root system, there are similar fluctuating redox conditions and a supply of labile carbon that facilitates microbial methylmercury production. Most periodically inundated systems have similar soil conditions as wetlands. Both have densely rooted surface soils, coinciding with the zone where methylmercury production is highest, where methylmercury becomes available for uptake by benthic invertebrates or diffused into overlying surface waters.

In a unique series of experiments, Windham-Myers et al. (2009) tested the hypothesis that there is a direct linkage between the processes of methylmercury production in wetland surface sediment and impact of emergent wetland plants on microbial processes in the rhizosphere zone, measuring availability of Hg+2 and microbial methylation rates. This was accomplished by de-vegetating candidate, periodically flooded areas to determine the relative influence of vegetated vs de-vegetated areas, adjacent to each other. De-vegetated plots had all vegetation, including roots, removed during the course of the investigation. In this study, four separate wetland studies were conducted within the San Francisco Bay-Delta region and included two tidal salt marsh areas, an agricultural and non-agricultural managed freshwater wetland and a seasonally inundated freshwater river floodplain of the Cosumnes River. This discussion focuses on the latter, Cosumnes River results, which has the greatest similarity to Carpenter Reservoir.

In general, Windham-Myers et al. (2009) showed that across wetland types, that production of methylmercury in de-vegetated plots decreased by an average of 38%. Sediment Hg+2 levels did not change. In the Cosumnes River, despite differences in hydrology and vegetation among the freshwater wetland types studied, the activity of Hg+2 methylating bacteria decreased (17–87%) as a result of de-vegetation, in nearly all sub-habitats. Sediment methylmercury concentrations also decreased between 13% and 55%.

All indices of methylmercury production, (rate of production, % methylmercury, concentration) in surface sediments were higher in the presence of actively growing emergent vegetation, compared to de-vegetated plots. This was true for all areas studied. Removal of actively growing plants and roots reduced methylation potential by an average of about 36%. Windham-Myers et al. (2009) confirmed that actively growing vegetation *increases* methylmercury production in intermittently flooded areas. They postulated that the main influence of actively growing vegetation was simulation of microbial activity and methylation. This study supports the hypothesis that the primary controlling factors of methylmercury production in sediment are driven by inputs of carbon and *in situ* microbial activity.

Another finding of this study involved the influence of root density surface area, which was positively correlated with microbial biomass and acetate, a source of labile carbon as a nutrient. De-vegetation led to a reduction in microbial biomass and limitation of carbon supply is seen as a critical rate-limiting factor in methylmercury production.

In a more recent 2014 summary paper, Windham-Myers et al. examined mercury cycling in agricultural and managed wetlands, including seasonally flooded rice paddies, similar to what was done in China (e.g., Li et al. 2010, Rothenberg and Feng 2012). Results of a variety of studies conducted over a several year period concluded that seasonally flooded wetlands, especially agricultural (e.g. rice-growing) wetlands, were a major site of net methylmercury production. Of course, the magnitude of methylmercury production, degradation and retention in soils varied according to geographic location and site-specific physic-chemical and hydraulic conditions. Thus, depending on conditions, seasonally flooded wetlands were a net source of methylmercury or a sink to downstream environments, depending on active management practices and seasonal variations. Temporal spikes in methylmercury production, export, and bioaccumulation varied by season and these processes were linked to specific seasonal hydrologic practices in managed agricultural areas. Methylmercury concentrations in sediment and water of seasonally flooded agricultural wetlands exceeded observed concentrations in neighboring permanently flooded wetlands for the entire annual cycle. Concentrations were similar in range to a neighboring seasonal, non-agricultural wildlife managed wetland during its fall/winter flooded period (Windham-Myers et al. 2014).

Methylmercury production was also positively correlated with regions where total mercury (Hg+2) availability in sediment was relatively high. Periodic flooding and drying exacerbated the influence of redox-sensitive elements in the sediment (carbon, sulfur, iron, manganese) as well as the production of labile organic matter. This implies enhanced bioaccumulation and potentially toxic effects to resident or migratory organisms and rice consumers (Windham-Myers et al. 2014).

In summary, by de-vegetating plots adjacent to vegetated plots in a diversity of intermittently flooded environments, Windham-Myers et al. (2009, 2014) demonstrated that actively growing freshwater wetland plants promote mercury methylation. This process occurs in the rhizosphere primarily through the exudation of labile carbon products (e.g., acetate), that stimulate sulfate- and iron-reducing bacterial activity. This study conclusively demonstrates that introduction of vegetation into previously un-vegetated soil/sediment is highly likely to increase sediment methylmercury production on the order of at least 35% above baseline. These field data represent a unique experimental contribution to our understanding of the direct and indirect roles of vegetation on MeHg production.

2.6.3. Mercury Dynamics in High-Drawdown Reservoirs

In addition to the well-known ‘reservoir phenomenon’, water level fluctuation in high-drawdown reservoirs has also been implicated in exacerbating methylmercury generation (Evers et al. 2007), although this aspect has not been well studied. For example, shallow depth and variable changes in water elevation have been shown to be associated with increased fish mercury concentrations in southeastern US ponds (Snodgrass et al. 2000). Snodgrass et al. (2000) speculated that methylmercury formed in the exposed littoral zone sediment can be transported to the open-water portion of the reservoir either during rain events or when the reservoir is refilled. In northern Maine, Sorensen et al. (2005) demonstrated that the ratio of methyl to total mercury in sediment cores increased considerably and remained elevated after the onset of reservoir fluctuation. In another Maine study of five interconnected reservoirs, there was a significant, positive correlation between mercury concentration in loon tissue and magnitude of reservoir fluctuation. In reservoirs that had ‘large’ drawdowns (i.e., > 3 m), mercury concentrations in adult loon blood were significantly higher than for loons from low-drawdown (<1 m) reservoirs. Sorensen et al. (2005) also reported a similar pattern in smallmouth bass and yellow perch mercury concentrations from Connecticut reservoirs. In Minnesota reservoirs, dampening water-level fluctuations reduced fish mercury concentrations (Sorensen et al. 2005). Thus, there is a growing body of evidence suggesting that there is a positive correlation between drawdown and elevated mercury concentrations in upper trophic level biota, fish and birds. However, the mechanisms by which this occurs have not been well described.

Evers et al. (2007) has speculated that reduced sulfide S-2 and ferric iron Fe+2 accumulate in the sediment under submerged, reducing conditions. When reservoir levels drop, sediments are exposed to air and these compounds are re-oxidized to form sulfate and ferrous iron, providing a fresh fuel source for sulphate reducing bacteria when the water levels are raised again. Evers et al. (2007) also reported that the degree to which this happens was positively correlated with the aerial extent and relative percentage of exposed reservoir area. These studies infer that changing reservoir water levels are responsible for elevated mercury concentrations in fish – however there are few studies that have directly quantified this dynamic in sediments.

In recent discussions, Rolfhus et al. (2015; personal communication) have in press, a paper that addresses the retention of methylmercury in soil for up to a decade after inundation and dewatering. This is from research carried out at the Experimental Lakes Area (ELA) in northwestern Ontario as part of the Flooded Uplands Dynamics Experiment (FLUDEX), which was an ecosystem scale, experimentally created reservoir. The FLUDEX experimental reservoir has been studied extensively over the last decade with the objective of monitoring and measuring isotopically labeled mercury through the terrestrial and aquatic food webs of an upland boreal forest landscape. Rolfhus et al. (2015) and others have showed that following inundation, this small reservoir performed similar to other reservoirs with respect to methylmercury generation. That is, methylmercury production in the flooded soils increased exponentially following inundation, peaking within 2-3 years, with mercury in higher organisms lagging behind. After this time, the net rate of methylation decreased and was followed by an increase in methylmercury concentration within the aquatic food web, at different trophic levels in zooplankton, benthic invertebrates and ultimately, fish.

Once the experimental phase of monitoring mercury through the aquatic food web of this experimental reservoir ended, the dam was removed and the reservoir was de-watered, returning it to its original condition. However, nine years after de-watering, Rolfhus et al. (2015) returned to the area and sampled previously flooded soils for mercury. They found that methylmercury concentrations just below the soil / air interface were 5 to 30 fold *higher* than prior to flooding, averaging 92% of the methylmercury concentration during the height of methylation following reservoir creation. Methylmercury concentration was highly correlated with organic content of the soil, indicating that the methylmercury was strongly adsorbed to organic particles beneath the litter layer and was quite stable. These results effectively suggest that there is a pool or reservoir of available methylmercury trapped by organic material in upland soils following a period of inundation and enhanced methylation by sulfate reducing bacteria. Results of this very recent study showed that previously flooded soils can retain methylmercury, potentially on a decadal scale.

In another very recent study, Eckley et al. (2015; personal communication) have investigated Cottage Grove Reservoir in Oregon. Although smaller in size than Carpenter Reservoir (468 ha), the reservoir is also 70 y old and is located 15 km downstream of an historic mercury mine, now a Superfund site. During the course of a year, approximately half of the reservoir area is exposed during drawdown in winter and re-filled over summer. Fish mercury concentrations are elevated in this reservoir relative to nearby lakes and it is speculated that drawdown conditions are primarily responsible. However, the contribution of historic and/or contemporary mercury from mine or mineralization sources and atmospheric deposition is not known. As well mercury from non-mine sources (e.g. atmospheric deposition) for methylation is not known. Conditions in Cottage Grove are remarkably similar to Carpenter.

The main objective of the Eckley et al. (2015) investigation was to identify the role of water-level fluctuations on methylmercury production. This was achieved by measuring total and methylmercury and several ancillary parameters, from reservoir surface sediment, sediment cores and water column. They found that mercury methylation was highest in the top 2 cm of sediments in the de-watered region of the reservoir, even though these sediments had lower total inorganic mercury concentrations. Thus, water level changes appear to cause recycling of sulphate – that is, oxidation of sulfide in exposed sediments that re-stimulate microbial methylation once re-flooded. Despite an import of mercury to the reservoir from an upstream mine source, it appears that water-level fluctuations and dewatering may be a more important driver of methylmercury production than cycling of inorganic mercury concentrations within reservoir sediment in the permanently submerged zone. Further work is being conducted on this reservoir to attempt to elucidate the limiting factors to mercury methylation, such as a source of inorganic mercury, labile carbon or sulfate, which are low in Cottage Grove reservoir. The authors state that understanding those variables that stimulate or limit mercury methylation are necessary in order to identify possible management strategies to minimize methylation.

2.7. What are current vegetation conditions in Carpenter Reservoir and how will this change under WORKS-1?

Information in this section is summarized based on the Splitrock Environmental (2015) report, provided in **Appendix A** of this document. The Splitrock report was undertaken at the request of Azimuth Consulting Group and addressed two key objectives, as laid out in the introduction of this report. They are:

- What is the relative proportion, or the aerial extent that Carpenter Reservoir becomes exposed each year, and what proportion of this area re-vegetates? and;
- What is the predicted incremental change in vegetation aerial extent and biomass between current 'baseline conditions' and what is being proposed by the WORKS-1 vegetation plan?

An important first step was to establish current or 'baseline' vegetation conditions within the area of the reservoir that is 'typically' exposed on an annual basis. Of course, this differs each year depending principally on annual precipitation, electrical demand and reservoir management strategy within the province. Thus, normal 'high' and 'low' reservoir elevations will differ from year to year. To simplify this task, we used data from the last 15 years to determine average elevation differences between low and high water. Maximum high and low elevation data are also provided for contrast. Once average elevations were established, the next step was to layer the proposed WORKS-1 vegetation strategy over the baseline to determine the potential magnitude of change in vegetative cover, in terms of aerial extent and an approximation of vegetation biomass.

2.7.1. Baseline Assumptions and Conditions

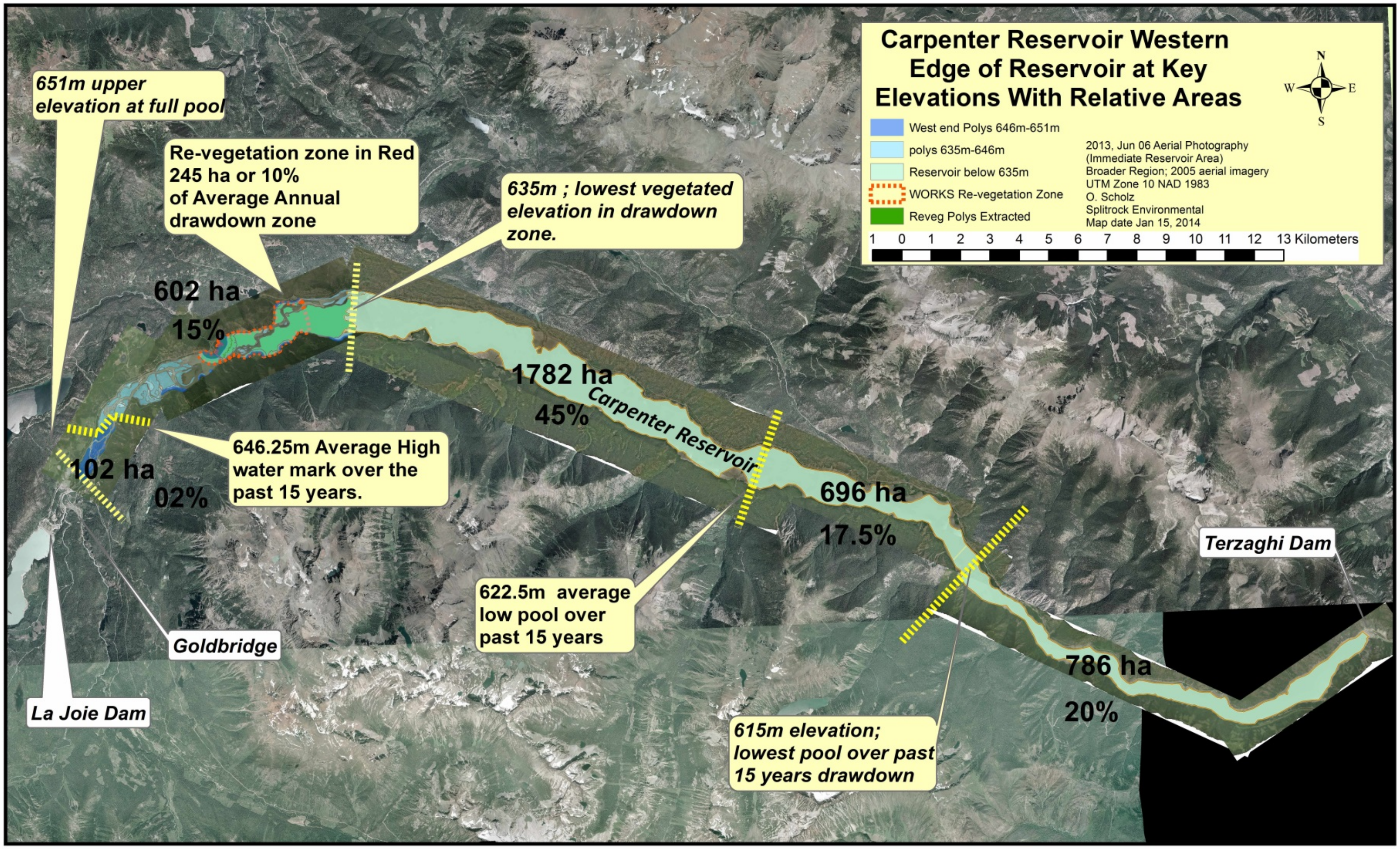
Over the last 15 years, Carpenter Reservoir has fluctuated between an average drawdown low pool elevation of 622.5 m asl and an average high water elevation of 646.3 m asl, a vertical elevation difference of 24 m (**Appendix A**). This is equivalent to a total average annual surface area of 2384 ha[1] that is alternately exposed and wetted each year (**Table 1**; **Figure 1**). From elevation 622 – 635 m (1782 ha), this area is virtually un-vegetated and consists of exposed mudflat with no perennial plant species, although bacterial and algal growth is likely. Between 635 m and 646 m, the percent cover and abundance of vegetation increases from low to high, with increasing amounts of both with increasing elevation (corresponding to growing season). This partially vegetated mudflat covers an area of 602 ha (25% of total) and is comprised of the low mudflat zone (LMF; 243 ha), which is sparsely vegetated (< 5%) and the mid mudflat zone (MMF; 359 ha), with higher vegetation cover (>5%) (**Figure 1**). Based on average elevation changes over the past 15 years, the LMF has been exposed for between 27% and 46% of the growing season (153 d between May 1 and September 30) or 41 to 70 days. Elevation 642m marks the lowest point in the mudflat area where perennial native plant species provide a more significant amount of ground cover; above that, both cover and species diversity increase with increasing elevation (Scholz and Gibeau 2014).

Table 1. Relevant elevations and surface areas within the dewatered zone of Carpenter Reservoir.

Elevation (m asl)	Surface Area (ha)	Description
622 - 646	2384	Average total annual dewatered area, 2000-2014
622 - 635	1782	Exposed mudflat area, unvegetated
635 - 646	602	Partially vegetated mudflat area
635 - 642	243	Low Mudflat Zone (171 ha), vegetation < 5%
		Steep-sloped alluvial & beach (72 ha)
642 - 646	359	Mid Mudflat Zone (MMF), vegetation > 5%

[1] The elevations and areas presented herein are based on those presented by Splitrock (see **Appendix A**), but have been simplified slightly herein for presentation purposes; these changes have no material bearing on any conclusions or recommendations contained within this report and serve only to improve clarity of the text.

Figure 1. Baseline conditions (2000 – 2015) in Carpenter Reservoir showing key elevations and aerial extent of drawdown zones.



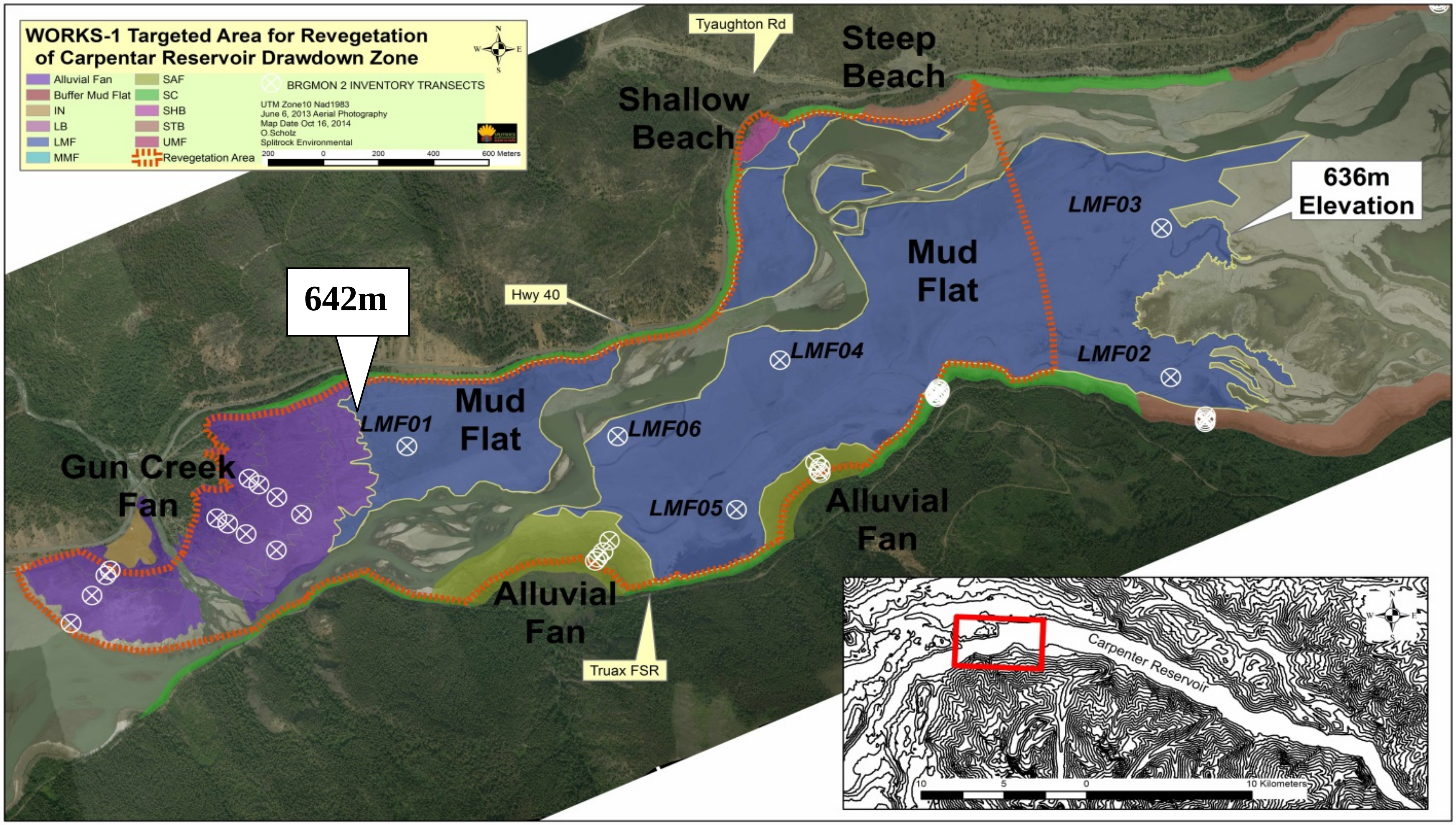
2.7.2. Predicted changes under WORKS-1

The WORKS-1 project aims to vegetate up to 243 ha of the poorly-vegetated drawdown zone area (**Figure 2**). The goal of the vegetation program is to achieve a vegetation cover and structure similar to the existing MMF flat polygon (see **Appendix A** for details, including photos). Based on that goal, and assuming that the vegetation effort is fully successful, the newly vegetated areas will contain between 500-1000kg/ha of biomass productivity.

The proposed vegetation zone is comprised of two major habitat types: 171 ha of mudflat (LMF) habitat and 72 ha of steep-sloped, coarse-grained alluvial fan and beach habitat. The LMF is low gradient, very poorly vegetated, fine grain size material and depositional in nature. Given the nature of habitat present in the LMF zone (i.e., fine-grained sediments), this area is important from a mercury methylation perspective. The remaining 72 ha (30%) of the proposed vegetation zone is situated on sloped, coarse substrates of the surrounding alluvial fans (e.g., Gun Creek fan) and beaches. Substrate in this area is much coarser than the remaining target area, consisting of sandy gravel and cobble and may be more erosional in nature than the remainder of the target LMF area. This type of habitat is not considered ideal for generation of methylmercury in sediment.

Photo showing largely unvegetated mudflat habitat.

Figure 2. Close up view of upper Carpenter Reservoir showing lower mudflat and Gun Creek fan areas targeted for planting.



As discussed in **Section 2.7.1** and presented in **Table 1**, the average draw down area (2384 ha) currently includes 359 ha (15% of total area) of vegetated habitat (all within the mid mudflat area). The additional 171 ha of vegetated low mudflat (LMF) habitat potentially added by WORKS-1 represents a 7% increase in vegetated habitat relative to the entire average draw down area (i.e., vegetated portion will be 22% of draw down area after WORKS1), or a 65% increase relative to baseline vegetated habitat (i.e., 171 ha of new vegetated habitat compared to 359 ha of baseline). Splitrock (**Appendix A**) indicated that variable microsite conditions in the target re-vegetation area will result in variability in the degree of successful establishment of vegetation. The changes discussed above, therefore, should be considered the maximum possible increase in habitat with greater than 5% cover by vegetation, assuming that the re-vegetation program is completely successful. In addition, the increase in vegetation biomass (kg/ha) resulting from WORKS-1 is also highly. According to Splitrock (**Appendix A**), if completely successful, the WORKS-1 program could increase biomass by an order of magnitude (i.e., 50 kg/ha to over 500 kg/ha). This would be a significant change, however, a major portion of this biomass would be woody material, not easily decomposable leafy material. Nevertheless, change in biomass will contribute to the available carbon load and should be incorporated as a metric into the long-term monitoring plan.

2.8. Will the WORKS-1 vegetation program change methylmercury concentrations in Carpenter Reservoir?

The Bridge River hydroelectric complex was created in the late 1940s, nearly 70 years ago. In the absence of high-drawdown dynamics, the state-of-science on mercury dynamics mercury in reservoirs would suggest stable, equilibrium conditions should exist within all of the impoundments. Results of three surveys conducted between 2000 and 2013 confirmed that fish mercury concentrations in Carpenter Reservoir remain high relative to connected waterbodies that do not experience high drawdown (lower Bridge River and Seton Lake). This also occurs in Downton Reservoir, just upstream and also a high drawdown reservoir, where rainbow trout are also elevated in mercury, with similar concentrations as in Carpenter. This corroborates the positive relationship between drawdown magnitude and fish mercury concentrations.

There is also evidence to suggest that fish mercury concentrations may be more dynamic than would be expected in the absence of high drawdown fluctuations in water level. While the 2000 and 2013 relationships between fish size and mercury concentration were similar, this relationship was lower for bull trout in 2008 than in 2000 and 2013. However, the available data preclude ruling out potential sampling event related bias (e.g., related to differential use of reservoir and tributary habitats by bull trout). Increasing sampling frequency (i.e., more events) and intensity (i.e., more fish per event) would be needed to be more definitive. Thus, these data suggest that there are particular hydraulic, chemical and ecological mechanisms at work in Carpenter Reservoir that interact to sustain elevated, and possibly dynamic, mercury methylation rates and loadings of methylmercury to the system. This phenomenon is ultimately reflected as the elevated fish mercury concentrations that we observe today.

As discussed within the text of this document, the rate and magnitude of methylmercury generation is affected by many factors, in sometimes complex mechanisms and interactions. The most important drivers appear to be abundance and availability of 'raw materials', inorganic Hg+2, labile organic carbon and sulphate, under favorable sediment redox conditions. It is noteworthy that it is possible there are natural inputs of inorganic mercury as a result of mineralization within the Carpenter Reservoir watershed. However, the historic or current contributions to the watershed appear to be low (except Cadwallader Creek which has not been surveyed), based on sediment data (Azimuth 2009) and water data (Azimuth 2012). Nevertheless, this is a potential factor that may contribute to the existing mercury loading and that has not been quantified.

Although high drawdown reservoirs have been poorly studied, the limited information that is available from such reservoirs, as well as from seasonally flooded wetlands and rice paddy environments, suggest that periodic inundation and drying of sediments provides favorable conditions for enhanced methylmercury generation. The mechanisms for this are complex, but appear to be strongly linked to changes in redox conditions in sediment. Under dry, oxidizing conditions, sulfide and possibly ferric iron are re-cycled or 'recharged' during dewatered conditions. When soils are re-inundated, organic material breaks down, reducing conditions dominate and sulphate becomes available as an energy source for sulphate reducing bacteria (Windham-Myers 2009, 2015; Eckley 2015). In addition, Rolfhus et al. (2015) have demonstrated that methylmercury generated during past inundation events may also be sequestered within the sediments and made available for release and uptake by biota when re-flooded.

Carpenter Reservoir is a large reservoir, 50 km in length with about half that surface area being alternately wetted and dried annually. During re-charge and re-inundation, new organic material is introduced from vegetation growth within the reservoir (e.g., algae and plants) and externally from upstream areas and tributaries. New mercury can also be introduced via dry and wet deposition, similar to the creation of a new reservoir, as well as from mineralized sources, or mines (e.g., Cottage Grove Reservoir; Eckley et al. 2015).

The nature of the bacterial community in the submerged part of the reservoir and exposed wetlands is undoubtedly very important, along with the abundance and 'availability' of labile organic carbon and reducible mercury (Hg+2) and other abiotic condition factors such as redox conditions (sulfate, iron), pH, oxygen and temperatures. However, there are no quantitative data from Carpenter Reservoir for any of these parameters, so it cannot be said how these site-specific conditions drive mercury methylation. This is only inferred given the similarity of Carpenter Reservoir with other, similar environments.

Ultimately, the long-term objective of BRGMON-12 is to determine whether mercury in water, sediment or fish will change as a result of changing conditions within the reservoir. Should the magnitude of change be large enough, it may be detectable on a reservoir-wide scale in the fish population. Given the site-specific nature of conditions within sediment, it may be possible to measure the change there, but it is highly unlikely a signature in water can be detected.

From the introduction, the null hypothesis of this work is:

> H_0: Implementation of the WORKS-1 re-vegetation program will not result in an increase in methylmercury concentrations in Carpenter Reservoir water, sediment or fish.

As discussed in **Section 2.7.2**, WORKS-1 targets only a portion of the annually wetted / dried area of Carpenter Reservoir. The targeted area falls entirely within the low mud flat area between 635 and 642 m asl, that is sparsely vegetated (>5% cover). On an aerial basis, the total vegetated area under the WORKS-1 program would increase the existing vegetated area of 359 ha (in the MMF area) by 171 ha in the LMF area to 530 ha. This is a 7% increase (from 15% to 22%) in vegetated area relative to the total average annual dewatered portion of the reservoir (**Appendix A**). This equates to an increase in vegetated habitat cover by 65% relative to baseline vegetated habitat cover. Increases in biomass were considered too uncertain to , independent of the projected increase in biomass (kg/ha) of vegetation associated with this change.

It is our opinion that an increase of this magnitude may be sufficient to increase mercury methylation in sediment in spatially discrete areas. However, there is much uncertainty as to how increased sediment methylmercury concentration in discrete areas may translate into an increase within the fish community of Carpenter Reservoir. Reservoir and experimental studies (e.g., (Bodaly et al. 1997, Hall et al. 2008, St. Louis et al. 2004 and many others) have definitively linked the increase in mercury methylation of inundated terrestrial soils with an increase in methylmercury concentrations in aquatic biota, especially fish. While small-scale, re-vegetation or de-vegetation studies (e.g., Windham-Myers et al. 2009, 2014) have demonstrated that mercury methylation can be significantly altered in sediments, a link between this phenomenon and an increase in mercury in higher organisms and fish in particular, has not been definitively shown. Consequently we conclude that there is too much uncertainty between the WORKS-1 vegetation program and this phenomenon in Carpenter Reservoir to fully resolve this question at this time.

With respect to the null hypothesis for water and sediment, we accept the null hypothesis at this time. For water, the magnitude of change in concentration would be much too small to detect on a reservoir-wide basis. For sediment, there is an absence of empirical data on methylation chemistry within Carpenter Reservoir sediment. While it is possible that mercury methylation will increase in sediment in discrete areas (e.g., vegetated areas), like water, it is uncertain if this will occur and how this would alter conditions on a reservoir-wide basis. As discussed earlier, the pathway of exposure to methylmercury by fish is via dietary sources (Hall et al. 1997). Thus, methylmercury generated in sediments would be accumulated within the lower food web (e.g., benthic invertebrates) before it can be passed on to fish.

Regarding fish, there is too much uncertainty at this time to definitively accept or reject the null hypothesis. Although the vegetated area within the LMF is small, a successful WORKS-1 program will increase the vegetated area by >50% above baseline, or a 7% increase in coverage of the reservoir draw down area by vegetation. There is simply too much uncertainty as to how a potential change in sediment methylmercury dynamics may translate to reservoir-wide changes in fish mercury concentrations. Nevertheless, given that fish mercury concentrations are already elevated (and among the highest in the province), we cannot reject it either. Consequently, we recommend to err on the side of caution and suggest that further investigation of this phenomenon is warranted.

WORKS-1 provides a unique opportunity to study the phenomenon of sediment mercury methylation dynamics under baseline high-drawdown conditions and upon implementation of the vegetation program in the LMF zone of the reservoir. The current WORKS-1 plan is to vegetate progressively over a five-year period, with less planting in initial years in an effort to learn what methods work best. This will result in a gradual change in vegetated area over time. From a fish mercury perspective, the gradual change due to WORKS-1 will be "superimposed" onto the normally variable annual draw down cycles, making it hard to detect. Consequently, the proposed strategy for monitoring is to conduct more intensive monitoring temporally (e.g., every two years for 8 years) focusing on sediments and fish (e.g., mountain whitefish as a surrogate fish). Measuring changes in sediment mercury will provide critically lacking empirical data to determine whether vegetating a portion of Carpenter Reservoir will affect local mercury methylation dynamics. This will be complemented by the fish data, which will provide a more reservoir-wide context for assessing change (i.e., to determine whether any observed changes in sediment mercury dynamics cascade up to fish communities in the reservoir). Ultimately this information will be used to determine if this magnitude of change is sufficient to incrementally increase fish mercury concentrations.

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Appendix A – Splitrock Environmental WORKS-1, 2015 Report

WORKS-1 Supplemental Report;

Influence of the WORKS-1 Re vegetation Project on BRGMON-12

Mercury in Carpenter Reservoir

Reference: BRGMON-12 (supplemental)

Study Period: 2014

Splitrock Environmental
PO BOX 798
Lillooet BC
V0K 1V0

Produced by;

Splitrock Environmental

Odin Scholz B.Sc.

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BACKGROUND

The BRGMON-12 project, undertaken by Azimuth Consulting Group has been tasked with determining whether metals and mercury concentrations in water, sediment and fish tissue have changed over time within the Bridge River system including Carpenter Reservoir, Seton Lake and the lower Bridge River. Findings of the most recent 2013 fish collection program (Azimuth 2014) determined that while mercury concentrations in fish tissue do not appear to have changed significantly since monitoring was initiated in 2000 (Baker and Mann 2001), fish mercury concentrations in Carpenter Reservoir fish are about 3 x higher than in Seton Lake and lower Bridge River fish. The reasons why this is so, are not known.

Carpenter Reservoir was created more than 40 years ago, well beyond the maximum time that fish mercury concentrations increase and decrease, following initial flooding and reservoir creation (Bodaly et al. 2007, Schetagne et al. 2003). Thus, present conditions reflect an equilibrium status, as fish mercury concentrations have not changed in nearly 15 years (Azimuth 2014). Carpenter Reservoir however, is a ‘large drawdown’ reservoir, with a >40 m annual fluctuation in water level elevation between low and high elevation. This annual raising and lowering of water level elevations results in alternate wetting and drying of large exposed areas. It has been postulated that reservoirs with large annual fluctuations in water level generate more methylmercury in bottom sediments than reservoirs that do not undergo large fluctuations (Hall et al. 2005, Rolfhus 2015). It is presumed that changes in redox conditions, methylation and demethylation associated with the sulfur cycle, combined with additional nutrients in the form of annual vegetation growth over the annual cycle, contributes to enhanced mercury methylation generation in sediments. This results in elevated mercury concentrations throughout the food web, including in fish.

Reservoir Water Level Management

According to the water Comptroller “*Carpenter Reservoir will be regulated between its licensed minimum and maximum levels of 606.55 and 651.08 m….To manage the reservoir for generation, fish habitat, and to minimize spills from Terzaghi Dam into Bridge River, BC Hydro will make reasonable efforts to target a maximum elevation of 648.00 m (buffer zone) for the end of snowmelt season in mid-August. Extended reservoir excursions above 648.0 m are expected as a result of meeting other constraints with higher priorities. If operations are expected to exceed 648.00 m for 8 weeks or more, BC Hydro will inform the Comptroller of Water Rights, provincial and federal fisheries agencies and the St’at’imc.*”(BC Hydro, 2011).

The spatial extent of Carpenter Reservoir that undergoes periodic wetting and drying at elevations greater than the minimum low pool level of 606m asl fluctuates annually according to precipitation and hydroelectric demand. The greater the fluctuation between full and low pool elevation, the more area is exposed and available for colonization by algae and plants during spring/summer of the drawdown period. The duration of time water levels are at low pool and the subsequent rate of reservoir filling will influence the amount of vegetation (biomass) produced in any given year. Carpenter Reservoir annual water levels since the implementation of the N2-P2 water management parameters in 2000 are presented in **Figure 1**. The growing season for the region is estimated to be between May 1st and October 31st with expected annual variability. Annual biomass productivity in the drawdown zone will vary given annual climatic variability as well as variable reservoir pooling rates and inundation periods. At lower elevations the growing season is shorter. In the past 15 years there has only been one year when the 635m elevation was under water for an entire growing season. It is accepted that there is no measureable vegetation growth below 635m elevation and there has been no studies done to measure algae growth of to determine if and where suitable growing conditions exist for its production in the drawdown zone. Elevations between 635m and 643m in the silt dominated mud flat zones are currently limited to producing small annual plant species (Scholz and Gibeau, 2014). A large part of the targeted re-vegetation zone for the WORKS-1 project is within the low mud flat (LMF) classification. The 643m elevation marks the lowest point in the mud flats where perennial native plant species provide significant amount of ground cover. Vegetation cover and plant species diversity both increase as the elevation increases.

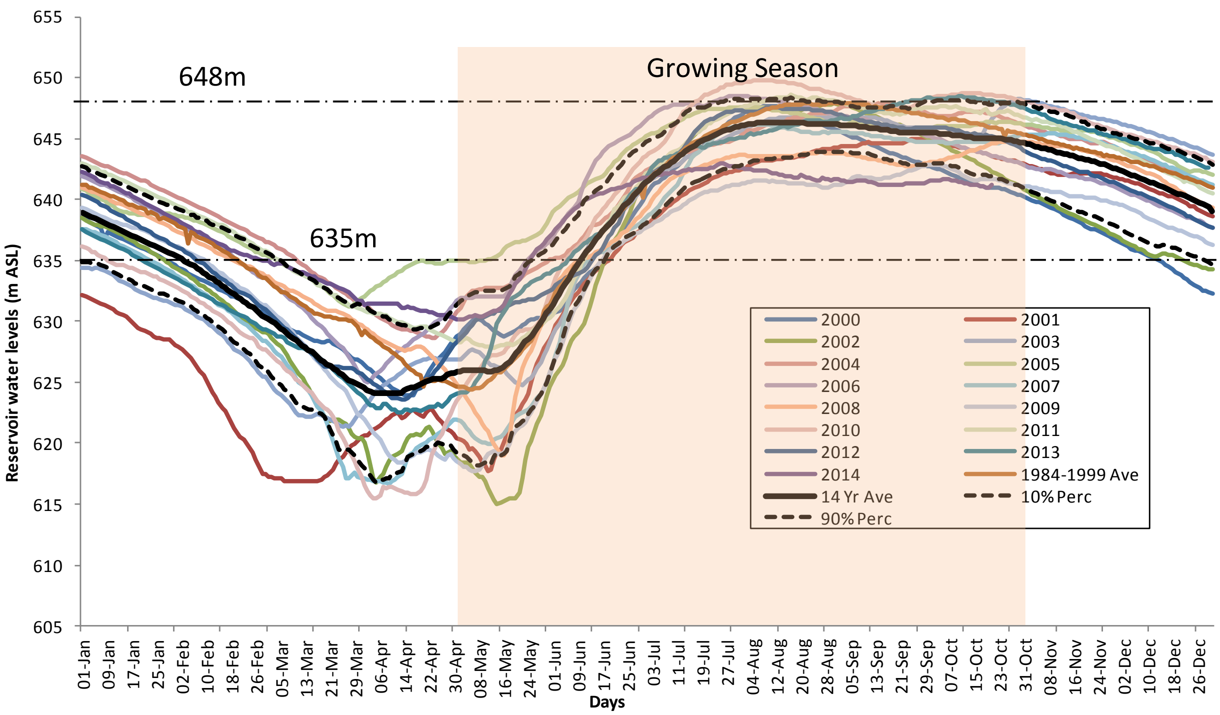


Figure 1. Carpenter Reservoir water levels since 2000. The 648m elevation marks BC Hydro's high water target for operational management, the 635m line indicates elevation that has in at least one year of the past 15, been under water for the entire growing season. The Growing season period is highlighted in pink.

OBJECTIVES

One of the objectives of the WORKS-1 project, is to vegetate a portion of Carpenter Reservoir with perennial native vegetation species. This is intended to stabilize exposed sediment preventing mobilization of dust during the drawdown period as well as improve aesthetic appeal of the area, increase recreation activities, improve wildlife habitat and enhance aquatic habitat. However, an unintended consequence of the revegetation effort may be to provide additional ‘raw materials’ for mercury methylation in the reservoir. This issue was raised by Azimuth Consulting Group (Azimuth), who are conducting BRGMON-12, as a potential issue during a meeting between the project team, BC Hydro and St’at’imx Eco-resources. Consequently, to determine whether the WORKS-1 initiative has the potential to change the chemical dynamics of mercury methylation in Carpenter Reservoir sediments, Splitrock Environmental was hired to assist Azimuth to provide information that addresses the following key questions:

- What is the relative proportion, or the aerial extent that Carpenter Reservoir becomes exposed each year, and what proportion of this area naturally re-vegetates each year? and;
- What is the predicted additive difference in vegetation aerial extent and biomass between current ‘baseline conditions’ and what is being proposed by the WORKS-1 re-vegetation plan?

Establishing the relative difference between baseline and predicted abundance and biomass of vegetation in Carpenter Reservoir, post-WORKS-1 is a key metric in understanding the potential magnitude of increase in sediment methylmercury generation.

To answer the above questions, this report presents the re-vegetation objectives and scope of the WORKS-1 Bridge Seton Water Use Planning project within the context of the existing riparian/drawdown zone vegetation in Carpenter Reservoir. We drew upon the riparian vegetation survey work conducted by Splitrock Environmental in 2013 for the BRGMON-2 WUP (Scholz and Gibeau, 2014) project to present the scope of the current annual vegetative growth within the drawdown zone. BRGMON-2 of the Bridge Seton Water Use Planning Project stratified Carpenter Reservoir drawdown zone by terrain class and elevation to then gather baseline data on the riparian vegetation surrounding Carpenter Reservoir in 2013. This report pairs the BRGMON-2 2013 study with the scope of the WORKS-1 re-vegetation project initiated in 2014 and infers potential change in biomass productivity to inform the hypothesis as to what degree the WORKS project may influence the production of methylmercury (MeHg) in the Carpenter Reservoir aquatic system, a mandate of BRGMON-12.

Baseline Conditions

In the BC government produced field manual for describing terrestrial ecosystems (Ministry of Forests and Range and Ministry of Environment, 2010) the site description section identifying and classifying the successional status of plant community defines a non-vegetated site as a site where;

> *"Vegetation is either absent or less than five percent cover because of substrate conditions or recent severe disturbance such as fire, mass-wasting, flooding, or anthropogenic causes."*

The BRGMON2 study from 2013 found that the low mud flat zone had an average vegetation cover of 8% with a range in average cover from 0.2 to 19 per cent cover based on 6 randomly located transects with four 1m X 1m plots sampled along each transect (**Figure 4**). The lower mud flat zone occurs between 642m and 636m. The LMF transects sampled at the lowest elevations within the LMF zone (LMF 02 and LMF03 636m (**Figure 8**)) had the lowest average vegetation cover values. It is concluded based on the sampling results and additional anecdotal observations of the lower drawdown pre flooding, that the elevations below the 635m elevation are classifiable as non-vegetated on an average annual timeframe due to the long period of inundation and subsequent extremely short growing season.

Over the past 15 years Carpenter Reservoir water levels have fluctuated from a high of 649m to a low of 615m (**Figure 2**). The reservoir has operated with an average 23.5m drawdown between an average high of 646.25m asl and an average low of 622.75m. The range in

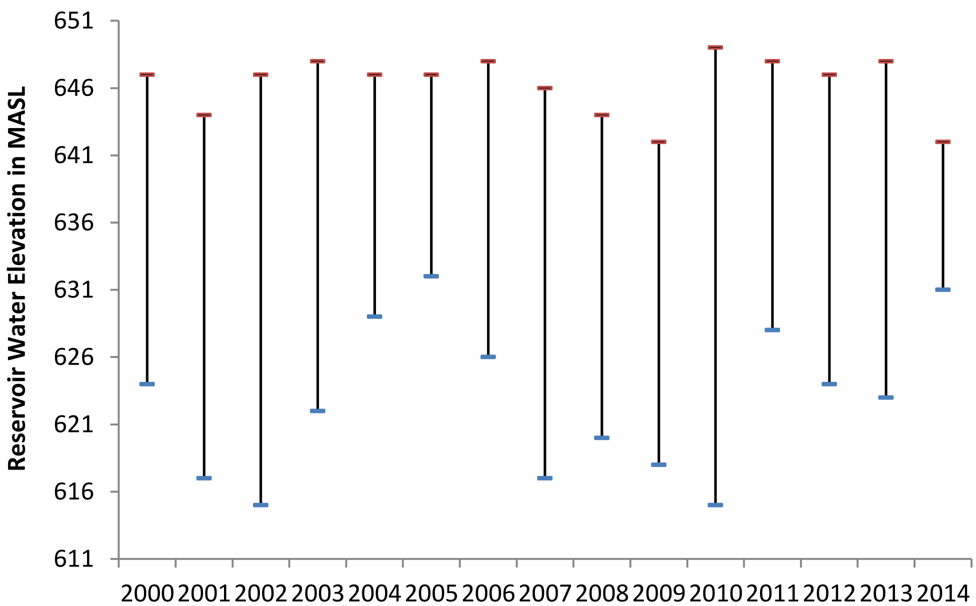


Figure 2. Carpenter Reservoir annual fluctuations between High and Low water levels over the past 15 years 2000-2014 in meters above sea level.

variability of the high water levels was 7m with the lowest high water event at 642 m and the highest high water event at 649m. Low pool levels were much more variable with a range of 17m with a high low pool level of 632m and a low low pool level of 616m from 2000-2014 (**Figure 2**). Presumably the variation in water levels has some influence on the vegetation productivity in the LMF zone but with only one year of sampling it is unknown to what degree productivity and cover varies.

Based on an average drawdown low pool elevation of 622.5m asl and an average high water elevation of 646.25m asl approximately 2384 ha of the reservoir drawdown were wetted and exposed over the past 15 year time frame **(Figure 3**). Twenty-five per cent or 602ha of the exposed drawdown is vegetated (>5per cent cover) annually. The other 1782ha, is below the 635m elevation and is considered to be non-vegetated (<5 per cent cover). The LMF surveyed and mapped in 2013 for the BRGMON 2 project, covered 312ha or 52 per cent of the vegetated drawdown zone, or 13 percent of the overall total exposed drawdown area. The LMF had very low vegetation cover values as is apparent in **Figure 4,** with an average cover of 8 per cent. It is estimated based on images that the biomass productivity is <50kg/ha for the vegetated LMF (R. Tucker P.Ag. personal communication).

Table 1 Average annual high and low pool levels in Carpenter Reservoir for the past 15 year period, including overall average highs, lows, and drawdown drafting levels.

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Average
low (masl)	624	617	615	622	629	632	626	617	620	618	615	628	624	623	631	622.73
high (masl)	647	644	647	648	647	647	648	646	644	642	649	648	647	648	642	646.27
drawdown (m)	23	27	32	26	18	15	22	29	24	24	34	20	23	25	11	23.53

Above the 642m elevation and below the average high water mark of 646.25m the vast majority of the remaining 359ha of vegetated drawdown zone area was classified as the Mid Mud Flat terrain class (MMF) in the BRGMON 2 study (170ha) (**Figure 5, Figure 6, Figure 7**). The MMF has comparable site conditions to the LMF including micro topography, slope, aspect and soil textures found to be 100 per cent silt/clay deposits. The substrate cover in the MMF zone was roughly 50 per cent bare mineral soil (silts) and 50% organic matter. The organic matter was an accumulated litter layer from the herbaceous vegetation growing *in situ*. MMF vegetation was predominantly comprised of horsetails (*Equisetum sp.*), lakeshore sedge (*Carex lenticularis*), and to a lesser degree bluejoint grass (*Calamagrostis canadensis*) all are perennial native plant species (Figure 5 and **Figure 6**). Based on 2013 sampling The average cover of vegetation in the MMF zone, was estimated at 63 per cent (Scholz and Gibeau, 2104) No destructive sampling of vegetation was carried out with the BRGMON 2 sampling but an estimate of the biomass productivity in the MMF zone based on a combination of photo monitoring and per cent cover values has been made at 500-1000kg per hectare (R. Tucker P. Ag. Personal communication).

Table 2. Proportion of the growing season (May 1 to September 30, 153 days) for which each elevation band was above reservoir water levels from 2000 to 2014, and average over the 15 years.

Elevation band (m ASL)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Average
616	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0
617	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	1
618	0	1	11	0	0	0	0	0	0	3	0	0	0	0	0	1
619	0	4	15	0	0	0	0	0	0	7	0	0	0	0	0	2
620	0	8	16	0	0	0	0	1	3	11	0	0	0	0	0	3
621	0	11	17	0	0	0	0	7	5	12	0	0	0	0	0	3
622	0	12	18	0	0	0	0	12	7	15	0	0	0	0	0	4
623	0	14	18	0	0	0	0	16	8	17	0	0	0	0	0	5
624	0	15	19	0	0	0	0	18	11	18	1	0	0	0	0	5
625	0	16	20	1	0	0	0	19	13	19	3	0	0	4	0	6
626	0	17	22	7	0	0	0	20	14	20	5	0	0	5	0	7
627	0	18	23	14	0	0	0	21	15	21	7	0	0	7	0	8
628	0	19	24	20	0	0	0	22	16	22	11	3	0	8	0	10
629	3	20	25	21	0	0	0	22	18	23	13	16	2	8	0	11
630	12	22	27	22	0	0	0	23	18	24	18	19	4	9	0	13
631	22	24	28	24	1	0	0	24	19	25	19	22	10	10	9	16
632	24	25	29	24	2	0	4	24	20	27	20	23	17	12	11	17
633	25	27	29	25	11	0	12	25	21	27	21	24	22	15	12	20
634	28	29	31	25	15	0	13	26	23	29	22	25	26	20	14	22
635	31	32	31	27	20	5	15	27	25	31	23	27	29	24	16	24
636	33	35	33	28	24	10	18	32	31	33	25	28	31	25	18	27
637	34	38	34	29	27	17	21	35	35	37	27	29	33	29	20	30
638	36	41	35	32	30	19	22	39	37	41	29	32	34	32	22	32
639	38	43	37	35	33	21	24	42	40	46	31	33	35	35	24	34
640	39	46	38	38	35	24	26	44	42	50	33	35	37	36	27	37
641	41	51	39	40	37	27	27	46	43	57	35	38	39	40	34	40
642	44	56	41	42	39	31	28	48	46	93	37	40	41	41	71	46
643	48	63	44	47	42	33	29	49	59	100	39	44	45	42	99	52
644	60	76	47	51	49	36	31	52	100	100	42	46	48	48	100	59
645	69	97	50	56	59	39	35	59	100	100	44	50	50	58	100	64
646	78	100	58	67	65	51	47	91	100	100	46	52	59	69	100	72
647	88	100	69	100	75	76	60	100	100	100	48	58	75	85	100	82
648	100	100	100	100	100	100	84	100	100	100	61	82	100	95	100	95
649	100	100	100	100	100	100	100	100	100	100	77	100	100	100	100	98
650	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
651	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

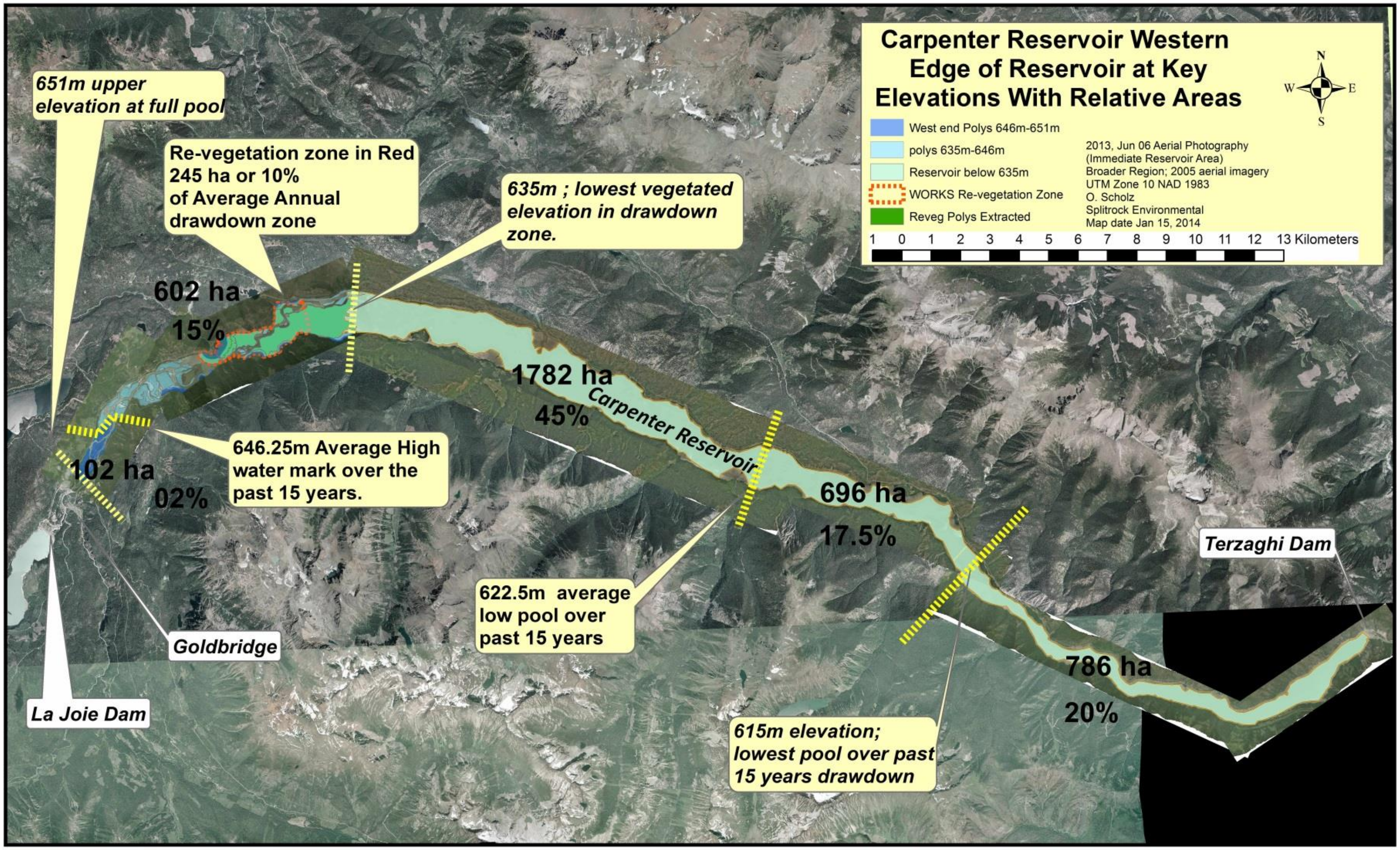


Figure 3. Map detailing approximate locations of westernmost edge of reservoir at key elevations. Also indicated are the areas of respective zones and relative per cent cover of the total possible drawdown zone.

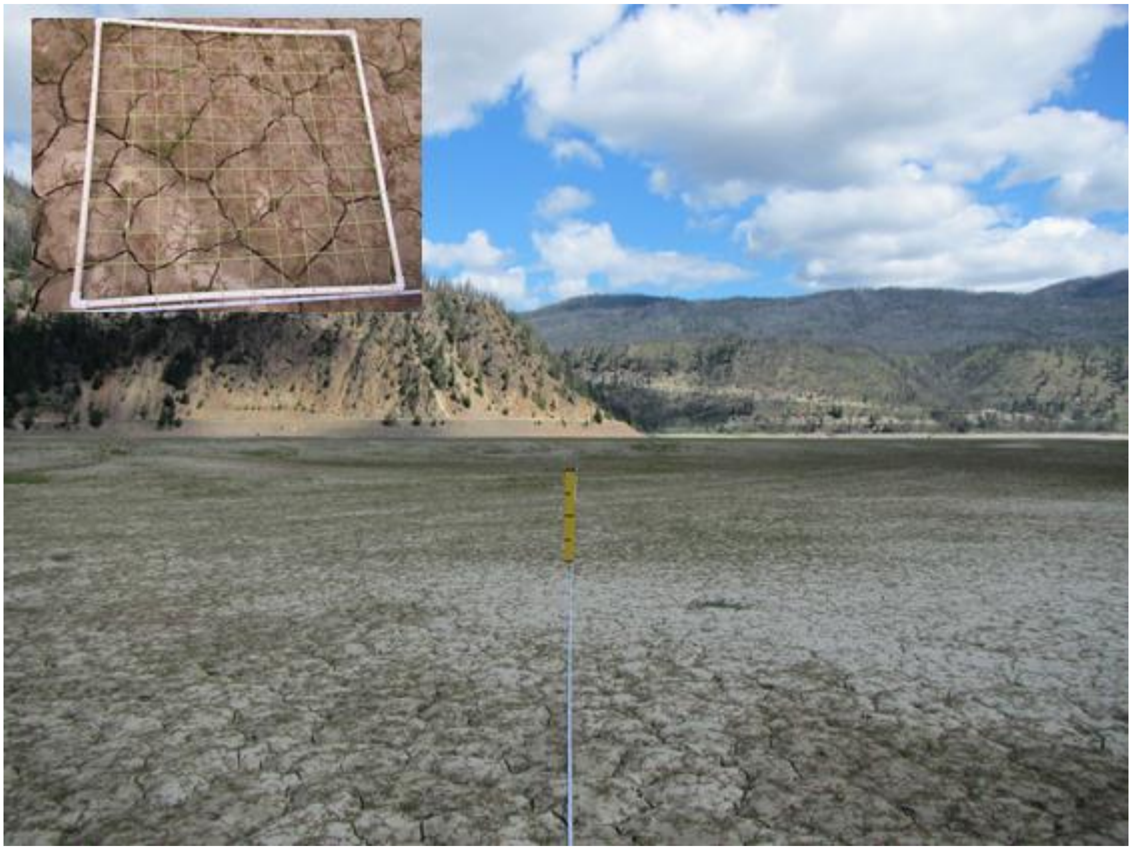


Figure 4. LMF05 transect facing North, inset plot highlighting the minimal amount of vegetation found throughout this 169ha area. This photo represents an area targeted for re-vegetation within the WORKS 1 project Biomass productivity estimated at <50kg/ha.

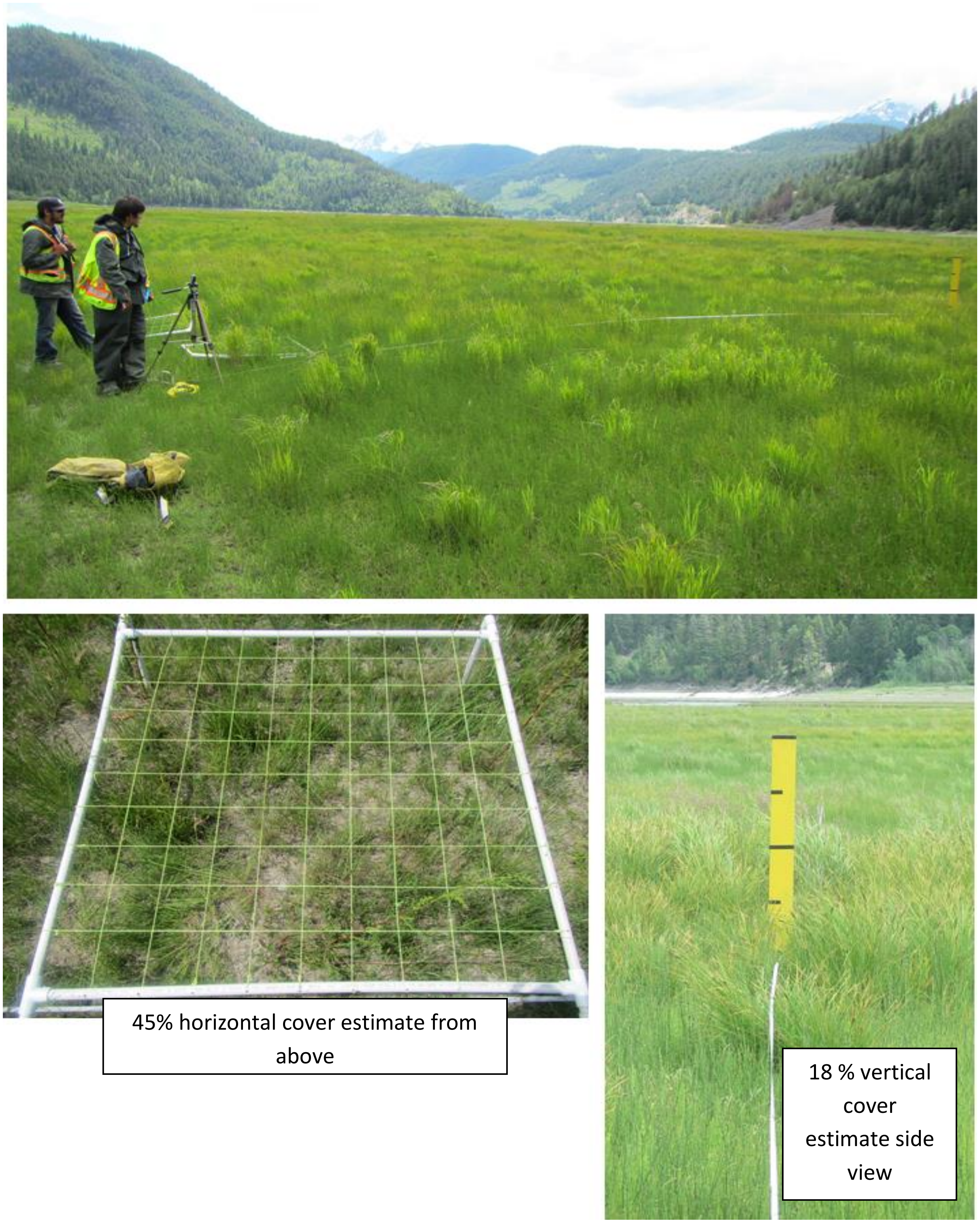


Figure 5. Example of two types of photo monitoring captured during BRGMON-2 project in 2013. Top setting up photo point along sampling transect. Lower left MMF03 plot 1, 1mX1m frame, 4 plots recoded per transect. Lower right image from photo monitoring point MMF04 (bearing 114°), 1mX0.10m board with estimate of vertical vegetation cover.

Table 3. List of terrain types and elevations that were stratified and sampled through the BRGMON2 study of Carpenter Reservoir Riparian Vegetation in 2013.

		BRGMON-2 Sampling Elevations					
		15 yr Avg % of growing season exposed	*46%*	*59%*	*82%*	*95%*	*100%*
TERRAIN TYPE	**SLOPE TEXTURE CHARACHTERISTICS**	**ELEVATION SPAN (masl)**	**642m**	**644m**	**647m**	**648.5m**	**650.5m**
Steep Colluvium	Slope greater than 30%	642-651		X	X	X	X
Steep Beach	Slope 15% to 30%	642-651		X	X	X	X
Alluvial Fan	Slopes less than 10%	642-651		X	X	X	X
Shallow Beach	Slopes less than 15%	642-651		X	X	X	X
Industrial	Varied anthropogenically modified terrain						
Bedrock	Varied bedrock and veneers of decomposing bedrock						
Buffer Mud flat	Flat generally silty	648-651					X
Upper Mud flat	Flat generaly silty	647-648			X		
Mid Mud flat	Flat generaly silty	>642≤647		X			
LowMud flat	Flat generaly silty	≤642->635	X				
Higher Fluvial bar	Proximal to active fluvial channel						
Lower fluvial bar	Within active fluvial channel						

Table 4. Terrain Class areas for re-vegetation zone covered by WORKS-1 project.

Terrain Type	Area ha	% Works Re-vegetation Area
Steep Beach	2.9	1%
Shallow Beach	1.7	1%
Alluvial Fan (*Gun Creek Fan*)	55.0	23%
Steep alluvial fan	14.8	6%
Low mudflat	168.9	69%
	243.3	100%

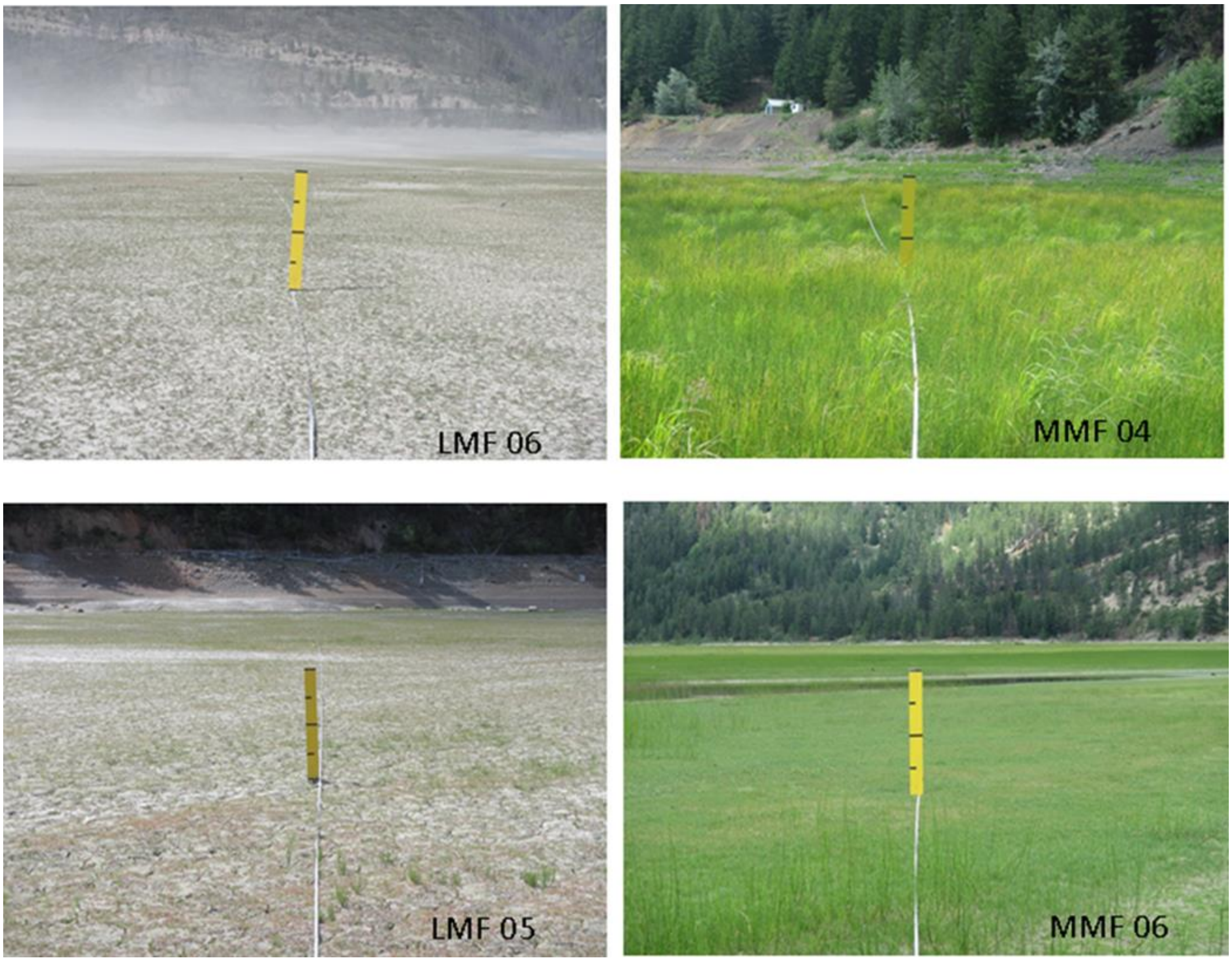


Figure 6. Comparative images from the Low Mud Flats and the Mid Mud Flats. MMF 06 was the MMF transect with the lowest amount of vegetation cover, Biomass estimate LMF <50kg/ha, MMF 500-1000 kg/ha.

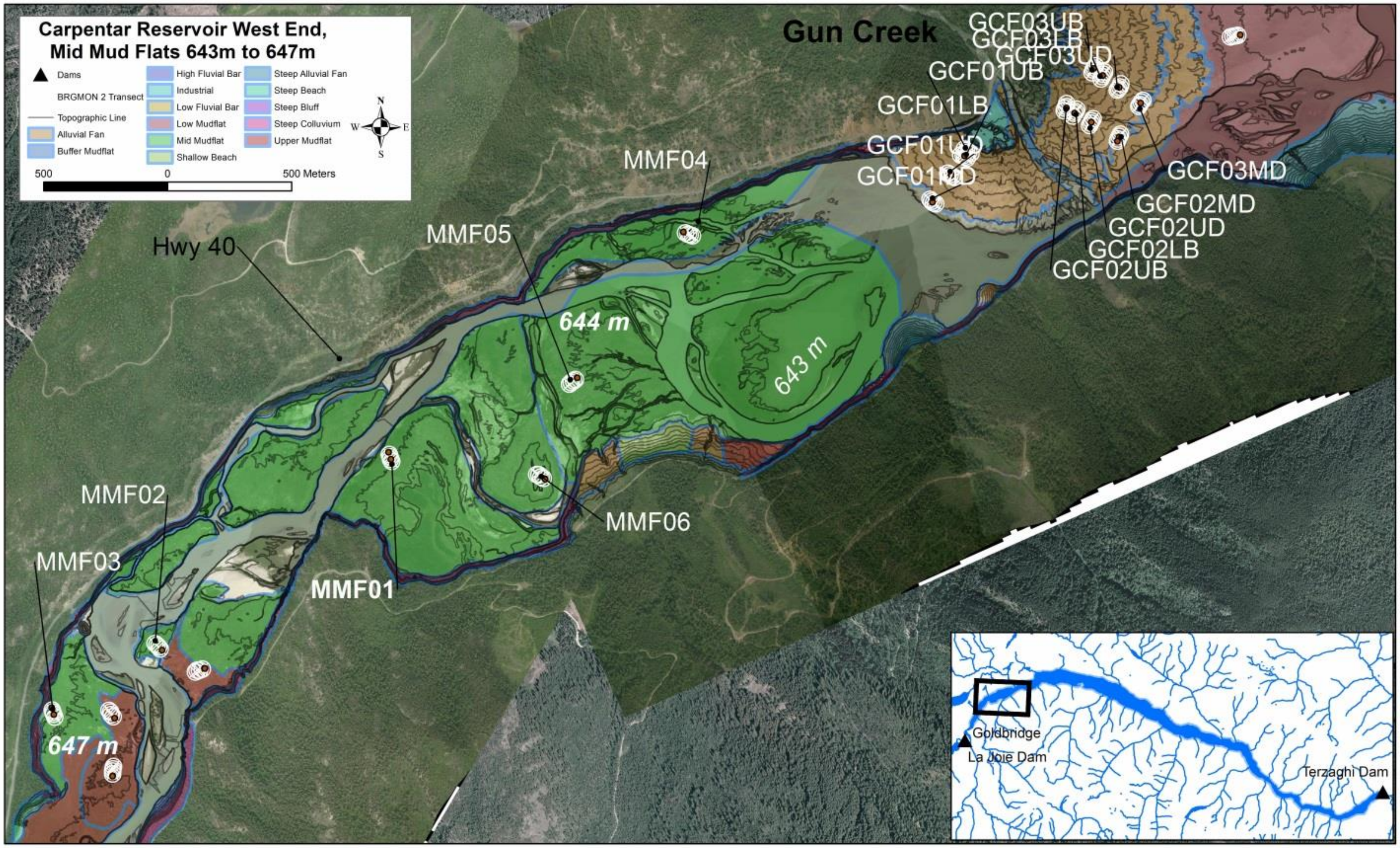


Figure 7. Mid Mud Flat Polygons West of the Gun Creek fan making up approximately 170ha of annually flooded, dewatered and vegetated drawdown zone. BRGMON 2 2013 survey point locations are indicated.

METHODS

BRGMON 2 Study Methods

To capture and establish small-scale baseline data regarding the extent of riparian vegetation distribution across Carpenter Reservoir, aerial imagery and digital elevation data were gathered during an aerial survey, flown on June 6th 2013 (Scholz and Gibeau, 2014). On the date of capture, reservoir water level was at 635.05m elevation at 7:00am and at 635.34m 24 hrs later on the 7th of June. Based on the inferences made from the BRGMON 2 field data all of the vegetated drawdown zone (i.e., Having >5% cover) was captured in flight, the drawdown zone below 635m is largely expected to be devoid of vegetation on an average year. Elevation data were processed by BC Hydro's geomatics department to produce 1m contour lines for the reservoir. The lowest contour line produced from analysis of the June 2013 flight was the 636m line, with the upper topographic lines varying by a couple of meters above licensed full pool elevation of 651m.

The BRGMON-2 Water Use Plan project field work was carried out during the summer of 2013 (Scholz and Gibeau, 2014). The objective of this survey was to map and quantify existing vegetation cover, diversity and distribution in the Carpenter Reservoir drawdown zone. The survey included analysis of existing aerial imagery (taken in 2005) to stratify the reservoir into terrain polygon units for planning vegetation sampling on the ground. Several days of ground-truthing were carried out to confirm mapped polygons. Polygon stratification led to grouping of the surrounding drawdown zone terrain of Carpenter Reservoir into the following categories: beaches, alluvial fans, steep colluvium and mud flats. These terrain classes were further stratified by elevation class for sampling (**Table 3)**. Vegetation sampling transects were laid out to sample vegetation on all terrain elevation types to form a baseline of data for vegetation distribution, composition and cover. Species composition, percent cover, soil texture, substrate cover, vegetation vigor, vegetative and generative growth and sign of use by wildlife was gathered for each monitoring plot. Photo monitoring was carried out using a set protocol and an assessment of height and density of vegetation growth was estimated for each. Vegetation biomass kg/ha were not collected but detailed photo monitoring was conducted to capture cover and the images are used here to estimate and predict biomass productivity (**Figure 5**).

RESULTS

Predicted Changes under WORKS-1

The Bridge Seton Water Use Plan projects (BC Hydro, 2011) include WORKS-1 Water Use Plan, a project that focusses on planting vegetation throughout the western end of Carpenter reservoir between the Gun Creek Fan and the Tyaughton Rd Turnoff (**Figure 8**). The area targeted for re-vegetation under the WORKS-1 project measures 243.3ha. The re-vegetation area is 10 per cent of the average annual drawdown area based on the past 15 year average. The re-vegetation area is also 40% of the average annual drawdown zone area that is vegetated each year with an average cover above 5 per cent. The re-vegetation area includes five terrain classes, the vast majority 69% of which is in the Low Mud Flat zone (**Table 4**). Steep colluvium zones characterized by coarse rock, steep slopes and highly mobilized substrates due to wave action, have been excluded from re-vegetation trials because they are considered un-plantable.

In total 169ha of the 312ha LMF zone (54%) is targeted for re-vegetation representing an enhancement of up to 7% of the 2384ha total drawdown zone area exposed between average high and low pool levels of 646.25m and 622.5m. The objective of the WORKS-1 project is to convert just over half of the Low Mud Flat area into a more productive vegetated zone, with planting as low in elevation as 636m. A reasonable reference goal for the WORKS-1 re-vegetation of the LMF zone is assisting the establishment of vegetation cover, composition and productivity similar to that of the MMF zone (**Figure 6**). If the re-vegetation effort in the Low Mud flat zone is fully successful, the distribution of vegetation cover that typifies the MMF zone with between 500-1000kg/ha of biomass productivity would be increased to 328 ha.

The LMF zone covers 70 per cent (169ha) of the 243.3ha re-vegetation zone encompassed by the WORKS-1 project (**Figure 8**). Based on the cover values and photo monitoring gathered in 2013, the biomass productivity in the LMF zone is estimated to be <50kg dry weight per hectare (**Figure 4**). The amount of productivity may vary based on annual shifts in climatic conditions and the length of growing season (**Table 2**). The growing season for the area was estimated to be between May 01 and September 30 (153 days). Since the year 2000, the inception of the N2-P2 water management strategy, the lower mud flats areas that are targeted for re-vegetation (between 642m and 636m asl) were on average above water for between 27 and 46% of the growing season. The year of the initial BRGMON 2 surveys (2013) the periodicity of the reservoir drawdown was slightly below average for the amount of time that the LMF was exposed. Therefore on an average year there would be a slightly longer growing season which could mean higher cover values and greater biomass productivity in the lower drawdown zone. This variation could only be quantified through annual monitoring.

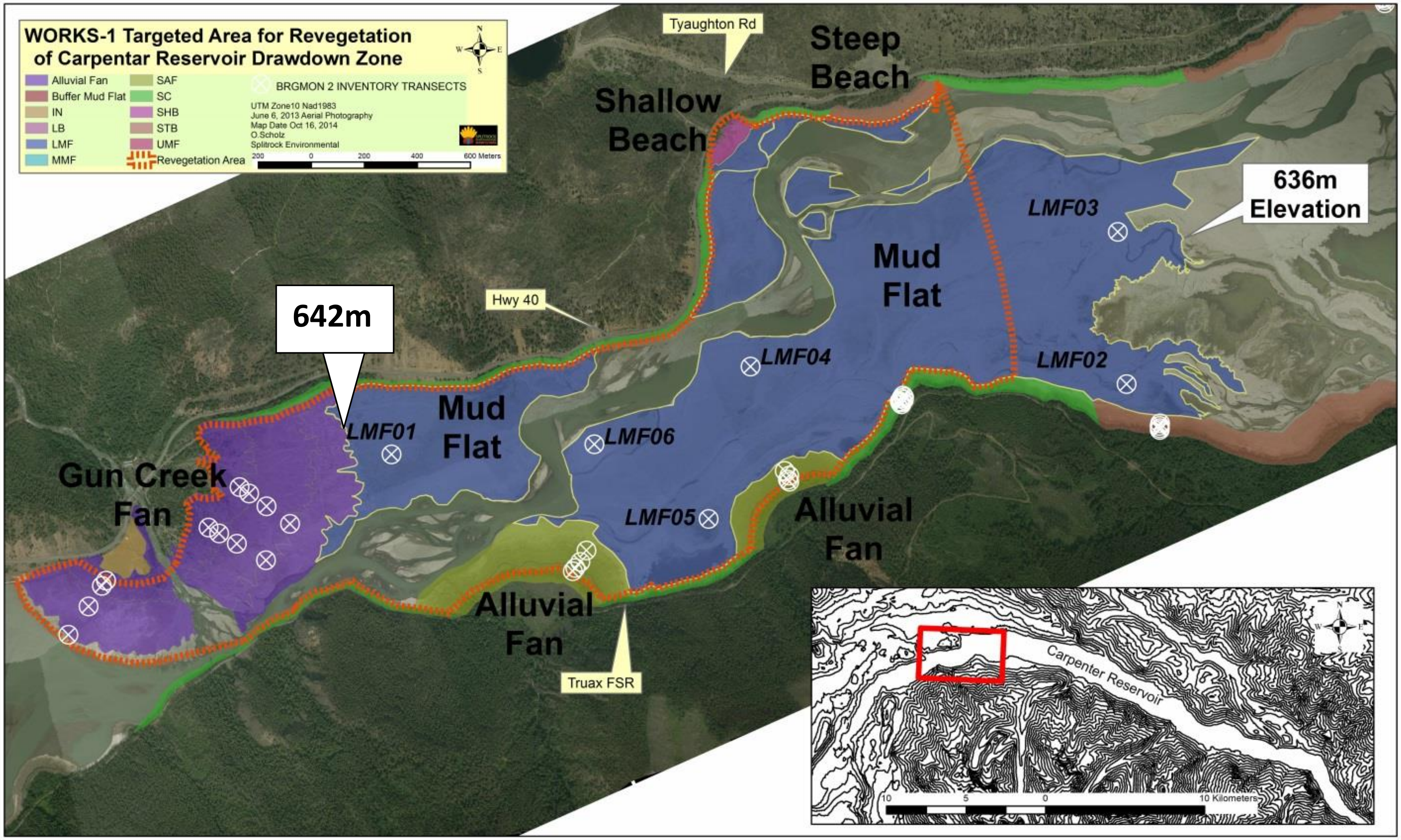


Figure 8. Targeted area for re-vegetation under the WORKS 1 Carpenter Reservoir Re- vegetation Project, Note the variety of terrain classes, mud flat, alluvial fans (including the Gun Creek fan), shallow and steep beaches

The Gun Creek alluvial fan was stratified as an independent terrain class as it was a unique feature in the landscape of Carpenter Reservoir as well as being a targeted site for re-vegetation under the WORKS-1 project. The Gun Fan makes up 23 per cent (55ha) of the area targeted for re- vegetation or 9% of the annual re-vegetated drawdown area, based on the past 15 year average. The fan occupies an elevation range within the drawdown zone from 642m up to 651m. Below the average high water elevation of 646.25m is 34.5 ha of the Gun Creek Fan's targeted re-vegetation area. The average high water mark serves as the high point of the middle zone polygon in **Figure 9**.

Vegetation cover across the Gun Fan was sparse and patchy during the 2013 BRGMON-2 survey. There was a general increase in cover with an increase in elevation up to about a 50% cover at the upper buffer elevations that are infrequently under water. In the BRGMON-2 study of 2013, three randomly located permanent monitoring transects were established to gather baseline data across four elevation bands to determine vegetation cover on the fan's drawdown zone. In general vegetation cover across the Gun Fan was heterogeneous and scattered. The 2013 sampling found a relatively sparse amount of vegetation cover from the mid drawdown elevation transects on the fan measured at the 644m contour, through to the upper buffer zone transects measured at the 650.5m contour (Scholz and Gibeau, 2014). Vegetation cover at the mid drawdown had a range in cover values between 4 and 36% with an average of 17% (**Table 5**). Vegetation height in the mid zone ranged from 1 cm and 7 cm. The WORKS 1 re-vegetation targets for the Gun Creek fan middle drawdown zones are similar to those of the LMF and that is the vegetation will ideally resemble the current cover on the MMF where cover is 63% on average and biomass productivity is between 500 and 1000 kg/ha. The vegetation cover will be more diverse than on the LMF zone with the emphasis on planting perennial native sedges lakeshore sedge (*Carex lenticularis*) but also plantings will focus on but not be limited to native grass species, namely bluejoint (*Calamagrostis canadensis*), fowl bluegrass (*Poa palustris*) blue wildrye (*Elymus glaucus*) and foxtail barley (*Hordeum jubatum*). The 33.5 ha of mid drawdown re-vegetation area on the Gun Fan brings the total area with a targeted biomass productivity in the range of 500-1000kg per hectare to 202.5ha.

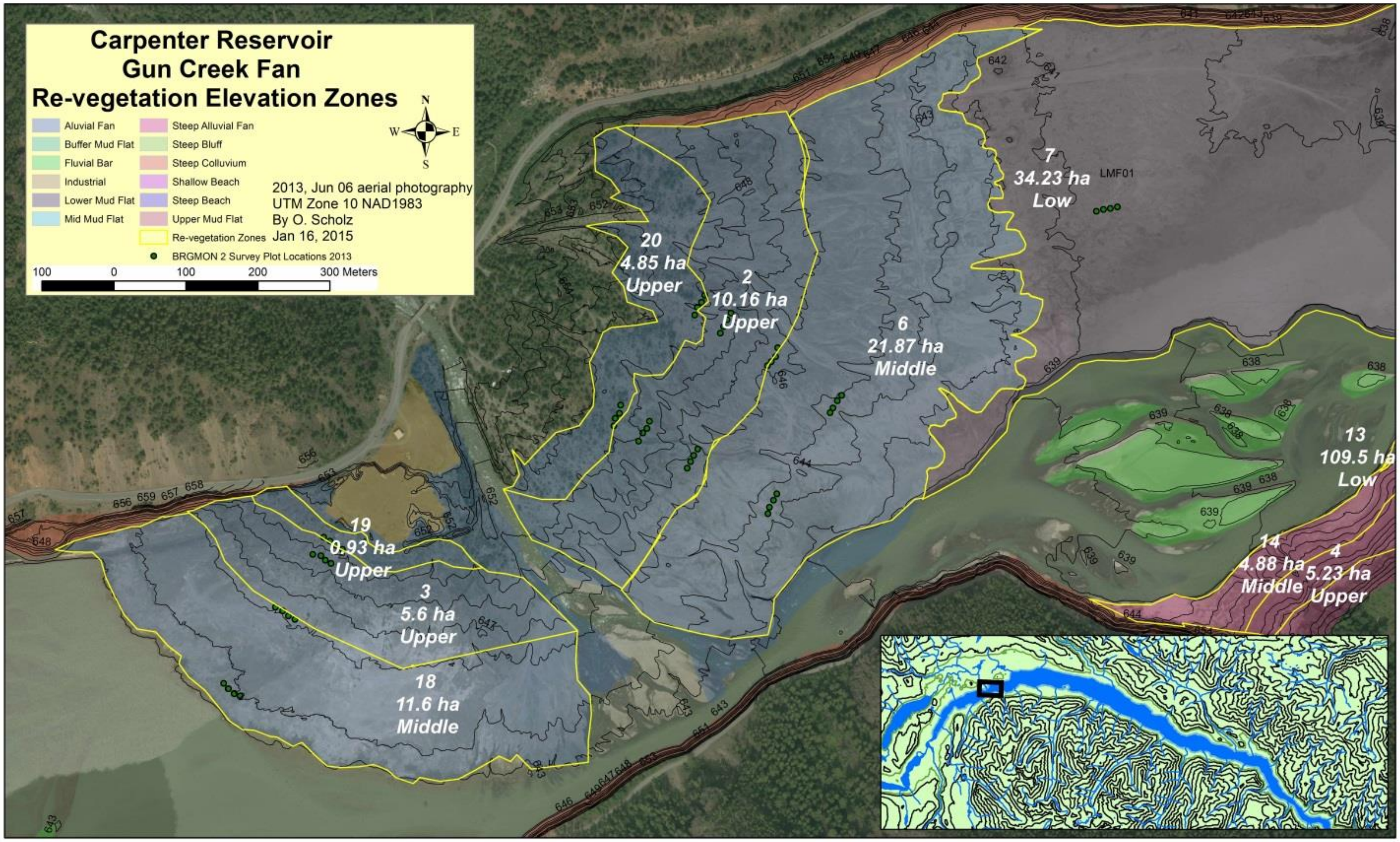


Figure 9. Gun Creek Fan re-vegetation polygons broken into general elevation bands , low is mud flats where sedges will be focal vegetation, middle will also be sedges with some possible grasses, upper will be grasses and deciduous tree and shrubs.

The upper drawdown zone elevations on the Gun Fan of area between 646m and 681m targeted the 647m band elevation for sampling. On average the 647m elevation was exposed for 82 per cent of the growing season and lay above the average annual high water mark over for the past 15 years. One exception to this pattern happened in 2010 when the 647m elevation was exposed for less than 50 per cent of the growing season. Occasional years where there are long periods of flooding may drown perennial vegetation that has been encroached and established at lower elevations in the drawdown zone posing a potential threat to the long-term success of some of the low elevation WORKS1 plantings.

In order to account for all of the possible organic 'raw material' inputs added to Carpenter Reservoir due to the WORKS-1 project it is necessary to account for the treatments of the upper elevations where deciduous tree and shrub species become key tools in the re-vegetation effort even though inundation periods are infrequent. The upper zones on the Gun Fan in general had coarse rapidly draining soils with very sparse vegetation cover with an average cover value of 5.5 per cent. The height of vegetation sampled in the upper drawdown zone of the Gun Fan ranged from 7 cm to 50 cm representing a very sparse cover with low amounts of biomass being produced. The predominant species found at the upper drawdown elevation was quack grass (*Elytrigia repens*) an exotic perennial grass species. Substrate cover in the upper drawdown was one third rock and two thirds mineral soil.

The Works-1 project will attempt to enhance with deciduous trees and shrubs the cover in the upper fan zone 644m-651m by planting nursery stock and installing live stakes of cottonwood (*Populus balsamifera ssp. trichocarpa*) and willow species (*Salix sp.*) deep into the substrate. The goal at higher elevations is to assist the succession of the site towards the development of multilayered shrub herb vegetation cover. On years with higher water levels the leaf drop from planted deciduous species will contribute organic matter into the reservoir water.

The upper elevations of the Gun Creek Fan represent the largest area (21.5ha) that will undergo planting with deciduous tree and shrub species. Initial trial plantings were carried out in 2014 under the WORKS-1 project with test plots spanning elevations from 644m to 649m with an associated range in length of growing season from 52 to 98%.

Deciduous tree and shrubs are targeted for planting in the upper elevations of the two south shore alluvial fans and the steep and shallow beach sites in the re-vegetation zone on the north shore a total of 6.97ha (**Figure 10**) bringing the total area targeted for re-vegetation with trees and shrubs to 33.2ha. Natural encroachment of cottonwood and trembling aspen (*Populus tremuloides*) trees and willows into the drawdown zone are observed in patches on the alluvial fan and beach terrain classes (**Figure 1, Figure 1**). A patch of willows planted during an experimental planting in the year 2000 was observed with surviving plants persisting between the 646m elevation up to the would be considered successful if the vegetation establishes at least as well as this previous trial (**Figure 13, Figure 14,**).

Table 5. Summary table of horizontal cover (1X1m quadrats, 4 per transect) , GCF= Gun Creek Fan, SAF= Steep Alluvial Fan, STB= Steep Beach. (MD= mid drawdown, UD= Upper Drawdown, LB= Lower Buffer, UB= Upper Buffer).

Avg growing season exposure	644m 59%	647m 82%	648.5m 95%	650.5m 100%

Transect Name	MD (644M)	UD (647M)	LB (648.5M)	UB (650.5)
GCF01	3.92	10.77	16.77	6.52
GCF02	36.28	5.83	21.64	38.89
GCF03	12.41	0.43	5.54	26.88
average cover %	17.5	5.7	14.6	24.1

Transect Name	MD (644M)	UD (647M)	LB (648.5M)	UB (650.5)
SAF01	2.18	21.92	87.04	35.42
SAF02	3.27	13.65	37.38	31.76
SAF03	17.77	17.55	41.88	54.26
SAF04	20.55	19.01	35.53	64.27
SAF05	16.91	13.05	66.27	63.76
average cover %	12.1	17.0	53.6	49.9

Transect Name	MD (644M)	UD (647M)	LB (648.5M)	UB (650.5)
STB01	0.81	3.66	68.88	51.16
STB02	2.76	21.51	15.51	33.76
STB03	99.17	73.02	26.41	45.69
STB04	1.01	0.53	15.52	6.78
STB05	3.42	3.49	0.15	26.8
average cover %	21.4	20.4	25.3	32.8

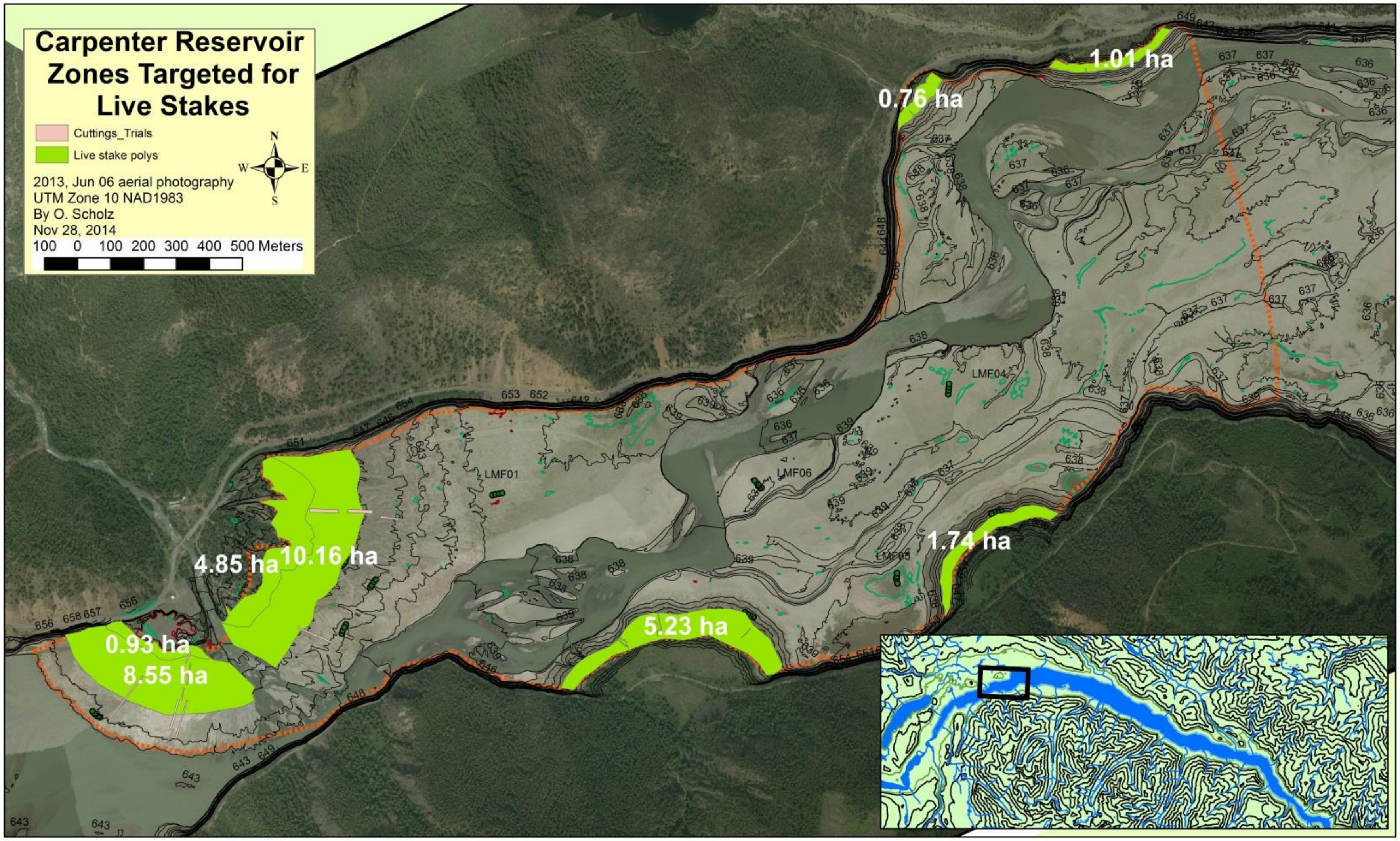
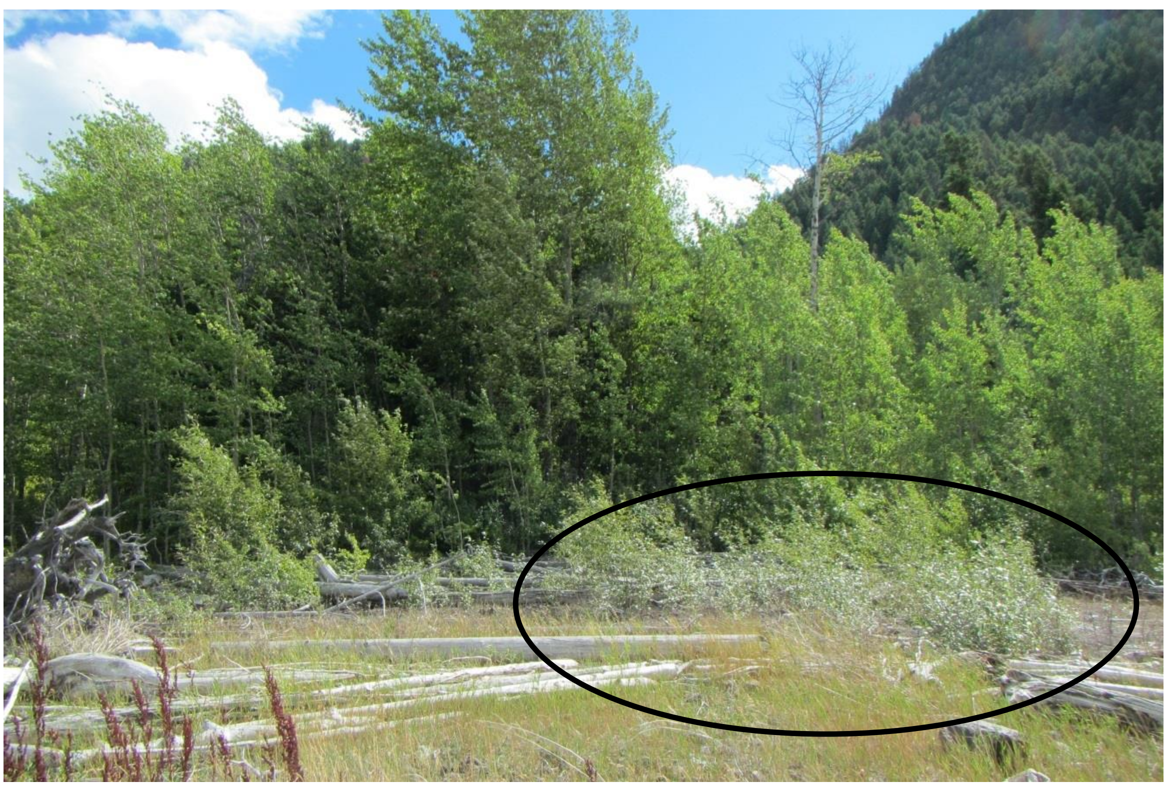


Figure 10. Polygon areas where live stakes are part of the re-vegetation effort. These polygon areas have deciduous trees and shrubs as a key component of the final vegetation stand composition.

Figure 121. Trembling Aspen suckering, advancing into the drawdown zone.

Figure 112. An example of black cottonwood encroachment into drawdown buffer zone, on South side of Carpenter alluvial fan.



In addition to the trees and shrubs, native grass and sedge species will be planted between the 646 and 650m mark where necessary). The deciduous tree and shrub planting in the upper elevation portions of the drawdown zone will be coupled with herbaceous plantings to attempt to encourage the development of a complex multistoried vegetation community with consequently more biomass productivity and potentially more 'raw materials' that could contribute to the generation of Hg in the reservoir. If this multilayered planting is successful, the end result for the upper drawdown zones could be somewhat similar to the Buffer Mud Flat Polygons sampled in the BRGMON-2 Study of 2013. A coarse estimate of biomass for the BMF would be >2000kg/ha. The buffer mud flat sites do differ in that they are richer sites that have finer textured soils with more even groundwater supply than the alluvial fans and beaches in the WORKS-1 re-vegetation zone where the soils are coarse and prone to drought. In that sense it is unlikely that biomass productivity will ever be as lush on the Gun Fan.

There are many micro site variations across the terrain types in the targeted re-vegetation zone of the WORKS-1 project. This variability in micro topography, substrate texture, depth and ground water supply not to mention local disturbances from wildlife, livestock and human activities, is as in natural settings, likely to be produce patchy and variable results in vegetation establishment resulting from the efforts of the WORKS project. The summary conditions in this report assume a 100 per cent success rate of even establishment and growth. This is probably an unrealistic expectation. That said, it is anticipated that there will be a substantial increase in the vegetation cover due to the efforts under the WORKS-1 project.

BRGMON-2 has been set up to monitor and guide the progress of the WORKS-1 project over its 5 year duration. Based on the interest in assessing biomass in relation to potential as an ingredient for methylmercury generation within the reservoir, it is recommended that biomass sampling using clip plots be included as part of the monitoring regime. This will provide some empirical data for comparing biomass values before and after WORKS 1 treatments, as well as establish relative control sites for comparison within the MMF reference sites as well as within the re-vegetation sites. Collecting and measuring clipped biomass will also assist in correlating biomass values with the detailed photo monitoring data collected via the BRGMON-2 project.

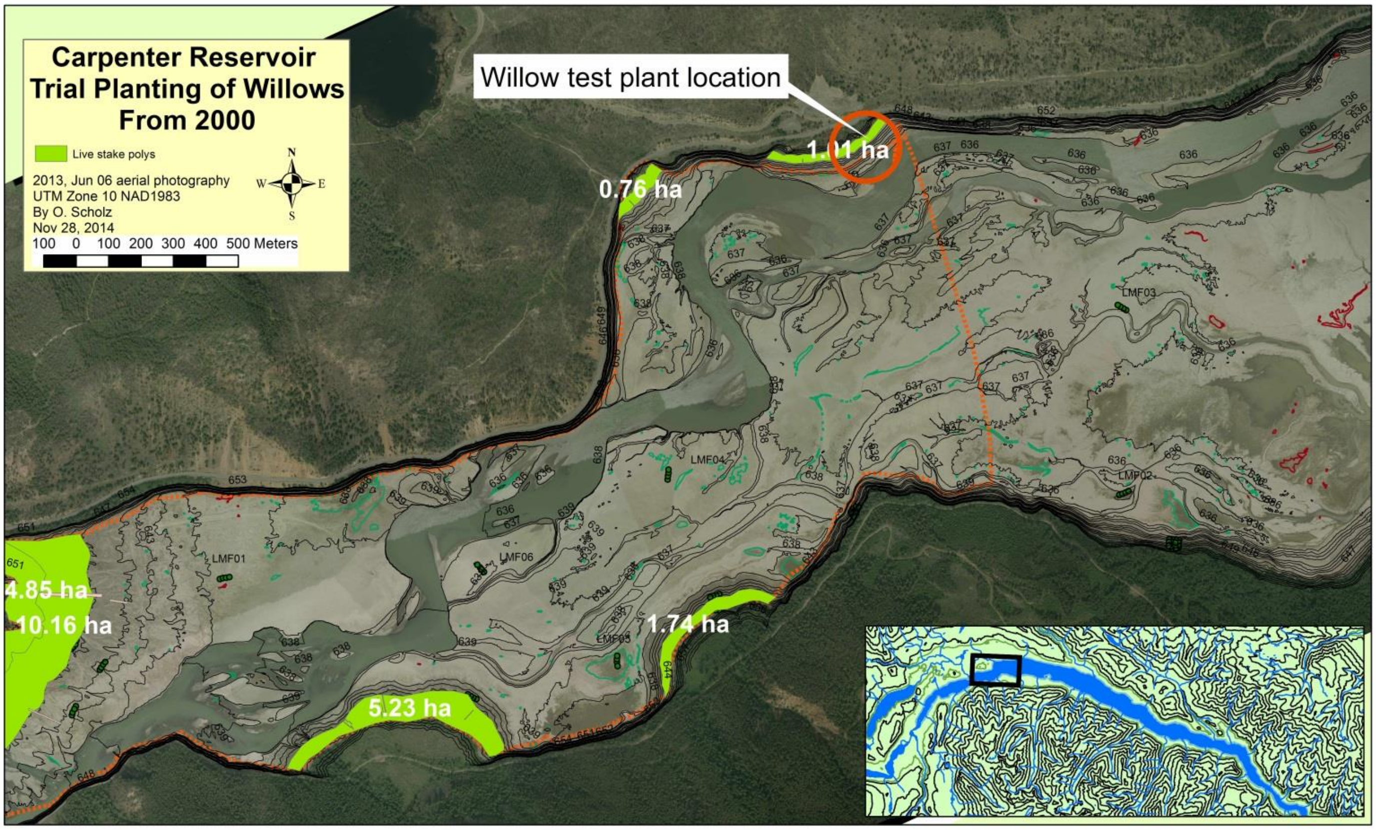


Figure 14. Map of 2000 trial site in relation to the polygons targeted for live staking under the works 1 project.

Figure 13 . Willows at test plant site summer 2012 water level approx. 646m, plants on steep beach terrain class. Willow was planted in the upper drawdown between 646m and 648m elevation, plants below 646m mark have died back.

SUMMARY

To pursue the goals of dust abatement, aesthetic improvement and habitat enhancement the WORKS-1 project will conduct re-vegetation works across a 243.3 ha area of the Carpenter Reservoir Drawdown zone. Much of this area is only marginally vegetated based on surveys conducted in 2013. Based on an average of the past 15 years of water level data 602 ha of the Carpenter Reservoir drawdown zone are annually dewatered, vegetated and then re-flooded. The bulk of the drawdown area 312 ha is low elevation (<642m asl) silt covered mud flats that make up 52% of the annually vegetated drawdown zone based on 2013 findings. The vegetated mud flat zone stretches down to 636m asl and comprises 13% of the total (2384 ha) of the annual exposed drawdown zone. The vegetated low mud flats are exposed for between 27% and 46% of the growing season based on the past 15 year average. Vegetation cover on the mud flats is marginal especially, at the lower elevations with an average cover of 8% and an estimated average biomass productivity of <50 kg per/ha. WORKS1 targets 243 ha of the vegetated drawdown zone area for re-vegetation through the water use planning project that began in 2014. The majority of this area 168.9 ha (or 70%) is situated in the marginally vegetated low mud flats. An additional 30 per cent of re-vegetation zone is on the sloping, coarse substrates of the surrounding alluvial fans and beaches. The objective of the planting program is to assist 210 ha of the low mud flats and the lower elevations (<646.25m) on the sloping terrain classes towards a vegetation cover and structure similar to the mid mud flat polygons surveyed in 2013 where the estimated biomass productivity is 500-1000 kg/ha. Additionally the WORKS-1 project will attempt to put an additional 33.23 ha of upland sloping terrain class (>646.25m) that is infrequently and for short durations inundated, to a deciduous shrub herb vegetation structure with >2000k g/ha biomass produced.

Based on a comparative reference with the MMF polygons located between 643 and 647 m asl in the drawdown zone, vegetation cover is sedges, horsetails and grasses with covers averaging 63% and biomass productivity in the range of between 500 and 1000 kg/ha. If completely successful, the WORKS-1 program could increase biomass productivity of 210 ha of the drawdown zone from a current high of 50 kg/ha to over 500 kg/ha. This would equate to a 100 fold increase for the total area from a current production of 10,500 kg to up to 105,000 kg in total biomass inundated annually in the Carpenter Reservoir. However, a good portion of this biomass would be woody material. Leaves and other annually produced plant material on grasses and sedges are most meaningful from a nutrient perspective for contributions to the mercury methylation process. This amount of material would form a portion of the value above and would have to be verified during ground-truthing following planting.

The total area of the targeted planting region 243.3 ha is approximately 10% of the total average drawdown zone area of 2384 ha. The variable microsite conditions existing throughout the target re-vegetation area of the WORKS-1 project mean that there will be variability in the degree of successful establishment from the efforts of the WORKS-1 project. The degree of success will affect the degree to which there will be a contribution of organic material as a nutrient source into the Carpenter Reservoir biotic system. If the amount of vegetative biomass being recruited through the works project needs more quantification to assess the impacts on possible mercury concentrations in the reservoir, which is being investigated by the BRGMON-

12 program. It will be necessary to direct the BRGMON-2 monitoring to include destructive biomass sampling to establish baseline and comparative data to monitor shifts in biomass productivity throughout the course of the WORKS-1 project.

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