Peace Project Water Use Plan

WILLISTON TRIAL TRIBUTARIES

Implementation Year 8

Reference: GMSMON-17

Study Period: April 2018 to December 2018

LGL Limited environmental research associates
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PEACE PROJECT WATER USE PLAN

Program No. GMSMON-17

Williston Trial Tributaries




Final Report Year 8 (2018)

Prepared for

BC Hydro Generation
Peace River Water Use Plan
6911 Southpoint Drive
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BC Hydro Reference # EC13-490459

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Cover photos:

From left to right: Ole Creek constructed Berm B, Ole Creek debris catchers and planted vegetation on Berm A, Six-Mile Creek planted vegetation on Berm J, Six-Mile Creek embedded Large Woody Debris along Berm D. All photos © Shane Johnson, LGL Limited.

EXECUTIVE SUMMARY

Under project GMSWORK-17 (Williston Reservoir Trial Wetlands), six management questions and associated hypotheses were developed through the review of the GMSMON-17 (Revision 1, July 23, 2015) Terms of Reference to direct the study design and monitoring program. This report presents the results of the eighth year of the program. Monitoring during the first seven years of the program was completed by DWB Consulting Services Ltd. and Cooper Beauchesne and Associates Ltd. Monitoring in 2018 was conducted by LGL Limited. In 2018, all habitat restoration or enhancement works in the estuary of Ole and Six Mile Creeks were inspected and deemed functional with regards to their most important purpose of limiting Ole and Six Mile Creeks throughout the draw down zone (DDZ) to one fish-passable channel at spring water levels.

Training Berms: The berms constructed at both creeks are still preventing creek braiding and the related shallow and high velocity creek morphology can pose an obstacle to fish migration. While berm erosion does not appear to have progressed, settlement of fines and sand on the berm crests was observed, but may not need to be addressed since this may be enforcing berm stability and function.

Embedded Large Woody Debris (LWD) Structures: The embedded LWD structures are still working with regards to their primary function in stabilization of constructed banks and berms. With regard to their secondary purpose of initiating scouring of holding pools and providing shading and cover to fish, the erosion of the trained channels has lowered the thalweg and the water surface levels in both creeks leaving the embedded LWD structures elevated above the creek surfaces. Without direct contact to creek flow, even at spring discharge levels, the LWD structures cannot initiate or maintain pool scour or provide shading and submerged cover for fish. Since the creek channel is prevented from braiding and no obstacles to fish migration were identified, the LWD triggered creation of low flow and shaded fish holding habitat in the DDZ does not appear to be essential.

Debris Catchers: In general, the installed debris catchers are preventing driftwood accumulation, log jam creation and fish migration obstacles from forming. Nevertheless, small amounts of driftwood have started to penetrate the creek channel and may need to be removed in the future. A good portion of the driftwood inside the debris catchers has a length and weight that may make it possible to be removed manually.

Vegetation: The successful growth and establishment of the planted vegetation was directly correlated with period of reservoir inundation during the growth season from May to October. Establishment of vegetation at lower elevations, which were close to being permanently inundated, were generally not successful while vegetation planted at higher elevations was successful in stabilizing berms and creating shade. Natural vegetation is establishing itself alongside the planted vegetation on the constructed berms.

Flow Velocity, Discharge and Water Depths as an Obstacle to Fish Migration: Flow velocities and water depth in the “trained” channels of both creeks throughout the DDZ at the 2018 discharge levels ranged from 1.13-10.64 m/s Ole Creek and from 0.53-10.92 m/s in Six Mile Creek in the fish migration depths of > 10 cm. The maximum burst speeds of Arctic Grayling at approximately 1.6 m/s and of Rainbow Trout (<40 cm in length) at 1,47 m/s would likely allow both species to overcome the high velocity areas by seeking out low velocity areas on the creek margins to migrate upstream through the trained sections of both creeks at the observed discharges. At higher discharges, migration for both species would likely be impeded by current

velocities exceeding maximum burst swimming speed throughout the fish migration depths of > 10 cm.

Table 1 Year 8 (22018) status of the GMSMON-17 management questions and management hypothesis

Management Question (MQ)	Management Hypothesis	Year 8 (2018) Status
MQ1: Does access for spring spawners (i.e., Rainbow Trout and/or Arctic Grayling) improve as a result of enhancement?	H_{01}: Access to spawning habitat in the spring period – as measured by the proportion of modified channel with sufficient depth for target fish passage – increases following enhancements to tributaries.	In Year 8, the depth of the modified channels throughout the DDZ in both creeks is still sufficient for target fish passage.
MQ2: Is the area and quality of fish habitat created by the tributary enhancement maintained over time?	H_{02}: Total rearing area for fish increases following enhancement to tributaries.	Yes, when compared to the 2016 results, the increase of rearing habitat following enhancement has been maintained in 2018.
MQ3: Does riparian vegetation along tributaries increase in abundance and diversity as a result of enhancement?	H_{03}: Riparian vegetation abundance and diversity along the tributaries increases following enhancement to tributaries.	In 2018, the inspection of riparian vegetation was limited to a visual assessment of planting success for riparian vegetation (as per contract). The detailed riparian vegetation assessment will be carried out in 2010 (Year 10). In general, riparian vegetation increased as a result of enhancement in the higher elevation locations but was not successful at the lower (mostly inundated) elevations.
MQ4: Does abundance and diversity of song birds (passerines) around tributaries change as a result of enhancement?	H_{06}: Song bird abundance and diversity near tributaries increases following tributary enhancement.	Songbird assessments were not planned for 2018 (as per contract) but may be scheduled for 2020 (Year 10) based on an internal BC Hydro review.
MQ5: Does amphibian abundance and diversity in tributaries change as a result of enhancement?	H_{04}: Amphibian abundance and diversity in and near tributaries changes following tributary enhancement.	Amphibian monitoring or sampling was not planned for 2018 as per contract.
MQ6: Does tributary enhancement change the area and quality of amphibian breeding habitat over time? If so, is the area and quality maintained over time?	H_{05}: Total amphibian breeding area changes following enhancement.	Amphibian monitoring or sampling was not planned for 2018 as per contract.

ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

The annual reservoir cycling in Williston Reservoir created a drawdown zone of approximately 450 km^2 that was unproductive in both the inundated state as aquatic habitat and in the drawdown state as terrestrial habitat (BC Hydro 2003). The Peace Water Use Plan Committee (hereafter known as the Committee) recognized that the largely unproductive drawdown zone (DDZ) on Williston Reservoir contributed to low fishery productivity, a lack of riparian and wildlife habitat, and potentially increased predation risk for wildlife. In addition, a large amount of woody debris, mainly originating from the initial flooding, is annually deposited on most beaches when the water level is falling in the fall and re-floated in the spring at rising water levels. In total, an estimated 105,260 m^3 of debris are occupying the Williston DDZ (Thompson, Schofield & McDermid 2015). In some bays the large amounts of woody debris have blocked fish passage into creeks and are scouring the shore while destroying emerging vegetation.

To address all of these issues, the Committee recommended the Riparian and Wetland Habitat management plan to improve foreshore habitat for fisheries, wildlife, and riparian areas. As part of this habitat management plan, BC Hydro is currently implementing the last three years of the 10-year “GMSMON-17: Williston Tributary Habitat” monitoring project to assess the effectiveness of tributary enhancement sites constructed under a related project (GMSWORKS-19: Williston Trial Tributaries) on the Williston Reservoir. The project monitors the effect of two constructed sites for enhancing fish access and habitat as well as the impact to vegetation and wildlife habitat.

The following tributary enhancements were constructed in 2014 at two locations:

- Six Mile Creek is a tributary to the Parsnip Reach of the Williston Reservoir, emptying into Six Mile Bay approximately 40 km north of Mackenzie. Enhancement work at Six Mile Creek consisted of a series of seven geogrid soil wrap berms along the left bank of the existing channel, two of which were vegetated with live willow stakes to enhance riparian vegetation. In addition to the constructed works, a significant volume of accumulated large wood debris was removed from in and around the creek channels within the reservoir drawdown zone.

- Ole Creek is on the west side of the reservoir, approximately 180 km northwest of Mackenzie. Enhancement work at Ole Creek consisted of the construction of a series of four gravel training berms along both banks of the existing creek channel, two of which included wood debris catchers. Live willow stakes were planted, and local grass seed was applied to the upstream-most berms.

- Additionally, nearby Factor Ross and Lamonti Creeks were used as control creeks during the first three years of the program. These control creeks are believed to have provided sufficient information and little additional benefit is expected; therefore, no further monitoring at these control creeks was conducted since 2013.

Pre-construction monitoring on all four creeks occurred from 2011 to 2013. Post-construction monitoring occurred in 2014, during the construction period, and in 2015 and 2016. In total, 6 years of monitoring data have been collected. The project is currently entering Year 8 (2018) of ten years.

In Year 8 to 10 (2018 to 2020) of this monitoring program the following tasks will be completed:

i. annual habitat assessments and hydrometric surveys to qualify instream flows as they relate to fish passage for Years 8-10 (2018, 2019, and 2020);
ii. annual visual inspections of the Ole Creek and Six Mile Creek locations in 2018, and 2020 and completion of inspection template for each site;
iii. vegetation monitoring and sampling in Year 10 (2020) - scope to be determined by BC Hydro following an internal consolidation and review of data;
iv. songbird monitoring and sampling in Year 10 (2020) - scope to be determined by BC Hydro following an internal consolidation and review of data;
v. preparation of an annual memo following each field season that summarizes the methods, findings of the year and a status of the management questions; and
vi. in the final year (2020), a comprehensive report will be prepared which summarizes overall program work and conclusions applicable to fish and incorporates results from the 2018 internal consolidation and review for songbirds, amphibians and vegetation, plus the 2020 field season.

2.0 STUDY OBJECTIVES

2.1 Study Design

2.2 Management Questions and Hypotheses

BC Hydro developed six management questions (MQs) to address the effectiveness of tributary enhancements to improve fish habitat based on a review of the GMSMON-17 Terms of Reference on July 23, 2015 (BC Hydro 2015):

MQ1: Does access for spring spawners (i.e., rainbow trout and/or arctic grayling) improve as a result of enhancement?

MQ2: Is the area and quality of fish habitat created by the tributary enhancement maintained over time?

MQ3: Does riparian vegetation along tributaries increase in abundance and diversity as a result of enhancement?

MQ4: Does abundance and diversity of song birds (passerines) around tributaries change as a result of enhancement?

MQ5: Does amphibian abundance and diversity in tributaries change as a result of enhancement?

MQ6: Does tributary enhancement change the area and quality of amphibian breeding habitat over time? If so, is the area and quality maintained over time?

Based on the management questions, the study was designed to test the following alternate hypotheses stated in the Terms of Reference (BC Hydro 2015):

- H_{01} Access to spawning habitat in the spring period - as measured by the proportion of modified channel area with sufficient depth for target fish passage - increases following enhancements to tributaries;
- H_{02} Total rearing area for fish increases following enhancement to tributaries;
- H_{03} Riparian vegetation abundance and diversity along the tributaries increases following enhancement to tributaries;
- H_{04} Amphibian abundance and diversity in and near tributaries changes following tributary enhancement;
- H_{05} Total amphibian breeding area changes following enhancement;
- H_{06} Songbird abundance and diversity near tributaries increases following tributary enhancement.

These questions and hypotheses are tested directly by this monitoring program to evaluate the effectiveness of tributary enhancement to improve fish habitat as well as maintain this habitat over the life of the project.

3.0 STUDY AREA

3.1 Williston Reservoir

Williston Reservoir is located in northeastern British Columbia and was created by construction of the W.A.C. Bennett Dam at the head of the Peace River Canyon, about 20 km west of Hudson's Hope, B.C (BC Hydro 2015a). The reservoir extends for about 260 km along the Rocky Mountain Trench from the Finlay River in the north to the Parsnip River in the south (Figure 1). The reservoir is generally divided into three geographic regions (from north to south): Finlay Reach, Peace Reach and Parsnip Reach (BC Hydro 2015a).

Since 1971, reservoir elevations have ranged between 654 m and 672 m, with reservoir elevations fluctuating from year to year, driven by inflow and system generation needs. Inflows to the reservoir are primarily driven by snowmelt in the Peace River watershed and are much higher in summer than in winter. The reservoir is typically ice covered between the end of January and the beginning of May and generally reaches an annual minimum elevation in April or May, followed by reservoir refilling in the spring freshet. The reservoir generally reaches the maximum elevation in July or August and is then drafted through the winter as generation is increased to meet peak winter loads. The Normal Maximum Reservoir Level (NMRL) is 672 m and BC Hydro normally maintains a minimum elevation of approximately 655 m (BC Hydro 2015a).

3.2 Physiography

The Williston Reservoir is nestled between the Hart Range of the Northern Rockies Mountain on its east and the Omenica Mountains on its west, which lie in a north-northwest to south-southeast orientation. The Finlay and Parsnip Reaches lie within the wide, flat-bottomed Rocky Mountain

Trench and the former stream channels are deeply incised. Glacial till is the most abundant surficial deposit in the region.

The reservoir is located within the Sub-Boreal Spruce and Boreal White and Black Spruce biogeoclimatic zones (Meidinger and Pojar 1991). The Sub-Boreal Spruce zone is the dominant zone and occurs as two subzones and variants at lower elevations along most of the reservoir (Meidinger and Pojar 1991). The Boreal White and Black Spruce zone occurs only at the northern end of the reservoir in the Finlay Arm (Meidinger and Pojar 1991). The drawdown zone consists of large areas of mud, sand, and gravel flats with stranded large woody debris. Limited amounts of vegetation occur even following extended periods of drawdown.

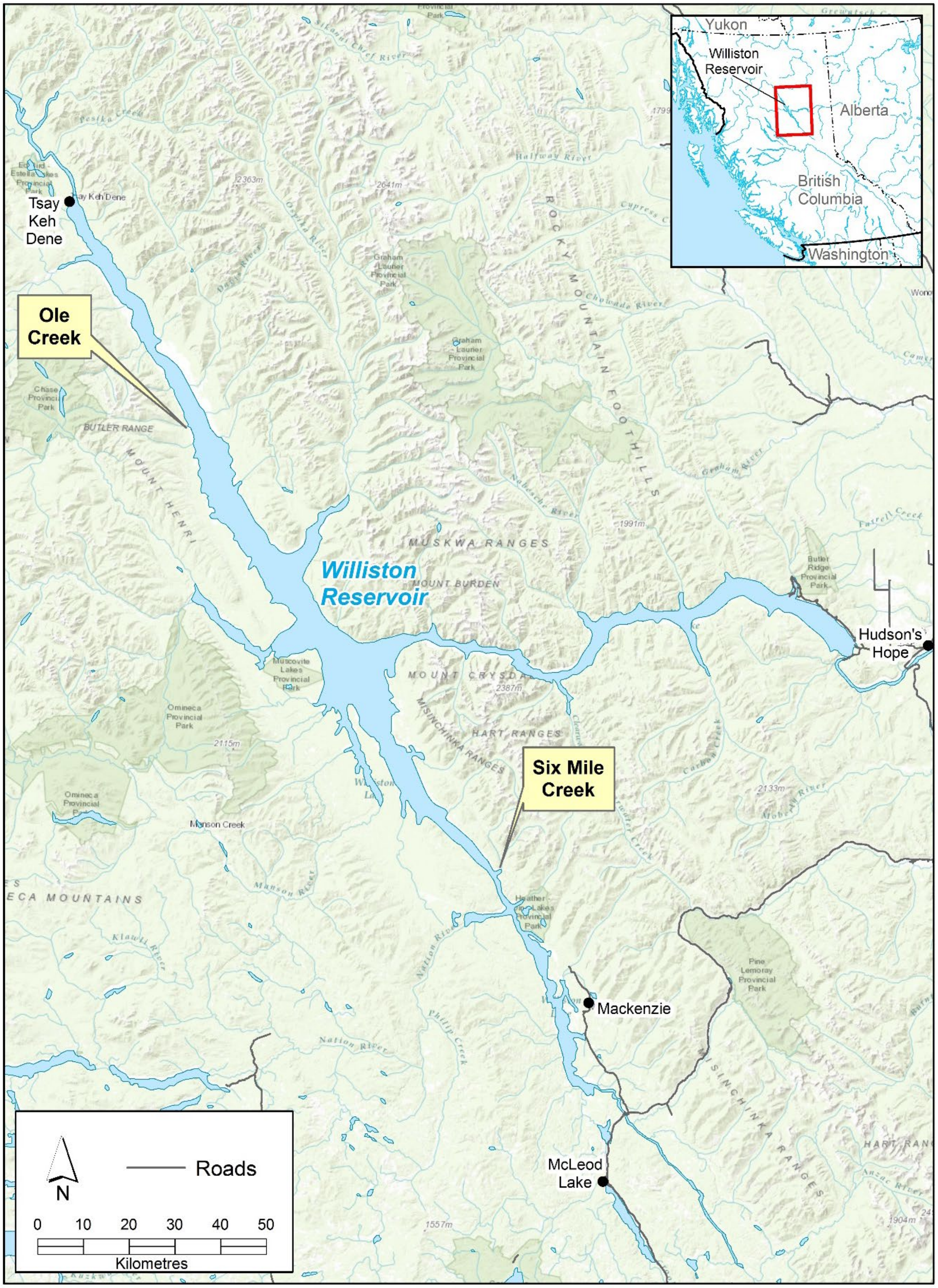


Figure 1 Location of Ole Creek in the Finlay Reach and Six Mile Creek in Parsnip Reach at Williston Reservoir.

3.3 Climatology

Daily weather in the region is influenced by middle-latitude cyclones that typically move from southwest to northeast British Columbia that respond to large scale features of the Rocky Mountains (Whiteman 2000, Klock and Mullock 2001). These lows tend to move over mountains and produce a widespread area of precipitation as well as unstable air where bands of clouds and showers develop. The middle-latitude cyclones dominate the weather during the fall through spring, while convection dominates during the summer months. The lows can become very slow moving and result in large amounts of precipitation in one place (Klock and Mullock 2001); combined with moist air that originates over the Pacific Ocean, that makes its way eastward through the narrow and deep valleys that occur through the Rocky Mountains (Vickers et al. 2001). The region experiences long, cold winters and ice formation on the reservoir begins as early as November and can extend into the beginning of May. Annual precipitation ranges between 40 cm to 50 cm with snowfall accounting for 35-45% of the annual precipitation. The Williston Reservoir receives and stores most of its hydrologic input from snowmelt. The large spring runoff typically begins in mid-May and peaks in June (Stockner et al. 2005).

3.3.1 Site Enhancement Construction (from Thompson and Carson 2017)

For both Six Mile and Ole Creeks, the habitat enhancement works were constructed with the objective to stabilize the channel and improve fish access in the DDZ. Construction was implemented under the guidance of Environmental Protection Plans (DWB 2014a, 2014 b).

<u>Six Mile Creek Mouth</u>

At the mouth of Six Mile Creek into Williston Reservoir approximately 650 m of stream construction work was completed in the DDZ. All construction was guided by and Environmental Protection Plan (DWB, 2014a, 2014b). The construction works included (Kerr Wood Leidal and Associates Ltd 2011; DWB 2014a, 2014b; Kerr Wood Leidal and Associates Ltd 2015):

1) Lower reservoir berms:
    a. Layered and weighted with:
        i. One tonne grain bags filled with gravel and sand,
        ii. LWD pieces,
        iii. Gravels and,
        iv. Rocks;
    b. Gravel toe with rip rap base;
    c. Vegetated geogrid was pinned to the surface.
2) Lower reservoir, woody revetment log jams:
    a. Stream bed materials (cobble, gravel and sand) were used to moor and armor the LWD.
3) Upper reservoir earth berm:
    a. Willow wattles layered along the stream bank edge surrounded by shoreline soil, sand, gravel;
    b. Weighted with LWD, boulders, rocks, and gravels;

c. Gravel toe with rip rap base;

d. Topped with vegetated geogrid (pinned), live willow stakes, and grass seed.

The Six Mile enhancements were confined to the eastern bank in parallel with the main channel and to prevent continued braiding of the channel through the DDZ. Field fit changes were made to the planned design and this resulted in an extension of the earth berm around a small beaver pond. The beaver pond is located along the eastern bank of the main channel at the northern-most transition of the DDZ. Large root wads were placed into the riparian area of the pond to potentially improve habitat for amphibians. Fish salvage was not required, but amphibians were salvaged from the pond and stream riparian area during active construction of the berm (DWB, 2014a, 2014b).

Ole Creek Mouth

The construction works at Ole Creek had an approximate length of 250 m within the DDZ. Parts of the channel were isolated during construction and a single rainbow trout was salvaged. Woody debris was cleared from the DDZ prior to commencement of the main works. Surveys for amphibians were conducted and a single long-toed salamander was detected in a south bank debris pile approximately 10 m from debris clearing and berm construction site (DWB, 2014a, 2014b). Field fit changes were made to the planned design as the channel had shifted from previous surveys. The construction works included (Kerr Wood Leidal and Associates Ltd 2011, 2014; DWB 2014a, 2014b):

1) Lower reservoir berm:
   a. Gravel and rock revetments.
2) Upper reservoir berm:
   a. Layered with LWD;
   b. Vegetated geogrid pinned to the surface;
   c. Grass seed and live willow stakes.
3) Woody debris catcher:
   a. Imported LWD pieces staked into the upper gravel-rock berm with the length extended vertically and on slope.

4.0 METHODS

The field sampling methods employed in Year 8 of the GMSMON-17 were consistent with those used in the previous years of the monitoring program. The sampling methods are described below, along with any adjustments that were required due to reservoir elevation or weather conditions at the time of sampling.

4.1 Environmental Conditions

Daily reservoir elevations were provided by BC Hydro (BC Hydro Commercial Resource Optimization (CRO) database) and daily mean air temperature and precipitation data prior to and during the survey period were downloaded from the Environment and Climate Change Canada's historical climate data web portal (Environment and Climate Change Canada 2018).

Specific data was compiled from the Mackenzie Airport weather station (Station name: Mackenzie Airport Auto). Daily environmental parameters, specific to each survey type, were recorded at the start of each survey. These parameters included temperature, precipitation, cloud cover, relative humidity, wind speed and direction.

4.2 Visual Surveys

Surveys of the condition of the constructed berms, the embedded LWD structures and embedded live willow cuttings were carried out visually and in comparison to their condition of the last inspection in 2016. At the same time, it was visually assessed whether the berm structural materials such as coir (coconut fibre based) matting or 1 m^3 bulk bags were still covered and, if visible, whether these were structurally supportive.

For the embedded LWD structures it was also visually assessed whether they scoured the creek bed to create pools and whether they provided submerged cover and shading for fish. If LWD structures were observed to be elevated above the creek surface at high discharge they were assumed to not create scour pools, submerged cover or shading.

Similarly, woody debris catchers (WDCs) were assessed visually for their structural integrity and their functionality was based on the accumulation of woody debris or driftwood on the creek side or the zone between the WDCs and in the creek bed.

Vegetation was also visually assessed, and results were reported in relation to the success of the 2015 plantings and vegetation that established itself naturally along the berms.

4.3 Discharge Measurements and Channel Depth Assessments

The discharge measurement followed the instructions described in "Chapter 4.2.5.1 Measuring by Wading" (p. 78-83) in the Manual of British Columbia Hydrometric Standards – Version 1.0 (2009). For the current velocity and depth measurements a Pygmy Current Meter was used in combination with a four-piece calibrated wand. Discharge in Six Mile Creek was measured at Berm 'B' (Lat: 55°36'32.95"N; Long: 123°24'7.76"W). Discharge in Ole Creek was measured at Berm 'A (56°27'14.00"N; Long: 124°31'43.73"W). Permanent survey points for both locations were not established since discharge for a creek should be independent of the location it is measured and measurement locations will likely change from year to year based on accessibility and wadeability of the creeks.

4.4 Data Entry and Analysis

Data was collected on printed data forms in the field and transcribed into Microsoft Excel. GPS waypoint and photographs were labelled accordingly. Other than the results of the habitat classification, data analysis presented in this report is for data that was collected in Year 8 only. The comprehensive report, prepared at the conclusion of Year 10 of the monitoring program, will test the null hypotheses of no effect or difference.

5.0 RESULTS

5.1 Reservoir Conditions

During the 2018 field season, the elevation of Williston Reservoir ranged from a daily average low of 656.47 m ASL in late April to a daily average high of 667.11 masl in the middle of July (Table 2). On June 12, 2018, reservoir elevations (664.42 masl) were approximately 1.1 m above the toe of the lowest constructed berms on Ole Creek. On June 13, 2018 (reservoir elevation = 664.52 masl) the lowest constructed berms on Six-Mile creek were approximately 0.3 m above the reservoir level. Therefore, habitat enhancement works could be visually assessed at the field inspection dates, since both sites were not obscured by high reservoir levels or snow.

Table 2 Dates and reservoir elevations of for the 2018 field sessions for GMSMON-15

Field Session	Project	2018		Reservoir Elevation (masl)*		
		Start Date	End Date	Min	Max	Mean
Ole Creek Works Inspection	**GMSMON- 17**	**Jun 12**	**Jun 12**	**664.42**	**664.42**	**664.42**
Six-Mile Creek Works Inspection	**GMSMON- 17**	**Jun 13**	**Jun 13**	**664.52**	**664.52**	**664.52**

*elevations where the Ole and Six Mile Creeks works begin to get inundated: Ole Creek=663.3 masl; Six Mile Creek = 664.8 masl.

Reservoir elevations in 2018 were lowest in April, hitting the lowest daily average (656.48 masl) on April 26, 2018 (Figure 2). Water levels increased after that, peaking on August 1, 2018 (667.65 masl). In 2018, the reservoir levels were lower than most previous years, reaching minimum elevations earlier. The timing of maximum elevation in 2018 was comparable to previous years, but the reservoir elevations were much lower in 2018 compared to the previous years of the monitoring program and the highest 2018 elevation was far below the range of variability of the long-term trends (Figure 2).

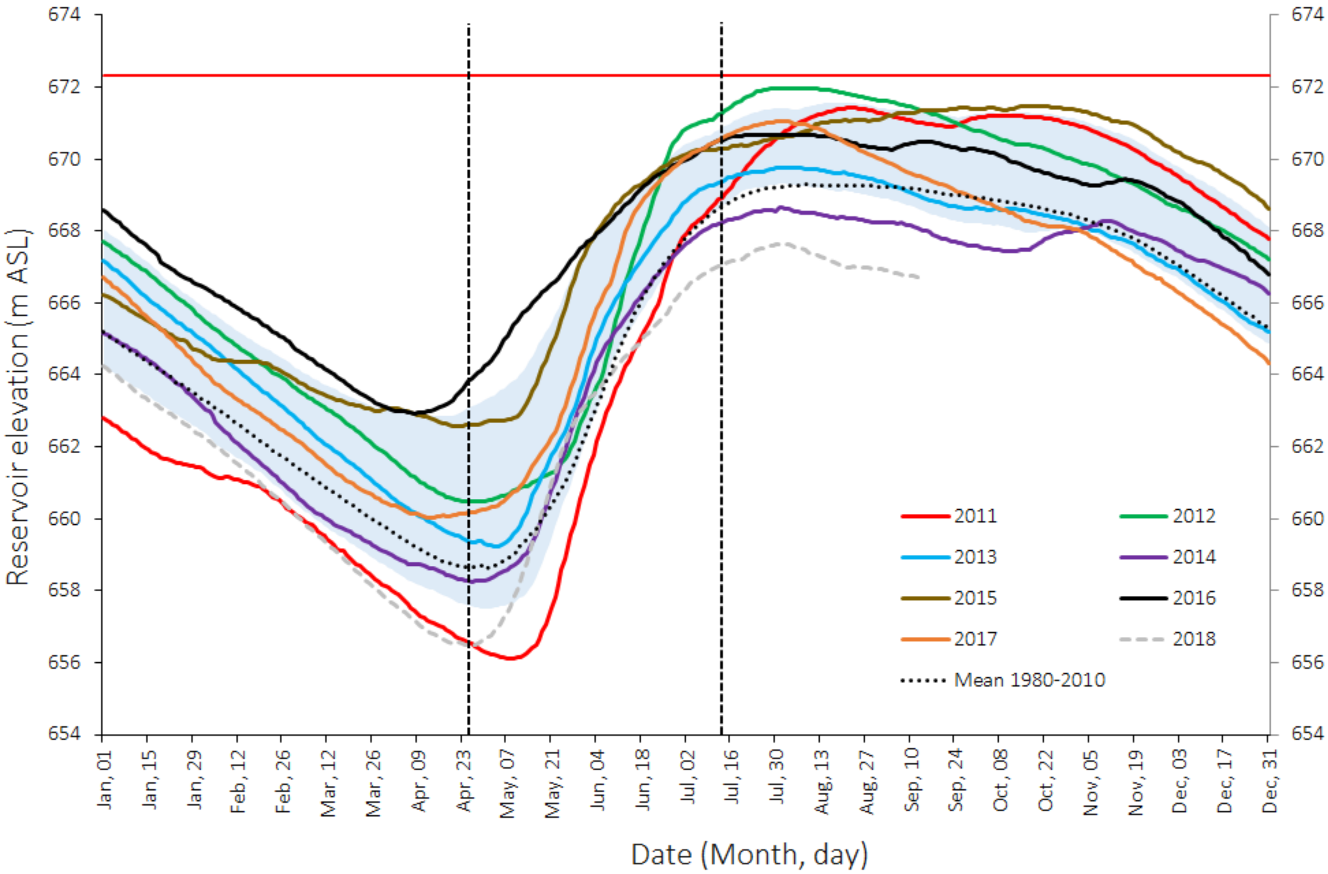


Figure 2 Williston Reservoir elevations from 2011 to 2018. The shaded area represents the 10th and 90th percentile for the period 2011 to 2017; the dashed horizontal red line is the normal operating maximum. Vertical dashed lines indicated start and end dates of GMSMON-15 and GMSMON-17 sampling in 2018.

5.2 Environmental Conditions

The average daily temperatures in 2018 were within the range of variability of the daily mean temperatures during the previous years of monitoring (Figure 3). Daily mean temperatures were colder at the beginning of April 2018, compared to previous years, but rapidly increased in late April and May 2018. During June and July, average daily temperatures fluctuated within the range of variability of the previous monitoring period.

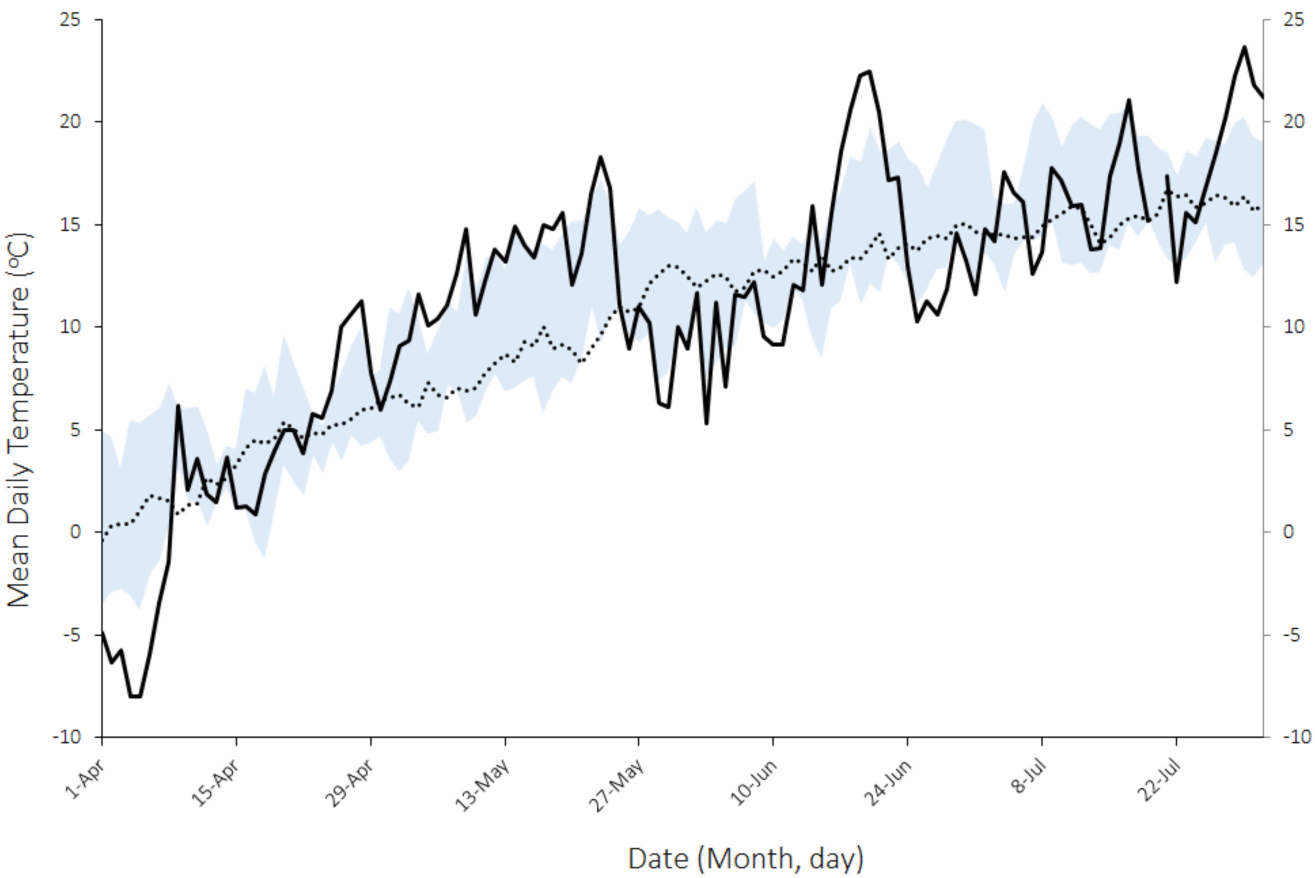


Figure 3 Daily mean air temperature for 2018 (black line) in the study region for the monthly periods when field surveys occurred. The shaded area represents the standard deviation (+/-) of the daily mean air temperatures for Years 1-7 (2011-2017) of the monitoring program. Dotted line represents the average mean temperature from 1980-2010.

Cumulative precipitation during the survey period in 2018 was typically within the range of variability measured during the previous years of monitoring (Figure 4). Conditions in April 2018 appeared to be average of what was experienced in previous years, whereas conditions in May of 2018 appeared to be drier than previous years. Likewise, conditions in June and July of 2018 appeared to be consistent with cumulative precipitation in previous years.

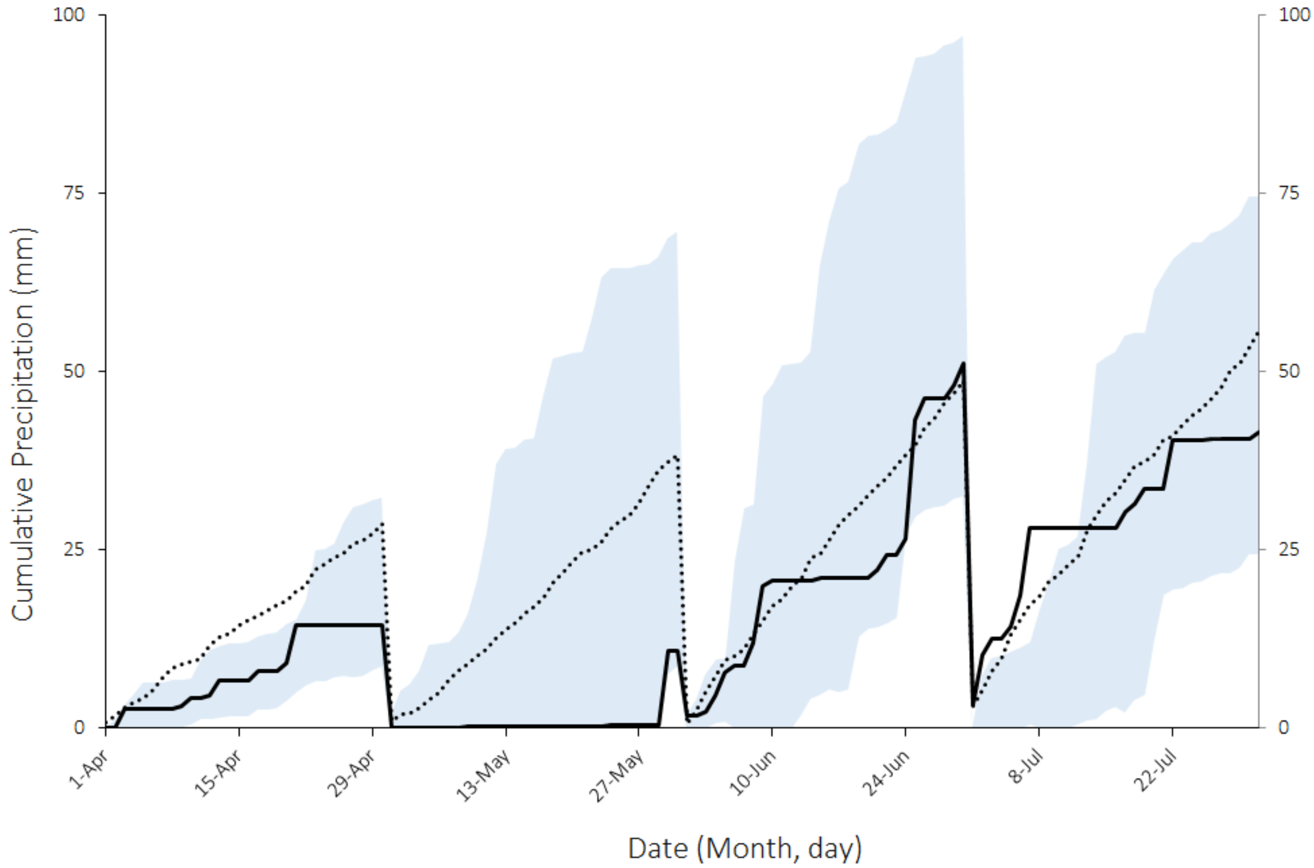


Figure 4 Cumulative monthly total precipitation for 2018 (black line) in the study region for the monthly periods when field surveys occurred. The shaded area represents the standard deviation (+/-) of the cumulative monthly total precipitation for Years 1-7 (2011-2017) of the monitoring program. The dotted line represents the average cumulative precipitation from 1980-2010.

5.3 Ole Creek

During the June 12, 2018 Ole Creek site inspection none of the structures constructed in 2014 were inundated by Williston Reservoir (reservoir level=664.4 m), all snow had melted, and vegetation had started to grow. In addition, Ole Creek discharge was moderate (14.64 m^3/s) and the creek was safe to wade. Therefore, conditions during the 2018 site inspection were ideal. An overview orthophoto showing the location of all enhancement structures as originally constructed is provided in Figure 5.

Maintenance of an Unbraided Single Channel and Fish Access: In general, Ole Creek works adequately met the performance objective of maintaining a single thread channel as designed. Within this single channel, water depth and velocity, measured during the site inspection, may allow for access of Rainbow Trout and Arctic Grayling into Ole Creek for spawning and rearing based on the current velocity values measured on June 12 and shown in Table 3.

Table 3 Current velocities and water depths for discharge measurement undertaken at Ole Creek on June 12, 2018.

Field Survey Distance (m)	Water Depth (m)	Velocity (m/s)	Area (m^2)	Discharge (m^3/s)	Total Discharge (m^3/s)
1.65	0.00	0.00	0.000	0.000	
2.00	0.23	1.13	0.117	0.131	
2.50	0.38	8.03	0.186	1.496	
3.00	0.50	10.64	0.238	2.527	
3.50	0.52	8.17	0.345	2.817	**14.64**
4.00	0.35	9.79	0.286	2.803	
4.50	0.36	5.73	0.273	1.562	
5.00	0.4	7.04	0.188	1.320	
5.50	0.34	4.50	0.170	0.765	
6.00	0.28	4.41	0.195	0.861	
6.50	0.19	3.16	0.113	0.357	
7.07	0	0.00	0.054	0.000	

Erosion of or Settlement on Berms: As already mentioned, in the May 5, 2016 site survey, there appeared to be some settlement / erosion on the right bank (looking downstream) berm crest. The same was observed in 2018 but did not appear to have progressed over the last two years.

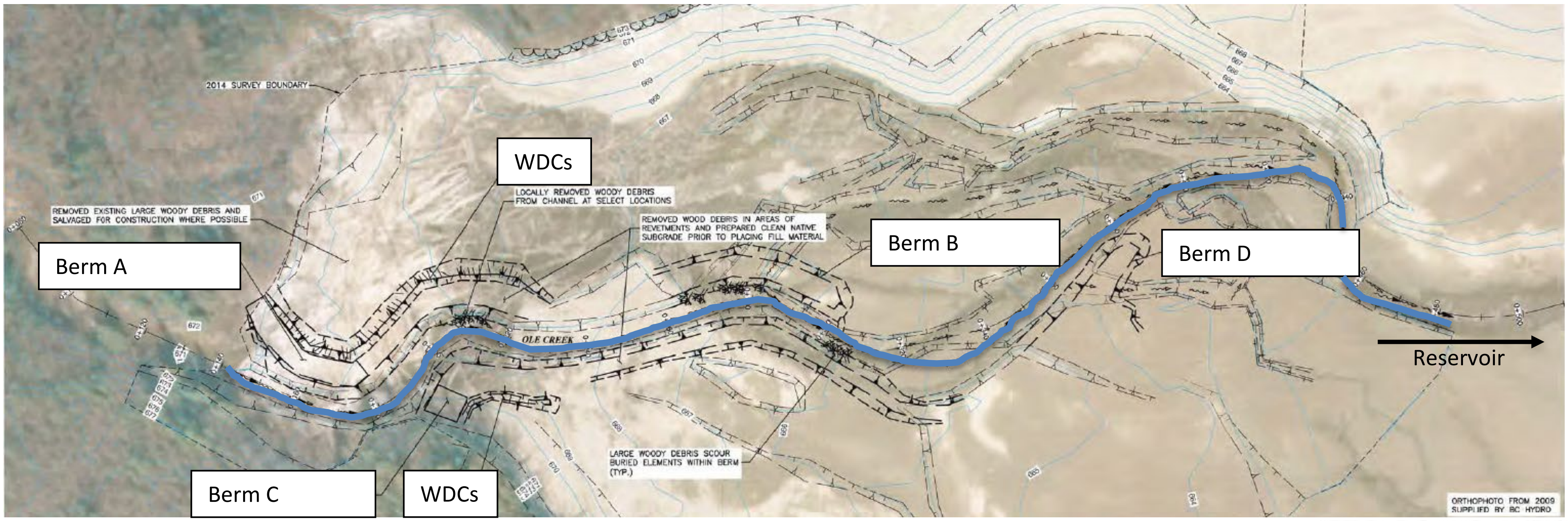
Plantings: While all but two of the willow stakes planted in 2014 had withered; although, a decent number of natural willows had established.

Seeded Erosion Control Matting: The seeded erosion control matting (ECM) was showing promising growth of grass, clover and other natural vegetation. To maintain this development additional seeding may need to occur.

LWD Structures: The embedded LWD structures were still stabilizing the toe of the constructed berms but the LWD structures were neither creating scour pools, nor did they provide fish cover or shading at the creek level. It appeared as if Ole Creek may have lowered its thalweg through erosion, leaving the LWD structures elevated above creek levels at all but the highest discharges. The observation that the creek thalweg has been lowered, will need to be confirmed through a detailed elevational survey.

Detailed and Structure-Specific Assessment Results: Detailed June 12, 2018 inspection results for all Ole Creek structures are shown in Table 3 and Table 4 and related photographs are shown in Figure 6 and Figure 7.

An Ole Creek enhancement structure overview is shown in Figure 5.



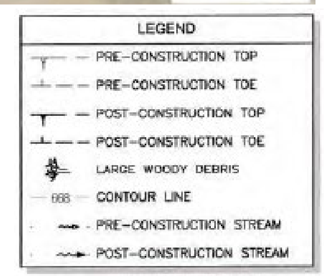


Figure 5 The DDZ of Ole Creek with construction overview orthophoto (modified from: Kerr Wood Leidal Associates Ltd. 2015). The blue line highlights the main constructed channel (WDC = woody debris catchers).

Table 4 Summary table for detailed 2018 observations made at Ole Creek structures Berms D, B and C built in 2014 (woody debris catchers=WDC).

Structure	2018 Structural Integrity	Likely Deterioration Cause	2018 Ecological Function	Action Needed
Berm D: Low gravel-cobble berm	Berm structurally sound; we observed a small amount of cobble erosion on berm crest	Driftwood, ice movement, rising and falling reservoir	Berm D maintained a single channel	Inspection in 2019 to see whether erosion progressed
Berm B: Low gravel-cobble berm; embedded LWD	Berm structurally sound; embedded LWD structures were present and stable	None observed	Berm B maintained a single channel; embedded LWD stabilized berm toe but created little scour, cover or shading because they were elevated above the creek	2019 inspection; detailed elevational survey
Berm C: Low gravel-cobble berm, embedded LWD; WDC	Berm structurally sound; embedded LWD structures present and stable; woody debris catchers were intact; a small amount of erosion and cobble movement on the crest of the downstream berm portion	Driftwood, ice movement, rising and falling reservoir	Berm C maintained a single channel; embedded LWD stabilized berm toe but created little scour, cover or shading because it was elevated above the creek; WDC intact and functional; small amount of driftwood inside WDC did not interfere with works yet	Inspection in 2019 to monitor erosion; possible manual removal of driftwood inside of WDC



Figure 6 From left to right, Berm D, Berm B and Berm C with embedded LWD (Ole Creek, June 12, 2018).

Table 5 Summary table for detailed 2018 observations made at Ole Creek structures Berms A, a log jam and for discharge, water velocities and depths

Structure	2018 Structural Integrity	Likely Deterioration Cause	2018 Ecological Function	Action Needed
Berm A: Low gravel-cobble berm; WDC; embedded LWD; planted willow stakes	Berm structurally sound; small amount of cobble erosion at base of upright WDC logs; small amount of driftwood inside of WDC; embedded LWD present and stable; all but 2 willow plantings failed; natural vegetation (mainly grass) was starting to establish	Driftwood, ice movement, rising and falling reservoir	Berm A maintained a single channel; embedded LWD stabilized berm toe but created little scour, cover or shading because it was elevated above the creek; WDC intact and functional; small amount of driftwood inside WDC did not interfere with works yet	Inspection in 2019 to monitor erosion; possible manual removal of driftwood inside of WDC
Log Jam at Long.: 124°31'48.53"W; Lat.: 56°27'15.54"N;	Previously (2016) reported log jam still present but did not create backwatering or an obstacle to fish migration	Logs deposited from upstream at high discharges	Did neither hold water back nor posed obstacle to fish migration	Inspection in 2019 to assess backwatering and passability
Current velocities, water depths, discharge (14.6 m^3/s) at 56°27'14.00"N; 124°31'43.73"W	Based on visual assessment, Ole Creek current velocities and water depths through the DDZ were suitable for fish migration with a minimum thalweg depth of 0.5 m and velocity breaks behind cobbles and boulders.	None observed	Facilitated fish migration	Inspection in 2019

Figure 7 From left to right: Berm A with WDC and natural revegetation; log jam; discharge measurement site (Ole Creek, June 12, 2018).

5.4 Six Mile Creek

During the June 13, 2018 Six Mile Creek inspection, most of the structures constructed in 2014 were not inundated by Williston Reservoir (reservoir level=664.5 masl), all snow had melted, and vegetation had started to grow. The only submerged structure (the downstream section of Berm A) was submerged by <1.2 m and could therefore still be visually inspected. In addition, Six Mile Creek discharge was moderate to high (35.62 m^3/s) and the creek was just safe enough to wade. Therefore, conditions during the 2018 site inspection were good but not ideal. An overview orthophoto showing the location of all enhancement structures as originally constructed is provided in Figure 8.

Maintenance of an Unbraided Single Channel and Fish Access: In general, the Six Mile Creek works adequately met the performance objective of maintaining a single thread channel as designed. Within this single channel, water depth and velocity, measured during the inspection, may allow for access of Rainbow Trout and Arctic Grayling into Six Mile Creek for spawning and rearing based on the current velocity values in Table 6.

Table 6 Current velocities and water depths for discharge measurement undertaken at Six Mile Creek on June 13, 2018.

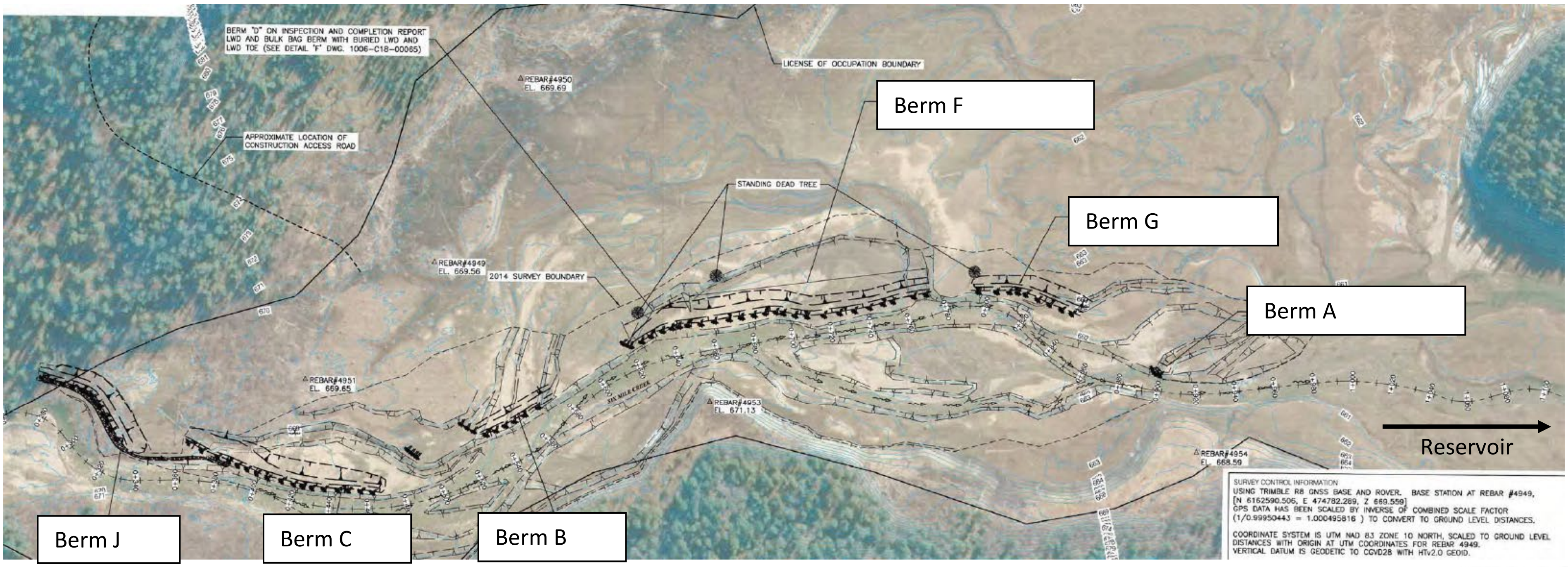
Field Survey Distance (m)	Water Depth (m)	velocity (m/s)	Area (m^2)	Discharge (m^3/s)	Total Discharge (m^3/s)
1.83	0.00	0.00	0.000	0.000	
2.00	0.03	0.00	0.031	0.000	
2.50	0.20	3.34	0.095	0.317	
3.00	0.33	3.62	0.154	0.556	
3.50	0.37	4.00	0.179	0.715	**35.62**
4.00	0.36	5.22	0.186	0.971	
4.50	0.40	5.83	0.198	1.151	
5.00	0.42	5.68	0.215	1.221	
5.50	0.48	5.05	0.229	1.155	
6.00	0.45	6.10	0.238	1.448	
6.50	0.52	6.18	0.254	1.568	
7.00	0.54	10.36	0.271	2.810	
7.50	0.57	7.56	0.278	2.097	
8.00	0.54	7.92	0.279	2.208	
8.50	0.58	7.50	0.280	2.100	
9.00	0.54	10.71	0.273	2.918	
9.50	0.52	10.13	0.255	2.583	
10.00	0.46	10.92	0.243	2.648	
10.50	0.50	9.06	0.230	2.083	
11.00	0.38	10.05	0.210	2.111	
11.50	0.42	8.11	0.205	1.662	
12.00	0.42	5.11	0.189	0.964	
12.50	0.25	7.243	0.146	1.059	
13.00	0.25	6.529	0.116	0.759	
13.50	0.18	5.483	0.089	0.487	
14.00	0.10	0.527	0.063	0.033	
15.12	0.00	0	0.028	0.000	

Erosion of or Settlement on Berms: A small amount of erosion and fines accumulation was observed on the Six Mile Creek berms. The observed erosion did not appear to be affecting the hydrological of ecological function of the berms.

Plantings: Stakes embedded horizontally into the longer inundated Berm C did not sprout and grow while the horizontally embedded stakes on the higher elevation Berm J did sprout and grow and provided shading and cover for fish. Similarly, Willow stakes vertically planted on Berm J sprouted and grew along with planted grasses to form a stabilizing vegetation root system.

LWD Structures: The embedded LWD structures were still stabilizing the toe of the constructed berms but the LWD structures were neither creating scour pools, nor did they provide fish cover or shading at the creek level. It appeared as if Six Mile Creek may have lowered its thalweg through erosion, leaving the LWD structures elevated above creek levels at all but the highest discharges. The observation that the creek thalweg has been lowered, will need to be confirmed through a detailed elevational survey.

Detailed and Structure-Specific Assessment Results: Detailed June 13, 2018 inspection results for all Six Mile Creek structures are shown in Table 5, Table 6 and Table 7 and related photographs are shown in Figure 9, Figure 10 and Figure 11. An overview orthophoto showing the location of all enhancement structures is provided in Figure 8 .



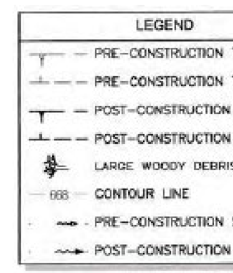


Figure 8 The DDZ of Six Mile Creek with construction overview orthophoto (modified from: Kerr Wood Leidal Associates Ltd. 2015). WDC = woody debris catchers

Table 7 Summary table for detailed 2018 observations made at Six Mile Creek structures Berm A, Berm F and Berm D built in 2014.

Structure	2018 Structural Integrity	Likely Deterioration Cause	2018 Ecological Function	Action Needed
Berm A: Large buried bulk bag berm with embedded LWD	The submerged berm appeared structurally sound but mild continuous erosion along all of the berm crest (which needs to be confirmed through a detailed elevational survey) was observed	Driftwood, ice movement, rising and falling reservoir	Berm A appears to be still functioning in maintaining a single channel	Detailed elevational survey below reservoir elevation of 663 m to check for berm crest erosion
Berm G: A buried bulk bag berm with embedded LWD	Berm structurally sound; embedded LWD structures present and stable; coir material used in soil wraps was in good condition and stable	Driftwood, ice movement, rising and falling reservoir	Berm D maintains a single channel; embedded LWD stabilized the berm toe	Inspection in 2019
Berm F: Non-vegetated geogrid soil wrap berm with embedded LWD	Berm structurally sound; embedded LWD structures present and stable; coir material used in soil wraps was in good condition and stable	Driftwood, ice movement, rising and falling reservoir	Berm F maintains a single channel; embedded LWD stabilized the berm toe and used to create scour (2016) but scouring function was lost	2019 inspection; detailed elevational survey (to monitor potential accumulations of fines or erosion on berm crest)

Figure 9 From left to right: Submerged Berm A; Berm F with embedded LWD; Berm G with embedded LWD (Six Mile Creek, June 13, 2018).

Table 8 Summary table for detailed 2018 observations made at Six Mile Creek structures Berm B and C built in 2014.

Structure	2018 Structural Integrity	Likely Deterioration Cause	2018 Ecological Function	Action Needed
Berm B: Non-vegetated geogrid soil wrap berm with embedded LWD	Berm structurally sound; embedded LWD structures present and stable; coir material was in good condition and stable	Driftwood, ice movement, rising and falling reservoir	Berm D maintained a single channel; embedded LWD stabilized the berm toe	Inspection in 2019
Berm C: vegetated geogrid soil wrap berm with embedded LWD, willow stake plantings and rock spur	Berm structurally sound; embedded LWD structures present and stable; willow live stakes withered away but grass cover appears healthy; rock spur was structurally sound; coir material in good condition and stable; tie-in to beaver pond was stable	Driftwood, ice movement, rising and falling reservoir	Berm C and the rock spur maintained a single channel; embedded LWD stabilized the berm toe; no larger plants for shading established	2019 inspection, possible re-planting of willow stakes in 2019

Figure 10 From left to right: Berm B with embedded LWD; Berm C with embedded stakes and rock spur; (Six Mile Creek, June 13, 2018).

Table 9 Summary table for detailed 2018 observations made at Six Mile Creek Berm J built in 2014.

Structure	2018 Structural Integrity	Likely Deterioration Cause	2018 Ecological Function	Action Needed
Berm J: vegetated geogrid soil wrap berm with embedded LWD and stakes with willow stake plantings	Berm structurally sound; embedded LWD present and stable; embedded stakes sprouted; planted willow shoots and other vegetation growing well; coir material in good condition and deteriorating as planned	None observed	Berm J maintained a single channel; embedded LWD stabilized the berm toe; embedded stakes were sprouting and providing shade and cover; willow stakes on berm were growing well and provided shade	Inspection in 2019
Current velocities, water depths, discharge (35.6 m^3/s) at Lat: 55°36'32.95"N; Long: 123°24'7.76"W	Based on visual assessment, current velocities and water depths in Six Mile Creek throughout the works in the DDZ were suitable for fish migration with a minimum thalweg depth of 0.5 m and velocity breaks behind cobbles and boulders	None observed	Facilitated fish migration	Inspection in 2019

Figure 11 From left to right: Berm J with embedded LWD, sprouting embedded stakes and sprouting willow stakes on berm crest; discharge measurement site (Six Mile Creek, June 13, 2018)

6.0 DISCUSSION

GMSMON-17, initiated in 2011, is a long-term monitoring program that aims to understand the effectiveness of Ole Creek and Six Mile Creek habitat enhancement demonstration projects in improving creek access for fish in spring during low reservoir levels. Data collected in 2018 represented Year 8 of the 10-year monitoring. The habitat enhancement works on both creeks were completed in 2014, so data collected in Year 8 represented the conditions four years after construction. Year 8 also represented the first year that data was collected at the sites by LGL Limited. Previous data collection was completed by Cooper Beauchesne and Associates Ltd. For the most part, the methods employed in previous years of the monitoring program were used in Year 8.

6.1 Discussion of GMSMON-17 Management Question 1: Does access for spring spawners (i.e., rainbow trout and/or arctic grayling) improve as a result of enhancement?

The original channels of Ole and Six Mile Creeks in the Williston Reservoir DDZ were heavily braided with very shallow water depths, possibly perched channels and a heavy load of large woody debris. The accumulation of large woody debris is in the DDZ is typical for almost all Williston Reservoir tributaries based on the large amount of wood drifting on Williston Reservoir.

Roscoe et al. (2014) reported based on visual observations that fish access to either creek was not blocked by perched channels or log jams (although a large amount of logs had accumulated in the mouths of both rivers) before habitat enhancement measures were undertaken, but that habitat quality throughout the DDZ was generally poor and not suitable for salmonid spawning or holding.

The suitability as salmonid holding and spawning habitat of both creeks in the DDZ appears to have improved four years after construction measures were completed. The formerly heavily braided channels have been trained into one non-perched channel with higher water depth throughout the DDZ. In addition to increased depths, current velocities in the trained portion of both creeks still appears to allow for salmonid migration at flows as measured in 2018 while the installed debris catchers mainly prevent log jam formations and related creek channel blockage.

6.2 Discussion of GMSMON-17 Management Question 2: Is the area and quality of fish habitat created by the tributary enhancement maintained over time?

The berms and debris catchers constructed throughout the DDZ of Ole and Six Mile Creek in 2014 are still functional and maintain the trained creeks in their planned unbraided channels. The root wads installed into the toes of the berms to create back eddies along the trained channel and thus provide current refuges for fish are now mainly perched (due to scour) above the water level and therefore do not have a hydrological function anymore. Additional placement of anchored Large Woody Debris structures should be considered to provide current refuges and fish holding habitat.

The plantings on berms in both creeks, as expected, have established permanent and thriving vegetation above the Williston Reservoir inundation elevation. Plantings below the annual inundation elevations were not successful an have disappeared.

6.3 Environmental Conditions

Reservoir operations and annual environmental conditions affect the exposure of habitat enhancements to air, water, driftwood and the potential resulting damage caused by these factors on the enhancement works. Therefore, factors such as reservoir elevations and environmental conditions were considered when analyzing the success and perseverance of the constructed habitat features in allowing access to spawning creeks at low reservoir levels in the spring. A final analysis to account for possible confounding effects of reservoir operations and environmental conditions on the function and perseverance of the enhancement works will be conducted in Year 10 (2020) of GMSMON-17.

In general, the conditions during the 2018 site visits were ideal for the assessment of all structures on June 12 in Ole Creek where none of the structures were inundated and good, but not ideal, for the assessment of structures on June 13 at Six Mile Creek where one berm was completely inundated but could still be inspected by wading. Obscuring snow cover was completely absent, and vegetation had sprouted which allowed for a quick visual assessment of vegetation condition.

In future years, Six Mile Creek works should be inspected at a reservoir level of approximately 663 masl to allow for inspection of all structures without being inundated. Nevertheless, the June 13, 2018, reservoir level of 664.5 masl allowed for a coarse visual inspection of the submerged Berm A and showed that the berm was structurally sound and did not show any potential erosion or failure. Berm A in Six Mile Creek should therefore be fully ecologically functional and appeared to be able to maintain a single channel at lower reservoir elevations.

6.4 Vegetation

In 2018, and as per contract, the vegetation assessment was limited to the recording of continued presence and function the vegetation planted in 2014 under GMSWORKS-19 and vegetation that established itself naturally. A detailed inventory of all plant species and their abundances will be conducted in Year 10 (2020) of GMSMON-17.

While none of the vegetation planted or embedded below a reservoir level of approximately 666 masl (elevation needs to be confirmed by a survey) sprouted or grew, vegetation planted or embedded above this level grew well and provides shading and cover for fish, in addition to stabilizing constructed banks and berms.

6.5 Fish Presence

In Year 8, and from hereon, the monitoring of fish presence was not part of GMSMON-17.

6.6 Depth, Current Velocity and Fish Access

The depths and current velocities (shown in Table 3 for Ole Creek and Table 6 for Six Mile Creek) even at the most restricted channel locations of the constructed channels at both creeks appeared to allow for fish migration at the measured flows in 2018. Arctic Grayling have a maximum burst (>20 sec) swimming speed of approximately 1.6 m/s while a swimming speed of approximately at 0.5 m/s can be maintained of periods of up to 20 minutes (Cahoon et al. 2018, Mac Phee and Watts 1975). Rainbow Trout have a maximum swimming speed of 1.47 m/s and average prolonged speeds of 0.4-0.8 m/s for fish >0.41 m fork length, which overlaps with the length of Rainbow Trout that are spawning in Ole and Six Mile Creeks (Katopodis and Gervais 2016). Based on these swim speed values, migration along the margins of both creeks in water depth of 10-15 cm should have been possible at the discharges measured in June of 2018. Discharge measurements as per Resource Inventory Standards are carried out at one third of the water depth where current velocities are typically much higher than close to the bottom as can be seen in Figure 12 on an example of a culvert where currents at one third of the water depth were approximately 2 m/s while the current velocity close to the culvert bottom was much slower at 0.3-0.8 m/s. In a natural creek with rougher bottom substrate the differences between one third depth and bottom current velocity are likely even more pronounced. We therefore assume that in addition to using the creek margins for migration in depth of 10-15 cm, migration may also have been possible in slightly deeper water close to the bottom.

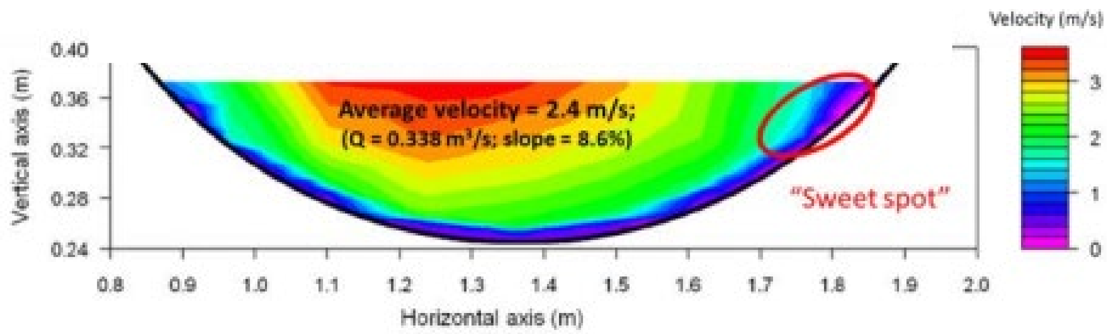


Figure 12 Current velocities measured in a culvert at different depths and distance from the bottom (from: Katopodis and Gervais 2016).

Nevertheless, additional scour pools created by adding LWD structures, which are either anchored in the stream channel or embedded in the berms at an elevation that allows them to be in the water, are recommended for consideration. These added LWD structures would create additional low current and resting areas between the long runs and rifles that may pose physical exhaustion for smaller fish.

7.0 CONCLUSIONS

Vegetation development and establishment can be a relatively slow ecological process, so the longer time series (i.e., 10 years) is necessary and the conditions under which the vegetation communities persist will become evident with the proceeding results. Two additional years of monitoring are planned for 2019 and 2020. Vegetation was successfully established at elevations that are inundated for only short annual periods of time. Natural vegetation established itself on the constructed berms at the same elevations. We therefore recommend surveying the lowest elevation for successful vegetation establishment as a guideline for future plantings.

The berms built to contain both creeks in a single channel to avoid the formation of shallow fast flowing and braided channels that can become an obstacle to fish passage are in good condition and fully functional.

The same is true for the constructed Woody Debris Catchers that are still intact and keep the majority of driftwood out of the creek channels. The manual removal of small amounts of driftwood inside of the Woody Debris Catchers should nevertheless be considered for 2019.

The embedded LWD structures are still functioning in preventing or slowing erosion of berm toes but are now elevated above creek level for most of the year and therefore will not create scour pools or provide low velocity refuges for fish. LWD structures anchored to reach below the creek level or the addition of boulders and general complexing of the creek channels may be needed to create low current velocity pockets in the future.

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