Deer Creek Drawdown Zone Fish Habitat Enhancement: A Pilot Study (Phase II) for Lower Arrow Lakes Tributary Access Improvements 2016 – 2017

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Photo Credit: Michael Zimmer

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Executive Summary

Deer Park is a small community approximately 30 km northwest of Castlegar, British Columbia. Deer Creek flows through Deer Park into the Lower Arrow Lakes Reservoir, which is regulated by the downstream Hugh L. Keenleyside Dam (HLK) and upstream Revelstoke Dam (REV). When reservoir levels drop, the lower section of Deer Creek is exposed in the drawdown zone and has little cover for spawning Kokanee (*Oncorhynchus nerka*) and resident Rainbow Trout (*Oncorhynchus mykiss*). Low water levels also create diffuse, shallow water conditions through the drawdown zone, impeding fish migration. As a result, Kokanee are vulnerable to predation. Past efforts have focused on improving fish migration well upstream of the drawdown zone by removing obstacles impeding access (e.g., a relic WSC weir and Deer Park resident's waterline intake weir). However, prior to Phase I of this project no work had been conducted in the drawdown zone.

The primary goal, adding in-stream cover and increasing water depth from the end of Phase I works downstream 100 m to an old bridge cribbing, included objectives to create: (1) stable wood and rock structures that would provide cover for migrating Kokanee and other inhabiting fish, and (2) a defined single channel to increase water depth and reduce the potential for channel braiding. The second Goal, to monitor the effectiveness of enhancement structures implemented in Phase II, included objectives: (1) to develop a map of pre-enhancement conditions and post-enhancement conditions, (2) to conduct post-freshet and post reservoir infilling, georeferenced stability assessments of structures in 2017, and (3) observe Kokanee use in the treated section (Phases I and II).

A centralized channel was constructed from the bottom of the Phase I works downstream 75 m to the reservoir level at the time of construction (August 2016). Using natural wetted and bankfull widths as design references, we developed structures that worked to mimic the natural dimensions and sinuosity in the drawdown zone and ultimately increase wetted depths. Structures were similar to those constructed in Phase I and comprised of combinations of woody debris, root-wads and boulders to create cover for migrating Kokanee. Topographic surveys were completed in November 2016 to establish a baseline to assess any potential structure movement during freshet and reservoir filling events.

In total, 11 structures were constructed in Phase II. All structures were created using logs anchored with rock with the purpose of adding stability to banks, defining a centralized channel and providing cover and holding areas for migrating fish. Boulder structures were also used to protect the banks and stabilize important habitat features at greater than bankfull flows.

Phase II structures increased the in-stream habitat complexity which will contribute to improving fish survival during migration. Following implementation, Kokanee were observed utilizing structures as they migrated through the treated portion of the drawdown zone in late August and September 2016. Kokanee were even observed to be spawning amongst the structures. Preliminary observations indicate the project (Phases I and II) has improved fish habitat and access in Deer Creek through the Arrow Lakes drawdown zone and responded well channel forming processes during freshet and reservoir filling.

We recommended annual monitoring of Kokanee usage (redd surveys/spawner counts) of works completed in Phases I and II, and of structure stability assessments following freshet / high water levels to determine maintenance requirements and evaluate the long term benefits of this project. Phase III works may be recommended if monitoring indicates low water depths and high predation persisting from the end of Phase II downstream.

Acknowledgements

This project was made possible with funding from the Fish and Wildlife Compensation Program on behalf of its program partners BC Hydro, the Province of BC, Fisheries and Oceans Canada, First Nations and the public who work together to conserve and enhance fish and wildlife impacted by the construction of BC Hydro dams.

We would also like to acknowledge Doug Haines of Brooklyn Contracting for operating the excavator used to create the structures, John and Edith Eriksson and all other volunteers of the Deer Creek Water Users Group who dedicated their time to the improvement of the environment around them for all to enjoy, Bud Stanchuck for the donation of woody debris, employees of Kabatoff Sand and Gravel Ltd. for supplying and transporting the rock, and Amy Duncan of the Okanagan Nation Alliance for a critical review of this report. We also recognize and thank Robert Wagner of Ecoscape Environmental Consultants Ltd. for providing detailed topographic geo-referencing and mapping services.

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Introduction

This project supports the FWCP's (Fish and Wildlife Compensation Program) Large Lakes Action Plan which builds on the FWCP Columbia Basin Plan (2011) to focus compensation efforts in five high priority Lakes: Kootenay Lake, Duncan Reservoir, Arrow Lakes Reservoir, Kinbasket Reservoir, and Revelstoke Reservoir (FWCP 2012). This project specifically aligns with Arrow Lakes Reservoir Fish Priority number two; which includes increasing Kokanee fishing opportunities in the Upper and Lower Arrow Lakes Reservoir by improving access to spawning habitat (FWCP 2012).

Deer Creek is a major tributary to the Lower Arrow Lakes section of the Columbia River. This 16.4 km creek flows through Deer Park, a small community located approximately 30 km northwest of Castlegar, BC (Fig 1). Deer Creek has high potential spawning and rearing habitat for Kokanee and provides important habitat for resident and adfluvial Rainbow Trout (Hawes and Drieschner 2012). Spawning surveys conducted by the MFLNRO (Ministry of Forest Lands and Natural Resource Operations) recorded 6,651 and 10,254 kokanee in 2015 and 2016 respectively (Steve Arndt, MFLNRO, pers. comm. 2016). It is estimated that the lower reaches of Deer Creek (2.5 km to an impassable falls) have the potential to provide habitat for up to 34,500 spawning Kokanee (MFLNRO, 2016 unpublished data). However, like all the tributaries in the Arrow Lakes Reservoir, the lowest reach of Deer Creek is within the drawdown zone, and is directly affected by reservoir management from downstream Hugh L. Keenleyside Dam and the Revelstoke Dam upstream.

Previous habitat work conducted on Deer Creek included Phase I (2015) of the Deer Creek Drawdown Zone Fish Habitat Enhancement Pilot Study by the Okanagan Nation Alliance (ONA). During Phase I, nine log and boulder structures were created in the top 100 m of the drawdown zone at Deer Creek (Smith and Zimmer 2016). A Water Survey of Canada Weir was removed by Michael Zimmer in partnership with the Deer Creek Water Users Group (DCWUG at Deer Park; Zimmer 2002) and the Fish and Wildlife Compensation Program (FWCP), and in 2006 debris congesting a private intake weir was removed to improve Kokanee access (Zimmer 2007).

These projects resulted in improved access to spawning habitat in and above the drawdown zone. Prior to the works completed in 2015, habitat enhancements within the drawdown zone had not yet been attempted. Monitoring of Phase I indicated positive results in both structure stability and effectiveness of improving access and providing cover for migrating Kokanee. Following this success, the ONA proposed to add additional habitat structures continuing downstream through the drawdown zone (Phase II), where braiding and seasonally shallow water levels are still occurring (Fig 2). The results of the Phase II (2016) works are outlined in this report.

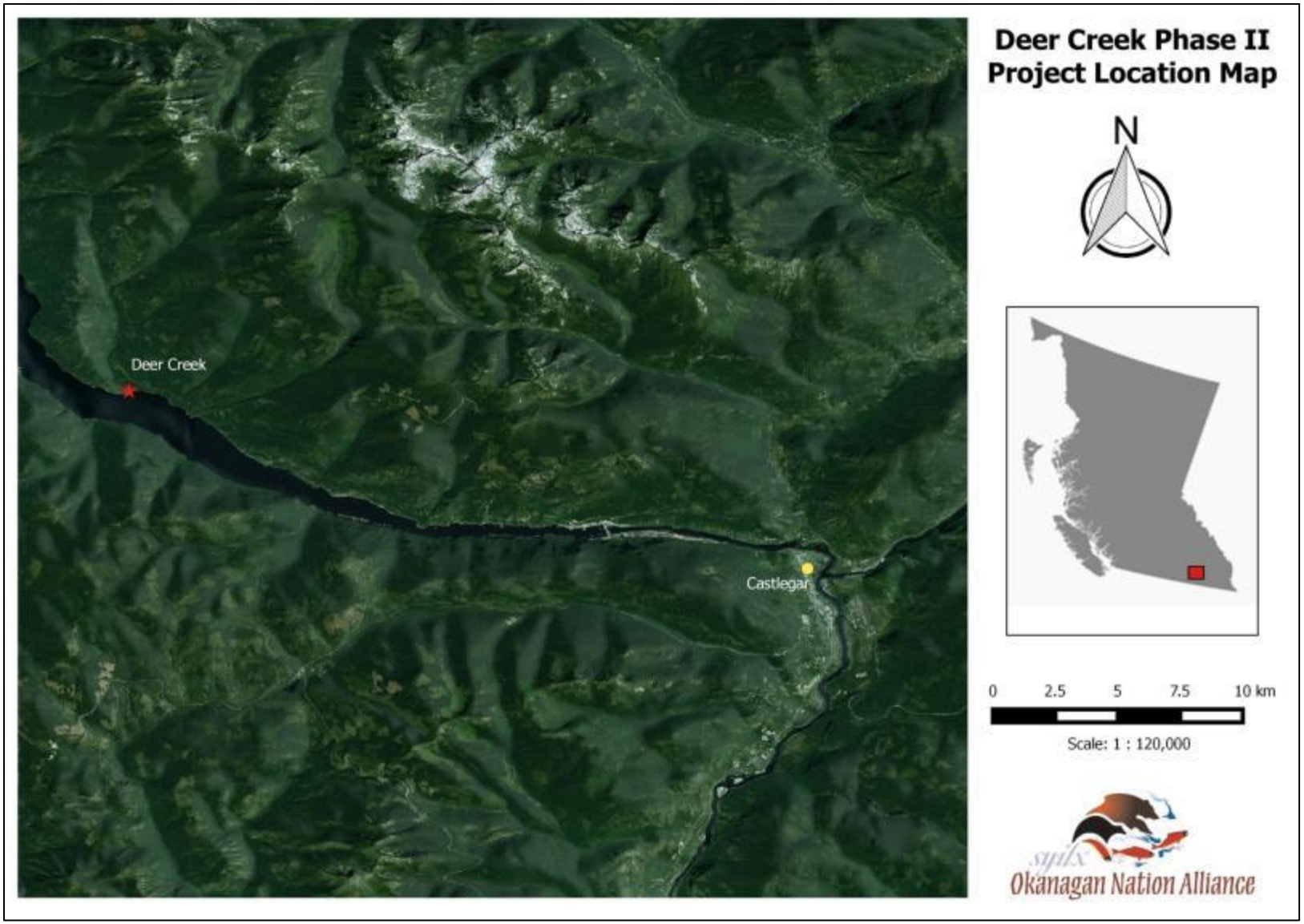

Figure 1. The location of Deer Creek relative to Castlegar, BC (Image Source: ESRI World Imagery).

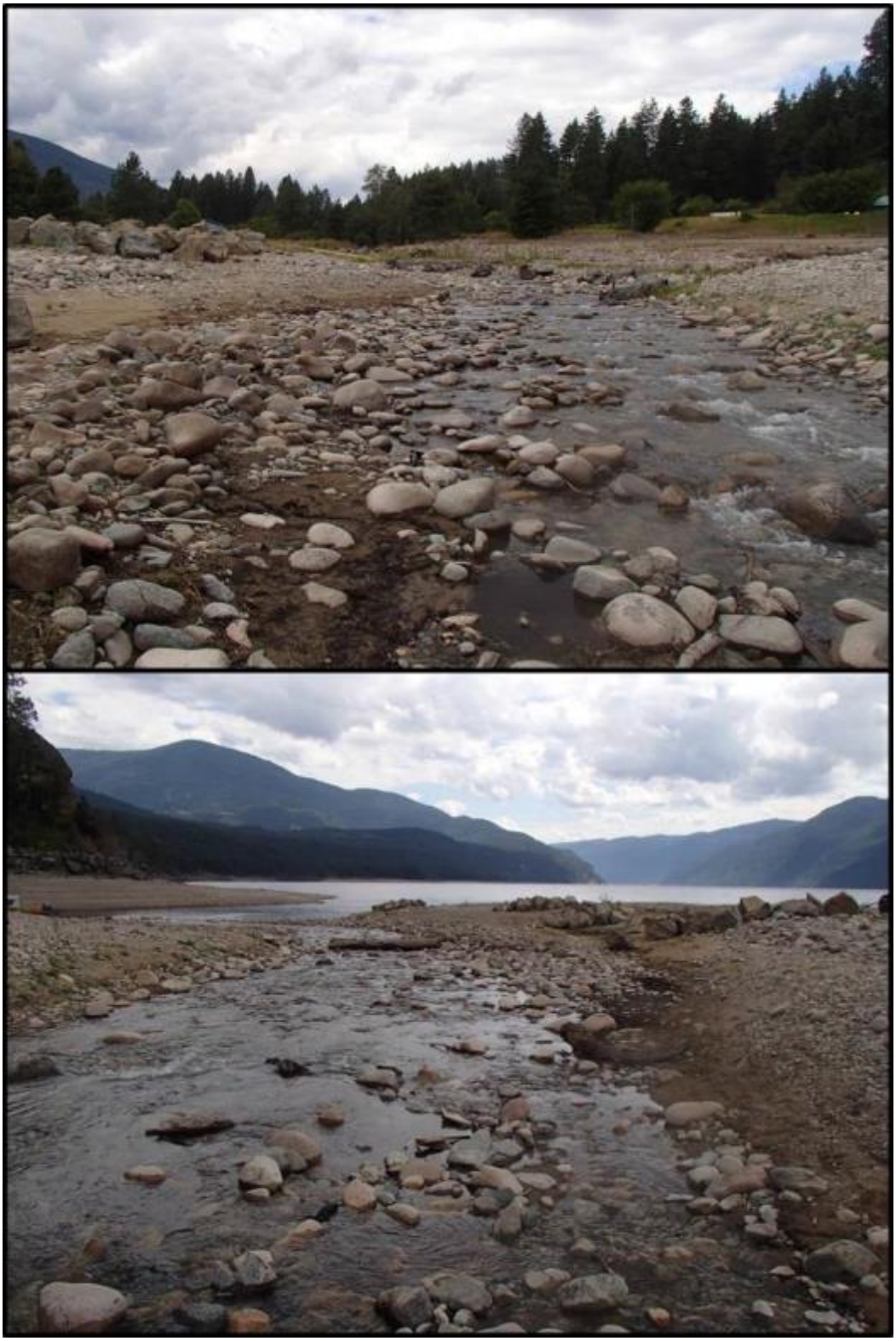

Figure 2. (Top) Deer Creek's lower reach within the drawdown zone from a downstream perspective showing an absence of cover and shallow water impeding Kokanee access; (bottom) Deer Creek's lower reach within the lower drawdown zone from an upstream perspective which is prone to braiding. Photos by Evan Smith, Okanagan Nation Alliance, August 2016.

Goals and Objectives

The two main goals of Phase II (2016) were:

Goal 1: Add in-stream cover and increase water depth from the end of Phase I works downstream 100 m to an old bridge cribbing.

Objective 1 – Create stable wood and rock structures that will provide cover for migrating Kokanee and other inhabiting fish, and

Objective 2 – Create a defined single channel to increase water depth and reduce the potential for channel braiding.

Goal 2: Monitor the effectiveness of enhancement structures implemented in Phase II

Objective 1 – Develop a map of pre and post-enhancement conditions,

Objective 2 – Conduct post-freshet and post reservoir infilling, georeferenced stability assessment of structures in 2017, and

Objective 3 – Observe Kokanee use in the treated section (Phases I and II).

Study Area

The study area is located at the end of Deer Park Road in the community of Deer Park approximately 30 km northwest of Castlegar, BC. The Phase II treatment area encompassed approximately 75 meters of Deer Creek, spanning immediately downstream from of the Phase I works to the current reservoir level (Fig 3). Structures were originally planned to extend another 25 m downstream to an old bridge cribbing, which channelizes the stream beyond, but reservoir levels during the in-stream work window were too high to access the full site. The study area parallels Deer Park Road, providing easy access for large machinery. This area was targeted because of:

1) An apparent lack of instream cover and diffuse channel characteristics,
2) A heightened risk of Kokanee predation as observed by local residents,
3) A locally established stewardship group with a vested interest in the management of Deer Creek and Kokanee,
4) Ease of access for heavy equipment and materials, and
5) The opportunity to build upon previous successful habitat projects.

Due to the lack of a defined channel, this section of the creek fans out during low water resulting in meandering, shallow sections that ultimately impede fish access and often strand fish. During high reservoir levels (full pool, April-June) the drawdown zone is inundated, limiting the establishment of vegetation and floating material that could be used for cover (trees, driftwood). As the reservoir level recedes (July/August), more of the site becomes exposed. During fluctuating water levels the structures within Deer Creek work to retain the defined channel during low water. At high reservoir levels, the structures are submerged yet continue to provide cover to fry and adult fish from predators that hunt in the littoral zone. At low reservoir levels the structures help to maintain a defined channel and provide cover/resting areas for Kokanee and Rainbow Trout.

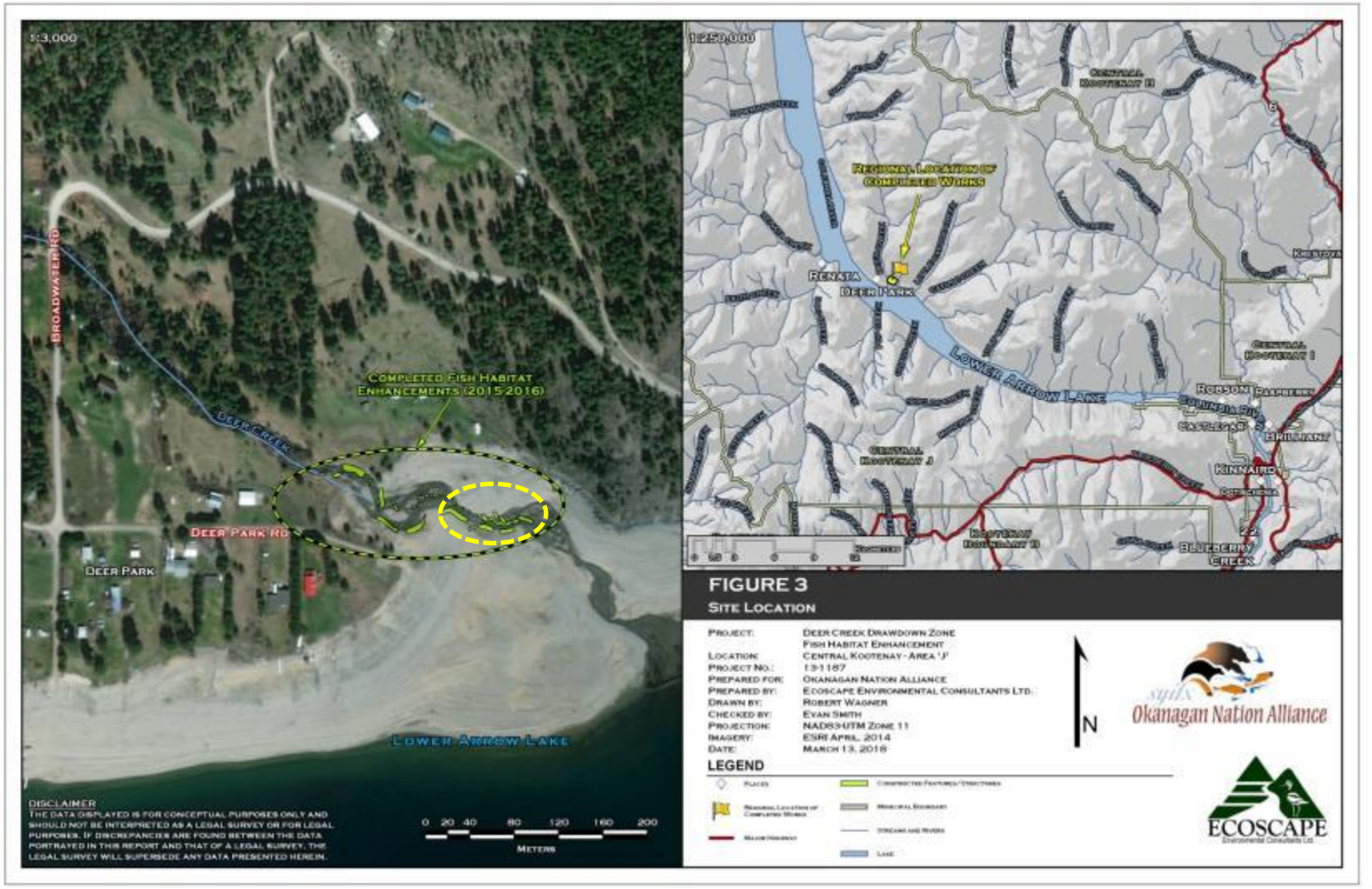

Figure 3. Phase II treatment area (yellow dashed circle) extending from the end of Phase I downstream to the low-water mark at time of construction (adapted from map created by Ecoscape, 2018).

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Methods

Design

Natural channel design principals were used in the development of fish habitat structures by mimicking analogous wetted and bankfull width conditions as assessed in reaches upstream of the drawdown zone (Zimmer 2002). Sinuosity was paramount to the design in an attempt to replicate upstream reaches with consideration to parent creek-bed material and channel slope. This was achieved by focusing on a single channel within the drawdown zone with similar characteristics (meander pattern, gradient/substrate composition). The newly-defined, single stream channel was designed to mimic a riffle-pool system in order to provide habitat associated with resident Kokanee spawning and rearing requirements (Hogan and Ward 1997). Structures consisting of large-woody debris anchored by large rock were used to define a bankfull channel and protect streambanks starting at the end of Phase I and working downstream 75 m. Several structures were created with the intent to improve holding/resting habitat within the low-flow wetted width. Most structures served both these purposes.

Implementation

As in Phase I, habitat structures made from large wood were based on guidelines set by Cederholm *et al.* (1997). Alterations to these guidelines were made to address permit requirements and available material. Large wood (diameter between 0.18 – 0.64 m and length of 1.0 – 15.0 m and associated root wads) donated by Bud Stanchuck, a resident of Deer Park, was cut to size by chainsaw. A ≥ 3 m stem was left on all root wads to allow space for boulders (b-axis 0.8 – 1.6 m) to be placed on top, weighing the structure down and preventing it from dislodging during high water. A Hitachi 160 series excavator was used to construct the structures by placing large wood and boulders. An ad-hoc stability test was performed on all placed rock to ensure they would not move under the weight of a person. Turbidity measurements (a BC Hydro permitting condition) were taken with a Lamotte turbidity meter upstream of the work site in the morning (baseline), downstream of site during construction and downstream of site after construction was completed each day.

To manage the resulting altered stream flow, target banks and features were reinforced with boulders placed strategically by an excavator and tested for stability. Deflection structures were created outside the wetted width to guide water back into the stream proper during anticipated larger flows. All work was conducted within the 2016 in-stream work window for the Kootenays (July 16 – August 16) under Permit A4-6512.

Documentation and Monitoring

As with Phase I, a post-enhancement map was developed through a topographic survey to depict constructed habitat features. This map shows each structure's position within the drawdown zone and relative three-dimensional measurements. This map can be used as a baseline to monitor structure shifting over years. These maps, along with photo documentation, will provide information regarding structure stability and function for both Phase I and II. The components of each structure and their order of placement within the stream were also documented for monitoring purposes. If a structure fails we

can reference this information to identify any potential limiting factors (wood volume by anchoring rock size). Kokanee counts from the MFLNRO and observations of general use and migration success will be monitored annually by volunteers from the DCWUG. These observations and numeration data will be used to determine long-term success of structures if specific funding for monitoring is unavailable.

Results

Construction

Eleven structures were constructed within the 75 m study area immediately downstream of the end of Phase I within the drawdown zone of Deer Creek (Fig 4). These structures included wood, root-wad and boulder anchored structures, root structures ballast by boulders, and boulder-lined banks. Boulders used to anchor large wood were an average diameter of 1.20 m b-axis. Three or four of these boulders were used on each wood component, and additional 40 – 60 cm size rock was used as fill. For a breakdown of each structure's components see Appendix A. Structures were numbered consecutively following those placed in Phase I. Minor excavation took place in front of Structures 18 and 19 to increase the wetted width depth profile. Layout maps were created to document structure positions following construction (Fig 5 and 6).

Figure 4. A downstream perspective from Phase I of Phase II before (top left) and after (top right) structure construction, and an upstream perspective from within the drawdown zone of Phase II before (bottom left) and after (bottom right) structure construction Photos by Evan Smith, Okanagan Nation Alliance, August 2016.

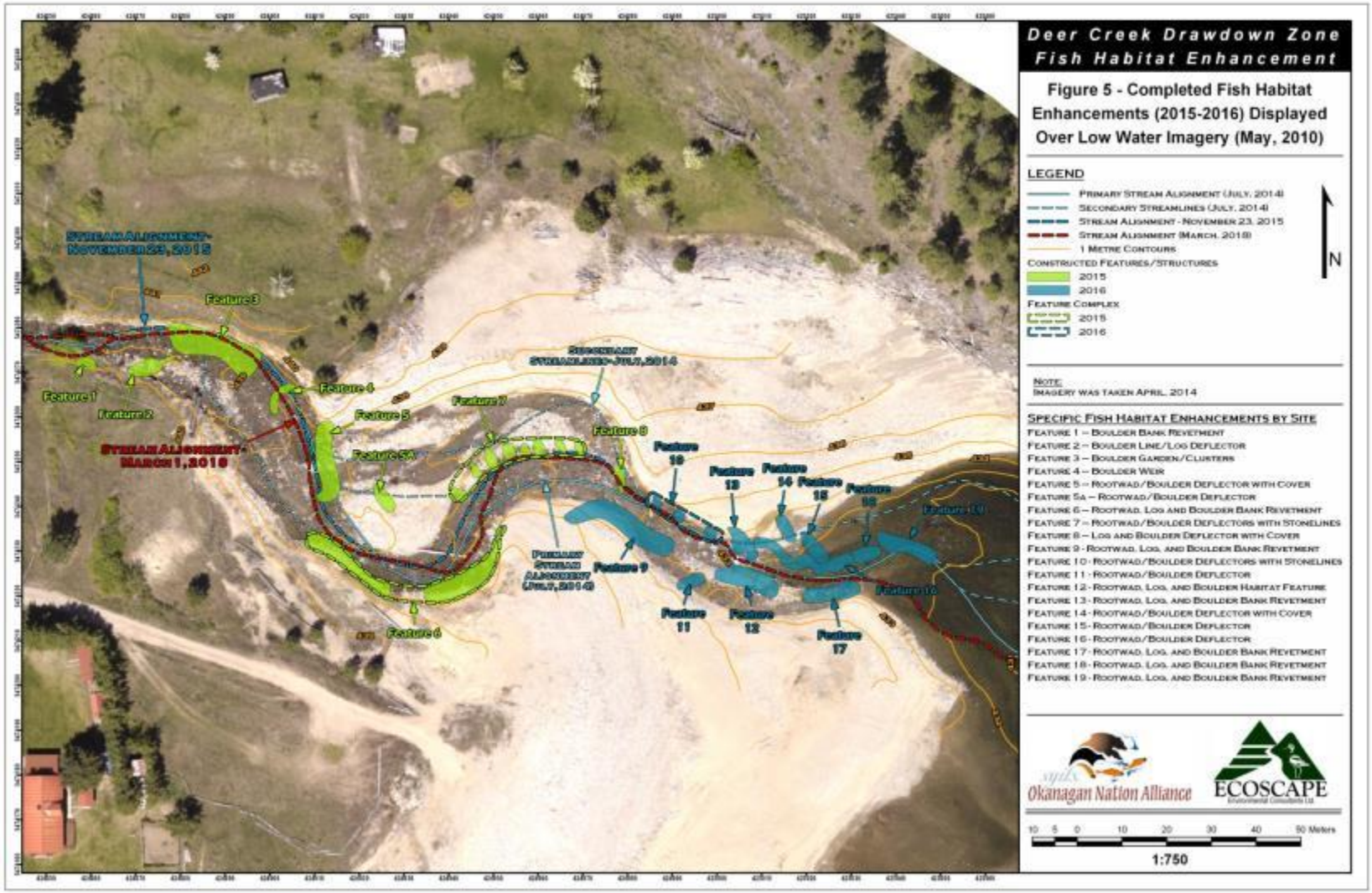

Figure 5. Phase II completed structures (2016, blue) in relation to Phase I structures (2015, green) in the section of Deer Creek within the drawdown zone during low-water levels (map created by Ecoscape 2018).

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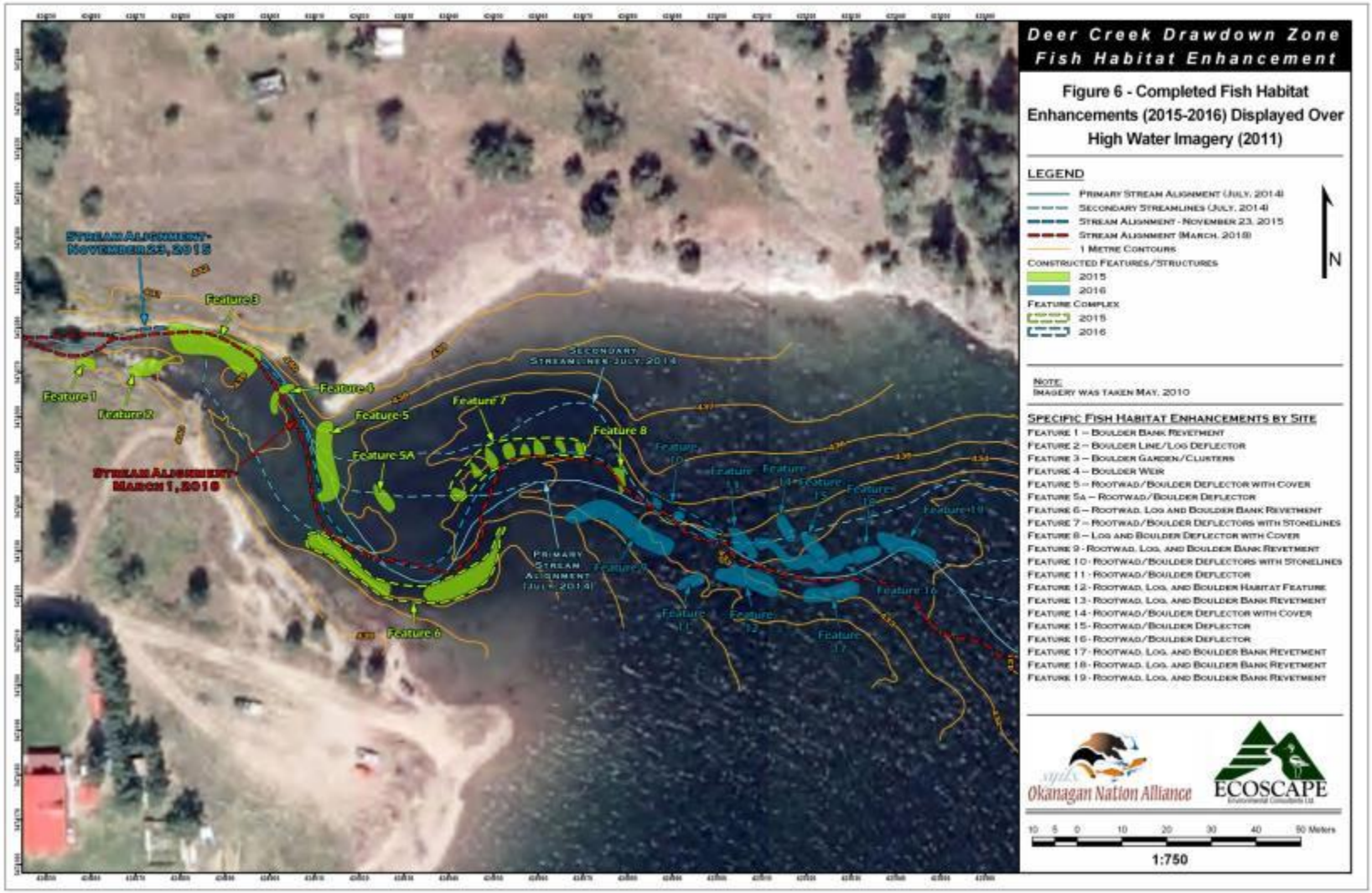

Figure 6. Phase II completed structures (blue) in relation to Phase I structures (green) in the section of Deer Creek within the drawdown zone during high-water levels (map created by Ecoscape 2018).

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A detailed summary of each structure and its components follows:

Structure 9 is made up of two log-root-rock structures and is used to promote low-flow channel definition (Fig 7). This feature provides cover for fish during high and low reservoir levels. Wood shelves were constructed to mimic cut banks for use as overhead cover.

Figure 7. Before (top left) and after (top right) comparison from a upstream perspective of Structure 9 on the right bank in the section of Deer Creek within the drawdown zone; (bottom left) closer view of Structure 9 from a downstream perspective depicting overhanging cover for Kokanee; (bottom right) Close up of the artificial cut banks that fish can utilize for cover. Photos by Evan Smith, Okanagan Nation Alliance, August 2016.

Structure 10 is two root wads ballasted with rock (Fig 8). A third root wad was added later to utilize available material. This structures' function is to deflect water from the left bank into the center of the stream while providing cover for Kokanee during high and low water periods.

Figure 8. Before (top left) and after (top right) comparison from a downstream perspective of Structure 10 on the left bank in the section of Deer Creek within the drawdown zone; (bottom left) close view of one root in Structure 10 from a downstream perspective depicting its value as cover and refuge; (bottom right) Closer view of two of three root structures comprising Structure 10. Photos by Evan Smith, Okanagan Nation Alliance, August 2016.

Structure 11 is a deflection structure located above the bankfull channel elevation, made of a log with ballast rock to guide water back into the stream (Fig 9). On-site evidence suggests at some point in the year the creek may be high enough to flow behind the structures in this zone. Deflection structures such as this one are designed to encourage the water to return to the newly-defined main channel when high flows recede.

Figure 9. Structure 11 from a right bank perspective designed to deflect water into the original stream bed as higher flows recede. Photo by Evan Smith, Okanagan Nation Alliance, August 2016.

Structure 12 is similar to Structure 9 but consists of one log-root-rock structure designed to promote low-flow channel definition (Fig 10). This feature provides cover for fish during high and low reservoir periods while deflecting water from the right bank to the center of the creek during low flows. Wood shelves were constructed to mimic cut banks which fish use as overhead cover.

Figure 10. Before (top left and bottom left) and after (top right and bottom right) comparison from upstream and downstream perspectives, respectively, of Structure 12 on the right bank in the Deer Creek drawdown zone Photos by Evan Smith, Okanagan Nation Alliance, August 2016.

Structure 13 is made of a large log and root ballasted by boulders (Fig 11). This feature provides pool habitat for refuge and cover from predators in high and low water while deflecting flows from the left bank to the right bank, reducing braiding and increasing low flow water depth.

Figure 11. Before (top left) and after (top right) comparison of Structure 13 on the left bank in the section of Deer Creek within the drawdown zone from across the stream; (bottom left) a downstream perspective of Structure 13 in relation to Structure 12; (bottom right) a close up of Structure 13 from an upstream perspective depicting its effectiveness of creating pools and cover for fish. Photos by Evan Smith, Okanagan Nation Alliance, August 2016.

Structures 14 and 15 are similar to Structure 11 in composition and function (Fig 12). Like Structure 11, Structure 14 is comprised of a log with ballast rock. Structure 15, however, is constructed entirely of rock. Both these structures work to deflect water back into the newly-defined channel when higher water levels recede.

Figure 12. Structure 14 (left) and Structure 15 (right) located on the left bank in the Deer Creek drawdown zone between Structures 13 and 16. Photos by Evan Smith, Okanagan Nation Alliance, August 2016.

Structure 16 is a large structure with a combination of vertical roots, horizontal roots and cover logs all ballasted with rock (Fig 13). This structure reduces braiding, increases water depth and provides cover for fish during both high and low water levels.

Figure 13. Before (top left) and after (top right) comparison of Structure 16 from an upstream perspective located on the left bank of the Deer Creek drawdown zone; (bottom left) view of Structure 16 from across the stream; (bottom right) continuation of Structure 16 from across the stream (point of reference indicated via yellow arrows. Photos by Evan Smith, Okanagan Nation Alliance, August 2016.

Structure 17 is a replicate of Structure 12 consisting of one log-root-rock structure to promote low-flow channel definition (Fig 14). This feature provides cover for fish during high and low reservoir levels while deflecting water from the right bank to the center of the creek during low flows. Wood shelves were constructed to mimic cut banks for fish to use as overhead cover and boulders were placed on top of the structure for reinforcement and added bank protection.

Figure 14. Before (top left) and after (top right) comparison from an upstream perspective of Structure 12 on the right bank in the section of Deer Creek within the drawdown zone. Before (bottom left) and after (bottom Right) comparison of Structure 12 from across the stream. Photos by Evan Smith, Okanagan Nation Alliance, August 2016.

Structure 18 is similar to Structure 17 and Structure 12 consisting of a log-root-rock structure to promote channel definition, but also has an added log structure to provide cover and promote scouring of a pool (Fig 15). This structure design was based on monitoring Structure 8 in Phase I and is designed to provide cover during high and low water levels, form a pool for Kokanee refuge and encourage channel definition.

Figure 15. Before (top left) and after (top right) comparison of Structure 18 from an upstream perspective on the left bank in the Deer Creek drawdown zone; (bottom left) closer view of Structure 18 shows its use as cover; (bottom right) four logs at the end of Structure 18 that are designed to create a pool for Kokanee refuge based on monitoring results of Structure 8 in Phase I. Photos by Evan Smith, Okanagan Nation Alliance, August 2016.

Structure 19 is a log-root-rock structure reinforced to promote channel definition at the creek bend (Fig 16). This structure is designed to provide cover at high and low water levels and to reduce braiding in the drawdown zone. Having this structure on the bend of the creek is expected to increase velocity downstream, with the intention of scouring the sand and promoting channel definition.

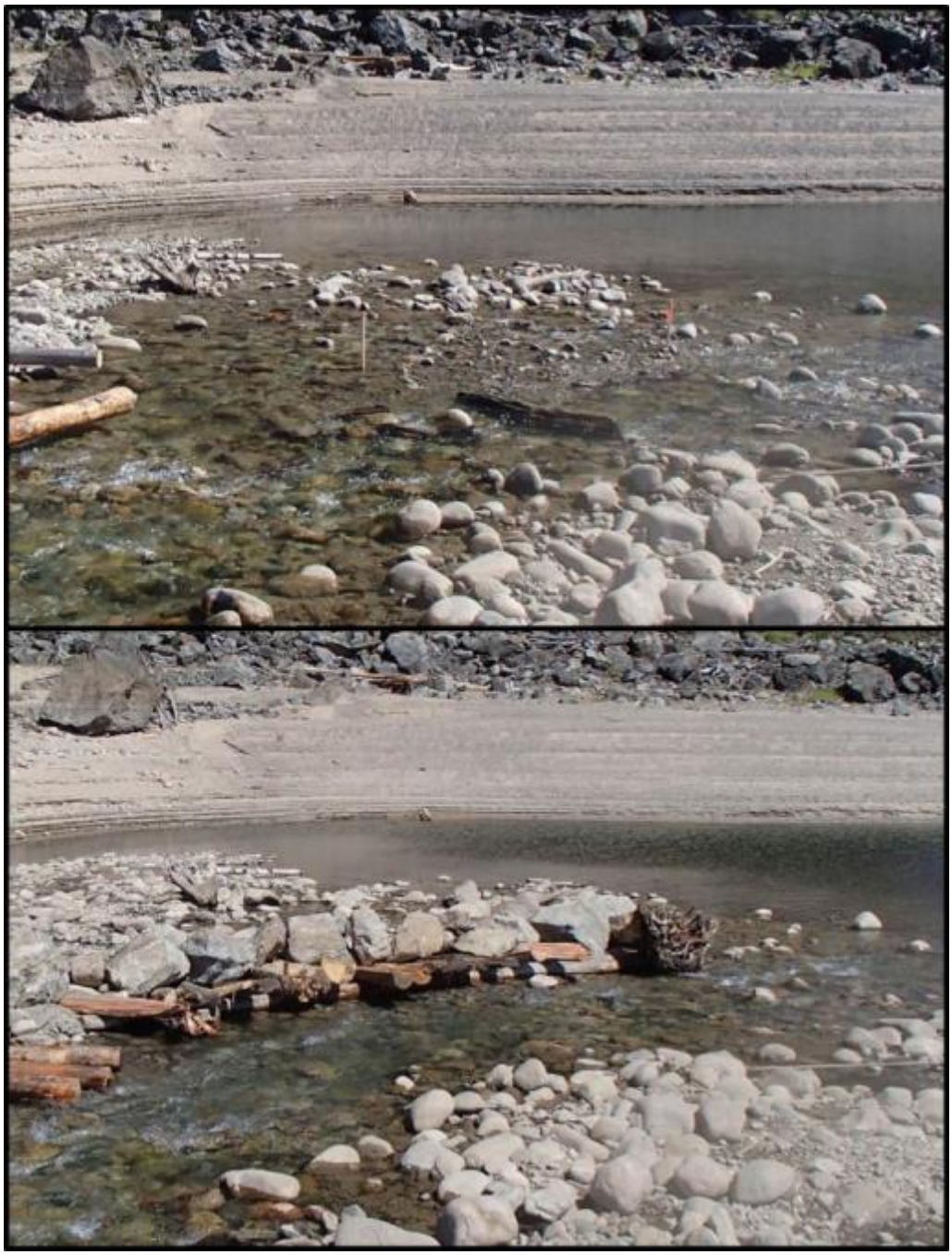

Figure 16. Before (top left) and after (top right) comparison of Structure 19 from an upstream perspective on the left bank in the Deer Creek drawdown zone. Photos by Evan Smith, Okanagan Nation Alliance, August 2016.

Kokanee Monitoring

Preliminary monitoring of Kokanee usage in Phase I and II areas was encouraging, as Kokanee were observed using structures as cover and holding areas. Several hundred Kokanee were observed in the Phase II section of the drawdown zone in September 2016, whereas no Kokanee were observed in the stretch below the last structure (Structure 19) to the reservoir. Kokanee were also observed spawning under structures on September 10 2016 (Michael Zimmer, pers. comm.; Fig 17). Following construction, Kokanee were observed using Phase II structures as cover during migration in late August into September 2016 (Michael Zimmer, pers. comm.; Fig 18).

Turbidity Monitoring

Turbidity was monitored two to four times a day (depending on activity) for the duration of the project. To minimize turbidity in the stream, excavator crossings only occurred when necessary and work within the wetted width of the stream was limited to 15 - 20 minutes at a time. On average, turbidity at the end of the day was 0.19 NTU's higher than baseline with a maximum of 0.57 NTU's above baseline on August 10 2016. These values fall well within the British Columbia Water Quality Guidelines for aquatic life (Singleton 2001). The highest turbidity recorded was 62.6 NTU's (62.22 NTU's higher than baseline) on August 11th 2016 at 10:15 following an excavator crossing and instream work. However, turbidity dropped to 1.28 NTU's (0.90 NTU's above baseline) within five minutes. A table of all turbidity measurements can be viewed in Appendix B.

Figure 17. (Top) Kokanee taking cover under a root component of Structure # as they migrate to upstream reaches of Deer Creek to spawn; (bottom) Kokanee using the artificial bank feature for cover and utilizing the deeper thalweg created by Structure 19 for easier travel upstream. Photos by Michael Zimmer, Okanagan Nation Alliance, September 2016.

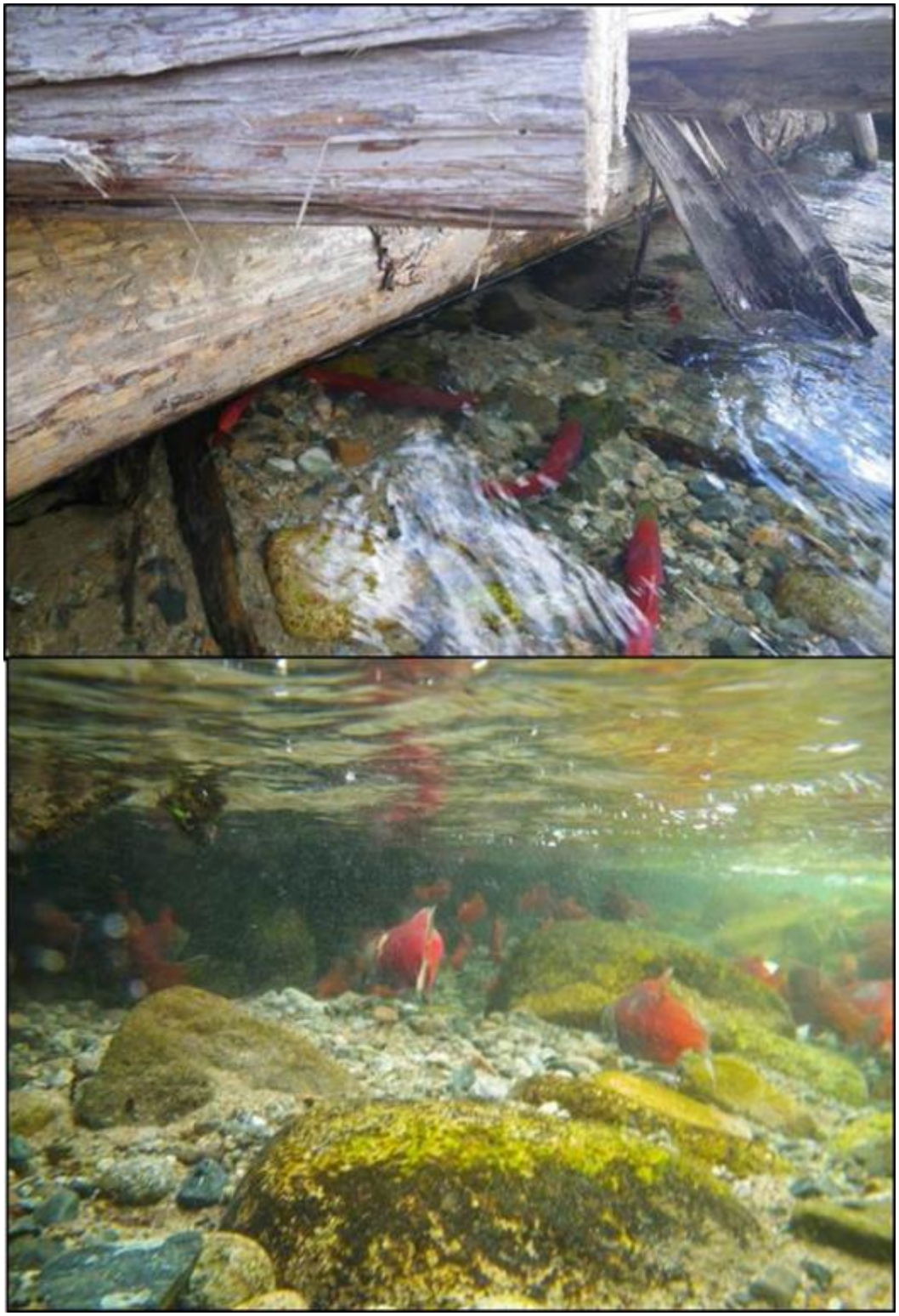

Figure 18. (Top) Kokanee spawning under Structure 6 (Phase I) from a downstream perspective on the left bank in the Deer Creek drawdown zone; (bottom) underwater photo of Kokanee spawning under Structure 6 from a downstream perspective. Photos by Michael Zimmer, Okanagan Nation Alliance, September 2016.

Post-Freshet and Reservoir Infill Monitoring 2018

Water Levels

Deer Creek discharge peaked at 13.0 m^3/s in late May 2017; discharge was markedly higher in 2017 compared to 2015 and 2016 records (Water Survey of Canada Station 08NE087;Fig 19). Lower Arrow Lakes Reservoir elevation data from 2016 and 2017 were taken from the Water Survey of Canada data Fauquier Stations 08NE102 and are shown in Figure 20.

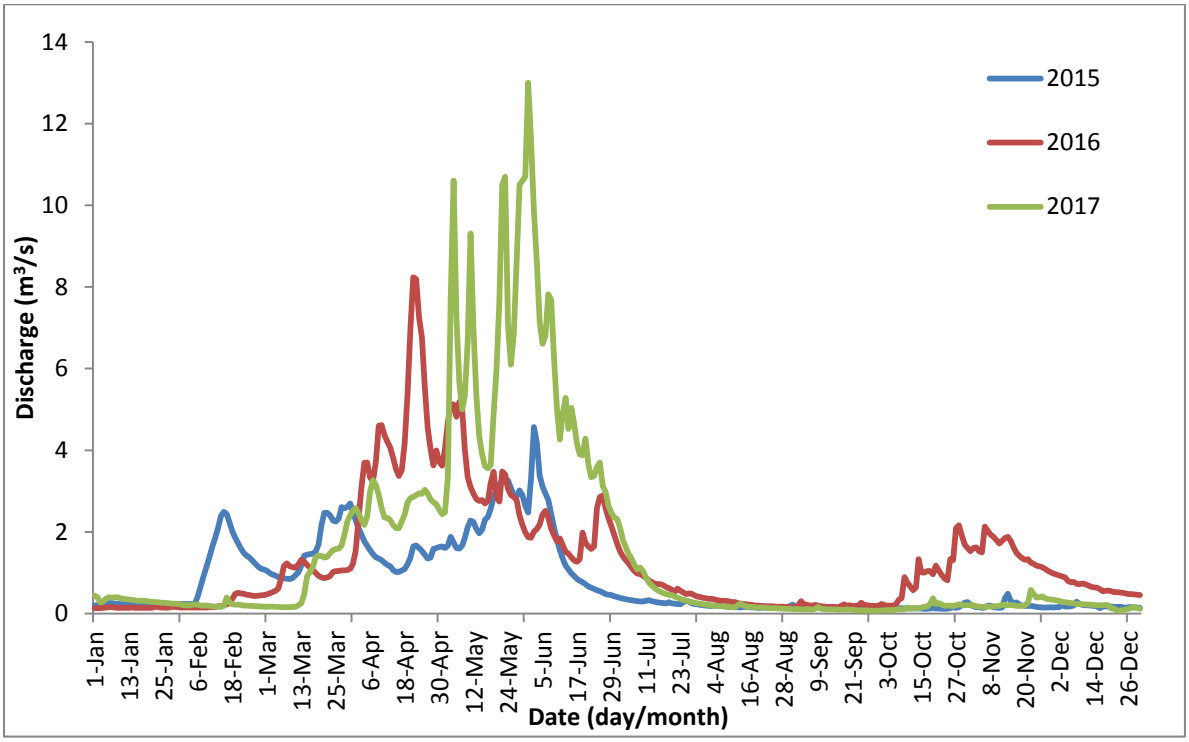

Figure 19. Annual hydrographs for Water Survey of Canada Station 08NE087 at Deer Creek in 2015, 2016 and 2017.

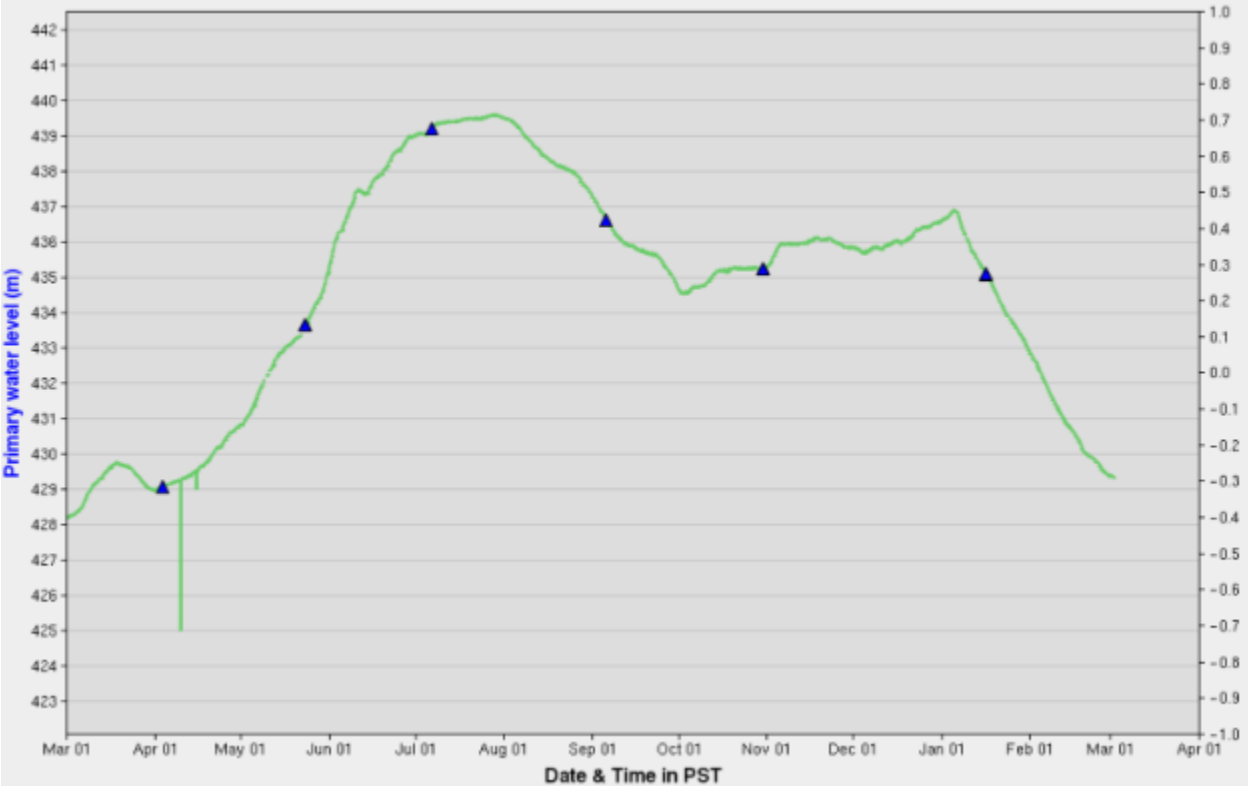

Figure 20. Water level of Arrow Lake Reservoir at Fauquier (WSC Station 08NE102) from March 1, 2017 to March 2, 2018 (post-freshet monitoring date).

Structure and Stream Monitoring

Structures were monitored for stability and function on March 2 2018 to assess the effects of the 2017 freshet and reservoir infilling. Minimal structure movement and degradation was identified at this time (Table 1). Photos were taken to document the movements of specific components in each structure (Fig 20 - 32). Deer Creek remained in a defined channel from the tree line through the drawdown zone to its confluence with the Arrow Lakes Reservoir. All previously identified side channels were dry, or contained very little water (< 3.0 cm). Channel width in the drawdown zone (1.5 – 5 m) was comparable to channel width upstream based on measurements taken in 2015. A detailed georeferenced topographic survey was completed to identify overall structure positions and hydraulic changes (Fig 34 and 35).

Table 1. Assessment of each habitat structure in Deer Creek following freshet and reservoir infilling taken March 1 2018.

Structure	Fig.	Description	Condition
1	Fig 21	Small rip-rap bank	Bank Slumped; 19-21/49 rocks remain the rest washed away
2	Fig 21	Rip rap and existing log	Intact
3	Fig 22	Boulder Garden (~40 boulders)	21 - 25/40 rocks remain, possibly added from Structure 1, the rest washed away
4	Fig 22	Rock Weir	30/43 rocks remain, most removed by freshet; remanence of structure still visible on right and left bank.
5	Fig 23	Root wads and rock wall	All roots present; two ballast rocks fallen into stream between Root 3 and 4 (1.06 - 1.27 m in size); large pools formed behind moved rocks
5a	Fig 24	Single root/log with rock	Intact
6	Fig 25	Two-part, log and rock revetments with small woody debris shelving	Upstream side of structure partially collapsed, possibly from velocity of smaller side channel; Log 1 has become misaligned and Root 2 is missing
7	Fig 26	Series of root wad and rock structures	All intact except for the 4th structure from the downstream end which is missing; large pool formed under Roots 9 & 10
8	Fig 27	Multiple logs and rock	Intact; some sediment deposition on structure; 1 rock missing or imbedded
9	Fig 28	Log and rock revetments with small woody debris shelving	Intact; almost all imbedded in reservoir sediment
10	Fig 28	Series of root wad and rock structures	Upstream root missing (Root 1) and rocks are imbedded in reservoir sediment; other two roots (Root 2 and 3) are partially imbedded but look intact
11	Fig 29	Single log with rock	Intact; partially imbedded in reservoir sediment
12	Fig 29	Log and rock revetments with small woody debris shelving	Intact; partially imbedded in reservoir sediment
13	Fig 30	Log and Root structure with rock ballast	Intact; partially imbedded in reservoir sediment
14	Fig 30	Single log with rock	Intact; partially imbedded in reservoir sediment
15	Fig 31	Rock deflection	Intact; partially imbedded in reservoir sediment
16	Fig 31	Vertical roots, horizontal roots, and cover logs ballasted by rock	Intact; partially imbedded in reservoir sediment
17	Fig 32	Log and rock revetments with small woody debris shelving	Missing downstream root (Root 4); some cover logs missing or miss-aligned; upstream end difficult to discern due to being partially imbedded in reservoir sediment
18	Fig 32	Log and rock revetments with small woody debris shelving	Mostly imbedded in reservoir sediment; downstream root (Root 5) missing or buried
19	Fig 33	Log and rock revetments with small woody debris shelving	Mostly imbedded in reservoir sediment; all roots gone or buried

Figure 21. (Top Left) Structure 1 post -construction in November 2015; (top right) Structure 1 in March 2018 after two years of being subjected to freshet and reservoir inundation; (bottom left) Structure 2 post-construction in November 2015; (bottom right) Structure 2 in March 2018 after two years of being subjected to freshet and reservoir inundation. Photos by Evan Smith, Okanagan Nation Alliance, November 2015 and March 2018).

Figure 22. (Top Left) Structure 3 post -construction in November 2015; (top right) Structure 3 in March 2018 after two years of being subjected to freshet and reservoir inundation; (bottom left) Structure 4 post-construction in November 2015; (bottom right) Structure 4 in March 2018 after two years of being subjected to freshet and reservoir inundation. Photos by Evan Smith, Okanagan Nation Alliance, November 2015 and March 2018).

Figure 23.(Top) Structure 5 post -construction in November 2015 with coloured arrows (green, red, blue, yellow) highlighting the positions of four specific rocks; (bottom) Structure 5 in March 2018 after two years of being subjected to freshet and reservoir inundation with coloured arrows (green, red, blue, yellow) highlighting the movements of specific rocks. Photos by Evan Smith, Okanagan Nation Alliance, November 2015 and March 2018).

Figure 24. (Top) Structure 5a post -construction in November 2015; (bottom) Structure 5 in March 2018 after two years of being subjected to freshet and reservoir inundation. Photos by Evan Smith, Okanagan Nation Alliance, November 2015 and March 2018).

Figure 25. (Top Left) upstream portion of Structure 6 post -construction in November 2015 with red arrow highlighting Root 2; (top right) upstream portion of Structure 6 in March 2018 after two years of being subjected to freshet and reservoir inundation with red arrow highlighting the absence of Root 2; (bottom left) downstream portion of Structure 6 post-construction in November 2015; (bottom right) downstream portion of Structure 6 in March 2018 after two years of being subjected to freshet and reservoir inundation. Photos by Evan Smith, Okanagan Nation Alliance, November 2015 and March 2018).

Figure 26. (Top) Structure 7 post -construction in November 2015 with a red arrow highlighting Roots 7 & 8; (bottom) Structure 7 in March 2018 after two years of being subjected to freshet and reservoir inundation with a red arrow highlighting the missing root structure consisting of Roots 7 & 8. Photos by Evan Smith, Okanagan Nation Alliance, November 2015 and March 2018).

Figure 27. (Top) Structure 8 post -construction in November 2015; (bottom) Structure 8 in March 2018 after two years of being subjected to freshet and reservoir inundation. Photos by Evan Smith, Okanagan Nation Alliance, November 2015 and March 2018).

Figure 28. (Top Left) Structure 9 post -construction in August 2016; (top right) Structure 9 in March 2018 after one year of being subjected to freshet and reservoir inundation: note the amount of sediment deposition on top of the structure; (bottom left) Structure 10 post-construction in August 2016; (bottom right) Structure 10 in March 2018 after one year of being subjected to freshet and reservoir inundation. Photos by Evan Smith, Okanagan Nation Alliance, August 2016 and March 2018).

Figure 29. (Top Left) Structure 11 post -construction in August 2016; (top right) Structure 11 in March 2018 after one year of being subjected to freshet and reservoir inundation; (bottom left) Structure 12 post-construction in August 2016; (bottom right) Structure 12 in March 2018 after one year of being subjected to freshet and reservoir inundation. Photos by Evan Smith, Okanagan Nation Alliance, August 2016 and March 2018).

Figure 30. (Top Left) Structure 13 post -construction in August 2016; (top right) Structure 13 in March 2018 after one year of being subjected to freshet and reservoir inundation; (bottom left) Structure 14 post-construction in August 2016 highlighted with a red arrow; (bottom right) Structure 14 in March 2018 after one year of being subjected to freshet and reservoir inundation highlighted by a red arrow. Photos by Evan Smith, Okanagan Nation Alliance, August 2016 and March 2018).

Figure 31. (Top Left) Structure 15 post -construction in August 2016; (top right) Structure 15 in March 2018 after one year of being subjected to freshet and reservoir inundation; (bottom left) Structure 16 post-construction in August 2016; (bottom right) Structure 16 in March 2018 after one year of being subjected to freshet and reservoir inundation. Photos by Evan Smith, Okanagan Nation Alliance, August 2016 and March 2018).

Figure 32. (Top Left) Structure 17 post -construction in August 2016; (top right) Structure 17 in March 2018 after one year of being subjected to freshet and reservoir inundation; (bottom left) Structure 18 post-construction in August 2016; (bottom right) Structure 18 in March 2018 after one year of being subjected to freshet and reservoir inundation. Photos by Evan Smith, Okanagan Nation Alliance, August 2016 and March 2018).

Figure 33. (Top) Structure 19 post -construction in August 2016; (bottom) Structure 17 in March 2018 after one year of being subjected to freshet and reservoir inundation. Photos by Evan Smith, Okanagan Nation Alliance, August 2016 and March 2018).

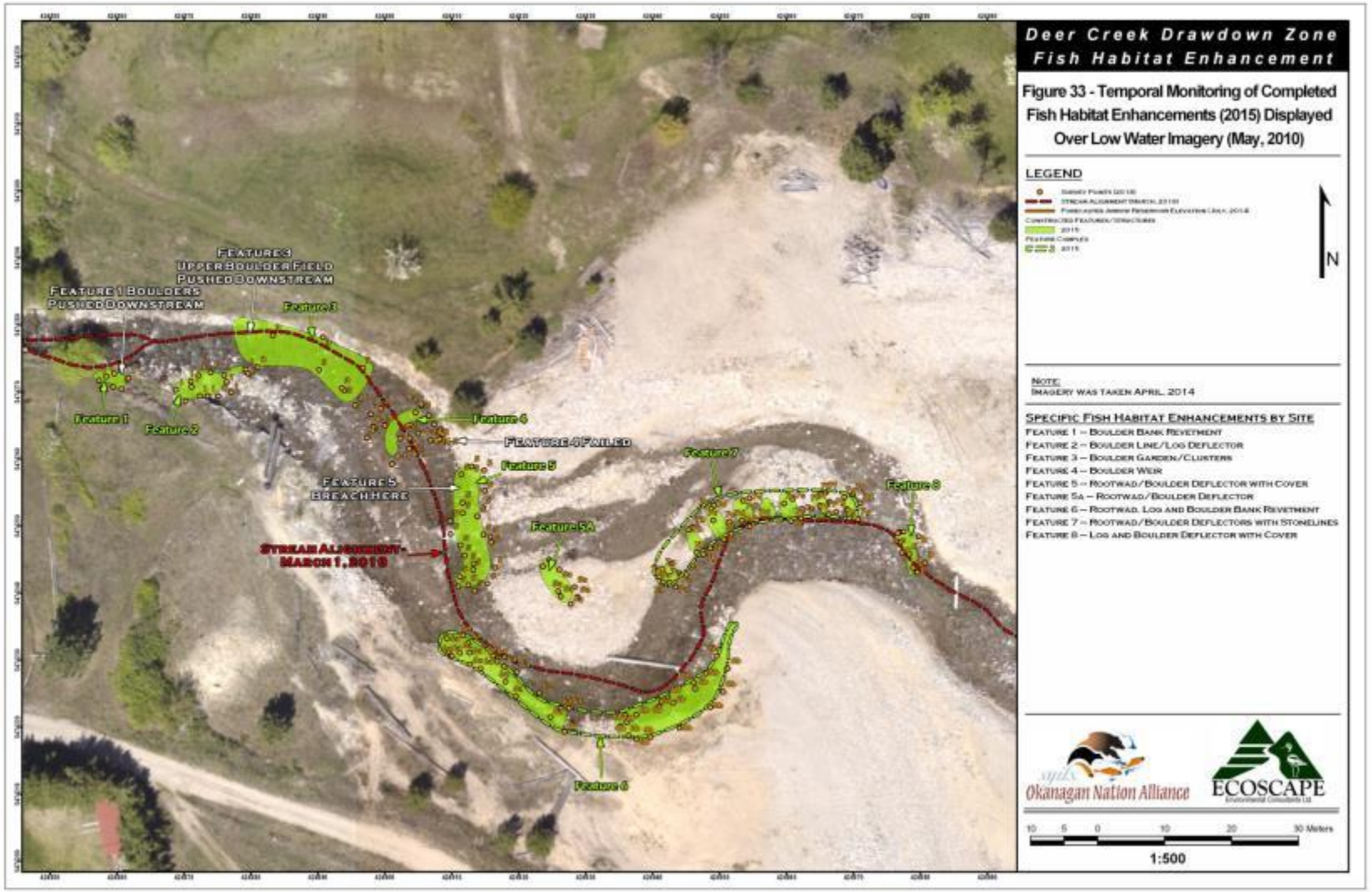

Figure 34. Post-freshet and inundation monitoring results in Phase I depicting structure placement before (2015; green polygons) and after (2018; yellow dots) two years of in the upper Deer Creek Draw Down Zone (map created by Ecoscape, 2018).

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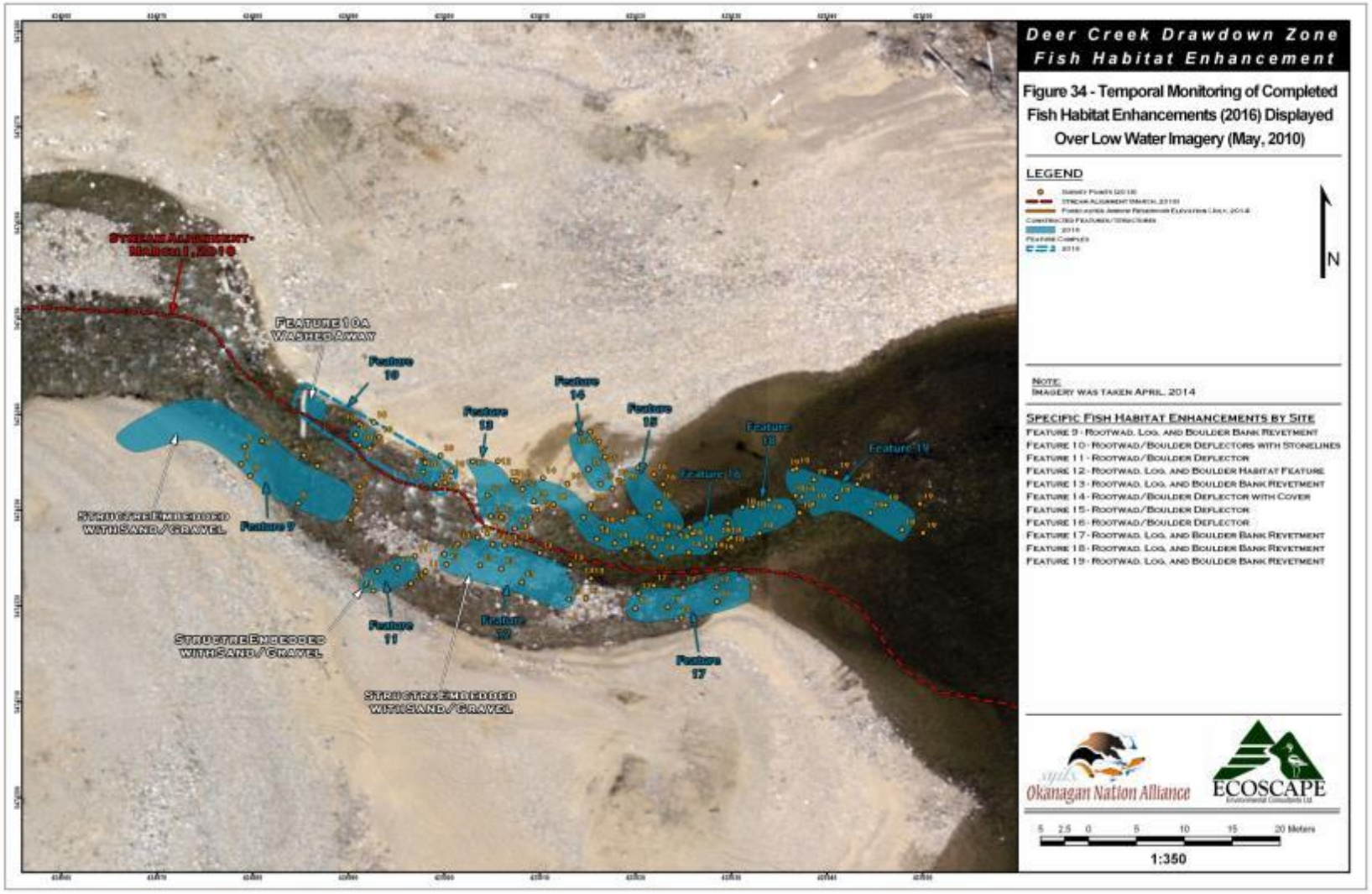

Figure 35. Post-freshet and inundation monitoring results of Phase II depicting structure placement before (2016; blue polygons) and after (2018; yellow dots) in the upper Deer Creek Draw Down Zone (map created by Ecoscape, 2018).

Discussion

The Deer Creek Fish Habitat Enhancement Project was initiated with local interest in improving Kokanee access in Deer Creek during annual spawning migrations. In 2015, the Okanagan Nation Alliance worked with concerned citizens to address a 100 m section of Deer Creek within the drawdown zone of the Arrow Lakes Reservoir (Phase I). Nine structures comprised of logs, root wads and boulders were constructed with the objective of defining a single channel, providing bank stability and overhead cover for migrating fish. In 2016, ONA continued enhancement efforts from the last structure in Phase I another 75 m further into the drawdown zone. Eleven more structures were added in 2016 to further stabilize and define the channel to its confluence with the reservoir.

The completion of the Deer Creek Drawdown Zone Fish Habitat Enhancement Pilot Study for Lower Arrow Lakes Tributary Access Improvements Phases I and II resulted in 20 structures constructed in the drawdown zone section of Deer Creek. These structures were designed and developed to maintain channel definition, add complexity to fish habitat and improve Kokanee access to the upper reaches of Deer Creek. Density of structures in Phase II was greater than Phase I due to the limited area available for structure placement (75 m compared to the expected 100 m), however all the wood and boulder material was used. Permitting limitations did not allow the use of cable in either Phase I or II, therefore boulders were used to support each structure containing wood I. Large roots were halved lengthwise to reduce their potential buoyancy when submerged.

There is strong evidence that large-woody debris in streams is utilized by juvenile salmonids in the winter (Cederholm *et al.* 1997). The Arrow Lakes Reservoir reaches its lowest water levels in winter, exposing several hundreds of meters of Deer Creek through the barren beach of the drawdown zone. These woody debris structures may be utilized as habitat for juvenile salmonids and may even increase the streams capacity to produce fish (Cederholm *et al.* 1997). Similarly, boulder clusters and rock structures can increase a streams' capacity to support fish (Ward 1997). These structures increase the habitat complexity of the lowest reach of Deer Creek, which will hopefully promote adult Kokanee survival and ultimately result in a higher abundance of returning fish (Solazzi *et al*. 2000).

Post freshet monitoring in March 2018 resulted in some observations of movement and/or missing components of Phase I & II Structures. Changes may be attributed to a high freshet (peaking at 13.0 m^3/s) in 2017 (green line; Fig 18). Observations indicated at these flows approximately 50% of rock less than 1 m in size was moved downstream. Therefore future efforts should consider using rock greater than 1 m in size in streams likely to reach flows above 13 m^3/s. Some larger ballast rocks (1.00 – 1.25 m) had also shifted, primarily in Structures 5 and 6 (Phase I). However, movement of these rocks appears to be the result of undercutting/erosion and not velocity as they moved less than 1 m from their original position. Roots from Structures 6, 7, and 10 were confirmed missing while roots from Structures 17, 18 and 19 were not observed, but may have been buried in reservoir sediment. Roots from Structures 7 and 10 may have been lost due to insufficient ballast for the volume of wood, while the mobilization of Root 2 from Structure 6 may have resulted from erosion.

Although movement and displacement of some structure components has occurred, the overall goal of the project was achieved. Natural bank formation and single channel definition was observed in March 2018 (Fig 36). Channel width through the drawdown zone varied from 1.5 – 5 m which resembles the natural channel width in reaches above the drawdown zone. Structures which have been imbedded in reservoir sediment are no longer providing cover for Kokanee, but still work to provide structure for bank creation (addressing Goal 1, Objective 2). Structures which are not fully imbedded in sediment are still functioning as habitat/cover structures for migrating Kokanee (addressing Goal 1, Objective 2).

Figure 36. (Left) Phase II Habitat structures, from a downstream perspective, forming banks in the drawdown zone contributing to the formation of a single defined channel; (right) Deer Creek in a defined channel flowing through the drawdown zone downstream of Phase I & II structures from a downstream perspective. Photos by Evan Smith, Okanagan Nation Alliance, March 2018.

Kokanee have been utilizing the structures as cover while migrating through the drawdown zone and were seen forming Redds under some structures in fall 2016. This could be the first instance, to our knowledge, of Kokanee spawning in the drawdown zone section of Deer Creek. Though preliminary observations indicate the structures have been successful in improving Kokanee access to spawning habitat in Deer Creek, there is not enough data to verify this claim. Since Kokanee usually spawn in their fourth year, the impacts of this project may not be apparent until the year 2020; when Kokanee born at Deer Creek in 2016 will return to spawn. Spawning survey data collected by the MFLNRO from 1966 to 2016 will be used as a baseline to compare pre/post-treatment relative spawning success in Deer Creek (Fig. 37). Data from future spawning surveys will be compared with this baseline data, while considering seasonal variability, to evaluate the project's success.

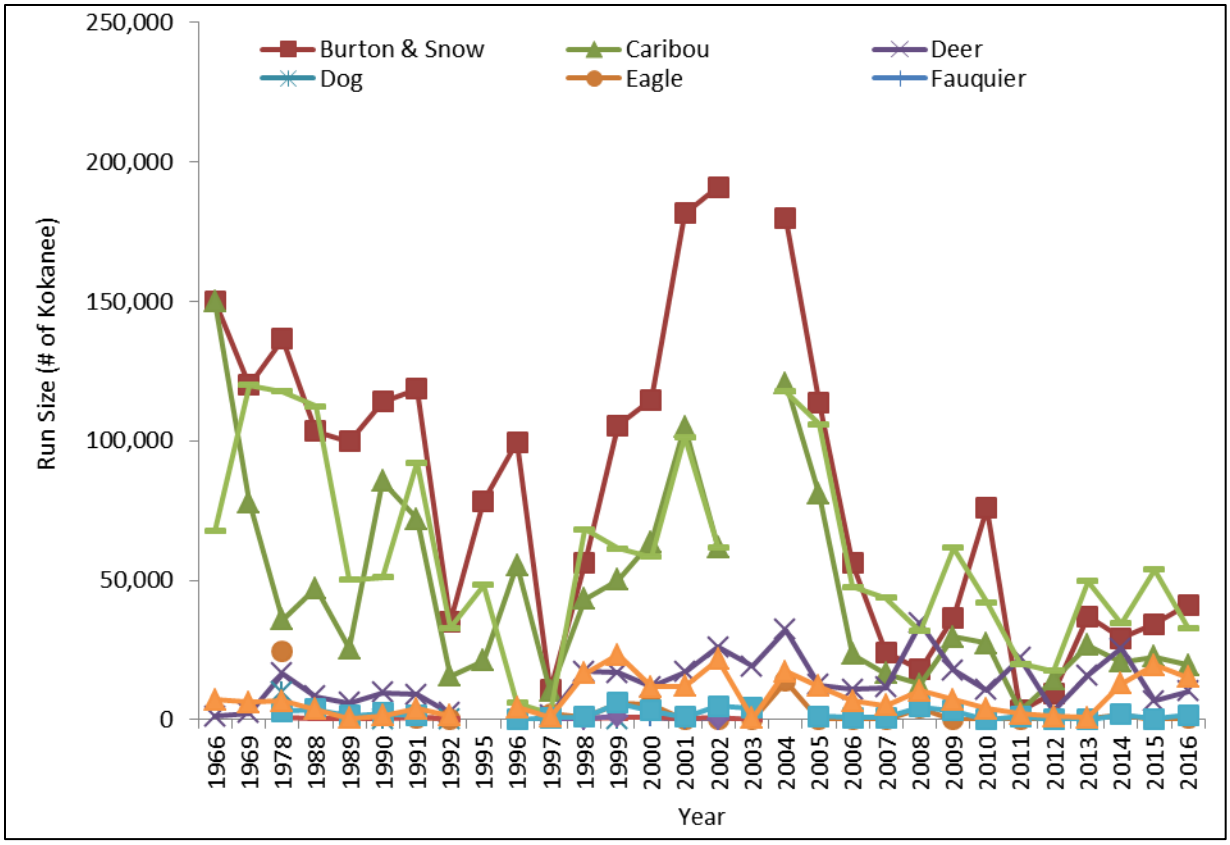

Figure 37. Kokanee spawning survey results in the Lower Arrow Lakes Reservoir from 1966 to 2016 (MFLNRO, unpublished data)

Recommendations

To continue evaluating the success of this project, annual structure monitoring is recommended. Monitoring will identify aspects of the treatment that can be improved upon and be used to document structure stability and function. If possible, we recommend exploring the use of georeferenced drone photography in place of topographic surveys to document structure locations, movement, and function over the years. This is due to difficulty in replicating exact measurement points from previous year based solely on the available geographic base layers.

Kokanee spawning surveys should also be conducted to quantify the structures effectiveness in protecting Kokanee during migration and use as spawning cover. If funding is not available, spawning surveys conducted by the MFLNRO should be used to compare with data from previous years, as well as regional data, to account for seasonal variability. Structures will be considered effective if long term spawning counts indicate an increase of spawning activity in Deer Creek while other adjacent tributaries remain similar to past years.

As the reservoir level during the in-stream work window did not allow construction in the full 100 m planned in 2016, additional installation of habitat structures from the end of Phase II downstream to the old bridge cribbing is recommended (i.e., Phase III; Fig. 38). However, if monitoring indicates the existing structures are sufficient for significantly improving Kokanee access into Deer Creek, then the existing completed work may suffice.

Figure 38. Untreated area of the Deer Creek drawdown zone downstream of Phase I and II which may require additional work (Phase III) which would extend from the bottom of Phase II downstream to an old bridge cribbing (yellow arrow) depending on future monitoring results. Photo by Evan Smith, Okanagan Nation Alliance, March 2016.

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APPENDIX A: Structure Composition for Phase II

Table 2. Components of Structure 9 including its material, order and size. All measurements were taken upstream to downstream, closest to the stream to farthest. Comments have been added for easier material position identification. Roots were measured from the ground to the top of the root wad and their diameter was taken just above the root wad. Measurements were recorded on August 8th and 9th 2016.

Structure #	Material	Order	Length (m) x Dia. (m) or B axis (m)	Comments
9	Log	1	8.5 x 0.30	Upstream Base Log
9	Root	2	15.0 x 0.45	Upstream Ballast Root for Order # 1
9	Root	3	3.2 x 0.37	Downstream Ballast Root for Order # 1
9	Rock	4	1.4	Ballast for Order # 2
9	Rock	5	1.2	Ballast for Order # 2
9	Rock	6	1.1	Ballast for Order # 2
9	Rock	7	1.3	Ballast for Order # 2
9	Rock	8	1.5	Ballast for Order # 2
9	Rock	9	1.2	Ballast for Order # 3
9	Rock	10	1.1	Ballast for Order # 3
9	Rock	11	1.3	Ballast for Order # 3
9	Log	12	11.3 x 0.28	Base Log Downstream
9	Root	13	4.6 x 0.36	Upstream Ballast Root for Order # 12
9	Root	14	3.6 x 0.32	Downstream Ballast Root for Order # 12
9	Root	15	3.5 x 0.44	Middle Ballast Root for Order # 12
9	Rock	16	1.5	Ballast for Order # 2
9	Rock	17	1.3	Ballast for Order # 2
9	Rock	18	1.4	Ballast for Order # 2
9	Rock	19	1.2	Ballast for Order # 2
9	Rock	20	1.3	Ballast for Order # 2
9	Rock	21	1.0	Ballast for Order # 2
9	Rock	22	1.2	Ballast for Order # 2
9	Rock	23	1.2	Ballast for Order # 4
9	Rock	24	1.5	Ballast for Order # 4
9	Rock	25	1.2	Ballast for Order # 4
9	Rock	26	1.6	Ballast for Order # 4
9	Rock	27	1.5	Ballast for Order # 4
9	Rock	28	1.6	Ballast for Order # 4
9	Rock	29	1.6	Ballast for Order # 3
9	Rock	30	1.6	Ballast for Order # 3
9	Rock	31	1.3	Ballast for Order # 3
9	Rock	32	1.1	Ballast for Order # 3
9	Rock	33	0.8	Ballast for Order # 3
9	Rock	34	1.1	Ballast for Order # 3

* Cover wood was added to the structure and secured with 32 pieces of 1.0 m + rock.

Figure 39. Structure 9 post-construction from an upstream perspective on August 9th 2016. Photo by Evan Smith, Okanagan Nation Alliance, August 2016.

Table 3. Components of Structure 10 including material, order and size. All measurements were taken upstream to downstream, closest to the stream to farthest. Comments have been added for easier material position identification. Roots were measured from the ground to the top of the root wad and their diameter was taken just above the root wad. Measurements were recorded on August 10th and 12th 2016.

Structure #	Material	Order	Length (m) x Dia. (m) or B axis (m)	Comments
10	Root	1	1.7 x 0.42	Upstream Root
10	Root	2	1.5 x 0.35	Middle Root
10	Root	3	1.5 x 0.25	Downstream Root
10	Rock	4	1.4	Ballast for Order # 1
10	Rock	5	1.0	Ballast for Order # 1
10	Rock	6	1.1	Ballast for Order # 1
10	Rock	7	1.2	Ballast for Order # 2
10	Rock	8	1.0	Ballast for Order # 2
10	Rock	9	1.3	Ballast for Order # 2
10	Rock	10	1.2	Ballast for Order # 2
10	Rock	11	1.3	Ballast for Order # 3
10	Rock	12	0.9	Ballast for Order # 3
10	Rock	13	1.1	Ballast for Order # 3
10	Rock	14	1.0	Ballast for Order # 3
10	Rock	15	1.0	Ballast for Order # 3
10	Rock	16	1.0	Ballast for Order # 3

Figure 40. Structure 10 post-construction from a downstream perspective on August 12th 2016. Photo by Evan Smith, Okanagan Nation Alliance, August 2016.

Table 4. Components of Structure 11 including material, order and size. All measurements were taken upstream to downstream, closest to the stream to farthest. Comments have been added for easier material position identification. Measurements were recorded on August 12th 2016.

Structure #	Material	Order	Length (m) x Dia. (m) or B axis (m)	Comments
11	Log	1	5.0 x 0.33	Base Log
11	Rock	2	1.0 +	Ballast for Order # 1
11	Rock	3	1.0 +	Ballast for Order # 1
11	Rock	4	1.0 +	Ballast for Order # 1
11	Rock	5	1.0 +	Ballast for Order # 1
11	Rock	6	1.0 +	Ballast for Order # 1
11	Rock	7	1.0 +	Ballast for Order # 1
11	Rock	8	1.0 +	Ballast for Order # 1
11	Rock	9	1.0 +	Ballast for Order # 1

Figure 41. Structure 11 post-construction from an upstream perspective on August 12th 2016. Photo by Evan Smith, Okanagan Nation Alliance, August 2016.

Table 5. Components of Structure 12 including its material, order and size. All measurements were taken upstream to downstream, closest to the stream to farthest. Comments have been added for easier material position identification. Roots were measured from the ground to the top of the root wad and their diameter was taken just above the root wad. Measurements were recorded on August 9th 2016.

Structure #	Material	Order	Length (m) x Dia (m) or B axis (m)	Comments
12	Log	1	7.6 x 0.43	Upstream Base Log
12	Log	2	6.3 x 0.52	Downstream Base Log
12	Root	3	5.8 x 0.32	Downstream Ballast Root
12	Root	4	6.2 x 0.34	Middle Ballast Root
12	Root	5	3.0 x 0.32	Upstream Ballast Root
12	Rock	6	1.3	Ballast for Order # 5
12	Rock	7	1.5	Ballast for Order # 5
12	Rock	8	1.3	Ballast for Order # 5
12	Rock	9	0.9	Ballast for Order # 5
12	Rock	10	1.6	Ballast for Order # 4
12	Rock	11	1.3	Ballast for Order # 4
12	Rock	12	1.4	Ballast for Order # 4
12	Rock	13	1.1	Ballast for Order # 3
12	Rock	14	1.2	Ballast for Order # 3
12	Rock	15	1.3	Ballast for Order # 3
12	Rock	16	1.1	Ballast for Order # 3

* Cover wood was added to the structure and secured with 16 pieces of 1.0 m + rock.

Figure 42. Structure 12 post-construction from across the stream on August 10th 2016 . Photo by Evan Smith, August 2016.

Table 6. Components of Structure 13 including material, order and size. All measurements were taken upstream to downstream, closest to the stream to farthest. Comments have been added for easier material position identification. Roots were measured from the ground to the top of the root wad and their diameter was taken just above the root wad. Measurements were recorded on August 10th 2016.

Structure #	Material	Order	Length (m) x Dia. (m) or B axis (m)	Comments
13	Log	1	4.7 x 0.64	Base Log (found on site)
13	Root	2	3.0 x 0.34	Root Cover
13	Rock	3	1.5	Ballast for Order # 1
13	Rock	4	1.2	Ballast for Order # 1
13	Rock	5	1.1	Ballast for Order # 1
13	Rock	6	1.2	Ballast for Order # 1
13	Rock	7	1.2	Ballast for Order # 1
13	Rock	8	1.6	Ballast for Order # 1
13	Rock	9	1.4	Ballast for Order # 2
13	Rock	10	1.3	Ballast for Order # 2
13	Rock	11	1.1	Ballast for Order # 2
13	Rock	12	1.5	Ballast for Order # 2
13	Rock	13	1.1	Ballast for Order # 2
13	Rock	14	1.1	Ballast for Order # 2

Figure 43. Structure 13 post-construction from across the stream on August 12th 2016.Photo by Evan Smith, Okanagan Nation Alliance, August 2016.

Table 7. Components of Structure 14 including material, order and size. All measurements were taken upstream to downstream, closest to the stream to farthest. Comments have been added for easier material position identification. Measurements were recorded on August 12th 2016.

Structure #	Material	Order	Length (m) x Dia. (m) or B axis (m)	Comments
14	Log	1	4.5 x 0.33	Base Log
14	Rock	2	1.0 +	Ballast Rock for Order # 1
14	Rock	3	1.0 +	Ballast Rock for Order # 1
14	Rock	4	1.0 +	Ballast Rock for Order # 1
14	Rock	5	1.0 +	Ballast Rock for Order # 1
14	Rock	6	1.0 +	Ballast Rock for Order # 1
14	Rock	7	1.0 +	Ballast Rock for Order # 1
14	Rock	8	1.0 +	Ballast Rock for Order # 1
14	Rock	9	1.0 +	Ballast Rock for Order # 1
14	Rock	10	1.0 +	Ballast Rock for Order # 1

Figure 44. Structure 14 post-construction from the upstream left bank perspective on August 12th 2016. Photo by Evan Smith, Okanagan Nation Alliance, August 2016.

Table 8. Components of Structure 15 including material, order and size. All measurements were taken upstream to downstream, closest to the stream to farthest. Comments have been added for easier material position identification. Measurements were recorded on August 12th 2016.

Structure #	Material	Order	Length (m) x Dia. (m) or B axis (m)	Comments
15	Rock	1	1.0 +	Rock for Berm
15	Rock	2	1.0 +	Rock for Berm
15	Rock	3	1.0 +	Rock for Berm
15	Rock	4	1.0 +	Rock for Berm
15	Rock	5	1.0 +	Rock for Berm
15	Rock	6	1.0 +	Rock for Berm
15	Rock	7	1.0 +	Rock for Berm

Figure 45. Structure 15 post-construction from a downstream perspective on the left bank on August 12th 2016. Photo by Evan Smith, Okanagan Nation Alliance, August 2016.

Table 9. Components of Structure 16 including material, order and size. All measurements were taken upstream to downstream, closest to the stream to farthest. Comments have been added for easier material position identification. Roots were measured from the ground to the top of the root wad; their diameter was taken just above the root wad. Measurements were recorded on August 10th and 11th 2016.

Structure #	Material	Order	Length (m) x Dia. (m) or B axis (m)	Comments
16	Root	1	1.5 x 0.45	Upstream Root
16	Root	2	1.3 x 0.50	Middle Root
16	Root	3	2.5 x 0.44	In-Stream Root
16	Root	4	1.3 x 0.46	Downstream Root
16	Rock	5	1.0	Ballast for Order # 1
16	Rock	6	1.0	Ballast for Order # 1
16	Rock	7	1.3	Ballast for Order # 1
16	Rock	8	1.1	Ballast for Order # 1
16	Rock	9	1.5	Ballast for Order # 1
16	Rock	10	1.6	Ballast for Order # 2
16	Rock	11	1.2	Ballast for Order # 2
16	Rock	12	1.2	Ballast for Order # 2
16	Rock	13	1.0	Ballast for Order # 2
16	Rock	14	1.0	Ballast for Order # 2
16	Rock	15	0.8	Ballast for Order # 2
16	Rock	16	1.0	Ballast for Order # 2
16	Rock	17	1.3	Ballast for Order # 3
16	Rock	18	1.2	Ballast for Order # 3
16	Rock	19	1.1	Ballast for Order # 3
16	Rock	20	1.1	Ballast for Order # 3
16	Rock	21	0.8	Ballast for Order # 3
16	Rock	22	1.2	Ballast for Order # 3
16	Rock	23	0.9	Ballast for Order # 3
16	Rock	24	1.1	Ballast for Order # 3
16	Rock	25	1.4	Ballast for Order # 3
16	Log	26	3.3 x 0.20	Upstream Log
16	Log	27	3.4 x 0.26	Middle Upstream Log
16	Log	28	3.3 x 0.25	Middle downstream Log
16	Log	29	4.5 x 0.25	Downstream Log
16	Rock	30	1.5	Ballast for Order # 26 - 29
16	Rock	31	0.9	Ballast for Order # 26 - 29
16	Rock	32	1.5	Ballast for Order # 26 - 29
16	Rock	33	1.1	Ballast for Order # 26 - 29
16	Rock	34	1.2	Ballast for Order # 26 - 29
16	Rock	35	1.0	Ballast for Order # 26 - 29
16	Root	36	1.6 x 0.42	Upstream Root

16	Root	37	3.0 x 0.50	Downstream Root
16	Rock	38	1.3	Ballast for Order # 36
16	Rock	39	0.9	Ballast for Order # 36
16	Rock	40	0.9	Ballast for Order # 36
16	Rock	41	1.2	Ballast for Order # 36
16	Rock	42	1.1	Ballast for Order # 36
16	Rock	43	1.1	Ballast for Order # 36
16	Rock	44	1.3	Ballast for Order # 36
16	Rock	45	1.2	Ballast for Order # 37
16	Rock	46	1.5	Ballast for Order # 37
16	Rock	47	1.3	Ballast for Order # 37
16	Rock	48	1.1	Ballast for Order # 37
16	Rock	49	1.2	Ballast for Order # 37
16	Rock	50	1.2	Ballast for Order # 37

Figure 46. Structure 16 post-construction from an upstream perspective on August 12th 2016. Photo by Evan Smith, Okanagan Nation Alliance, August 2016..

Table 10. Components of Structure 17 including material, order and size. All measurements were taken upstream to downstream, closest to the stream to farthest. Comments have been added for easier material position identification. Roots were measured from the ground to the top of the root wad; their diameter was taken just above the root wad. Measurements were recorded on August 10th 2016.

Structure #	Material	Order	Length (m) x Dia. (m) or B axis (m)	Comments
17	Log	1	6.0 x 0.38	Downstream Base Log
17	Log	2	4.0 x 0.48	Upstream Base Log
17	Root	3	2.2 x 0.28	Upstream Ballast Root
17	Root	4	3.5 x 0.48	Middle Ballast Root
17	Root	5	1.8 x 0.21	Downstream Ballast Root
17	Rock	6	1.2	Ballast for Order # 5
17	Rock	7	1.0	Ballast for Order # 5
17	Rock	8	1.1	Ballast for Order # 5
17	Rock	9	1.2	Ballast for Order # 5
17	Rock	10	1.1	Ballast for Order # 4
17	Rock	11	1.3	Ballast for Order # 4
17	Rock	12	1.3	Ballast for Order # 4
17	Rock	13	1.1	Ballast for Order # 4
17	Rock	14	1.3	Ballast for Order # 3
17	Rock	15	1.1	Ballast for Order # 3
17	Rock	16	1.4	Ballast for Order # 3
17	Rock	17	1.3	Ballast for Order # 3
17	Rock	18	1.1	Ballast for Order # 3

* Cover wood was added to the structure and secured with 19 pieces of 1.0 m + rock.

Figure 47. Structure 17 post-construction from an upstream perspective on August 12th 2016. Photo by Evan Smith, Okanagan Nation Alliance, August 2016.

Table 11. Components of Structure 18 including material, order and size. All measurements were taken upstream to downstream, closest to the stream to farthest. Comments have been added for easier material position identification. Roots were measured from the ground to the top of the root wad; their diameter was taken just above the root wad. Measurements were recorded on August 11th 2016.

Structure #	Material	Order	Length (m) x Dia. (m) or B axis (m)	Comments
18	Log	1	6.7 x 0.26	Base Log
18	Root	2	3.2 x 0.52	Downstream Root
18	Root	3	2.7 x 0.21	Upstream Root
18	Rock	4	1.4	Ballast for Order # 2
18	Rock	5	1.3	Ballast for Order # 2
18	Rock	6	1.4	Ballast for Order # 2
18	Rock	7	1.2	Ballast for Order # 2
18	Rock	8	1.3	Ballast for Order # 2
18	Rock	9	1.0	Ballast for Order # 3
18	Rock	10	1.0	Ballast for Order # 3
18	Rock	11	1.4	Ballast for Order # 3
18	Rock	12	1.0	Ballast for Order # 3
18	Rock	13	1.0	Ballast for Order # 3
18	Log	14	4.8 x 0.26	Upstream Log
18	Log	15	2.0 x 0.18	Middle Upstream Log
18	Log	16	3.0 x 0.24	Middle Downstream Log
18	Log	17	4.5 x 0.25	Downstream Log
18	Rock	18	1.2	Ballast for Order # 14 - 17
18	Rock	19	1.0	Ballast for Order # 14 - 17
18	Rock	20	1.2	Ballast for Order # 14 - 17
18	Rock	21	1.2	Ballast for Order # 14 - 17
18	Rock	22	1.0	Ballast for Order # 14 - 17
18	Rock	23	1.0	Ballast for Order # 14 - 17

* Cover wood was added to the structure and secured with 10 pieces of 1.0 m + rock.

Figure 48. Structure 18 post construction from across the stream on August 12th 2016. Photo by Evan Smith, Okanagan Nation Alliance, August 2016.

Table 12. Components of Structure 19 including material, order and size. All measurements were taken upstream to downstream, closest to the stream to farthest. Comments have been added for easier material position identification. Roots were measured from the ground to the top of the root wad; their diameter was taken just above the root wad. Measurements were recorded on August 11th 2016.

Structure #	Material	Order	Length (m) x Dia. (m) or B axis (m)	Comments
19	Log	1	4.8 x 0.29	Base Log
19	Root	2	3.0 x 0.21	Upstream Ballast Root
19	Root	3	2.8 x 0.98	Downstream Ballast Root
19	Rock	4	0.8	Ballast for Order # 13
19	Rock	5	1.0	Ballast for Order # 13
19	Rock	6	1.4	Ballast for Order # 13
19	Rock	7	1.1	Ballast for Order # 13
19	Rock	8	1.1	Ballast for Order # 12
19	Rock	9	1.0	Ballast for Order # 12
19	Rock	10	1.0	Ballast for Order # 12
19	Rock	11	1.6	Ballast for Order # 12
19	Rock	12	1.0	Ballast for Order # 12
19	Root	13	1.0 x 0.30	Ballast Root for Order # 11
19	Rock	14	1.1	Ballast for Order # 23
19	Rock	15	0.9	Ballast for Order # 23
19	Rock	16	1.1	Ballast for Order # 23
19	Rock	17	1.0	Ballast for Order # 23
19	Rock	18	1.2	Ballast for Order # 23

* Cover wood was added to the structure and secured with 7 pieces of 1.0 m + rock.

Figure 49. Structure 19 post construction from across the stream on August 11th 2016. Photo by Evan Smith, Okanagan Nation Alliance, August 2016.

APPENDIX B: Turbidity Monitoring Results

Table 13. Monitoring results from Deer Creek between August 9th and 12th 2016 including date, time, turbidity level and activity taking place during or just before the measurement was taken.

Date	Time	Turbidity (NTU)	Activity
9-Aug-16	9:20	0.32	Baseline
9-Aug-16	10:40	8.47	Excavator Crossing
9-Aug-16	15:49	0.47	20 minutes after work stoppage
10-Aug-16	9:25	0.33	Baseline
10-Aug-16	11:50	0.55	10 minutes after excavator crossing
10-Aug-16	14:55	0.42	25 minutes after instream work
11-Aug-16	9:15	0.38	Baseline
11-Aug-16	10:15	62.6	Excavator crossing & instream work
11-Aug-16	10:20	1.28	5 minutes after excavator crossing
11-Aug-16	14:45	0.95	15 minutes after work stoppage
12-Aug-16	9:05	0.48	Baseline
12-Aug-16	11:05	0.46	25 minutes after instream work