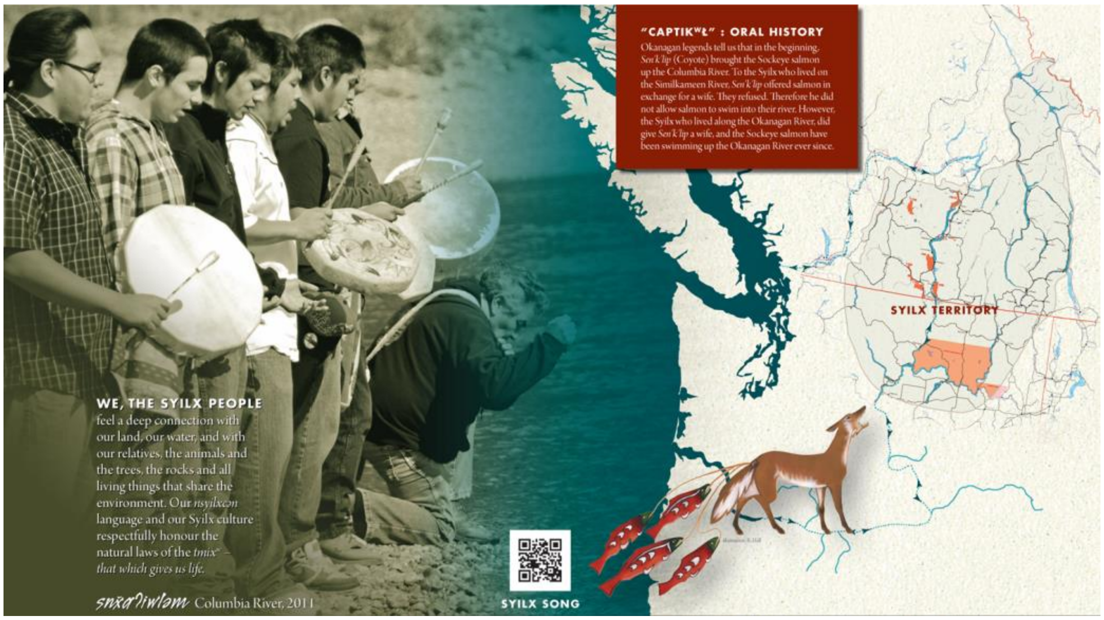
Tributary Assessment of Potential Sockeye, Chinook, and Steelhead Spawning Habitat in the Upper Columbia River, Canada, for Prioritizing Salmon Reintroduction.



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Executive Summary

Habitat Suitability models have been extensively used by fisheries management to estimate the spatial distribution of species which are threatened and/or of harvest interest. Similar to the approach by the Colville Confederate Tribes and Spokane Tribe within the US, Okanagan Nation Alliance implemented the Intrinsic Potential methodology to identify candidate streams for salmon and steelhead production within the Upper Columbia basin, Canada. Suitable sites and potential standing crop within the Okanagan Nation territory is reported for adult sockeye, chinook, and steelhead spawners. These values and ranking of total habitat among all species and 'high potential potential' spawning habitat will guide future planning for salmon reintroduction to the key tributaries identified from this exercise. Recommendations to improve our understanding from this desk top exercise includes additional GIS analysis of the Upper Arrow Lake area, including second order stream segments for steelhead assessment, strategic field validation, and hydraulic modeling of the Columbia mainstem specific to summer-fall Chinook salmon.

Chief Albert Saddleman,

Okanagan Indian Band,

" … *put the water back, and put the salmon back*."

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Introduction

The Okanagan are a ‘Salmon’ People, and inherently acknowledge ‘Ntytix’ as one of four Food Chiefs. Re-establishing salmon and salmon-ecosystems within the Columbia Basin has gained incredible momentum, in light of renewing the Columbia River Treaty. In collaboration with the members of the Upper Columbia United Tribes (UCUT, https://ucut.org/), the Okanagan Nation Alliance (ONA) uses a science-based approach for assessing and promoting fish, habitat, and ecosystem recovery. Improving salmon production and biodiversity in the Columbia River will require reconnecting salmon with salmon bearing streams upstream of numerous High Head Dams (e.g. Grand Coulee). A daunting task, but not impossible as demonstrated by novel fish passage technologies developed within the Columbia Basin. As a key step, habitat suitability modeling specific to anadromous salmon is required for planning, implementing and evaluating adult salmon mitigation strategies. Estimating spatial distribution and potential abundance using Intrinsic Potential (IP) methodology has been extensively used throughout the Pacific Northwest for salmonids (Burnett et al., 2003, Agrawal et al., 2005, Busch et al., 2011), as a first step. For our purpose, we present potential habitat and abundance for adult spawners for Columbia tributaries within ONA area of interest, including the Kettle River, ‘Transboundary’ Reach, Slocan River (Kootenay), and Lower Arrows (including Whatshan River). Pending future funding, Upper Arrows, and the Salmo River will be completed.

1. Columbia River System

As the 52nd longest river in the world, the Columbia River (2250 km in length) drains 669,000 km^2. Historical runs reconstructed from early written records, canneries, archaeological, ethnohistoric and ethnographic data suggests up to 10,023,525 kg of salmon was harvest on the Columbia, annually. Potential salmonid spawning and rearing habitat in the Upper Columbia River basin (upstream of Chief Joe Dam) has been inaccessible from hydro-electric development for nearly 80 years. Numerous high head dams alter the flow of the Columbia River on its course from northern British Columbia to its outlet at the Pacific Ocean. Throughout history, the construction of dams has caused great controversy due to their destruction of habitat, changes in water access, and displacement of communities (Nelson Museum of Art and History, 2007). Changes in the landscape of tributaries of Upper and Lower Arrow Reservoirs and alterations of the foreshore habitat following the construction of Hugh Keenleyside dam is shown in Figures 1 & 2. Chief Joe Dam and Grand Coulee Dam in Washington do not support any fish passage facilities, resulting in 55% of previously accessible potential mainstem and tributary habitat made inaccessible to anadromous salmonids upstream of Chief Joe Dam (Northwest Power and Conservation Council, 2008). Figure 3 shows the course of the Columbia River before the construction of dams began. Table 1 outlines the distance between dams on the Columbia River in terms of migratory travel distance. We focused on five key dams, within the scope of this work:

1. Hugh Keenleyside Dam near Castlegar. Hugh Keenleyside Dam is 52m high with a crest length of 853.4m and a drainage area of 3,650,000ha (BC Hydro, 2017),
2. Arrow Lakes Generating Station,
3. Whatshan Lake Dam; a 12m high, 82m long dam with a drainage area of 39,000ha (BC Hydro, 2005),
4. Brilliant Dam near the Kootenay-Columbia River confluence, and

5. Waneta Dam near the Pend d'Oreille-Columbia River confluence fall outside the study area, though may still impact water levels within the study area.

Figure 1. Burton Creek, a tributary of Lower Arrow Reservoir, before (1962) and after (2009) the construction of Hugh Keenleyside Dam near Castlegar (Columbia Basin Trust, 2017a)

Figure 2. McDonald Creek, a tributary of Upper Arrow Reservoir, before (1962) and after (2009) the construction of Hugh Keenleyside Dam near Castlegar (Columbia Basin Trust, 2017b)

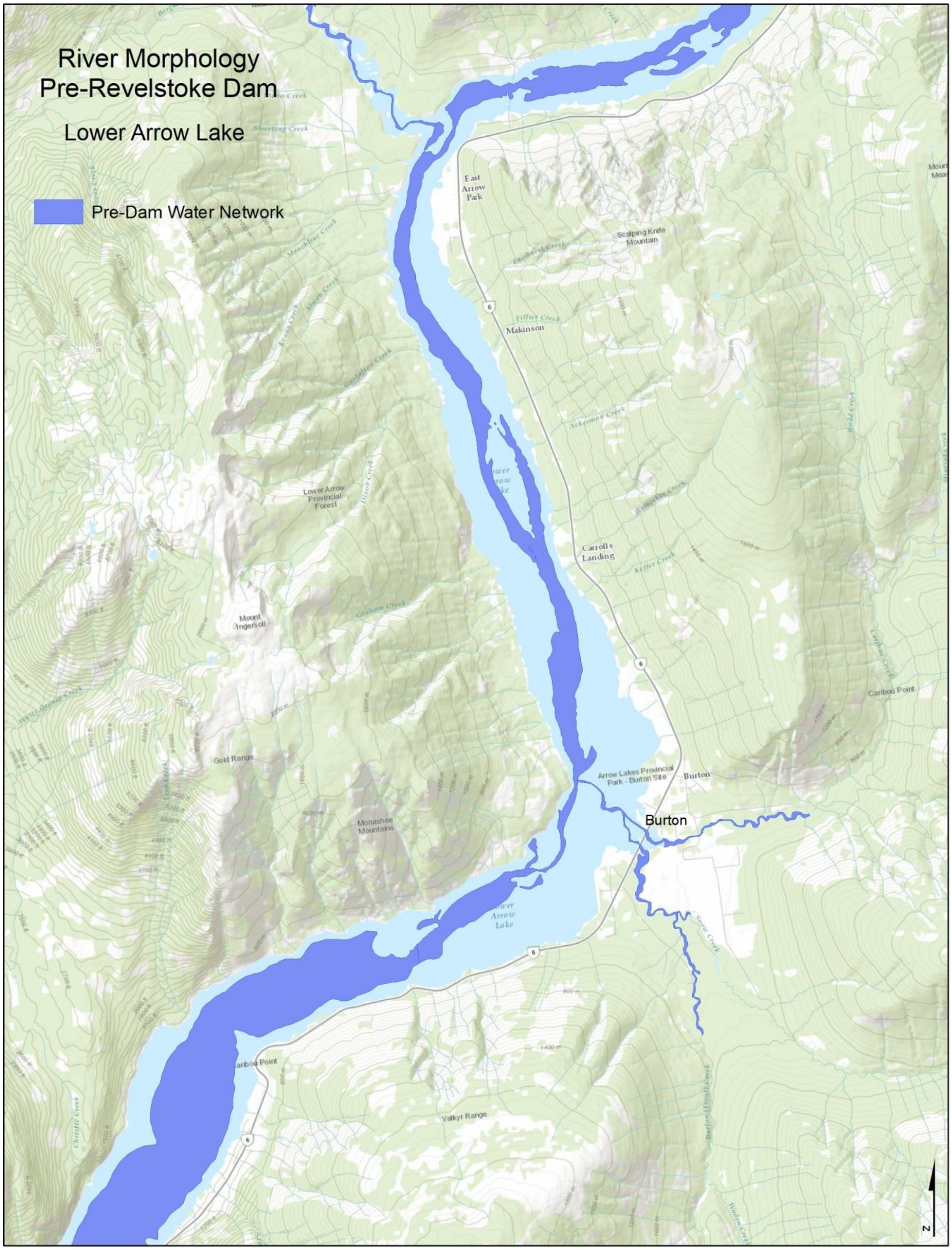

Figure 3. River morphology of Lower Arrow Lake, before Revelstoke Dam construction (Selkirk College, 2017)

Table 1. River kilometer distances between dams and major tributaries on the Columbia River

	Hugh Keenleyside Dam	Kootenay River mouth at Columbia	CAN/USA Border	Kettle River mouth at Columbia	Grand Coulee Dam	Chief Joseph Dam	Wells Dam	Rocky Reach Dam	Wenatchee River mouth at Columbia	Rock Island Dam	Mouth of Columbia River at Pacific Ocean
Hugh Keenleyside Dam		10.7	52.0	113.6	289.7	372.6	419.8	487.5	493.5	520.2	1249.8
Kootenay River mouth at Columbia	10.7		41.3	102.9	279.0	361.9	409.1	476.8	482.8	509.5	1239.1
CAN/USA Border	52.0	41.3		61.6	237.7	320.6	367.8	435.5	441.5	468.2	1197.8
Kettle River mouth at Columbia	113.6	102.9	61.6		176.1	259.0	306.1	373.9	379.8	406.6	1136.2
Grand Coulee Dam	289.7	279.0	237.7	176.1		82.9	130.0	197.8	203.7	230.5	960.1
Chief Joseph Dam	372.6	361.9	320.6	259.0	82.9		47.2	114.9	120.9	147.6	877.3
Wells Dam	419.8	409.1	367.8	306.1	130.0	47.2		67.8	73.7	100.4	830.1
Rocky Reach Dam	487.5	476.8	435.5	373.9	197.8	114.9	67.8		6.0	32.7	762.4
Wenatchee River mouth at Columbia	493.5	482.8	441.5	379.8	203.7	120.9	73.7	6.0		26.7	756.4
Rock Island Dam	520.2	509.5	468.2	406.6	230.5	147.6	100.4	32.7	26.7		729.7
Mouth of Columbia River at Pacific Ocean	1249.8	1239.1	1197.8	1136.2	960.1	877.3	830.1	762.4	756.4	729.7	

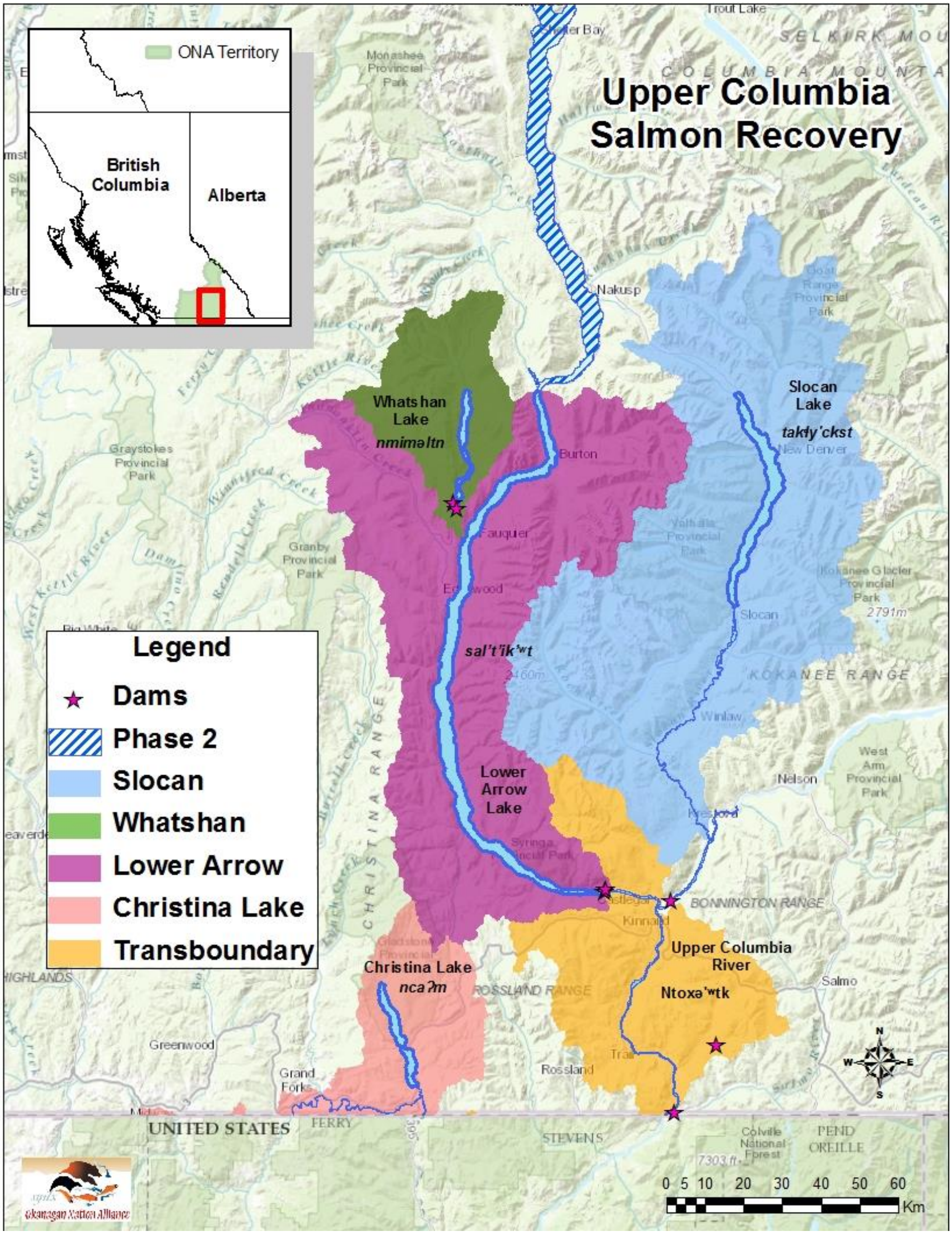

Figure 4. Watersheds of interest for salmon recovery efforts in the Upper Columbia River basin

2. Areas of Interest – Phase 1

2.1 Christina Lake Tributaries

The western-most area of interest is the Kettle River, which branches off the Columbia River in the northeastern corner of Washington, approximately 52rkm from the Canadian border to Christina Lake is the only area evaluated within the Kettle River watershed as accessible by anadromous salmon. Habitat upstream of Cascade Falls (a natural barrier) within a kilometer upstream of Christina Lake was excluded from analysis. The Kettle River is a 6^{th} order tributary at the Canadian border and meets Christina Lake as the 5^{th} order Christina Creek, about 6.5rkm from the border. Christina Lake is 19km long with an average width of 0.6km. It has a drainage area of 519km^2 and an elevation of 446m (LaCroix et al., 2005). This lake is situated in the Interior Cedar-Hemlock biogeoclimatic zone, meaning long, warm summers and cool, wet winters (Forest Service BC, 2016). The average yearly rainfall and snowfall are 42cm and 44cm, respectively (Christina Lake, 2017). From spring-fall, water temperatures range from approximately 8.5-20°C (BC Ministry of Environment, 2017a). Christina Lake and its tributaries support a large population of both native and introduced fish species. These species include trout, bass, whitefish, kokanee, walleye, and perch. Christina Lake was historically stocked with rainbow trout and kokanee and supported a shore spawning kokanee fishery (CLSS, 2009). The climate and fishing of Christina Lake has created a very popular tourist destination in the summer months. The town of Christina Lake has a resident population of 1,4000, which more than doubles during tourist season (HelloBC, 2017a). The continued development of the Christina Lake area raises concerns over the destruction of prime kokanee spawning habitat. The tributaries of Christina Lake used by kokanee have been shifting in recent years, possibly due to removal of habitat and major tributaries with low water flow (LaCroix, 2009). No natural or manmade barriers which would prevent fish passage have been reported in Christina Lake or its tributaries. Cascade Falls, southwest of Christina Lake in the Kettle River, does pose as a barrier to fish passage (BC Ministry of Environment, 2017b,c). A map of Christina Lake and its tributaries of interest is shown in Figure 5.

2.2 Columbia River- Transboundary Tributaries

There are a large number of tributaries located in the transboundary region of the Upper Columbia watershed that present potential habitat for sockeye, steelhead, and/or chinook. The region spans from where the Columbia River crosses the Canadian border to the Hugh Keenleyside Dam near Castlegar. The Columbia River transitions from an 8^{th} order to 7^{th} order stream as it flows through the transboundary region. This region is also located in the Interior Cedar-Hemlock biogeoclimatic zone, meaning cool, wet winters and warm, dry summers (Forest Service BC, 2016). The main cities of this region are Trail (pop. 7,237) and Castlegar (pop. 8,992) and are both built near the banks of the Columbia River (HelloBC, 2017b,c). The temperature range for the Columbia River in this region is roughly 10.5-16.5°C between spring-fall (Environment Canada, 2016). In Trail, the average yearly rainfall and snowfall are 559mm and 211cm, respectively (The Weather Network, 2017a). The Columbia River in this region supports a strong sport fishing industry. The section of river near Trail and Castlegar is known for its excellent walleye and rainbow trout fishing and draws in many tourists for fly fishing and charters (City of Castlegar, 2017). Other species found here include brook trout, whitefish, and perch. Monitoring of large river fish in this section of the Columbia River has been conducted for several years by BC Hydro to study the effects of flow reductions caused by nearby dams (BC Hydro, 2015). Blueberry Creek, a 4^{th} order tributary, is known to be an important spawning area for rainbow trout and efforts have been made to mitigate any potential fish barriers (Arndt, 2009). Manmade barriers in this region impacting fish passage are the Hugh Keenleyside Dam 8rkm upstream of Castlegar and the Arrow Lakes Generating Station located directly below the dam. Brilliant Dam is located 2.8rkm upstream from the confluence of the Koonetay-Columbia Rivers (BC Hydro, 2015). Kelly Creek dam, at 4.6m high, is located in a tributary of interest on the east side of the river. There are four recorded falls within the tributaries of interest in this region which may pose as barriers to fish passage (>5m high). There are also four round culverts, two in Blueberry Creek and two in Murphy Creek, which have been assessed as barriers (BC Ministry of Environment, 2017b,c). A map of the Transboundary region and its tributaries of interest is shown in Figure 6.

2.3 Slocan Watershed Tributaries

The Slocan watershed is the eastern-most region of the study area. Potential habitat for sockeye, steelhead, and/or chinook exists in the tributaries of both the Slocan River and Slocan Lake. The Slocan River flows for 58rkm between the southern point of Slocan Lake to the Kootenay River near the town of South Slocan. The Slocan River is a 6^{th}-5^{th} order river with a drainage area of 3,290km^2 (Northwest Hydraulic Consultants Ltd., 1989). Surface water temperatures range from 8-18°C in the river from spring-fall (Columbia Basin Watershed Network, 2017). Slocan Lake is 39km long and 3km wide with a drainage area of 1800km^2 and sits at an elevation of 542m (Lakepedia, 2017). The water temperature at the lake's surface ranges from 11-19°C during spring-fall. Both Slocan River and Lake are located in the Interior Cedar-Hemlock biogeoclimatic zone (Forest Service BC, 2016). There are several small towns located on the eastern shore of Slocan Lake, including New Denver, Silverton, and Slocan, with populations under 1,000. The west side of the lake is bordered by Valhalla Provincial Park. Due to the number of silver, zinc, and lead mines located in the area in the early 1800s, water testing shows high concentrations of cadmium and zinc in Slocan Lake and some of its tributaries (Grau et al., 2014). The average annual rainfall and snowfall in New Denver are 691mm and 188cm, respectively (The Weather Network, 2017b). Fish species known to inhabit Slocan Lake include kokanee, whitefish, burbot, rainbow trout, and sculpin. Extensive foreshore mapping and aquatic habitat index rankings have been conducted for the shoreline of Slocan Lake. Rearing habitat for juveniles was ranked as high for 16,337m, moderate for 53,365m, and low for 18,233m (Galena Environmental Ltd., 2011). The largest tributary of Slocan Lake, Wilson Creek, is known to support rainbow trout and a small population of kokanee. Bonanza Creek at the north end of the lake is a known kokanee spawning area (Lawrence et al., 2015). Major tributaries of interest for Slocan River include Little Slocan River and Lemon Creek. Fish species observed in these tributaries include rainbow trout, bull trout, sculpin, and suckers (BC Ministry of Environment, 2017d). There is one concrete weir in Bonanza Creek that is classed as a barrier to fish passage. Additionally, there are two waterfalls >5m high in Shannon Creek and one in Evans Creek, tributaries of interest off of Slocan Lake (BC Ministry of Environment, 2017b,c). A map of the Slocan watershed and tributaries of interest is shown in Figure 7.

2.4 Whatshan Reservoir Tributaries

Whatshan River connects Whatshan Reservoir to Lower Arrow Reservoir at its west bank across from the town of Fauquier. Very little data has been collected on Whatshan Reservoir. Whatshan Reservoir is an oligotrophic lake, with a surface area of 16.91km^2 and volume of 0.82km^3. It has a surface elevation of 665m and maximum depth of 116m (BC Hydro, 2005). The reservoir is within the Interior Cedar-Hemlock biogeoclimatic zone. No towns have been built around Whatshan Reservoir. The 12m high Whatshan Dam located at the south end of the reservoir is an impassable barrier to fish passage. There is also one culvert in the Stevens Creek tributary which is impassable to fish (BC Ministry of Environment, 2017b,c). Rainbow trout, bull trout, and kokanee have been reported in Whatshan River and Reservoir. Some fish habitat restoration/enhancement projects, such as nutrient additions, have been proposed for Whatshan River and Reservoir, partially to enhance the sport fishing industry in the area. These waters were previously stocked with rainbow trout and kokanee during the first half of the 20th century, before the Whatshan Dam was constructed. There are some areas of potential kokanee spawning habitat, though overall the lake is classed as unproductive (Andrusak, 2014). A map of Whatshan Reservoir is shown in Figure 8.

2.5 Lower Arrow Reservoir Tributaries

Lower Arrow Reservoir has three tributaries with potential habitat: Taite Creek, Burton Creek, and Caribou Creek. Combined, Upper and Lower Arrow Reservoirs are 230km long with an average width of >3km. Lower Arrow Reservoir has a maximum depth of 180m and surface elevation of 457m (Matzinger et al., 2007). The reservoir stretches from the Hugh Keenleyside Dam to Arrow Park at the Narrows and is located in the Interior Cedar-Hemlock biogeoclimatic zone. There are several historic towns built around the reservoir, including Fauquier (pop. 170) and Burton (pop. 115) (Statistics Canada, 2011). Fauquier has an average rainfall of 577mm and average snowfall of 164cm (The Weather Network, 2017c). The surface water temperature of Lower Arrow Reservoir ranges from 14-20°C during spring-fall (Schindler et al., 2011). Extensive nutrient supplementation has occurred throughout the Upper and Lower Arrow Reservoirs to restore productivity. Both reservoirs support populations of kokanee, rainbow trout, and bull trout. Currently, Gerrard rainbow trout stocking persists in both reservoirs (Schindler et al., 2010). Barriers in this area of interest include the Hugh Keenleyside Dam at the south end of the reservoir and one waterfall >5m in Burton Creek and two in Taite Creek (BC Ministry of Environment, 2017b,c). A map of Lower Arrow Reservoir is shown in Figure 9.

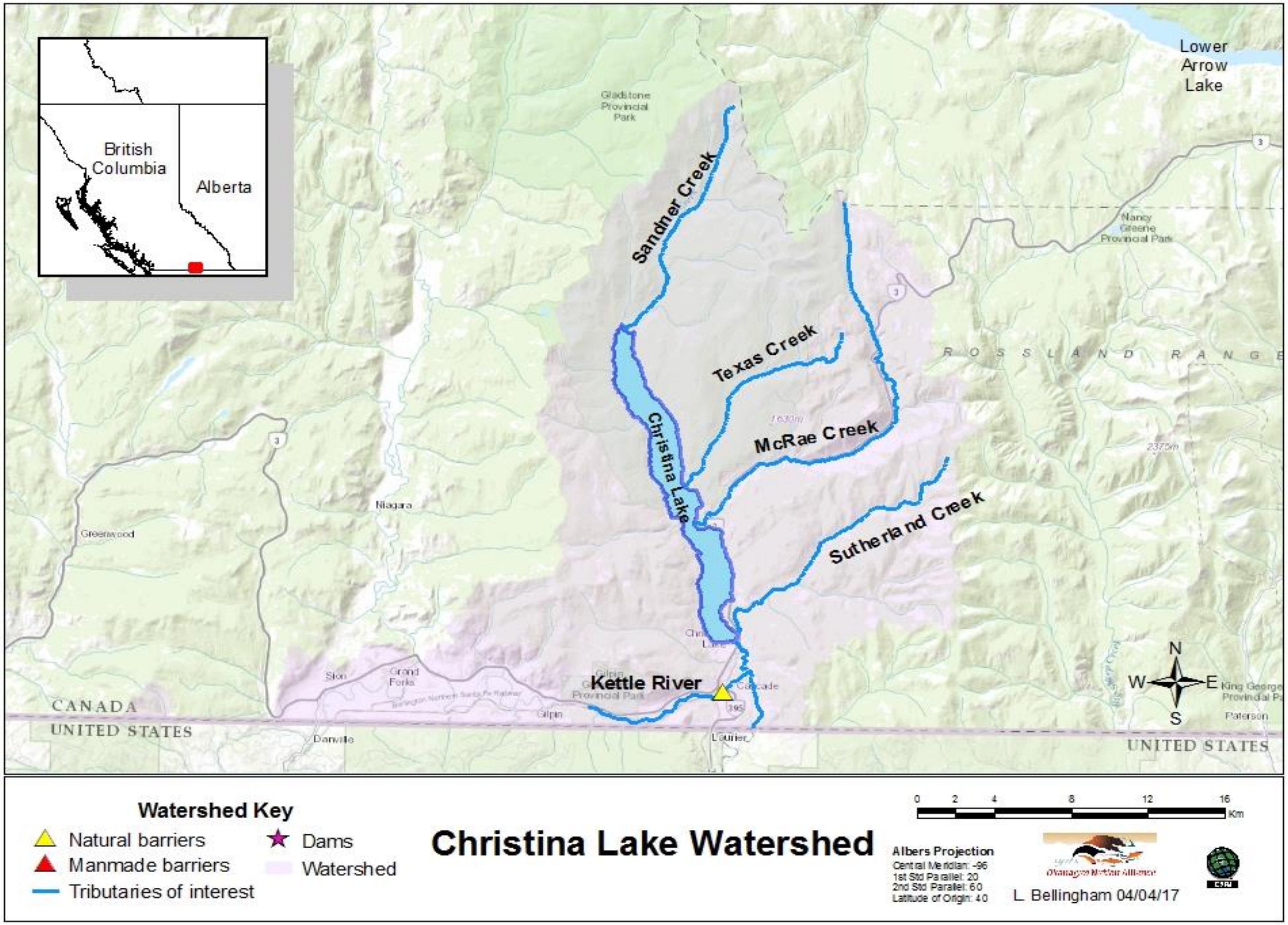

Figure 5. Christina Lake tributaries of interest for salmon recovery and barriers to fish passage

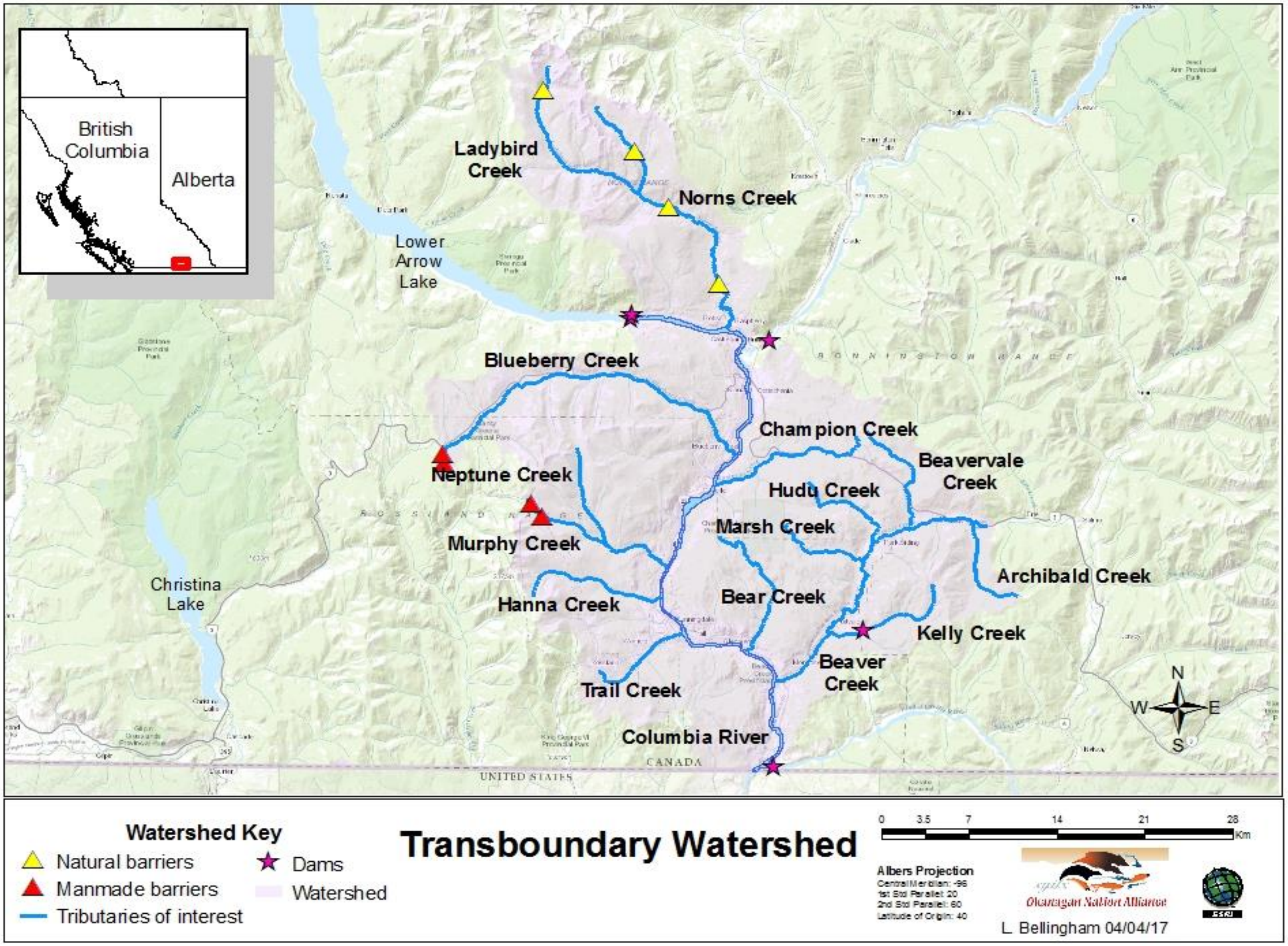

Figure 6. Columbia River transboundary tributaries of interest for salmon recovery and barriers to fish passage

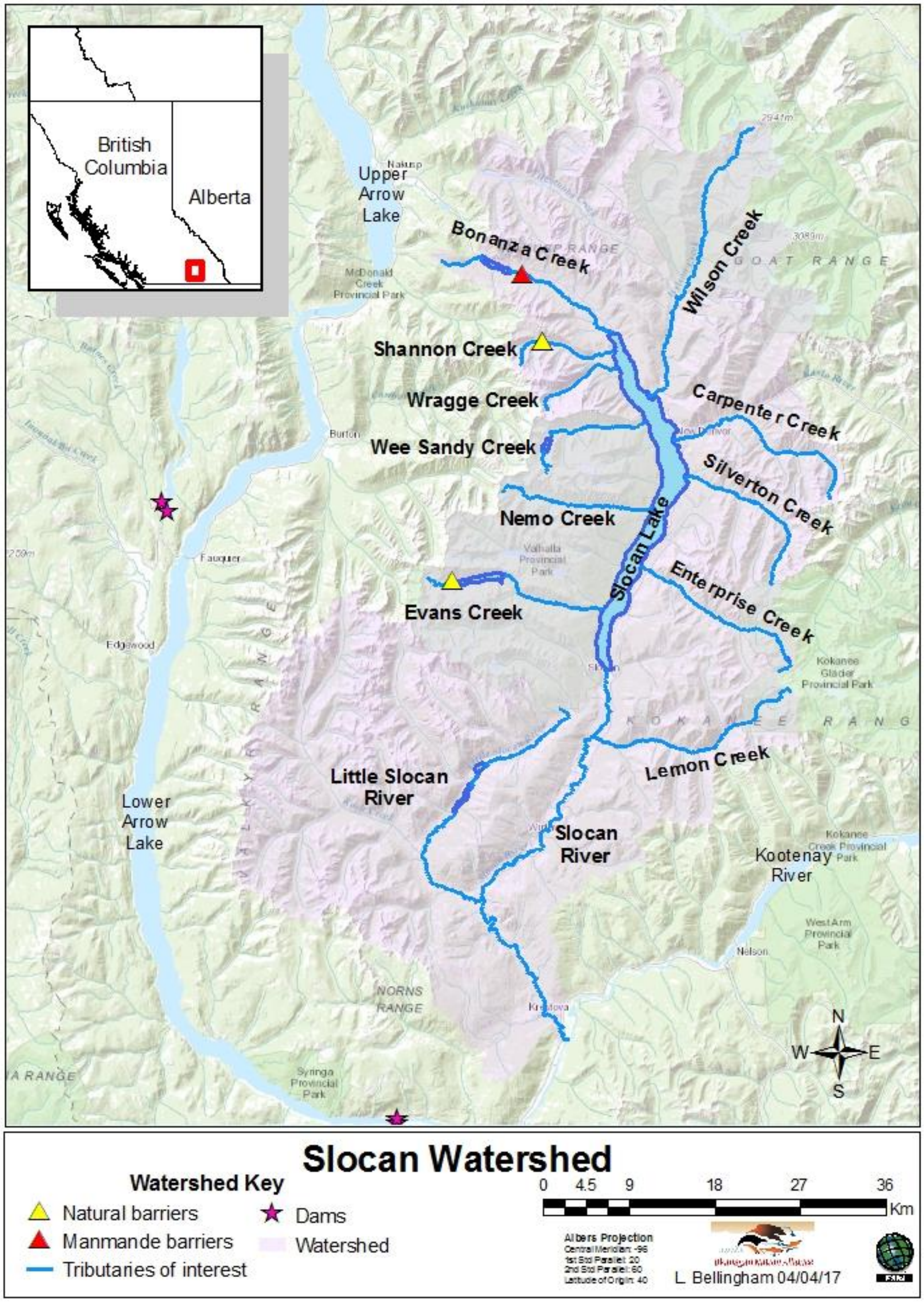

Figure 7. Slocan watershed tributaries of interest for salmon recovery and barriers to fish passage

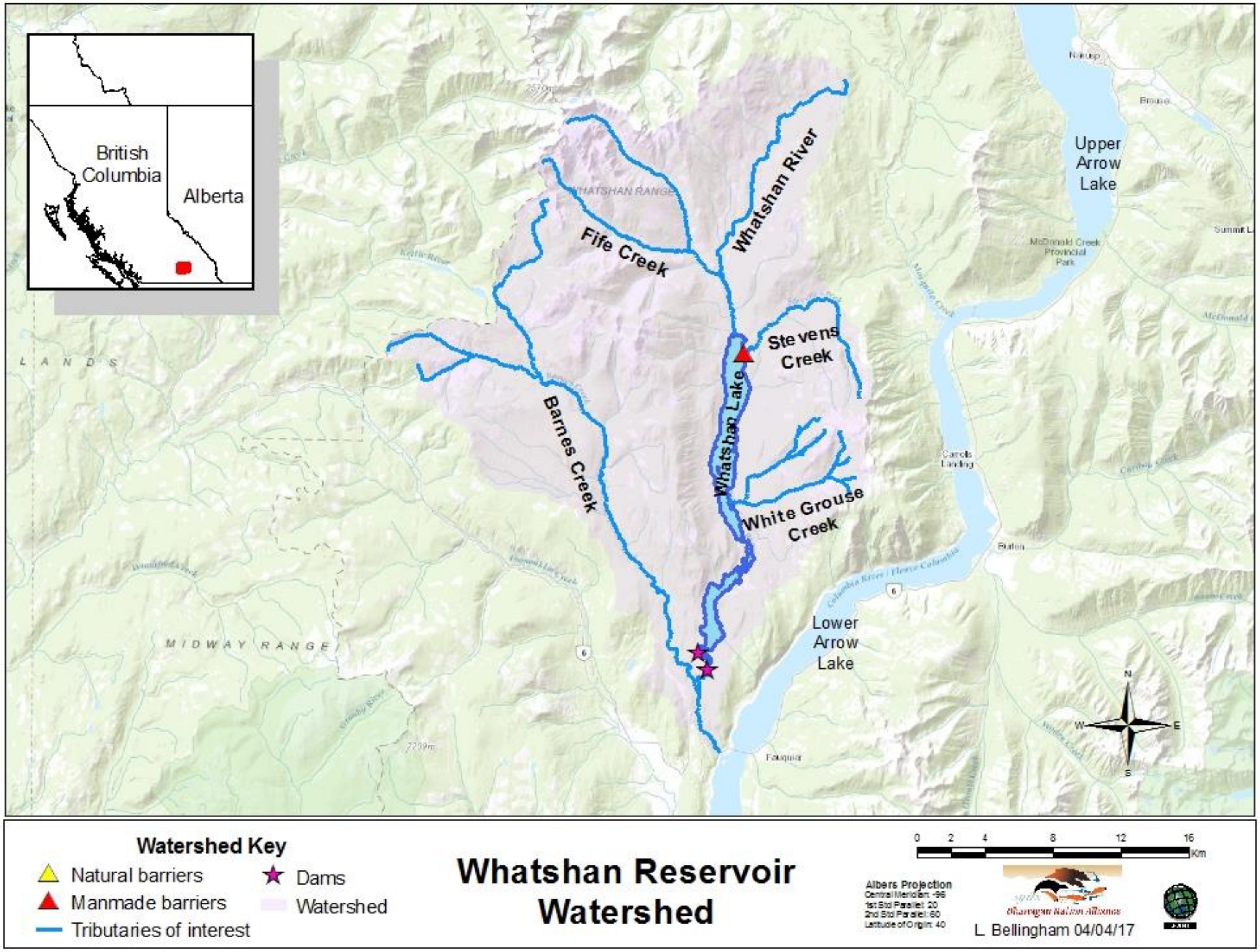

Figure 8. Whatshan Reservoir tributaries of interest for salmon recovery and barriers to fish passage

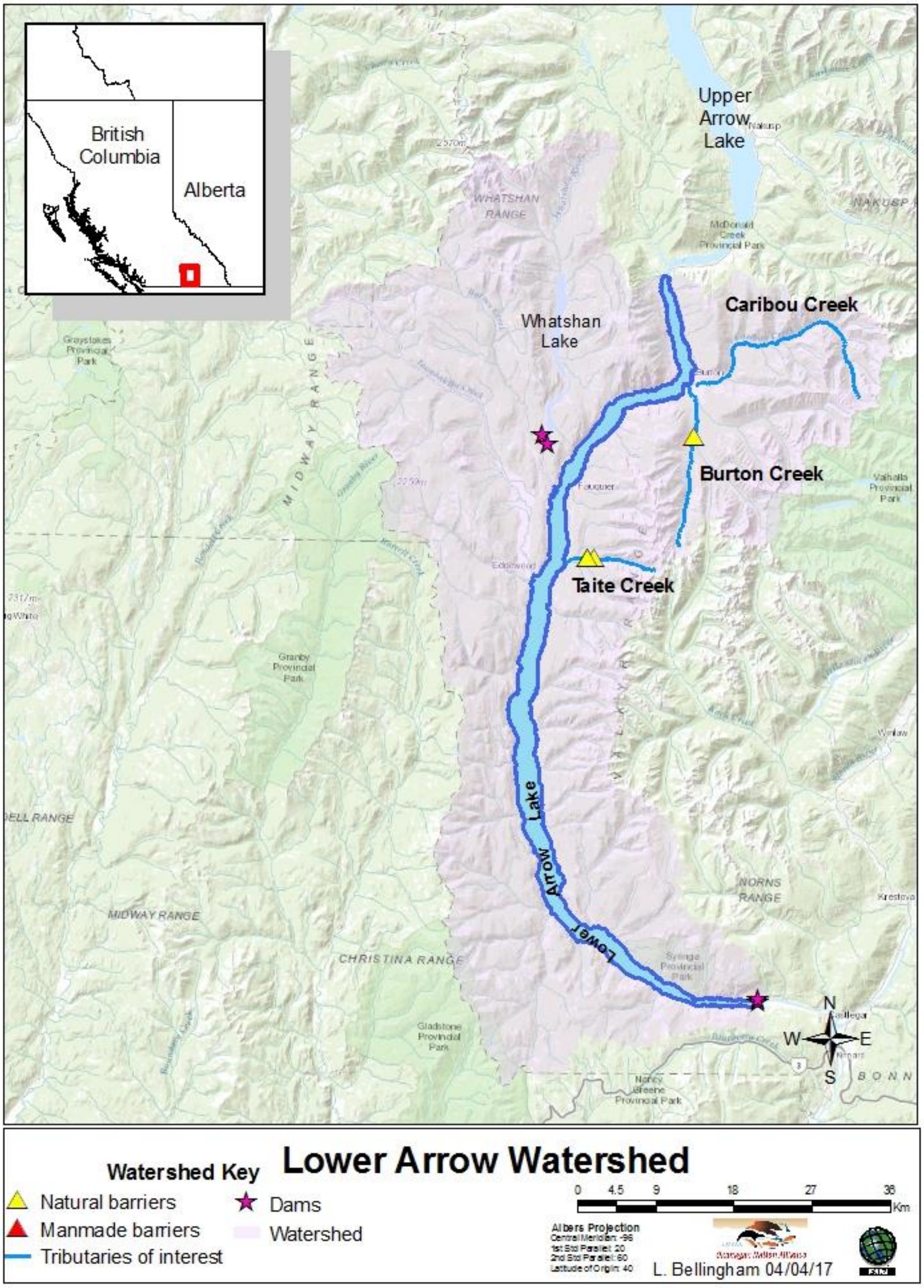

Figure 9. Lower Arrow Reservoir watershed tributaries of interest for salmon recovery and barriers to fish passage

3. Intrinsic Potential Modeling

In our evaluation, we employed a weighted area calculation from intrinsic attributes to calculate potential salmonid abundance and productivity. To determine the potential of salmonid habitat in the Upper Columbia River basin, we combined topographic data, potential migration barriers, salmonid habitat preferences, and existing salmonid habitat utilization data from reference streams throughout the Columbia basin. These data were used to develop intrinsic potential (IP) spawning habitat maps for sockeye, chinook, and steelhead. Reach level channel characteristics, slope and width, and valley form were derived from topographic data using hydrologic and terrain modeling performed by the National Oceanic and Atmospheric Administration (NOAA). Salmonid barrier data from previous studies were used to identify limits to salmon extent for the candidate species (BC Ministry of Environment, 2017b, c). Current juvenile and adult habitat utilization data below the dam were used to identify the relative importance of general habitat types including mainstem and floodplain use. We used species-specific information on spawning habitat preferences based on stream slope, wetted and bankfull width, and channel complexity. By identifying the areas with greatest habitat potential, recovery efforts can be focused in areas most likely to produce the greatest gains and assurance of viability.

Intrinsic Potential (IP) data were received from NOAA Fisheries Northwest Fisheries Science Center) including data for watersheds of the Upper Columbia River in British Columbia to the Narrows between the Upper and Lower Arrow Reservoirs. These IP data were generated on the assumption that habitat preferences of sockeye, chinook, and steelhead preside within a narrow set of hydrological and streambed conditions (Reiser and Bjornn, 1979, Cooney & Holzer, 2006). For chinook and steelhead we implemented the same screening elements as Cooney and Holzer (2006), and adapted new criteria for sockeye via connectivity to a lake system. The primary variables used in IP models for determining reach specific habitat potential are bankfull width, gradient, valley width, and valley confinement. These variables are used to infer the presence of key habitat areas. The development of IP models involves extensive literature research to collect available data on fish habitat and density. The data are used to develop species specific habitat criteria which are applied by GIS to determine the range of species movement within the study area and classify reaches within the range based on species habitat preferences. The IP model used for our research was modeled on the National Hydrography Dataset (NHD) 1:100,000-scale networked reach model, with reaches broken into 200m sections. Using the data from the IP model, ArcGIS maps were created to illustrate the distribution of high, medium, and low potential habitat throughout the major tributaries in each watershed. Upstream macro-reach segments with impassable barriers (natural and non-natural) were also displayed in these maps. In addition to GIS maps, shapefiles were export to the KML file format enabling dynamic viewing with Google Earth imagery for potential control and validation of fish habitat.

Only streams of 3rd order or greater were considered based on species-specific habitat needs and the possibility of smaller streams having no flow in summer months. For the collection and analysis of IP data, the lengths of tributaries were divided into 200m macro-reaches. It is noted that steelhead may be using the smaller streams as spawning areas during peak flows, and therefore estimates of potential are considered conservative. Additional key references included:

Nelitz, M. M. (February 2011). *Evaluating the Status of Fraser River Sockeye Salmon and Role of Freshwater Ecology in their Decline.* The Cohen Commission. Vancouver B.C.: ESSA Technologies Ltd.

Burnett, K. M., Reeves, G. H., Miller, D. J., Clarke, S., Vance-Borland, K., & Christiansen, K. (2007). Distribution of Salmon - Habitat Potential Relative to Landscape Characteristics and Implications for Conservation. *Ecological Applications* (17(1)), 66-80.

4.0 Mapping the Spatial Data

The stream macro-reach data were populated with a select set of known natural and non-natural barriers reviewed for their specific impact on salmon movement. The IP Habitat productivity spreadsheets for each stream network were table-joined using ArcGIS to the macro-reach spatial data attributes referencing a shared unique ID. This layer was themed for each of three salmon species based on two classification fields: the productivity rating and barriers. Macro-reach segments including a barrier were given a colour slightly lighter than the non-barrier productivity rate class. The productivity rate classes were given three colours:

Black – No productivity
Red – Low productivity
Yellow – Moderate productivity
Green- High productivity

The themed layers were exported to a kml file for viewing and visual validation using imagery available with Google Earth.

4.1 Spatial Data Gaps

Spatial data used within the context of a transboundary study area generally have variations in origination, gaps connectivity across the Canada/US border and differing attributes describing the spatial features. These systemic differences pose numerous challenges particular to hydrological network analysis that is based on connectivity.

1) Hydrological network spatial data has border discontinuity and in the Washington State spatial data some dangling macro-reach segments. IP data in British Columbia is largely incomplete and exists for parts of the study area due to US work extended northwards.
2) The BC portion of the transboundary IP macro-reach stream spatial attributes is missing stream order information
3) Further gaps in the National Hydrography Dataset (NHD) 1:100,000-scale networked reach model can be seen in Figure 10. There are data gaps where branching of the Kettle River occurs and the network of creeks flowing into Christina Lake are incomplete

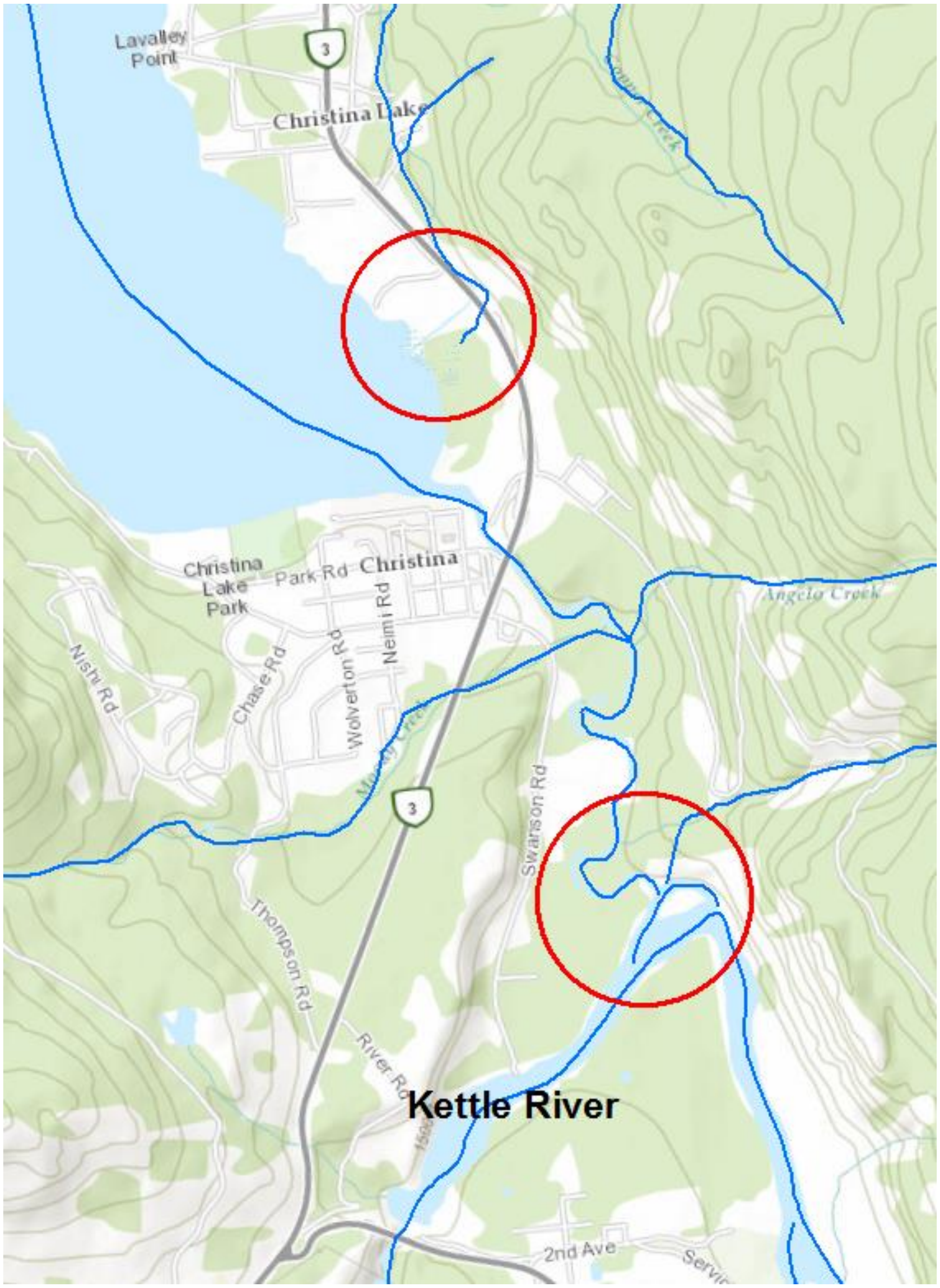

Figure 10. Example of connectivity breaks in NHD 1:100,000 network

5.0 Results- IP Outputs for sockeye, chinook, and steelhead

Notably, salmonids of interest for this exercise have species-specific habitat suitability criteria. The potential of available habitat may differ for each species within one stream based on factors such as depth, stream velocity, and substrate size. Sockeye prefer spawning areas ≥15cm deep, while steelhead prefer ≥24cm deep. The temperature of streams further impact the potential of habitat provided for each species. The recommended spawning temperature for sockeye is 10.6-12.2°C, considerably higher than the 3.9-9.4°C recommended for steelhead. The area used by spawning pairs also varies by species, affecting the amount of spawning carried out by each species in the same stream. For example, the average area of redds for steelhead is 4.7m^2, compared to 1.8m^2 for sockeye (Levy et al., 1993). All of these factors contribute to the significant differences in habitat availability and predicted abundances for each tributary and species.

An estimate of potential spawning habitat area provided a relative measure for abundance criteria. Therefore, availability of suitable 'high' quality would associate with high abundance. We weighted the amount of habitat (length and area) in each 200 m reach by a simple proportion corresponding to the assigned reach rating (high, medium or low). Units of habitat rated high potential were given a weight of '1', medium a weight of '0.5', and low a weight of '0.25'. Habitat rating for each 200 m was adjusted for density and biomass based on expert opinion. Density ratings for chinook ranged from 0.0013 redd/m^2 (low), 0.005 redd/m^2 (medium), and 0.02 redd/m^2 (high). Density ratings for steelhead ranged from 0.0008 redd/m^2 (low), 0.0031 redd/m^2 (medium), and 0.0125 redd/m^2 (high). Density ratings for sockeye ranged from 0.05 redd/m^2 (low), 0.20 redd/m^2 (medium), and 0.75 redd/m^2 (high). Median 'weights' of each species (chinook (8.2 kg), steelhead (3.6 kg), and sockeye (1.4kg)) was expanded by approximate densities and respective biomass. For our purposes, relative abundance and biomass is in reference to standing crop potential.

5.1 Christina Lake

Christina Lake has four main tributaries containing potential habitat to support salmon recovery efforts. These tributaries provide 60.9km of stream ≥3^{rd} order (Table 2). Within these tributaries, there are no manmade or natural barriers to fish passage.

Table 2. Christina Lake tributary stream orders and magnitude

Stream order	Frequency	Magnitude ≥3^{rd} order (km)
3rd	5	47.1
4th	1	13.8
Total	6	60.9

In every watershed, there are factors that can limit the abundance of fish species. The key limiting factors of the Christina Lake watershed include smaller tributaries that provide salmonid habitat drying up in summer months and increased urban development around the lake, causing decreases in available habitat. Invasive species also have an impact on fish abundance by the lake and its tributaries. *Mysis relicta* were introduced to Christina Lake in 1966, in an effort to increase the productivity of the lake. Recent empirical studies show that these shrimp compete with young kokanee for zooplankton, reducing the food available for juvenile kokanee (CLSS, 2009). Given the close proximity of Christina Lake to the USA border, there is concern that invasive Zebra and Quagga mussels may be transferred into the lake from visiting boats. These mussels consume food sources needed by fish species and can alter the clarity of water, causing changes in vegetation. To date, these mussels have not been observed in Christina Lake.

5.1.1 Potential spawning and rearing habitat

Sockeye

There are no areas of high or moderate productivity habitat for sockeye within the major tributaries of Christina Lake. Low potential habitat exists within Sutherland and Sandner Creeks, amounting to 225m^2 and 1740m^2 of habitat, respectively. Given the size of available habitat, the predicted abundance for sockeye production within the Christina Lake watershed is 465. Habitat in Sutherland Creek is isolated to one macro-reach near the mouth of the creek, while habitat in Sandner Creek is spread between several macro-reaches within the 6km nearest the mouth of the creek. Based on this analysis, the area of Christina Lake with the highest recovery potential for sockeye is Sandner Creek. Given that Sandner and Sutherland Creeks are situated as opposite ends of Christina Lake, there is not high connectivity between tributaries containing habitat. Figures 11 & 12 show the habitat and abundance in each creek.

Chinook

A range of chinook habitat is present in the Christina Lake watershed. High potential habitat is identified within one macro-reach in Sandner Creek at 5.6km from its outlet. This 800m^2 section will result in a conservative abundance of 16 chinook. Sandner Creek also contains 4,200m^2 of moderate habitat, and may support 21 chinook. This habitat is distributed throughout the 7.6km of stream nearest the mouth. Additionally, Sandner Creek has 5,370m^2 of low potential chinook habitat estimated to abundance 7 chinook. Areas of low and no habitat are located between areas of moderate habitat.

Sutherland Creek contains no high potential habitat, but does contain 2,220m^2 and 4,210m^2 of moderate and low potential habitat; and, may result in 11 and 6 chinook, respectively. These macro-reaches of habitat are scattered within the lower 5.4km of stream, nearest the mouth, with moderate habitat dispersed between sections of low potential habitat.

McRae Creek does not have any areas of high productivity and only 520m^2 of moderate productivity habitat, supporting less than three chinook. Low productivity habitat is spread throughout the lower 17.6km of stream, nearest the mouth. There is 12,420m^2 of low habitat in McRae creek, for supporting 17 chinook. This low productivity habitat is interspersed with macro-reaches of no productivity and a concentrated area of moderate productivity.

Overall, within the four main tributaries of Christina Lake, there is 800m^2, 6,940m^2, and 22,000m^2 of high, moderate, and low potential chinook habitat, respectively. Our results show a total estimated 81 chinook (see Figure 13 & 14). When all the tributaries of Christina Lake are taken into consideration, including <3rd order streams, there is 4,640m^2, 9810m^2, and 24,415m^2 of high, moderate, and low potential chinook habitat, respectively. Including 2nd order streams, we estimated a 2-fold increase in abundance (total of 175 chinook) for the entire watershed. The majority of this additional habitat concentrated in Christina Creek between the Kettle River and Christina Lake. Based on the IP data evaluation of the major tributaries, Sandner Creek has the highest recovery potential for chinook. McRae Creek is a secondary option, followed by Sutherland Creek. In each tributary, potential habitat is concentrated near the outlet to Christina Lake. Given the distribution of habitat between major tributaries, there is high connectivity of chinook habitat within the watershed.

<u>Steelhead</u>

All four main tributaries of the Christina Lake watershed contain low and high potential steelhead habitat. Sutherland Creek contains 18,925m^2 of low potential and 15,580m^2 of high potential habitat (16 and 195 steelhead, respectively). Of the total 17.4 km, 16.6 km exist for steelhead production. Low potential habitat sections range from 0.2-3.2km long and are is interspersed with short sections of high potential and no habitat. McRae Creek contains 6,240m^2 and 19,680m^2 of low potential and high potential habitat, respectively. The areas of high potential habitat are predicted to support 246 steelhead, while low potential areas 5 steelhead. Steelhead habitat extends throughout only 7.2km of the 27.2km creek. Sections of high, low, and no habitat are spread through this area, with areas of high potential habitat located between areas of low potential habitat.

Sandner Creek contains the greatest area of high potential habitat, at 31,695m^2 (396 steelhead). It also contains 8,260m^2 of low potential habitat (7 steelhead). This habitat is spread throughout 9.2km of the 15.8km stream. Macro-reaches of high, low, and no habitat are interspersed. Steelhead is the only species with potential habitat in Texas Creek. A total 760m^2 of high potential habitat (10 steelhead), and 14,055m^2 of low potential habitat (12 steelhead) is esimated. Low potential steelhead habitat is situated in the 12.2km nearest the mouth and is interspersed with areas of no habitat. High potential habitat is found in only one macro-reach at 12.4km upstream of Christina Lake.

Overall, within the four main tributaries of Christina Lake, there is 67,679m^2 and 47,480m^2 of high and low potential steelhead habitat, respectively (887 steelhead). Of these four tributaries, Sandner Creek contains the greatest area of habitat and potential for steelhead abundance (see Figure 15 & 16). When second order streams are added to the analysis, there is 171,374m^2 and 63,735m^2 of high and low potential steelhead habitat, respectively. Based on second order or greater, a total abundance of 1,398 steelhead for the whole Christina Lake watershed is estimated (or 1.5X fold increase). Much of this additional habitat is located in Christina Creek, Moody Creek (tributary of Christina Creek), and Italy Creek (tributary of Sutherland Creek). As with chinook habitat, the steelhead habitat within each major tributaries is most densely concentrated near the outlet to Christina Lake. Given that all the tributaries provide steelhead habitat, there is high connectivity between possible recovery sites.

<u>Christina Lake watershed</u>

Figure 17 represents potential habitat for each species within the main tributaries of the watershed. Most of the potential habitat within these tributaries is best suited for steelhead, followed by sockeye then chinook. Table 3 outlines the predicted abundance of each species for the watershed by abundance.

Table 3. Predicted salmon abundance and abundance in Christina Lake watershed

	Relative abundance			**Biomass (kg)**		
Stream	Chinook	Steelhead	Sockeye	Chinook	Steelhead	Sockeye
Sutherland	17	211	47	139.4	759.6	65.8
McRae	20	251	0	164	903.6	0
Texas	0	22	0	0	79.2	0
Sandner	44	403	417	360.8	1450.8	583.8
Key tributaries total	81	887	464	664.2	3193.2	649.6
Watershed total	175	1398	465	1435	5032.8	651

*abundances calculated as chinook=8.2kgs, sockeye=1.4kgs, steelhead=3.6kgs

5.1.2 Spatial Distribution

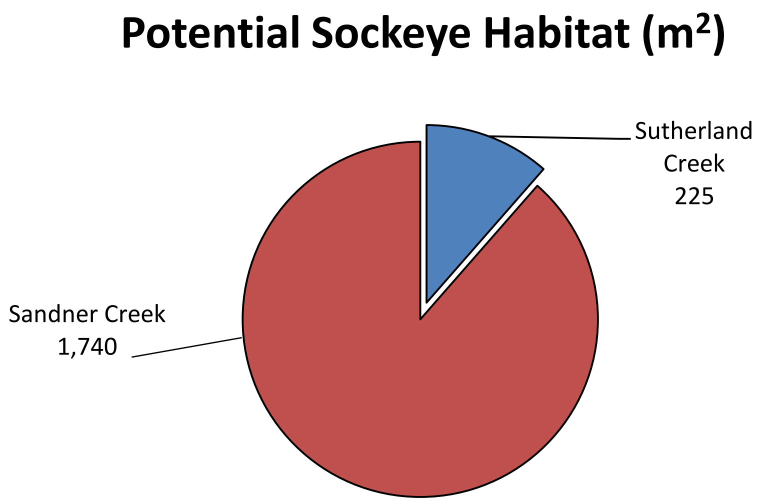

Figure 14. Sockeye habitat in Christina Lake key tributaries

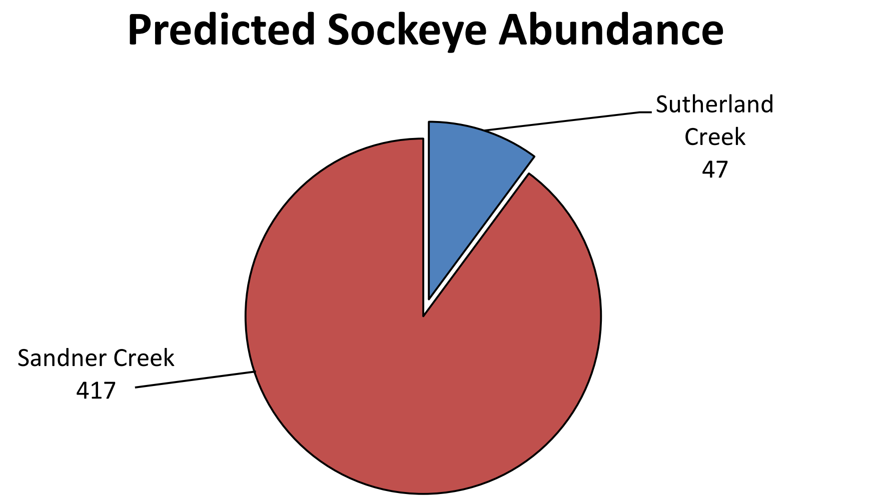

Figure 12. Sockeye abundance in Christina Lake key tributaries

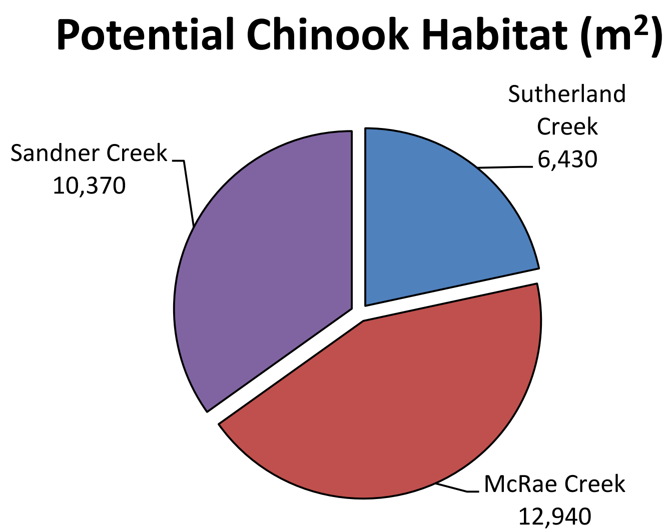

Figure 13. Chinook habitat in Christina Lake key tributaries

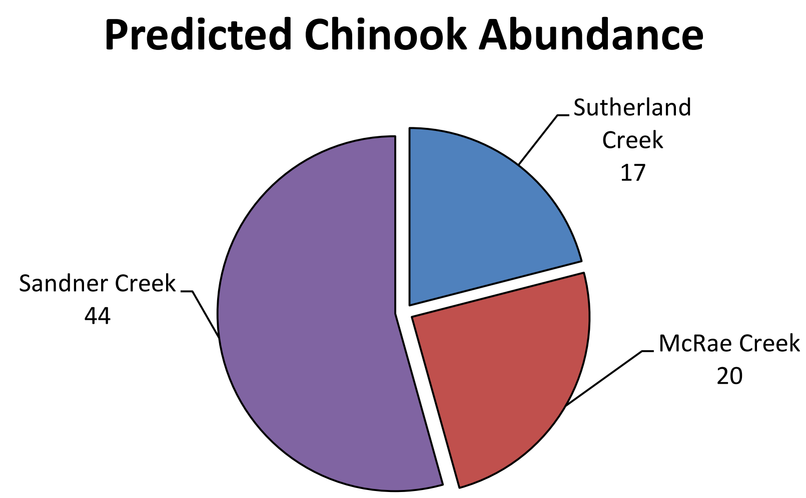

Figure 11. Chinook abundance in Christina Lake key tributaries

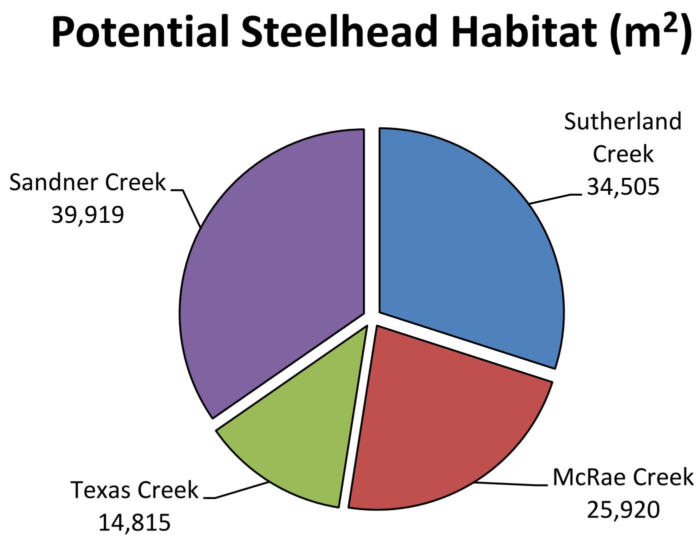

Figure 16. Steelhead habitat in Christina Lake key tributaries

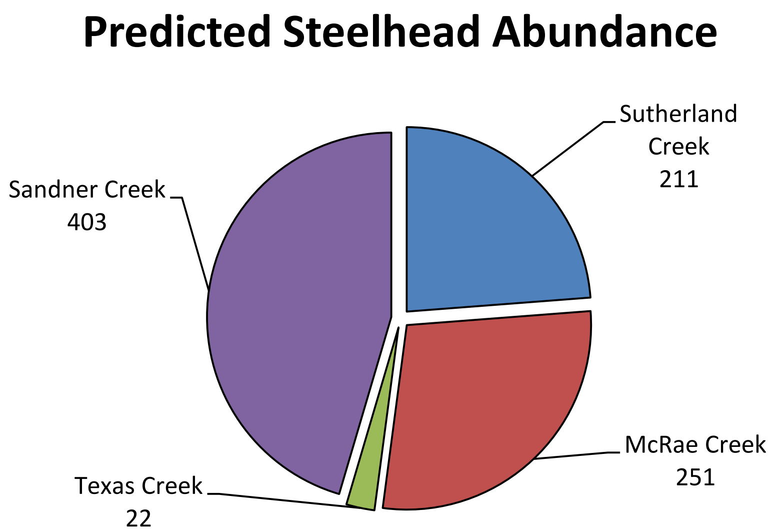

Figure 15. Steelhead abundance in Christina Lake key tributaries

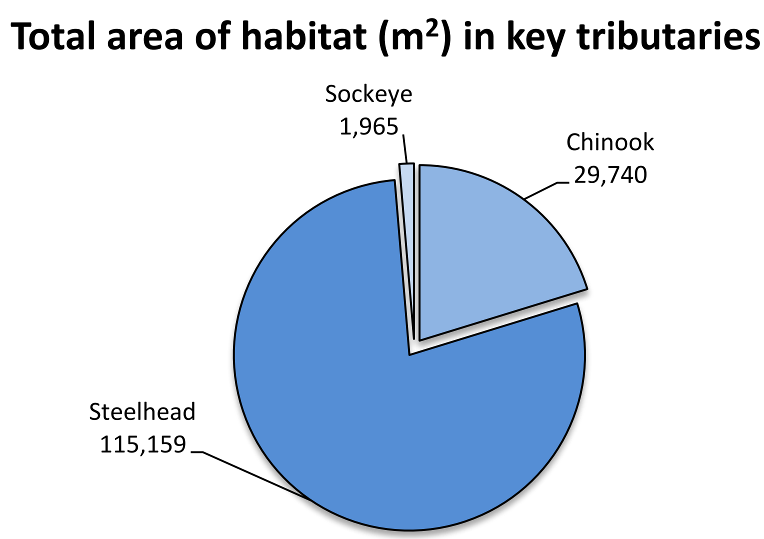

Figure 17. Total area of salmon habitat in Christina Lake key tributaries

5.2 Transboundary Region

The Columbia River Transboundary region extends from the Canada-USA border to the Hugh Keenleyside Dam. This section of the Columbia River has eight main tributaries that provide habitat for sockeye, chinook, and/or steelhead. Within this watershed, there is 145.1km of stream ≥3rd order (Table 4). These tributaries contain four natural barriers, four man-made barriers, and one dam. Table 5 provides details of these barriers.

In previous summers, there have been fisheries closures in the majority of Transboundary tributaries due to warm temperatures and low flows. Changes in discharge and flow at Hugh Keenleyside Dam can result in events of fish stranding downstream. Stranding may result in lethal effects on fish, though recent studies have not found occurrences of significant fish stranding in this area (BC Hydro, 2015). Given the movement of water in this section of the Columbia River, the introduction of invasive species in these tributaries is a possibility.

Table 4. Transboundary watershed tributary stream orders and magnitude

Stream order	Frequency	Magnitude ≥3rd order (km)
3rd	13	108.1
4th	2	37.0
Total	15	145.1

Table 5. Barriers within Transboundary watershed tributaries

Barrier Type	Location	Distance from mouth of tributary
Falls	Norns Creek	6.3km
Falls	Norns Creek	16.5km
Falls	Norns Creek	23.5km
Falls	Ladybird Creek	14.6km
Round culvert	Blueberry Creek	31.2km
Round culvert	Blueberry Creek	31.8km
Round culvert	Murphy Creek	12.2km
Round culvert	Murphy Creek	13.6km
Dam	Kelly Creek	3.0km

5.2.1 Potential spawning and rearing habitat

<u>Sockeye</u>

There is very limited sockeye habitat in the Columbia River tributaries in the Transboundary Region, despite known observations of minor kokanee spawning .

Chinook

There are nine creeks in the Transboundary watershed that provide chinook habitat. Bear Creek and Murphy Creek only contain 185m^2 and 6,675m^2 of low potential chinook habitat, respectively. This small amount of habitat in Bear Creek is predicted to support less than two chinook, while Murphy Creek is conservatively predicted to support nine chinook. Beaver Creek is the southern most tributary and expected to produce the highest abundance. The creek contains 54,080m^2 of high, 20,030m^2 of moderate, and 15,140m^2 of low potential chinook habitat. High potential habitat is concentrated in two main sections in the upstream half of the creek and could support 1,082 chinook. Short sections of moderate habitat are distributed throughout the creek, to support 100 chinook. There is an additional 20 chinook expected to spawn in the low potential habitat distributed through 23.6 km of the 29.6 km creek. Kelly Creek is a tributary of Beaver Creek containing a total of 2,970 m^2 of chinook habitat and supporting eight chinook. This habitat is proximate to the downstream 2.6km of the 11.5km tributary. The dam located in Kelly Creek does not affect the accessibility of chinook habitat.

Trail Creek and Champion Creek are expected to be marginally used by chinook (5 and 18, respectively). Trail Creek contains only one macro-reach of moderate potential habitat and its remaining low potential habitat is located within the 4km nearest its outlet. Champion Creek has several large sections of low potential habitat spread throughout the 8.8km section near the mouth, and are separated by short sections of moderate to no potential habitat. Trail and Champion Creek chinook habitat totals are 2,940m^2 and 8,350m^2, respectively.

Blueberry Creek provides 4,340m^2, 14,810m^2, and 20,406m^2 of high, moderate, and low potential chinook habitat. High potential habitat is located in five macro-reaches dispersed through the creek and could support 87 chinook. Low potential habitat predominates the creek from 0.2 R-km to 3.4R-km, with fragments of moderate habitat. We predict low and moderate potential habitat to support 27 and 74 chinook, respectively. The culvert barriers in Blueberry Creek do not block passage to any chinook habitat.

Norns Creek and its tributary Ladybird Creek are located at the northern end of the watershed. Approxiamtely 5,658m^2, 5,090m^2, and 17,970m^2 of high, moderate, and low potential habitat is estimated for Norns Creek. The falls barriers in Norns Creek does impact the full potential of the stream. Only one macro-reach of high potential habitat, 1,539m^2, is currently accessible, changing the expected chinook abundance from 113 to 31. Three macro-reaches of moderate potential habitat, 2,250m^2, are located downstream of the falls, supporting 11 of the 25 predicted chinook. Low potential habitat is then reduced from 24 to 9 chinook in the 6,745m^2 of accessible habitat. The entire Ladybird Creek is currently inaccessible as it is located upstream of the Norns Creek falls. In this creek there is potentially a total of 10,150m^2 of habitat that could support 19 chinook.

Based on these estimates of habitat area and chinook abundance, Beaver Creek is the best option for recovery efforts. This tributary has the highest chinook potential and greatest area of habitat (Figure 18 & 19). Blueberry Creek would be a secondary option, with considerably less habitat and lower abundance. Norns Creek is a potential tertiary option if the impassable barriers are resolved. These possible recovery sites have considerable distances between them; Norns Creek is at the north end of the watershed and Beaver Creek at the south end.

Blueberry Creek is situated about 19km downstream of Norns Creek. Therefore, connectivity is low between the optimal recovery sites.

Steelhead

There are 14 creeks in the Transboundary region providing steelhead habitat. Beaver Creek has the greatest area of high potential habitat and overall steelhead habitat. From 4.8km upstream until the end of creek there is 24.4km of stream containing low, moderate, and high potential habitat. High potential habitat occupies the greatest area, 221,656m^2, and predicted to support 2,771 steelhead. Moderate potential habitat exists in one macro-reach, providing 700m^2 of habitat and supporting two steelhead. An estimated at 11,520m^2 of low potential habitat sould support 10 steelhead. Beaver Creek has five tributaries containing steelhead habitat; Kelly Creek, Marsh Creek, Hudu Creek, Beavervale Creek, and Archibald Creek. These tributaries provide a mix of high, moderate, and low potential steelhead habitat totaling 85,272m^2. Combined, these tributaries could support 664 steelhead. The only habitat impacted by impassable barriers is in Kelly Creek. Accessible low potential habitat is decreased from 10,635m^2 to 3,570m^2 and the steelhead abundance is reduced by six.

Blueberry Creek provides the second greatest area of steelhead habitat, with 168,646m^2 (or 1,903 steelhead). This habitat is distributed through the entire creek, with large sections 0.2-3.2km long of high potential habitat divided by macro-reaches of low and no potential habitat. Only one reach containing low potential habitat is inaccessible due to the culvert barriers in Blueberry Creek. Combined, Norns Creek and its tributary Ladybird Creek provide 149,646m^2 of steelhead habitat, supporting 1,493 steelhead. However, given the natural barriers located in these tributaries, there is currently only 34,876m^2 of accessible habitat that could support 356 steelhead.

Bear Creek, Hanna Creek, and Champion Creek are all small tributaries containing high and low potential steelhead habitat. Bear Creek is composed of short sections of low potential habitat spread throughout the creek separated by reaches of high and no potential habitat, amounting to a total of 22,370m^2. Hanna Creek has one macro-reach of high potential habitat and sections of low potential habitat spread evenly through the creek, providing 7,860m^2 of steelhead habitat. The habitat in Champion Creek is all restricted to the 1.4km nearest the outlet, totaling 9,130m^2. Bear Creek, Hanna Creek, and Champion Creek are predicted to support 173, 22, and 105 steelhead, respectively. Murphy Creek and its tributary Neptune Creek provide 27,595m^2 of chinook habitat and are predicted to support 86 chinook. Both Creeks are primarily low potential chinook habitat divided by macro-reaches of no habitat and few reaches of high potential habitat. There is 850m^2 of inaccessible low potential habitat in Murphy Creek that could support less than two steelhead.

As with chinook recovery sites, the recommended recovery sites for steelhead are Beaver Creek followed by Blueberry Creek and Norns Creek (Figure 20 & 21). Again, the impassable barriers in Norns Creek would first need to be addressed to make this tributary a viable option as a recovery effort site. The low connectivity of these tributaries is discussed in the chinook recommendations.

Transboundary watershed

Given that there is no sockeye habitat in the Transboundary watershed, it is best suited for steelhead recovery efforts, followed by chinook (Figure 22). In total, the watershed provides 893,243m^2 of chinook and steelhead habitat. The predicted stream abundance and weight abundance of these species is shown in Table 6.

Table 6. Predicted salmon relative abundance and biomass in Transboundary watershed

	Relative abundance			Biomass (kgs)		
Streams	Chinook	Steelhead	Sockeye	Chinook	Steelhead	Sockeye
Archibald	0	56	0	0	201.6	0
Bear	0	173	0	0	622.8	0
Beaver	1202	2783	0	9856.4	10018.8	0
Beavervale	0	136	0	0	489.6	0
Blueberry	188	1903	0	1541.6	6850.8	0
Champion	18	105	0	147.6	378	0
Hanna	0	22	0	0	79.2	0
Hudu	0	319	0	0	1148.4	0
Kelly	8	63	0	65.6	226.8	0
Ladybird	19	490	0	155.8	1764	0
Marsh	0	90	0	0	324	0
Murphy	9	67	0	73.8	241.2	0
Neptune	0	19	0	0	68.4	0
Noons	162	1003	0	1328.4	3610.8	0
Trail	5	0	0	41	0	0
Transboundary watershed total	1611	7229	0	13210.2	26024.4	0

*abundances calculated as chinook=8.2kgs, sockeye=1.4kgs, steelhead=3.6kgs

5.2.2 Spatial Distribution

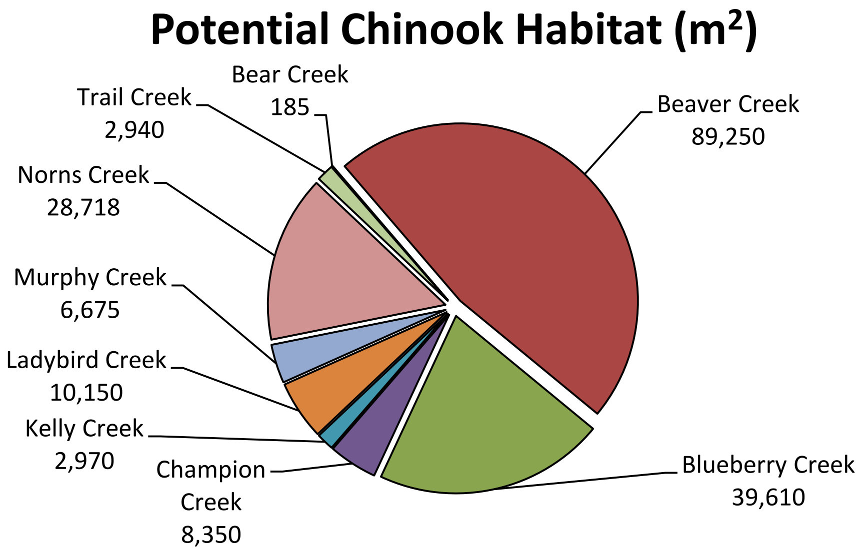

Figure 21. Chinook habitat in Transboundary watershed key tributaries

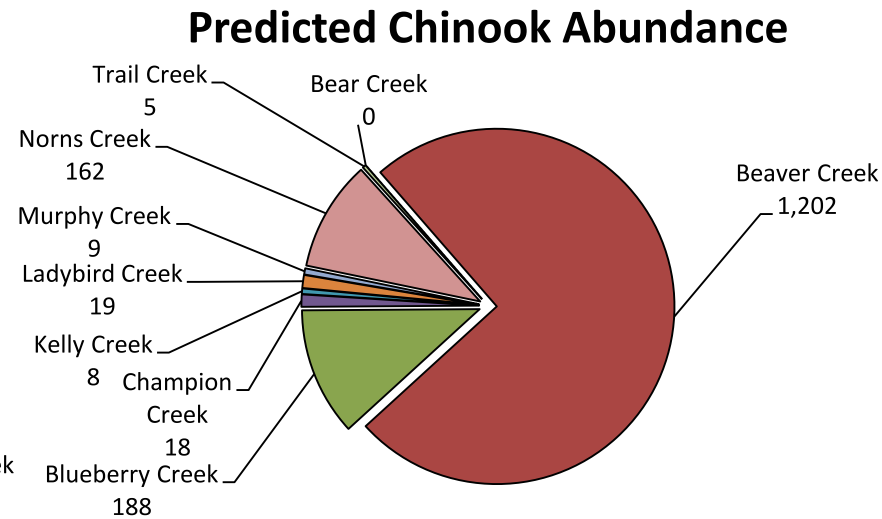

Figure 19. Chinook abundance in Transboundary watershed key tributaries

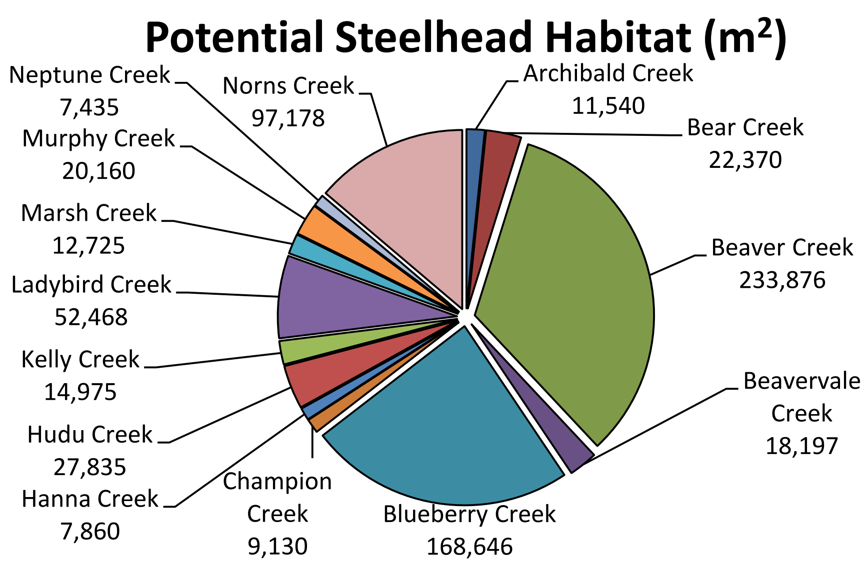

Figure 20. Steelhead habitat in Transboundary watershed key tributaries

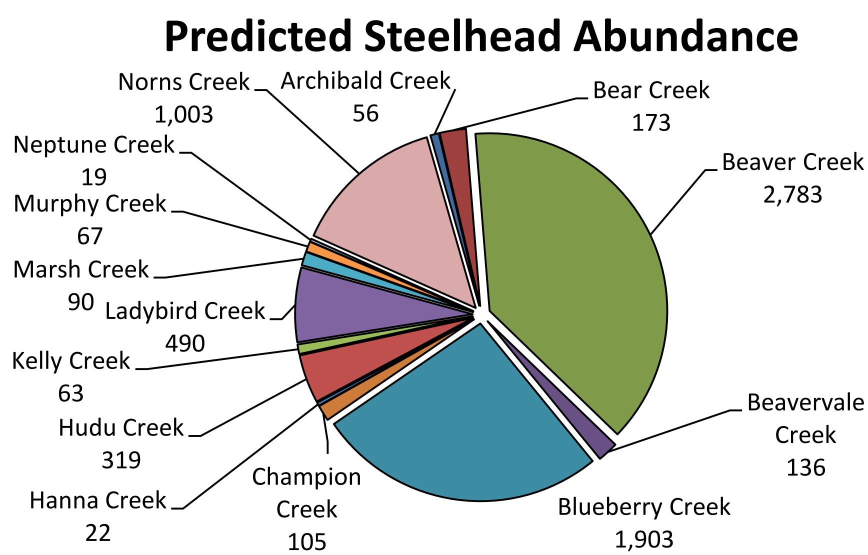

Figure 18. Steelhead abundance in Transboundary watershed key tributaries

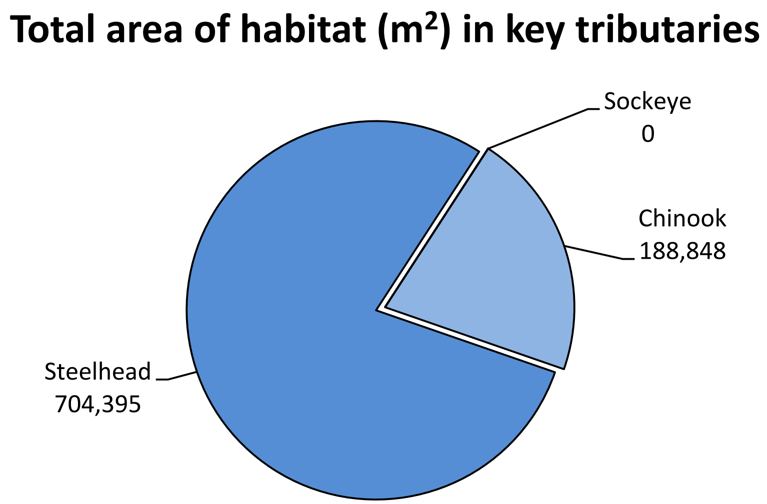

Figure 22. Total area of salmon habitat in Transboundary watershed key tributaries

5.3 Slocan Watershed

The Slocan watershed, comprised of the Slocan River and Slocan Lake, has nine main tributaries that provide habitat for sockeye, chinook, and/or steelhead. Taking into account all tributaries ≥3rd order in the watershed, there are 40 streams providing more than 533km of ≥3rd stream (Table 7). Within the nine tributaries, there are three natural barriers and one manmade barrier (Table 8).

Not all tributaries in the Slocan watershed had their total lengths evaluated for salmonid habitat. The habitat in Evans, Enterprise, Nemo, Carpenter, Wee Sandy, and Wragge Creeks was analyzed for the lower one kilometer, nearest the outlet. Assessment for other tributaries included: Shannon Creek (lower 3.4 km), Silverton Creek (lower 13.4km), Bonanza Creek (downstream of Summit Lake, and Wilson Creek (lower 15km).

The majority (93%) of the Slocan Lake watershed is currently undisturbed by human development. However, there is potential for increased recreational use of the lake and further shoreline development in the future. In previous years, there has been concern over the water potential of Slocan Lake due to high levels of cadmium and zinc and rising E.coli counts, along with decreases in zooplankton (Grau et al., 2014). As a popular fishing destination, the lake is susceptible to overfishing. Slocan Lake is oligotrophic (low productivity).

Table 7. Slocan watershed tributary stream orders and magnitude

Stream order	Frequency	Magnitude ≥3rd order (km)
3rd	29	188.8
4th	8	175.2
5th	2	72.3
6th	1	97.4
Total	40	533.7

Table 8. Barriers within Slocan watershed tributaries

Barrier Type	Location	Distance from mouth of tributary
Weir	Bonanza Creek	13.2km
Falls	Shannon Creek	8.4km
Falls	Shannon Creek	8.5km
Falls	Evans Creek	17.8km

5.3.1 Potential spawning and rearing habitat

Sockeye

High potential sockeye habitat is only located within the Slocan River. The river contains 5,878m^2, 14,771m^2, and 29,337m^2 of high, moderate, and low potential sockeye habitat, respectively. The high potential habitat is restricted to just one macro-reach 21.2km from the confluence with the Kootenay River, and predicted to conservatively support 4,409 sockeye. The macro-reach is bordered by reaches of low and moderate potential habitat. The majority of moderate potential habitat is also confined to this area. This habitat could support 2,954 sockeye. Low potential habitat is distributed within the downstream 23.4km of the 58.2km river and is expected to support 1,467 sockeye. Bonanza Creek contains the second greatest amount of sockeye habitat. The 12,073m^2 of moderate habitat and 9,081m^2 of low potential habitat are interspersed throughout the 12.2km nearest the outlet. These areas of habitat are divided into short sections by macro-reaches of no habitat. Moderate and low potential habitats are predicted to support 2,415 and 454 sockeye, respectively. Sockeye habitat accessibility is not impacted by the weir at 13.2km.

Wilson Creek is the final tributary containing sockeye habitat. The creek provides 3,454m^2 of low potential habitat, supporting 173 sockeye. This habitat is concentrated within the 1.2km upstream of the mouth of the creek. Figures 23 & 24 show that the Slocan River is the best site to focus recovery efforts, followed by Bonanza Creek. In terms of connectivity to the lake environment, recovery efforts should be focused at the Slocan Lake outlet, to provide access to a nursery lake, otherwise, emergent fry have limited opportunity for downstream rearing. For this reason, Bonanza though rated lower than Slocan River, would be the preferred system for sockeye recovery. There is considerable distance between tributaries providing sockeye habitat. Slocan River meets Slocan Lake at its southern tip, while Bonanza Creek is located at the northern tip of the 39km long lake. Wilson Creek is located approximately 7.6km downstream of Bonanza Creek.

Chinook

The Little Slocan River provides the greatest area of chinook habitat. Its 39,414m^2 of high potential habitat, supporting 788 chinook, is concentrated from 27.9 R-km to 36.9 R-km. The 32,149m^2 of moderate habitat is spread throughout the 35.5km nearest the Slocan River in short sections and could support 161 chinook. There are 27,545m^2 of low potential habitat in the river that are broken into short sections, mostly concentrated in the lower half of the river. These sections predict an additional 37 chinook.

The Slocan River could support the second highest abundance of chinook relative to our reference watersheds. Its 67,491m^2 of moderate potential habitat, distributed across the entire river in short sections, may support 337 chinook. The remaining 33 chinook are attributed to 24,917m^2 of low potential habitat which is divided into small areas by reaches of moderate and no potential habitat.

Bonanza Creek is the only other tributary providing high potential chinook habitat in the watershed. It contains 8,134m^2, 11,340m^2, and 13,076m^2 of high, moderate, and low potential chinook habitat. The high potential habitat is primarily located at the southern end of Summit Lake and supports 163 chinook. Low potential habitat is evenly distributed among the stream network, with large sections intersected by reaches of moderate habitat. Low and moderate potential habitat could support 17 and 57 chinook, respectively. Due to the impassable weir near Summit Lake, accessible high potential habitat is reduced to 5,328m^2 (or to 107 chinook), and low potential habitat is reduced to 12,564m^2 (or to 17 chinook). The barrier does not affect moderate habitat accessibility.

Lemon Creek has two macro-reaches of moderate potential habitat situated in the 1-km section proximate to the outlet. It provides 1,682m^2 of habitat (or 8 chinook). The remainder of the creek has sections of low to no habitat. The 13,965m^2 of low potential habitat could support 19 chinook.

Wilson Creek has 6,854m^2 of moderate and 23,262m^2 of low potential habitat. Moderate habitat is mainly confined to the 1.2km of creek upstream of the mouth (a total 34 chinook). The low potential habitat is evenly distributed throughout the 13.8km nearest the outlet, supporting 31 chinook. Silverton and Carpenter Creeks contain a mix of moderate and low potential habitat. Habitat in these creeks totals 8,003m^2 and 2,664m^2 (13 and 6 chinook, respectively). Shannon, Enterprise, and Wragge Creeks all provide only small areas of low potential chinook habitat; 925m^2, 660m^2, and 250m^2, respectively. All three creeks potential is less than two chinook, each. The falls barriers do not affect accessibility to chinook habitat in Shannon Creek.

Given these results, the best recovery site for chinook is Little Slocan River, followed by Slocan River and Bonanza Creek (Figure 25 & 26). Little Slocan River is the major tributary of Slocan River; therefore these waterbodies have high connectivity. Bonanza Creek is located at the opposite of Slocan Lake, resulting in lower connectivity. Overall, there is easy access between tributaries with habitat given that they all flow into Slocan Lake.

<u>Steelhead</u>

The Slocan River provides more than twice the area of steelhead habitat than any other tributary in the Slocan watershed. In total, it contains 700,500m^2 of habitat, divided into 11,652m^2 of high, 505,208m^2 of moderate, and 183,640m^2 of low potential habitat. High potential habitat is most densely concentrated upstream of Lemon Creek. Short sections of moderate and low potential habitat are interspersed with sections of no habitat throughout the entire length of the river. High, moderate, and low potential habitat could support 146, 1,579, and 153 steelhead, respectively.

The Little Slocan River has the second largest area of steelhead habitat and the largest abundance of steelhead. The Little Slocan could support 3,996 steelhead, with 3,981 produced in the 318,478m^2 of high potential habitat. The remaining 15 steelhead occupy 18,216m^2 of low potential habitat. Large areas of high potential habitat are dispersed throughout the river, separated by short sections of low to no potential habitat.

Lemon Creek steelhead habitat is restricted to the lower 3.2km, upstream of the mouth. There are three macro-reaches containing high potential habitat; equaling 8,223m^2 (103 steelhead). These reaches are divided by low potential habitat. Three steelhead could be supported in the 4,084m^2 of low potential habitat.

Bonanza Creek could support 1,178 steelhead within 94,259m^2 of high potential habitat. An additional 10 steelhead could spawn within 11,968m^2 of low potential habitat. Only six macro-reaches (1.2km) contain no habitat in Bonanza Creek. Short sections of high and low potential habitat is dispersed throughout the creek. The weir barrier near Summit Lake reduces the accessible area and abundance of high potential habitat to 89,309m^2 and 1,116 steelhead. Of a total low potential habitat area of 11,086m^2, we estimate nine steelhead spawners.

Silverton Creek has 9,474m^2 of high potential habitat for supporting 122 steelhead. This habitat is located in five macro-reaches spread throughout the creek. 10,749m^2 of low potential habitat may support nine sockeye and is most densely concentrated in the upstream 6.8-13.4km section of the creek.

Wilson Creek contains 55,285m^2 and 1,650m^2 of high and low potential habitat, respectively. High potential habitat could to support 691 steelhead, while low potential habitat results in 29 steelhead. The high potential habitat is mainly concentrated within 1.2km of the mouth and low potential habitat is clustered in large sections through the creek.

Carpenter Creek could support 134 steelhead, with just one produced from 1,048m^2 of low potential habitat. Four macro-reaches provide the 10,602m^2 of high potential steelhead habitat. Shannon Creek and Wragge Creek provide only small areas of low potential steelhead habitat; 1,629m^2 and 370m^2, respectively. Both creeks could support less than two steelhead, each. The falls (barrier) does not affect accessibility to chinook habitat in Shannon Creek.

Figures 27 & 28 show that steelhead and chinook have the same recommended recovery sites; Little Slocan River, Slocan River, and Bonanza Creek. Again, Little Slocan River and Slocan River have good connectivity, while Bonanza Creek is located at the opposite end of the watershed.

Slocan watershed

The graph below (Figure 29) represents potential habitat for each species within the main tributaries of the watershed. Most of the potential habitat within these tributaries is best suited for steelhead. In total, the Slocan watershed tributaries provide 1,603,733m^2 of potential habitat for sockeye, chinook, and steelhead. The predicted relative abundance and biomass of each species for the watershed is outlined in Table 9. Steelhead produce the highest abundance by weight, but sockeye have a higher stream abundance in the watershed.

Table 9. Predicted salmon abundance and abundance in Slocan watershed

	Relative abundance			**Biomass (kg)**		
Stream	Chinook	Steelhead	Sockeye	Chinook	Steelhead	Sockeye
Lemon	27	106	0	221.4	381.6	0
Little Slocan	986	3996	0	8085.2	14385.6	0
Shannon	1	1	0	8.2	3.6	0
Silverton	13	131	0	106.6	471.6	0
Slocan River	370	1878	8830	3034	6760.8	12362
Wilson	65	720	173	533	2592	242.2
Enterprise	1	0	0	8.2	0	0
Carpenter	6	134	0	49.2	482.4	0
Wragge	1	1	0	8.2	3.6	0
Bonanza	237	1188	2869	1943.4	4276.8	4016.6
Slocan watershed total	1707	8155	11872	13997.4	29358	16620.8

*abundances calculated as chinook=8.2kgs, sockeye=1.4kgs, steelhead=3.6kgs

5.3.2 Spatial Distribution

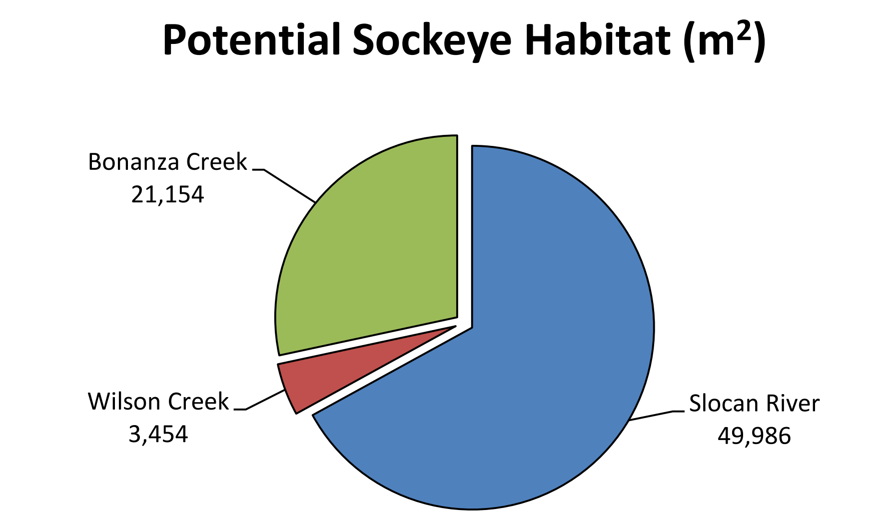

Figure 26. Sockeye habitat in Slocan watershed key tributaries

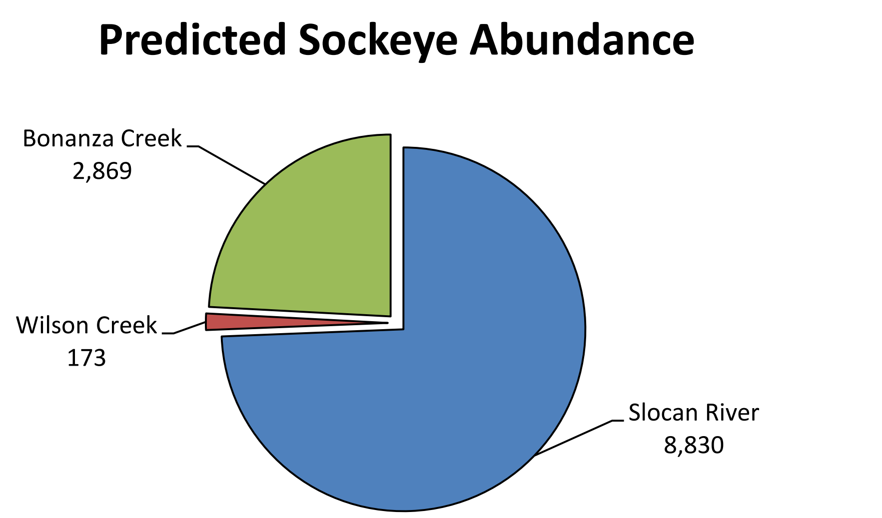

Figure 25. Sockeye abundance in Slocan watershed key tributaries

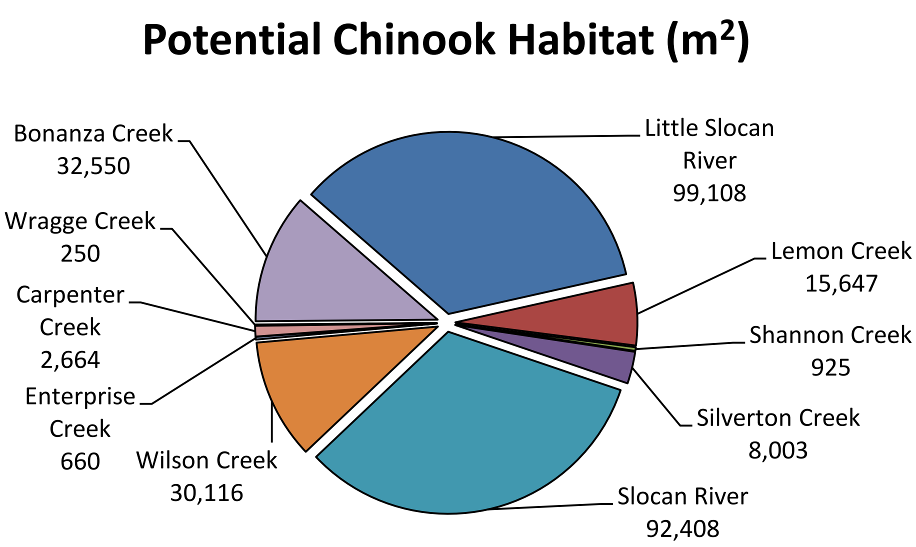

Figure 23. Chinook habitat in Slocan watershed key tributaries

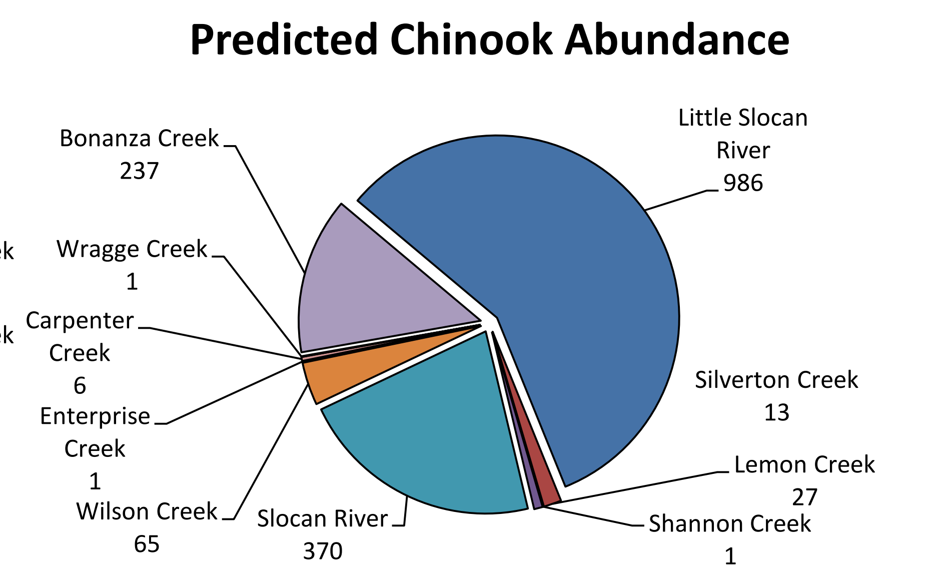

Figure 24. Chinook abundance in Slocan watershed key tributaries

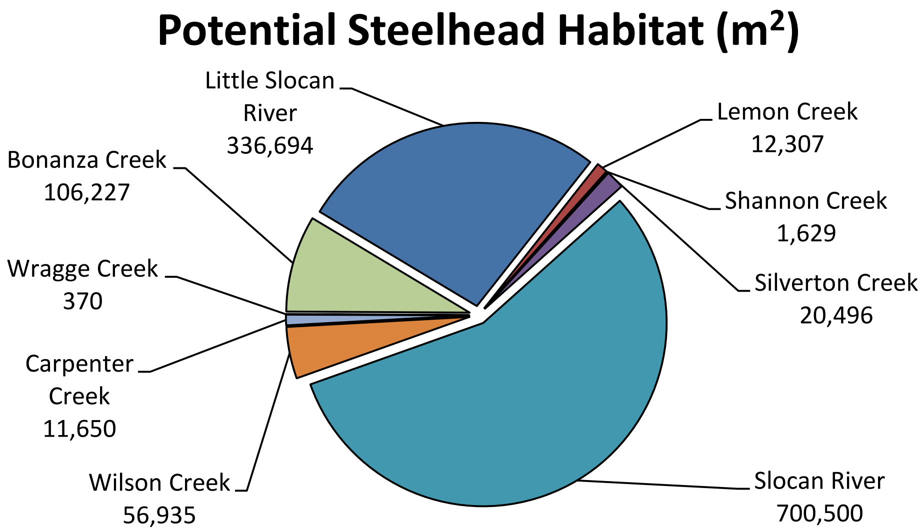

Figure 29. Steelhead habitat in Slocan watershed key tributaries

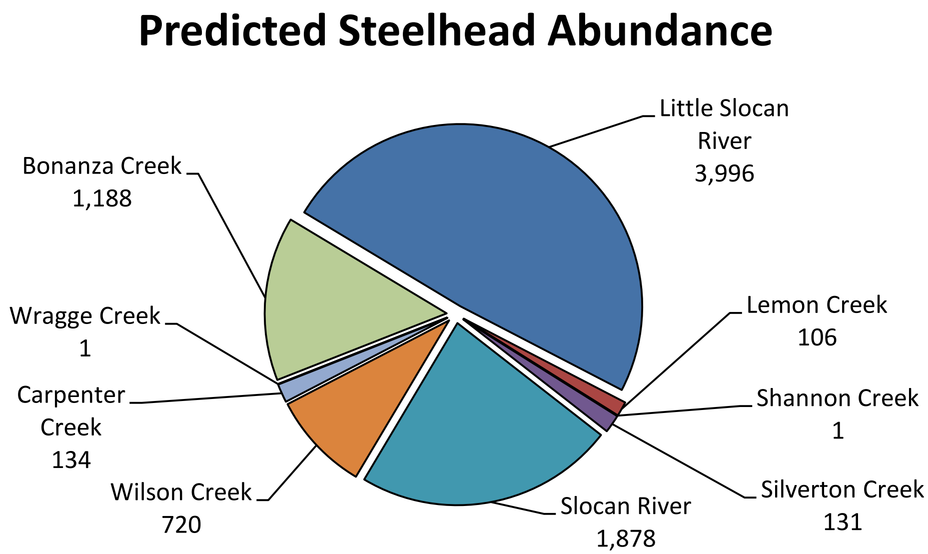

Figure 27. Steelhead abundance in Slocan watershed key tributaries

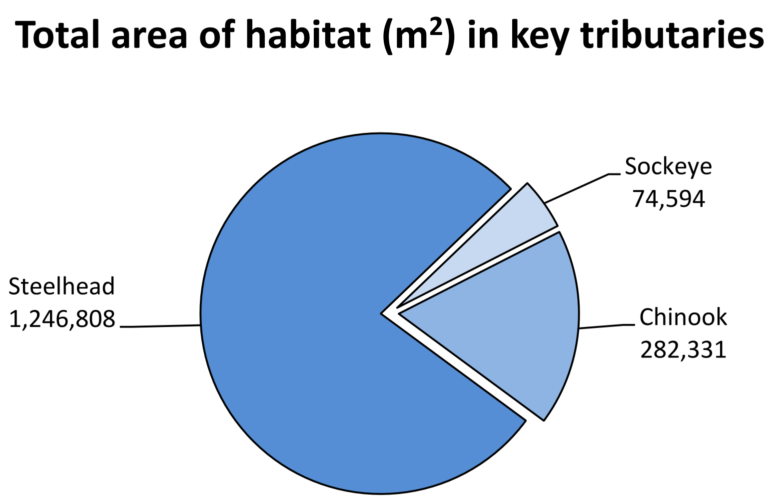

Figure 28. Total area of salmon habitat in Slocan watershed key tributaries

5.4 Whatshan Reservoir

Whatshan Reservoir has seven tributaries ≥3rd order which provide a variety of habitat for sockeye, chinook, and/or steelhead, totaling 85.4km of stream ≥3rd order (Table 10). Within these tributaries, there are three man-made barriers and no natural barriers to fish passage (Table 11). Whatshan Dam is located in the southern section of Whatshan River/Reservoir, about 6.6km upstream of the confluence with Lower Arrow Reservoir. The dam blocks fish passage to all potential fish habitat upstream. Therefore, within the watershed, only the southern Whatshan River and Barnes Creek and its tributaries contain currently accessible habitat.

The most significant limiting factor to fish production in the Whatshan Reservoir watershed is its oligotrophic state. The reservoir does not contain high amounts of nutrients to support large fish populations. Additionally, reservoir drawdown can result in increased sedimentation and changes in productivity of areas impacted by fluctuating water levels (Andrusak, 2004). There is not significant development on the shorelines surrounding the reservoir. The Whatshan River and its tributaries are closed to fishing all year above Whatshan Lake.

Table 10. Whatshan Reservoir tributary stream orders and magnitude

Stream order	Frequency	Magnitude ≥3rd order (km)
3rd	4	38.6
4th	3	48.6
Total	7	85.4

Table 11. Barriers within Whatshan Reservoir tributaries

Barrier Type	Location	Distance from mouth of tributary
Round culvert	Stevens Creek	150m
Round culvert	Unnamed tributary	200m
Whatshan dam	Whatshan River	6.6km

5.4.1 Potential spawning and rearing habitat

Sockeye

Within the Whatshan Reservoir watershed, potential habitat for sockeye is found only in the mainstem of the Whatshan River at the north end of the reservoir. A mix of low and moderate habitat is observed throughout the 9.4km nearest the mouth of this 22.0km section of the river. There is 2,767m^2 of moderate potential habitat and 10,652m^2 of low potential habitat. Macro-reaches of moderate potential habitat isdistributed between macro-reaches of low and no habitat. Predicted sockeye abundance for areas of moderate and low potential habitat are 553 and 533 sockeye, respectively. In total, the northern Whatshan River mainstem contains

13,419m^2 of habitat and support 1,086 sockeye. Given that this is the only area with sockeye habitat in the watershed, this is the recommended site to focus recovery efforts. Currently, the Whatshan Dam blocks fish passage to the Whatshan Reservoir, making this habitat upstream inaccessible.

Chinook

The northern Whatshan River mainstem contains areas of high, moderate, and low potential chinook habitat. There exists 11,328m^2 of high, 9,601m^2 of moderate, and 14,766m^2 of low potential habitat. Relative abundances of 227, 48, and 20 Habitat occurs throughout the 19.6km of river nearest the reservoir with areas of high potential habitat separated by moderate and low potential habitat. Fife Creek, a 4th order tributary of the northern Whatshan River mainstem, contains reaches of low potential habitat interspersed with areas of no habitat and one macro-reach of moderate habitat. This mix of habitat extends for 5km into both the west and north arms of Fife Creek. The Fife creek system has 10,701m^2 of low and 631m^2 of moderate potential chinook habitat. These areas are predicted to support 14 and 3 chinook, respectively. The final major tributary in the northern section of Whatshan Reservoir containing chinook habitat is Stevens Creek. This creek has 2,465m^2 of low and 400m^2 of moderate potential habitat, supporting three and two chinook, respectively. However, there is currently an impassable culvert 150m upstream from the mouth of Stevens Creek that makes this habitat inaccessible. There is one 1st order stream south of Stevens Creek with similar habitat potential; 2410m^2 of low and 440m^2 of moderate potential habitat supporting three and two chinook. This stream also contains an impassable barrier about 200m from its mouth, making the majority of habitat upstream inaccessible.

The southern Whatshan mainstem, between Whatshan and Lower Arrow Reservoirs, contains only macro-reaches of low potential habitat. There are 9,790m^2 of habitat within a 5km section of the river predicted to support 13 chinook. Barnes Creek is a 3rd order tributary of the southern Whatshan River and contains the greatest area of chinook habitat. The creek and its tributaries have 27,726m^2 of low, 7725m^2 of moderate, and 7,698m^2 of high potential chinook habitat. These areas of habitat are predicted to support 37, 39, and 154 chinook, respectively. Areas of low productivity and no productivity are observed throughout the mainstem, with fragments of moderate and high habitat concentrated in two main areas at opposite ends of the system.

Overall, within the main tributaries of Whatshan Reservoir, there is 105,681m^2 of chinook habitat. However, only 52,939m^2 is accessible as it is situated downstream of Whatshan Dam. In total, the reservoir watershed could support 565 chinook, with 243 of these chinook being produced in areas of accessible habitat. Without this barrier, the watershed has high connectivity of potential habitat as Whatshan Reservoir and River offer easy passage between tributaries with salmon habitat. Figures 30 & 31 show a comparison of chinook habitat and abundance between tributaries of interest in the watershed. Barnes Creek and the northern Whatshan River offer the greatest area of habitat and highest relative abundance. A third possible recovery site is Fife Creek, though it is predicted for lower abundance of chinook.

Steelhead

Steelhead habitat predominates within the watershed compared to the other species of interest. Sections of low and high potential habitat are dispersed throughout all of the major tributaries.

The southern Whatshan River and Barnes Creek are the only systems not blocked by Whatshan Dam. The southern Whatshan River contains 14,220m^2 of low potential habitat and 17,427m^2 of high potential habitat. These areas are predicted to support 12 and 218 steelhead, respectively. This short section of river mostly contains macro-reaches of low potential habitat, with two small areas of high potential habitat. Barnes Creek and its tributaries are estimated to have 51,126m^2 of low potential habitat that may support 43 steelhead. There is also 147,286m^2 of high potential habitat, supporting 1,841 steelhead. A concentrated area of high potential habitat is located within the 6.5km of stream nearest Whatshan River. The remainder of the creek system is populated with short areas of no, low, and high potential habitat.

In the currently inaccessible section of the reservoir, there are several 1st and 2nd order tributaries of Whatshan Reservoir that may provide steelhead habitat. Combined, these small tributaries provide 3,312m^2 of low potential habitat and 9,294m^2 of high potential habitat. Relative abundance is estimated for 3 and 116 steelhead, respectively. One of the tributaries contains an impassable barrier about 200m from its mouth, making the majority of habitat upstream inaccessible. These tributaries are located at the north and south ends of the reservoir.

White Grouse Creek and its tributaries provided limited habitat for sockeye or chinook, but they do contain 4,533m^2 of low and 4,277m^2 of high potential habitat for steelhead. These habitats could support4 and 53 steelhead, respectively. These areas of habitat extend for 1.8km from the mouths of both White Grouse Creek and Ingersoll Creek. Christy Creek, a 2nd tributary of Whatshan Reservoir, is situated directly south of White Grouse Creek. This creek extends for 7.8km, with steelhead habitat found throughout the 5.9km nearest the mouth. Within this creek, there is 2,765m^2 and 18,777m^2 of low potential and high potential steelhead. These areas of habitat may support 2 and 235 steelhead, respectively.

Stevens Creek has an impassable culvert 150m upstream from its mouth, resulting in its 7,140m^2 of low potential and 18,660m^2 of high potential habitat being inaccessible. If passage was restored to the entire creek, these habitats may support 6 and 233 steelhead, respectively. The northern Whatshan River contains the largest areas of high potential steelhead habitat. Throughout the mainstem and small tributaries, there is 166,713m^2 of high potential habitat with a relative abundance of 2,084 steelhead. This habitat is concentrated into several large sections 0.2-3.6km long. These sections are interspersed with smaller areas of low potential habitat and few macro-reaches of no habitat. The low potential habitat results in 22,016m^2 and a relative abundance of 18 additional steelhead. The final system in the watershed containing steelhead habitat is Fife Creek. There is 18,334m^2 of high potential habitat dispersed through Fife Creek and its tributaries. Macro-reaches of high potential habitat are divided by long creek sections containing low or no potential habitat. There is 24,513m^2 of low potential habitat. Areas of high and low potential habitat are conservatively predicted to support 229 and 21 steelhead, respectively.

Throughout the entire Whatshan Reservoir watershed, there is 530,158m^2 of steelhead habitat. A total of 5,118 steelhead is estimated when excluding the Whatshan Dam barrier. Figures 32 & 33 show a comparison of steelhead habitat and abundance between tributaries of interest in the watershed. to Including the barrier, we predict accessible habitat to be 230,059m^2 supporting 2,114 steelhead. These outputs are significantly greater than for sockeye or chinook. Based on the results of the IP modeling, the area best suited for chinook recovery are Barnes Creek and the northern Whatshan River. A tertiary option is Fife Creek, though it has considerably smaller habitat area and abundance.

<u>Whatshan Reservoir watershed</u>

Figure 34 summarizes the predicted potential habitat for each salmon species within the main tributaries of the Whatshan Reservoir watershed. Steelhead are predicted to have the largest area of habitat and produce the highest abundance and biomass. Sockeye abundance is the second highest, despite the habitat area for sockeye being smallest. The main tributaries of Whatshan Reservoir have a total of 612,495m^2 of potential habitat for salmon recovery efforts, though only 282,998m^2 is currently accessible. The potential abundance of each species for the watershed and the biomass are shown in Table 12.

Table 12. Predicted salmon abundance and abundance in Whatshan Reservoir watershed

	Relative abundance			**Biomass(kg)**		
Stream	Chinook	Steelhead	Sockeye	Chinook	Steelhead	Sockeye
Whatshan River	308	2332	1086	2525.6	8395.2	1520.4
Barnes Creek	230	1884	0	1886	6782.4	0
Stevens Creek	5	239	0	41	860.4	0
Fife Creek	17	250	0	139.4	900	0
White Grouse Creek	0	57	0	0	205.2	0
Christy Creek	0	237	0	0	853.2	0
Small tributaries	5	119	0	41	428.4	0
Whatshan watershed total	565	5118	1086	4633	18424.8	1520.4

*abundances calculated as chinook=8.2kgs, sockeye=1.4kgs, steelhead=3.6kgs

5.4.2 Spatial Distribution

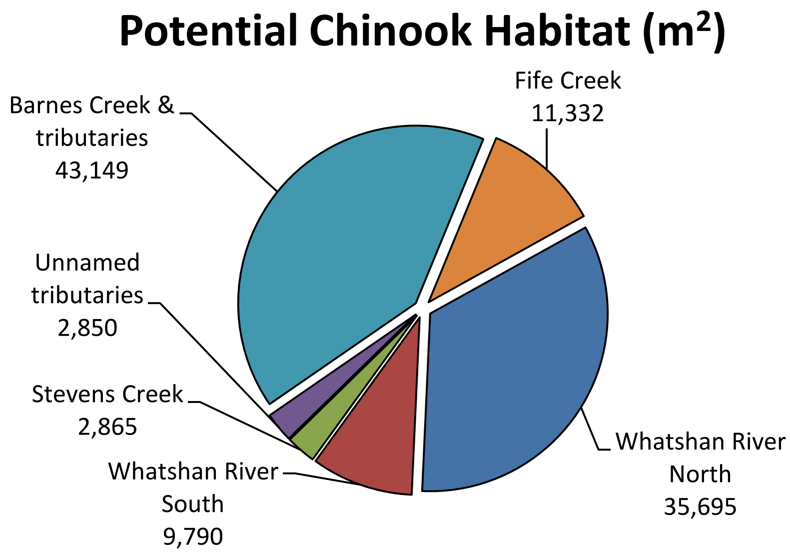

Figure 33. Chinook habitat in Whatshan Reservoir key tributaries

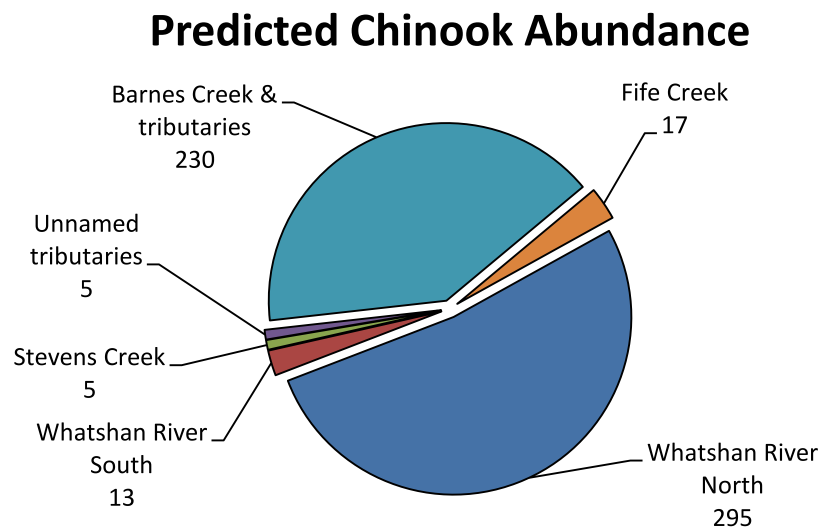

Figure 31. Chinook abundance in Whatshan Reservoir key tributaries

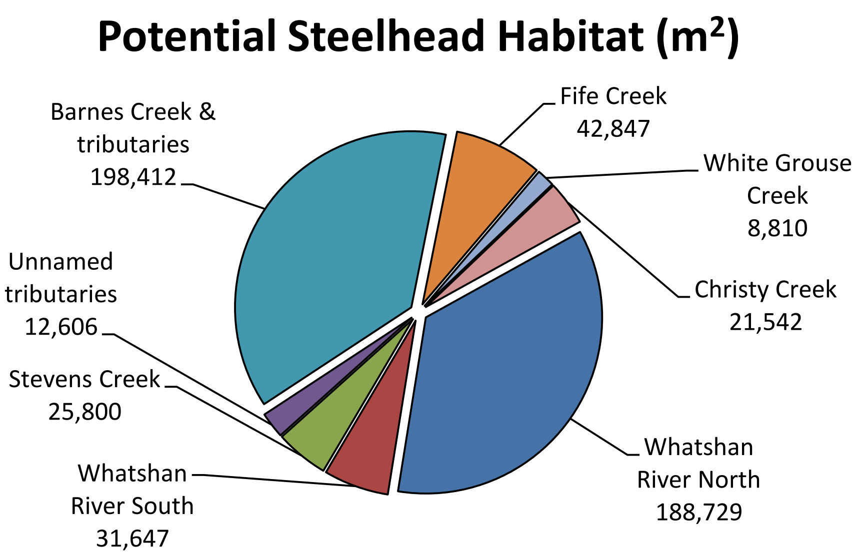

Figure 32. Steelhead habitat in Whatshan Reservoir key tributaries

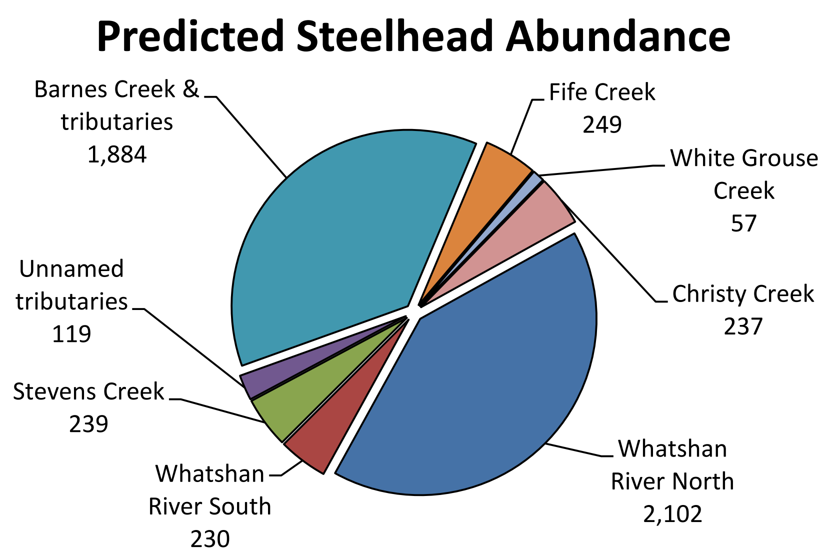

Figure 30. Steelhead abundance in Whatshan Reservoir key tributaries

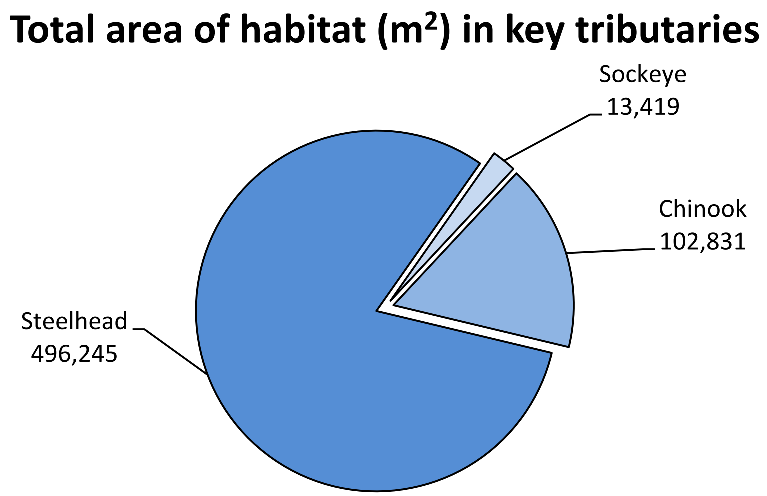

Figure 34. Total area of salmon habitat in Whatshan Reservoir key tributaries

5.5 Lower Arrow Reservoir

The Lower Arrow Reservoir has three key tributaries (excluding Whatshan River) that are ≥3rd order and contain potential salmon habitat. These tributaries, plus all other tributaries of this order in the watershed, total 28 streams and provide 251.4km of stream ≥3rd order (Table 13). Within the three key tributaries, there are four natural barriers and no manmade barriers to fish passage (Table 14).

There are a number of factors that can limit the population size of salmonids supported in Lower Arrow Reservoir. Hydraulic changes in the watershed can result in low stream flows, channel braiding, and displacement of substrate and debris at high levels creating barriers. In previous years, tributaries in a small section of the watershed have been closed to fishing due to warm temperatures and low flows. Mysids were introduced for the Arrow Reservoir in 1968 in attempt to increase food availability for fish. These mysids now compete with fish for zooplankton.

Table 13. Lower Arrow Reservoir tributary stream orders and magnitude

Stream order	Frequency	Magnitude ≥3rd order (km)
3rd	24	145.9
4th	4	105.5
Total	28	251.4

Table 14. Barriers within Lower Arrow Reservoir key tributaries

Barrier Type	Location	Distance from mouth of tributary
Falls	Taite Creek	2.8km
Falls	Taite Creek	2.9km
Falls	Taite Creek	3.6km
Falls	Burton Creek	6.8km

5.5.1 Potential spawning and rearing habitat

Sockeye

Burton Creek provides the greatest area of sockeye habitat. A total 12,814m^2 of high potential habitat is estimated, which is most densely concentrated at the mouth of the creek, within a 1.6km section. It also contains 6,154m^2 of moderate and 709m^2 of low potential habitat. The expected sockeye abundance is 641, 77, and 2 for the areas of high, moderate, and low potential habitat, respectively. The sockeye habitat within Burton Creek is well connected, as it is all situated in the 4.0km nearest the mouth of the 20.3km creek. The falls barrier 6.8km upstream of Burton Creek does not affect the accessibility of the sockeye habitat.

Caribou Creek has four macro-reaches providing moderate and one macro-reach providing low potential habitat. Reaches of moderate potential habitat amount to 3,523m^2 and 44 sockeye. Low potential habitat occupies only 440m^2 and resulting in less than two sockeye. These macro-reaches are all located within 3.6km of the mouth of Caribou Creek.

Taite Creek does not contain any sockeye habitat.

Given the results of the IP modeling, the best recovery site for sockeye in the watershed would be Burton Creek, followed by Caribou Creek (Figures 35 & 36). These potential recovery sites have good connectivity as Caribou Creek is located less than 1 km upstream of Burton Creek in the Lower Arrow Reservoir.

<u>Chinook</u>

Both moderate and low potential chinook habitat is found in all three main tributaries, though the only area of high potential habitat is found in one macro-reach in Burton Creek. This macro-reach provides 1,418m^2 of habitat and may result in28 chinook. This high potential habitat is located 3.4km upstream of the outlet and is proximate to reaches of moderate and low potential habitat. The creek contains 6,877m^2 of moderate habitat which is concentrated near the mouth of the creek, interspersed with areas of low and no potential habitat. Moderate habitat may result in 34 chinook. Low potential habitat is most abundant in the creek, totaling 11,610m^2. This habitat extends for 15.8km from the mouth and creates several densely concentrated areas divided by areas of no habitat. This is the only class of habitat impacted by the falls at 6.8km. Without restoring fish passage at the falls, only 5,195m^2 of low potential habitat is accessible. These falls reduce chinook abundance by 50% (~ seven).

Caribou Creek provides the largest area for chinook recovery efforts. The 4,094m^2 of moderate habitat is concentrated in the lower 1.4km, upstream of the outlet. This area could support 20 chinook. Low potential habitat extends for 27.6km upstream of the 32.1km creek and amounts to 25,401m^2. This habitat is interspersed with sections of no habitat and is estimated to support 34 chinook.

Taite Creek provides the smallest area of chinook habitat. The creek contains 461m^2 of moderate habitat and 1,230m^2 of low potential habitat, supporting 4 chinook in total. This habitat is isolated to the lower 1.4km, upstream of the mouth, with the two sections of low productivity divided by one macro-reach of moderate habitat and one macro-reach of no habitat. The three falls in Taite Creek do not impact accessibility to chinook habitat.

Caribou Creek would be the best option to focus chinook recovery efforts in this watershed, closely followed by Burton Creek. Taite Creek does not provide sufficient habitat As with sockeye habitat connectivity, chinook are free to move between these two main creeks of habitat given their proximity to one another. Taite Creek is located nearly 30km downstream of the other creeks, but is not a practical option for recovery efforts. Figures 37 and 38 show total chinook habitat and abundance for the watershed.

<u>Steelhead</u>

High and low potential steelhead habitat are spread throughout Burton, Caribou, and Taite Creeks. Burton Creek provides 48,033m^2 of high potential and 17,938m^2 of low potential steelhead habitat. We predict 600 and 15 steelhead, respectively. High potential habitat is densely concentrated in the 4.2km upstream of the mouth of the creek. This section of creek also contains several macro-reaches of low potential habitat and one macro-reach of no habitat. Low potential habitat is distributed throughout the whole creek at several concentrated areas, ranging 0.2-2.0km long. The falls at 6.8km upstream affects the accessibility of areas of high and low potential habitat. Accessible high potential habitat is estimated at42,621m^2, supporting 533 steelhead. Accessible low potential habitat is 4,108m^2, supporting three steelhead. Low potential habitat is impacted by this impassable barrier.

Caribou Creek provides the largest areas of high and low potential steelhead habitat. These areas are interspersed throughout the entire length of the creek. The creek provides 64,097m^2 of high potential habitat for an estimated 801 steelhead. Short sections of high potential habitat are separated by sections of low potential habiitat(34,672m^2) and supporting 29 steelhead.

Taite Creek contains one macro-reach with an estimated 1,621m^2 high potential habitat es supporting 20 steelhead. This macro-reach is located between a section of low and no potential habitat. Low potential habitat occupies 2,789m^2 of the creek,which may support two steelhead. Steelhead habitat extends only 2.2km upstream; therefore, the falls barriers do not affect its accessibility.

Steelhead habitat and abundance are greatest in Caribou Creek, making it the preferred candidate for recovery efforts. Burton Creek would also be a practical option. Again, Taite Creek is not predicted to have great enough habitat. The connectivity of possible recovery areas is good given their close proximity. Figures 39 & 40 show total steelhead habitat and abundance for the watershed.

<u>Lower Arrow Reservoir watershed</u>

Figure 41 represents potential habitat for each species within the main tributaries of Lower Arrow Reservoir, totaling242,463m^2. Over 60%of habitat in these tributaries is suited for steelhead habitat preferences. Steelhead are predicted to have the greatest recovery potential, followed by sockeye(Table 15).

Table 15. Predicted salmon abundance and biomass in Lower Arrow Reservoir watershed

	Relative abundance			**Biomass (kg)**		
Stream	Chinook	Steelhead	Sockeye	Chinook	Steelhead	Sockeye
Burton	50	615	720	410	2214	1008
Caribou	54	830	45	442.8	2988	63
Taite	4	23	0	32.8	82.8	0
Lower Arrow watershed total	108	1468	765	885.6	5284.8	1071

*abundances calculated as chinook=8.2kgs, sockeye=1.4kgs, steelhead=3.6kgs

5.5.2 Spatial Distribution

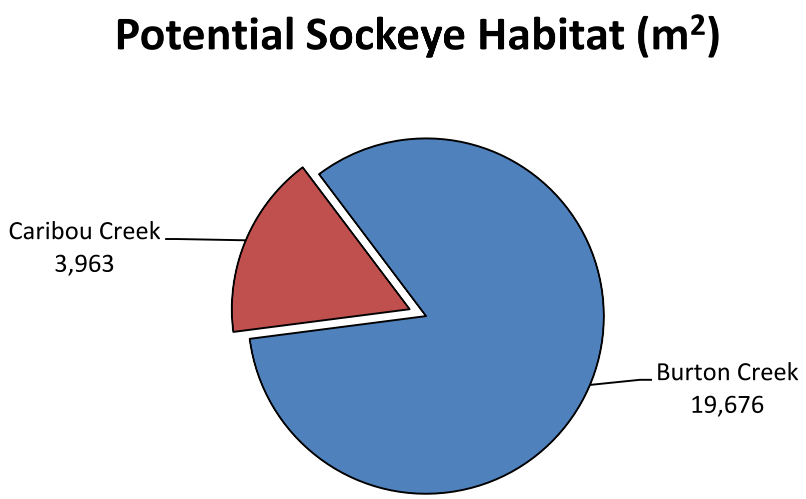

Figure 38. Sockeye habitat in Lower Arrow Reservoir key tributaries

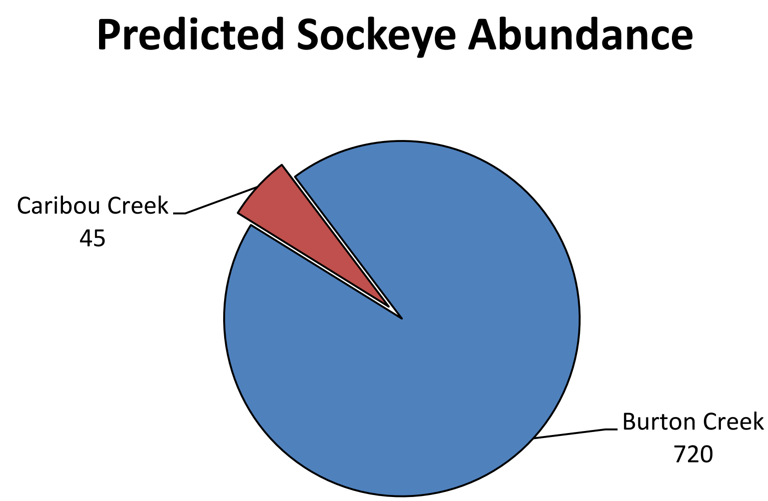

Figure 36. Sockeye abundance in Lower Arrow Reservoir key tributaries

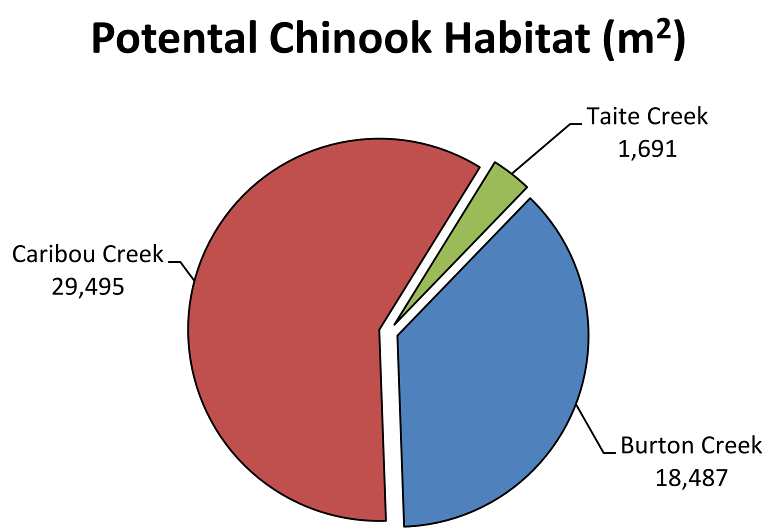

Figure 37. Chinook habitat in Lower Arrow Reservoir key tributaries

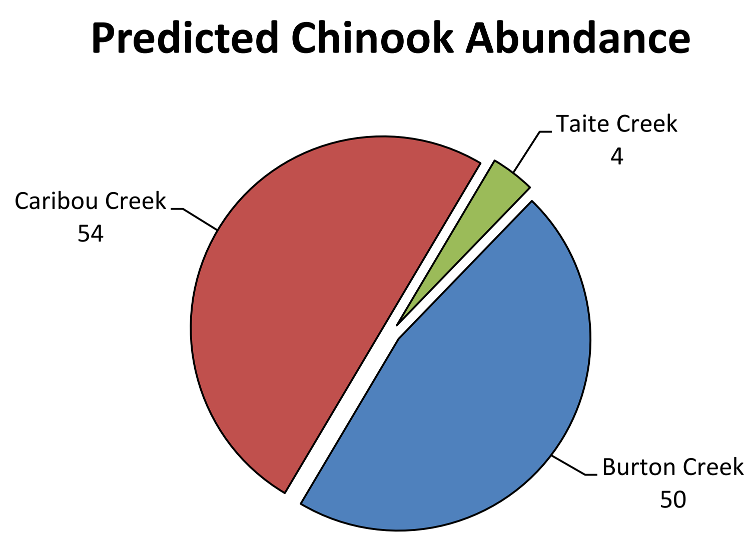

Figure 35. Chinook abundance in Lower Arrow Reservoir key tributaries

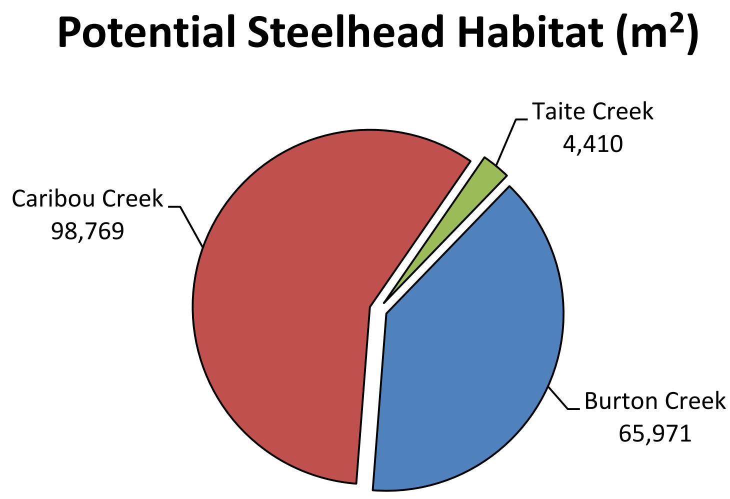

Figure 41. Steelhead habitat in Lower Arrow Reservoir key tributaries

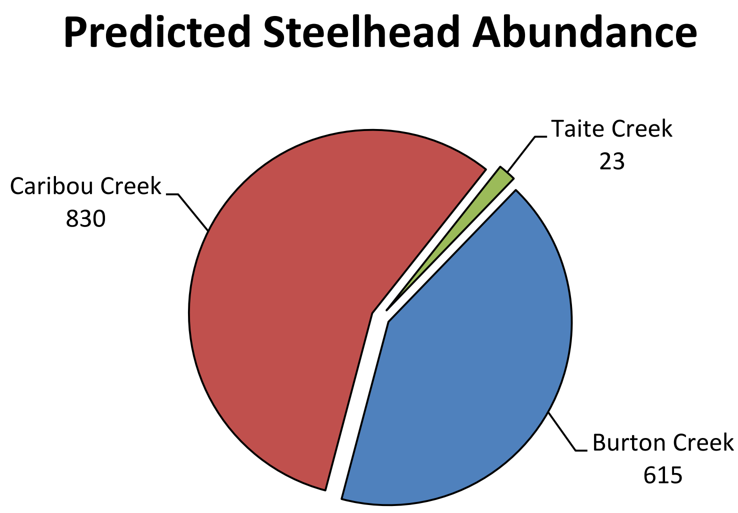

Figure 39. Steelhead abundance in Lower Arrow Reservoir key tributaries

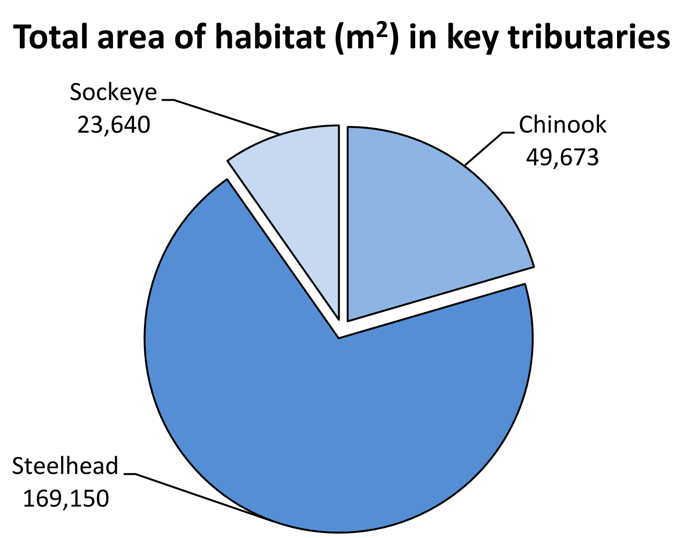

Figure 40. Total area of salmon habitat in Lower Arrow Reservoir key tributaries

5.6 Summary of results

	Sockeye				Chinook				Steelhead			
	Total habitat (m^2)	Accessible habitat (m^2)	IRelative abundance (excludes barrier)	Relative abundance (includes barrier)	Total habitat (m^2)	Accessible habitat (m^2)	IRelative abundance (excludes barrier)	Relative abundance (includes barrier)	Total habitat (m^2)	Accessible habitat (m^2)	IRelative abundance (excludes barrier)	Relative abundance (includes barrier)
Christina Lake*	1,965	1,965	465	465	38,865	38,865	175	175	235,109	235,109	1,398	1,398
Transboundary Region	0	0	0	0	188,848	160,514	1,611	1,481	704,395	581,520	7,229	6,085
Slocan Watershed	74,594	74,594	11,872	11,872	282,331	279,013	1,707	1,651	1,246,808	1,240,976	8,155	8,092
Whatshan Reservoir*	13,419	0	1,086	0	105,681	52,939	565	243	530,158	230,059	5,118	2,114
Lower Arrow Reservoir	23,640	23,640	765	765	49,673	43,258	108	100	169,150	149,908	1,468	1,389

*IP data for Christina Lake and Whatshan Reservoir includes <3rd order tributaries, while the predicted habitats and abundances of all other watershed only take into consideration tributaries ≥3 order

Our findings provide a baseline of habitat condition and relative abundance of anadromous salmonids specific to tributaries in select watersheds. The information presented in this report is key to assessing trade-offs for anadromous salmonid recovery based on spawning potential. Further investigations could include network analysis (spatial analysis), and juvenile habitat modeling for sockeye lake standing crop.

Table 16. Interim ranking of select watershed for salmon recovery, by relative abundance and habitat suitability for chinook, sockeye, and steelhead species. Delineated as major production potential and minor production potential.

Species	**Kettle River**	**Transboundary**	**Slocan**	**Lower Arrow**	**Whatshan**
Chinook	3 (Minor)	1 (Major)	1 (Major)	3 (Minor)	0 (not accessible)
Sockeye	3 (Christina, Minor)	0 (no nursery area)	2 (Bonanza, Minor)	1 (Major)	0 (not accessible)
Steelhead	3 (Minor)	2 (Major)	1 (Major)	4 (Minor)	3 (Minor)

6.0 Phase 2 Action Items

Phase 1 of this study was exclusively a desktop exercise. Phase 2 will address remaining IP modeling gaps, as follows:

- integrate remote sensing data (Aerial and/or Lidar), with field validation to complete the Upper Arrow Reservoir, and Salmo River for a full assessment of Okanagan territorial waters,
- validate partial or undocumented barriers in the key streams identified in this report via sub-sampling a proportion of the reaches to confirm physical measures (bankfull, wetted, and channel complexity) used to rate habitat conditions in late summer, early fall,
- assess the upper watershed for juvenile sockeye lakes production (e.g. TP, Daphnia, Euphotic Volume) and chinook mainstem spawning (HEC RAS modeling supplemented with substrate),
- re-survey Slocan and Christina lakes, and survey Whatshan (beach spawning, sockeye fry capacity)for fish, fish habitat, water potential; and
- survey for bathymetry, velocities, and substrates in Slocan and key tributaries for chinook and steelhead capacity estimates (chinook adult, egg, fry, parr) fish, fish habitat, water potential.

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