DISTRICT OF SQUAMISH
PROJECT #: 18P-00095-00

UPPER JIMMY-JIMMY (JUDD) SLOUGH ENHANCEMENT CULVERT

FEASIBILITY MEMORANDUM

MAY 28, 2020

QUALITY MANAGEMENT

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Prepared by	Simon Kras	Simon Kras	Simon Kras	Simon Kras	Simon Kras
Signature					2020-06-01
Checked by	Ethan McGowan		Ethan McGowan	Ethan McGowan	Ethan McGowan
Signature					
Authorised by	Simon Kras		Simon Kras	Simon Kras	Simon Kras
Signature					2020-06-01
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1 BACKGROUND AND OBJECTIVES

1.1 PROJECT DESCRIPTION

Judd Slough, also referred to as Jimmy-Jimmy Slough by the Squamish First Nation, is a 2 km long channel located in Brackendale, BC, running parallel to the Squamish River. Historically, the Slough was connected to the Squamish River, and was regularly flooded by the river during periods of high water. In the past, this periodic flooding of the Slough provided scouring of fine sediments, exposing gravels and cobbles for fish spawning.

The construction of the Squamish River dike isolated the Slough from the Squamish River. The Slough currently serves as a substantial storage area for the streams and urban areas in Brackendale (KWL, 2005).

The District, the Squamish First Nation and Fisheries and Oceans Canada have all expressed an interest in restoring the fish bearing capacity of the Slough, and have proposed allowing inflow of water from the Squamish River with the purpose of:

a) scouring the fine sediments and organic deposits which have accumulated in the Slough to uncover underlying gravel beds for spawning;

b) improving water quality during the late summer low flow period; and

c) increasing attraction flow for fish spawning.

This technical memorandum evaluates the feasibility of a manual gate-controlled culvert at the north end of the Slough.

Figure 1-1: Judd Slough Overview Map

1.2 BACKGROUND INFORMATION

WSP reviewed the following background documents in the preparation of this memorandum. The headings in bold are used to refer to these documents in the body of this memorandum.

- **Flood Box Record Drawings**: Judd Slough Outlet Control Structure Record Drawings (Department of Lands, Forests and Water Resources, Water Resources Service, Water Investigations Branch, 1975)—Sheets 1-3 of 3.
- **Judd Slough Outlet Diking Plan:** Squamish River Dyking Plan and Profile Chainage 9+900 to 10+800, Ministry of Environment, Lands and Parks, Water Management Division, Province of British Columbia
- **KWL 2005 report**: "Performance of Drainage Pump Stations in October 2003 Flood", Draft report dated December 2005 by Kerr Wood Leidal.
- **Flood Box Upgrades Records**: These include:
    - Scope of work, product and pricing specifications by PBX Engineering Ltd, dated January 11, 2016.
    - Quote and product brochure for Emerson EIM M2CP motorized actuators by Spartan Controls dated November 26, 2015.
    - Shop drawing for slide gate rehabilitation by Golden Harvest dated January 16, 2014.
    - Issued for Tender drawings titled "Judd Slough Pump Station Electrical Upgrades" by PBX Engineering Ltd., dated January 11, 2016.
    - Project description letter by Sam Skalsvik, District of Squamish, dated January 28, 2016.
- **Slough Outlet Record Drawings**: Squamish River Dike Record Drawing, Ministry of Environment, Lands and Parks, Water Management Division, Province of British Columbia, December 1995 (Drawing 95-9-12)
- **Cattermole Record Drawings**: Cattermole Creek Floodgate Structure As-Constructed Drawings (December 1984, WEB Engineering Ltd.)—Drawing 360-03, General Arrangement and Sections.
- **Whittaker Record Drawings**: Whittaker Slough Flood Box Upgrade Record Drawings (February 2013, R.F. Binnie & Associates Ltd.)—Sheets 1-2 of 2.
- **USDOT**: Hydraulic Design of Highway Culverts (United States Department of Transportation Federal Highway Administration, April 2012)
- **Brisbane Design Guidelines**: City of Brisbane, Australia Natural Channel Design Guidelines Appendix C.
- **USGS 1967 Natural Channel Roughness Guide**: "Roughness Characteristics of Natural Channels, Color photographs and descriptive data for 50 stream channels for which roughness coefficients have been determined", by Harry H. Barnes Jr., United States Geological Survey Water Supply Paper 1849.
- **Upper Judd Slough Dike Raise Drawings**: Issued for Construction drawings by WSP dated December 3, 2018, titled "Squamish River Dike Raising Upper Judd Slough"
- **Lower Judd Slough Dike Raise Drawings**: Issued for Construction drawings by Kerr Wood Leidal Consulting Engineers, dated January 3, 2013 titled "Contract No. 31-2012, 2012 Dike Raising at Judd Slough – Phase 1".
- **Rip-rap Design Guidelines**: Riprap Design and Construction Guide, Public Safety Branch, Water Management Section, Ministry of Environment, Lands and Parks, Province of British Columbia, March 2000.

WSP's Project Engineer, Mr. Simon Kras, completed a site reconnaissance visit on January 11, 2019. The reconnaissance visit included a visual review of the entire length of the Slough. The northern 1.1 km (north of the bridge to 1050 Depot Road) were reviewed by foot. The southern 1.0 km were reviewed by canoe.

WSP retained Bunbury & Associated Ltd. to survey the Slough water level, channel bottom and outlet culvert elevations. The survey was completed on January 6, 2019.

On May 13, 2019, WSP's Field Reviewer, Mr. Ethan McGowan completed a site reconnaissance of Horse Creek, which is hydraulically linked with the Slough.

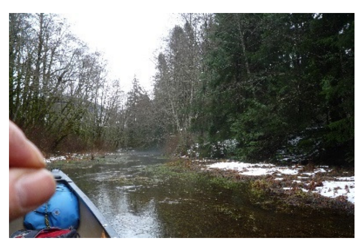
WSP retained Bunbury & Associated Ltd. to set elevation markers at the proposed culvert location to allow visual monitoring of river levels by WSP field personnel in July, August and September 2019. The markers were set on June 11, 2019. River level measurements were visually recorded on July 3, July 19, August 2 and August 15, 2019. The measurement on August 15 coincided with a significant storm event.

2 DESIGN PARAMETERS

2.1 SLOUGH DIMENSIONS AND CHARACTERISTICS

For discussion and analysis purposes, the Slough is divided into four reaches. The characteristics of each reach based on our site reconnaissance and background information review are provided in Table 2-1 below:

Table 2-1: Characterization of Slough Reaches

Reach*	**Channel Width ****	**Bank Height (m) ****		**Channel Roughness and Notes*****	**Typical Photo**
		Landside	**Riverside**		
1: 0-400	7 m	>2	>2	Fallen trees across channel. n=0.09	
2: 400-900	7 m	~1	~1	The central channel is approximately 1 m deep and 7 m wide, with a surrounding treed floodplain ~20 m wide. n=0.05 (for central channel)	
3: 900-1500	20 m	~1	~2	The channel is overgrown with reeds. There are a few houses visible on the landside. n=0.07	

4: 1500-2000	20-40 m	~1	~2	The channel becomes a wetland. Multiple homes very near the Slough. n=0.09	

* Stationing is based on approximate distance in metres from the northern end of the Slough.
** Channel Width and Bank Height are approximate based on visual observations only.
*** Manning's n values were approximated conservatively using the Modified Cowan Method, as described in the City of Brisbane, Australia Natural Channel Design Guidelines. The n-values were checked against typical channels from the 1967 USGS Verified Roughness Characteristics of Natural Channels.

Additional photos are provided in the Appendix which illustrate the channel conditions in the various reaches.

2.2 EXISTING HYDROLOGY AND HYDRAULICS

Judd Slough is a low point fed by groundwater, and to a lesser extent, by surface runoff during storm events. The Slough has a two small side-channels projecting west of the Slough within the Squamish First Nation Wawaik'um Territory, and one larger side-channel projecting west of the Slough within the 1050 Depot Road property.

The Horse Creek watercourse is located east of Judd Slough. Like Judd Slough, Horse Creek is mostly fed by groundwater, but also conveys surface runoff during storm events. The Creek is connected to the Slough at the south end with a 1500 mm culvert. The diagram below illustrates the hydraulics.

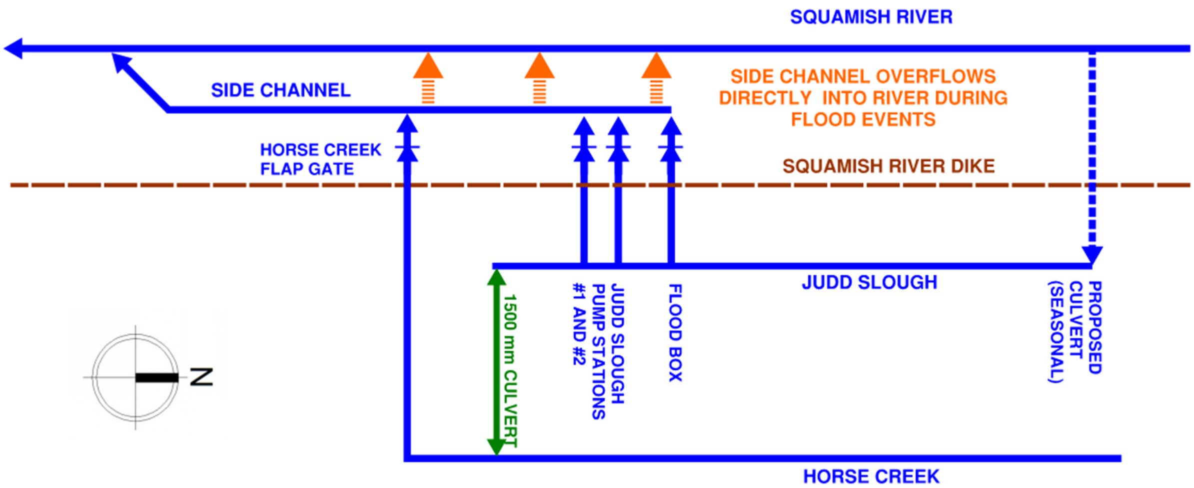


Figure 2-1: Schematic Diagram of Judd Slough and Horse Creek

Based on our site reconnaissance visit and our review of LiDAR data, Horse Creek is approximately 1 meter higher than Judd Slough, except at the south end.

2.3 WATER LEVEL MEASUREMENTS

Water level measurements were taken on six separate days, including both upstream and downstream. The purpose of the measurements was to correlate the Environment Canada (EC) levels from the "Squamish River at Brackendale" measuring station with the local water levels both upstream and downstream of Judd Slough.

The measurements included August 2, 2019—estimated to be a 1-year return period event; the river levels recorded at Brackendale (EC) were exceeded 5 times between 2011 and 2017.

2.3.1 UPSTREAM WATER LEVEL MEASUREMENTS

To correlate the EC data with the local river level elevations at the proposed culvert location, WSP recorded water levels on six separate days. The river level was recorded photographically at the proposed culvert location, using elevation markers set by survey (Bunbury and Associates).

One of the photographs taken on July 19, 2019 was poor quality and the upstream water level could not be properly determined. For this reason, the measurement was discarded. The visual measurements are considered to be accurate to within +/- 0.1 m. The data is presented in the table below.

Meas #	Date	Time of Day	EC River Level†	Upstream River Level Measured	Measured Minus EC River Level
1	7-Jan-2019	10:00††	2.36	10.4	8.04
2	11-Jun-2019	11:30	3.349	11.3	7.95
3	3-Jul-2019	08:26	3.731	11.4	7.67
4	2-Aug-2019	19:30	5.803	13.3	7.50
5	15-Aug-2019	10:00	3.308	11.4	8.09
Average					7.85

† Datum not confirmed

†† Estimated

The average difference between the measured river level at the culvert location and the Environment Canada readings is 7.85 m. For this reason, we have added 7.85 m to the Environment Canada data to estimate river level statistics at the culvert location.

2.3.2 DOWNSTREAM WATER LEVEL MEASUREMENTS

WSP recorded downstream water levels on five separate days in the pond located downstream of Judd Slough. The pond maintains a constant level, except during very high river levels, when the Squamish River backwater raises the level of the pond. The pond level was recorded photographically downstream of the flood box structure at the south end of Judd Slough. No appreciable change in pond level was observed, even during the 1-year storm event on August 2nd. Based on the pond elevation of 8.4 m measured on August 2, 2019 at 19:00 hrs, and the Brackendale (EC) monitoring station reading of 5.381 m for the same time period, an adjustment of 8.4 m – 5.381 m = 2.5 m could be considered appropriate.

Another approach is to consider the change in dike crest elevation between the north and south ends of Judd Slough, which should correspond with the difference in river level during a design high river level event. Based on the Issued for Construction drawings by WSP for the Upper Judd Slough Dike Raise, the dike crest elevation near the culvert at the north end of Judd Slough is approximately 17.5 m. Based on the Lower Judd Slough Dike Raise drawings by KWL, the dike crest elevation at the flood box at the south end of Judd Slough is approximately 13.15 m—4.35 lower than at the upstream end. The estimated downstream water levels are therefore 4.35 m lower than the upstream water levels. The upstream correction of 7.85 m can therefore be reduced by 4.35 m, for an net adjustment of 7.85 m – 4.35 m = 3.5 m at the south end.

The adjustment factor chosen is 3.5 m, which is the most conservative of the two methods considered, with higher estimated downstream river levels.

2.4 UPSTREAM WATER LEVELS

Based on the historical water level data, the average water level in the Squamish River is generally below the bottom of the proposed Slough inlet between December and March, so inflow is not feasibly during these months.

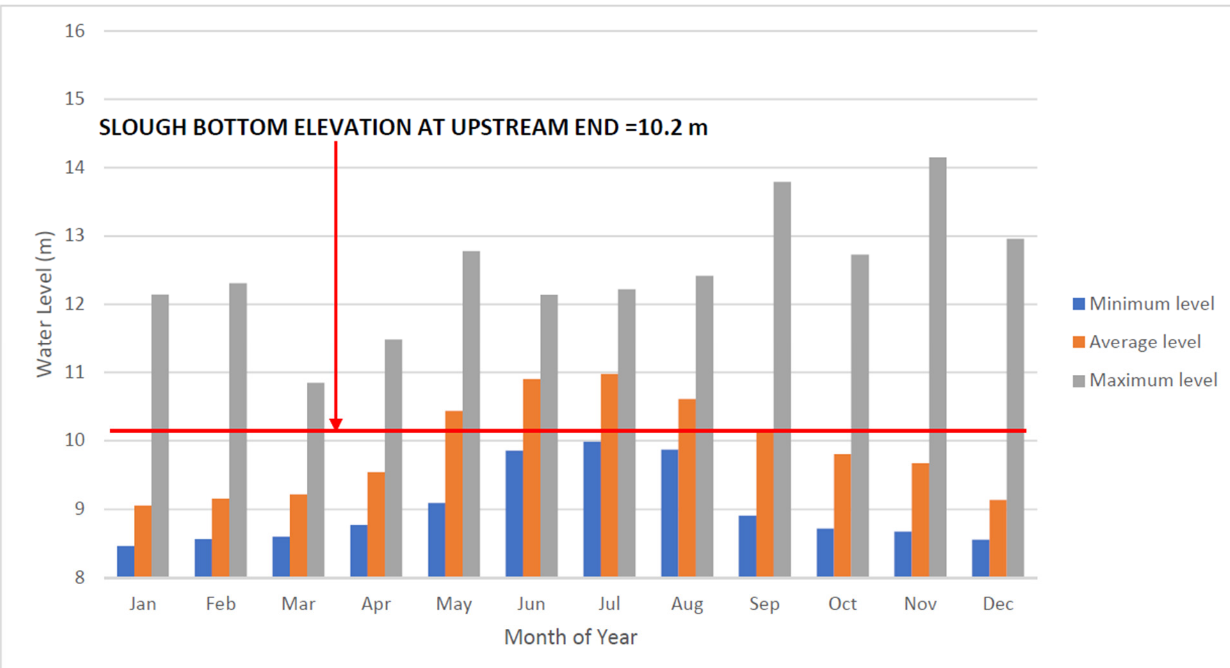


Figure 2-2: Estimated Historical Squamish River water levels upstream of the Slough inlet (Squamish River Level at Brackendale Environment Canada Reading + 7.85 m)

2.5 DOWNSTREAM WATER LEVELS

The maximum operating water level in the Flood Box shown in Figure 2-3 is calculated as follows:

- Maximum operating level with respect to flood box invert according to record drawings = 31.0 feet – 22.55 feet = 8.45 feet = 2.58 m
- Flood invert elevation based on January 7, 2019 survey = 6.65 m

- Maximum operating level in survey datum = 6.65 m + 2.58 m = 9.23 m.

The Squamish River water levels downstream of the Slough outlet flood box are illustrated in Figure 2-3 below. The average water level in the Squamish River downstream of the Slough is below the downstream pond elevation for all months of the year. However, the maximum water level exceeds the maximum operating water level for May and September-December, indicating a chance of excessive backwater during heavy storm events. The peaks do not coincide with springtime snow melt, suggesting that they are driven primarily by rainfall. Given that major rainfall events could occur during any month of the year, the option to close the gates during a major storm event should be maintained at all times.

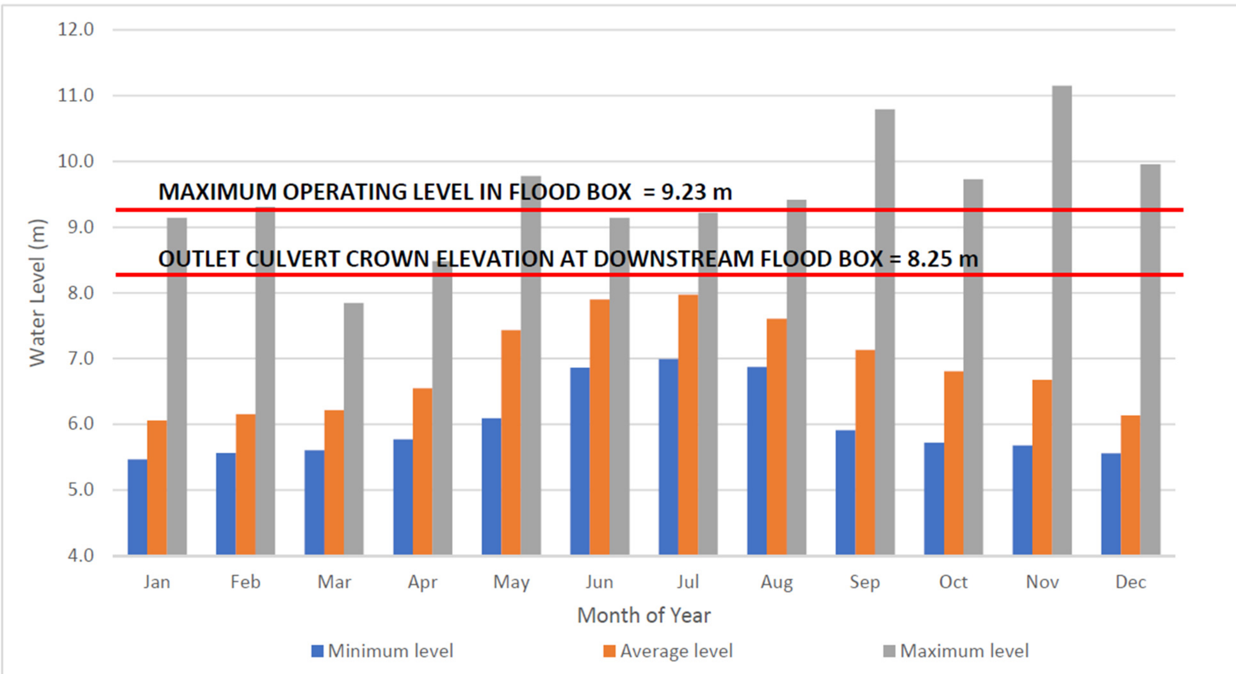


Figure 2-3: Estimated Historical Squamish River water levels downstream of the Slough outlet (Squamish River Level at Brackendale Environment Canada Reading + 3.5 m)

2.6 OUTLET CONTROL

There are three discharge structures at the outlet of Judd Slough (see also Figure 2-4 below):

- **Flood box**: Based on the 1982 Flood Box Record Drawings, the gravity outlet consists of two 7'3" x 4'9" (2.2 m x 1.45 m) pipe arch culverts. The culverts are controlled on the downstream side with mechanically operated sluice gates. *We note that there is contradictory information on the 1995 Slough Outlet Record Drawings, which show the culvert diameters as 1.37 m and 0.91 m. However, the shop drawings by Golden Harvest dated January 16, 2014, for the 2016 sluice gate upgrades are for a 96"x60" existing slide gate, which supports the size of culverts shown in the 1982 Flood Box Record Drawings.*
- **Judd Slough Pump Station No. 1**: Consists of two parallel 50 hp vertical lineshaft pumps in a concrete wet well discharging through two 24" (600 mm) outlet pipes, with a combined measured capacity of 1.39 m^3/s (KWL, 2005).
- **Judd Slough Pump Station No. 2**: Consists of three parallel pumps—one 75 hp and two 60 hp with a combined capacity of 1.7 m^3/s (KWL, 2005).

For design of the culvert at the Slough inlet, the flood box is the outlet structure of interest. The inlet culvert sluice gates will remain closed during high water levels in the Squamish River, so the pump station capacity will not be relied upon to discharge inflow from the proposed culvert.

The capacity of the flood box outlet culverts has been modelled using the USDOT HY-8 software package. Based on the HY-8 output, the culverts can convey 7.6 m^3/s of flow with the headwater level in the Slough at 8.25 m, which corresponds with the culverts' crown elevation. The flow profile is provided in the figure below.

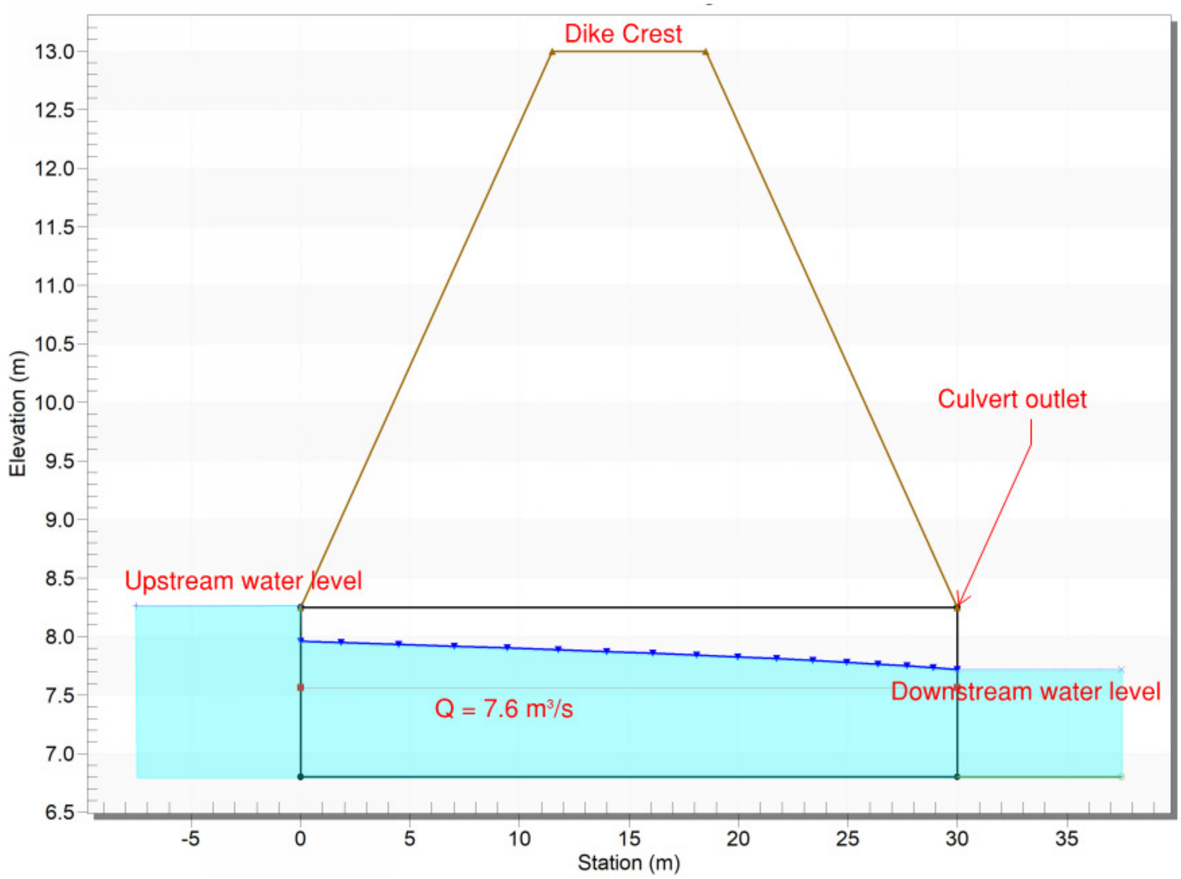


Figure 2-4: Modelled profile of 2 downstream culverts at flood box using USDOT HY-8 software

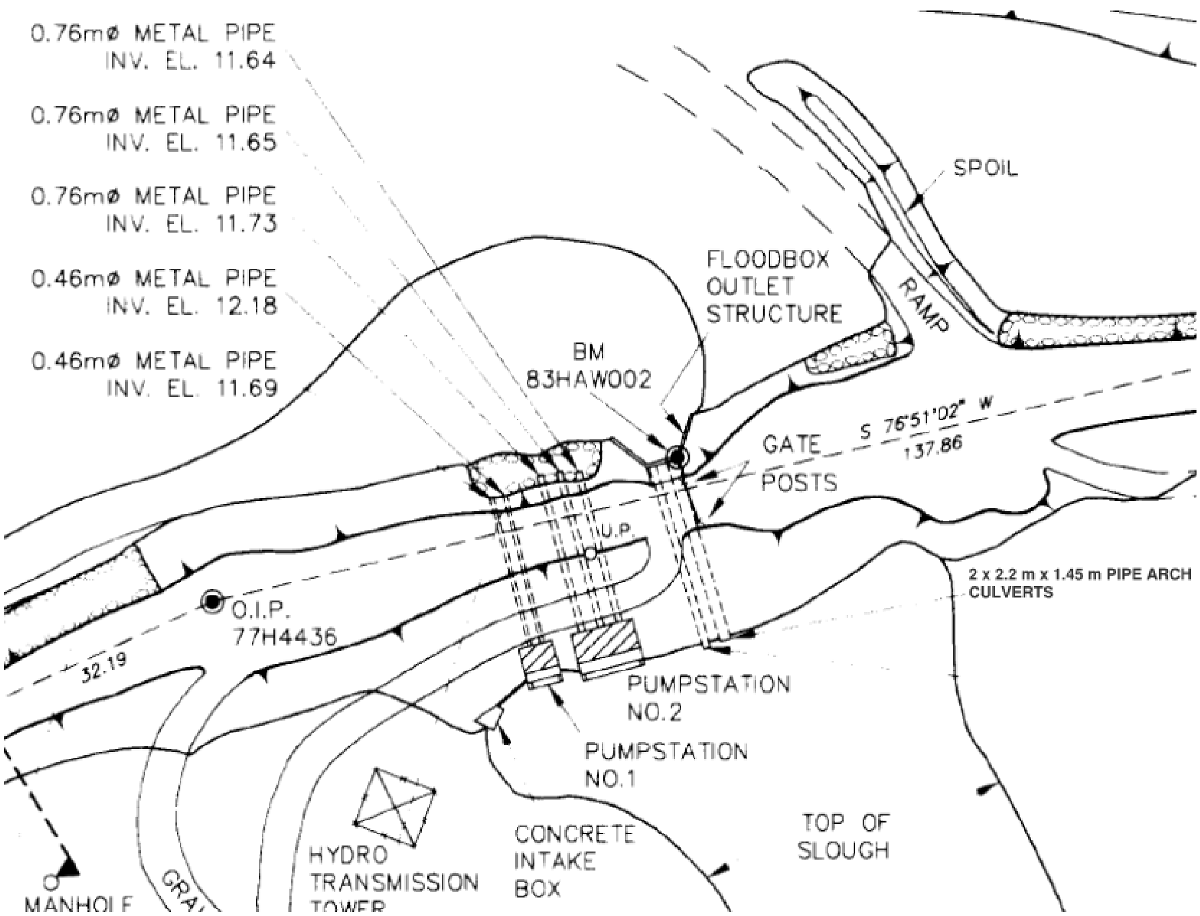


Figure 2-5: Slough outlet configuration from record drawings

Based on Kerr Wood Leidal's 2005 report, the capacity of the pumping stations was supplemented with three 100 HP submersible rental pumps with 10" (250 mm) outlets, with a combined capacity of 1.05 m^3/s supplied by Canadian Dewatering Ltd., which suggests that the two existing pump stations may be unable to provide sufficient pumping capacity during high intensity storm events.

Based on shop drawings by Golden Harvest for the 2016 sluice gate upgrades dated January 16, 2014, the outlet culvert sluice gates are 96" x 60" (2.44 m x 1.53 m) rectangular gates. Based on the electrical Issued for Tender drawings by PBX Engineering Ltd. dated January 11, 2016, there are two pressure transducers providing level information at the Slough outlet—one on the Slough side and one on the River side.

Based on information provided by the District (e-mail correspondence PBX Engineering Ltd. dated January 30, 2019), the control strategy for the gates is as follows:

- There are three modes to operation – Manual, Auto (River Mode), Auto (Differential Mode)
- Manual mode allows operators to manually operate the gates when required. This can be done through SCADA or at the pump station using the manual controls on the gate controllers.
- Auto (River Mode) performs a comparison between the active river level and a pre-defined setpoint in SCADA and closes both gates when the river level exceeds the setpoint.

- Auto (Differential Mode) performs a comparison between the active river level and the active Slough forebay level. When the river level exceeds the slough/ forebay level, both gates close.

The assumption for this memorandum is that the system would be operated in Auto Differential Mode during Slough inflow at the north end. Because inflow will only be permitted when the level in the Squamish River is lower than the level in the Slough at the flood box, the outlet sluice gates would remain open, allowing unrestricted discharge at the South end.

2.7 ADJACENT PROPERTIES

There are residential properties on both sides of Judd Slough. The properties to the west of the Slough consist of two uninhabited properties owned by the Squamish First Nation at the north and south ends (Wawaik'um and Aik'wuks Reserves respectively), and three large lots with houses (1050 Laramee Road, 1000 Laramee Road and 1050 Depot Road from south to north). The closest structure west of the Slough is more than 70 m from the Slough.

To the east of the Slough, residential properties are much smaller, more numerous, with homes much closer to the Slough. There are 36 homes directly adjacent to the Slough, including 20 homes within the Wawaik'um Reserve owned by the Squamish First Nation. Ten of these homes are within the 30-metre setback required by current Riparian Area Regulations, including eight (8) homes near the south end of the Slough, and two (2) homes on the Wawaik'um Reserve. It is possible that the 30-metre setback requirement was not in place at the time the homes were built and that these homes were grandfathered.

The proximity of the homes located west of the Slough makes these homes particularly prone to flooding, especially at the south end of the Slough, where the elevation of the homes appears to be less than 2 m above the top-of bank in some cases based on our site reconnaissance. Appendix 3 illustrates the historical 15-metre and current 30-metre riparian setbacks for Judd Slough.

2.8 HORSE CREEK

Because Horse Creek is approximately 1 m higher than Judd Slough at the north end, and the proposed culvert will not be opened during high levels in the Squamish River, the proposed inflow into Judd Slough at the north end is not anticipated to have any impact on the water levels in Horse Creek. Horse Creek would provide additional outflow capacity into the Squamish River via the 1500 mm diameter culvert at the south end of Judd Slough (see Figure 2-1).

3 SLOUGH HYDRAULICS AND SCOURING

3.1 MODEL

For hydraulic analysis purposes, the Slough was treated as a uniform channel with a trapezoidal cross-section separated into four uniform reaches. The parameters for the four reaches are summarized below:

Reach*	**Chainage**	**Width at channel bottom (m)**	**Bank Slope**	Channel bottom slope	**Bank height (m)**	**Manning's 'n' roughness parameter**
1	0-400	7	50%	0.11%	2	0.09
2	400-900	7	50%	0.11%	1.4	0.05
3	900-1500	20	50%	0.09%	1	0.07
4	1500-2000	20	50%	0.09%	1	0.07

The LiDAR data was used to determine the slope from the channel approximately between Chainage 800 and 1850, where data was available. The observed channel bottom slope varied between 0.00% and 0.27% with an average slope of 0.09%. A uniform slope was assumed for Reaches #1 and #2 based on the elevations at the inlet and at Chainage 800.

At 1050 Laramee Road there is a bridge crossing where the channel narrows down to approximately 8 metres. This constriction is treated as a open bottom culvert for analysis purposes.

Approximate water levels in the Slough were calculated using Manning's Equation:

$$Q = \frac{1}{n} \cdot {R_H}^{\frac{2}{3}} \cdot \sqrt{S}$$

where Q is the flowrate in m^3/s, n is Manning's roughness parameter, R_H is the hydraulic radius in meters (as calculated below), and S is the channel slope.

$$R_H = \frac{A}{P}$$

Where A is the channel cross-sectional area in square metres and P is the wetted perimeter in metres.

3.2 FLOW CAPACITY

Using Manning's equation, the capacity of the four reaches of the Slough were calculated, allowing a flow depth equal to the observed bank height, minus 0.4 metres of freeboard.

The resulting flow capacities for the four reaches of the Slough were calculated as:

Reach*	Chainage	Flow capacity (m^3/s)
1	0-400	6.6
2	400-900	5.1
3	900-1500	3.7
4	1500-2000	3.2

Based on Kerr Wood Leidal's 2003 report, the estimated peak flow resulting from stormwater runoff during the 2003 flood was estimated at 3.32 m^3/s. The estimate was generated by using the 2003 precipitation data from the Squamish Airport with the HEC-HMS watershed model originally developed by Kerr Wood Leidal for the Brackendale and Garibaldi Master Drainage Plans. The estimate does not account for infiltration or groundwater movement.

The capacity estimates above for the four reaches of the Slough indicate that Reach 4 is the limiting factor for the amount of water which the Slough can convey. A design flowrate of 3.2 m^3/s is assumed for purposes of this memorandum. This flow is approximately the same as the estimated peak flow for the 2003 flood event.

At a flow of 3.2 m^3/s, the average channel flow velocities and depths in the four reaches would be:

Reach*	Chainage	Average channel velocity (m/s)	Flow depth (m)
1	0-400	0.33	1.07
2	400-900	0.49	0.77
3	900-1500	0.28	0.55
Bridge at 1050 Laramee	1500	0.69	0.67
4	1500-2000	0.25	0.60

3.3 SCOURING REQUIREMENTS

To improve the spawning habitat in the Slough, the use of supplementary flow from the Squamish River to potentially increase the scouring capacity of the Slough channel has been proposed. The flow velocity would need to be sufficient to scour silt and fine sand.

Based on the Hjulströms curve (see Figure 3-1), there is the potential for some scouring of silts, especially in Reaches #1 and 2 of the Slough.   Scour is expected to be more pronounced in the thalweg (centre of channel), where the localized flow velocities are higher.

Although the Hjulströms curve does not show the potential for deposition based on the average channel velocity, it is possible for localized velocities to be significantly lower in parts of the channel. Reach 3 would be a likely location for deposition, close to where the channel widens.

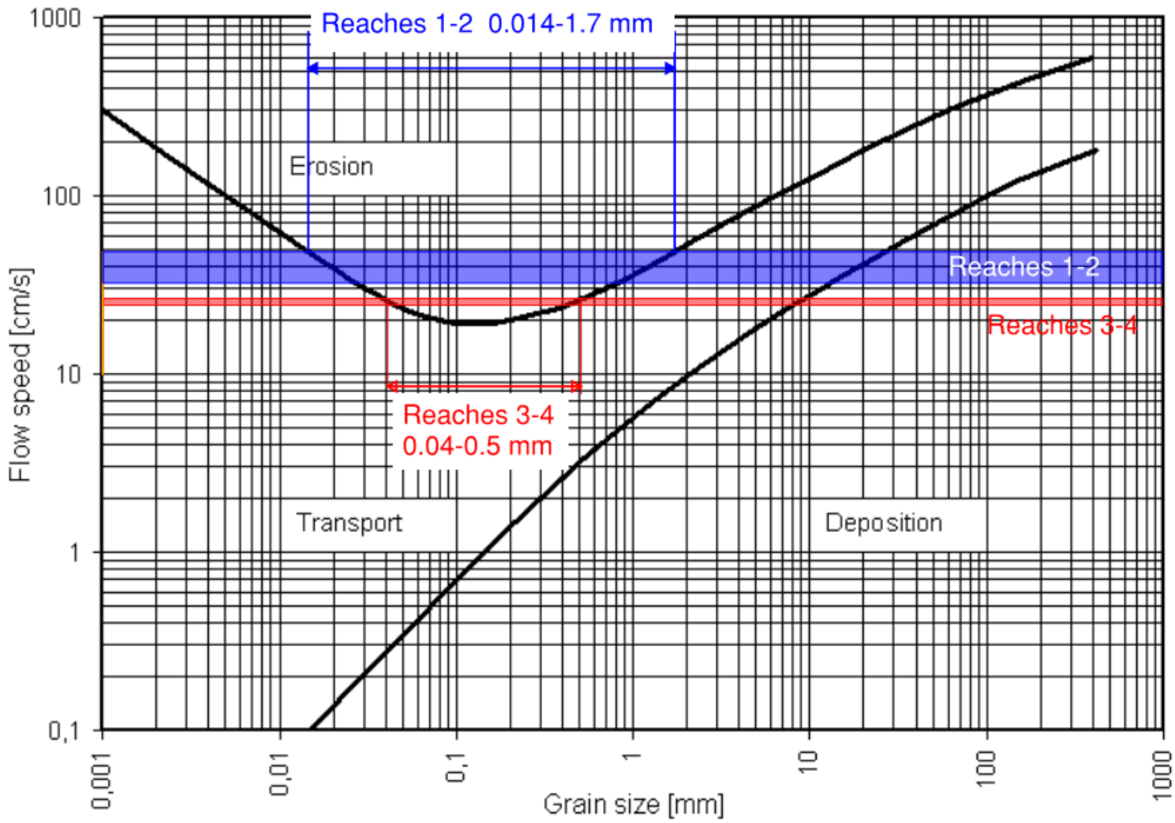


Figure 3-1: Hjulström erosion-deposition curve

4 DISCUSSION AND CONCLUSIONS

Based on our understanding, the design objectives for the proposed upstream culvert are:

1) Scouring silts from the Slough bottom to uncover underlying gravels.
2) Improving water quality during the late summer low-flow period.
3) Increasing attraction flow for fish spawning.

Based on our analysis of the Slough hydraulics, we have provided comments regarding the feasibility of achieving these objectives.

4.1 OBJECTIVE 1: SCOURING SILTS

The proposed culvert may be capable of scouring silt, especially in Reaches 1 and 2. Removal of sediments by other methods, including excavation may be required for consolidated cohesive silts. Scour is expected to be most pronounced along the thalweg. Based on comments provided by Fisheries and Oceans Canada, spawning salmon are likely to assist in the erosion process through redd excavation, provided that some areas of gravel are initially uncovered through scour (e-mail from Al Jonsson dated February 14, 2019).

It is possible that deposition will occur in Reaches 3 and 4 where the channel widens. The major concerns associated with deposition in Reaches 3 and 4 are: (i) a reduction in the flood storage capacity of the Slough, and (ii) alteration of the hydraulic profile during a flooding event, which may result in higher water levels. Both of these concerns can be addressed by excavating retention pools near the upstream end of Reach 3. The pools would encourage deposition of sediments in a location where the they can be easily removed. Any deposition would occur below the low water level, so the storage volume of the Slough would be unaffected. The area near the bridge to 1050 Depot Road was proposed by Fisheries and Oceans Canada as a possible location for retention pools.

4.2 OBJECTIVES 2 AND 3 IMPROVING WATER QUALITY IN THE LATE SUMMER AND INCREASING ATTRACTION FLOW FOR SPAWNING

Based on the estimated average historical water levels, the water level in the Squamish River is generally high enough to allow inflow in the late summer (Figure 2-2), but low enough to allow free discharge at the downstream end of the Slough (Figure 2-3).

The inflow could likely be maintained into the early fall, provided that the sluice gate remains closed for storm events. Inflow during the early fall would provide additional attraction flow during the salmon spawning period.

5 LIMITATIONS AND ASSUMPTIONS

This feasibility study is preliminary and involves basic hydraulic calculations along selected points in the channel. We note the following limitations and assumptions associated with this study:

- A detailed ground-based survey of the Slough was not done for this study. The width, bank slopes, and bank heights were estimated based on visual observations and rough measurements from orthophotos. Although the calculations are considered valuable for feasibility purposes, the input parameters for the hydraulic calculations are subject to significant uncertainty.
- Our study used LiDAR data on the Slough where available to determine the channel profile and estimate slopes for hydraulic calculations. There were no points on the Slough bottom or water surface north of Chainage 800 or south of Chainage 1850. A Uniform slope was assumed between Chainage 800 and the proposed culvert invert at the north end.
- The actual sediment composition of the Slough bottom has not been studied.
- The Squamish River profile is assumed to follow the dike profile for determination of average upstream and downstream water levels. The dike profile is based on the modelled river profile during a design flood event, which is not the same as the average profile. Any operating strategy developed for the proposed culvert should be based on actual modelled or measured river levels.

APPENDICES

- Appendix A: Photo index and photos
- Appendix B: Calculations
- Appendix C: Judd Slough Riparian Setbacks

APPENDICES

APPENDIX A: PHOTO INDEX AND PHOTOS

Location of elevation makers set by Bunbury Associates
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16
Jimmy Rd
Axen Rd
Parkwood Pl
Rayburn Rd
50

Photo 01: Looking downstream near inlet at north end.
Approx. 10 m channel width. >2 m banks on both sides.

Photo 02: Slough width ~7m.   Banks >2m both sides.

Photo 03: Central channel is ~7 m wide, but has low banks (~1 m). Surrounding floodplain rises gradually and is heavily treed. Overtopping of channel would flood treed area.

Photo 04: Channel is ~15 m wide and overgrown with reeds. Banks are genearally ~2m high. Swale visible on landside bank in this photo.

Photo 05: Channel is ~15 m wide and overgrown with reeds. Banks are genearally ~2m high. 1050 Depot Road bridge visible in this photo.

Photo 06 Channel is ~15 m wide with lots of branches/reeds. Banks are ~1.5-2 m both sides.

Photo 07: Channel is ~15 m wide with lots of branches/reeds. Banks are ~1.5-2 m both sides. Looking upstream.

Photo 08: Upstream of bridge at 1050 Laramee Road. Channel is ~20 m wide with lots of reeds. Banks on landside are very low (<1 m).

Photo 09: Just downstream of bridge at 1050 Laramee Road. Channel is ~20 m wide. Banks on landside are very low [<1 m]. House on landside seen in this photo.

Photo 10: Just downstream of bridge at 1050 Laramee Road. Heavy growth of reeds across channel. Looking upstream. Channel is >20 m wide. Banks are very low on landside.

Photo 11: Heavy reeds. Channel is >20 m wide. Houses on landside have very little (<1m) bank protection.

Photo 12: Channel is >20 m wide. Houses on landside have very little (<1m) bank protection.

Photo 13: Channel is >20 m wide. Houses on landside have very little (<1m) bank protection. Some houses have furnishings near Slough.

Photo 14: Judd Slough Pump Stations #1 and #2 from Slough

Photo 15: Judd Slough looking upstream from outlet end.

Photo 16: Flood box and Pump Stations. Looking East within Slough.

Bunbury Survey: Photo 01

Bunbury Survey: Photo 02

Bunbury Survey: Photo 03

APPENDIX B: CALCULATIONS

Squamish Dike Upgrade--Upper Judd Slough **26-Feb-2019**
Slough Capacity Calculations -- REACH 1 **Calculations by Simon Kras**

Width	m	7		
Depth	m	1.6	Allowing 0.4 m freeboard	
Manning's n coeff		0.09	Natural channel, very poor conditions	
Slope		0.11%	Velocity	0.405183869 m/s
Bank slope		50%		
X-section (m2)		16.32		
Wetted perim (m)		14.15541753		
Hyd. radius R_H (m)		1.15291548		

Manning formula
Q = A/n*R^(2/3)*S^0.5

Flow (m3/s) 6.612600739

Modified Cowan Method for channel roughness

nb	0.024	Sand/fine gravel
n1	0.02	Severe irregularity
n2	0.005	X-sections alternate occasionally
n3	0.03	Appreciable obstructions
n4	0.01	Small
m	1	Minor meander

n=(nb+n1+n2+n3+n4) * m
n 0.089

Squamish Dike Upgrade--Upper Judd Slough **26-Feb-2019**
Slough Capacity Calculations -- REACH 2 **Calculations by Simon Kras**

Width	m	7		
Depth	m	1	Allowing 0.4 m freeboard	
Manning's n coeff		0.05	Natural channel, very poor conditions	
Slope		0.11%	Velocity	0.564233 m/s
Bank slope		50%		
X-section (m2)		9		
Wetted perim (m)		11.47213595		
Hyd. radius R_H (m)		0.784509531		

Manning formula
Q = A/n*R^(2/3)*S^0.5

Flow (m3/s)	5.078097057

Modified Cowan Method for channel roughness

nb	0.024	Sand/fine gravel
n1	0.01	Considerable bed roughness
n2	0.003	X-section Alternates occasionally
n3	0.004	A few scattered obstructions
n4	0.002	Very little vegetation in channel
m	1	Minor meander

n=(nb+n1+n2+n3+n4) * m

n	0.043

Squamish Dike Upgrade--Upper Judd Slough **26-Feb-2019**
Slough Capacity Calculations -- REACH 3 **Calculations by Simon Kras**

Width	m	20		
Depth	m	0.6	Allowing 0.4 m freeboard	
Manning's n coeff		0.07	Natural channel, very poor conditions	
Slope		0.09%	Velocity	0.291437 m/s
Bank slope		50%		
X-section (m2)		12.72		
Wetted perim (m)		22.68328157		
Hyd. radius R_H (m)		0.560765424		

Manning formula
Q = A/n*R^(2/3)*S^0.5

Flow (m3/s)	3.707073052

Modified Cowan Method for channel roughness

nb	0.024	Sand/fine gravel
n1	0.02	Severe irregularity
n2	0.003	Near uniform section
n3	0.01	Obstructions 5-10% of channel
n4	0.01	Grasses and well below flow depth
m	1	Minor meander

n=(nb+n1+n2+n3+n4) * m

n	0.067

Squamish Dike Upgrade--Upper Judd Slough **26-Feb-2019**
Slough Capacity Calculations -- REACH 4 **Calculations by Simon Kras**

Width	m	20		
Depth	m	0.6	Allowing 0.4 m freeboard	
Manning's n coeff		0.08	Natural channel, very poor conditions	
Slope		0.09%	Velocity	0.255007 m/s
Bank slope		50%		
X-section (m2)		12.72		
Wetted perim (m)		22.68328157		
Hyd. radius R_H (m)		0.560765424		

Manning formula
Q = A/n*R^(2/3)*S^0.5

Flow (m3/s)	3.24368892

Modified Cowan Method for channel roughness

nb	0.024	Sand/fine gravel
n1	0.02	Severe irregularity
n2	0.003	Near uniform section
n3	0.01	Obstructions 5-10% of channel
n4	0.025	Heavy grasses and weeds--almost to flow depth
m	1	Minor meander

n=(nb+n1+n2+n3+n4) * m

n	0.082

Squamish Dike Upgrade--Upper Judd Slough **26-Feb-2019**

Slough Flow Velocity Calculations -- REACH 1 **Calculations by Simon Kras**

Width	m	7			
Depth	m	1.07321207			
Manning's n coeff		0.09	Natural channel, very poor conditions		
Slope		0.11%	Velocity	0.325963	m/s
Bank slope		50%			
X-section (m2)		9.816052789			
Wetted perim (m)		11.79955029			
Hyd. radius R_H (m)		0.831900585			

Manning formula

Q = A/n*R^(2/3)*S^0.5

Flow (m3/s)	3.199668641	
Desired flow	3.2	
Difference	-0.00033136	*Set to Zero with Goal Seek*

Modified Cowan Method for channel roughness

nb	0.024	Sand/fine gravel
n1	0.02	Severe irregularity
n2	0.005	X-sections alternate occasionally
n3	0.03	Appreciable obstructions
n4	0.01	Small
m	1	Minor meander

n=(nb+n1+n2+n3+n4) * m

n 0.089

Squamish Dike Upgrade--Upper Judd Slough **26-Feb-2019**
Slough Flow Velocity Calculations -- REACH 2 **Calculations by Simon Kras**

Width	m	7			
Depth	m	0.769370812			
Manning's n coeff		0.05	Natural channel, very poor conditions		
Slope		0.11%	Velocity	0.487071	m/s
Bank slope		50%			
X-section (m2)		6.569458578			
Wetted perim (m)		10.44073087			
Hyd. radius R_H (m)		0.629214435			

Manning formula
Q = A/n*R^(2/3)*S^0.5

Flow (m3/s)	3.199791658	
Desired flow	3.2	
Difference	-0.00020834	*Set to Zero with Goal Seek*

Modified Cowan Method for channel roughness

nb	0.024	Sand/fine gravel
n1	0.01	Considerable bed roughness
n2	0.003	X-section Alternates occasionally
n3	0.004	A few scattered obstructions
n4	0.002	Very little vegetation in channel
m	1	Minor meander

n=(nb+n1+n2+n3+n4) * m
n 0.043

Squamish Dike Upgrade--Upper Judd Slough **26-Feb-2019**
Slough Flow Velocity Calculations -- REACH 3 **Calculations by Simon Kras**

Width	m	20			
Depth	m	0.549785409			
Manning's n coeff		0.07	Natural channel, very poor conditions		
Slope		0.09%	Velocity	0.275895	m/s
Bank slope		50%			
X-section (m2)		11.60023617			
Wetted perim (m)		22.45871509			
Hyd. radius R_H (m)		0.516513795			

Manning formula
Q = A/n*R^(2/3)*S^0.5

Flow (m3/s)	3.200452082	
Desired flow	3.2	
Difference	0.000452082	*Set to Zero with Goal Seek*

Modified Cowan Method for channel roughness

nb	0.024	Sand/fine gravel
n1	0.02	Severe irregularity
n2	0.003	Near uniform section
n3	0.01	Obstructions 5-10% of channel
n4	0.01	Grasses and well below flow depth
m	1	Minor meander

n=(nb+n1+n2+n3+n4) * m

n	0.067

Squamish Dike Upgrade--Upper Judd Slough **26-Feb-2019**
Slough Flow Velocity Calculations -- BRIDGE AT 1050 LARAMEE ROAD **Calculations by Simon Kras**

Width	m	7		
Depth	m	0.665627875		
Manning's n coeff		0.07	Natural channel, very poor conditions	
Slope		0.50%	Velocity	0.686129 m/s
Bank slope		10000%		
X-section (m2)		4.663825731		
Wetted perim (m)		8.331322312		
Hyd. radius R_H (m)		0.559794179		

Manning formula
Q = A/n*R^(2/3)*S^0.5

Flow (m3/s)	3.19998686	
Desired flow	3.2	
Difference	-1.31401E-05	*Set to Zero with Goal Seek*

Modified Cowan Method for channel roughness

nb	0.024	Sand/fine gravel
n1	0.02	Severe irregularity
n2	0.003	Near uniform section
n3	0.01	Obstructions 5-10% of channel
n4	0.01	Grasses and well below flow depth
m	1	Minor meander

n=(nb+n1+n2+n3+n4) * m

n	0.067

Squamish Dike Upgrade--Upper Judd Slough **26-Feb-2019**
Slough Flow Velocity Calculations -- REACH 4 **Calculations by Simon Kras**

Width	m	20			
Depth	m	0.595205448			
Manning's n coeff		0.08	Natural channel, very poor conditions		
Slope		0.09%	Velocity	0.25373	m/s
Bank slope		50%			
X-section (m2)		12.612648			
Wetted perim (m)		22.66183968			
Hyd. radius R_H (m)		0.556558875			

Manning formula
Q = A/n*R^(2/3)*S^0.5

Flow (m3/s)	3.200208579	
Desired flow	3.2	
Difference	0.000208579	*Set to Zero with Goal Seek*

Modified Cowan Method for channel roughness

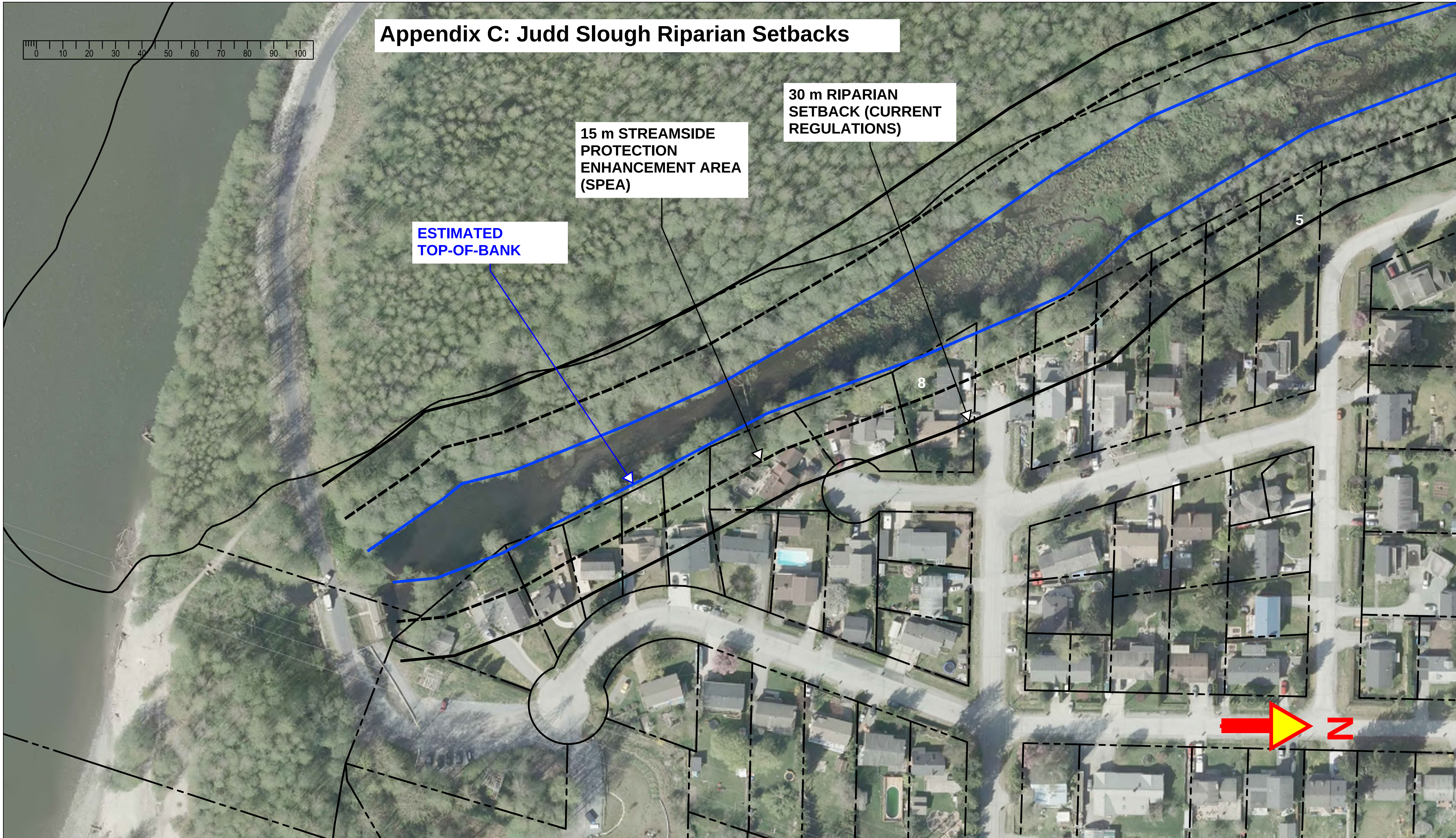
nb	0.024	Sand/fine gravel
n1	0.01	Severe irregularity
n2	0.003	Near uniform section
n3	0.01	Obstructions 5-10% of channel
n4	0.025	Heavy grasses and weeds--almost to flow depth
m	1	Minor meander

n=(nb+n1+n2+n3+n4) * m

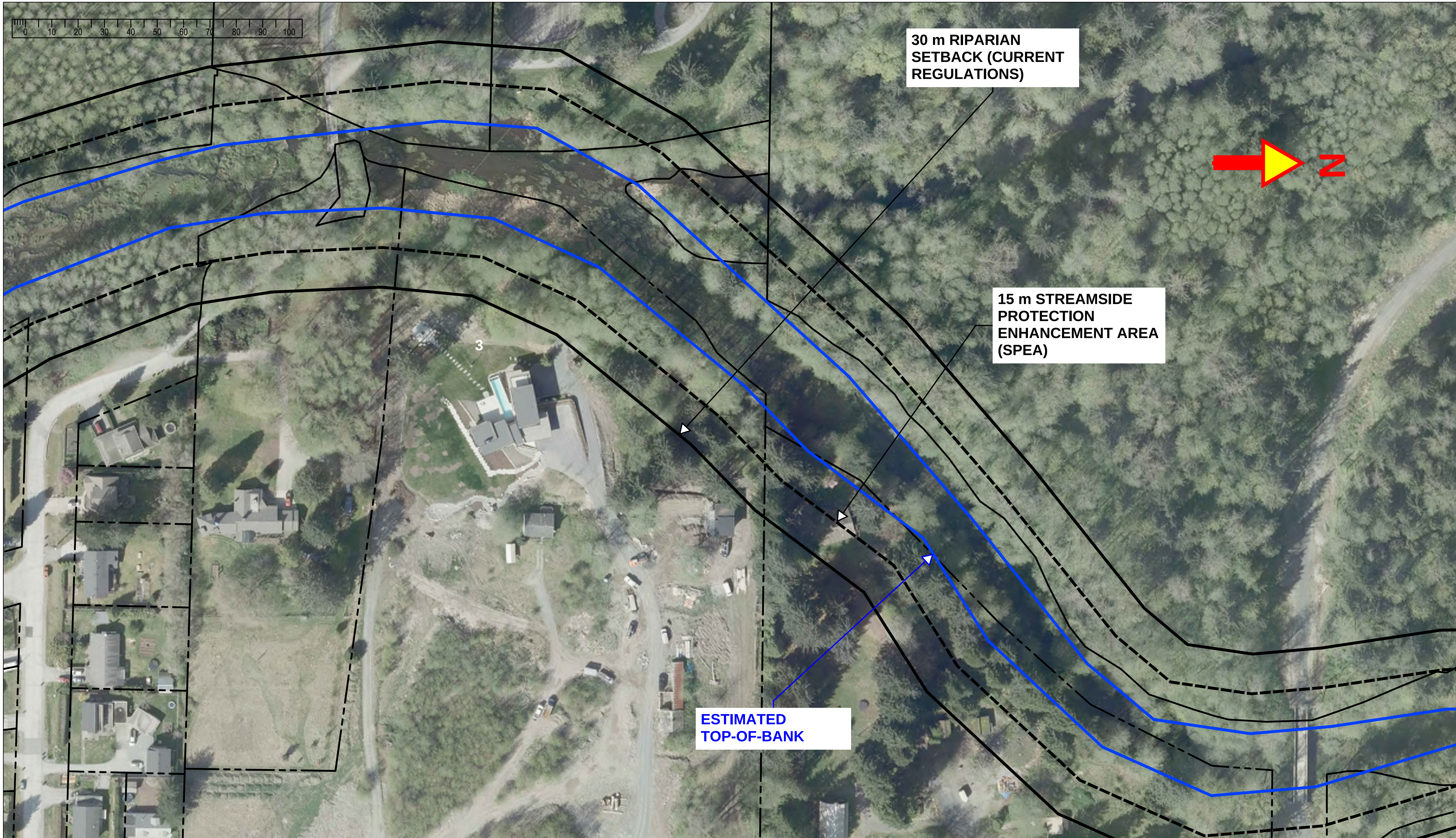
n	0.072

APPENDIX C: JUDD SLOUGH RIPARIAN SETBACKS

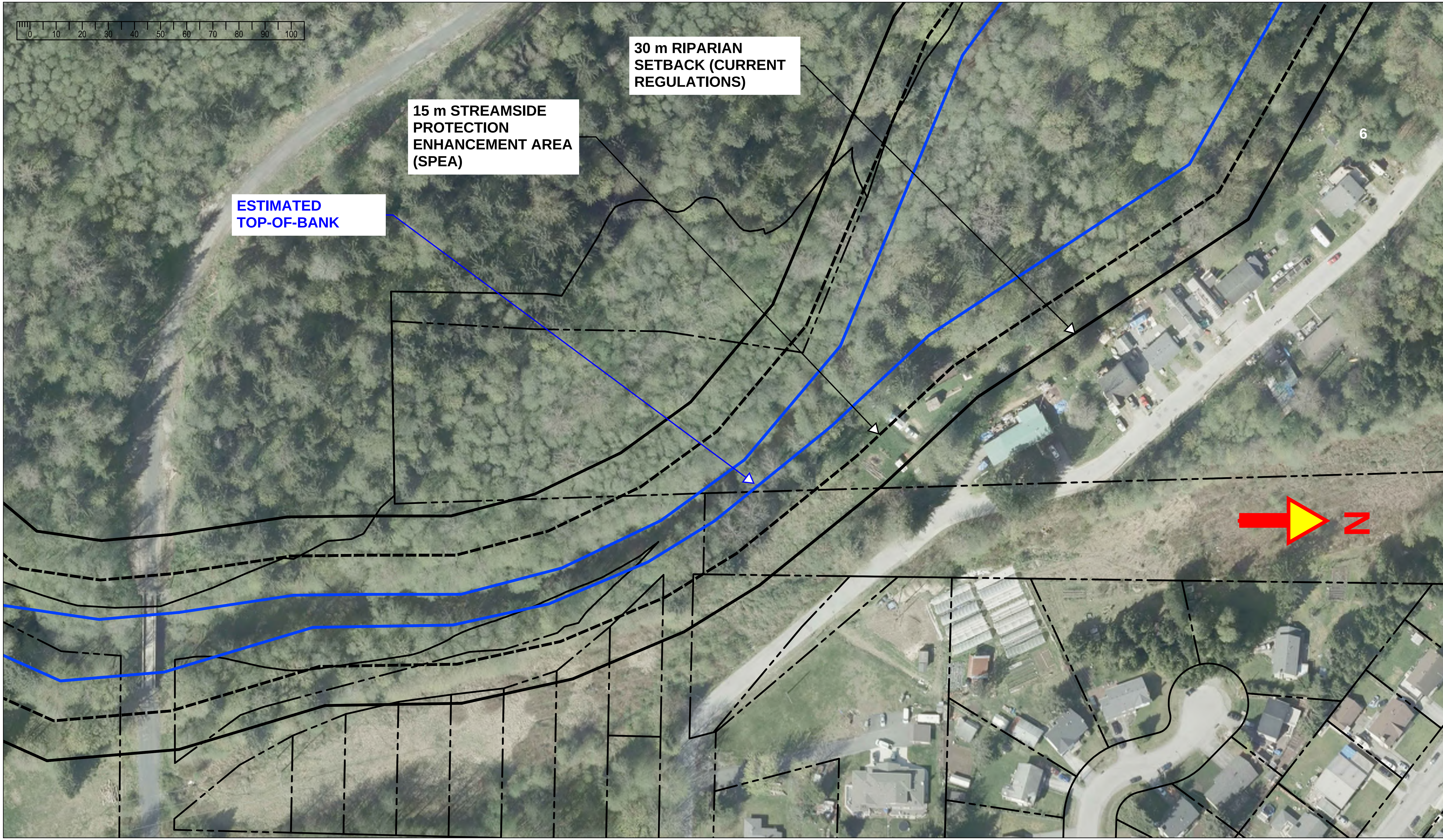
Appendix C: Judd Slough Riparian Setbacks



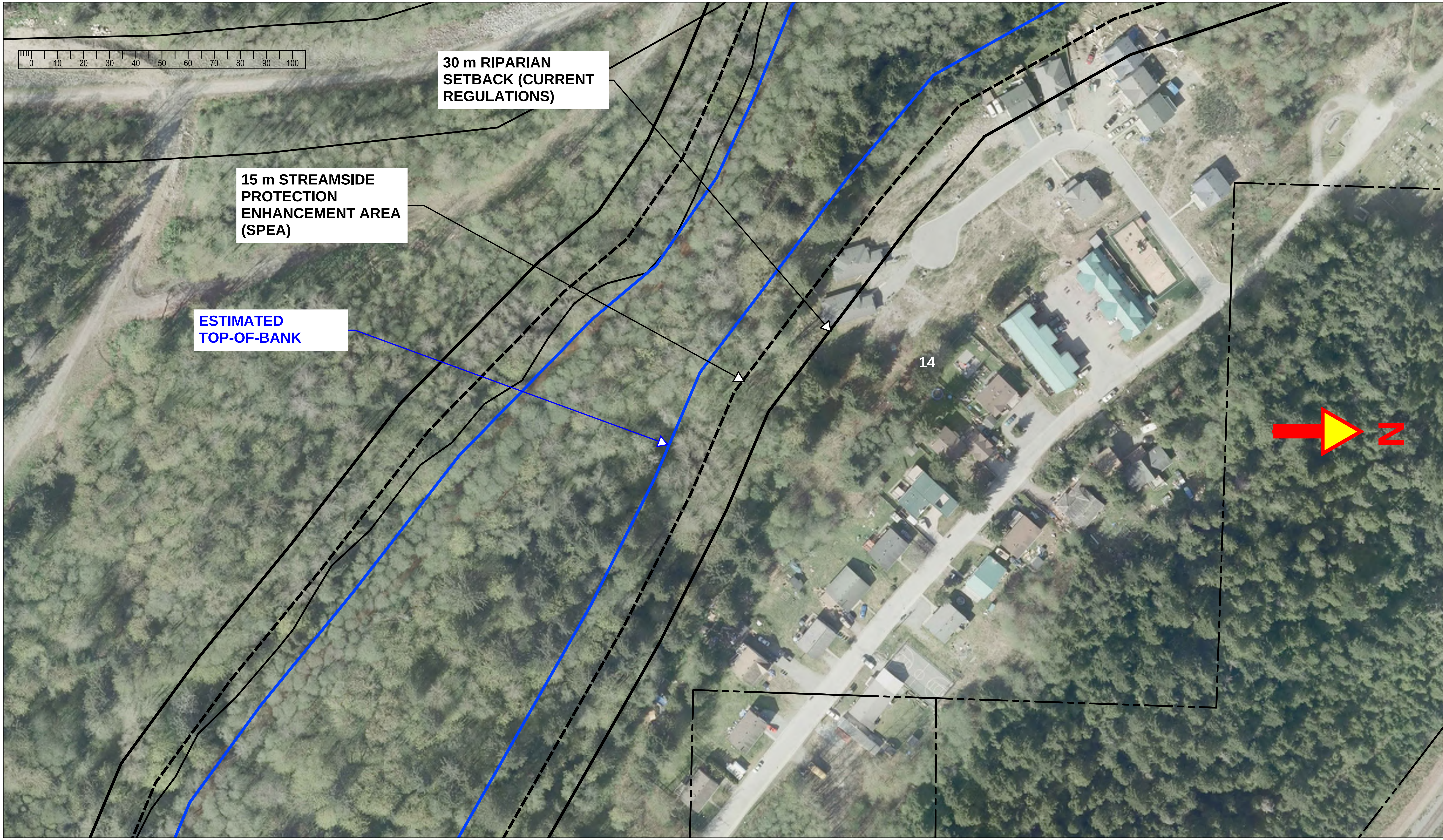
Appendix C: Judd Slough Riparian Setbacks



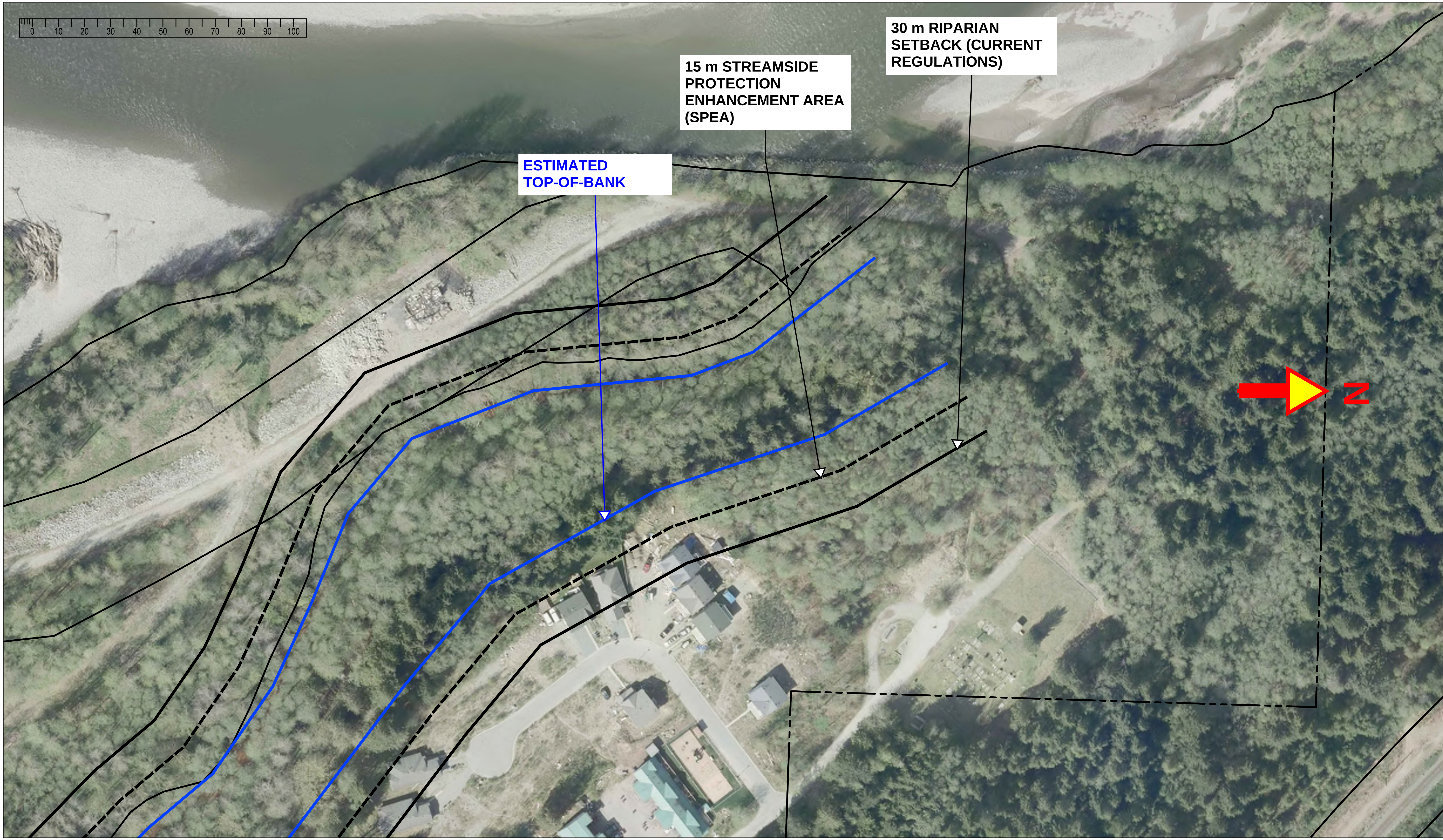
Appendix C: Judd Slough Riparian Setbacks



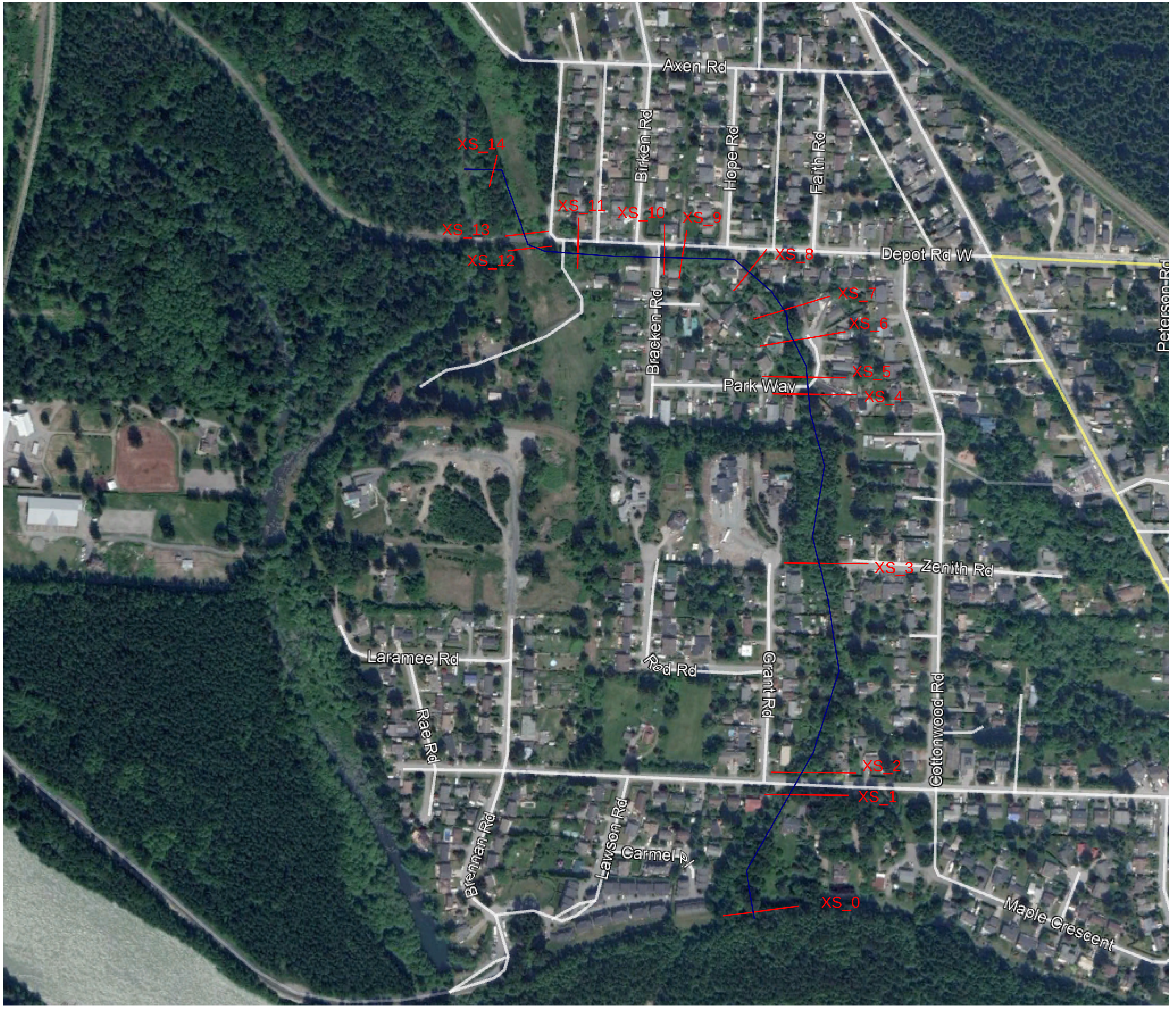
Appendix C: Judd Slough Riparian Setbacks



Appendix C: Judd Slough Riparian Setbacks



APPENDIX D: HORSE CREEK RECONNAISSANCE PHOTOS



XS_14
XS_13
XS_12
XS_11
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XS_3
XS_2
XS_1
XS_0
Axen Rd
Birken Rd
Hope Rd
Faith Rd
Depot Rd W
Peterson Rd
Bracken Rd
Park Way
Zenith Rd
Laramee Rd
Red Rd
Grant Rd
Rae Rd
Cottonwood Rd
Brennan Rd
Lawson Rd
Carmel Pl
Maple Crescent

Photo XS_0_US

Photo XS_1_DS 1

Photo XS_1_DS 2


Photo XS_1_LB


Photo XS1_US


Photo XS2_US 1

Photo XS2_US 2


Photo XS3_DS_RB


Photo XS3_US

Photo XS4_DS 1


Photo XS4_DS 2


Photo XS4_US

Photo XS5_DS


Photo XS5_US

Photo XS6_US 1


Photo XS6_US 2


Photo XS6_US 3


Photo XS7_DS


Photo XS7_RB 1


Photo XS7_RB 2


Photo XS7_US

Photo XS10_DS 1


Photo XS10_DS 2

Photo XS10_DS 3

Photo XS10_DS 4


Photo XS11_US


Photo XS11 - 12

Photo XS12


Photo XS13_RB

Photo XS13_US


Photo XS14_DS 1

Photo XS14_DS 2


Photo XS14_DS 3


Photo XS14_US 1


Photo XS14_US 2