Mamquam River Stranding Sensitivity Mapping and Method for Estimating Fish Stranding

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by

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TABLE OF CONTENTS

ABSTRACT

Munn K.L.C., Dare, G.C., and Klassen, H. 2016. Mamquam River Stranding Sensitivity Mapping and Stranding Estimation. Can. Manuscr. Rep. Fish. Aquat. Sci. 3102: v + 45 p.

Hydroelectric projects can increase fish stranding due to emergency shutdowns that rapidly dewater fish habitat. Other factors affect the river’s natural susceptibility to stranding, primarily cross-section slope and substrate composition. We mapped sites of varying stranding risk along the Mamquam River based on these characteristics. We conducted transect surveys within high risk sites measuring slopes and estimating percent substrate composition and embeddedness. We developed a fish stranding estimation tool that approximates the total number of fish stranded along the Mamquam following emergency shutdowns. Our map and tool can be used to target high priority areas for fish salvage operations and calculate systemic fish mortalities during emergency shutdowns. In addition to estimating the total number of fish stranded, the tool could also be useful in influencing decisions on ramping guidelines, and powerhouse operation practices.

RÉSUMÉ

Munn K.L.C., Dare, G.C., and Klassen, H. 2016. Mamquam River Stranding Sensitivity Mapping and Stranding Estimation. Can. Manuscr. Rep. Fish. Aquat. Sci. 3102: v + 45 p.

Les projets hydroélectriques peuvent accroître le risque d'échouement de poissons en raison des arrêts d'urgence qui évacuent rapidement l'eau de leur habitat. D'autres facteurs influent sur la vulnérabilité naturelle de la rivière à l'égard des échouements, soit principalement les talus transversaux et la composition du substrat. Nous avons cartographié des sites qui présentaient différents risques d'échouement le long de la rivière Mamquam en fonction de ces caractéristiques. Nous avons également effectué des levés de transect dans les sites à risque élevé et avons mesuré les talus et estimé la composition du substrat et le pourcentage d'intégration. Enfin, nous avons élaboré un outil d'estimation des échouements de poisson qui permet d'évaluer approximativement le nombre total de poissons échoués le long de la rivière Mamquam à la suite d'arrêts d'urgence. Notre carte et notre outil peuvent être utilisés pour cibler des zones à priorité élevée où mener les opérations de sauvetage de poisson et pour calculer le taux de mortalité systémique pendant ces arrêts. En plus d'estimer le nombre total de poissons échoués, l'outil pourrait être utile pour orienter les décisions qui se rapportent aux lignes directrices sur la variation du débit et les pratiques d'exploitation des centrales hydroélectriques.

1.0. INTRODUCTION

In British Columbia much of the energy demand is met using renewable energy generated by hydropower facilities, including larger hydroelectric dams, smaller systems, and non-storage or run-of-the-river projects (Pacific Salmon Foundation 2014). The operation of run-of-river facilities alters the state of the streams they are built on, causing long-term reductions in river flow and river stage within the diversion reach between intake and tailrace, as well as potential fluctuations on a smaller (daily) temporal scale within the diversion and downstream reaches (Knight Piésold 2005, Hunter 1992, Csiki and Rhoads 2010).

This alteration in stream flow may be optimized in order to have positive impacts on fish and fish habitat, including habitat maintenance via the flushing out of smaller less desirable substrate (Young et al. 2011), and the production of environmental cues triggering fish development from pulsed flow (Young et al. 2011). However regulating flows also causes adverse effects, including downstream fish displacement resulting from stage drop and reductions in reproductive success from redd dewatering (Young et al. 2011). Fish stranding is one of the detrimental impacts of flow alteration (Cushman 1985, Irvine et al. 2014, Young et al. 2011).

Fish stranding can occur naturally, but it can also occur as a consequence of a dewatering event, which can be defined as the rapid change in river stage resulting from changes in diversion or discharge regulated by a hydroelectric facility (Hunter 1992). Plant start-up, shutdown, and powerhouse failure are examples of events that may induce a decrease in flow (Lewis et al. 2011). Decreases in flow can lead to the stranding of fish on gravel bars (beaching) or entrapment in shallow side channels and ponds (Hunter 1992, Bradford 1997). Stranding may subject fish to temperature stress, asphyxiation, and increased risk of predation (Lewis et al. 2011). Such stressors may result in mortalities if river stage does not increase to re-submerge fish within a sufficient time period. For example, mortalities have been observed to occur for some salmonid species in as little as 10 minutes (Saltveit et al. 2001, Hunter 1992).

A number of both biotic and abiotic factors determine whether and to what degree stranding is likely to occur. Wetted history, dewatering rate, distance downstream, time of day and year, substrate characteristics, and river contour and bathymetry have all been identified as important abiotic factors when considering the risk of stranding (Hunter 1992, Bradford et al. 1995, Bradford 1997, Halleraker et al. 2003, Irvine et al. 2009, Irvine et al. 2014). For instance, rapid fluctuations in flow and water level are associated with a higher degree of stranding risk (Hunter 1992, Irvine et al. 2009, Halleraker et al. 2013). Biotic factors such as species and life history stage of the fish concerned are also important. Different fish species behave in unique ways that ultimately influence stranding potential, and adults are less susceptible to stranding than juveniles due to their greater swimming abilities (Nagrodski et al. 2012, Dabrowski et al. 1986).

The present study aims to provide a systematic approach to better understand the link between flow reduction and the potential for stranding fish. The knowledge gained from this study could apply to the potential impacts of hydroelectric projects on in-stream productivity of fisheries resources. We selected the Mamquam River for our study as it hosts three operational run-of-the-river hydroelectric power projects, all of which influence instream flow and river stage in downstream fish habitat.

The purposes of this study are to:

(i) provide a readily-available map of stranding sensitive sites along the Mamquam River with which to target as high priority areas for fish salvage operations, and
(ii) develop a tool to estimate systemic fish mortalities caused by stranding events.

1.1. STUDY AREA

Mamquam River flows as a tributary into the Squamish River at Squamish B.C., draining an area of approximately 380 km^2 (Kerr Wood Leidal 2010). The Mamquam River (Figure 1) has three main tributaries: the Ring, Skookum, and Mashiter Creeks

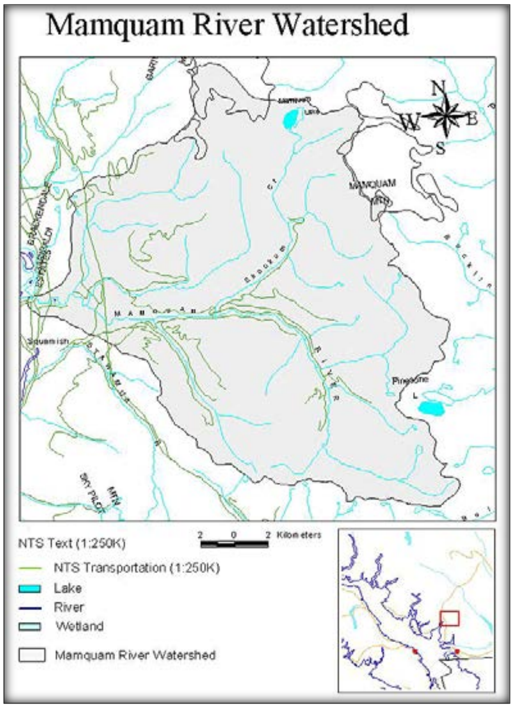


Figure 1: Map taken from the Greater Georgia Basin Steelhead Recovery website of the BC Conservation Foundation.

which all enter from the north. An active gravel bed with gravel bars and side channels in the 6.2 kilometers of Mamquam River's lower reaches poses increased opportunity for fish stranding (Kerr Wood Leidal 2010).

The mean basin elevation of the Mamquam is 1,300 m with 19% of its watershed consisting of either glacial or alpine area (Kerr Wood Leidal 2010). These factors influence the streamflow regime, which reflects a hybridization of both rain runoff and snowmelt, depending on the season (Pike et al. 2010). High flows usually occur in the late spring and early summer, which are periods of high snowmelt. Low flow is typically seen in late summer and the middle of winter. Storms occur frequently during the fall, which also contribute to increased flow in the medium to high range.

The river supports four species of salmon downstream of the hydroelectric facilities: Coho (*Oncorhynchus kisutch*), Pink (*O. gorbuscha*), Chinook (*O. tshawytscha*) and Chum (*O. keta*) (Whitehead 2009), as well as a variety of trout species throughout. A barrier to upstream fish passage is located just downstream of the tailrace for the lowest facility, therefore the river is only accessible to anadromous fish below this point. Rainbow trout (*O. mykiss*) and Dolly Varden char (*Savelinus malma*) are the only species present within the upper reaches of the Mamquam (B.C. Government 2015b).

2.0. METHODOLOGY

2.1. PRE-FIELD WORK

Prior to our initial site visit we analyzed satellite photography in Google Earth to identify potential areas of high, moderate, and low stranding risk based on observable characteristics such as slope, vegetation, and channel morphology. Using Google Earth tools we created a colour coded map denoting anticipated areas of high, moderate, and low stranding sensitivity. The length and position of each high risk area was noted with reference to river mile distance of the corresponding river bank. We also included previously identified stranding sensitive sites used by the hydroelectric facility operators during fish salvage operations (Ecofish Research Ltd. 2014).

2.2. FIELD METHODS

We reassessed our initial satellite photography classification of stranding sensitive sites during a preliminary walkthrough of the study area. As we walked along the river we recorded the start and end points of each high risk site using a Garmin GPS and measured the length of each site using a 100 m Elson surveyor's tape. We used a 5% bank gradient as the threshold for distinguishing between high, moderate, and low stranding susceptibility, based on previous studies' findings as summarized by Irvine et al. (2014). Sites under 5% bank slope were categorized as either high or moderate risk, and sites above 5% were categorized as low stranding risk. Of those sites under 5% bank slope, we designated those as high risk if the site met the following factors:

- site had 0-1% bank slope for a width >1 m and contiguous length >~3 m
- site had drainage depressions without fish exit paths that would dry during a dewatering event
- site had cobble with accessible interstices or other cover that could entice juvenile fish to stay during a dewatering event
- sites with ponds that retained water through a drawdown event were excluded
- sites downstream of channel feature with a hydraulic head causing upwelling through the gravel were excluded
- sites that wetted only during flood events were excluded unless drainage depressions were substantial, i.e. greater than 10 m^2.

For inaccessible locations on islands or across the river we used a rangefinder and GPS points parallel to the start and end points of a site to obtain the site's coordinates. We also ran a surveyor's tape parallel to the site to estimate the length.

As we walked the river we updated our site map with new or altered features such as gravel beds or side channels as well as refined borders of stranding sensitive sites. We applied this map data together with recorded GPS points to update our map in Google Earth. We also plotted a path along each side of the river to enable designation of the river mile start and end points of high risk sites on either bank for later use in random transect placement.

We identified a sample of high stranding risk sites along 40 transects located using a random number generator to select river chainage distances downstream from the lower Mamquam powerhouse, excluding sites with low or moderate sensitivity from our transect location selections. The length of the portion of the river from the powerhouse to where the Mamquam joins the Squamish is approximately 6,200 m.

The lateral start and end points of these transects were determined in the field by taking into account the realistic flow range and where stranding sensitive habitat at the site was in relation to that flow range. Accordingly, our transect slope gave a suitable representation of stranding sensitive habitat during our target flows.

We surveyed the sample 40 transects using a tripod, a Wild Heerbrugg N2 surveying level, a 100 m Eslon fiberglass surveyor's tape and a 5 m surveying staff. The GPS location of each transect was found with Google Earth using the start or end point of the high risk site and the transect river station, with cross reference to identifiable markers in the field. Once the transect's location was found it was marked at river's edge and another marker was placed at the shore end of the transect, usually at rooted edge, to ensure a straight line was maintained. Each transect was oriented perpendicular to the river bank. We assigned the transect's origin to the river's wetted edge when possible, with points extending into the shallows of the primary channel assigned negative values and points shoreward positive. River discharge remained relatively constant during our time in the field at approximately 13.8 cms (Appendix 8.1).

Measurements of elevation relative to the wetted edge, water depth (if applicable), and distance from wetted edge were taken at each significant slope break. For each transect location, we identified mesohabitat type (run, riffle, cascade, glide or pool), channel type (primary, secondary, side or off channel) and critical habitat type (rearing, spawning, overwintering or migration) for the breadth of the channel. We also estimated the proportion of different cover types and quality and quantities of critical habitat. At two or three representative points along each transect we also estimated substrate composition, cover area, and embeddedness within a 1 m radius using criteria from EcoFish Research Ltd. (O'Toole and Faulkner 2011).

When considering substrate composition substrate was categorized into one of six categories, including boulder, large cobble, small cobble, large gravel, small gravel or fines, and the percent area occupied by each substrate type was estimated (O'Toole and Faulkner 2011). The percent cover provided by boulders, large woody debris, small woody debris, instream vegetation, overstream vegetation, cutbanks, and deep pools was also estimated for each sample point (O'Toole and Faulkner 2011). We determined embeddedness using the methods outlined in the CABIN field manual (Environment Canada 2010). Embeddedness was classified as either trace (<5%), low (5-25%), medium (25-50%), high (50-75%), or very high (>75%), following EcoFish Research Ltd. criteria (O'Toole and Faulkner 2011). We recorded the collected data on customized forms.

We initially encountered errors in re-locating transects, with GPS readings sometimes 45 m from where they were taken. Subsequent changes to GPS practice improved our accuracy, and most locations were re-measured by the improved technique. Complementary measurements of sites with a survey tape further improved mapping accuracies for transposing site data to polygons drawn on Google Earth imagery.

Shapes of the polygons generally depicting stranding sensitive sites were based on sketches hand drawn on site. The polygons tended to have a continuous distribution of high stranding risk areas running along the channel, with varying degrees of risk posed shoreward from the channel.

2.3. STATISTICAL ANALYSIS, MAPPING & TOOL

We used Google Earth to map the studied sites along the Mamquam River according to their category of stranding sensitivity. Map creation involved a high resolution image of the Mamquam, to which we then added a second layer of polygons. The polygons are colour-coded as red, yellow, or green to represent high, moderate, and low stranding sensitivity sites, respectively.

We chose three different flow levels to incorporate into our systemic fish stranding estimation tool (hereafter referred to as our estimation tool): high, medium, and low flow. We based our definition of high, medium and low flows on their perceived frequency. In the Mamquam River high flows occur only during storm events which predominantly occur in the fall or during periods of high snowmelt in the late spring and early summer. Low flows occur during the late summer and throughout winter when snowmelt and precipitation are low. By examining and comparing discharge graphs from previous years, we concluded that discharge events over 50 m^3/s were infrequent for this river and thus flows over this value were categorized as high flow (Appendix 8.2). Low flows were also rare and therefore we assigned the low boundary as 20 m^3/s and below (Appendix 8.2). N.B. These values serve as approximate guidelines for distinguishing between different flow levels and do not represent exact boundaries.

Transect slope data were sorted into these three categories to improve representation of stranding risk at various flow levels as reflected in different gradient frequencies at different flow elevations (Figure 2). The maximum for the low flow category was set at a height of 25% of the total transect elevation range (from the lowest surveyed depth to the maximum height at rooted edge), above water's edge. Thus, any slopes that were located below water's edge, or below 25% of the total transect range above water's edge were considered low flow slopes. The medium flow range extended from 10% of the total transect elevation range below the low flow maximum, to the halfway point of the remaining elevation range above the low flow maximum. The high flow category included all slopes above a point 10% of the total transect elevation range below the medium flow maximum.

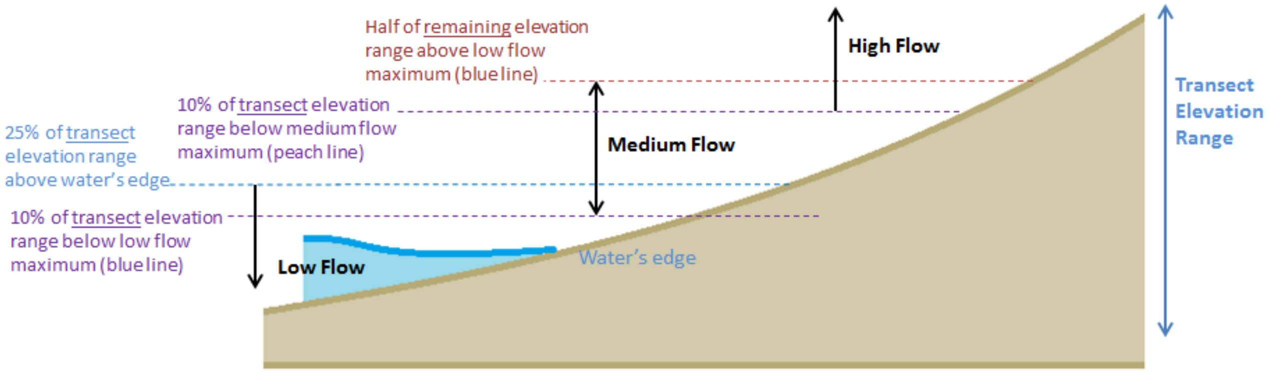


Figure 2: Elevation ranges used for classifying slope data as belonging to either low, medium, or high flow areas.

We allowed for a 10% elevation overlap between flow categories in recognition of the fact that the transition between flow levels is gradual rather than discrete. We kept water's edge consistently in the low flow category as all our transect surveys were conducted in the summer of 2015, a period noted for low flows on the Mamquam and dry conditions and a lack of rain and snowpack on the Southern BC coast in general, leading to a level 4 drought advisory (B.C. Government 2015a). While conducting our surveys we estimated that water's edge at any given transect site could fluctuate by as much as 20 cm, depending on the day we revisited the site. Thus we took 20 cm to represent the natural variation in water's edge elevation at low flow, and made the low flow category maximum 25% of the transect elevation range above water's edge, as we found that 25% was the average percentage required to cover 20 cm of transect elevation. The remaining elevation range above the low flow maximum was arbitrarily divided equally between medium and high flow.

With this system, the proportions of transect elevation allotted to low, medium and high flow will vary depending on the nature of the transect, but the data is expected to correspond to the different flow levels.

We used the collected transect slope data to create frequency distributions of gradients at high risk sites at high, medium, and low flow levels. To calculate these frequency distributions, we first calculated the proportion of transect meters or slope-meters belonging to each slope bin using the frequency distribution, which differed depending on the initial flow level of the river: high, medium, or low (Table 1). We then multiplied the percentage frequency of each slope bin by the total length of high risk sites measured along the river (2,585.94 m) to calculate the dewatered proportional shore length corresponding to each slope bin (Table 1). We used these proportional shore lengths and their corresponding calculated dewatered widths to determine the total area of potential dewatering high risk sites during an emergency shutdown for a given stage and flow.

With these calculations we created a tool in an Excel spreadsheet that estimates the total number of fish stranded along the Mamquam River following an emergency shutdown, given the event-specific values for stage drop, river flow level, recovery efficiency, and fish found per square meter during the initial fish salvage, as detailed in the fish stranding report.

We designed the estimation tool to calculate the bank width of the dewatered area using the initial observed flow level and a specific stage drop. The stage drop value can be entered under the low, medium, or high flow level section of the tool; results for each of the flow levels are different due to the unique combination of gradients observed at each level.

Table 1: Slope range bins, number and proportion of total transect meters or ‘slope-meters’ for each bin, and the corresponding proportional dewatered shore length of high risk sites for each bin at low, medium, and high flows.

	Low Flow (20 cms and below)			*Medium Flow (20 cms - 50 cms)*			*High Flow (50 cms and above)*		
Slope Range (%)	**Slope Meters[1] (m)**	**Proportion[2] (%)**	**Proportional Shore Length[3] (m)**	**Slope Meters (m)**	**Proportion (%)**	**Proportional Shore Length (m)**	**Slope Meters (m)**	**Proportion (%)**	**Proportional Shore Length (m)**
0 - .0025	19.05	4.05	104.7	12.36	5.97	154.5	18.83	7.08	183.0
.0025 - .005	11.00	2.34	60.5	4.42	2.14	55.2	21.65	8.14	210.5
.005 - .0075	34.94	7.43	192.1	16.52	7.98	206.5	12.22	4.59	118.8
.0075 - .01	13.54	2.88	74.4	16.27	7.86	203.3	11.84	4.45	115.1
.01 - .015	64.84	13.79	356.5	18.45	8.92	230.6	26.54	9.98	258.0
.015 - .02	77.07	16.39	423.7	21.36	10.32	267.0	39.82	14.97	387.1
.02 - .025	31.09	6.61	170.9	18.99	9.18	237.3	39.11	14.70	380.2
.025 - .03	66.25	14.09	364.2	21.22	10.26	265.2	30.59	11.50	297.4
.03 - .035	56.80	12.08	312.3	31.30	15.13	391.2	13.02	4.89	126.6
.035 - .04	48.15	10.24	264.7	19.94	9.64	249.2	17.97	6.75	174.7
.04 - 05	47.61	10.12	261.8	26.08	12.60	326.0	34.44	12.95	334.8

1. "Slope meters" are the sum of slope transects for a given slope bin.
2. "Proportion" values are the proportion of slope metres divided by sum of the slope lengths.
3. "Proportional shore length" values are the proportion values multiplied by total length of high risk sites measured along the river (2,585.94 m).

The dewatered bank width for each slope bin is obtained by dividing the specified stage drop by the average slope of the bin (Equation 1). The tool then multiplies the dewatered bank width for each bin by the corresponding collective proportional shore length of high risk sites belonging to that slope bin to determine the dewatered area for each bin.

Equation 1:

$$Average\ Slope\ (\%) = \frac{Stage\ drop\ (m)}{dewatered\ bank\ width\ \ (m)} \qquad (i.e.\ \frac{rise}{run}\ )$$

The dewatered areas for each slope bin are then summed to find the total dewatered area of high risk sites along the river.

Finally, an estimate of the number of fish stranded throughout the Mamquam River during the dewatering event can be calculated using the fish stranded per square meter (from the incident report values for total area searched and number of fish found) multiplied by the total dewatered area and divided by the recovery efficiency.

Recovery efficiency can be set to a default value that depends on the search method used: broad based search, hotspot search, or a combination of the two. According to

Chin (2015), a broad based search involves walking the entire search area and scanning visually for any obvious signs of stranded fish. Whereas broad based search is purely observational, a hotspot search is more thorough and involves actively searching through the substrate (Chin 2015). The tool uses default values of 11.9%, 57.0%, and 60.7% for recovery efficiencies using broad based, hot spot, and combined search techniques, respectively. These values have been obtained from Chin (2015) for the Lynn Creek river system but should provide an adequate approximation for recovery efficiencies on the Mamquam. Ideally similar salvage studies should be conducted on the Mamquam to obtain recovery efficiency values that better represent the river system and can be entered into the tool.

Estimation Tool Calculations Overview

1. Select which of the three flow categories represent the conditions at the time of the fish stranding incident. Flows lower than 20 m^3/s, between 20 m^3/s and 50 m^3/s, and greater than 50 m^3/s would be considered low, medium, and high flows, respectively.
2. Calculate fish per square meter stranded using proponent's fish salvage values.
3. Calculate the proportional shore length of each slope bin by multiplying the total shore length of high risk stranding sites by the frequency proportion for each slope bin.
4. Calculate the dewatered bank width by dividing the stage drop by the average slope for each slope bin.
5. Multiply dewatered bank width for each slope bin by the corresponding proportional shore length to calculate the dewatered area for each bin.
6. Total the dewatered areas for all slope bins.
7. Multiply total dewatered area by the number of fish stranded per square meter and divide by the recovery efficiency value, which yields the systemic number of fish stranded for that event.

On the next page is a hypothetical scenario on the Mamquam River to demonstrate the steps taken by the tool in estimating total stranding incidence, and to provide examples of the calculations involved. The final version of our stranding estimation tool is attached as an Excel spreadsheet in Appendix 8.3.

> As an example, consider a dewatering event occurring during low flows on the Mamquam River resulting in a stage drop of 10 cm and 100 fish salvaged during a hotspot search in a 500 m^2 area.

1. Determine the flow category at the time of the incident
2. Calculate fish stranded per square meter using proponent's values

$$\frac{100\, fish}{500\, m^2} = 0.2\, fish/m^2$$

3. Calculate the proportional shore length of each slope bin by multiplying the total shore length of high risk stranding sites by the frequency proportion (Table 1) for each slope bin

$$Shore\ Length\ (m)_{0.00-0.25} = 2{,}590\ \mathrm{m} \times 0.0405 = 105\ \mathrm{m}$$

Proportional shore lengths for all slope bins were calculated similarly and are summarized in Table 1.

4. Calculate the dewatered bank width by dividing the given stage drop by the average slope for each slope bin (Table 2)

$$Dewatered\ Bank\ Width\ _{0.00-0.25} = \frac{0.100\, m}{0.00125} = 80.0\, m$$

$$Dewatered\ Bank\ Width\ _{0.25-0.50} = 26.\overline{6}\, m$$

$$Dewatered\ Bank\ Width\ _{0.50-0.75} = 16.0\, m$$

$$Dewatered\ Bank\ Width\ _{0.75-1.00} = 11.4\, m$$

$$Dewatered\ Bank\ Width\ _{1.00-1.50} = 8.00\, m$$

$$Dewatered\ Bank\ Width\ _{1.50-2.00} = 5.72\, m$$

$$Dewatered\ Bank\ Width\ _{2.00-2.50} = 4.\overline{44}\, m$$

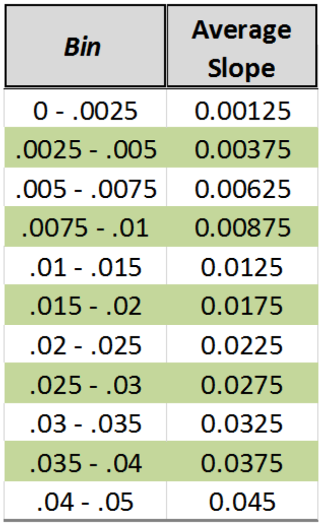
$$Dewatered\ Bank\ Width\ _{2.50-3.00} = 3.\overline{63}\, m$$

$$Dewatered\ Bank\ Width\ _{3.00-3.50} = 3.08\, m$$

$$Dewatered\ Bank\ Width\ _{3.50-4.00} = 2.\overline{66}\, m$$

$$Dewatered\ Bank\ Width\ _{4.00-5.00} = 2.\overline{22}\, m$$

Table 2: Average slopes for each slope bin.



Bin	Average Slope
0 - .0025	0.00125
.0025 - .005	0.00375
.005 - .0075	0.00625
.0075 - .01	0.00875
.01 - .015	0.0125
.015 - .02	0.0175
.02 - .025	0.0225
.025 - .03	0.0275
.03 - .035	0.0325
.035 - .04	0.0375
.04 - .05	0.045

5. Multiply dewatered bank width for each slope bin by the corresponding proportional shore length to obtain the dewatered area for each bin

$$Dewatered\ Area_{\,0.00-0.25} = 80.0\ m\ x\ 104\ m = 8{,}380\ m^2$$

$$Dewatered\ Area_{\,0.25-0.50} = 1{,}610\ m^2$$

$$Dewatered\ Area_{\,0.50-0.75} = 3{,}070\ m^2$$

$$Dewatered\ Area_{0.75-1.00} = 850\ m^2$$

$$Dewatered\ Area_{\,1.00-1.50} = 2{,}850\ m^2$$

$$Dewatered\ Area_{\,1.50-2.00} = 2{,}421\ m^2$$

$$Dewatered\ Area_{\,2.00-2.50} = 760\ m^2$$

$$Dewatered\ Area_{\,2.50-3.00} = 1{,}320\ m^2$$

$$Dewatered\ Area_{\,3.00-3.50} = 961\ m^2$$

$$Dewatered\ Area_{\,3.50-4.00} = 706\ m^2$$

$$Dewatered\ Area_{\,4.00-5.00} = 582\ m^2$$

6. Totaling the dewatered areas above for all slope bins gives us 23,510 m^2.

7. Multiply total dewatered area by the number of fish stranded per square meter and divide by the recovery efficiency, to obtain the total number of fish stranded for that event

$$Total\ Fish\ Stranded = 23{,}510\ m^2 \times 0.2\frac{fish}{m^2} \div\ 0.57 = 8{,}249\ fish$$

   Note that this is slightly different from the tool output value of 8,253 fish due to rounding in the example.

We calculated the average value for substrate characteristics across the 40 transect sites. We also compared data from points taken above and below the 5% slope threshold. We conducted a T-test to determine whether the differences found were statistically significant.

3.0. RESULTS

Figure 3 illustrates the distribution of fish stranding site sensitivities within the lower Mamquam River accessible to anadromous fish. More detailed maps are included in Appendix 8.4.

3.1. MAPPING

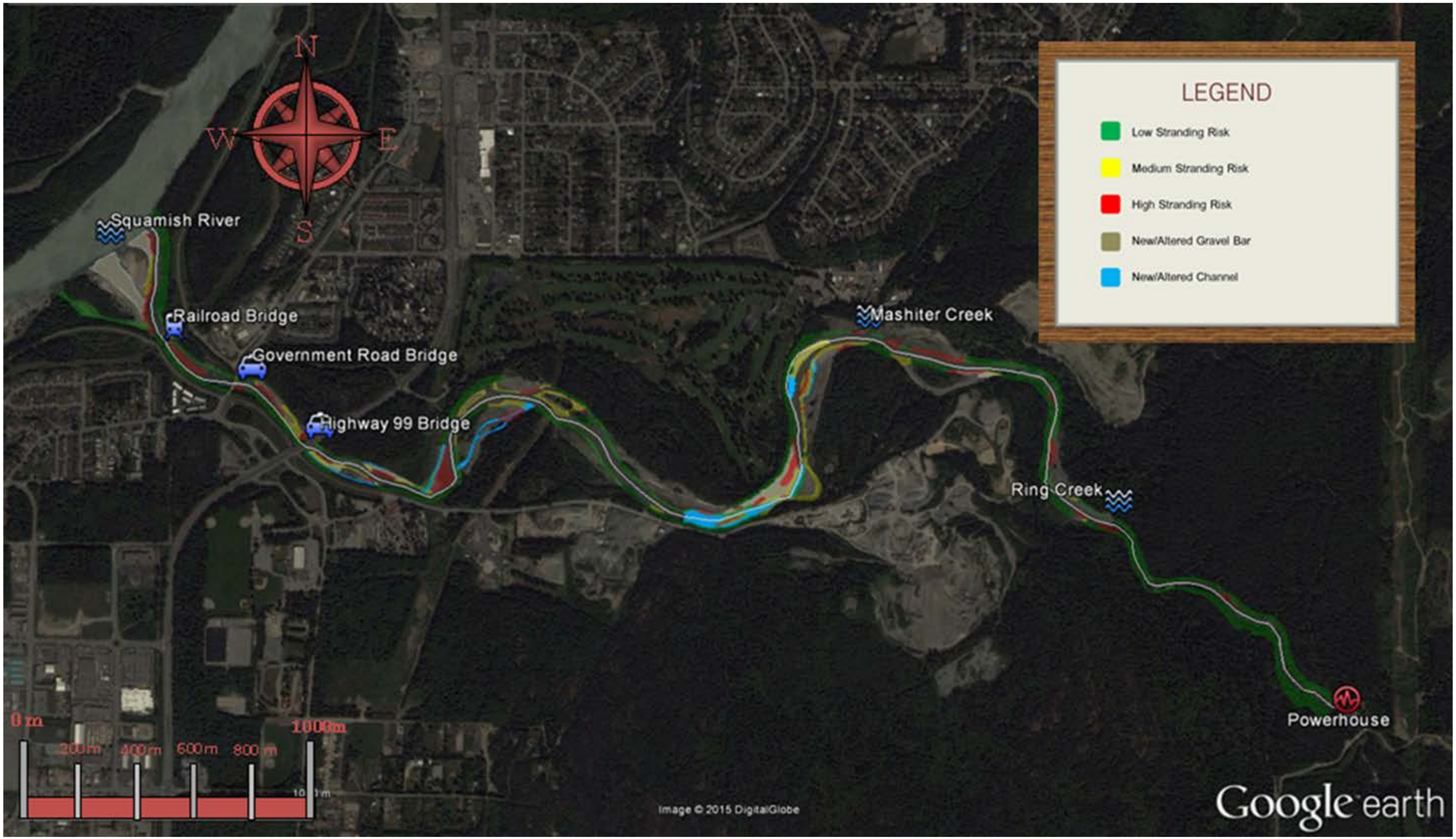


Figure 3: Distribution of fish stranding sensitivities within the lower Mamquam River. The white line represents river thalweg in Summer 2015.

Through the recording of both GPS points and physical measurements, we tallied a total 2,585.9 m of high risk stranding sites along both sides of the Mamquam River (Table 3). This includes 1,473.9 m of high risk sites on the right side of the river and another 1,112.1 m of high stranding risk on the left side. For context, the distance from the lowest powerhouse down to the Squamish River is 6,400 m. Therefore the total river shore length is approximately 12,800 m, with 20.2% of the Mamquam River's shore containing high risk stranding sites.

Table 3: Lengths of high risk stranding sites. Asterisks indicate sites that were on top of bar.

High Sensitivity Site # (Right Bank)	*Site Length (km)*	*High Sensitivity Site # (Left Bank)*	*Site Length (km)*
1	0.09928	21	0.16887
2	0.17862	22	0.10949
3	0.04136	23	0.02812
4	0.01746	24	0.07251
5	0.0805	25	0.03447
5	0.01871	26	0.13433
6	0.0112	27	0.0875
9	0.05645	28	0.00839
10	n/a	29	0.11336
11	n/a	30	0.05696
12	0.01398	31	0.12377
13	0.01247	32	0.012
14	0.06674	33	0.03973
15	0.24413	34	0.04488
16	0.09277	35	0.07768
17	0.03855	**Total**	**1.11206**
18	0.14941		
19	0.16989		
20	0.0097		
36	0.04937		
37	0.01587		
5*	0.07682		
8*	0.0306		
Total	**1.47388**		

Grand Total
2.58594

The shortest site was Site 20 with a 9.7 m length of wetted edge (Table 3). The longest was Site 15 with a 244.1 m length of wetted edge (Table 3). This site also had the largest total area.

3.2. STRANDING ESTIMATION TOOL

The stranding estimation tool uses the slope data we collected as well as information provided to us in the incident report by the plant operators. These reports are provided after every incident, and include results from the fish salvage operation. Data used from the incident reports include the start and end stage level, the stage drop, the type of search conducted, the number of fish stranded, and the area searched in square meters.

Figure 4 shows that the distribution of slope meters across bins approximates a normal distribution. Bank width segments (perpendicular to the channel) of low slope (< 2%) ranged from 20 cm to 18 m, with 90% being under 6 m wide (Figure 5).

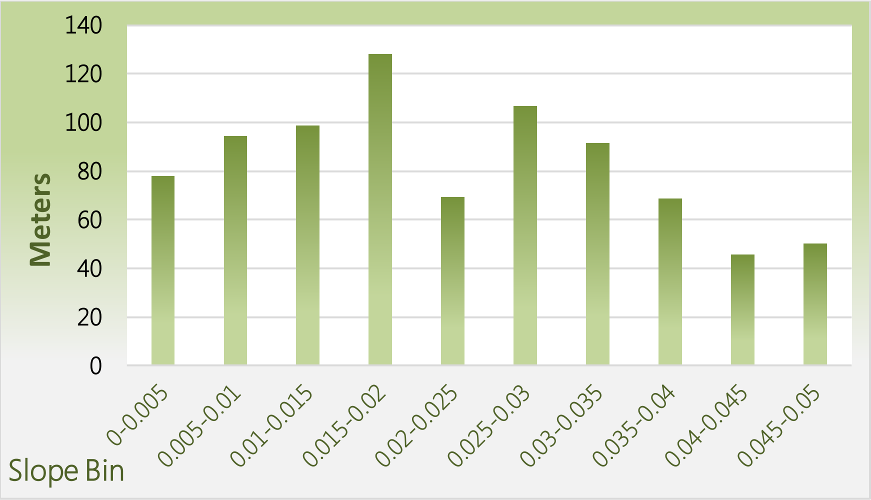


Figure 4: The frequency distribution of slope meters for all 40 surveyed transects.

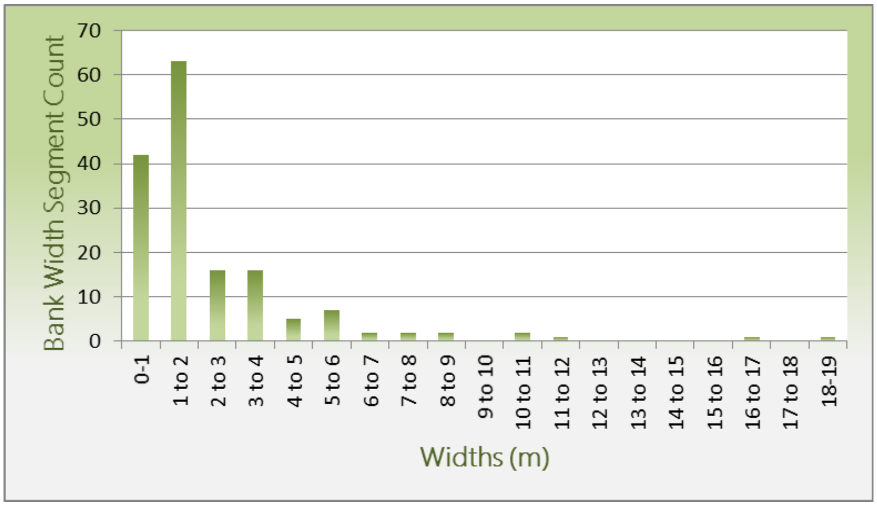


Figure 5: Histogram of bank width segment lengths < 2%.

Transect slope data was used to create frequency distributions of gradients at high stranding risk sites for high, medium, and low flow levels. Frequency distributions were produced using eleven slope bins (slope range categories) covering 0% to 5% bank slope. The majority of the slope bins cover half a percent of slope (e.g. 1.5% to 2%). However the first percent was divided equally between four bins at a quarter of a percent to provide more detail, as these are the lowest slopes that present the highest stranding risk to fish. Similarly, the last bin covers a whole percent (4% to 5%), as these slopes are relatively high and thus pose less of a hazard than lower slopes.

3.3. SUBSTRATE SURVEYS

The complete set of collected substrate data is provided as Appendix 8.5. The average cover, embeddedness, and substrate proportions within-site were first obtained for each of the 40 surveyed transect sites. We then calculated the mean of the 40 sites for each of these values to give an idea of the average substrate conditions for high risk stranding sites, overall.

The average amount of cover for juvenile salmonids in high risk areas was relatively low at 9%, with a large standard error of ± 8% (Table 4). The average embeddedness across the transect sites was 37% ± 12% (Table 4). Embeddedness for sites with slope <2% was 40% ±16%.

Table 4: The average percent (area) of cover and embeddedness across 40 surveyed transects in high risk stranding areas.

	Cover	*Embeddedness*
Average	9%	37%
Error (Standard Deviation)	± 8%	± 12%

Boulders and large cobbles were found to comprise the smallest proportion of substrate at high stranding risk sites, with values of 4% and 10%, respectively (Figure 6). Small gravel percent area was also low (Figure 6). Conversely, fines and large gravel had a large presence in our transect sites, with similar average percent areas of approximately 27% (Figure 6). The four largest substrates (boulders, large and small cobble, and large gravel) combined averaged 63% of the total substrate.

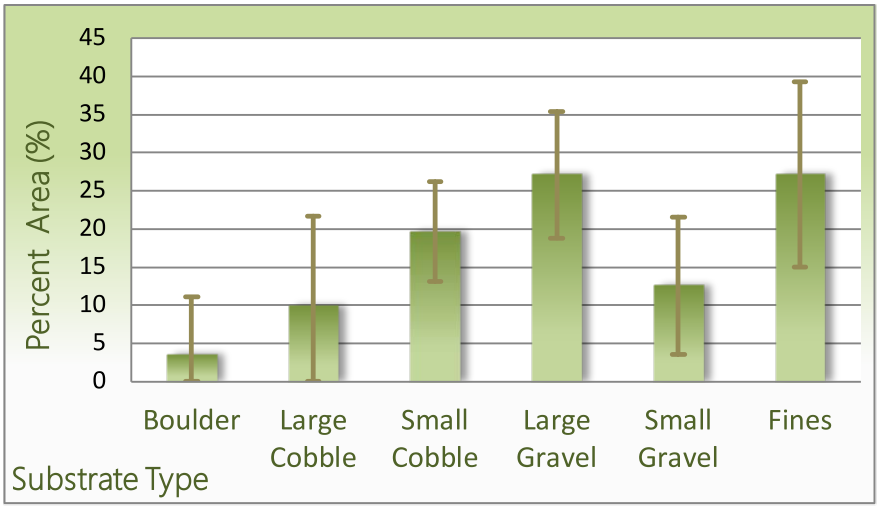


Figure 6: The average proportions (percent area) of different substrate types across 40 surveyed transects in high stranding risk area.

4.0. DISCUSSION

4.1. MAPPING ANDSUBSTRATE SURVEYS

The fish stranding sensitivity map produced in this report (Figure 3) will be useful to assess likelihood of fish stranding from dewatering events that occur from emergency shutdowns at any one of the three plants upstream in the Mamquam River drainage. Its prime use is to focus fish salvage operations on the river. Applying this mapping data together with our stranding estimation tool enables calculation of systemic fish losses for a given dewatering event.

Some sites had changed since our 2013 Google Earth image was taken. Many gravel bars had shifted and one has been dredged, along with changes in side channel locations. Water levels were also different from the image so this may have also caused differences between the images and what we actually observed.

While we relied on professional judgement when differentiating between moderate and high stranding risk areas, our observations suggested that certain features or characteristics influenced the sensitivity status of a site more than others.

For example, at the site pictured in Figure 7, there was a prominent hydraulic head which would provide constant flow to the sensitive areas at lower elevation during a stage drop, reducing the risk of stranding. Furthermore, the slope of each individual terrace or step at this location was relatively steep, further diminishing the site's risk.

Accordingly, those areas observed with significant hydraulic head groundwater flow were not included as high risk sites.

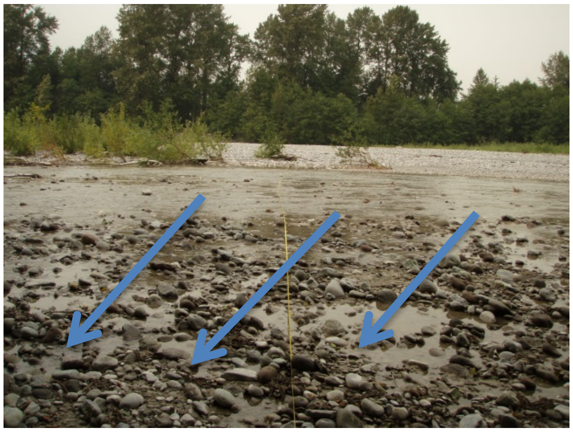


Figure 7: Hydraulic head.

The presence of depressions was one of the indicators for high stranding sensitivity, as juveniles could become isolated and dewatered in these depressions during flow reductions. However, clear exit paths or drainage points (Figure 8) would increase the chance of fish escaping, so in this situation, the risk was considered reduced and the site would then have been classified as moderate stranding risk.

Figure 8: Clear exit in depressions.

Substrates in which there is combination of high amounts of boulder, cobble or large gravel and low to moderate embeddedness (Figure 9) provide cover habitat from water currents as well as interstitial spaces in which juvenile salmonids tend to seek refuge from predation and desiccation during dewatering events (Helfman 1981, McMahon and Hartman 1989) and could become trapped (Bradford et al. 1995). These comprised about a third of the total substrate cover at the high risk sites we surveyed (Appendix 8.5), with substrate composition of boulders, cobbles and large gravels combined that averaged 63% of substrate composition (Figure 6) further confirming potential high risk of fish stranding. However, high embeddedness values (37% - Table 4) from fines and sands filling in a portion of the interstices reduce risk of stranding by forcing fish to move to deeper water as the stage drops.

While substrate composition provides some indication of the risk of fish stranding, low bank slopes also influence that risk. At our high risk sites, the terraces with low bank slopes <2% gradient averaged 2.4 m in width (± 2.6 m), providing opportunity for stranding by dewatering.

Figure 9: A gravel bar with high proportion of cobbles and boulders and low embeddedness.

Surprisingly, in consideration of the above factors (hydraulic gradient, bank slope, drainage depressions, substrate characteristics), a high proportion (20.1%) of the river's shoreline were classified as high stranding risk. The majority of the high stranding risk sites are in the low gradient gravel-dominated lower section of Mamquam River. We note the section of the river upstream of Ring Creek contains a deep canyon and long stretch of large boulders with limited shoreline likely to strand fish.

4.2. STRANDING ESTIMATION TOOL

In addition to estimating the total number of fish stranded, the stranding estimation tool could also be useful in influencing decisions on ramping guidelines and powerhouse operational practices.

The tool's inputs are the flow level of the river (high, medium, or low), the total stage drop resulting from a dewatering event (cm), the number of fish found in the area searched (m^2) during the preliminary fish salvage, and the predetermined recovery efficiency (%). This information should be supplied by the proponent or consultant concerned in the incident report written after any stranding event. The complete and functioning estimation tool is attached to this report as Appendix 8.3 and can be used directly through an electronic copy. Hardcopies will only have an image of the tool's layout, but calculations can be done manually following the stepwise process described in detail in section 2.3.

Our estimation tool is based on a number of assumptions:

- Bank slope distribution is representative of the flow range dewatered during the emergency shutdown. This is related to our assumption that attenuation of flows from the hydroelectric plant to the Squamish River is negligible in the lower Mamquam River. Changing channel morphology and braidedness affect the local magnitude of a given flow drop. For instance, a section of the river that is broad and shallow will experience a smaller flow drop than a section of river that is narrow and deep. For the purposes of our tool, we can justify these assumptions as most of the high sensitivity areas are relatively uniform in morphology compared to the river as a whole. Furthermore, the separation of slopes into high, medium, and low flow categories for each transect should help account for this issue by eliminating slopes that are not within range of the stage drop.
- Our collected slope data reflects actual high risk slopes on the Mamquam River, and the 40 survey transects selected are representative of high stranding risk sites within the system. The histogram of slope-meters across the 40 transects (Figure 4) supports our assumption, as the distribution follows a smooth curve which could reasonably reflect the real distribution of high risk slopes.
- Our chosen ranges for separating low, medium, and high flow levels are appropriate. Transect data was recorded from June 30, 2015 to July 15, 2015. We consulted Atlantic Power's recorded stage and flow data for these months (Appendix 8.1) and calculated that the stage downstream of their powerhouse only varied by 15.5 cm during our time collecting slope data. This was 4.5 cm less than our assumed variance of 20 cm used in selecting flow ranges. Since the real variance is actually less than our assumed variance, our low flow category will always contain the true water's edge that we measured, confirming that the range of transect slopes used in the low flow category is valid.
- Our criteria for identifying high risk sites was corroborated by overlap of our sites with Ecofish Research Ltd.'s identified "hot spot" sites on Mamquam River. Accordingly, our criteria likely reflect industry standards.

- We relied on professional judgement and observation when locating transect slope breaks from which we would measure our next slope. We made an effort to include every visible change in slope in our measurements. Effects of slope breaks not measured should be insignificant, as any change in slope too minute to see or measure would not affect fish stranding on the gravel bar.
- The use of the average value of each slope bin in our calculations, as well as the use of 11 bins (as opposed to more), may decrease the accuracy of our dewatered area calculations relative to the actual dewatered area on the river, which features a broader variety of slopes. However we believe the bins are sufficiently narrow that the dewatered area calculated using the average slope is a fair proxy for the total dewatered area comprised of all the individual slopes combined. The irregularities of using finer unit gradation (shown in Figure 5) suggests that the size of the unit ranges (i.e. slope bins) are as small as the data collected are able to support.
- The default values for recovery efficiencies obtained from Chin (2015) are reasonable approximations for the actual recovery efficiencies on the Mamquam River.

A dewatering event at higher flows is unlikely to result in greater drops in river stage, as lower flow levels lose a higher proportion of their water following emergency shutdowns. The hydroelectric projects on the Mamquam River are allowed to divert up to 30 cms of the river's flow with a required instream flow release past their intake structures of 1 cms (BC Government 2009), a minimum that is only reached during low flows. Thus the sudden retention of that water during emergency plant shut-downs and the resultant flow decrease would be more pronounced at low river flows, and would increase stranding relative to the same operation at high flows. A dewatering event occurring at high flow would be less significant as the plant would be diverting a much smaller proportion of the total river flow, resulting in a smaller stage drop with a plant shut-down. Thus, the extent of fish stranding on the Mamquam River will be a function of both flow level and the corresponding stage drop. An example of this difference is provided in data obtained from the Water Survey of Canada for the most recently recorded year, 2012. During high flows, a drop in discharge of 30 cms produced a stage drop of 44 cm (Appendix 8.6). While at low flows, the same drop in discharge produced a stage drop of 70 cm.

One factor omitted from our study that would strengthen the validity of the estimation tool is the rate of flow change. The rate of change in river flow can influence stranding risk (Irvine et al. 2009, Bradford et al. 1995). Fish swimming in shallow water or extensions of the mainstem have less time to escape at higher flow change rates and are thus more susceptible to stranding (Bradford et al. 1995).

Changing river morphology should also be considered for improving the estimation tool. The tool is based on current channel morphology and thus will only provide acceptable fish stranding estimates as long as the measured slopes and high risk areas continue to provide a relatively accurate representation of the Mamquam River. However ongoing processes of erosion, transport, and deposition will ultimately alter the river morphology (Bizzi and Lerner 2015); periodic updates would be required to keep the estimation tool information accurate and useful.

Although we included the primary factors influencing stranding in the creation of our tool and map, several variables were not incorporated which could further improve upon the tool's functionality. To supplement our map and tool, a model could be created that would predict stranding risk along the Mamquam River based on multiple factors, including several variables that were not addressed in our study. In addition to incorporating information on substrate, flow, river morphology and habitat features, a future model could allow for event-specific parameters such as season, time of day, wetted history, stage/flow relationships, flow change, attenuation downstream of the facility, and the density, species, and life stage of the fish present. With such a model it would be possible to: (i) identify the key factors influencing stranding risk in certain areas; (ii) predict the probability of a stranding event occurring under a range of environmental and operational conditions; and importantly, (iii) aid consultants in allocating fish salvage resources appropriately, and to (iv) influence hydroelectric plant operations to minimize risk during particularly high periods of fish stranding sensitivity.

5.0. CONCLUSION

Fish populations in river systems utilized for hydroelectric projects are at increased risk of stranding from emergency shutdown events. Project-related flow reduction compounds the natural stranding sensitivity inherent in systems exhibiting physical characteristics such as low bank slopes or the presence of shallow depressions within the active flow range. Three small hydroelectric power generating facilities within the Mamquam River drainage elevate the risk of fish stranding, particularly with 20 percent of the lower reach's total shoreline now identified as high risk sites. Our stranding sensitivity map and estimation tool will help improve the efficiency of fish salvage operations by pinpointing priority search areas and providing an estimate of the impact a dewatering incident has on fish populations in the Mamquam River system.

6.0. ACKNOWLEDGEMENTS

Salary and logistical support for Simon Fraser University Co-op students K. Munn and G. Dare was provided through Fisheries and Oceans Canada. Editing and counsel was given by Brian Naito and Murray Manson. Thank you to Adam Lewis of Ecofish Research Ltd. for lending their expertise in forming the methodology used in this project. We would like to thank Atlantic Power for providing us with the river flow data used in this project.

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8.0. APPENDICES

8.1. RIVER FLOW AND STAGE DATA FROM ATLANTIC POWER

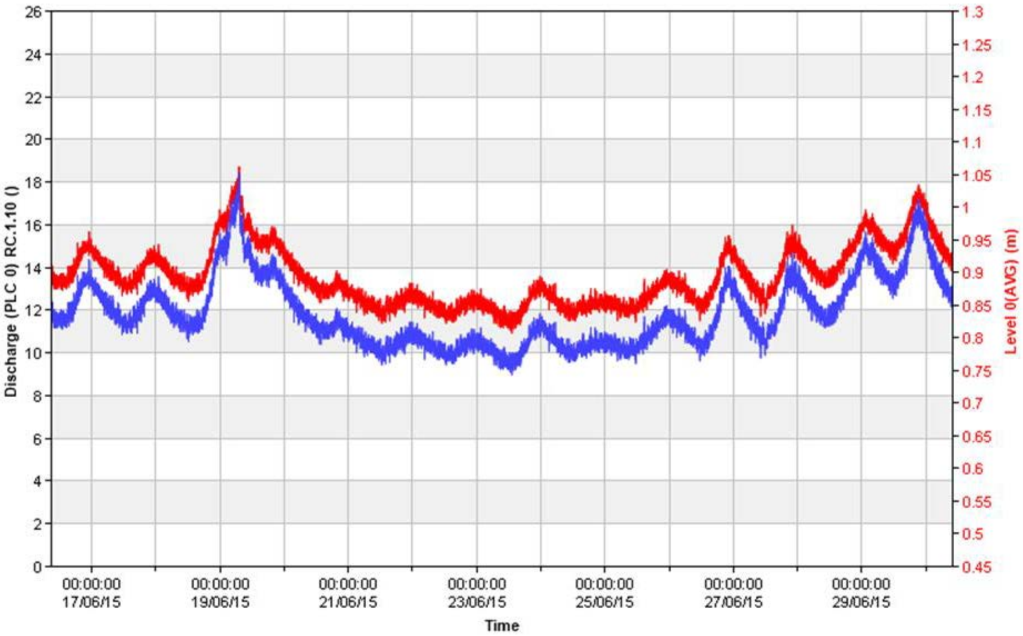


Figure 8.11: Atlantic Power river data: June 17 to June 30, 2015.

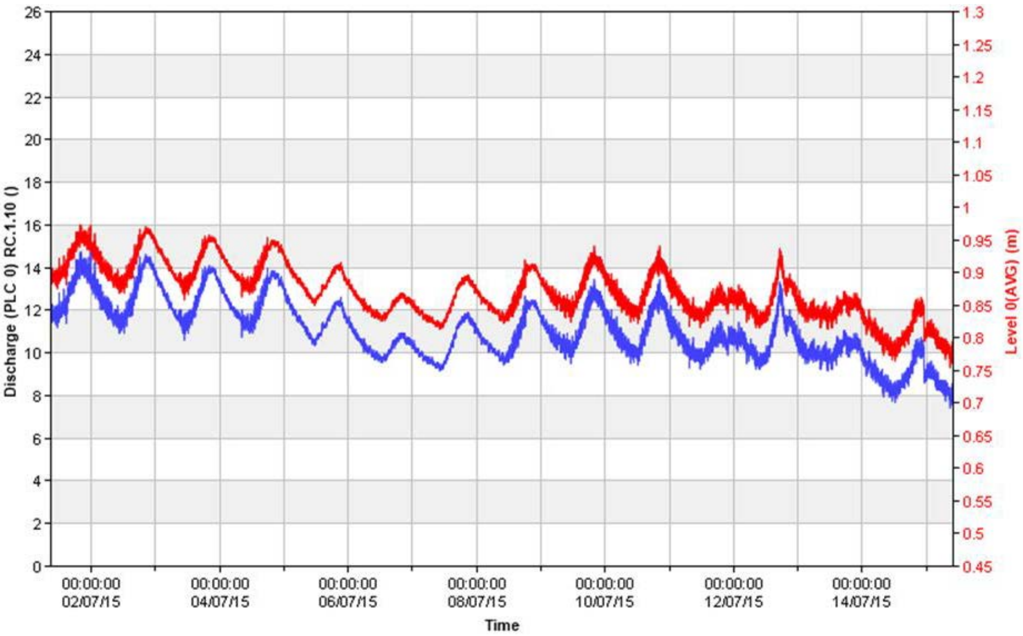


Figure 8.12: Atlantic Power river data: July 2 to July 15, 2015.

8.2. WATER SURVEY OF CANADA DATA: 2007, 2009-2012

Used in estimated high, medium and low flow ranges for estimation tool

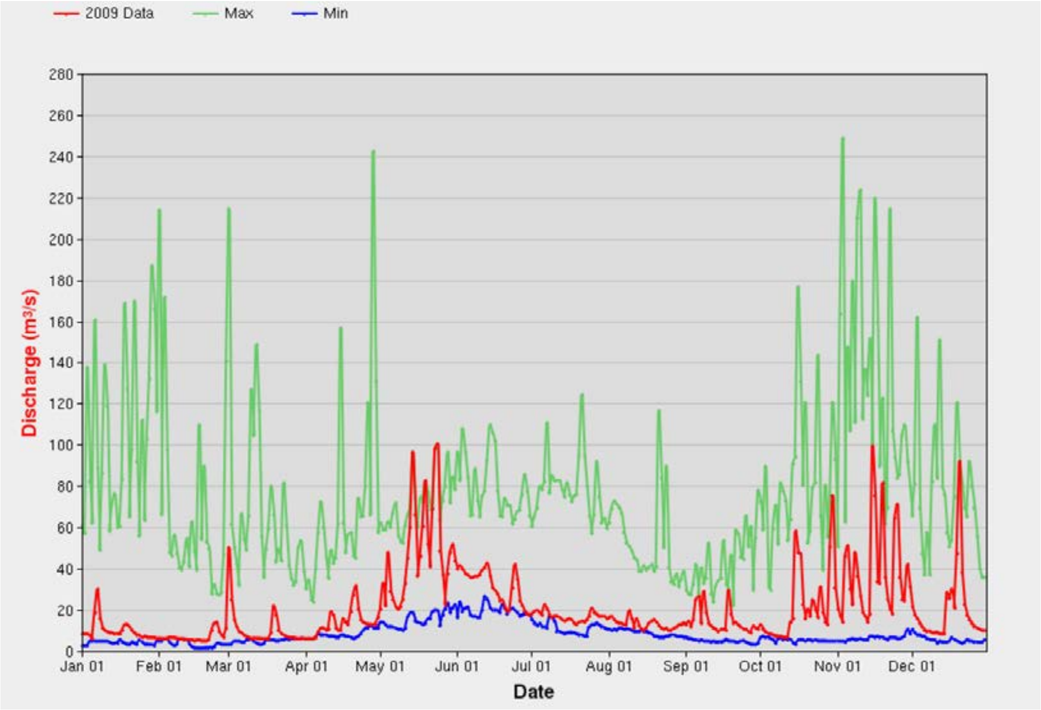


Figure 8.21: 2007 flow data for the Mamquam River above Ring Creek.

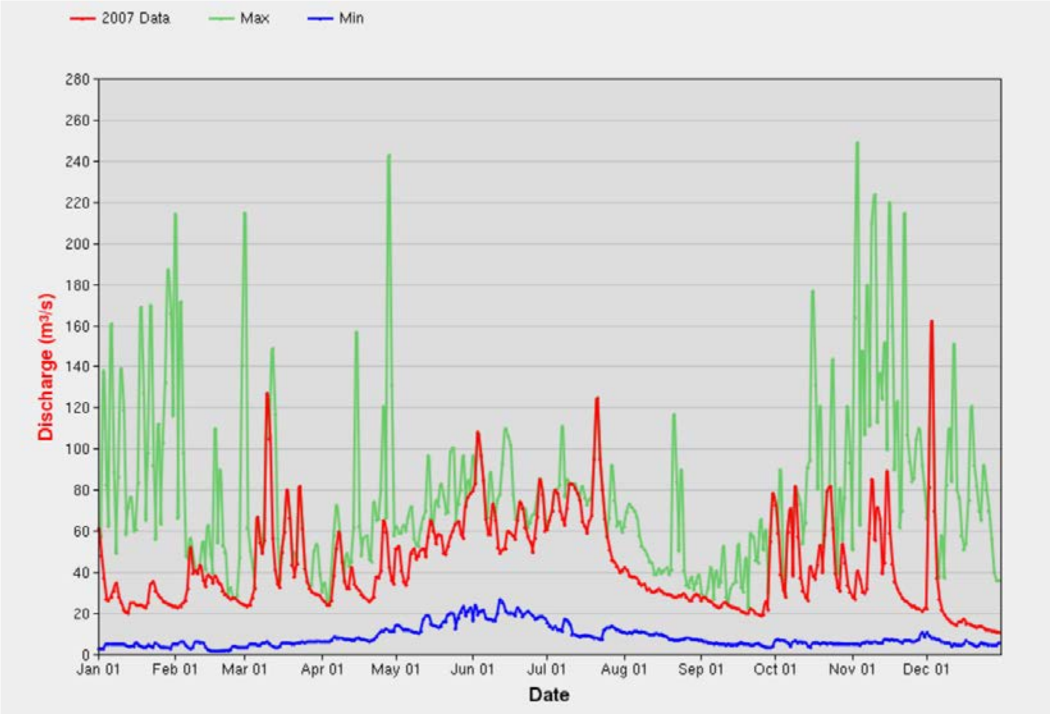


Figure 8.22: 2009 flow data for the Mamquam River above Ring Creek (note 2008 data unavailable).

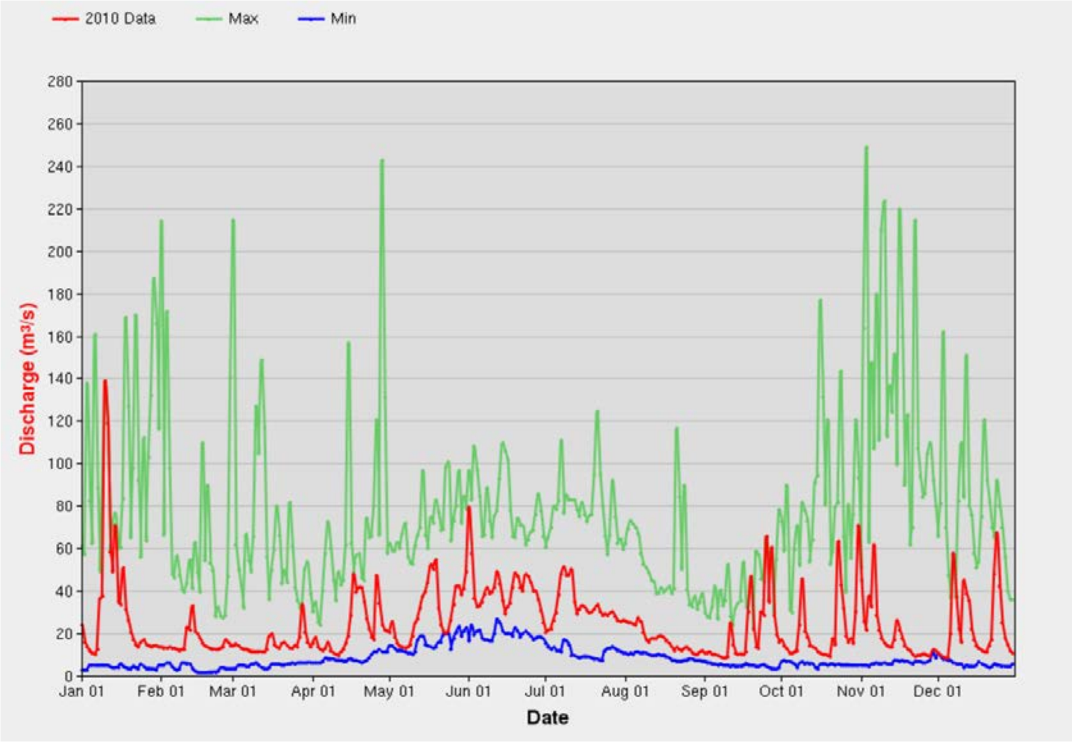


Figure 8.23: 2010 flow data for the Mamquam River above Ring Creek.

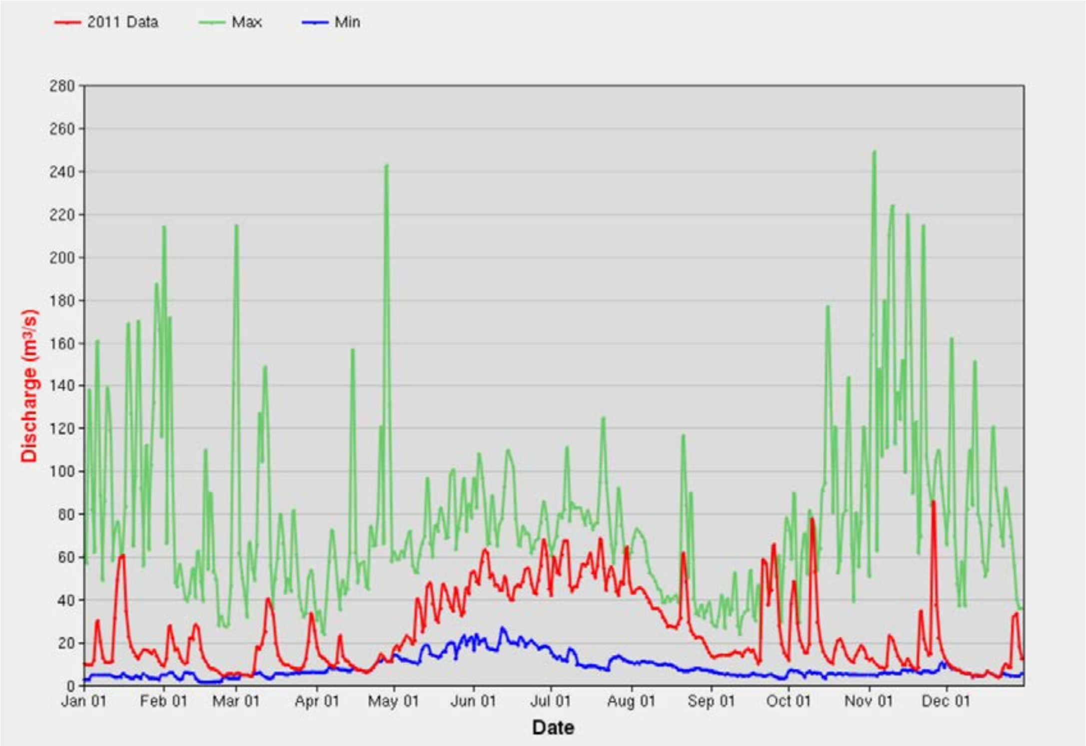


Figure 8.24: 2011 flow data for the Mamquam River above Ring Creek.

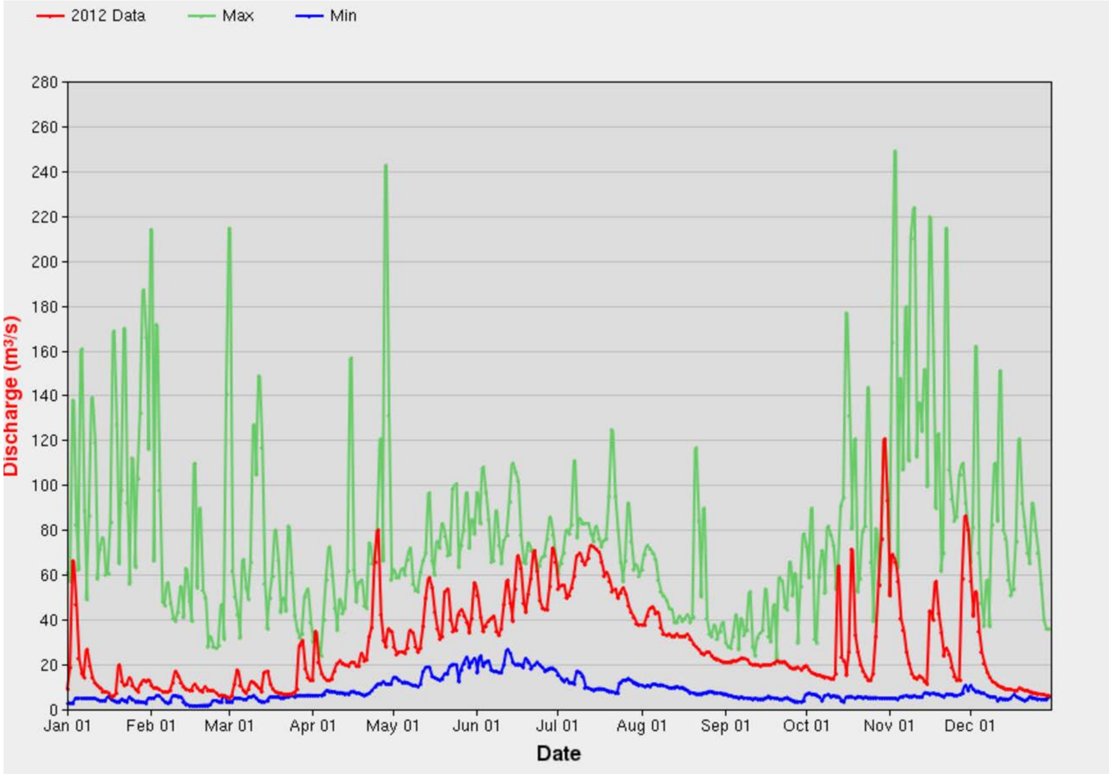
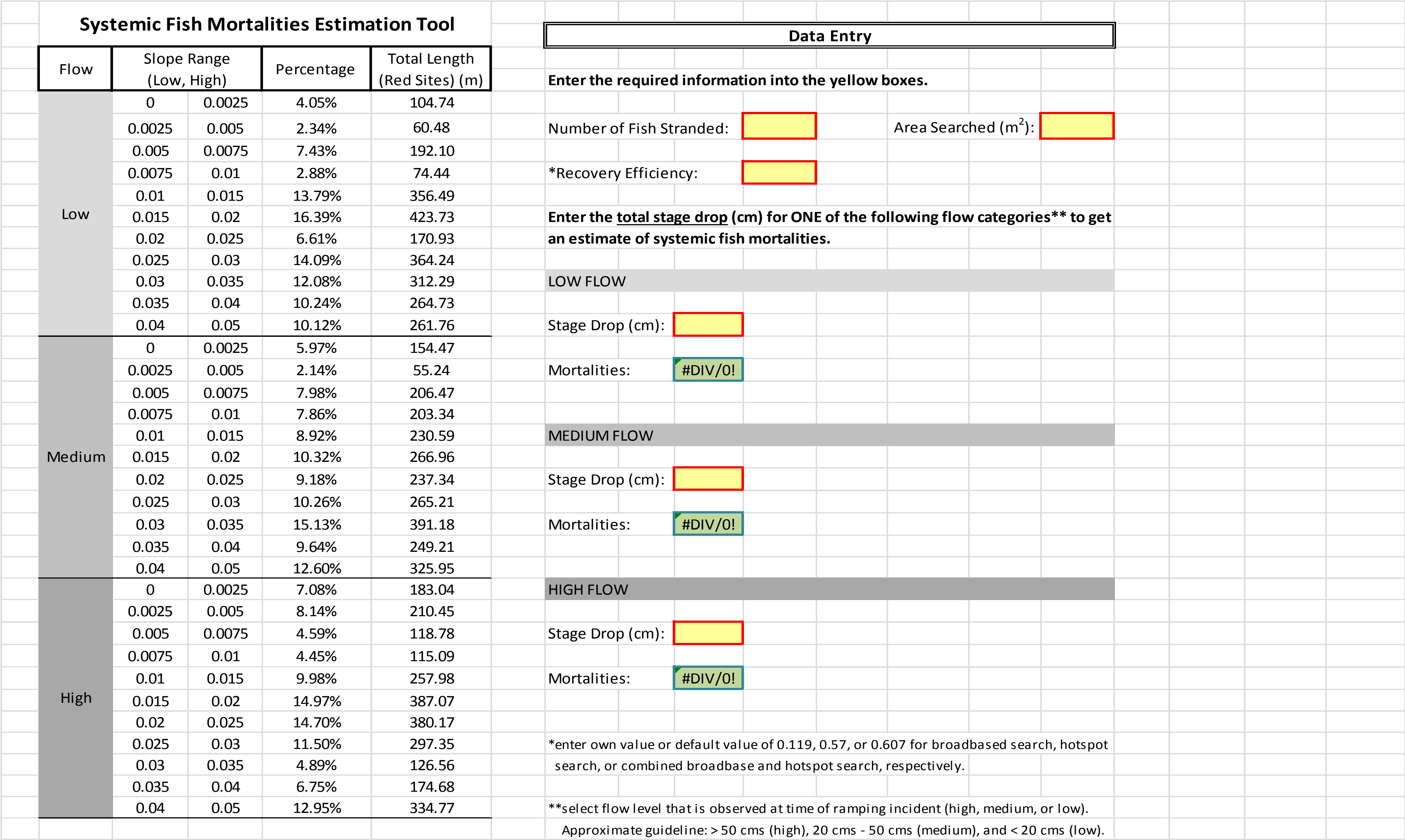


Figure 8.25: 2012 flow data for the Mamquam River above Ring Creek.

8.3. STRANDING ESTIMATION TOOL FOR MAMQUAM RIVER



Systemic Fish Mortalities Estimation Tool

Flow	Slope Range (Low, High)		Percentage	Total Length (Red Sites) (m)
Low	0	0.0025	4.05%	104.74
	0.0025	0.005	2.34%	60.48
	0.005	0.0075	7.43%	192.10
	0.0075	0.01	2.88%	74.44
	0.01	0.015	13.79%	356.49
	0.015	0.02	16.39%	423.73
	0.02	0.025	6.61%	170.93
	0.025	0.03	14.09%	364.24
	0.03	0.035	12.08%	312.29
	0.035	0.04	10.24%	264.73
	0.04	0.05	10.12%	261.76
Medium	0	0.0025	5.97%	154.47
	0.0025	0.005	2.14%	55.24
	0.005	0.0075	7.98%	206.47
	0.0075	0.01	7.86%	203.34
	0.01	0.015	8.92%	230.59
	0.015	0.02	10.32%	266.96
	0.02	0.025	9.18%	237.34
	0.025	0.03	10.26%	265.21
	0.03	0.035	15.13%	391.18
	0.035	0.04	9.64%	249.21
	0.04	0.05	12.60%	325.95
High	0	0.0025	7.08%	183.04
	0.0025	0.005	8.14%	210.45
	0.005	0.0075	4.59%	118.78
	0.0075	0.01	4.45%	115.09
	0.01	0.015	9.98%	257.98
	0.015	0.02	14.97%	387.07
	0.02	0.025	14.70%	380.17
	0.025	0.03	11.50%	297.35
	0.03	0.035	4.89%	126.56
	0.035	0.04	6.75%	174.68
	0.04	0.05	12.95%	334.77

Data Entry

Enter the required information into the yellow boxes.

Number of Fish Stranded: 🟨

Area Searched (m^2): 🟨

*Recovery Efficiency: 🟨

Enter the <u>total stage drop</u> (cm) for ONE of the following flow categories to get an estimate of systemic fish mortalities.**

LOW FLOW

Stage Drop (cm): 🟨

Mortalities: #DIV/0!

MEDIUM FLOW

Stage Drop (cm): 🟨

Mortalities: #DIV/0!

HIGH FLOW

Stage Drop (cm): 🟨

Mortalities: #DIV/0!

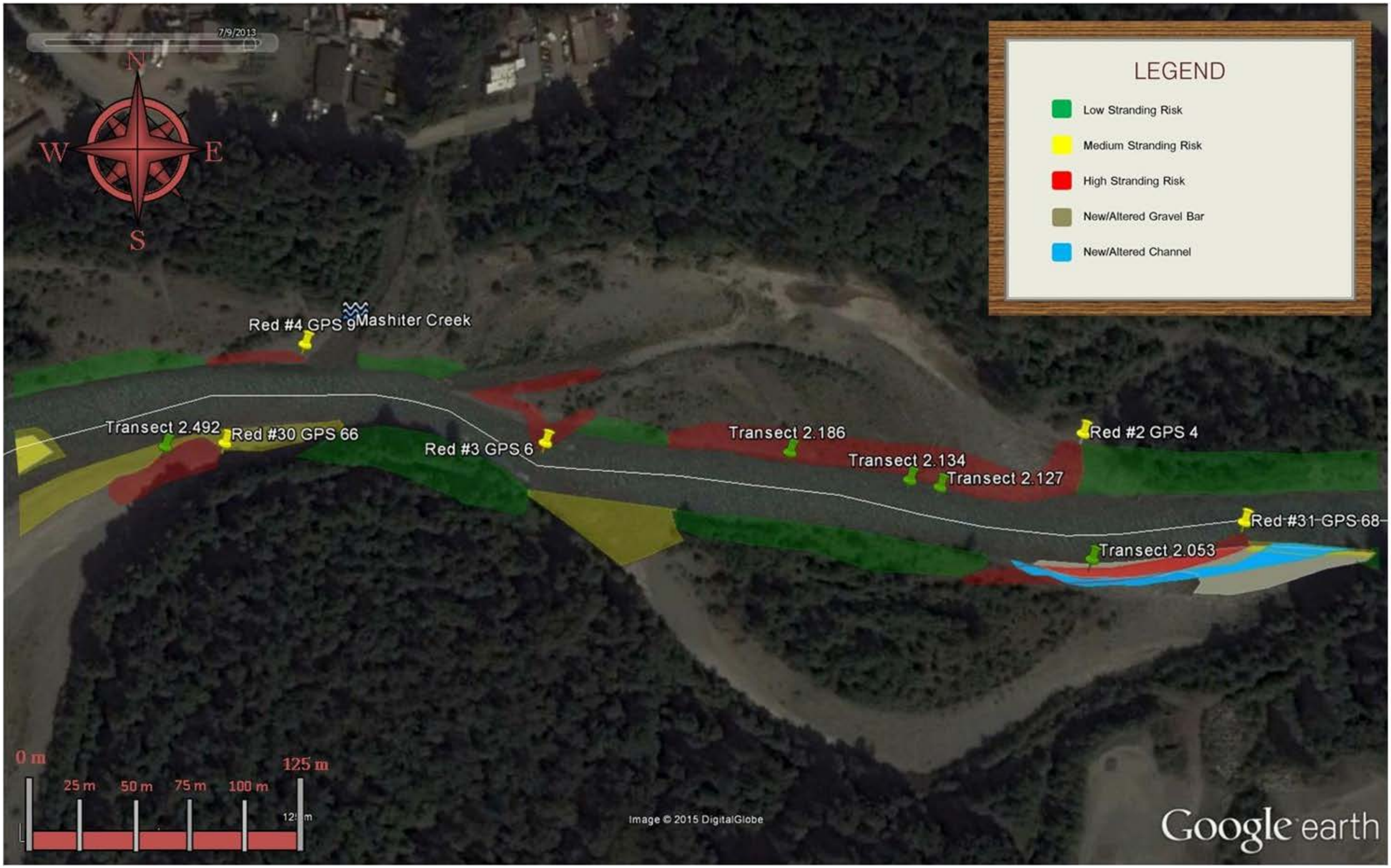
*enter own value or default value of 0.119, 0.57, or 0.607 for broadbased search, hotspot search, or combined broadbase and hotspot search, respectively.

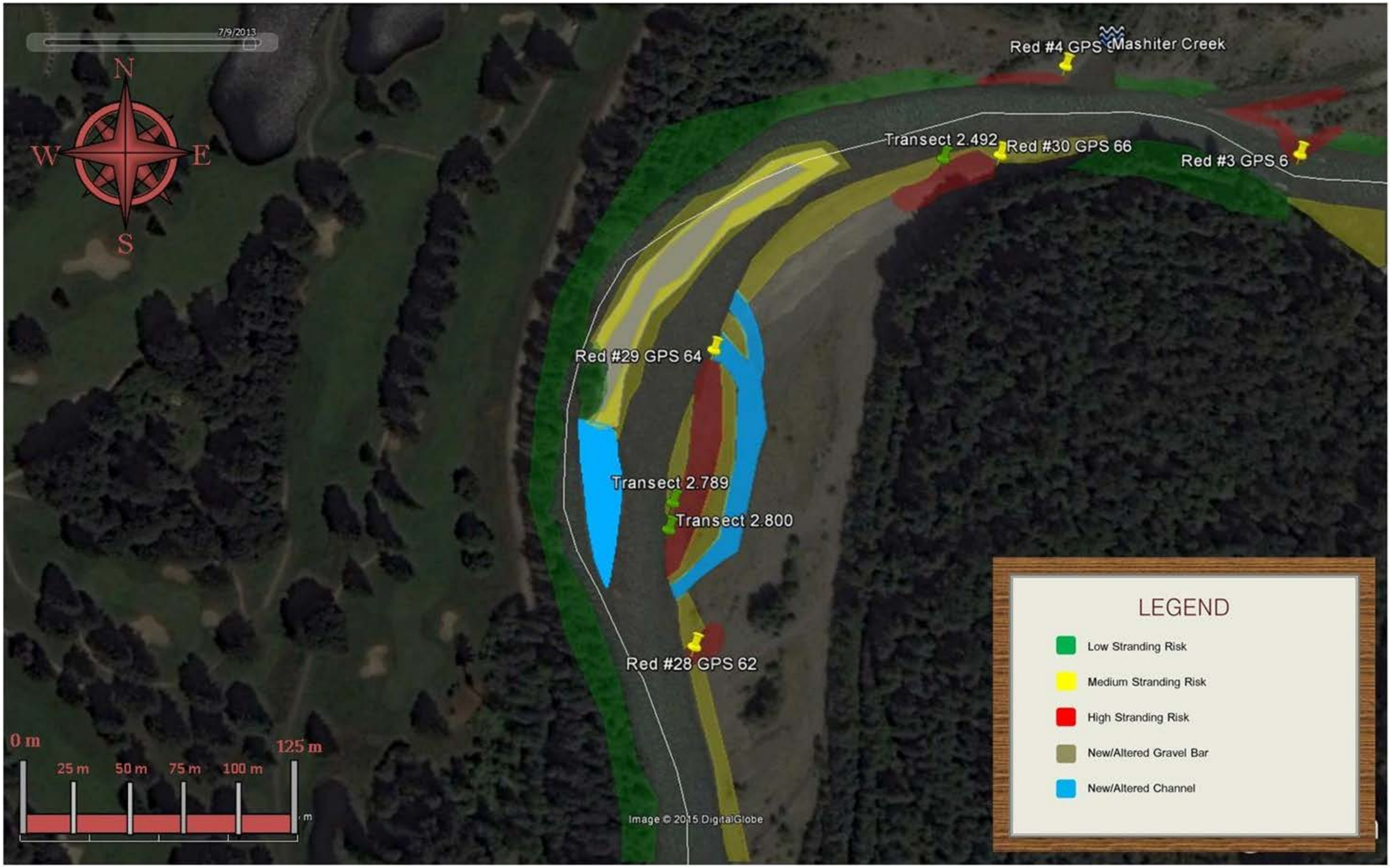
**select flow level that is observed at time of ramping incident (high, medium, or low). Approximate guideline: > 50 cms (high), 20 cms - 50 cms (medium), and < 20 cms (low).

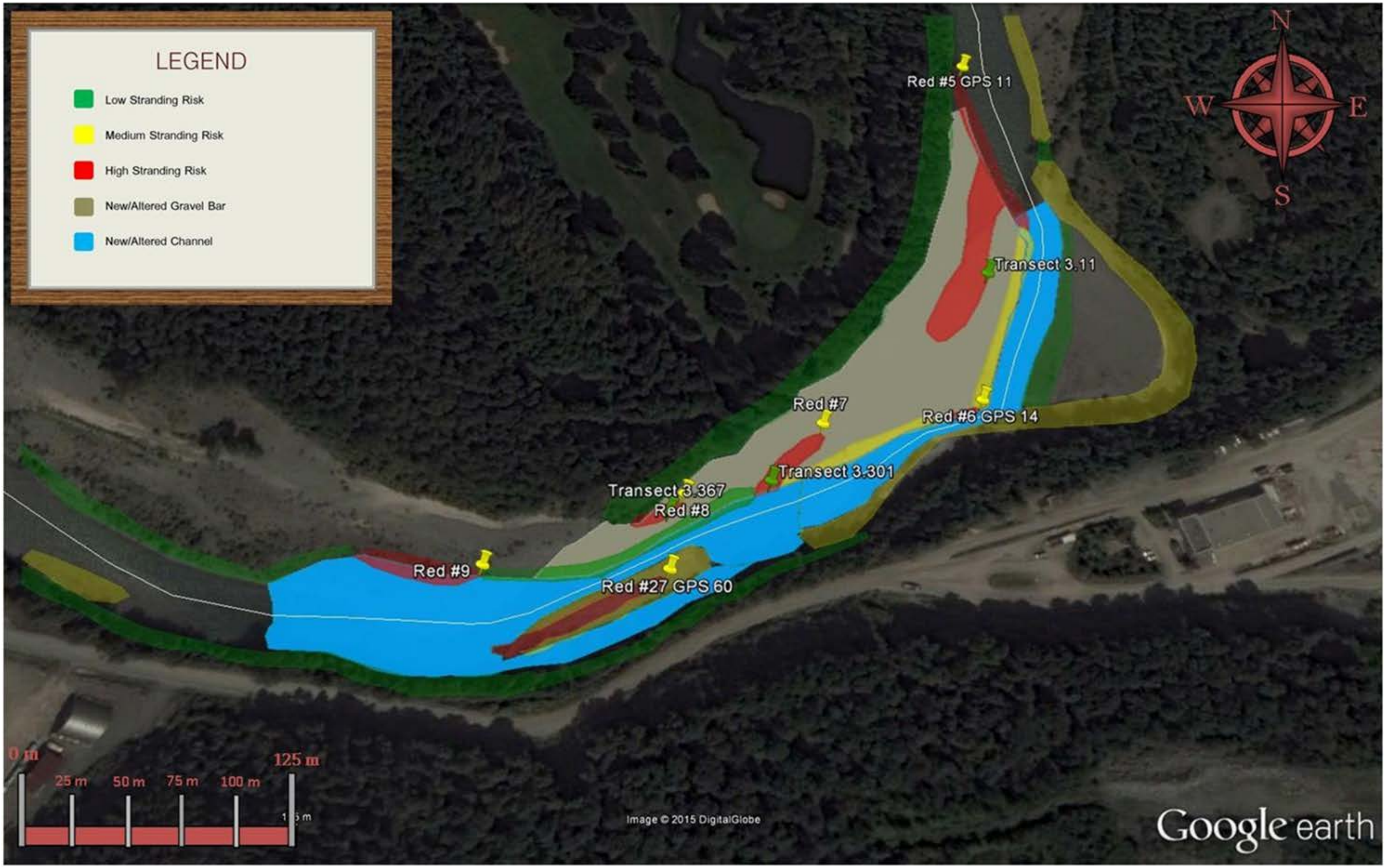
8.4. DETAILED STRANDING SENSITIVITY MAPS


7/9/2013
N
W
E
S
LEGEND
🟩 Low Stranding Risk
🟨 Medium Stranding Risk
🟥 High Stranding Risk
🟫 New/Altered Gravel Bar
🟦 New/Altered Channel
Ring Creek
Red #34 GPS 74
Transect 1.148
Transect 1.153
Red #35 GPS 75
0 m
25 m
50 m
75 m
100 m
125 m
Image © 2015 DigitalGlobe
Google earth


6
Transect 2.186
7/9/2013
Transect 2.134
Transect 2.127
Red #2 GPS 4
Red #31 GPS 68
Red #31 GPS
Transect 2.053
N
W
E
S
LEGEND
🟩 Low Stranding Risk
🟨 Medium Stranding Risk
🟥 High Stranding Risk
🟫 New/Altered Gravel Bar
🟦 New/Altered Channel
Transect 1.537
#1 Red GPS 1
0 m
25 m
50 m
75 m
100 m
125 m
Image © 2015 DigitalGlobe
Google earth

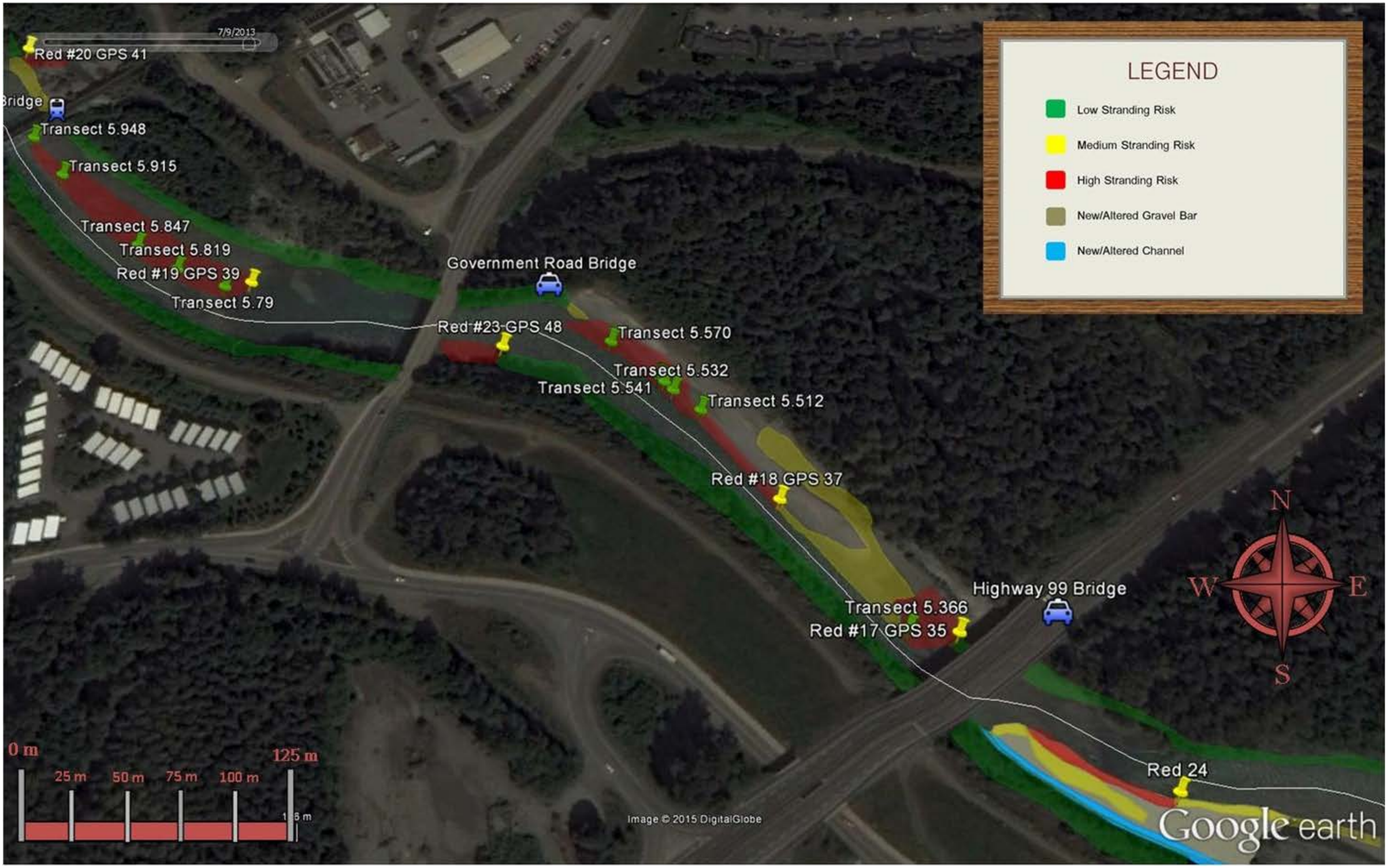

7/9/2013
N
W
E
S
LEGEND
🟩 Low Stranding Risk
🟨 Medium Stranding Risk
🟥 High Stranding Risk
🟫 New/Altered Gravel Bar
🟦 New/Altered Channel
Red #4 GPS 9
Mashiter Creek
Transect 2.492
Red #30 GPS 66
Red #3 GPS 6
Transect 2.186
Transect 2.134
Transect 2.127
Red #2 GPS 4
Red #31 GPS 68
Transect 2.053
0 m
25 m
50 m
75 m
100 m
125 m
Image © 2015 DigitalGlobe
Google earth

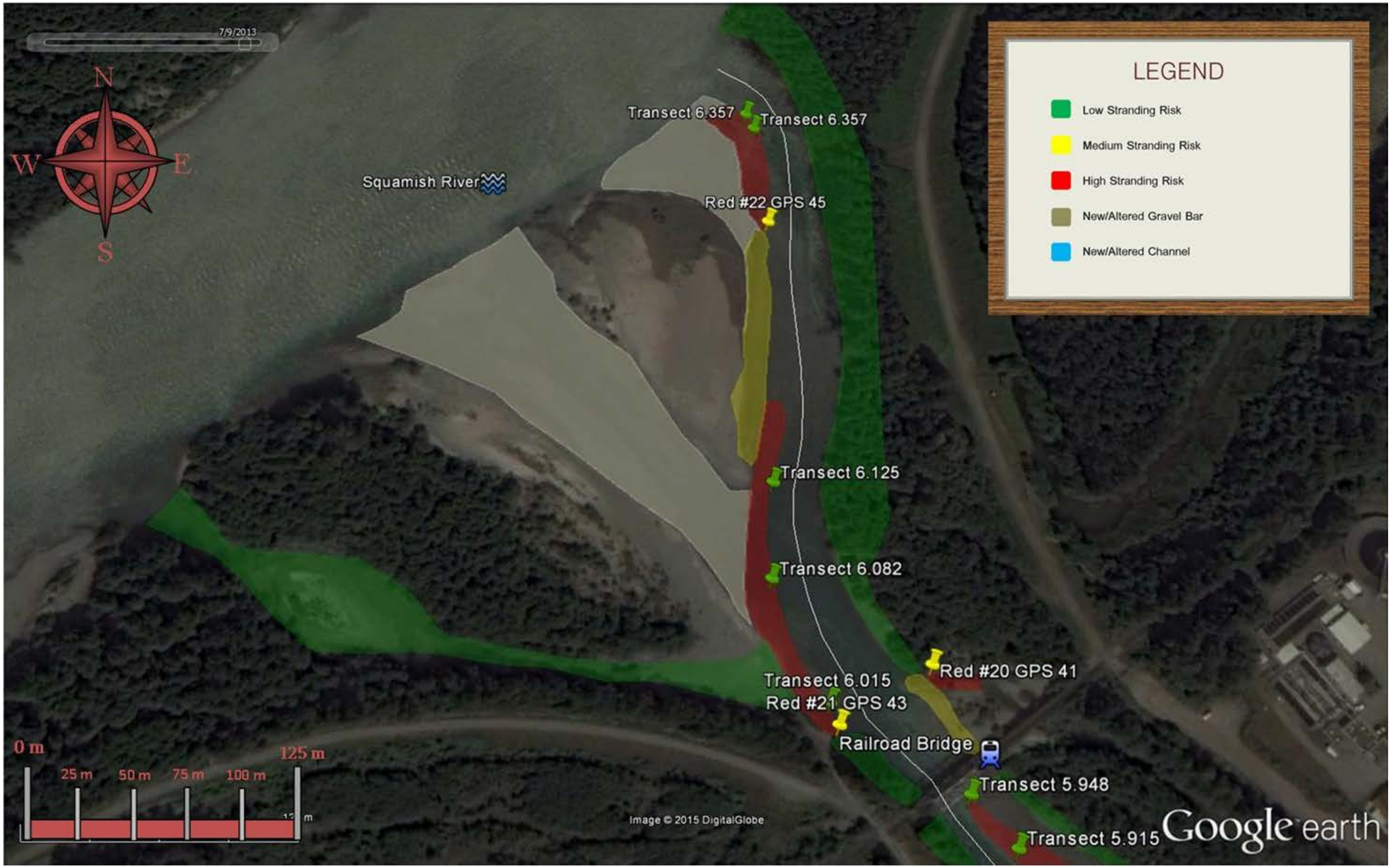

7/9/2013
N
W
E
S
Red #4 GPS
Mashiter Creek
Transect 2.492
Red #30 GPS 66
Red #3 GPS 6
Red #29 GPS 64
Transect 2.789
Transect 2.800
Red #28 GPS 62
0 m
25 m
50 m
75 m
100 m
125 m
Image © 2015 DigitalGlobe
LEGEND
🟩 Low Stranding Risk
🟨 Medium Stranding Risk
🟥 High Stranding Risk
🟫 New/Altered Gravel Bar
🟦 New/Altered Channel


LEGEND
🟩 Low Stranding Risk
🟨 Medium Stranding Risk
🟥 High Stranding Risk
🟫 New/Altered Gravel Bar
🟦 New/Altered Channel
N
W
E
S
Red #5 GPS 11
Transect 3.11
Red #7
Red #6 GPS 14
Transect 3.301
Transect 3.367
Red #8
Red #9
Red #27 GPS 60
0 m
25 m
50 m
75 m
100 m
125 m
Image © 2015 DigitalGlobe
Google earth


7/9/2013
Red #14 GPS 29
Red #13 GPS 27
Red #26 GPS 56
Red #12 GPS 25
Transect 4.363
Transect 4.363
LEGEND
🟩 Low Stranding Risk
🟨 Medium Stranding Risk
🟥 High Stranding Risk
🟫 New/Altered Gravel Bar
🟦 New/Altered Channel
N
W
E
S
0 m
125 m
25 m
50 m
75 m
100 m
Image © 2015 DigitalGlobe
Google earth


LEGEND
🟩 Low Stranding Risk
🟨 Medium Stranding Risk
🟥 High Stranding Risk
New/Altered Gravel Bar
New/Altered Channel
Red #26 GPS 56
Transect 4.318
Transect 4.363
Transect 4.363
Red #15 GPS 31
Transect 4.649
Transect 4.690
Transect 4.777
Transect 4.802
Transect 4.860
Red 24
Transect 5.077
Transect 5.065
Transect 5.012
Red #25 GPS 52
Red #16 GPS 33
N
W
E
S
0 m
25 m
50 m
75 m
100 m
125 m
Image © 2015 DigitalGlobe
Google earth


7/9/2013
Red #20 GPS 41
Bridge
Transect 5.948
Transect 5.915
Transect 5.847
Transect 5.819
Red #19 GPS 39
Transect 5.79
Government Road Bridge
Red #23 GPS 48
Transect 5.570
Transect 5.532
Transect 5.541
Transect 5.512
Red #18 GPS 37
Highway 99 Bridge
Transect 5.366
Red #17 GPS 35
Red 24
LEGEND
🟩 Low Stranding Risk
🟨 Medium Stranding Risk
🟥 High Stranding Risk
▨ New/Altered Gravel Bar
🟦 New/Altered Channel
N
W
E
S
0 m
25 m
50 m
75 m
100 m
125 m
Image © 2015 DigitalGlobe
Google earth


7/9/2013
N
W
E
S
Squamish River
Transect 6.357
Transect 6.357
Red #22 GPS 45
Transect 6.125
Transect 6.082
Red #20 GPS 41
Transect 6.015
Red #21 GPS 43
Railroad Bridge
Transect 5.948
Transect 5.915
LEGEND
🟩 Low Stranding Risk
🟨 Medium Stranding Risk
🟥 High Stranding Risk
▨ New/Altered Gravel Bar
🟦 New/Altered Channel
0 m
25 m
50 m
75 m
100 m
125 m
Image © 2015 DigitalGlobe
Google earth

8.5. COLLECTED SUBSTRATE DATA

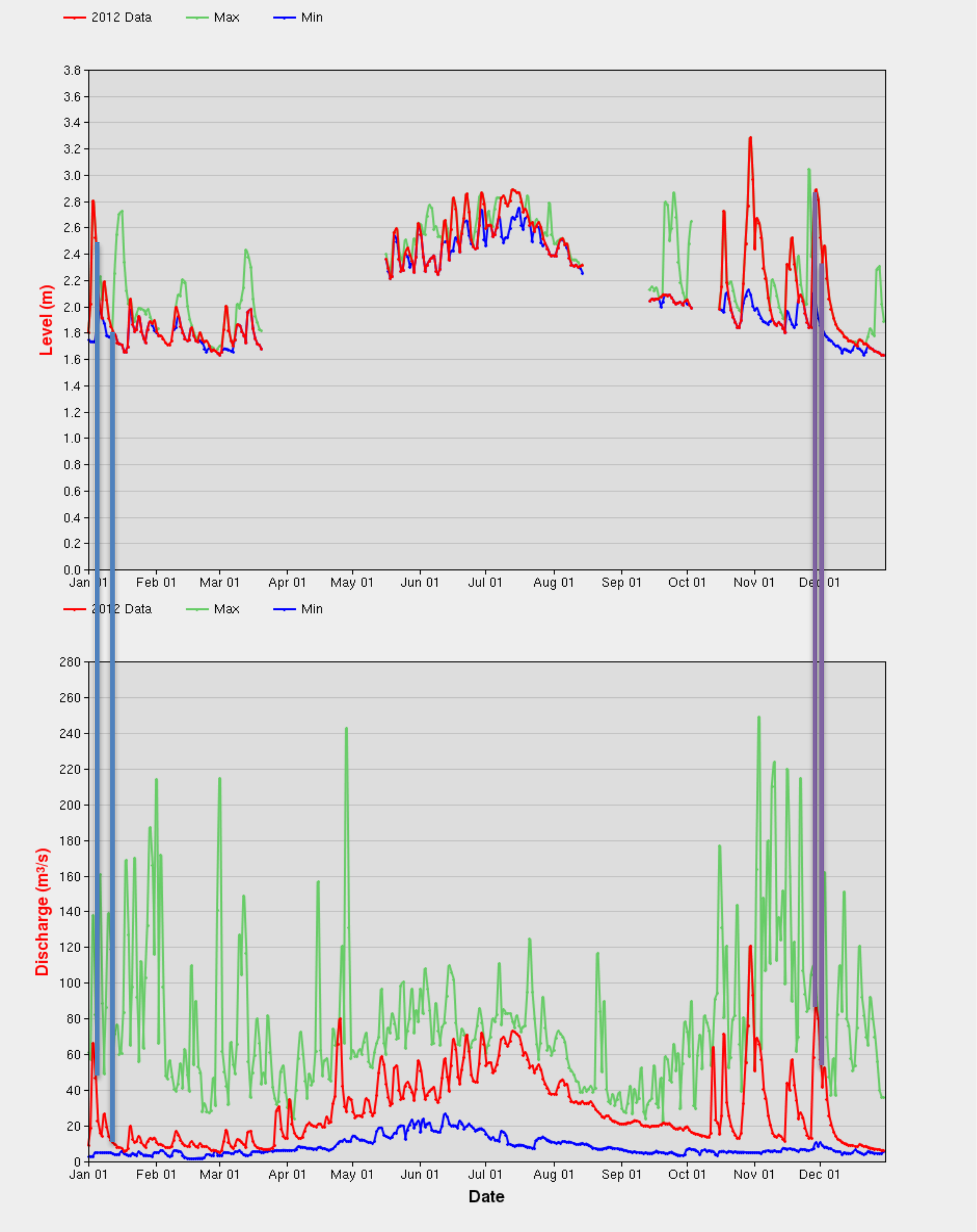
Table 8.51: Raw substrate data collected at the 40 transects including substrate type proportions, percent cover, and percent embeddedness at different distances from water’s edge. A negative distance indicates a point along the transect beyond water’s edge into the flowing river.

Transect #	Red Site #	Distance (m)	Substrate (%)						COV (%)	EMB (%)
			BO	LC	SC	LG	SG	FI		
1.148	35	0	0	10	10	50	25	5	10	30
		5	0	5	5	30	50	10	5	40
		11	10	30	10	25	20	5	15	40
1.153	35	0	0	5	15	30	45	5	5	30
		10	30	20	20	10	10	10	20	30
1.537	1	0	30	15	5	5	5	40	30	40
		-3.5	35	20	15	5	5	20	40	25
		6	20	25	20	15	10	10	20	30
2.053	31	-2	5	15	20	30	10	20	5	35
		0	5	10	15	20	10	40	5	55
		6	0	10	20	30	25	15	0	30
		20	30	20	20	5	15	10	30	40
2.127	2	0	30	20	35	5	0	10	30	40
		-4	15	25	35	10	5	10	30	30
		4	15	30	30	10	5	10	10	30
2.134	2	0	20	20	30	10	5	15	25	20
		8	10	25	30	20	5	10	20	10
2.186	2	-2	15	20	15	5	0	45	20	30
		0	10	20	25	10	0	35	10	40
		4	15	25	25	15	10	10	15	30
		12	10	10	10	5	0	65	5	40
2.492	30	0	0	15	10	20	0	55	5	70
		4	5	15	15	20	0	45	15	40
		8	10	20	10	15	5	40	5	60
2.789	29	28	15	15	20	30	10	10	20	40
		16	0	5	15	20	10	50	0	50
		0	0	15	30	25	25	5	10	30
2.800	29	0	0	15	15	35	20	15	10	30
		10	0	10	20	40	15	15	5	40
		28	10	20	15	30	10	15	20	30
3.110	5*	0	0	25	40	20	15	0	15	10
		10	0	25	20	35	15	5	15	15
		35	5	35	25	15	5	15	15	40

3.301	7	0	0	25	25	15	5	30	20	40
		4	0	5	25	40	20	10	5	20
		11	0	30	25	25	20	0	20	5
3.367	8	0	0	0	25	25	0	50	0	30
		2	0	0	15	30	0	55	0	20
		7	0	5	35	60	0	0	5	0
4.318	26	48	0	5	15	10	5	65	5	70
		28	0	0	5	5	0	90	0	90
		9	5	20	25	30	5	15	10	30
4.362	26	0	0	20	25	20	15	20	10	50
		17	0	15	10	5	65	5	5	45
		33	0	10	15	25	10	40	10	40
4.363	26	0	0	15	20	25	20	20	30	30
		4	0	10	15	25	10	40	5	40
		13	10	15	20	30	10	15	20	30
4.649	15	-1	0	20	30	20	10	20	20	30
		4	0	35	15	30	10	10	30	20
4.690	15	0	0	15	20	35	10	20	10	40
		12.4	0	5	25	50	20	0	5	5
4.777	15	0	0	15	15	10	5	55	5	60
		-4	0	0	30	10	0	60	5	60
		4	0	15	30	25	15	15	10	50
4.802	15	0	0	5	15	20	5	55	5	65
		-8	0	5	30	25	5	35	5	60
		4	0	20	25	15	10	30	5	40
4.860	15	0	0	0	10	25	15	50	0	60
		-2	0	0	5	60	25	10	0	20
		4	0	0	25	20	30	25	0	30
5.012	16	0	0	10	20	15	5	50	5	60
		-2	5	5	15	10	0	55	5	70
		7	0	0	20	50	20	10	0	20
5.065	25	0	0	20	20	15	5	50	10	20
		15	0	15	55	10	0	20	10	40
5.077	16	0	0	15	20	15	10	40	5	30
			0	20	20	20	25	5	5	20
5.366	17	0	0	5	20	15	10	50	5	40
		6	0	5	15	25	25	30	5	30
		-2	0	5	25	25	5	40	5	40
5.512	18	-2	0	5	15	50	5	25	5	60
		0	0	0	15	20	5	60	0	60
		8	0	0	15	55	10	20	0	30
5.532	18	0	0	0	40	20	10	30	0	50
		3.5	0	0	10	40	30	20	0	50

		10.4	0	0	10	20	15	55	0	60
		-4	0	0	5	40	5	50	0	50
5.541	18	-2	0	5	15	65	5	10	5	50
		0	0	5	15	30	5	45	0	50
		8	0	0	5	70	15	10	0	30
		15	5	10	10	15	5	65	5	40
5.546	18	-2	0	0	20	70	0	10	0	40
		0	0	0	10	30	0	60	0	60
		5	0	0	5	65	10	20	0	40
5.570	18	0	0	2	15	20	15	48	5	60
		-4	0	0	35	40	10	15	5	50
		4	0	0	20	30	20	30	5	40
5.790	19	0	5	10	15	20	0	50	10	50
		-4	0	5	35	50	0	10	5	20
		-17	0	5	20	40	10	25	0	40
5.819	19	0	0	10	15	10	5	60	35	30
		4	0	10	25	20	0	45	5	50
		12	0	5	20	50	10	15	0	30
5.847	19	0	5	15	20	15	10	35	10	40
		-5	0	0	15	35	5	45	5	50
		-11	0	5	15	45	5	30	0	30
5.915	19	0	0	0	5	5	55	35	1	20
		-2	0	0	0	0	0	100	0	0
		4	0	0	5	25	30	40	0	60
5.948	19	0	0	0	0	45	25	30	0	30
		-2	0	0	0	5	5	90	0	20
		5	0	0	5	30	25	35	0	40
6.015	21	0	25	5	25	15	5	25	35	30
		-9	0	0	20	40	10	30	0	40
6.082	21	0	0	0	40	45	10	5	5	20
		-4	0	0	35	45	15	5	5	15
		4	0	0	20	25	10	45	0	70
		17	0	0	10	60	25	5	0	0
6.125	21	0	0	10	20	10	5	50	5	40
		-2	5	15	25	35	10	10	10	20
		10	0	10	35	40	15	0		
6.282	22	0	0	0	10	30	35	25	0	30
		-5	0	0	10	25	35	30	0	50
		2.5	0	0	10	40	45	5	0	20
6.357	22	0	0	5	15	30	45	5	5	10
		-15	0	0	15	60	5	20	0	40
		7	0	0	20	40	35	5	0	30

8.6. WATER SURVEY OF CANADA DATA: 2012



Figures 8.61 and 8.62: Data for station above Ring Creek for 2012 showing level in 8.61 (top) and discharge in 8.62 (bottom). Lines represent the 30 cms change in discharge and the corresponding stage drop.