Crawford Creek Hydrogeomorphic Investigation and Identification of Habitat Restoration Opportunities

Apex File HA-15-PL-01

Looking upstream at top end of constructed flood protection berm (2012) on Crawford Creek

Prepared For: Fish and Wildlife Compensation Program

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Introduction and Background

The Eastshore Freshwater Habitat Society contracted Kim Green P.Geo., PhD of Apex Geoscience Consultants Ltd to undertake an initial assessment of Crawford Creek to determine its suitability for habitat enhancement works as part of a broader initiative directed improving kokanee habitat in streams that are tributary to the South Arm of Kootenay Lake. Funding for this initial study has been provided by Fish and Wildlife Compensation Program (FWCP) Grant # F-F16-029.

Historical significance of Crawford Creek as a kokanee spawning channels

Construction of Kootenay River dams in the 1960’s and 1970’s caused a decrease in the nutrient levels of Kootenay Lake which has severely impacted the population of kokanee (*Oncorhynchus nerka*) in the South Arm of Kootenay Lake (Andrusak and Fleck, 2005; Erikson et al., 2009). A lake fertilization program was initiated in the South Arm in 2003 as well as a program of egg planting in tributaries to improve kokanee numbers in the South Arm. Despite these efforts, numbers of spawning kokanee in tributaries to the South Arm have not improved substantially (Table , from Schindler et al., 2014).

Table 1. Kokanee spawner counts in BC South Arm tributaries, 1992–2012. Historical data in Ericksen et al. (2009). Blue shading indicates years and streams where we anticipated returns of age 3+ spawners from egg plants four years earlier (From Schindler et al., 2014).

Year	Crawford	Gray	La France	Lock-Hart	Akokli	Sanca	Boulder	Midge	Goat River	Summit	Cultus	Combined
1992						6	3		20	30		59
1993												
1994	2	0	0	0	100	4	0	0	0	0	0	106
1995	0	0	0	0	0	0	0	0	0	0	0	0
1996	40	30	20	20	200	0	0	50	4	0	50	414
1997	0	100	3	1	150	7	0	0	0	0		261
1998	0	5	0	0	50	2	0	5	2	0		64
1999	0	20	2	0	20	2	0	0	0	0		44
2000	0	2	0	0	20	0	1		0	0		23
2001	0	8	0	0	6	0	0	33	0	0		47
2002	0	10	0	0	5	0	0		0	0		15
2003	5	35	0	0	151	8	0	0	2	1		202
2004	0	8	0	0	8	0	0	0	0	0	0	16
2005	0	0	0	0	1	0	0		0	0		1
2006	0	9	0	0	2	0	0		0	1		12
2007	8	40	0	3	4	0	0		0	0	100	155
2008	0	6	2	0	0	0	0		0	0		8
2009	22	4	0	0	2	0	0		187	114		329
2010	0	19	2	0	NS	0	0		0	0		21
2011	575	10	0	0	10	0	0		274	203		1,072
2012	57	1	0	0	0	0	3	0	1441	315	0	1,817

Poor habitat has been cited as one of the reasons for the limited number of spawning kokanee in South Arm tributaries (See Table 2, Andrusak and Fleck, 2005). While most of the tributaries have steep alluvial fans and/or fisheries barriers within a relatively short distance from the lake, many of the tributaries, including Crawford Creek have also experienced direct impacts to aquatic habitat over the past 50 years associated with private land development. In particular, Crawford Creek has experienced extensive removal of riparian vegetation as well as re-alignment in association with Highway 3A works.

Historically, the lower reach of Crawford Creek provided valuable spawning habitat for many species of fish including Kokanee. Crawford Creek is the largest tributary in the South Arm of Kootenay Lake and is the only stream in the area that has a large, low gradient alluvial fan without fish barriers for 4 kilometers upstream from the Kootenay Lake confluence (Table 2 from Andrusak and Fleck, 2005). Although historical data on the size of kokanee runs has not been documented, anecdotal information suggests that the lower reaches of Crawford Creek likely supported runs in the order of 10,000 kokanee in the past (Andrusak and Fleck, 2005).

Table 2. Potential kokanee spawning habitat in tributary streams in the BC portion of the Kootenai/y River and South Arm of Kootenay Lake (Andrusak and Fleck (2004)

Name	Approximate Accessible Stream Length (km)	Suspected Historic Run Size	Upstream Migration Constraint
East Side			
Crawford Creek	4	1-10,000	waterfall
Gray Creek	<0.3	< 1000	gradient
La France	0.7		gradient
Lockhart Creek	<0.3	< 500	gradient
Akokli (Goat) Creek	<0.4	< 500	waterfall
Sanca Creek	<0.5	< 500	gradient
Boulder Creek	0.4	< 500	waterfall
Goat River	10	20-50,000	Hydro dam
West Side			
Boundary Creek	4	5-10,000	gradient
Corn Creek	<0.5	3-5000	waterfall
Summit Creek	2	10-20,000	gradient
Cultus Creek		< 500	gradient
Next Creek	< 0.2	< 1000	waterfall
Midge Creek	1.5	5-15,000	gradient
Wilson	0	0	gradient
Irvine Creek	0	0	gradient

Objectives of this study

The initial component of the Crawford Creek restoration project is intended an overview hydrological and geomorphic investigation of Crawford Creek along the lower reaches from above the golf course to the estuary. This assessment is intended to gain an understanding of the streamflow regime, channel morphology and hydraulic geometry of Crawford Creek and to assist in the identification and prioritization of sites for habitat restoration opportunities.

The three main deliverables for Part 1are;

1. A survey of the stream channel at representative cross-sections along the study reaches to record information on current channel morphology, hydraulic geometry, channel gradient and mobile bedload. This information is required for characterization of the study site.
2. Air-photo based investigation of the morphological changes that have occurred on Crawford Creek over the past few decades to assist in determining the primary causes of the current channel disturbance.
3. Creation of a photo-mosaic of the current stream channel along the study reach to be used as a base map for presentation of the survey data and for the identification of potential restoration sites.

Figure 1. Crawford Creek delineated in red is a 187km^2 watershed that flows southwest from the Purcell Range to Crawford Bay. Crawford Creek is the largest watershed tributary to the southern portion of Kootenay Lake and the only one with a well-developed alluvial fan ideally suited to Kokanee spawning.

Methods and Limitations

This study of the lower 2 kilometers of Crawford Creek is intended as an overview investigation of hydrological and geomorphological characteristics of the stream channel. The channel was surveyed on August 7th and 11th, 2015 by Kim Green, P.Geo., PhD, with the assistance of Will Halleran, P.Geo., L.Eng. The survey was conducted by walking in the upstream direction from the Highway 3A to the bedrock canyon above the old spawning channel. Survey sites were chosen to provide a representative measure of channel metrics including bankfull width, depth and gradient. The location of survey sites and the field data collected at the sites were recorded using an IPad Mini with an internal GPS. These survey sites were recorded as waypoints which were subsequently downloaded and imported into Google Earth (Figure 2). The satellite reception was generally excellent, the waypoints are assumed to be within five meters of the plotted locations shown on Figure 2.

Channel width was measured using a nylon tape stretched out across the active channel to the bankfull indicators. Channel depth was recorded at two meter intervals along the extended tape and averaged over the full width. Channel gradient upstream and downstream from the survey sites was measured using a Dewalt self-leveling laser level with a stadia rod in combination with the nylon tape to record horizontal distance from the level. The grain-size distribution of the channel bed at each of the survey sites was determined using the Wolman pebble count method. In addition the maximum mobile grain size was recorded by taking the average b-axis dimension of the five largest, obviously mobile grains on the bed surface. Variability in the size of mobile bed sediment provides an indication of the variability in sediment transport capacity along the two kilometer segment of surveyed channel.

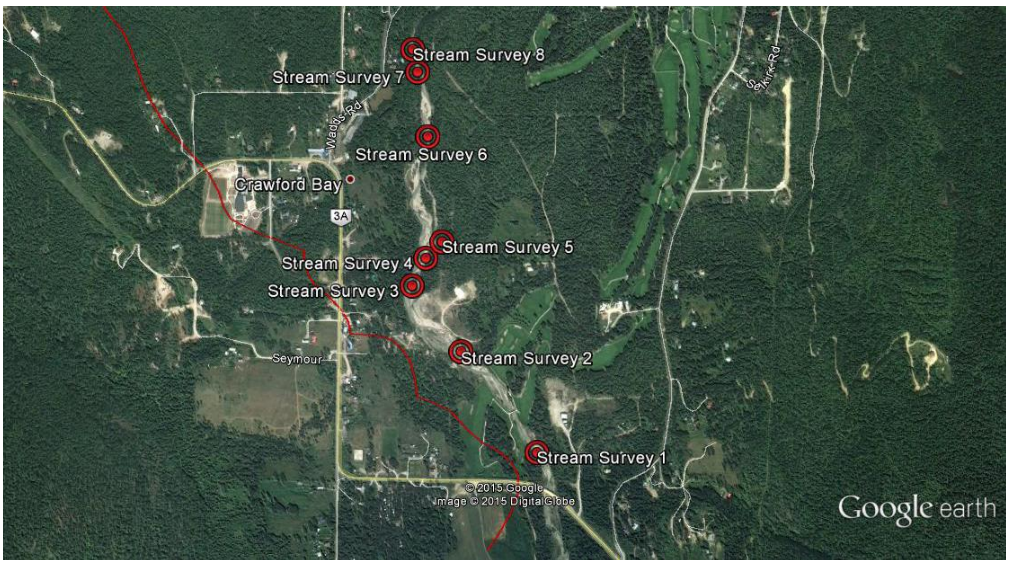


Figure 2. Location of survey sites along lower Crawford Creek

Indicators of past flood disturbance and channel instability was noted as part of the field survey. A compilation of historic air photographs dating back to 1958 was undertaken to provide an indication of the lateral channel stability and past disturbance events in Crawford Creek. A DJI Vision 2+ drone was used to collect air photographs of the channel and construct a photo mosaic to compare with the historic air photographs to determine the disturbance associated with the most recent (2012 and 2013) floods.

Project Outcomes

Historical Air photograph analysis

A series of air photographs from 1958 to 2015 provides some insight regarding the lateral stability and flood history of Crawford Creek below the canyon over the past 50 years (Figure 3a,b). The air photographs reveal that large floods in the late 1950's and 1960's caused the greatest amount of disturbance in the past 50 years including substantial channel widening and bank erosion. Between 1968 and 2009 the channel banks appear to have re-vegetated and the active width of the channel has narrowed. An expanded photograph comparison of the 2004 air photograph and 2015 drone mosaic (Figure 4) reveals that the channel disturbance associated with the 2012/2013 floods was greatest upstream from the Kootenay Springs Golf Course gravel pit. In this area (highlighted by red circles) the channel width has increased substantially. The second area of obvious channel change is adjacent to and immediately below the gravel pit area. Aside from these two locations recent flood disturbance to Crawford Creek appears to be limited to localized bank erosion and channel aggradation. Little change to the channel is apparent between the two photographs from below the golf course bridge to the mouth of the Crawford Creek at Crawford Bay.

Figure 3a. Historical Air Photograph compilation (1958-1997).

1958	1968	1988	1997

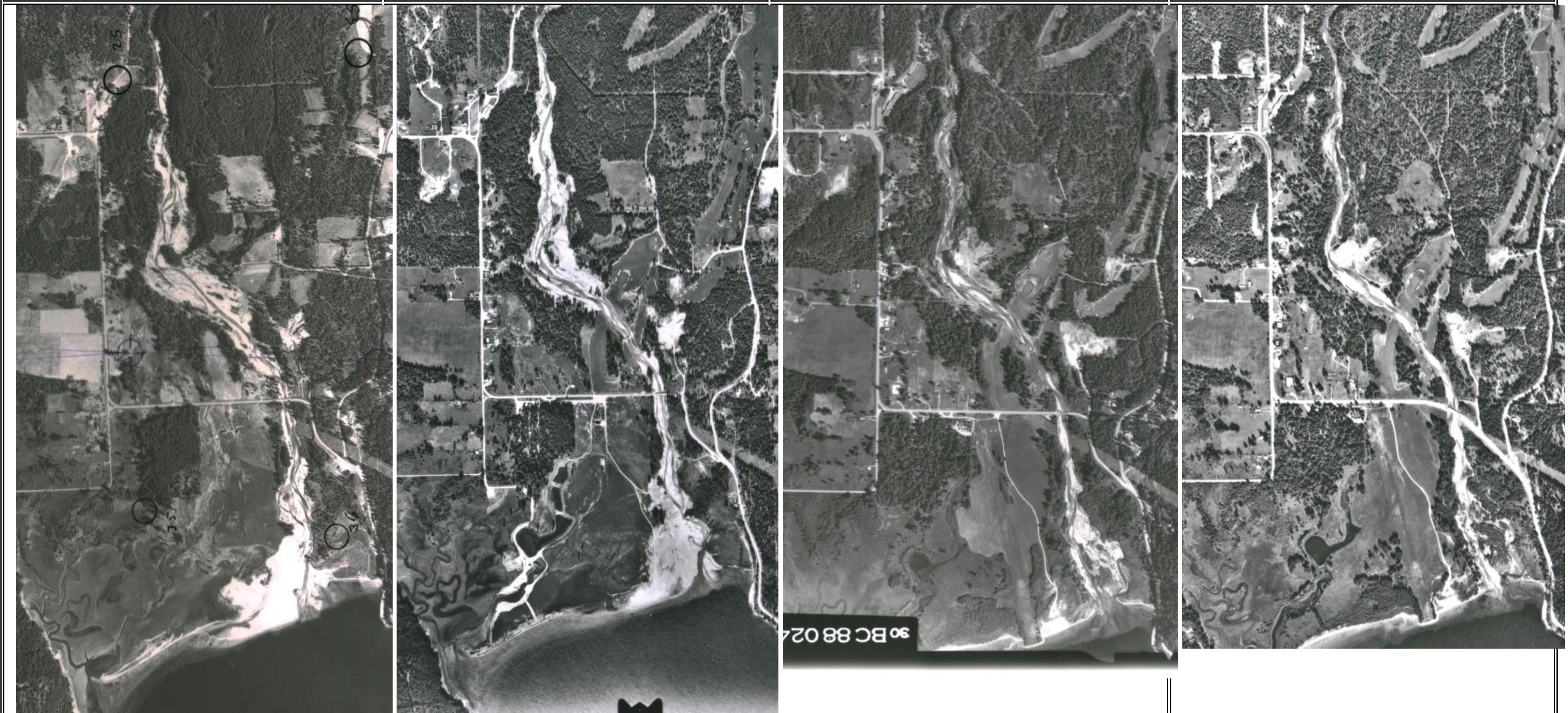


Figure 3b. Historical air photo compilation and drone imagery (1997-2015)

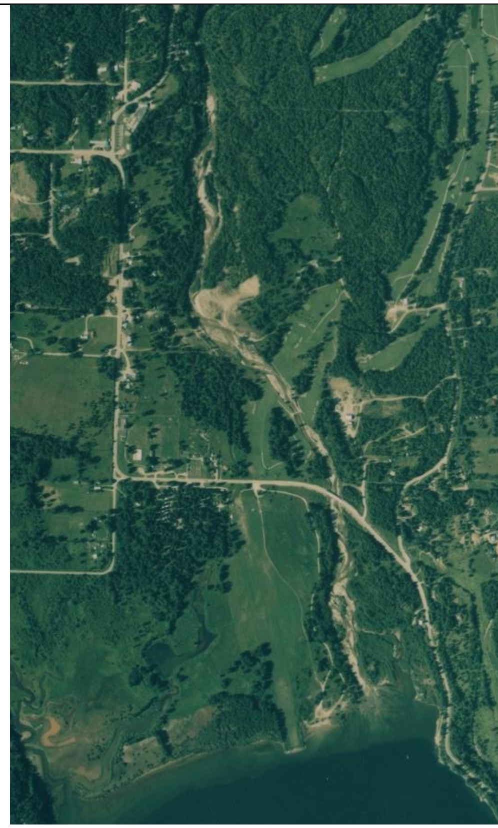
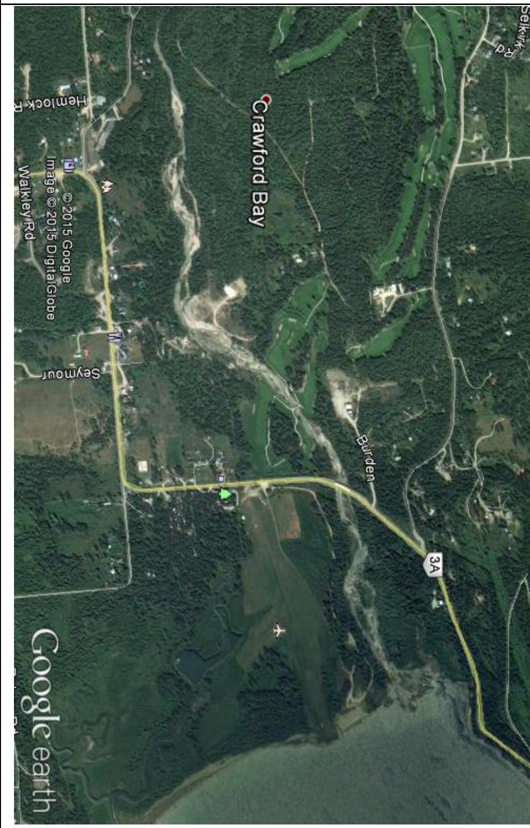
1997	2004	2009	2015
			

Figure 4. Larger scale comparison between 2004 air photograph and 2015 drone imagery shows that the disturbance associated with the 2012/2013 floods was greatest in the area upstream from the golf course gravel pit.

2004	2015
	

Hydrological analysis

Flows on Crawford Creek were gauged for a short time between 1947 and 1952 (Figure 5). During the period of gauging peak flows on Crawford Creek ranged from 17 m^3/s (1952) to 104m^3/s (1949). Historical information from a study by the B.C. Ministry of Environment of the flooding hazard on Crawford Creek fan (Nichols, 1987) indicate that large floods caused problems on the fan in 1910 and 1968. Recent large floods occurred in 2012 and 2013. Both of these recent floods were the result of late season, heavy rainfall on a saturated, high elevation snow pack.

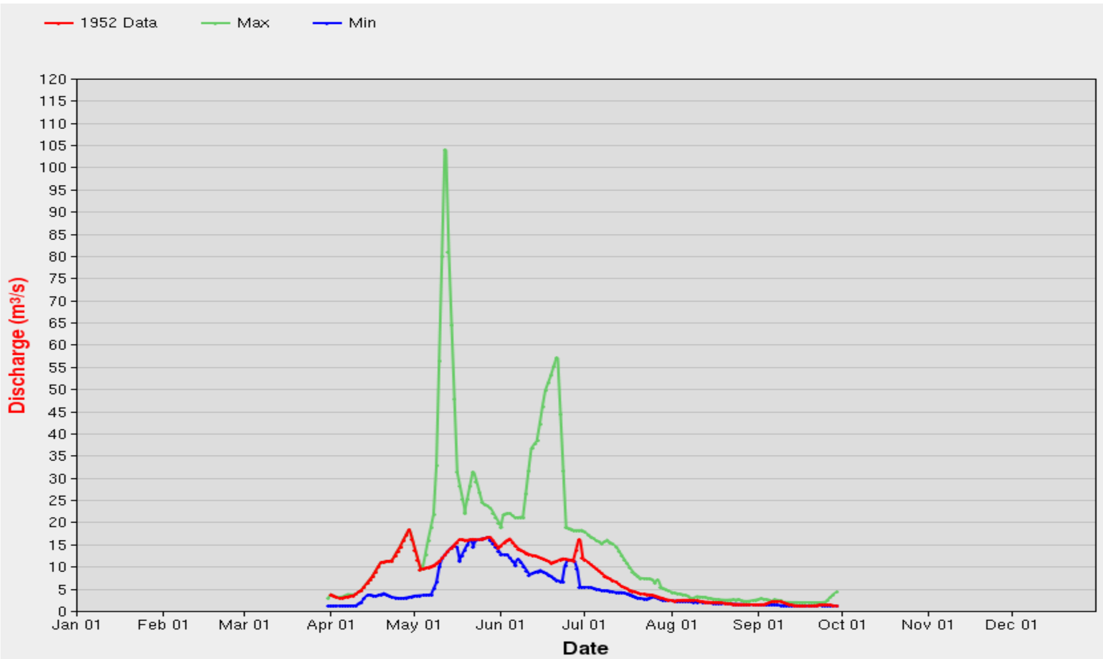


Figure 5. Daily discharge gauging on Crawford Creek between 1947 and 1952

The closest Environment Canada gauging station is St. Mary River below Morris Creek (St # 08NG077). This watershed is 208 km^2 and shares the same headwater area as Crawford Creek (187 Km^2) but flows east towards Kimberley, BC. Gauging at the St. Mary River station has been ongoing since 1973.

A time series graph of the annual extreme floods on the St Mary River since 1973 reveal that over the past 40 years the largest flood event on record up to 2012 actually occurred in 2012 (Figure 6) and had a magnitude of just under 85 cubic meters per second (84.8 m^3/s).

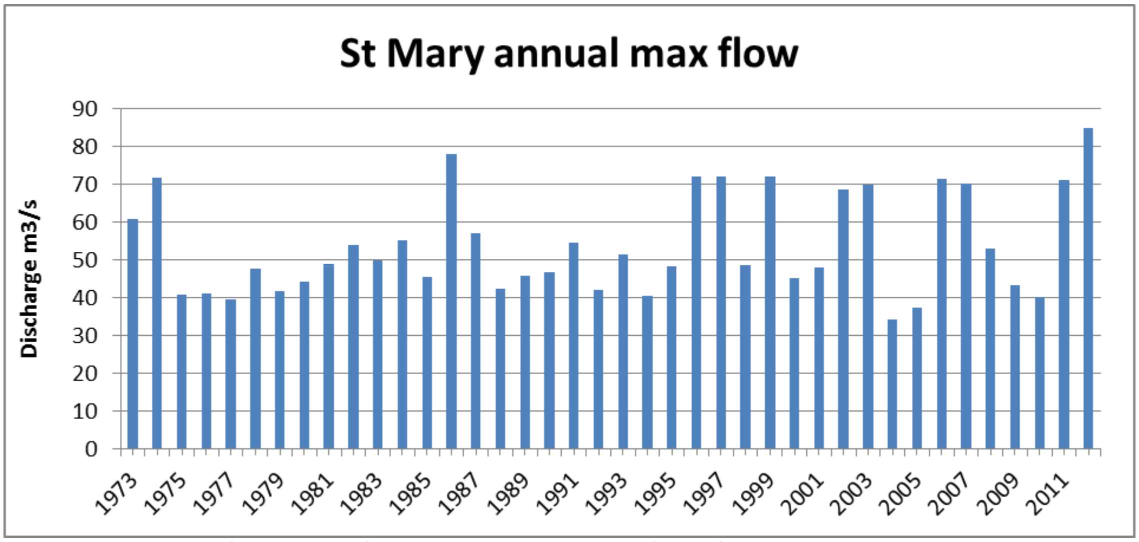


Figure 6. Time series of annual peak flows on St Mary River east of Crawford Creek.

A flood frequency analysis of this time series of annual floods using the Log Pearson III distribution indicates that the return period of the 2012 flood corresponds to roughly the 30 year return period event (1:30 year return period or annual probability of 0.033). However, a simple ranked distribution of the observed floods indicates that the historical return period of this event was roughly 70 years (i.e., 1:70 years, Figure 7).

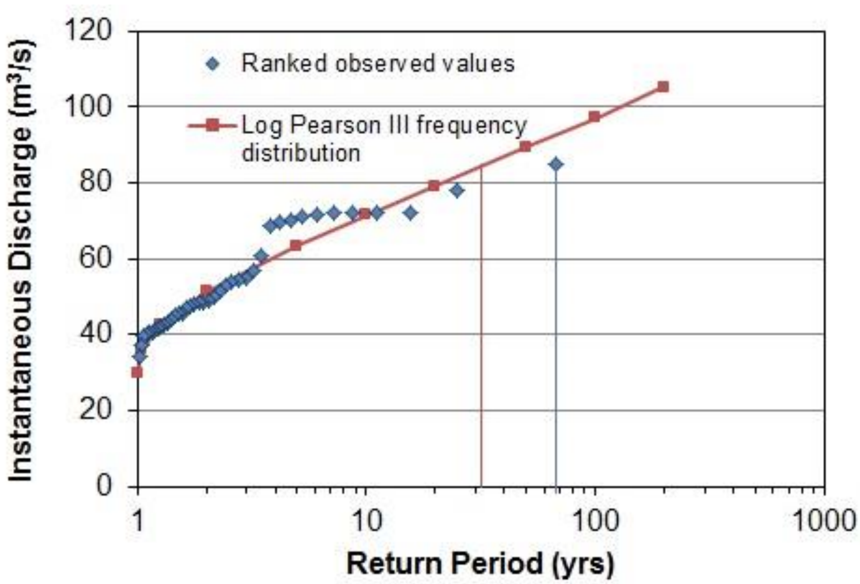


Figure 7. Flood frequency of instantaneous peak flows for St Mary River above Morris Creek. Blue diamonds show the actual ranked time series of annual maximum floods. Red squares are the constructed, predictive flood frequency curve using the Log Pearson III distribution. The two coloured, vertical lines show the difference in the return periods (annual probability of occurrence) of the two curves for a flood with a magnitude of 85m^3/s.

The 1987 flood hazard study by the B.C. Ministry of Environment estimated the 1:20 year and 1:200 year instantaneous flood on Crawford Creek at the Bridge at 93 and 115 m^3/s respectively based on the Manning's method (Nichols, 1987). The Manning's method uses the hydraulic geometry of Crawford

Creek together with a selected roughness coefficient to estimate discharge according to the following equation.

Discharge (m^3/s)=($A*S^{1/2}*R^{2/3}$)/n

Where A is the flow cross-sectional area, S is the channel gradient (m/m), R is the hydraulic radius of the channel (flow cross-sectional area divided by the wetted perimeter) and n is the Manning's roughness coefficient which is determined by the morphology of the channel.

For this analysis hydraulic geometry and gradient information collected during the channel survey is used to estimate bankfull discharge (average annual discharge which correspond approximately to the 2 year return period flood) and the 2012 flood discharge (Tables 3 and 4). The discharge for the 2012 event is estimated using evidence of flood stage (i.e., flow width and depth) from scour and deposition marks along channel banks. To be consistent with the 1987 study the same Manning's n value of 0.047 is used.

Table 3. Channel survey data for Crawford Creek above the Highway Bridge.

	Downstream Distance				Flow				Gradient range at site	
Stn	from canyon (m)	D90avg[1] (cm)	Wb[2] (m)	D_{wb}[3] (m)	x-section (m^2)	W2012[4] (m)	D2012[5] (m)	2012 x-sectn	S %	S%
8	74	79							3	3
7	165	42.25	20.7	0.323	6.68				0.5	1
6	389	51.6	19.9	0.477	9.49				1.7	3
4	796	62.8	14.6	0.572	8.36	41.8	0.635	26.54	1	3.5
2	1220	57.4	18.9	0.426	8.04	47.8	0.42	20.08	0.4	4
1	1651	44.4	19.7	0.333	6.56	31.0	1.01	31.31	0.5	2.5

1. D90 is the mean maximum mobile grain size estimated from measuring the intermediate axis of the 5 largest mobile stones at the survey site.
2. Wb is the bankfull width of the channel
3. Dwb is the average depth of the channel at the bankfull stage
4. W2012 is the width of the 2012 flood as identified by scour along channel banks
5. D2012 is the average depth of the 2012 flood.

Table 4. Manning's based discharge estimates for Crawford Creek using hydraulic geometry data in Table 3.

	Mannings = 0.047	
Stn	Qbf	Q2012
7	8.81	
6	21.66	
4	20.49	66.03
2	21.19	53.44
1	13.68	65.36

The Manning's-based estimate of discharge for the bankfull flood (approx. 2 year flood) ranges from about 9 to 21 m^3/s depending on the survey site (Table 4). If the lowest estimate is ignored as an outlier due to an aggraded channel cross-section that is not representative of the average channel dimensions, the average value for the bankfull flood is 19.3 m^3/s. The hydraulic geometry associated with the 2012 flood indicates that the discharge for this flood was roughly between 52 and 66 m^3/s or roughly three times the bankfull flood magnitude. This estimate is substantially less than the 20 year flood magnitude determined in the MOE study but is only about 20% lower than the observed discharge measured on St Mary River (85m^3/s) for the same flood event. The discharge estimates determined through the use of hydraulic geometry and Manning's n in this study are lower than those estimated previously. This may be the result of a substantial difference between current and previous hydraulic geometry measurements at the site of the original study over the past 40 years. Regardless, the estimates for bankfull and flood discharge made in this study of Crawford Creek should be considered only as rough estimates.

Geomorphic analysis

Channel bed grain size distribution was recorded using the Wolman pebble count method at five of the survey locations along lower Crawford Creek (Figure 8). Survey sites CR-01 and CR-02 display similar bed grain size distributions that are obviously finer in texture than sites CR-04 to CR-07. Figure 8 indicates a D50 (i.e., 50% of grains are finer than this diameter) of approximately 48mm at both CR-01 and CR-02 compared to a D50 diameter of roughly 96mm at sites CR-04 to CR-06. Of the five sites CR-01 displays the highest percentage of sand to fine gravel (i.e. sediment less than or equal to 4mm) on the bed surface.

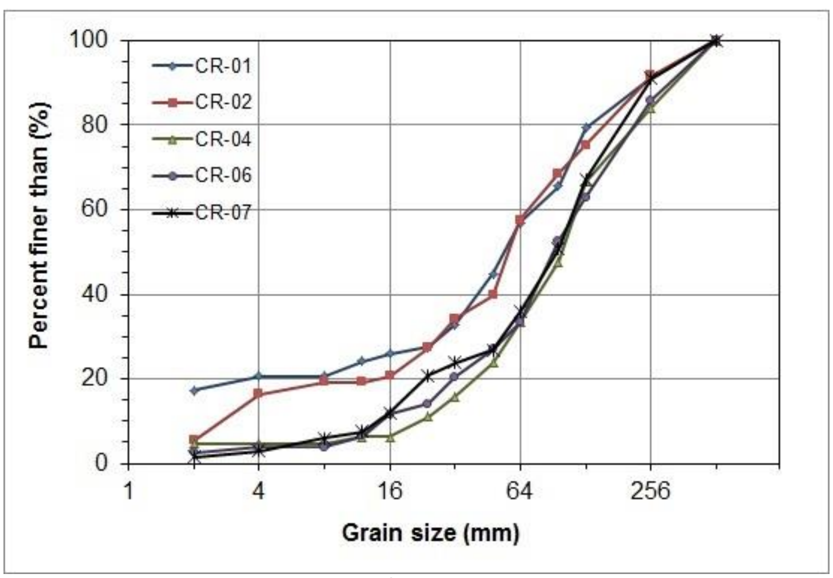


Figure 8. Wolman pebble count bed surface grain size distribution at 5 survey sites along lower Crawford Creek.

Channel bankfull width and depth vary considerably over the five survey sites. Moving downstream from the bedrock canyon exit just above site CR-07 channel width decreases and then increases and bankfull depth displays the reverse trend (Figure 9a,b). When flow cross-sectional area (the derivative of bankfull width and depth) is plotted against distance downstream (Figure 9c) it is apparent that there is an initial increase and then a decrease in the flow capacity of the channel over the surveyed section. Specifically, site CR-07 (the first survey site below the canyon in Figure 9a,b,c) has a relatively smaller flow cross-sectional area than site CR-06. From CR-06 to CR-01 flow cross-sectional area decreases. Figure 9c reveals the degree of channel aggradation immediately below the canyon outlet at site CR-07. Over time, with successive flood events this area becomes aggraded as sediment is deposited in response to the drop in velocity at the outlet of the canyon. The decrease in flow cross-sectional area between site CR-06 and the furthest downstream site (CR-01) possibly reflects the combined effects of channel aggradation (particularly following the 2012/2013 floods) and some degree of surface flow loss to subsurface flow on the permeable fan of Crawford Creek.

The variation of maximum mobile grain size with distance downstream from the canyon (Figure 9d) shows a similar pattern as the flow cross-section area relation (Figure 9c). In this figure the D90 (a.k.a. maximum mobile grain size on the channel bed) is given for 6 survey sites including CR-08 (immediately below the canyon outlet). Figure 9d shows an abrupt decrease in D90 grain size from site CR-08 to CR-07 and then an increasing trend in D90 grain size from site CR-07 to CR-04 followed by a decrease in maximum mobile grain size to site CR-01.

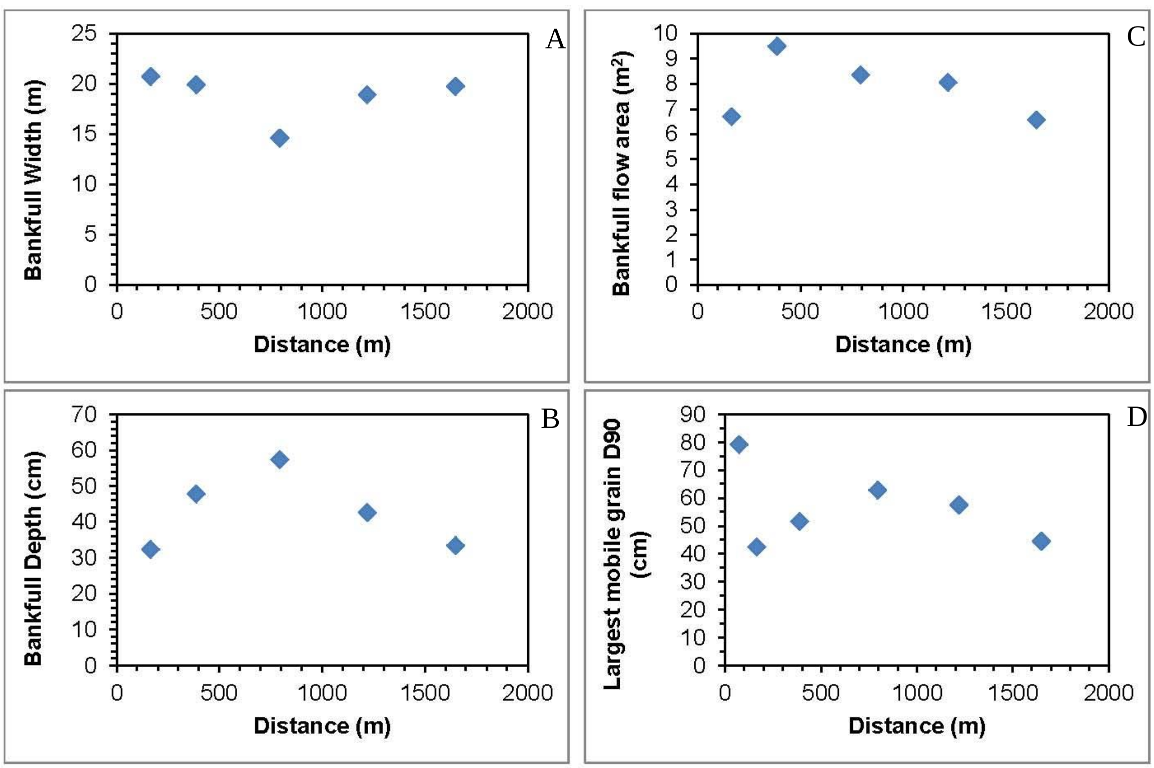


Figure 9. Variation in bankfull geometry and maximum mobile grain size below canyon. Survey sites included in plots are (from furthest upstream) CR-07, CR-06, CR-04, CR-02 and CR-01.

The variation in D90 with downstream distance from the canyon outlet highlights the variation in flow velocity and sediment transport capacity through this section of Crawford Creek. The highest flow velocity at the outlet of the canyon results in transport of the largest grains. At site CR-07 the fining of the bed surface (aggrading channel) indicates a decrease in flow velocity and a decrease in the capacity of the channel to transport larger sediment so the surface texture becomes finer. The increasing surface texture from site CR-06 to CR-04 reflects a progressive increase in flow velocity and transport capacity as channel width (figure 9a) decreases and channel depth increases (figure 9b). Finally the decrease in maximum mobile grain size from site CR-04 to CR-01 reflects the fining of the bed surface and a drop in the transport capacity with a decrease in channel confinement as channel width increases and channel depth decreases.

Observations of channel morphology by survey site

Detailed survey information was collected for sites CR-01, CR-02, CR-04, CR-06 and CR-07. CR-08, which has limited survey data is included but CR-03 and CR-05, which were only photo/comment sites, are not included in this section.

Site CR-01

Site CR-01 includes a 100 meter channel length downstream from the golf course bridge and above the Highway 3A bridge. The channel of Crawford Creek at site CR-01 has a riffle-pool morphology with limited development of pools. Channel gradient ranges from 0.5% through the pools to 2.5% across the riffles. Riffles are comprised of cobbles and small boulders. Recent flooding has resulted in the deposit/scour of a large mid-channel cobble bar. Channel banks are eroded and vertical resulting in an increased susceptibility to erosion during seasonal flooding. Where the mature riparian trees remain along the stream bank, channel banks are less disturbed and in places the banks are overhanging and the roots of the trees have protected the banks from extensive erosion.

Photo 1. Looking upstream in at the riffle-pool channel at site CR-01. Bank on right (looking upstream) is extensively eroded. Lack of coniferous vegetation is the result of clearing for the golf course.

Site CR-02

Site CR-02 is located at the bottom end of the wide, disturbed section of channel below the golf course gravel pit. Above this point the channel consists of multiple branches around bright cobble/boulder deposits. At the survey location the channel is contained in a single thread but the right bank and flood plain (looking downstream) have been eroded and scoured of vegetation. The left bank is also eroded but not as extensively where a few mature riparian trees are preserved. The channel appears to have a high degree of lateral and vertical instability through this section due to the presence of cobble and boulder bars and eroded stream banks.

The channel displays a plane-bed to step-pool morphology although the development of pools is limited. The channel gradient through this section ranges from 0.4% in the pools to 4% in the steeper step sections. Upstream from this site for at least 200 meters there is a complete lack mature riparian vegetation. Accumulations of large woody debris are deposited on the tops of the cobble bars and along the channel margins.

Photo 2. Looking downstream at site CR-02. Channel has a step-pool to plane-bed morphology. Lateral cobble bar on left bank (looking downstream) and scour of the right bank and flood-plain is the result of the 2012 and 2013 floods.

Photo 3. Panorama looking upstream at site 2. Recent flooding has deposited LWD along channel margins and on cobble/boulder bars. Floodplain on left (looking upstream) has been scoured of vegetation.

Site CR-04

Site CR-04 is situated immediately upstream of the end of the constructed berm. At this site the channel has a stepped-morphology with limited pool development and channel gradient ranges from 1% through the pools to 3.5% through the step segments. The channel is confined by or has become eroded into (incised) an existing cobble/boulder deposit that is over a meter in height along the left bank (looking upstream). A recently deposited cobble/boulder levee is present along the right bank (looking upstream).

Photo 4. Looking upstream at site 4. Channel has a step-pool morphology. Cobble/boulder deposits along both banks cause the channel to be narrower and deeper through this section.

An investigation of the forested floodplain on the east side (right side looking upstream) of the channel shows evidence of a large cobble/boulder flood deposit from roughly 50 to 70 years ago that is approximately half a meter above the current (2012/2013) flood stage. The vegetation on this flood deposit consists of juvenile conifers up to about 20 cm diameter at the butt as well as alder and cottonwood. The location of this deposit is identified as CR-05 on Figure 2.

Photo 5. Looking upstream just above Site CR-04. The channel here appears to have eroded down into an older cobble/boulder deposit that is evident in this photo along the left bank (looking upstream).

Site CR-06

This site is located at the bottom end of the old spawning channel. The confluence of the spawning channel is elevated roughly 1.2 meters above the current elevation of the bed of Crawford Creek which indicates that Crawford Creek has become degraded through this section compared to 30 years ago when the spawning channel was constructed.

The channel at site CR-06 has a step-pool morphology with limited occurrence of pools. Channel gradient ranges from about 1.7% to 3% over the surveyed section. Channel banks are eroded and have been scoured of vegetation in the recent floods. The channel is locally confined by bedrock along the right bank (looking upstream).

Riparian vegetation consists of juvenile coniferous and deciduous trees. Cobble bars and portions of the floodplain have recently been scoured of vegetation. There is a large woody debris jam (mega jam) 50 meters downstream from site CR-06

Photo 6. Looking upstream at site 6 at downstream end of spawning channel (red arrow on left). Channel has a step-pool morphology. Channel of Crawford Creek has degraded over a meter since the spawning channel was constructed in the 1980's.

The recent floods have eroded the outer portion of the original berm that protects the spawning channel from overbank floods in Crawford Creek. Flood deposits similar in age to those noted east of site CR-04 are also present along the eastern side of Crawford Creek in this location.

Photo 7. Looking upstream beside upper portion of spawning channel above site CR-06. The recent floods have eroded the bank/berm that separates the spawning channel from overbank floods in Crawford Creek.

Site CR-07

The uppermost detailed survey site is located just upstream from the entrance to the old spawning channel. The channel through this reach has a plane-bed to riffle-pool morphology although development of pools is limited to isolated locations along the bedrock cliffs. The channel is confined on the left bank (looking upstream) by bedrock cliffs. Channel gradient is 3% and the bed material is relatively finer cobbles compared to site CR-06. The right channel bank (looking upstream) is eroded and vertical.

Riparian vegetation consists of juvenile conifers and alder. Approximately 50 to 70 year flood deposits including cobbles, boulders, and woody debris including an old bridge timber are deposited along the eastern side of Crawford Creek. The riparian stand appears to date to this old flood event.

Photo 8. Looking upstream at site CR-07.

Photo 9. Just below site CR-07. Woody debris from recent flood has blocked Inlet of spawning channel.

Site CR-08

Site CR-08 was not a full survey site location. Photographs taken here, looking upstream, show the downstream end of the bedrock canyon. The boulder bar deposited here reveals the high velocity of the flow at this point. Boulders are imbricated indicating that they have been transported and deposited by the flowing water. Photo 10 also shows the scour along both sides of the channel associated with the recent large flood events.

Photo 10. Looking upstream into the canyon beyond site 8

Photo 11. Imbricated boulder bar at Site 8. These boulders are transported through the canyon during flood events and deposited at the canyon outlet in response to the drop in velocity where the channel is unconfined.

Discussion and Summary

Based on the overview assessment, the lower reaches of Crawford Creek are suitable for restoration and spawning enhancement activities and it is recommended that application be made for additional funds to support a restoration program.

Crawford Creek, between Highway 3A bridge and the canyon above the old spawning channel has a step-pool to riffle-pool morphology however pool development is very limited. Channel gradient varies from 0.4 to 4%. The channel bed texture is very coarse grained. The D50 (median grain size) ranges from roughly 48 mm (coarse gravel) in the reach above the Highway 3A bridge to 96 mm (small cobbles) in the reach above the golf course gravel pit. There is a complete lack of LWD in the active channel. LWD has been deposited along channel banks or on the top of lateral and medial channel bars.

The channel pattern includes both single thread and multi-thread segments. Channel banks are, for the most part, eroded and vertical with exposed cobbles and gravel and little vegetation. In a few locations the channel banks are overhanging and vegetated with mature riparian species including Douglas fir, cedar, alder and cottonwood. Where these mature riparian stands occur the channel banks display less erosion.

The channel of Crawford Creek below the canyon has experienced several large channel forming flood events over the past century. The greatest flood disturbance appears to be the result of a late 1950’s flood. The extent of the disturbance associate with this flood is evident on the 1958 air photograph. Physical evidence of the impacts of this flood is still apparent on floodplain areas along the east side of Crawford

Creek below the canyon. The 1950 flood appears to have been at least half a meter higher than the 2012/2013 floods and resulted in extensive damage to riparian stands. The recent 2012 and 2013 floods have caused extensive scour of the floodplain, erosion of channel banks, local channel avulsion, as well as channel bed aggradation.

Crawford Creek below the canyon displays lateral and vertical instability. Lateral instability is primarily due to the lack of mature riparian vegetation along channel banks which has resulted in erosion of channel banks and shifting (avulsion) of the channel on the floodplain. The vertical instability of the channel is, in part the result of a substantial influx of bedload sediment from the eroded banks that has caused the channel to become aggraded in several locations.

Opportunities for channel restoration and habitat enhancement

The extensive bank erosion and lack of pool development in Crawford Creek is due to the very limited occurrence of mature riparian vegetation along the channel banks and floodplain areas. In undisturbed streams, large woody debris recruited to the stream channel from the channel banks during flood events creates local areas for fine sediment deposition on the upstream side and pool scour below the woody debris. Riparian vegetation also protects the floodplain from erosion and limits the lateral migration of the stream channel during overbank flooding.

Stabilizing and revegetation stream banks and creating overhanging stream banks through the use of stream restoration and bioremediation techniques would improve both flood protection and salmonid habitat in the area upstream from the Highway 3A bridge. Stabilizing the stream banks will also reduce the rate of channel avulsion and aggradation/degradation of the channel bed. The highest priority area for channel bank restoration is the area adjacent to and downstream from the golf course gravel pit as this portion of the channel appears to have the greatest amount of instability and on-going erosion of channel banks and bar deposits.

Introduction of appropriately sized LWD structures to the stream channel will increase stability of the channel bed and, as well, increase the occurrence of pools that provide valuable habitat for salmonids. Staking cobble bars with cottonwood plugs and planting of cottonwood saplings may speed-up stabilization of scoured cobble bars.

The old spawning channel west of Sites 7 and 6 has become de-coupled from the channel of Crawford Creek as a result of degradation of the Crawford stream bed. In addition the 2012/2013 floods have eroded the berm separating the spawning channel from Crawford Creek. Restoring this spawning channel for immediate use will require excavation and re-grading of the outlet of the spawning channel to bring it down to the current elevation of Crawford Creek. The central portion of the spawning channel where the berm has been completely eroded will need to be reconstructed and the berm re-established. The current elevation of the berm and the material comprising the berm is insufficient to withstand overbank flooding on Crawford Creek. The inlet will also need to be designed to accommodate substantial changes in the elevation of the channel bed of Crawford Creek which occur relatively rapidly in this section of the channel.

A preliminary cost estimate for five sites considered highest priority for stabilization and habitat restoration is presented in Appendix 1.

Respectfully Submitted,

Kim Green, P.Geo. PhD.
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Apex Geoscience Consultants Ltd.
Nelson, B.C.,
V1L, 3K8

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Appendix 1

Priority Restoration Areas and Suggested Remediation for Kokanee Habitat Enhancement and Channel Stabilization on Crawford Creek

Prepared for: Eastshore Freshwater Habitat Society

Prepared by:

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October 22, 2015

Introduction

Following a reconnaissance level hydrogeomorphic field investigation by Kim Green, (P.Geo., PhD) and strategic planning sessions and field trips with governing members of the Eastshore Freshwater Habitat Society (Tom Lang, Mike Jeffries, Garth Norris and Brian Zytaruk) five restoration sites have been identified along the portion of Crawford Creek between the highway bridge and the spawning channel. These five sites have been identified as the highest priority sites for restoration activities to address the dual objectives of improving Kokanee habitat and channel stability.

Recommended restoration approaches for the five sites were determined with the expertise of Pierre Raymond, Bioengineering Specialist with Terra Erosion Control. The information provided in this report is intended to provide a very general estimate of the cost of developing and implementing the prescriptions for restoration activities for the purpose of grant application. In all cases the actual cost of prescription development and implementation is likely to differ from the estimated cost to some degree depending on the requirements of the site.

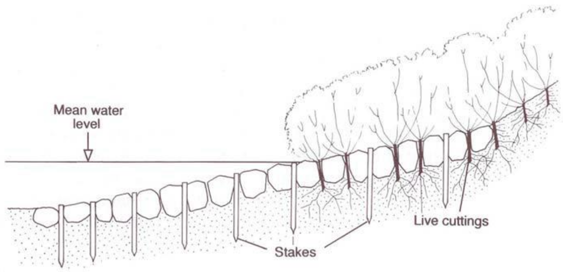
Area 1 – Spawning channel bank stabilization and armoring

Photo 12. Looking upstream at eroding bank that separates the spawning channel from Crawford Creek

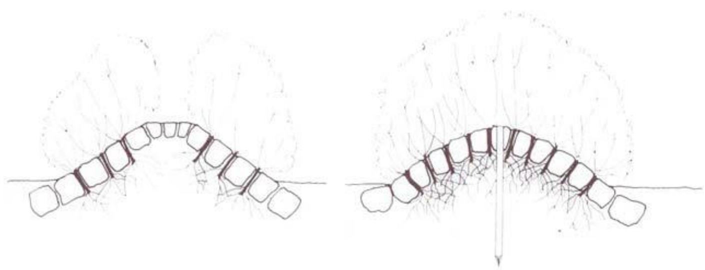
Photo 13. Looking down at approximately 100 meters of raveling bank on channel side of spawning channel.

Suggested remediation

Some of the areas visited during Oct 13 were vegetated directly above short eroded bank, in these locations and were bank is higher, but has conifer canopy directly above it, class I riprap can be placed by keying the toe and placing riprap within the eroded gaps and onto the bank (basically riprap protection with short vegetated spur (vane or groynes) oriented at a determined angle.

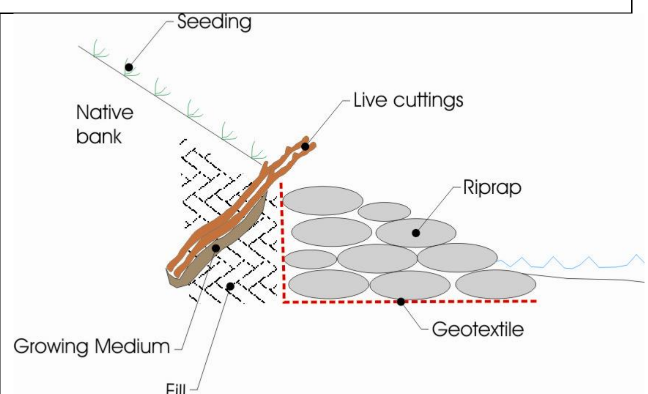


Vegetated Vane Profile [1]



Vegetated Vane Section[2]

Alternative construction of vegetated spur[3]



Vegetate riprap cross section

[1],[2] H.M Schiechtl and R. Stern. Water Bioengineering Techniques for Watercourse Bank and Shoreline Protection (Cambridge: Wiley-Blackwell, 1997), 96.

[3] Photo, Dr. Hans Peter Rauch, Universität für Bodenkultur

In areas with higher bank with no coniferous canopy directly above a vegetated rip-rap application (see drawing above and example in area 2) could be installed using a keyed in toe apron with first rows of vegetated cuttings (willow species and balsam poplar) located at similar elevation has existing vegetation within the channel were no erosion has occurred (across the stream?) these approaches would increase resistance to erosion during flood flows.

Approximate funding required

Prescription and specifications development, drawings for permitting and implementation assuming use of 154 tone of class I riprap at $10,000 from local source.

Implementation: **$80,000.00**

Monitoring and maintenance: $2000/year until vegetation has established

Area 2 – Flood protection berm

Photo 14. Looking downstream at portion of constructed berm that is contributing sediment and creating scour along opposite bank

Photo 15. Looking down at approximately 100 meters of berm that is contributing sediment and creating scour along opposite bank. Blue arrow shows location of flow being directed by the berm and the area on the opposite bank that is being eroded.

Suggested Remediation

Re-position lower 20 meters of berm and re-establish second channel to reduce flow concentration in confined channel segment.

Note: re-align berm should connect with existing bank that is evident in this photo by a line of large woody debris

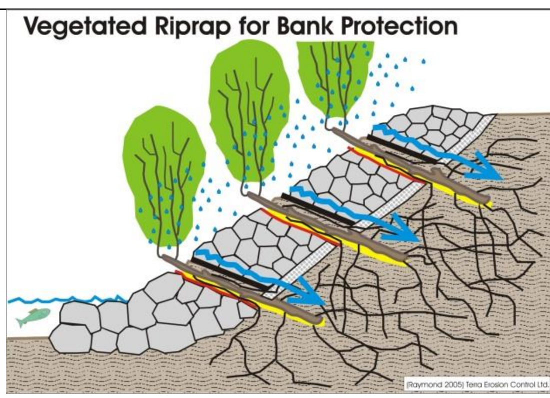
	
Toe of rock with row of live cuttings inserted above	Excavator bucket insertion planting technique (for existing berm)

Figure 10. Some suggested restoration methods.

Create vegetated, armored bank along berm to increase flood resistance and reduce ongoing erosion of cobble – gravel berm. Use toe of riprap along existing berm and insert live cutting of willow and balsam poplar species using the insertion planting method (see photo and drawing). Armour and vegetated entire berm and include vegetated riprap application and vegetated spurs (see photos Area 1) along bank downstream up to forested. Broadcast seed entire cobble / gravel berm and plant native riparian potted shrubs and trees on upper portion and top or berm and bank above vegetated riprap.

Additional bank armoring using vegetated spurs on the lower portion of the bank in the area of the green house on the photos is also recommended to provide additional bank protection and spawning habitat. The total length of bank/berm for remediation is estimate to be approximately 200 m.

Approximate funding required

Prescription and specifications development, drawings for permitting and implementation assuming use of 307 tones class I riprap: **$180,000**

Monitoring and maintenance: $5000/year until vegetation becomes established (approx. 10 years)

Area 3 – Eroding bank below gravel pit

Photo 16. Looking upstream at bank on right where flow from bermed area is eroding bank

Photo 17. Area of eroding bank from above.

Suggested remediation

Reconstruct overhanging vegetated, armored bank along a 77 meter section. This would provide kokanee habitat and protect existing mature riparian vegetation from ongoing erosion. Build vegetated crib wall with fish shelter habitat at interval of approximately 20 m (i.e. 20 m of vegetated crib wall and 20 m of fish shelter structure).

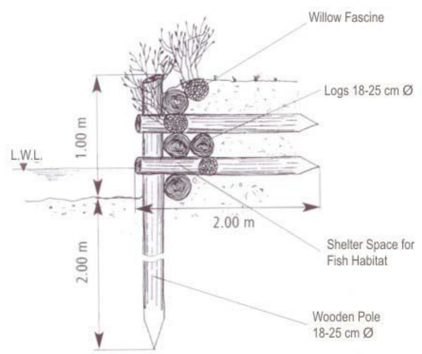
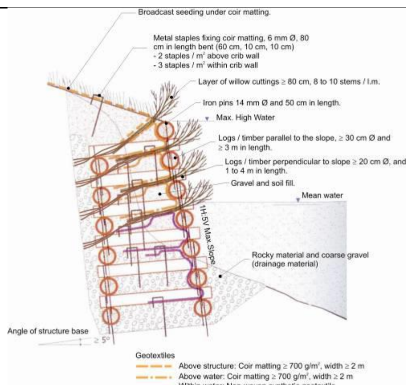
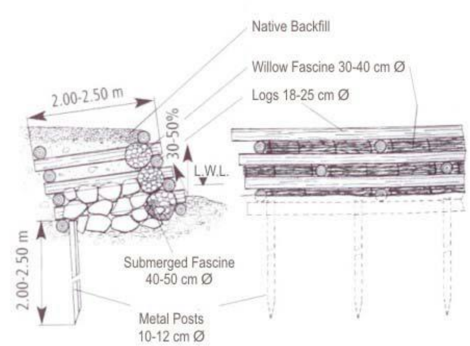
	
Shoreline Shelter Platform for Fish Habitat[4]	**Shoreline Shelter Platform for Fish Habitat**
	
Vegetated Crib Wall4[5]	Vegetated crib wall construction using fascines bundles placed on the face of the structures.[6]

Figure 11. Suggested remediation methods for Area 3.

Approximate funding required

Prescription and specifications development, drawings for permitting and implementation assuming use of 77 tone of class I riprap: **$100,000**

Monitoring and maintenance: $3000/year until vegetation become established (appx. 5 years)

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[4] Adapted from: Florin Florineth, Piante Al Posto Del Cemento Manuale di Ingegneria Naturalistica e Verde Tecnico, (Milano, Italy: Il Verde Editoriale S.r.l., 2007)
[5] Adam, 128.
[6] Photos, Dr. Hans Peter Rauch Universität für Bodenkultur

Area 4 Fairway bank – East

Photo 18. Erosion along fairway channel bank - east side

Suggested remediation

Create two or three zones of overhanging, armored banks vegetated with low-growing willow. This would provide habitat for kokanee and reduce the rate of bank erosion. As in Area 3, build vegetated crib wall with fish shelter habitat at interval of approximately 20 m (i.e. 20 m of vegetated crib wall and 20 m of fish shelter structure) and broadcast seed and plant low growing native riparian potted shrubs above of the constructed structures. Estimated length 160 m (including both sides).

Approximate funding required

$170,000

Monitoring and maintenance: $5000/year until vegetation become established (appx. 5 years)

Area 5 – Fairway bank - Northwest

Photo 19. Looking down at eroded channel bank at upstream end of fairway on west side of channel.

Suggested remediation

Create vegetated, armored bank along bank to increase flood resistance and reduce ongoing erosion of channel bank. Use vegetated riprap application and vegetated spurs along bank at upstream end of fairway. Broadcast seed and plant native riparian potted shrubs and trees along bank above the vegetated riprap structure. Estimated total length of 40m.

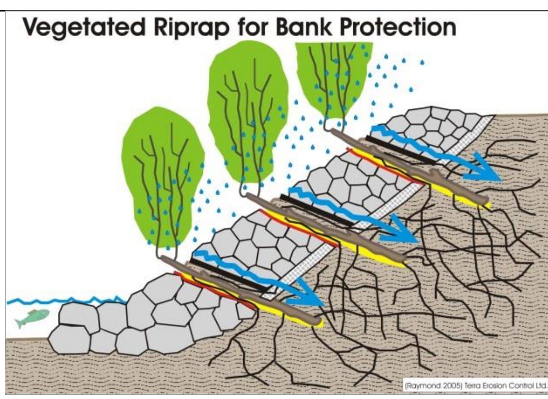	
Vegetated riprap application	Vegetated riprap application, Columbia River Trail BC after 8 years

Figure 12. Suggested remediation for northwest end of fairway.

Approximate funding required:

$50,000.00 Monitoring and maintenance: $2000/year until vegetation established (appx. 5 years)