STREAMFLOW AND FLUVIAL GEOMORPHOLOGY OF THE LOWER GOLDSTREAM RIVER

- SUPPLEMENTARY ANALYSIS AND REVIEW

prepared for BC Parks

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STREAMFLOW AND FLUVIAL GEOMORPHOLOGY OF THE LOWER GOLDSTREAM RIVER

Introduction

In October 2007 BC Parks completed a Level 1 Impact Assessment Report concerning previous year flood damage to streamside trails in the lower reach of the Goldstream River (Neufeld & Associates). This assessment highlighted the need for hydrologic and geomorphological assessment to guide future remediation and trail work resulting in this preliminary review.

The field assessment by Neufeld and Associates identified the following kinds of problems:

- flooding and loss of trail surface
- stream bank instability
- trail encroachment within the active stream channel
- trail drainage and cross trail erosion
- inadequate rip rap design and impacts on stream channel widening and migration
- log jam impacts
- pedestrian bridge location and abutment scour
- loss of riparian function (foot traffic and vegetation clearing)

The purpose of this report is to bring together what is known about the hydrology and stream morphology into a brief summary. Extensive stream attribute data was collected in stream surveys by LGL Ltd. in 1998 and 1999 as a basis for identifying fish habitat restoration opportunities and to develop prescriptions. While most of the field data information is now 10 years old, it provides a starting point for interpreting more recent changes in the watershed. Much of the data remains relevant and can be leveraged for use in current planning.

This report provides additional interpretation and analysis of selected stream attribute data in these reports together with analysis of available hydrometric records. This information was supplemented by field observations in February 2008. However, no new survey data has been collected. Additional field surveys are required to account for changes that have occurred and to meet design needs. The original documents listed below should be read for a complete background. Other sources are listed in the references section.

Bocking, R., M. Gaboury, R. Frith, and J. Ferguson. 1998. *Goldstream River Overview and Level 1 Fish Habitat Assessment and Rehabilitation Opportunities (including Riparian)* prep. by LGL Ltd. and submitted to Min. of Env., Lands & Parks by Te' mexw Treaty Association.

Bocking, R., M. Gaboury, R. Frith, and J. Ferguson. 1999. *Goldstream Watershed Restoration Program Fish Habitat Prescriptions prep.by LGL Limited and* submitted to Min. of Env., Lands & Parks by Te' mexw Treaty Association.

Murdoch, Scott. 1999. *Goldstream River Trail Rehabilitation: Implementation Options.* Prep. for BC Parks.

Wangsness, S.E. and E.A. Harding. 1999. *The Goldstream/Langford Creek Watershed Assessment.* prep. for The Capital Regional District. by Ship Environmental Consultants Ltd.

Watershed Description

The Goldstream Watershed is approximately 15 km NW of Victoria. The headwaters of the Goldstream River begin at a peak elevation of 630m in topography that is predominantly rolling plateau. The Goldstream River has 4 major sub-basin headwaters including the main stem of the Goldstream R., Waugh Creek, Langford Creek, and Niagara Creek.

The Goldstream Watershed upstream of the estuary including Niagara Creek encompasses an area of 58.3 km^2 as shown in Table 1.

The headwaters of Waugh Creek encompass Jack and Mavis Lake that were formerly raised reservoirs. The Goldstream River headwaters include the Buchart, Lubbe, and Goldstream Reservoirs. It also takes in Japan Gulch that is a small balancing reservoir for water received from the Sooke Lake Reservoir. Below approximately 400m, the topography drops off more steeply into a steep glacially carved valley before emptying out into Finlayson Arm, which is a fjord.

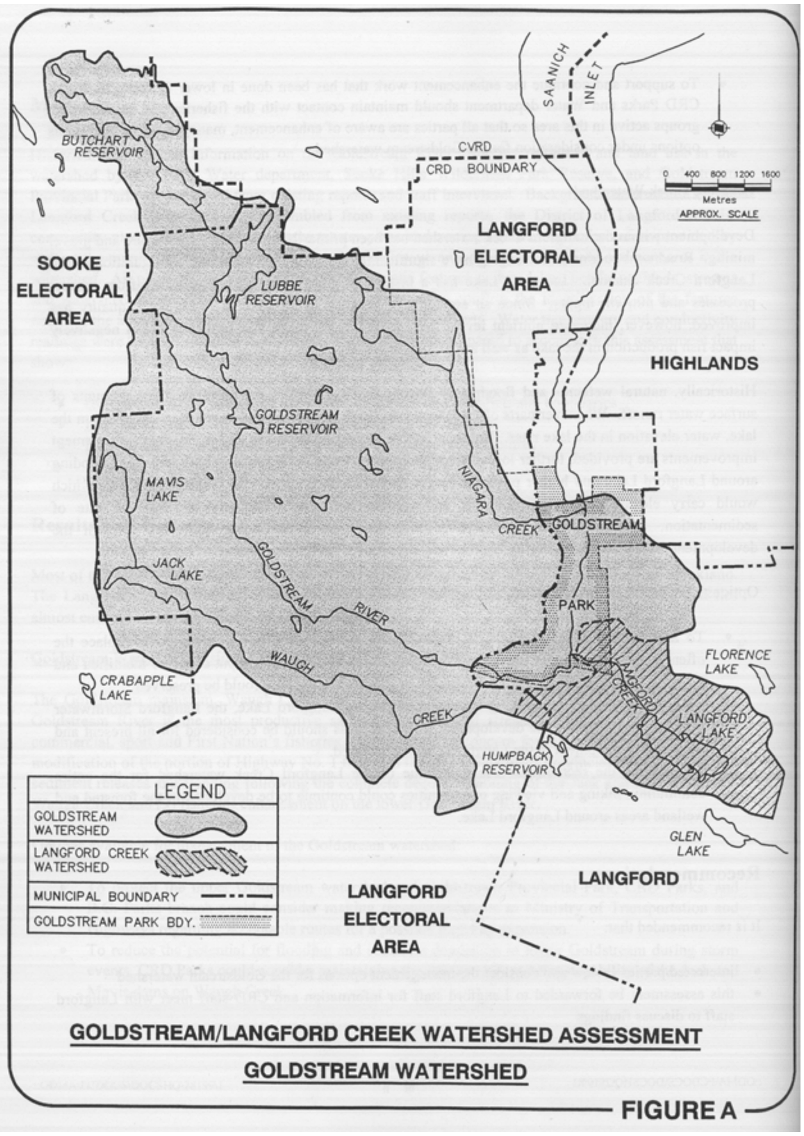
The lower valley broadens out into a wide floodplain within Goldstream Park. It is comprised of glacial-fluvial outwash sediments combined with newer sediment from erosion along steep valley sections upstream and re-working of the floodplain, which begins about 200m upstream of the Finlayson Road bridge.

Restoration of flows to near natural rates in Waugh Creek with draw down of Jack and Mavis reservoirs has reduced the total watershed area with regulated flows by 11.6 km^2. Currently the proportion of regulated watershed area above Niagara Creek in Goldstream Park is 46% as compared to 56.7% during the period of flow records.

The following information on flow regulation is taken from the Goldstream/Langford Creek Watershed Assessment by Wangness (1999) and from discussion with Sigi Gudavicius, Design Engineer for the CRD Water Department. Historically the watershed was the primary water supply to the city of Victoria through reservoir storage at Mavis and Jack reservoirs on Waugh Creek. Water was released into Humpback Lake balancing reservoir on Colwood Creek. This has since been replaced by water storage in Sooke Lake, which is piped through the Kapoor Tunnel to a treatment facility near Japan Gulch reservoir.

Figure 1 Goldstream River Watershed

(Map Source: *The Goldstream/ Langford Watershed Assessment*, SHIP Environmental Consultants ,1999)



The upper mainstem reservoirs at Lubbe and Butchart L. provide emergency backup flows. Diversion of flows can be made from Jack Lake into Cabin Pond and from Cabin Pond to Japan Gulch Reservoir

Table 1 Goldstream River Sub-basin Area Summary

Sub-basin		Area (km2)	Pre-draw down of Jack and Mavis Reservoirs	Post draw down of Jack and Mavis Reservoirs	% of watershed above Niagara Ck	Cumulative %	Cumulative Area
Above Goldstream Lake Dam		11.4	R	R	24.0%	24.0%	11.4
Japan Gulch to Goldstream Lake		10.4	R	R	21.9%	46.0%	21.8
Waugh Creek above Jack Reservoir		5.1	R	U	10.8%	56.7%	26.9
Waugh Creek below Jack Reservoir		6.0	U	U	12.7%	69.4%	32.9
WSC 08HA039 to Japan Gulch		3.7	U	U	7.9%	77.2%	36.6
Langford Creek		6.6	U	U	13.9%	91.1%	43.2
Finlayson Rd to WSC 08HA039		3.4	U	U	7.2%	98.3%	46.6
Finlayson Rd to Niagara Ck		0.8	U	U	1.7%	100.0%	47.4
	subtotal	47.4			100.0%		
	% Regulated		69.4%	46.0%			
	Unregulated		30.6%	54.0%			
Niagara Ck		10.9	U	U			
	Total	58.3					

R – Regulated
U – Unregulated

The Mavis and Jack dams on Waugh Creek have been drawn down in preparation for decommissioning. Although Humpback L. Reservoir is outside the Goldstream R. watershed, an overflow pipe has been added to divert overflow storm water into the Goldstream River. The capacity of culverts to handle storm flow on lower Langford Creek at 2 sites within the Provincial Park has been identified as a concern (Wangsness,1999, p. 26).

Japan Gulch is a balancing reservoir and has very little excess storage capacity during winter storm events and receives most of its storage volume from Sooke Lake diversion through the Kapoor tunnel. Most winter storm runoff from its “natural” catchment area of 10.4 km^2 excluding the upstream reservoirs may be expected to pass through. This area is included in the regulated watershed area nonetheless because releases may be controlled at different times.

Reservoir storage in the upper Goldstream River dams may completely store or regulate outflows from extreme event inflows from the reservoir catchments. Waugh Creek is expected to contribute at natural rates of peak flow.

Stream Flow

Flows are augmented by reservoir releases to maintain at least a minimum low flow of 0.2m^3/sec throughout the year to the lower Goldstream River, and 0.6m^3/sec during November for salmon spawning. The Goldstream Hatchery located downstream of Japan Gulch can request more if needed.

Approximately 250m above the confluence of Langford Creek and the Goldstream River, Water Survey of Canada operated hydrometric station 08HA039 from 1976 to 1978. The Ministry of Environment subsequently operated the station up to 1986.

Mean annual discharge for the 36.6 km^2 watershed above Station 08HA039 for the 1977-86 period was 0.9 m^3/sec. Ron Ptolemy of the Ministry of Environment previously developed an annual unit runoff estimate of 40L/sec per square kilometre ‘natural” flow based on mean annual precipitation of 1261mm. This would be the unit runoff if there was no consumptive diversion of flow or other basin losses. Assuming the difference in annual runoff is attributable to evaporation and consumptive use, the loss of flow is estimated to have been 22 L/sec/ km^2 of the regulated watershed area during the period from 1977-86. Assuming no regulation annual runoff would potentially have been 1.5 m^3/sec. The regulated area accounted for 74% of the watershed area above the WSC station and 57% of the total watershed area above Niagara Creek. Applying the unit area runoff estimates for regulated and unregulated flow to the watershed area above Niagara Creek yields a mean annual discharge equal to1.4 m^3/sec for the period 1977-86.

Previous estimates on record were made prior to draw down of the Mavis and Jack reservoirs and were based therefore on a higher percentage of regulated watershed area. The revised estimate of the draw down of the Jack and Mavis reservoirs should have restored approximately 5.1 km^2 to “natural” flows. This approach assumes all regulated watershed area contributes at the same rate per square kilometre annually which is admittedly an over simplification since regulation of flows is reservoir specific.

Maximum instantaneous flow ratios to maximum daily discharge for watersheds on the east coast range between 1.3 to 1.6 times the maximum daily stream discharge (Chapman, 1999). The ratio of 1.4 based on the 10 years of record for Goldstream is in the lower half of this range.

Figure 2 shows estimated conservation flows for fisheries for Goldstream River above Langford Creek from previous estimates (Source: Ron Ptolemy, Min. of Environment).

Figure 2 Monthly and Mean Annual Flows

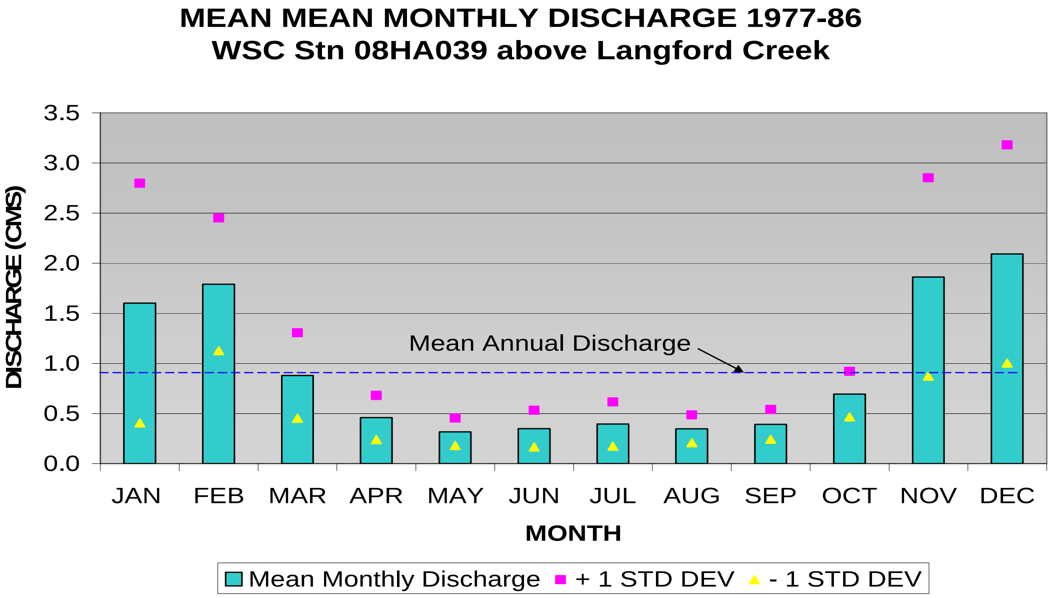
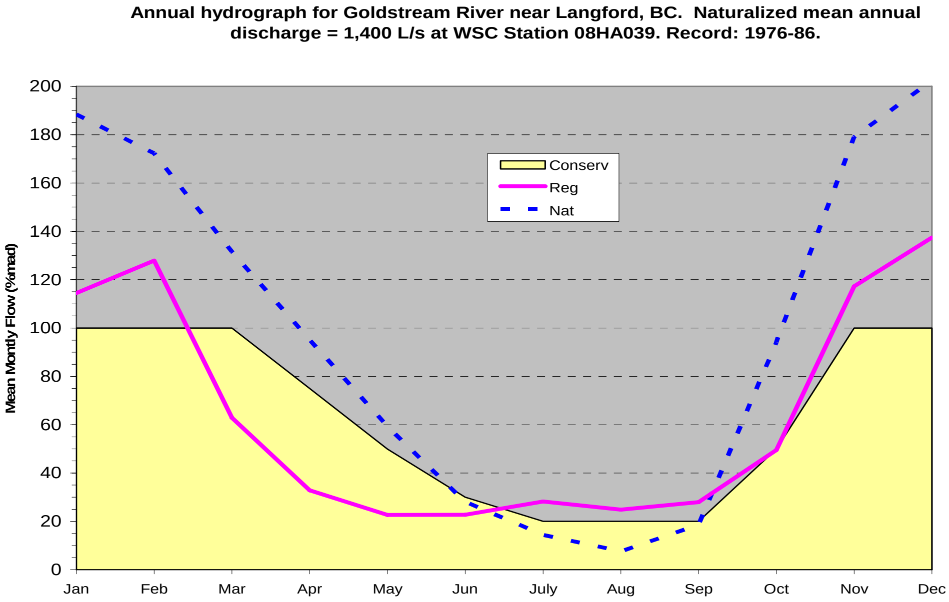


Figure 3 Comparison of Regulated and Non-Regulated Streamflow



Source: Ron Ptolemy, Min. of Environment.

Figure 4 Yearly Annual Maximum Instantaneous Flows at WSC 0HA013

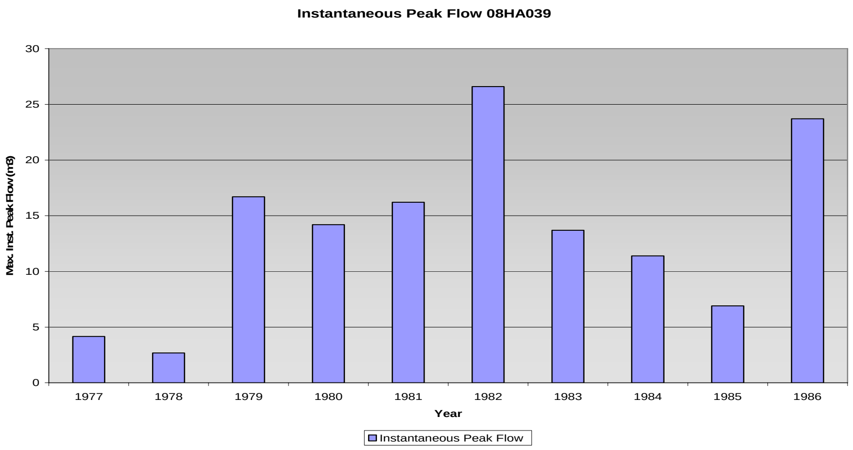


Table 2 Maximum Instantaneous Discharge above Langford Creek

	Date of Max Daily Discharge	Max Qd	Max Qi	Ratio of Qi/Qd	Qi at Goldstream Park based on Qi/Qd ratios for WSC 08HA039	Qd on same day as Qi
1977	09-Mar	3.7	4.2	1.3	5.4	3.7
1978	08-Jan	2.6	2.7	1.2	3.5	2.6
1979	14-Dec	16.7	21.1	1.3	26.0	16.7
1980	20-Nov	12.5	14.2	1.1	17.5	5.4
1981	16-Feb	14.0	16.2	1.2	20.0	14.0
1982	23-Jan	13.0	26.6	2.0	32.8	9.8
1983	08-Jan	13.7	18.3	1.3	22.6	13.7
1984	03-Nov	11.4	14.2	1.2	17.5	11.4
1985	01-Nov	4.2	6.9	1.6	8.5	4.2
1986	24-Feb	22.4	23.7	1.1	29.3	22.4
Mean		11.4	14.8	1.3	18.3	10.4

All maximum instantaneous flows were recorded on the same day as the maximum daily flow with the exception of flows for 1982. Because of missing data for November and December in 1979 and 1986 the maximum recorded values for these years may not be the true maximum instantaneous discharge.

The watershed area above Niagara Creek is 47.4 km^2 compared to the 36.6 km^2 above 08HA039 resulting in a scale factor of 1.3 yielding an estimated 1 in 2 year return period flow of 17 m^3/sec. The standard deviation on either side of this estimate is 8 cms.
Ten years of record is a short period of station flow records from which to estimate a statistical frequency. This results in high uncertainty in projecting return period flows as shown in Figure 5.

The 1.4 year return period flows are considered the channel forming flow that occurs with sufficient frequency that it will tend to control the stream morphology in the absence of disturbance. The 1 in 2 year return period flow is the discharge with 50 percent probability and is generally used as the starting point for frequency analysis. Bankfull flow is expected to lie between the 1.4 and 2 year return period flows.

Table 3 Expected Frequency of Peak Flows

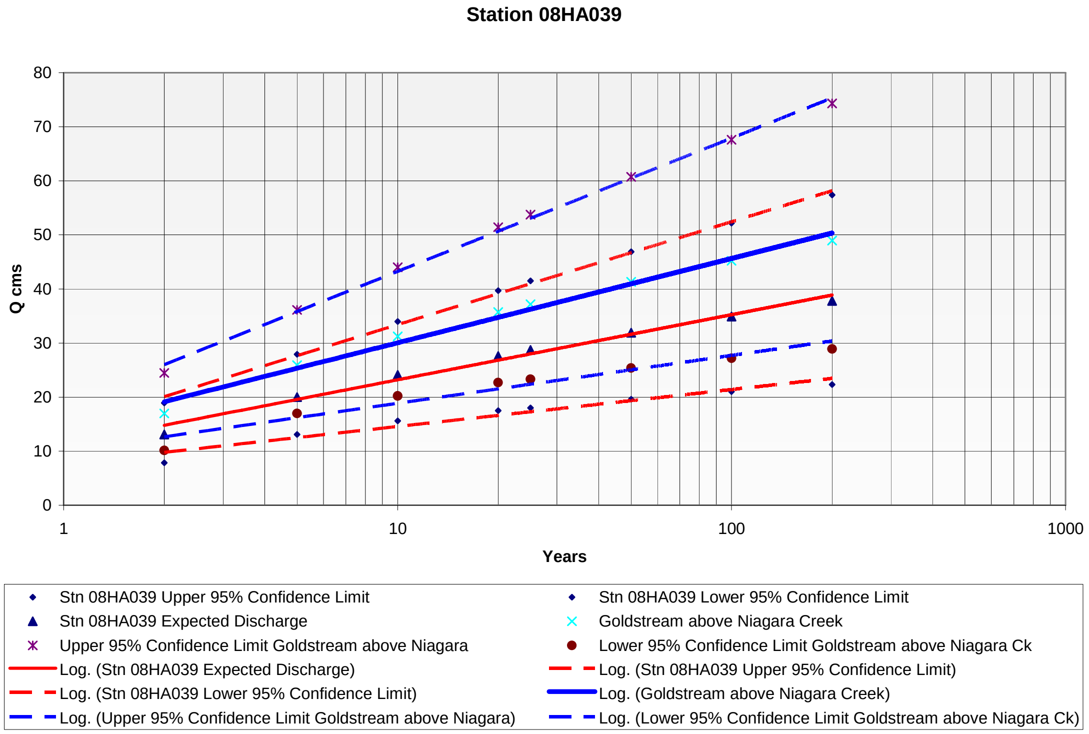
Return Period Years	Expected Discharge above Niagara Creek (m^3/sec)
1.4	12
2	17
5	26
10	31
20	36
25	37
50	41
100	45
200	49

Records are also available for the Goldstream River below Fish Weir (Sta. No. 1AHA045). The site was established in 1998 and was used as a demonstration site. There were reported problems with the A71 recorder. This data is stored on the MOE Water Information Data Management system (WIDMS) for 1999-2001. It has not been used because of these problems.

Recorded instantaneous discharge values may be expected to be less than what would be expected for non-regulated watersheds. However, Tolland (1998) concluded that there was no distinct pattern for the gauges on streams with regulated and unregulated flow regimes for Vancouver Island providing some confidence that regionalized estimates can be used that include all watersheds.

Figure 5 Peak Flow Frequency

Return Period Instantaneous Peak Flow Estimates for Station 08HA039 and Goldstream River above Niagara Creek



The re-naturalization of flow resulting from draw down of Mavis and Jack reservoir may be expected to increase peak flows generally compared to instantaneous peak flows recorded over the 1977-1986 period.

Precipitation does not provide a reliable basis for estimating short duration peak flow runoff because of routing and storage effects in the watershed. Most of the precipitation stations that Environment Canada maintains are at low elevation – the closest being Victoria International Airport near sea level. The CRD maintains a weather station at Sooke Dam at 183m. Return period rainfall intensities computed for Sooke Dam from 1996 to 2006 indicate a 1 in 2 year 24-hour precipitation of 4.5mm/hr. The 1965-1998 IDF for Victoria International Airport for the period only overlaps the Sooke Dam records for the 1996-1998 period. Over the 1965-1998 period the mean 24 hr hourly rate of precipitation was 2.2mm/hr at Victoria International Airport. The Sooke rainfall intensities are expected to be more representative given the higher elevation. Up to 65% of the total watershed is above 300 mm and is within the transient snowpack zone that is subject to rain-on-snow events. The additional rain-on-snow effect is non-quantifiable but is expected to be significant.

The November 16, 2006 storm event that resulted in significant windthrow and stream stability problems across Vancouver Island was characterized by extreme heavy rainfall over a 12-15 hour period beginning just before midnight on November 14th. The heaviest rainfalls were experienced in Cowichan Lake area, the west coast and Gold River area. Several stations recorded rainfall intensities exceeding 1 in 50 year return periods. By contrast Victoria Airport recorded 14mm over a 24-hour period. This equates to 0.58 mm/hr and is below the 1 in 2 year return period storm intensity for Victoria International Airport. Higher short duration intensities may have occurred but are not on record. Recorded peak flows for Water Survey of Canada stations on southeast Vancouver Island ranged between 3 and 9 year return period events. A high disparity in peak flow return periods for different stations indicates that high intensity storm cells are localized. Therefore it is not possible to determine what the peak flow runoff was at Goldstream Park from available data.

Section 4.1 of the Goldstream Watershed Restoration Program Fish Habitat Prescriptions report by LGL Ltd. makes use of a generalized equation described in Watershed Restoration Technical Circular 9 developed by Kellerhalls and Church (1989):

$W_{bf}=4.5(Q_{bf})^{0.5}$

Average bankfull discharge was estimated by assuming an average bankfull width of 16m derived from regional estimates of the bankfull width to watershed area as presented in Section 12-4 of WRP Tech Circular 9. Solving for Q_{bf} the corresponding bankfull discharge is 12.6 m^3/sec, which is very close to the estimate of the 1.4 return period flood. The watershed area used was 45.3 km^2 for the total drainage area above Finlayson Arm Rd. bridge. Flood frequency analysis of the Maximum instantaneous discharge for the 1977-86 period yielded an adjusted bankfull discharge of 14.2 cms at Finlayson Arm Rd Bridge. This is equivalent to the 1 in 2 year peak flow. This raised the estimated stream width in the equation to 16.9m. A stream width of 16m was used for design of stream restoration works.

Once the stream has overtopped the banks and is flowing unconfined within the floodplain, floodplain storage determines stage rather than channel capacity. Rosgen (1996) proposed defining the flood prone zone as being at a water surface elevation equal to 2 times the bankfull depth. This followed from investigation of rivers in the eastern U.S. and Idaho where the observed range was consistently from 1.7 to 2.3 times bankfull depth for all stream types. This was found to correspond to flows approximating the 1 in 50 year event. With reference to Table 3, this approach suggests looking at elevations that are between 0.5 and 1.0 m above bankfull elevation as being within the flood prone zone. This requires local validation.

Morphology and Stream Processes

Reach 1 is a riffle-pool morphology dominated by gravel with large woody debris complexing expected to be important. It has a stream slope between 0.5 and 1.0 percent characterized by a bi-modal distribution of sand and gravel dominated substrate. It has a sinuosity ratio of 1.2 as measured from Figure 7. It is generally a single thread channel that remains stable subject to periodic avulsion rather than undergoing continuous braiding. Channel cross sections are typical of the Rosgen classification C5 stream type with one low bank at low floodplain height (Rosgen, 1996).

Width to depth ratio is greater than 20. The distribution of energy within channels having high width to depth ratios is that near bank stress is increased and bank erosion increases resulting in channel widening. As the channel widens it looses competency to transport bedload and fine sediment. In the absence of additional sediment loading, the stream will adjust by balancing sediment input with deposition in point bars. At high sediment input levels channel aggrading will take place with development of transverse bars as observed.

Channel slope and bankfull discharge tend to put it on the cusp of becoming a braided channel. This indicates high vulnerability of the channel to become more braided with moderate increases in sediment supply. This type of stream morphology is characteristic of depositional stream environments in well developed floodplains. Rates of lateral stability are directly linked to changing sediment supply and direct channel disturbance.

Stream morphological attribute data were reported in the *Goldstream River Overview and Level 1 Fish Habitat Assessment and Rehabilitation Opportunities by Bocking, et al* (LGL Ltd, 1998) report to the Te' mexw Treaty Association that was submitted to the Ministry of Environment Lands and Parks (1998). This was followed in 1999 by the LGL Limited report: *Goldstream Watershed Restoration Program – Fish Habitat Prescriptions*.

The stream data was collected in 1997. While this assessment pre-dates the major debris jam event and channel changes resulting from the November 2006 storm it contains useful information that remains relevant to interpreting the hydrology and stream response. Key stream morphology characteristics include: stream gradient, left and right bank height, bankfull width, substrate size class distribution, and D90. Channel disturbance codes are also listed. There are 22 sampling points for R1 mainstem over a distance of 680m, 17 sampling points for R1-SC1 over 296m and 4 sampling points for R1-SC2 over a distance of 43m.

Figures 6 and 7 are reach maps from the 1998 and 1999 LGL Ltd. reports respectively. Figure 6 shows the broadening floodplain as it leaves the confined valley upstream of the Finlayson Road bridge. Figure 6 is at a scale of 1:2,500 and shows the numbered location of proposed restoration sites. It shows the bifurcation of the stream channel into east and west side channels. It has been annotated to show the location of the 2006 debris jam and corresponding reach names used in the 1998 overview assessment. At the time of assessment in 1997 the river had already avulsed into the west side channel causing widening at the inlet.

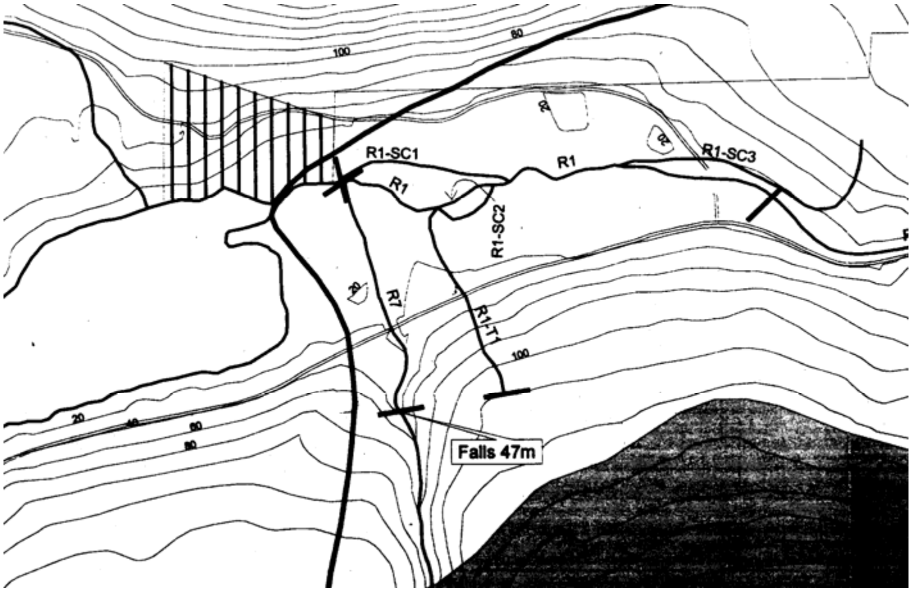
Main river flows diverted into the west side channel were greater than previous channel forming flows. Stream adjustment would be expected to include channel widening that increases cross section area of flow. Constriction of flow would result in higher stream velocities that would increase stream power. Higher stream power would increase stream competency to move larger bed material as the data for the 90 percentile stream size (D90) tends to confirm.

One of the objectives of stream restoration was to re-establish a pre-existing balance of flows by construction of riffle and spur above the inlet of the west side channel that would backwater and guide high flows into the centre channel. Aggraded sections of the centre channel were excavated and reconstructed to a deeper and narrower cross section designed to accommodate the 1 in 1.4 - 2 year channel forming flows.

In 2004 the BC Conservation Foundation completed additional instream works. This included placement of a deflector log perpendicular to flow located approximately 1.5 m upstream and parallel to the aluminum bridge structure. This bole (without rootwad) was placed in this orientation to deflect medium and large woody debris down the centre channel. The objective was to prevent debris becoming lodged under the footbridge at the top of the side channel and to facilitate removal. In addition a gradient control riffle structure was added to the side channel to direct more flow down the centre channel. The submerged log sill structure creates a distinct hydraulic drop and local backwatering upstream. It has not been determined how much backwatering influence this has at bankfull flow.

Figure 6 Lower Goldstream River

(Source: Goldstream River Overview and Level 1 Assessment (LGL Ltd., 1998)



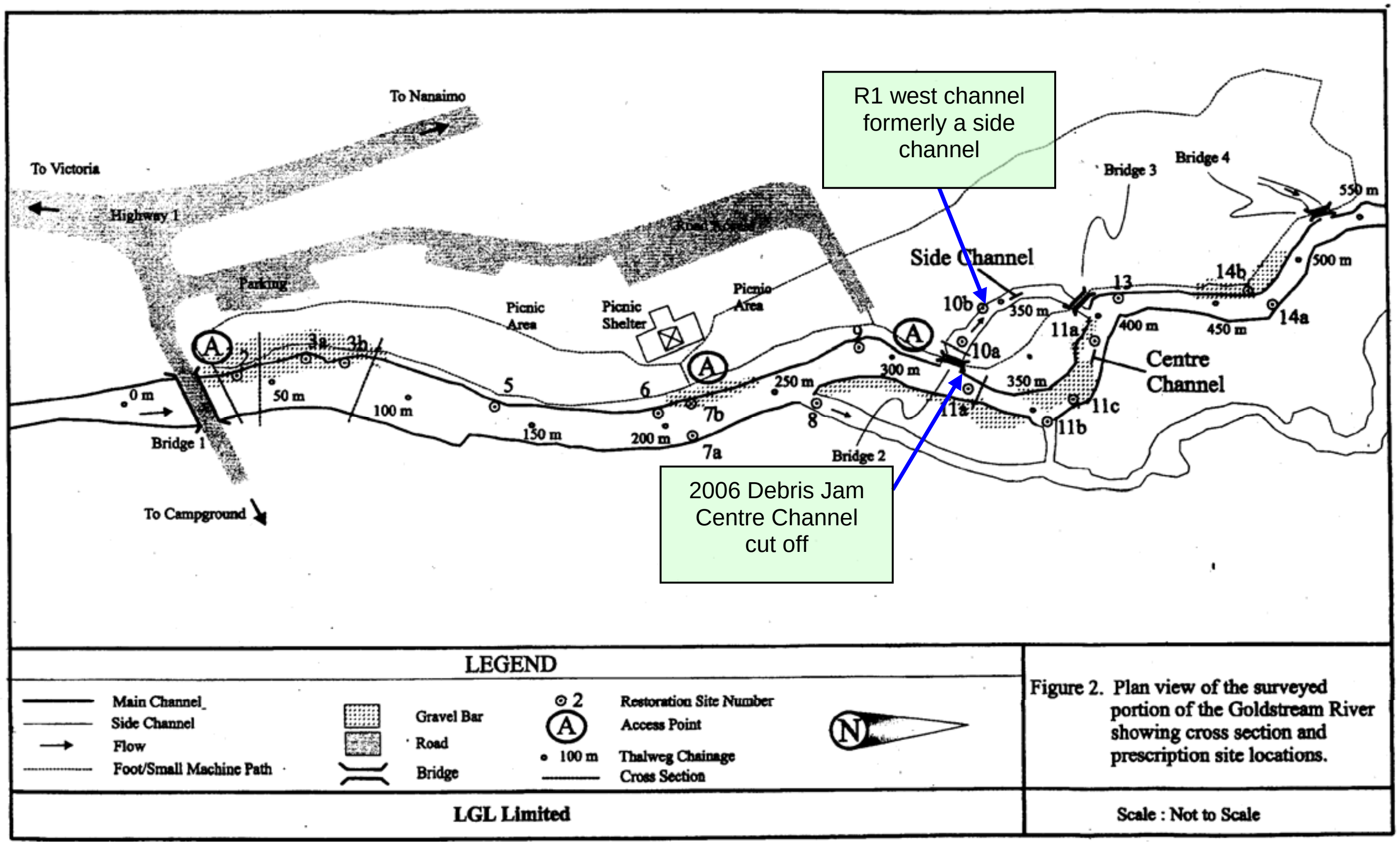
In 2006 winter storms resulted in formation of an extensive debris jam that now occupies the upper half of what was the centre channel R1-SC2 (former main channel). The November 16, 2006 storm was noted for accompanying high winds that resulted in extensive windthrow across Vancouver Island. Consequently, with the exception of side channel flow in the eastern side channel R1-SC1, all flow appears to be now diverted through the west channel.

Table 4 is a subset of data described in Tables 7-10 in Section 4.2 of the overview assessment by LGL (1998).

The lowest left or right bank height at each cross section is taken to be the low terrace flood plain. The lowest bank at each stream point was consistently between 0.3-0.5m in height.

Figure 7 Detailed planform of Reach 1 and Side Channels

(modified from: LGL Ltd. 1999.*Goldstream Watershed Restoration Program Fish Habitat Prescriptions*



R1 west channel formerly a side channel

2006 Debris Jam Centre Channel cut off

Measured Scale 1:2500

Table 4 Morphological Stream Channel Attributes

Source: (LGL Ltd, 1998)

Reach	Length m	Gradient %	Left Bank Ht (m)	Right Bank Ht (m)	Bankfull Width (m)
R1	713	1.0	0.8	1.0	18
R1-SC1	380	0.3	0.6	0.7	14
R1-SC2	73	0.2	0.6	1.0	24

R1 –SC2 is also referred to as the centre channel and former main channel

Figure 8 D90 Particle Size in the main channel and west diversion channel

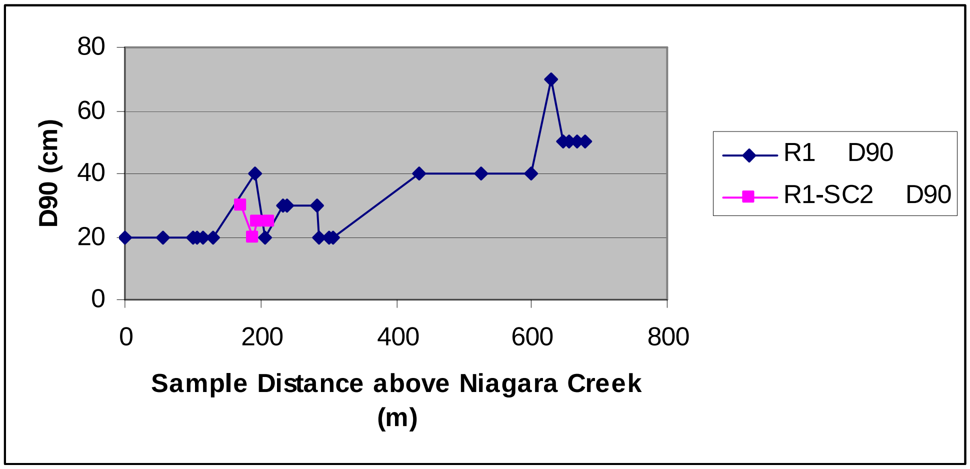


Table 5 Substrate Size Distribution

Source: (LGL Ltd, 1998)

Reach	<2 mm	2-64 mm	64-256 mm	>256 mm	Bedrock	D90
R1	27	42	24	7	0	33
R1-SC1	48	42	10	0	0	30
R1-SC2	46	48	6	0	0	25

Slightly less than 50 percent of the bed material in side channels was observed to be fines. Average 90 percentile diameter size (D90) for the west side channel is approximately 25cm with a maximum D90 of 40cm. The median diameter for the R1 reach is estimated to be approximately 1 cm based on a plot of the estimated mid point for each sediment class and an upper limit D90. This yields a calculated Mannings roughness co-efficient of 0.025.

Estimates of bankfull flow through the west channel can be made using the data on recorded bankfull depths, stream width, and the Manning's roughness co-efficient. Bankfull depth, and widths recorded in the LGL Ltd. 1998 overview assessment averaged 0.5m for the low bank side of each left and right bank pair of measurements. This is lower than the average for both banks. It is assumed to be the low terrace floodplain level above which flow becomes unconfined. Stream width through this section averaged 10 m. To calculate a bankfull estimate, a bank side slope of 1.5:1 is assumed. Average stream gradient from the data is 0.5%. Velocity is calculated as:

$V=(R^{2/3} \times S^{1/2})/n$ where

R is the hydraulic radius approximately equal to depth for wide channels.
S is slope
"n" is Manning's roughness coefficient.

Using the Manning's formula, the bankfull velocity is estimated to be 1.6 m/sec. The corresponding bankfull discharge is estimated as

$$Q=A \times V$$

This results in an estimated discharge of 7.7 m^3/sec for the low terrace floodplain bank level.

Bed shear stress is computed as $Shear_{bed}= \lambda RS$

where λ = specific density of water = 1000 kg/m^3

R= hydraulic radius ~depth in metres

S= stream slope

The corresponding bed shear stress is estimated to be 2.6 kg/m^2 for the west channel. An approximate relationship exists that equates diameter in cm of the particle moved to the magnitude of shear stress. This roughly suggests that flows at a bank depth of 0.5m are capable of moving material of approximately 2-3 cm in size in the west side channel.

Figure 8 shows a characteristic pattern of increasing D90 in an upstream direction. There is a local increase in the west channel where avulsions have diverted primary flow. Assuming no change in stream slope, particle size may be expected to vary inversely with sediment load and proportionately with discharge.

The critical shear stress required to move the average D90 25 cm cobble is estimated to be approximately 20-25 kg/m^2 and the corresponding shear velocity is 1.9m/sec for the upper end of the range, slightly higher than the velocity computed using Manning's formula. The maximum D90 value of 40 cm requires approximately 35-40 kg/m^2 and an estimated shear velocity of 2.2 m/sec for the upper end of the range. Bed Shear velocities are the expected velocity at the substrate boundary level. Most single measures of stream flow are taken at 40% of depth from stream bottom. Stream velocity may be expected to be higher away from the stream bottom boundary. Shear involves lifting force as well as lateral force.

The required depth of flow required to move the maximum 40 cm D90 is estimated to be 0.8m. This is close to the average bank height if both the low and high bank side are averaged together. The computed discharge associated with this is equal to the estimated 1 in 2 year flood for the main channel which is 2.2 times the estimated channel capacity discharge for the west side channel.

Bed shear stress is related to the radius of curvature and increases exponentially as stream radius is reduced. An estimate of the radius of curvature for the west channel taken from Figure 7 is approximately 35 m. Increased shear stress at the bend is estimated to be 1.6 times the straight channel shear stress. (Washington State Integrated Stream Bank Guidelines, 2003). Bankfull bed shear stress on the outside bend is estimated to be between 3.3 to 4.0 kg/m^2. Corresponding bank shear stress is expected to be approximately 80 percent of bed shear stress. These values correspond closely with straight channel tractive force in the main channel upstream based on a stream width of 18m and a bankfull depth of 0.8m. Maximum stress locations would normally be expected on the right bank at the inlet to the meander and along the outside left bank at the top of the loop. Additional variables and monitoring data would be required to predict rates of bank erosion. The method proposed by Rosgen (2001), that relates a bank erosion hazard index to near bank shear stress is one approach.

The foregoing estimates are applicable to the data extracted from the 1998 and 1999 LGL Ltd reports. With the cut off of the centre channel and potential channel geometry changes since 1998, it is expected that new data would improve or alter some of the interpretation. The information presented is approximate and relies on some interpolation of the existing data e.g. particle size distribution. These estimates are intended to illustrate the general order of magnitude and are not intended to replace independent estimates required to support engineering design of infrastructure.

Frequency of overbank flooding may be expected to occur at lower flows than reaches with higher channel capacity. One consequence of the main flow entering into the narrow side channel is contraction of flow that can be expected to increase velocity with transfer of larger stream momentum to cut banks and streambed scour. Inlet widening observed in 1998 and 1999 would appear to be the start of general widening expected through the west channel

In order for the west channel to accommodate the expected mean annual instantaneous discharge the west channel may be expected to widen between 5 to 8 metres locally to match stream widths observed in Reach 1 that average 18m. The radius of curvature for the side channel has been determined by lower flow regimes than the main channel. Widening of this radius favours erosion at the inlet and outlet.

The stream between 250 m and 450 m downstream of the bridge has a meander belt width of approximately 50m. Meander development and migration may be expected to occur within this belt. This appears to be approximately twice the amplitude observed upstream or downstream. Meanders are particularly prone to changes in lateral location because of the additional bank shear stress imposed along the outer cut bank and because subtle elevation changes can trigger avulsions.

There is visual evidence of high amounts of fine sediment deposited behind debris in the former centre channel. Removal of debris would be expected to expose high amounts of stored sediment. Further investigation would be needed to determine if removal of the debris jam would be sufficient to re-capture flow. As long as the sharp turn into the west channel is maintained, there is potential for floating debris to hang up at the inlet.

A concrete sill used for a temporary pedestrian bridge currently prevents low flows from entering the trail below the former crossing at the inlet to the west side channel but has been overtopped in high flows resulting in preferential flow down the trail causing surface erosion and downcutting. At the crossing, the trail is in general alignment with the river coming into the bend.

There is continued risk of debris accumulating at the inlet, particularly with the sharp turn that the stream is forced to make. Stream momentum will tend to carry debris into the inlet of the centre channel. This is exacerbated by the construction of the spur and that was intended to maintain flow in the centre channel.

There is currently a large tree bole anchored on the left bank that spans the active channel above the inlet to the west channel at the former crossing site. It has potential to catch debris. Revetment along the left bank to protect the former trail leading to the bridge prevents cut through by the stream that would otherwise improve the alignment with the west channel. The west channel had widened at the inlet in 1998. Additional widening is expected to have occurred since but needs to be measured.

Riparian Function

The riparian assessment that was carried out as part of the 1998 LGL overview delineated three major vegetation types controlled by flood regime and water tables. These vegetation types were as follows:

Type 1 – Low bench sites where flooding occurs almost every year – mostly red alder and black cottonwood with small amounts of western red cedar.

Type 2 – Medium bench sites – black cottonwood and Big-leaf maple where flooding occurs more often (<5 year intervals). The mature forest was expected to contain a dominant mix of western red cedar and big-leaf maple.

Type 4 – High bench sites – western red cedar, grand fir and snowberry where flooding occurs rarely.

Mapping of these types presented in the Appendix of the overview assessment by Bocking (LGL Ltd, 1999) denote relative flooding frequency and may correlate well with a survey of floodplain terrace elevations. This may facilitate relative risk rating for purposes of trail development. This mapping and report data should be leveraged to the extent possible.

However areas of flooding along the diverted section of the R1 side channel on the west bank may be expected to expand as a result of more frequent and broader flooding. In the R1-SC2 and west side channel these riparian classes may be expected to change as a result of increased flooding. As flooding occurs the stream will break out at low points and levee deposits will build up near the overflow points resulting in new controls affecting high flows.

Removal of mature tree cover and deep rooting of stream banks may result in several orders of magnitude increase in annual streambank erosion rate. Floods particularly do extensive damage as these streams become "set up" for failure. Meandering channel form may shift to a braided channel form (Rosgen, 2001). Rates of lateral adjustment in C5 channel types are influenced by the presence and condition of riparian vegetation and the channel is significantly vulnerable to lateral and vertical adjustment attributable to sediment regime that can be altered by increased rates of bank erosion.

Mid channel bars and eroding banks were listed as the primary disturbances in the 1998 Level 1 assessment by LGL Limited. Pool frequency was described as fair to poor indicating low channel stability. Functional LWD was found to be in short supply compared to a stream with mature coniferous forest cover. Relative absence of stable functional LWD would have significantly contributed to reduced pool frequency and increased uniform glides that are described in the overview assessment (LGL Ltd., 1998). LWD also provides local points for storing sediment. When functional LWD is absent development of mid channel bars is more likely to be prevalent. Channel widening and instability is at least in part attributed to loss of mature coniferous riparian forest cover as a source of bank rooting strength and as a source of large woody debris that would contribute to channel complexing and stability.

Gorsline (2001) states that “*Operationally, the channel migration zone (CMZ) should be equivalent to the area that a stream is expected to occupy in the time period it takes to grow a tree of sufficient size to provide geomorphic/ecological functions in the channel. Larger wood is needed to function in larger, high-energy channels. To be functional, recruitment trees must be very large, with root wads attached. As a consequence, on a larger stream, it may be necessary to include areas in the CMZ that the stream could occupy in the next 200 years or more”.*

Conclusions and Recommendations

The foregoing review is based on stream channel data collected prior to major recent changes in the channel. New data on stream channel characteristics should be collected to quantify the changes. Estimates of shear stress are sensitive to small changes in estimated channel depth, cross section area, and particle size distribution.

Since the east side channel inlet is upstream of the debris jam cut-off and diversion of flow into the west channel, it is expected that flows in the east side channel would remain unaffected. The current report does not estimate flows in the east side channel. Estimates of how bankfull flow is partitioned between the two outside channels would improve the basis for estimates. One objective of the restoration works was to cut off flows from the centre channel to the east side channel. The debris jam at the inlet of centre channel will have had the same result.

At the former upstream pedestrian bridge site bankfull flows are diverted down the trail that leads to the next downstream bridge. Therefore, it appears important to address how overbank flows are returned to the west side channel and to re-assess potential influence of the grade control structures at the inlet to the west channel.

Additional surveys are required to establish the flood prone zones. The Ministry of Environment has acquired 1m contour mapping from the Capital Regional District. This mapping very clearly delineates the margins of the floodplain and registers well with plan view drawings of the stream channel developed in the LGL reports. The contour mapping may be helpful in estimating flood stage boundaries.

Since water surface elevation profiles are critical it is suggested that sufficient data on channel cross sections and longitudinal profile be collected to support use of river modelling.

Upstream debris sources and bank erosion should be documented and assessed for potential to exacerbate the current debris jam and channel instability.

Reference sites for monitoring rates of erosion and channel change should be established with toe pins and permanent benchmarks. A method such as proposed by Rosgen (2006) may be appropriate. It would be useful to carry out a historical aerial photo review of stream channel changes and channel migration. Mapping from similar photo records for McMillan Park have facilitated risk assessment. For example, the plan form of the river may have undergone significant changes resulting from flooding in 1982 which had a 30 year return period flood event. Changes detectable on aerial photos may suggest the potential magnitude and frequency of changes particularly if they are mapped as a sequence in ArcGIS. Provision should be made for regular aerial photography so that future plan form changes in the channels can be tracked and re-assessed.

All of the existing riparian class maps, channel cross section locations, location of habitat restoration works, and channel plan form maps, contained in existing reports should be transferred into ArcGIS with associated attribute data. Registration points should be located in the field together with permanent station points. Repeatable photo reference points should be established at locations that are subject to change.

In a floodplain much of the sediment source may be re-distribution of sediment stored locally. Most of the sediment supply is expected to be from upstream sources. Deposition is expected to predominate as a process in the lower most reaches of the river. Sediment supply appears to exceed the sediment carrying capacity of side channels. Ongoing changes in channel migration resulting from avulsions, meander evolution and debris cut-off may be expected to continue indefinitely.

Previous attempts to train the river have had mixed results. In a post construction report on habitat structures installed in 2000, McCulloch (2004) concludes, "*It appears that wood incorporated into sites rarely met accepted minimum size criteria for instream work*." The role that these works may have played in subsequent channel changes, and how they operate now with some of the changes that have taken place has only been touched on. A review of the effectiveness of stream restoration structures is warranted for sections of stream other than the centre channel that has become infilled with debris. This should be coupled with assessment of how these structures are likely to affect flow patterns, scour and deposition under an altered flow regime.

Revetments and in-stream works designed to restore primary flow to the centre channel have been rendered counter productive with the channel cut-off created by the debris jam. Sharp bends that the river is forced into increase the stream power directed into banks and may be expected to result in additional accelerated local bank erosion and channel widening. Consideration should be given to improving stream alignment in the west channel by removing spurs and revetment that were formerly intended to maintain flow in the centre channel. The downstream confluence of the west loop would potentially benefit from similar improvement in alignment with the downstream main channel.

Conditions are currently in place for another potential avulsion if the river begins to cut through the meander on the left bank side of the debris jam. Bank over topping flows are already down cutting the existing trail. This situation could worsen if additional debris accumulates behind the log sill and suspended log at the upstream crossing. Natural re-adjustment of the river through this section may improve the alignment of the river. Partitioning of high flow down this section would reduce sediment scour in the west channel and accelerate aggrading and widening in the west channel.

The narrower west side channel is a potential choke point for debris accumulation. There is a risk that if debris accumulates in the side channel or at the entrance as is beginning to happen, that it could force an avulsion or deflection of flow resulting in channel migration further west into existing trails. The breadth of the floodplain suggests that the channel has occupied this area previously. Alternatively, upstream backwatering from debris could result in an avulsion further upstream above the current debris jam possibly connecting with the east side channel. Below the inlet of the west channel the infilling by debris in the centre channel will effectively be a barrier against eastward migration.

Removal of debris in the centre channel would reduce the potential for future debris accumulation. If the pre-existing channel becomes available to high flow from removal of debris, it would potentially result in partitioning of high flows between the west channel and “restored” centre channel. However, based on the expected sediment infilling behind debris and the previous avulsion of flow into the west side channel, it is unlikely that removal of the debris would result in significant recapture of flow. However, this would have to be evaluated on the basis of new channel profile surveys following removal of debris. Aerial photos of the debris jam should be taken and it should be assessed for quantity and size of material. Point of initiation should be confirmed and factors contributing to its formation should be further reviewed on the basis of field survey.

In 1997 the west side channel had considerably less capacity than the former main channel. Over the past 10 years adjustments may have been made to accommodate more flow through channel widening. New surveys will be required to determine the extent of channel geometry change. The low gradient of the west channel that the river is now using together with channel widening would be expected to result in long term aggrading similar to what has previously been observed in the centre channel as the channel slowly loses sediment carrying capacity.

Tides should be reviewed for potential influences on flood elevations. High tides and storm surge may result in backwatering effects that are not apparent by casual observation alone. Proximity to tidewater and low stream gradient suggest that tidal effects may be present.

Lastly, climate change is expected to increase intensity and frequency of storm events. This may be expected to increase rates of stream erosion, sedimentation, and debris accumulation due to windthrow. Return periods for a given magnitude of storm runoff may be expected to become shorter requiring higher design flow allowances for protection of infrastructure. As previously noted, indications are that the November 2006 storm runoff may have only been within the 1 in 10 year flows. This suggests that relatively low return period events may trigger disproportionate stream channel changes. There is high uncertainty in predicting return period flows or where the river will be after events such as this. Nonetheless, the kinds of response to anticipate are clearly evident and consistent with this channel type in a coastal floodplain.

References:

Bocking, R., *et al* (LGL Limited). 1998. *Goldstream River overview and Level 1 assessment and rehabilitation opportunities (including Riparian)*. prep. for the Te' mexw Treaty Assoc. and submitted to Ministry of Environment, Lands and Parks

Bocking, R. *et al* (LGL Limited). Goldstream watershed restoration program fish habitat prescriptions prep. for the Te' mexw Treaty Assoc. and submitted to Ministry of Environment, Lands and Parks

Chapman, A., 1999. *Guide to peak flow estimation for ungauged watersheds in the Vancouver Island Region (Nanaimo)*. Min. of Environment, Lands & Parks, Water Management Program. unpubl.

Fischenich, C. 2001. *Stability thresholds for stream restoration materials. USACE Research and Development Centre*. ERDC TN-EMRRP-SR-29

Gorsline, J. 2001. *Floodplains and channel migration zones.* Olympic Field Office, Washington Environmental Council

Gudavicius, S. 2008. information on CRD reservoir system and precipitation intensity duration frequency analysis for Sooke Dam 1996-2006.

Lane, E.W. 1955. *The importance of fluvial morphology in hydraulic engineering*. American Society of Civil Engineering, Proceedings, 81, paper 745, pp.1-17.

McCulloch, 2005. *Construction of artificial fish habitat in the Goldstream River*, 2004. prep. for Habitat Conservation Trust Fund, Min. of Water, Land & Air Protection.

Ministry of Environment. 1979-86. Hydrometric data for WSC Station 08HA039. unpubl.

Murdoch, S. 1999. Goldstream River trail rehabilitation – implementation options. unpubl. report to BC Parks

Newbury, R.W and M. N. Gaboury. *Stream analysis and fish habitat design - a field manual*. Newbury Hydraulics Ltd.

Ptolemy, R. 2008. correspondence relating to in-stream fisheries flows.

Rosgen, D.L. 1996. *Applied river morphology*. publ. by Wildland Hydrology

Rosgen, D L. 2001. *A practical method of computing streambank erosion rate.* Proceedings of the Seventh Federal Interagency Sedimentation Conference. Vol. 2, pp. II -9-15, March 25-29, 2001, Reno, NV

Seckin, G., N. Seckin, and R. Yurtal. 2006. *Boundary shear stress analysis in smooth rectangular channels*. Can. J. Civ. Eng. Vol. 33 p.336-342

Slaney, P.A. and D. Zaldokus eds. 1997. *Fish habitat rehabilitation procedures. Watershed Restoration Technical Circular No. 9.* Min. of Environment, Lands and Parks and Ministry of Forests.

Tolland, L., C. Zurbrugg, and S.O. Russell. 1998. *Estimating peak flows from forested watersheds in British Columbia*. in 1998 CWRA 51st Annual Conference Proceedings, “Mountains to Sea: Human Interaction with the Hydrologic Cycle”.

Wangness, S. E. (Ship Environmental Consultants Ltd).1999. The Goldstream/Langford Creek watershed assessment. prep. for The Capital Regional District

Washington Dept. of Fish & Wildlife. 2003*. Integrated stream protection guidelines*

Water Survey of Canada. 1977-78 archived hydrometric data for WSC Station 08HA039-Goldstream River in Goldstream Provincial Park.

Appendix 1 – Photos from February 12, 2008 field visit

Photo 1

Inlet to the west channel showing channel widening and near top of bank flow. Chip surface material and trail fill has eroded in high flow and deposited around base of trees on the left bank.

Photo 2

Same location from opposite bank showing suspended debris log and hydraulic drop associated with sill log installed in 2004 to deflect flow into centre channel. Concrete berm prevents low flow diversion down trail but high flows overtop it and flow down trail.

Photo 3

Downcut trail fill behind bank revetment below the public viewing area leading to the former bridge crossing shown in Photo 1 and 2 in far background

Photo 4

Debris and sediment clogged centre channel

Photo 5

Undermining of the boardwalk where rock protection has collapsed into the stream

Photo 6

Erosion caused by flooding along a trail between bridge crossings.