Gooding
Hydrology

Tsolum River
Biophysical Assessment
Hydrology and Channel Assessment

For
The Tsolum River Restoration Society

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Executive Summary

To assist in determining the factors which are affecting the recovery of the Tsolum River's once abundant Pink Salmon, changes in land use and river channel morphology from the 1930s through to the present were studied on the full airphoto record, from 1938 BC airphotos to 2005 Google Earth photos. A field channel assessment from the Puntledge up to the Tsolum's mid-elevation tributaries was done during late summer 2009 to determine current channel conditions. Water Survey Canada (WSC) flow data for the Tsolum River near Courtenay, as well as the neighboring Puntledge, were examined to determine if variations in yearly extremes of low and high flows were affecting spawning and in-river survival rates.

Airphoto studies showed the completion of a first wave of forest development by the late 1960s. In the late 1950s and early 1960s the channel morphology underwent significant changes. In Murex Creek and the Upper Tsolum (Blue Grouse) tributaries there was severe break-down of mid-elevation boulder line morphology with a lesser extent occurring in Dove and Headquarters Creeks. High levels of aggradation, with channel widening, occurred in the lower Murex and Upper Tsolum above Murex in the early 1960s, with a huge fan at the Murex confluence. The timing of these channel changes coincides with the major drop in Pink salmon escapements.

This wave of bed and bar material moved down the Tsolum during the 1960s and 70s, visible as deposits and widening nearly to Headquarters Confluence. A similar smaller wave of bedload entered the Tsolum from Dove Creek in the late 1960s. Lower Headquarters Creek did not experience this pulse of bedload from its upper tributary. While re-vegetation of gravel bars has increased stability of some of the mobile bedload, higher average flows of the last two decades have slowed recovery. With the additional factor of ongoing bank erosion on the lower floodplain, pool depths are generally reduced through most of the system, from the estuary to upper tributaries, with the exception of a few noted locations. Spawner access to the upper system is slowed by aggraded lower reaches, and still nearly completely blocked to Murex and the Upper Tsolum by the deposits at the Murex confluence.

Analysis of WSC flow records, and their relationship to escapements, shows a strong inverse relationship between the number of days of high flows and returns two years later, indicating that frequent movement of the unstable bedload affects the survival rates to out migration of incubating eggs. There appears to be a much weaker relationship between the average low flow, from Aug. 15 to Sept. 15, and the Pinks counted in that year, indicating some returning Pinks may go up the Puntledge if extreme flow conditions prevent access up the Tsolum.

Recommendations include continuing lower floodplain bank stabilization and low flow enhancement, access improvement on a yearly basis by stream keepers, and some options for assisting in stabilization, re-vegetation, and reduction of mobile aggraded bars in the lower reaches of some of the tributaries and parts of the mainstem. It is recommended that channels of the Murex and Upper Tsolum to well below Murex be treated as highly peak-flow sensitive.

Contents

1.0 Purpose of report

More than most Pink Salmon stocks along Vancouver Island, the once abundant Tsolum River Pinks have had very small escapements, for most of the years since the late 1950s. Salmon enhancement efforts of the last decade have seen very mixed results in returning escapements. What is affecting recovery, and limiting productivity? There have been concerns expressed that extreme low flows during hot weather may be affecting inmigration and spawning success. Flows records, weather, and the channel morphology of the river are examined in this hydrologist portion of a biophysical assessment, to attempt to discover the factors limiting recovery of the historically large Tsolum Pink runs.

1.1 Methods

Channel morphology and condition were assessed using a combination of historic airphoto analysis, and a field channel assessment of the Tsolum mainstem and tributaries. Flow records examined were of the WSC flow station 08HB011, Tsolum River near Courtenay, as well as the Puntledge River in Courtenay 08HB006, and the shorter Tsolum River below Murex Creek records.

Weather records were examined in this portion of the biophysical assessment as they relate to potential flow changes in the Tsolum from historic watershed development. Escapement records were compared to both historic changes in channel morphology and historic flows.

1.2 Acknowledgements

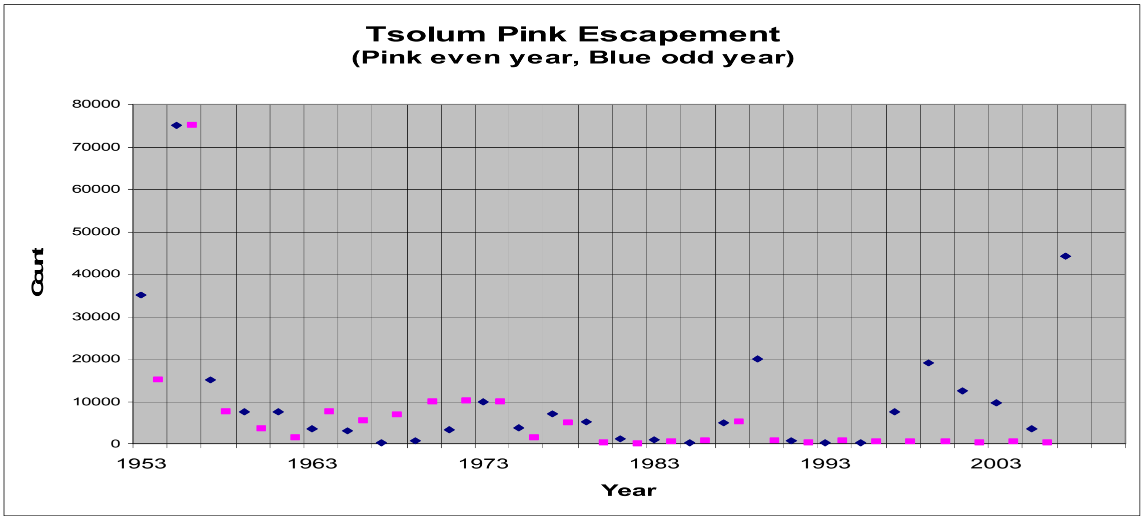
While our reports are written as separate portions, this assessment was done as a team effort with Kathy Campbell, fisheries biologist, and Jack Minard who provided information and coordinated efforts. We would like to also thank Timber West for access to streams on their lands, and for their ongoing cooperation.

2.0 Pink Salmon Historic Escapements

Prior to the mid 1950s, Pink Salmon escapements in the Tsolum were variable, with some low years, however there were frequent runs in the 50,000 to 100,000 range. This is discussed more fully in Kathy Campbell's portion of this report. The last runs of this magnitude, which were again approached by this year's large returns, were in 1957 and 1958, with escapements dropping to the hundreds during parts of the 1960s. Both odd and even year runs recovered to around 10,000 in the 1970s, the even year for three successive returns, the odd year only in 1975, probably helped by Headquarters Creek enhancement efforts during that time.

Since the 1970s, the even year run has dropped to consistently less than 1000 fish, with the exception of 5,150 in 1990. The odd year escapement has been variable, with a brief recovery to 20,000 in 1991, which dropped rapidly to 200 fish four years later. A more sustained recovery, peaking at 19,000 in 2001, dropped gradually to a less extreme low of 3,550 in 1997, until this year's current high of 44,500 returning. This recent increase can possibly be linked to resumption of a small hatchery program on the Tsolum.

Figure 1: Tsolum Pink Salmon Escapements



3.0 Airphoto Analysis

From visits to the provincial government Air Photo Lab in Sidney, a set of airphotos was selected, covering years from 1938 to 1996. Photos selected covered the Tsolum River channel from the estuary to Helldiver Lake, with varying lengths of the lower portions of all the tributaries. From analysis of airphoto hardcopies, it was determined that the watershed was at its highest degree of forest harvest in the mid 1960s. A full coverage of the watershed for 1964, and the very upper watershed in 1968, was also selected. Hardcopies of the airphotos selected were purchased. A list of flights, years, and photos acquired is attached as Appendix 1. 2005 airphotos were obtained for inclusion in the analysis from Google Earth.

Air photos were analysed by three methods:

- Viewing and analysis of selected photo pairs using a stereoscope, noting agricultural clearing of riparian areas, and methods and timing of forest development.
- Compilation of a mosaic of the entire watershed in 1964, near peak of forest development. This mosaic was used as a base map for mapping of historic forest development in the watershed.
- Selection of eight mainstem and one tributary (Murex) segments, and rotating and cropping the segments from each year's air photos. These cropped airphotos were then compiled in an individual document for each reach, displayed as a time-series allowing viewing of channel changes from 1938 to 2005.

The 1964 watershed mosaic, with historic forest development lines for 1938, 1957, and 1964, is attached as Appendix 2. The nine segments' air photo time-series studies are attached as separate time-series documents in Appendices 5-1 to 5-9.

3.1 Historic Development in the Watershed from Airphotos

3.1.1 Agricultural Clearing

Agricultural clearing along the banks of the lower Tsolum was visible from the earliest air photos in 1938. The most upstream, and still existing, two fields are 1.5 km downstream of the Headquarters confluence. No obvious bank erosion is apparent along these fields, which have narrow riparian leave strips in the time-series airphotos. A few fields along the river from Dove Creek confluence downstream for around 5 km, where the river winds through a narrow but varied width incised floodplain, have not varied much over the time-series photos. The fields along much of this reach are on the high raised upper floodplain, and do not appear from the photo series to have had significant erosion along their banks.

From 5 km below Dove Creek, past Portuguese Creek to the Puntledge confluence, a wide lower floodplain opens. The majority of the land along this lower reach has been cleared for farming, with the full west side (Dove Creek Road), and most of the east bank, including the Portuguese Creek sub-basin, being almost as developed in 1938 as today. Riparian leave strips (mostly second growth) vary from none or a single tree, to two wider portions. The airphoto series shows extensive bank erosion along and through some of these fields since the earliest photos, which continues to this day.

From around 1 km downstream of the Portuguese Creek confluence, the river appears to have been excavated and channelized, probably at the same time as the Courtenay River.

3.1.2 Forest Development

Pre 1940

By 1938, air photos show that nearly the entire valley bottom had been logged, as far up as Helldiver Lake on the east side of the river, and the Helldiver Creek confluence on the west side. The east side of the river shows good regeneration (where field aren't kept cleared) as high as Headquarters Creek, however upstream of HQ, the valley bottom clearcuts are relatively new at this date. Most of the Tsolum River from Helldiver down has had the riparian vegetation totally removed by 1938. Two of the exceptions to this full riparian clearing are the 1.8 km of river upstream of Headquarters Creek, (which today has the narrowest stream width in the lower river), and the inside of the oxbow bends upstream at today's inland highway crossing.

The earliest hillside logging on the airphotos (1938) is in the lower Dove sub-basin, working uphill from the agricultural areas, and along the base of Constitution Hill, above the mill town by the Tsolum River at Headquarters Road.

The early logging in the bottom 30% of Dove Creek sub-basin appears to have been relatively slow. Various methods, including small clearcuts, clearcut with non-merchantable or seed trees left, and selective harvest of varying degrees, appear to have been employed in the lower Dove sub-basin. Road works visible appear narrow. Some riparian leave strips, though broken and of inconsistent width, are observed in the early air photos. By 1940, when logging operations were beginning to accelerate, around a third of Dove Creek sub-basin had been logged by these methods. Due to the relatively slow speed of the pre-1938 forest harvesting, the very earliest was already showing significant re-vegetation in the early photos.

At Headquarters, the very earliest logging on the west side of the river, and up the side of Constitution Hill, appears to have been more selective, or possibly these lower slopes of Constitution were affected by the major fire which occurred prior to these photos. However, by the 1938 photo, tower sets along the lower hillside are actively clearcutting what had been left.

Post 1940
With increasing mechanization, the logging method became complete clearcutting, including riparian areas, along and up the mountain side. By 1946 the cut had been completed on Constitution Hill, and reached to above Wolf Lake and the Lost (Twin) Lakes.

By 1957 around 90% of the Upper Tsolum sub-basin (Lost Lakes, Blue Grouse, and Regan Lakes), had been cleared. The upper edge of the cut was around halfway up Murex and Dove Creeks (around a third of the Murex sub-basin area, half of the Dove sub-basin), and three quarters of the way up the Headquarters sub-basin, to well above Wolf Lake.

By 1964 clearing of virtually all of the Upper Tsolum and Headquarters sub-basins was completed. Over 80% of Dove Creek sub-basin, and over 50% of the Murex sub-basin, had been logged. A mosaic of 1964 airphotos is attached as Appendix 2. Operations in the Dove and Murex sub-basins appeared to slow in the 1970s, with cutblocks in the very last of upper Murex which appear relatively new in the Google Earth 2005 coverage.

The peak of hydrologic impacts from forest development probably occurred from 1960 to 1980. Equivalent Clearcut Area (ECA) percentages in 1964 were roughly estimated from the airphoto analysis (much depends on what percentage of a clearcut you rate the various revegetated areas). The extensive system of roads that was built up the mountainside, many of which are still in use today, was also near its longest and most complex by the mid-sixties.

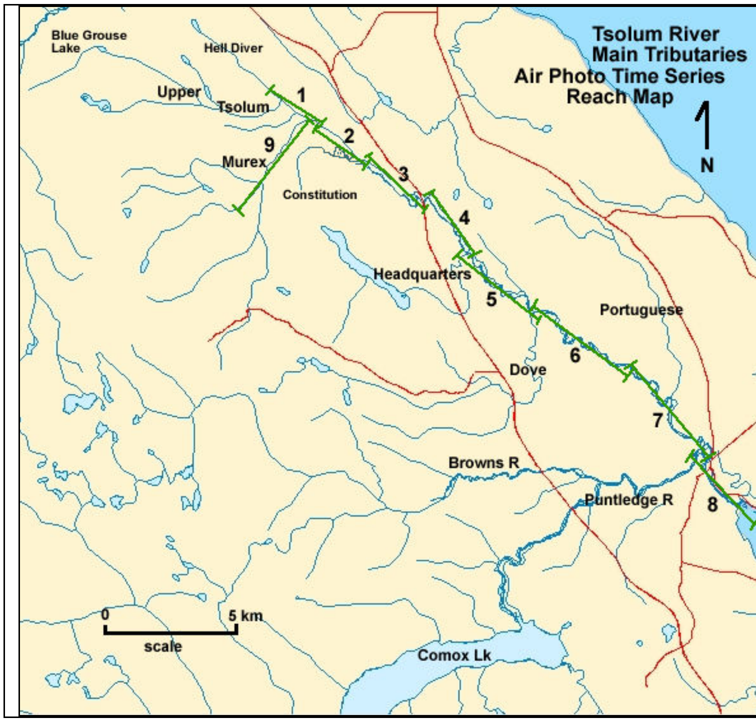
Table 1: 1964 Approximate % Equivalent Clearcut Areas in Tsolum sub-basins

Sub-basin and Reference point	1964 Approximate Equivalent Clearcut Area (% ECA) above reference point
Upper Tsolum above Murex confluence	70%
Upper Tsolum above Lost lake confluence	90%
Murex above Tsolum confluence	45%
Murex above McKay confluence	50%
Headquarters above Tsolum confluence	70%
Headquarters above Wolf Lake	80%
Dove above Tsolum confluence	50%
Dove above Jackass confluence	55%

3.1.3 Riparian Area Vegetation Cutting
The Tsolum River's riparian areas were almost completely cleared, from ocean to divide, from late 1800s on the lower floodplain, by 1938 along the entire valley bottom river, and by 1964 on all tributaries but the very upper Murex. Some scattered riparian vegetation was left along lower Dove Creek, and along portions of the Tsolum by residential and farming properties from HQ Creek downstream.

3.2 Channel Segment Time-Series Analysis

The Tsolum River main channel was divided into eight approximately equal length segments, from the estuary to upstream of the Upper Tsolum and Helldiver Creek confluence. As it became obvious from inspection of the airphotos that particular attention was needed to Murex Creek, an additional segment covering the lower and middle Murex Creek reaches was added.



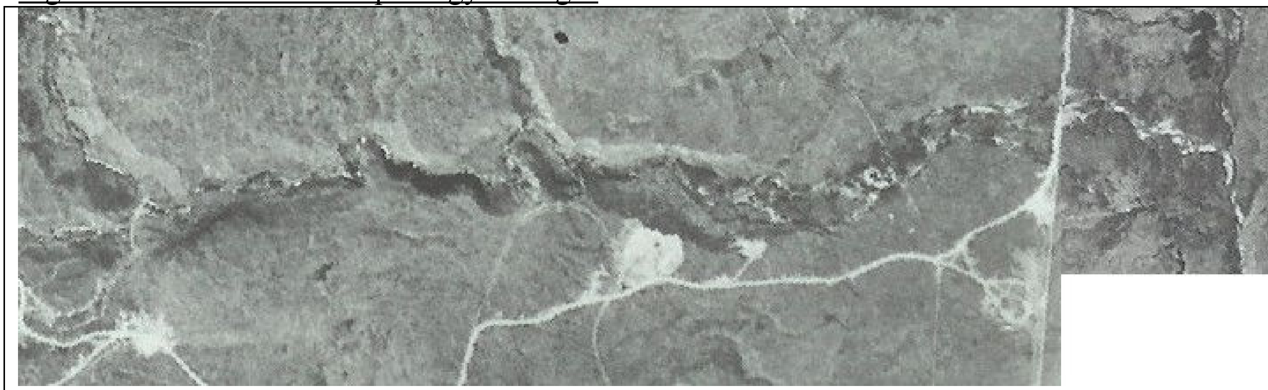
Segment selection is shown to the left. These segments were cropped from each flight's relevant airphotos, with the lower reaches of the tributaries included in the cropped areas. The segments were then reoriented, resized to a common direction and scale, and gathered in chronological time series documents. These time series photo documents were inspected for changes in channel width and structure, and for visible bars and any changes in bar size and locations. Time series documents are attached as separate documents Appendices 5-1 to 5-9.

3.2.1 Historic Channel Morphology Changes, from Airphoto Time-Series Analysis

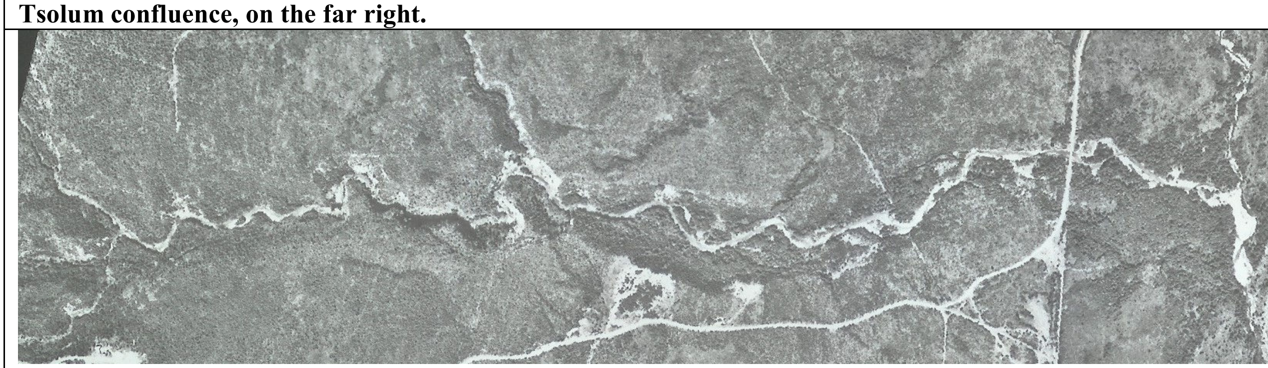
Earliest (1938) airphotos show a narrow stable channel from Dove Creek to the headwaters, although the riparian areas have largely been cleared as far upstream as the Helldiver Creek confluence. Bank erosion and wide point bars can be seen in the lower floodplain agricultural fields. Channel widening, as a result of weakened banks, and increased peak flows from forest development which is climbing the hillside, can be seen beginning in the 1946 photos of the Tsolum channel. The widening channel, and the aggradation shown by increased bar size, stretches from above the Helldiver Creek confluence, downstream to the big S-bend (also called the 'Oxbows', where the Inland Hwy now crosses the Tsolum). By the 1950s, as logging moved up the basins, the lower tributary channels begin to widen.

In the late 1950's and early '60s the morphology of the tributaries, particularly Murex Creek, changed fairly rapidly, with bank erosion and boulder line structures breaking up to various degrees in the middle and upper reaches. When boulder lines break the previously trapped bedload in the step, or cascade-pool morphology structures and pools (boulder, cobble, gravel, sand and silt), becomes mobile. Along with eroded bank materials, it is transported at high flows towards the valley bottom reaches, and deposited as gradients flatten. This mobilized bedload travels varying distances with each high flow, with boulders moving the least, cobble and gravel reaching towards the lower reaches and out into the Tsolum, and some fines travelling through to the estuary.

Figure 2. Murex Creek Morphology Changes



Murex Creek 1957 with boulder lines and pools from the left (upstream of McKay confluence) downstream to center of photo. Channel widening can be seen downstream of the road crossing, and the growth of a fan at the Tsolum confluence, on the far right.

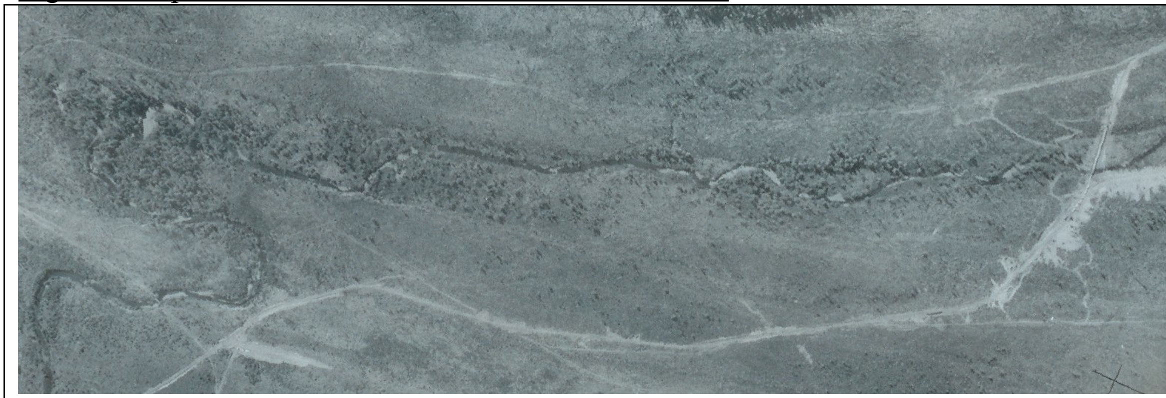


Murex Creek in 1968 (1964 photo similar but blurred). The entire Murex channel visible here, from upstream of Mckay confluence on left to the Tsolum River at right, has lost its pool retaining structures (boulder lines, LWD), with the entire length of channel's bedload mobilized and re-worked every high flow. Note the very large fan, at and downstream of the confluence with the upper Tsolum at far right.

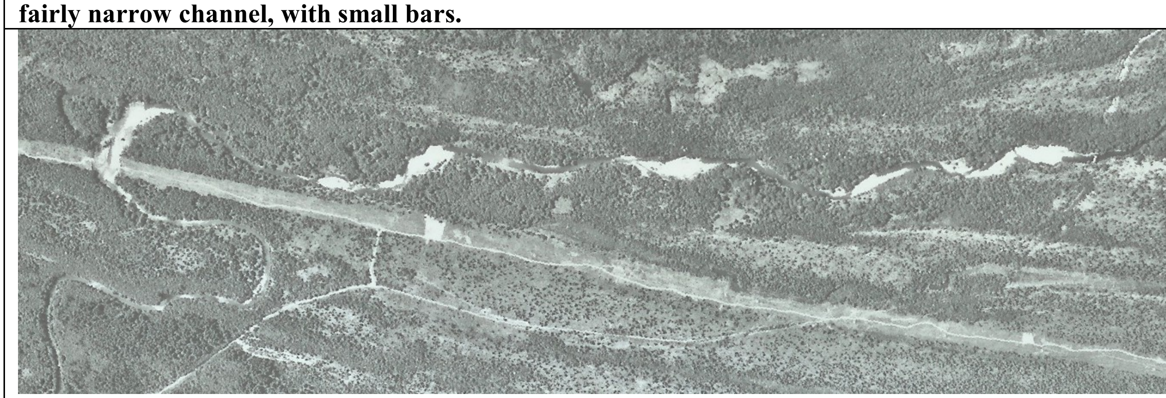
This large wave of bedload is visible in the early 1960's, in the lower reaches of Murex and Upper Tsolum, large fans at the Murex and Dove confluences, and in bars on the main river below Murex Creek. By 1964 this widening and severe growth of deposited bars of bedload was obvious as far downstream as just above the Headquarters Creek confluence, with a separate smaller pulse of bedload also coming out of Dove Creek at this time. Because of the buffer of Wolf Lake, lower HQ Creek did not get the large increase in bedload from upstream, and any increased peak flows increases were moderated. No fan was observed by its confluence over the photo record.

The aggradation in the Tsolum mainstem, from high bedload volumes moving out of the upper Tsolum and Murex tributaries, peaked from early 1960's to mid '70s upstream of Constitution Creek, slightly later on the bar complex upstream of HQ Creek. The pulse from Dove Creek peaked from around 1970 to 1980. From those peaks of deposition, and with growth of riparian vegetation, a gradual vegetation and slow stabilization of some of the material of these deposited bars has been occurring, becoming visible in the 1980's above Constitution Creek, and as late as the 1990's in the lower river.

Figure 3 Deposition in Mainstem Tsolum below Murex



1938 Tsolum channel from below Constitution Creek at right, downstream to the S-bend Oxbow at left. Note fairly narrow channel, with small bars.



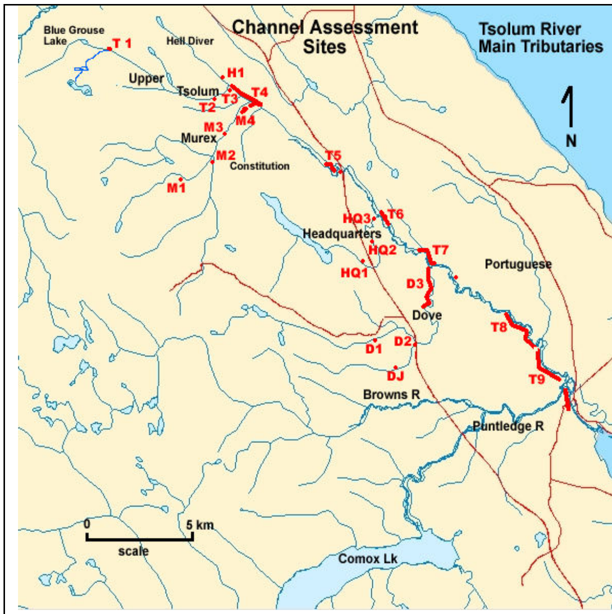
1968 photos shows channel widening and extensive bar growth through the entire river segment.

All years' air photos show bank erosion through fields still ongoing at multiple sites along the lowest floodplain reach, with associated large gravel point bars, as shown in the example below.

Figure 4. Erosion through entire field, lower Tsolum

The bedload movements discussed in this section are the larger visible bedloads of gravel and cobble. At the same time as these periods of vastly increased larger bedload movement, and in advance of the visible gravel cobble slugs, there would have been a large component of finer material (sand/silt/clay) travelling the entire length of the river during high flows. As upper tributary erosion and mainstem river widening and aggradation was occurring, there would also have been associated logjam formations, as decaying bank root structures and old large woody debris broke loose and gathered in deposition areas.

4.0 Field Channel Assessment

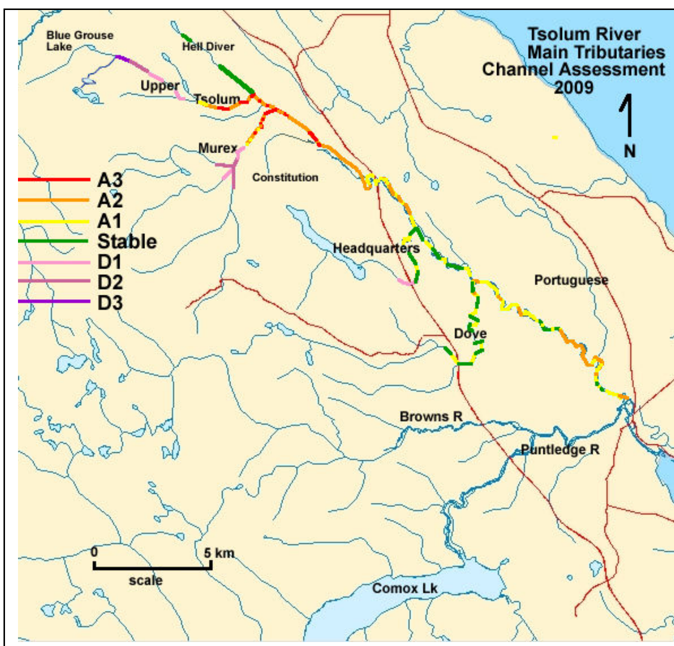


During late summer and autumn 2009, representative Tsolum mainstem and tributary sites and reaches, as shown on the map to right, were walked and assessed using a modified WRP Channel Assessment Procedure.

Channel width, gradient, bankfull depth, and bed material composition were noted. With size and extent of bar deposits, depths of pools, and existence of control structures such as LWD, or boulder lines where appropriate, the channel at each site was rated as being stable, aggraded, or degraded, and degree of widening noted.

Channel assessment photos, field data, analysis, and comments are attached as separate documents (Appendix 6A to 6D).

Based on these field surveys, and the time-series airphoto sets compiled for each reach, a map of channel conditions was drawn, classifying channels as stable, severely to partially aggraded, or severely to partially degraded.



The channel condition marking on the map does not extend through the entire channel lengths of the tributaries and upper watershed, but was only colored for condition near sites visited or where condition could be estimated from neighboring reaches and airphoto time-series analysis. In the Murex and Upper Tsolum tributaries, channel conditions vary around class given, with local sites of aggradation of deposits from the overall mobile bed caused by the generally degraded channel. Degree of aggradation also varies through lower reaches, with mapping partially indicating the variation.

A full page version of this map is attached as Appendix 3.

4.1 Interpretation of Channel Assessment Map

Some discussion of the rating system used for the channel assessment, and the habitat impacts which relate to each level of disturbance, is included here as an aid to interpretation of the above map. Each level of disturbance, either in the degraded or aggraded direction, implies a specific change in habitat characteristics. To paraphrase the CAP field manual:

A channel is rated as stable if it is neither down-cutting (degrading), with net movement of bedload out of the reach, or building up (aggrading), with more material depositing each high flow than leaving. Flow and bedload are balanced such that pools are adequately scoured in high flows and maintain their depth, cover at least half the channel length, and have relatively slow flow through them at most flows.

The mid and upper tributaries visited in the Tsolum are mostly cascade pool morphology, and were generally degraded. With bank erosion of weakened banks, and possibly increases in the channel forming flows (1.4 to 2 yr return flows), the stability of the boulder lines which control velocities and bedload movement decreased.

As any portion of a given line breaks, the pool behind it becomes shallower. A partially degraded stream has breaks in its boulder lines, with more rapid flow through shallower pools, and finer sediments moving downstream. A moderately degraded channel has boulder lines largely absent with rapid flow through the very shallow remaining pools. Coarse bedload is reworked each high flow. By severely degraded channels, bedrock can comprise much of the channel and there is little bed material, no sign of boulder lines, and no significant pools.

Lower tributaries and the mainstem in the Tsolum are nearly all riffle pool morphology, and vary from stable to severely aggraded, with build up of materials from upstream, and local erosion.

A low aggradation rating indicates a slightly widened stream (some bank erosion), with pools covering less than half the stream length. While some pools, around large woody debris or rock outcrops, have maintained their depth, many of them have lost up to half their depth.

A moderately aggraded stream has riffles for over half of its length, and extensive mid and side channel bars, some as high as the banks. Channel widening is more obvious on over half the reach, and pools are less frequent and shallower. Some old LWD has been mobilized by bank erosion, and is accumulating in logjams.

A highly or severely aggraded channel has general bank widening, and extensive high gravel bars, some with high unstable downstream banks. Shallow pools form less than a quarter of its length, with riffle forming the majority. Some small deeper pools may exist as remnants around scour locations. LWD is mostly in logjams.

In general, the higher the degree of channel disturbance rating, the less pool habitat present. Pool depth drops more rapidly with degree of degradation (the pool drains down from any break in the boulder line) than with degree of aggradation (gradual deposition) in this method of rating.

5.0 Hydrologic Data Analysis

The Water Survey of Canada (WSC) gauge 08HB011 (Tsolum River near Courtenay) has a flow record, with gaps, from 1914 to present. Only three very early years were recorded, 1914 to 1917, then a gap until a block of data from 1955 to 1957. There is another gap until the record resumes in 1964, with only short blocks of data missing between then and the present. The nearby Puntledge River has a very similar period of data, including a few more early years than the Tsolum, and though the hydrology of the two rivers is somewhat different due to the size of Comox Lake, data from WSC 08HB006 (Puntledge River at Courtenay) was considered. Weather station records used for comparisons of 1914-17 conditions and storm events with the later 1960's conditions in the watershed were: Cumberland, Alberni at Beaver Creek, Denman, and Hornby; all of which have records with gaps along the way from prior to 1914 until the 1960s. Together there is always at least two of the stations' data recorded.

Definitions:

Correlation Coefficient: measures the degree to which two measurement variables tend to move together, whether large values of one variable tend to be associated with large values of the other (positive correlation), or small values of one variable tend to be associated with large values of the other (negative correlation).

R squared: the R squared value indicates the proportion of the variation in one variable that can be explained by variations in another variable.

5.1 Low Flows

One suggested direction for the data analysis was to determine if possible changes in hydrology, specifically late summer low flows, may be related to changes in numbers of inmigrating salmon (due to Pinks selecting to go up the Puntledge River, if the Tsolum is too low and warm), or to their success in spawning.

The flow variables used in the analysis are the yearly 7-day low flow (the average flow for the lowest flow 7 consecutive days of the calendar year), the average Aug. 15 to Sept. 15 flow, and the average Sept. 10 to Sept. 30 flow. Average flows were chosen for these two time periods, as either a high summer base flow or significant rain pulse would raise the average, while a very low average flow indicates a lower base flow with no significant rain pulses. These three different yearly average flows were put through a regression analysis against that year and the Pink count of two years later, producing R^2 values, and a correlation coefficient.

Table 2: 1980-2007 Low Flow versus Pink Escapements Analysis Results Matrix

	Pinks counted that year		Pinks returning 2 years later	
	R squared	Correlation Coef	R squared	Correlation Coef
7 day low flow	0.012	0.109	0.024	0.156
Sept 10-30 avg	0.017	-0.129	0.006	0.075
Aug15-Sep15 avg	0.17	0.414	<0.001	-0.02
Aug 15-Sep 15 odd yrs	0.15	0.39		

Yearly seven day average low flows, and average flows between Sept. 10 to 30, show no significant relationship to either the number of Pinks choosing the Tsolum that year, or to Pink returns two years later. However, while the August 15 to September 15 average flow shows no relationship to Pink returns two years later, there is some correlation between August 15 to September 15 average flows and Pinks counted in the Tsolum River in the same year, with that relationship having a Correlation Coefficient of 0.414 and an R^2 of 0.17.

5.2 High Flows

As Pink eggs and then fry live and grow in the river gravels for the majority of the high flow season, the data was also examined for the size and frequency of high flows during the combined period of spawning and incubation, through to emergence and out migration of fry. Eggs, aluven, or fry could potentially be affected by siltation, or bedload movement. Changes in survival rates during this period were looked for in any relationship between high flow days and the Pink returns from those fry two years later. Spawning occurs from Oct 1 to Oct 15, and fry swim up or emergence from the gravel as late as mid April, (with out migration following). Average monthly flows at the Tsolum near Courtenay WSC station are listed below, showing the vast majority of yearly high flows over the October through April period.

Table 3: WSC gauge 08HB011 Tsolum R nr Courtenay avg monthly flows 1965-2006 (CMS)

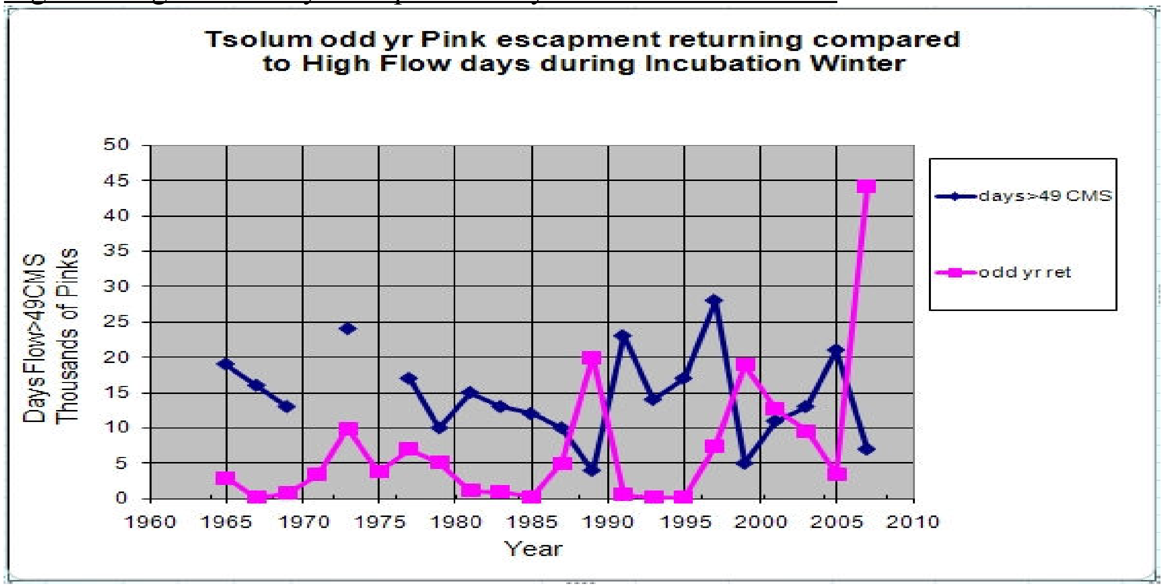
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
19.54	17.43	15.4	10.97	6.73	3.7	1.45	0.86	1.49	7.89	19.29	22.43

The number of high flow days during the winter incubation period was compared to the returns of Pinks two years later. For this purpose the Tsolum R near Courtenay WSC data was re-sorted into water years, which uses the end of one year's data, and the beginning of the next year's, to create a record of each full rainy season, instead of each calendar year. As nearly all high flow events of the year are within the period between spawning and emergence, peak flow and high flow days for the entire water year, or the entire wet season, were used in this analysis. No breakdown of high flow days each water year for month, or separate stage of egg or fry development, was done.

For each winter season, days with an average flow of 50 CMS or larger, as well as days with average flow 100, 150, and 200 CMS or larger, were compiled. 50 CMS was selected as an approximate threshold where significant bedload would begin to move. This is approximately half of a bankfull flow in recent times, and in the range of the 1915 and 1916 recorded peak flows measured. Since even year Pinks have been practically non-existent since 1980, with one year's exception, the odd year Pink escapement was used for this analysis.

Visual inspection of the graph of number of days 50+ CMS flow against returns 2 years later shows that since 1980, with only one exception in 1997, a low number of days (<10) of this flow or higher during the winter coincides with an improved return. The incubation years with 7 or less days over this flow have produced the best three returns since 1960.

Figure 5 High Flow Days compared to 2 years later Pink Returns



To determine whether the higher flow subsets of the days of flow 50 CMS and over (such as flows 100 CMS and over) had a greater or lesser effect, a flow factor was calculated which was intended to simulate the increasing bedload movement up to current bankfull flow (~100 CMS), with more extreme bedload transportation occurring at bankfull flow or higher. The flow factor ff = (#days 50+CMS)+(#days100+CMS) counts days at or over 100 CMS twice, giving them more weight. The flow factor was also compared to escapements returning 2 years later.

Table 4: Statistical results for Winter High Flow Days Compared to Odd Yr Pinks Returning

Comparison to odd yr Pink returns 2 yrs later	Correlation Coefficient	R squared
1977-2007 #days>49	-0.586	0.27
1977-2007 log #days>49	-0.62	0.385
1997-2007 log #days>49	-0.675	0.46
1997-2007 log flow factor	-0.696	0.485

The results show a good inverse correlation, growing stronger in the last decade, and would also indicate that flows as high, and higher than, bankfull flow (~100 CMS) have a more damaging effect than flows between 50 and 100 CMS.

5.3 Peak Flow Analysis

Peak flow data for the full record of the Tsolum R near Courtenay was analysed to attempt to determine if any changes in yearly peak flows have occurred from watershed development, or changing climatic conditions. Any increases in the 1.4 to 2 year return period flow (the range of generally accepted "channel forming" flows), would result in changes in the channel size needed to accommodate this flow, resulting in increased bank erosion, sediment, and bedload.

Estimation of return period flood flows was performed on the Tsolum near Courtenay WSC data, using the BC Environment program FFAME. 2 year return period (Mean Annual Flood MAF) and 100 year return period flows during the late, and post major forest harvest time period were computed from the 1956 to 2009 flow record.

Table 5: Tsolum R, Courtenay, Flood Frequency Analysis Results, 1956-2009 average daily flows data

From Daily Average Flows	Mean Annual Flood (2 yr r.p.)	100 year r.p.
1957 to 2009 WSC dataset	125 CMS	230 CMS

Pre-development peak flows

There is only a short WSC record of flows in the Tsolum prior to major forest development of the upper watershed, and so any speculation as to pre-development peak flow has statistically a wide margin of possible error. Two calendar years' peak flows were recorded by WSC, 1915 and 1916, at 52.4 and 50.4 CMS respectively. Estimation of MAF using only these two points would indicate a MAF of 51 CMS, however a minimum of three points are required for the flood frequency analysis program ffame.

Inspection of the data shows there are three water years' flow data, from Sept 1, 1914 to Mar 31, 1917, therefore a possible third data point. Peak daily flows recorded in the Tsolum near Courtenay for water years 1915-16 and 1916-17 were 51 CMS and 33 CMS. 1914-15 recorded a 60 CMS peak in September, however Nov 12, 1914, the WSC gauge apparently failed the second day of an extreme storm event, with a last daily flow recorded of 41 CMS, before 13 missing days of record.

This storm event had very intense and sustained rainfall, with 158 mm in two days at the Alberni Beaver station, 111 mm on Hornby, and created a 368 CMS flow in the Puntledge which has only been exceeded once since, in 2003. Early Puntledge WSC records have 5 years' data, 1914-1920, with continuous 'current' data from 1965 to present.

A comparison of the full record of Tsolum and Puntledge yearly peaks yields a very poor correlation (C.C. =.15, R^2=0.023), which is likely at least partially due the buffering effect of Comox Lake, and any reservoir operations there. However, a comparison of high flow events during the 1914-17 record was done comparing Tsolum and Puntledge flows, considering the three day precipitation associated with the events. For some events the Puntledge showed little reaction compared to the Tsolum, one cause of which may be that Comox Lake was not at full pool. For the remaining six events, where the Puntledge high reaction showed the lake was likely near full pool early in the event, the Tsolum peak reached was an average of 0.41 times the Puntledge peak (varied from 0.37 to 0.48). Using these results to estimate the November 1914 Tsolum peak gives us a flow estimate of between 135 to 177 CMS for that event. Using the average value 0.41 coefficient, event peak estimate for the Tsolum is 151 CMS.

Using the higher end estimate, with 177 CMS for a calendar year peak in 1914, 52.4 for 1915, 50.4 for 1916, a flood frequency analysis with n=3 gives a MAF of 75 CMS (daily flow). Using the average value, 151 CMS, for a 1914-15 water year peak, 52.4 for 1915-16, and 33 CMS for the 1916-17 water year, a flood frequency analysis gives a MAF of 63 CMS.

A clue as to how close these MAF estimates may be is found by looking at the peak flows recorded on the Puntledge. The Puntledge MAF over 50 years of data is 230 CMS. Use of 1915-1920 data gives a Puntledge MAF of 225, very similar to the long term MAF. Using only 1914-15 to 1916-17 water years, however, as we have done on the Tsolum, gives a Puntledge MAF of only 160 CMS, (long term MAF/1.4). As well, 1915 and 1916 Puntledge peaks of 126 and 119 CMS are well below the long term MAF of 225. It would appear, considering all of the above, that the pre-development Tsolum MAF would have been well above the 51 CMS that the recorded 1915 and 1916 values would indicate. It was also likely above the Tsolum 1914-15 to 1916-17 water year result of 63 CMS, or the higher estimate of 75. If the Tsolum MAF in the 1915-20 period was the same amount higher than the MAF from 1914-16 data as found in the Puntledge data, the pre 1920 MAF would have been as high as 63x1.4=89 CMS, or even, using the higher end 1914 event estimate MAF of 75 CMS in this equation, a very upper estimate of 105 CMS.

On the Puntledge, both 1915 & 1916 flows are exceeded 42 yrs out of 50 recorded. In 50 years of data on the Tsolum, the 1915 and 1916 peaks are exceeded 46 years out of 50. While this indicates that these were low storm intensity years, it may also indicate, assuming that relative intensities of the high flow producing precipitation events occurring in the neighboring basins were similar, that the Tsolum had a lower flow response, relative to conditions later in the century.

Based on the above different looks at the available data, with the various clues as to what the actual MAF was in the early 1900s, this writer's informed speculation places it in the range of 90 to 100 CMS.

Tsolum near Courtenay data from 1964 to 2009 was also separated into individual blocks of data by decade, to try to track the changes in the channel forming flows, and therefore the varying stresses, which the channel has experienced over the decades after nearly completed forest harvest. Results are shown in the table below.

Table 6: Variation of Tsolum near Courtenay Mean Annual Flood (daily avg. flow) with decade

Time interval for MAF calculation	Estimated Mean Annual Flood (CMS)
1955, 1956, 1964 to 2009	125
Pre 1920 estimate	90-100
1964 to 1969	130
1970 to 1979	122
1980 to 1989	109
1990 to 1999	140
2000 to 2009	143

These variations in MAF from pre-1920 through to the 1980s fit the hydrologic theory as to what is likely to occur to MAF from a fairly rapid harvest (in this case a 30 to 40% increase in MAF), then a gradual recovery through the following 20 years, to close to a pre-development MAF. Note that in the channel segment time series analysis, the 1960s were when the channel was undergoing rapid widening and aggradation, the 1980s were years when the new bars began to show significant re-vegetation. These channel observations would appear to also fit with the variations in MAF above.

However, the early 1990s photos show increased activity again in bedload movement. One cause of this renewed movement can be seen in the increased MAF (higher than the 1960s immediately after major forest harvest) from 1990 to present, which would have stressed the newly healing channels. It is probably worth noting, in this discussion of Tsolum peak flows, that the peak flows of 1968 (189 CMS) and 1973 (192 CMS) were not exceeded until 2007, and that in the last four years the peak flow has been over 200 CMS in three of those years. This trend may be a result of climate change's predicted increased storm intensities, possibly in combination with renewed forest harvest activity, however they are certain to be causing increased stress on the channels, slowing bar re-vegetation, and prolonging unstable channel conditions.

6.0 Discussion of Results

The Tsolum River underwent a profound change in channel morphology between the 1957 airphoto series and the 1964 series, with upper tributary morphology breaking down, and heavy aggradation in the lower reaches of the upper Tsolum and Murex, and beginning down the mainstem. This timing coincides with the major sustained drop in Pink salmon escapements. Bedload movement has been very high in the watershed since around 1960. While some healing and re-vegetation of bars had occurred by the 1980s, higher flow conditions in the 1990s destabilized the still sensitive channels, and continue to slow natural stabilization of bars.

The mapped Channel Assessment summarizes current channel conditions. In most of the mainstem channel, and lower Murex Creek, due to aggradation, there is a pronounced lack of good, deep, pool habitat, with only a few really deep pools between Helldiver Creek and the Puntledge confluence. Dove Creek's lower reaches were less impacted, with lower Headquarters Creek the least aggraded. All middle elevation tributary reaches visited also had a loss of pools from degraded channels and a loss of boulder structure, severely in Murex Creek, to only partially in Headquarters Creek below Wolf Lake. There are still some reaches (i.e. lower Murex, Upper Tsolum around the Helldiver Creek confluence) with very large mobile bars that are reworked on every high flow, and portions are transported further downstream. There is continuing bank erosion on the lower floodplain, which will continue this trend to loss of pool depth in the mainstem.

During the entire period of the airphoto record, back to 1946, significant bank erosion has been occurring at sites through the cleared agricultural fields on the lower floodplain below and well above Portuguese Creek, with large point bars, long shallow riffles, and migrating channels. These floodplain sites have a higher percentage of fine materials in the fields eroded, which continue to be transported and deposited downstream at high flows to the present day. These fines deposited downstream have likely had a significant cumulative effect over the years on survival in any redds downstream of the erosion.

The mobilized gravel from the eroded banks, in combination with increased bedload movement from further upstream, has made access across the riffles in this lower reach more difficult for inmigrating Pinks upstream. Most years this will only cause a delay until a there is a slight rise in flow. However holding in warmer pools, in or near a tidal reach accessible to seals, would not increase spawning success. Note that the old fish fence platform in the lower Tsolum would also likely delay passage upstream at very low flows. A fairly low but significant correlation between average Aug 15 to Sep 15 flows, and Pinks counted that year, may indicate that some inmigrating Pinks choose instead go up the Puntledge instead of the Tsolum, if lower Tsolum flows are too low for easy access.

At normal low flows, the large fan at the Murex confluence still almost totally blocks access for migrating Pinks into Murex, and into the Tsolum above Murex, and probably has since around 1960. Access to Dove Creek for spawning Pinks has also likely been blocked by the confluence fan for much of the period from the mid 1960s to the 1980s, and intermittently since. For much of the time since the late 1950s, Pinks have probably been limited to spawning in either the main river below Murex or in HQ Creek. It is possible that survival rate has been affected by spawning being limited, for much of the last 30 years, to Headquarters Creek, and the mainstem Tsolum below Murex Creek, instead of in the more spread out, diverse pattern which would occur without access problems.

Incubating eggs and pre-emergent fry are vulnerable to the combination of high flows and unstable mobile bedload. Considering the other factors influencing survival from incubation to return, such as ocean survival, the results of the statistical analysis showing correlations between Pink returns, and days of flow at 50 CMS or higher, or the Flow Factor during their incubation, are surprisingly high, with the number of high flow days, especially when over bankfull flow days are weighted, explaining nearly half the variation in returns. With the unstable bedload in the Tsolum, a large number of days with flows of a magnitude to create significant movement of that bedload appear to very much reduce survival to outmigration. The only three winters since 1980 with less than 10 days at 50+ CMS have each produced, two years later, the only returns of around 20,000 or more.

7.0 Recommendations

1. Continue bank stabilization and riparian re-vegetation efforts in the agricultural lower floodplain. This will reduce siltation on downstream redds of all species, and help move the channel towards a deeper narrower state, easing passage upstream from the warmer lower reaches, and hopefully eventually help reverse the losses of depth in holding pools. Creation of scour holes with cover should be incorporated into these bank protection works where appropriate.

2. Remove or create a break in the old fish fence platform near the fairgrounds to remove any impediment to upstream movement. While this structure may or may not have a large negative influence, there is no apparent benefit to favor keeping it in place.

3. Allow stream-keepers from TRRS to monitor, and if needed improve access to Murex Creek and the Upper Tsolum, on a yearly basis before and during the Pink count. Dove Creek fan, and a few locations on its lower reach, should also be monitored. Minor movement of gravel/cobble material by hand would open a significant length of channels to Pink spawning, or speed passage upstream to colder water.

4. Continue and if possible increase low flow enhancement. While not the largest factor, there will be incremental benefits from reduced losses during inmigration and more variety in selection of spawning locations. If Dove, Murex, or the Upper Tsolum are flow enhanced, access to a wider range of spawning areas will be improved, as well as improving habitat for resident fish and rearing Coho.

5. Probably the single largest factor limiting Pink success is the unstable excess bedload in combination with years of extended high flow days during the incubation winter. Two approaches to this problem are: stabilizing (or removing) the excess bedload, and minimizing any preventable increases in peak flows.

<u>Stabilization of Bedload</u>

- In the mid to lower reaches of Murex Creek, and the upper Tsolum above Helldiver's lower aggraded reaches, LWD placement to slow flow across bars, and for erosion protection, would encourage natural growth and reduce material transported from the bar.
- There has been some success in direct planting to establish vegetation on larger more mobile gravel bars by deeply digging in large live willow stakes.
- Root strength on bars which are already semi-stabilized with deciduous growth may benefit by planting of conifers underneath.
- Incorporating a bit of rock work at some stabilization sites would likely increase success rates

In the above, sites would have to be carefully selected for likelihood of success of a given option.

<u>Removal of Bedload</u>

- Removal of gravel from the lower reach of Murex Creek, and the confluence fan, should be investigated further for feasibility, with the caution that, if not done very carefully, removals may increase short term bedload movement to and past the Murex-Tsolum confluence significantly. Options looked at should include an extensive removal, from the confluence fan to upstream of the Duncan Bay Main (DBM) bridge, with LWD stabilization works upstream, locally around the confluence fan on a periodic basis, and/or creating a bedload 'trap' downstream of DBM bridge which is cleaned out to a deep pool on a yearly basis.

<u>Minimize any preventable increases in yearly peak flows</u>

To minimize bedload movement, and encourage natural and assisted bar re-vegetation and channel recovery, in land use decisions

- the mainstem Tsolum River channel below Murex should be treated as moderately peak flow sensitive.
- The Upper Tsolum (Blue Grouse) from ~ 2 km upstream of the Helldiver confluence to downstream of the Murex confluence should be treated as highly peak flow sensitive.
- The lower reaches of Murex Creek should be treated as extremely peak flow sensitive.

7.1 Monitoring or Further Study

With the consistent and ongoing efforts towards restoration of the Tsolum River, an agreed upon reach designation scheme would assist communication, long term morphology and habitat assessment and monitoring, as well as planning of works. The reach designation scheme should be based on stream morphology similarities within a reach, with stream length distance from some downstream point such as the Puntledge confluence or beginning of estuary as a 0 point incorporated.

Monitoring efforts should include:

- Selected deposition reaches in the upper Tsolum, lower Murex, and mainstem Tsolum between Murex and Puntledge should have a length of the channel marked out, and each low flow period have the thalwag depth measured at regular intervals (2 to 3 m) along the channel. The resulting depth frequency curve would monitor changes in pool extent and depth, and help track changing levels of aggradation through the channel system.

- Turbidity meter measurements during rising stage of high flows should be taken, with a reading every few hours as the river rises to peak, from at least two locations, one downstream of forest lands near HQ Creek, the other between the Puntledge confluence and single lane trestle bridge, below the agricultural lands. This would not have to be done for all events, but should be for the same events at each location, and would help clarify the relative inputs of fines from each source.

Further Study:

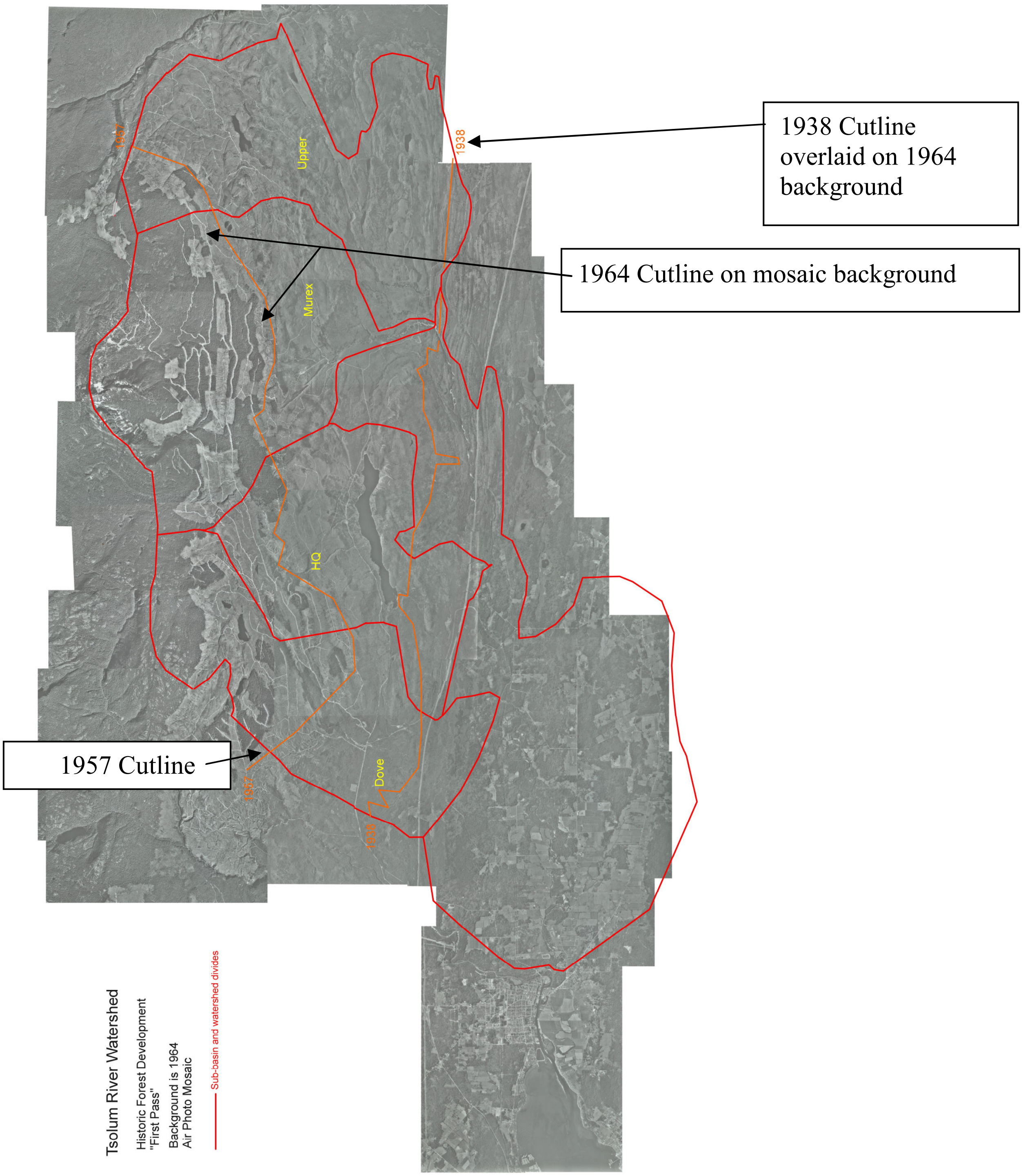
As high flow days appear to be a significant factor, and road systems are accepted as the major factors by which forest development can increase peak flows, the road system within the Tsolum basin should be looked at more closely, with a significant field component to the study.

Of particular interest would be to determine opportunities in the upper watershed for minimizing sub-surface flow interception, and diversion to streams by ditching, and also opportunities for returning ditch flow to sub-surface flow.

Appendix 1: Tsolum River Watershed Air Photos Available and Selected

Tsolum River Watershed Historic Air Photos					
			photos in blue to be ordered		
year	**flight**	**watershed photos**	**location notes**	**maintem photos**	**comments**
1938	BC80	47--49	Helldiver cutting		valley bottom logged
	BC78	35--43	mainstem, low elev	32--43	
	BC79	1--18	incl Murex - Brown lower slopes	1--10	Wolf uncut
		17--32			
1946	BC256	98--100	higher elev		1st rds into Regan
	BC257	33--45	midslopes		Lost (Twin) lakes logged, and ravine
		65--78	Wolf elev		Constitution Hill and Wolf Lk logged
		91--104	Estuary to Helldiver mainstem	91--104	lower tribs logged
1951	BC1268	11--15	Portuguese Cr		Not ordered
	BC1421	21	Estuary		
1957	BC2312	28--36	mainstem	28--36	
		59--66	upper		mid slope cutline (above Regan Lk to Oyster)
	BC2318	14--22	very upper		
1964	BC5097	8--16	mid upper	included in	midslope cutline
		53--60	mainstem	watershed series	
	BC5101	130--140	upper W/s (~max develop)	ordered	scattered blocks
1968	BC7077	155--160	Portuguese		
	BC7078	27--40	mainstem	34--40	
		130--150	ends E of Helldiver	137--146	
		188--208		189--194	
	BC7079	38--57	Punt to Bl Grouse		
		103--120	Regan to Comox Lk		
	BC7080	245--256	very upper w/s		cut into extreme upper
1972	BC7406	232	Portuguese		
		281--290	mainstem	285--290	only mainstem and lower trib morphology
	BC7403	140--155	upper mainstem	142--150	photos from this date
		79--100		93--98	
	BC7400	236--257	ends Puntledge		
		175--195			
		72--82	very upper		
1975	BBC7764	203--209			
		250--262	mainstem	251--262	
	BC7766	221-238		231-235	
	BC7767	16--31		18--21	
		253--268			
	BC7765	20--32	very upper		
1981	BC81080	111--112	Helldiver		
		131--137		132--134	
		161--167		165--166	
		182--194		186--187	
	BC81107	1--10		1--2	
	BC81070	125--133		132--133	
		145--152		144--145	
1984	BC84024	24--37		31--37	
		73--81		73--81	
	BC84025	157--160			
		106--118			
	BC84026	164--168			
1991	30BC91023	178--190	Browns		
		198--208		207--208	
		226--239		229--230	
		243--257		252--253	
		275--287		278--279	
	30BCB91024	33--40		6--7, 32--34,39--40	
1996	15BCB96014	129--133		129--130	
		127			
		177-183			
		223--224			

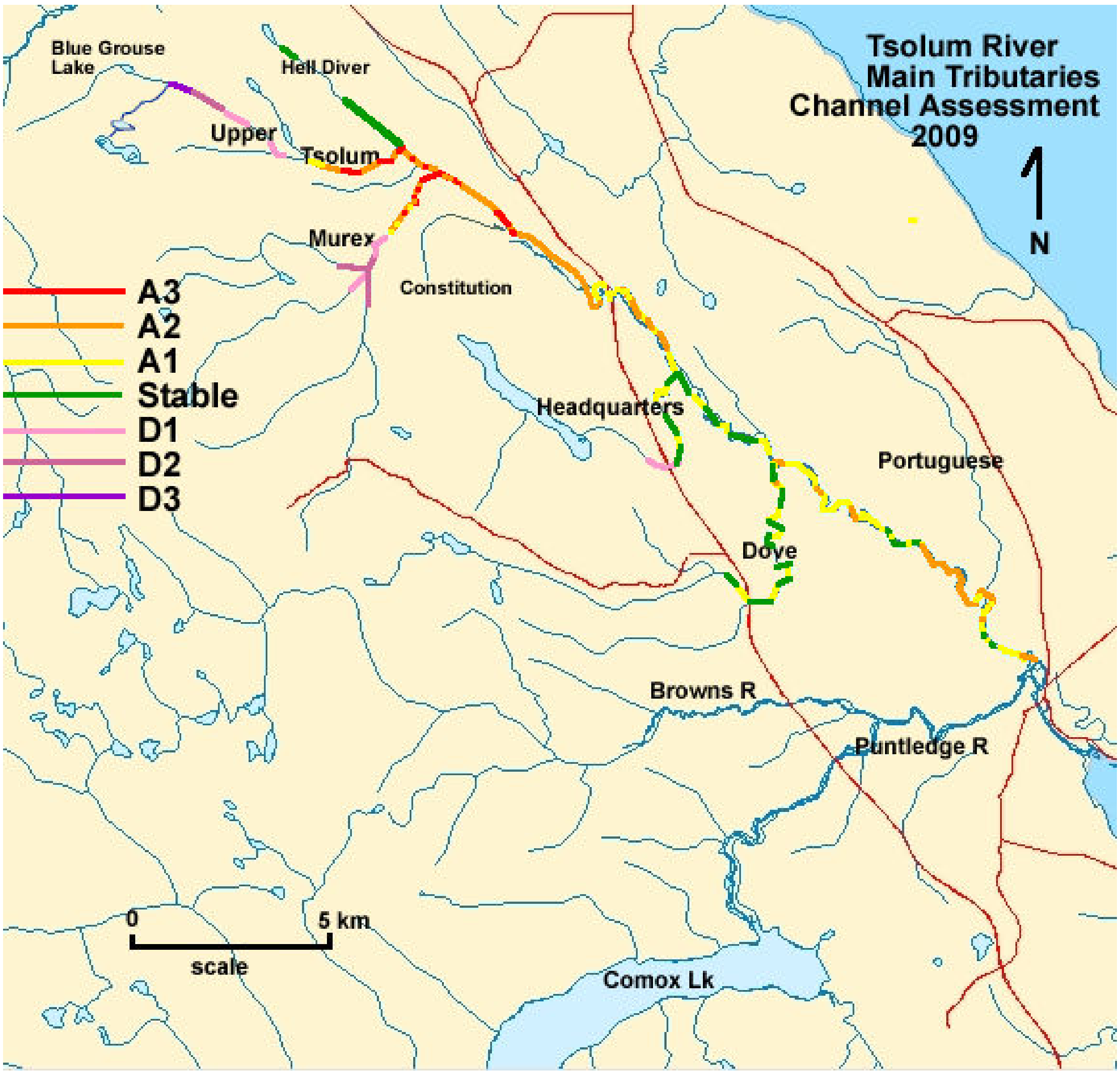
Appendix 2: 1964 Air Photo Mosaic with Historic Forest Development



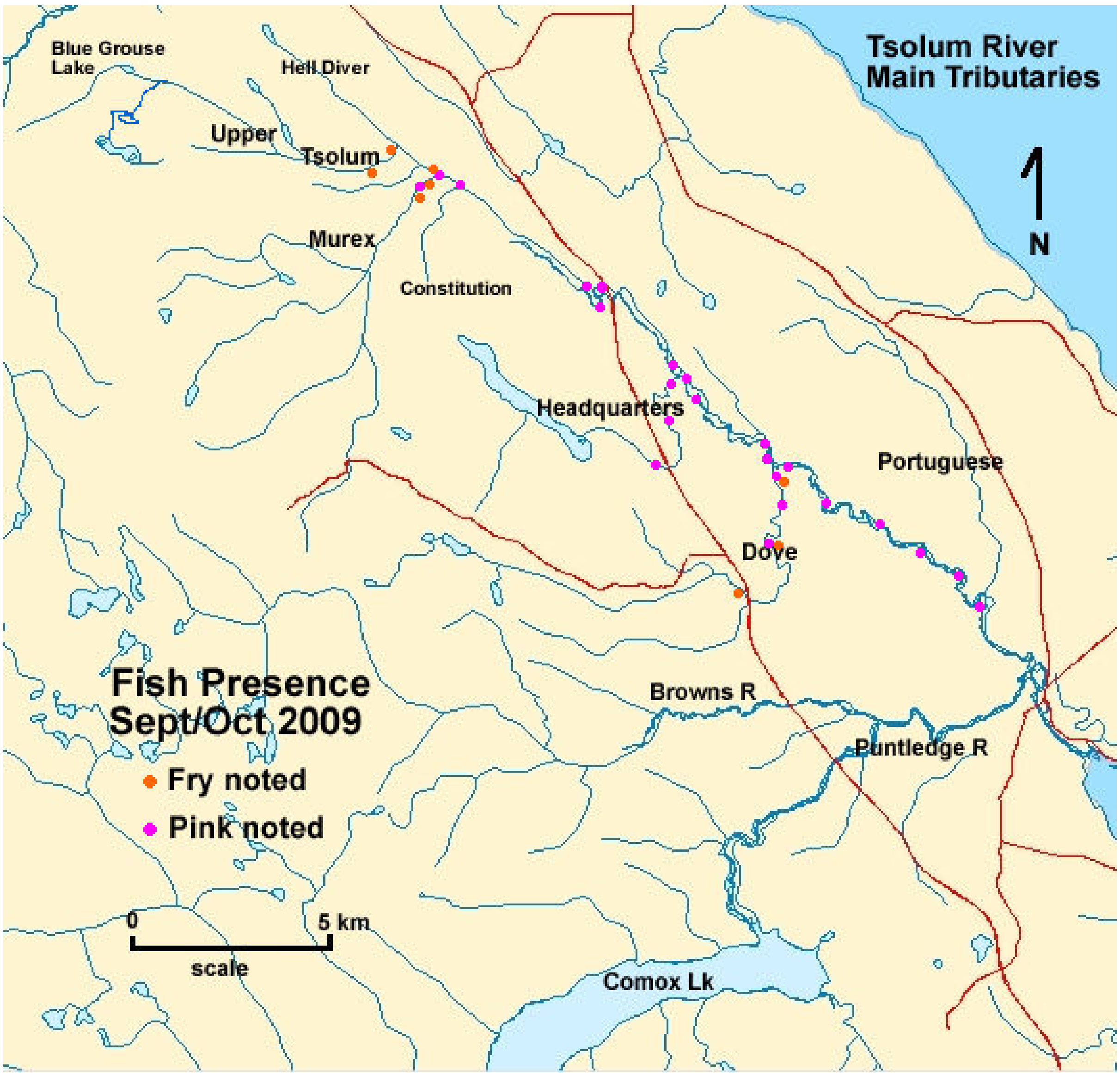
Note: For better detail, this mosaic views better with zoom at least 200%

Appendix 3: Results of the Channel Assessment 2009

Legend explanation: A3 severely aggraded, A2 moderately, A1 partially aggraded
D3 severely degraded, D2 moderately, D1 partially degraded



Appendix 4: Field Survey Sept/Oct 2009 Fish Presence Mapping



Additional Appendixes 5-1 to 5-9 for Air Photo Time Series Compilations as separate documents

Additional Separate Appendixes for Field Channel Assessment Procedures (CAP):
Appendix 6A CAP Tsolum Main
Appendix 6B CAP Murex
Appendix 6C CAP HQ
Appendix 6D CAP Dove

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