Gooding
Hydrology

# SUTTON CREEK
# Investigation of Flood Risks in Honeymoon Bay
# With
# Flood Mitigation Recommendations

For
The Provincial Emergency Program
Victoria, B.C.

By
Dave Gooding, P.Eng.
Gooding Hydrology
Saltspring Island

July 2007

| Contents | Page |
|---|---|
| | |
| Executive Summary | 3 |
| | |
| 1.0 Study Location | 4 |
| 1.1 Background | 4, 5 |
| 1.2 Method of Study | 5 |
| | |
| 2.0 Historic Watershed and Flood Mitigation Activity | 5, 6 |
| 2.1 Relevant Results from the Historic Air photo study | 6 |
| 2.2 Relevant Results from the Stream Channel Assessments | 6 |
| 2.3 Current Condition of Lower Stream Channel | 6, 7 |
| 2.4 Large Wood Debris | 7 |
| 2.5 Sediment Source Survey | 7 |
| | |
| 3.0 November 15, 2007 flood event | 7-10 |
| 3.1 Consultations | 10 |
| | |
| 4.0 Risks to Public Safety | 10, 11 |
| 4.1Recommendations for Flood Mitigation | |
| 4.2 Short Term | 11-13 |
| 4.3 Long Term | 13 |
| 4.4 Maintenance | 14 |
| 4.5 Flood Watch | 14 |
| | |
| 5.0 Watershed Hydrology | 14 |
| 5.1 Design return period flows and velocities | 15 |
| 5.2 Weir rock sizing | 15 |
| | |
| 6.0 Parks | 15 |
| 6.1 Fisheries Values | 15 |
| 6.2 Fisheries Mitigation | 15, 16 |
| | |
| Appendixes | |
| Appendix 1: Terms of Reference | 17 |
| Appendix 2: Photos of Lower Reaches of Sutton Creek | 18, 19 |
| Appendix 3: Recommended Flood Mitigation Works | 20, 21 |
| Appendix 4: Air photo Watershed Assessments | 22-29 |
| Appendix 5: Stream Channel Assessment | 30-34 |
| Appendix 6: Sediment Source Survey | 35-38 |

*Gooding Hydrology*
*Dgooding @saltspring.com*

**Executive Summary**

Sutton Creek stream channel, through the village of Honeymoon Bay on Cowichan Lake, has a very high bedload, and high Large Wood Debris movement, which has built into high bars, and even cross channel accumulations of deposited bedload and LWD, in the lower 1.5 km populated reach. Due to difficulties by the major landowner in getting approvals for instream works, the accumulating excess bedload has not been removed for the last 15 years. This accumulated bedload and LWD is reducing channel capacity, diverting flows, and generally producing more erosive forces on the banks. Where riparian vegetation zones were especially weak, this erosion has been rapid.

On November 15, 2006 heavy sustained rain raised flows in Sutton Creek to a 10 to 20 yr return period flow. It appears a landslide initiated debris flow ran down much of the length of one of the upper tributaries, creating heavy bank erosion in the upper mainstem of Sutton Creek, and contributing to heavy silt, LWD, and bedload entrainment in the high flows entering the lower reaches. Flow under a logging bridge above the village was obstructed, resulting in up to 6 m deep ponding, with the failure of an abutment fill releasing the ponded water, which increased and may have sustained peak flows experienced downstream. Eroded banks threaten the golf course bridge, and two homes downstream. Extensive overbank flows deposited silts through the golf course, inundated three homes, and flowed across the highway, cutting road access by either the logging road or the highway. Flows across the highway flooded through the trailer park to the lake and downstream channel. Bedload and LWD deposits from this event have further raised and obstructed the channel, so that overbank flows occurred on the golf course and over the bank into one of the previously flood damaged residences in what was around an average yearly flood in March 2007.

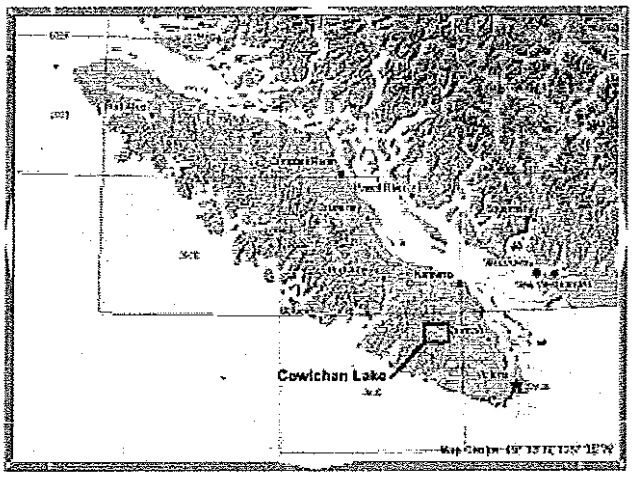
Successive flood events will continue to increase the material in the channel, and with it the flood risks. It is recommended that excess bedload accumulations be removed from the channel from the logging bridge to the highway bridge, with LWD relocated to form bank protection in less critical areas, and that two weir fields be constructed for bank protection above the golf course bridge and flooded residences. Set-back berms are also recommended, as is raising of the most severely flooded residences.

Sutton Creek stream channel has been disturbed by heavy forest harvest in the decades prior to 1970, contributing to a large amount of bedload moving down the lower four to five kilometers of the mainstem. Future channel maintenance will be needed, however some long term measures which could reduce the severity and duration of excessive bedload movement are suggested.

Sutton Creek is high value fish habitat, and any works must mitigate impacts to the fisheries. Bank protection and flood damage mitigation methods recommended are intended to also benefit fisheries values.

## 1.0 Study Location

The village of Honeymoon Bay, at the mouth of Sutton Creek, is located on the southwest shore of Cowichan Lake, on southern Vancouver Island, around 10 kilometers west of the town of Lake Cowichan. Sutton Creek drains from the Seymour range, with the 9 kilometer valley bottom main channel of Sutton Creek running approximately west to east. The lower kilometer of the stream runs through an ecological reserve, a golf course, and residential properties, and crosses under the South Shore Road MOT bridge just upstream of the lake delta, which is occupied by a trailer park.




## 1.1 Background

During the 2006-2007 winter rainy season, two separate high flow events caused flood damage to the golf course property and to residences, and flood flows crossed the highway, South Shore Road, to the northwest of the bridge. The first event occurred November 15, 2006, during an extreme rainfall storm event which covered much of Vancouver Island. A large LWD (Large Wood Debris) accumulation impeded flows upstream of the logging bridge just above the golf course, creating ponding to the level of the logging road. Eventual release of the water damaged the logging bridge approach, and rushed downstream through the village of Honeymoon Bay. Three homes were inundated, one to around 0.5 meters depth inside. Out of bank flows then flowed across the highway, where they are reported by locals to have been over 0.6 m in depth. Much of the trailer court on the downstream side of the road was inundated. A large amount of sediment, bedload, and LWD was transported in this dam break type of flood flow. Significant bank erosion, and deposition of bedload and LWD, occurred in the reach from above the logging road to the lake.

The second flood event occurred after heavy rains on March 11, 2007. Although the flows were smaller, likely in the range of the Mean Annual Flood (MAF), damaging flooding again occurred to at least one of the residences previously flooded. This was due largely to a decreased channel capacity, resulting from aggradation on the gravel bars and in the channel, and Large Wood Debris (LWD) accumulation, from the earlier event. Due to the severity of the November flooding, and risk to public safety at this populated location, followed by another event causing flood damage in the same year, PEP has asked Gooding Hydrology to investigate the reasons flooding seems to be becoming a more severe problem, and to recommend any short and long term solutions to mitigate the

problem. Terms of reference for the study are attached in appendix 1, and include investigation of historic watershed and channel conditions, and changes which may be affecting the stream in the lower populated reach.

**1.2 Method of Study**

An initial site visit was made to the lower reach of Sutton Creek on May 10, 2007, with PEP and regional district representatives, where flood damage to properties had occurred. The stream channel was found to be in a severely aggraded condition in this lower reach with a high amount of LWD, and active bank erosion.

To determine the source of this excess bedload and LWD, historic air photos have been analyzed, to determine historic land use in the watershed, and note any gross stream channel changes or sediment sources which might be apparent. Based on information from this analysis, a further site visit July 7 was made to communicate with landowners affected, and to do a field assessment of the Sutton Creek stream channel. This field assessment included the channel through the properties receiving flood damage this last year, locations on the nine kilometer mainstem of Sutton Creek, and the lower ends of the main tributaries and headwaters of the stream. On July 11 a helicopter flight was made over the stream and watershed further investigate potential sediment sources, and view the mainstem and tributaries' channels. The results of the watershed, stream channel, and sediment source assessments are given as Appendix 4, 5, and 6.

Further field trips were made to the lower reach of Sutton Creek, where flood mitigation works to protect public safety may be required, for preliminary conceptual design and discussions with property owners. Both short and long term options for mitigating flooding in the lower Sutton floodplain are considered, and discussed. In the short term, methods of reducing flood impacts considered include channel modification and flood protection works in the lower reach. Return period flood flows are estimated for their design. Over the longer term, upstream sources of the excess sediment and LWD flows affecting the lower channel are discussed, with possible mitigative methods considered, as well as maintenance of short term works.

**2.0 Historic watershed and flood mitigation activity**

Farming and forest harvesting activity in the Sutton Creek watershed was begun in the late 1800s on the lower floodplain, with logging proceeding up the stream valley's bottom and lower slopes gradually for the first half century. The rate of cut accelerated in the decades of the 1950 and 1960s, moving up the mountain sides and tributaries. By 1970, the first cut of the watershed was substantially completed. During the last ten years, harvest of the older second growth in the lower valley has been ongoing, currently covering approximately the eastern and lower 10% of the watershed area.

Lower Sutton Creek has a history of works in the lower reach to remove bedload accumulations over at least the last 50 years. Gravel removals to deepen the channel, and reduce gravels bars, and LWD relocation, was performed periodically since well before 1970, by Charlie March, whose family since before 1900 farmed the current golf course

fields. Damaging flooding of significance is not reported as occurring during this era of periodic channel clearing. Difficulties obtaining an approval to do instream works discouraged landowners from removing accumulating bedload in the fifteen years since 1992. Large gravel bars have accumulated in the lower reach since 1992, and are partially becoming vegetated with willow. The MOT highway bridge pilings were damaged in 1994, and repaired in 1995. Ongoing problems led to the replacement of the highway bridge with a clear span bridge in 2003. The lower trailer park, delta portion of Sutton channel was historically dredged periodically, to the lake, however the last dredging remembered by local residents was in around 1995.

**2.1 Relevant Results from the Historic Air photo study**
In 1968 photos, the watershed was in an approximately 2/3 recently clearcut condition, with many of the tributaries in an almost entirely recent clearcut condition, and was near its most extreme state of historic disturbance. Second growth was seen at the lower elevations, the valley bottom and some lower slopes. All riparian vegetation in the basin, and practically all steep slopes, were logged during the first full cut of the Sutton watershed, which was probably finished around 1970.

Later 1979 and 1984 air photos show re-growth of the forest, and indicate a few areas where mass wasting and landslides are still occurring. Tributary S2 appears to have a large fan and bar in the 1984 photo.

**2.2 Relevant Results from the Stream Channel Assessments**
Results of this channel assessment, given as Appendix 5, with map and photos, show a disturbed stream channel. There is a large amount of excess bedload in the Sutton Creek stream channel, for approximately the lower 2/3 of its 9 kilometer mainstem. Much higher bedload flows than prior to watershed development, into the populated area of the lower kilometer of channel, will continue to occur for decades. However, the amount of excessive bedload being transported into the lower populated reach, as well as the number of decades it will continue, could be reduced significantly. This is discussed further in the recommendations section of the report.

A debris flow from the upper north side tributary N4 appears to have been a major contributor to the severity of the November 15 2006 flood event. This is discussed further below.

**2.3 Current Condition of Lower Stream Channel through Honeymoon Bay**
The channel through the lower reach of Sutton Creek is highly aggraded, with large high gravel bars reducing channel capacity, and placing a higher erosive pressure on the banks. Gravel bar accumulations, with revegetation of the older point, side, and mid-channel bars, is constricting flow, causing the stream's meander pattern to migrate more quickly downstream to avoid the growing bars. Erosive pressure has increased on the outer banks on downstream ends of bends. The stream maintains a meander pattern of a suitable radius of curvature, which provides the most efficient flow for its size and gradient, by eroding more strongly where it is forced to turn more sharply, which gradually widens the

curve. In lower Sutton Creek the stream encounters obstacles and uneven bank strength in its migratory erosion of the banks on the outside of bends, and is forced into sharp turns. Through the golf course, these resistant areas of bank include stronger patches of riparian vegetation, LWD accumulations, the golf bridge abutments, and the riprapped bank downstream of the right golf bridge abutment. Allowing continued migration of the meander bends will erode not only the golf bridge abutment, but threatens significant lengths of the narrow, older riparian vegetation which is all that remains for riparian values along over half of the lower km of Sutton Creek. Where the stream banks have a weaker bank strength, or thinner riparian vegetation, erosion is very active.

**2.4 Large Wood Debris**

During both the channel assessment and helicopter reconnaissance a large amount of mobile LWD, mainly second growth deciduous, was noted in the mainstem of Sutton Creek. In the downstream third of the length of the Sutton mainstem stream channel, LWD was generally parallel to flow, often mid-channel. No channel spanning LWD mats were noted, although there are scattered loose accumulations.

In the center third of the 9 km length of the mainstem, relatively new LWD is beginning to span the channel. A large scattered accumulation, and wide bedload deposits, was noted at around half way down the mainstem, where the stream emerges onto floodplain from the confined reach below the debris torrented tributary N4. Much of the LWD in the channel has originated from bank erosion, with a lesser amount from slide activity.

LWD movement into the lower reach of Sutton Creek will continue to be relatively high, as the widened middle and upper channel, with the relatively young riparian vegetation, will tend to produce mobile LWD, instead of stable, stream spanning LWD which would occur with a narrower channel and larger trees. However, no large upstream cross channel accumulations, which could break loose and move downstream as a mass, were found in the lower reaches.

**2.5 Sediment Source Survey**

The sediment source survey, with photos and approximate locations of observed sources, is given in Appendix 6. Four debris slides into the Sutton Creek main channel, and one recent debris torrent, were observed. While this is not a high number of landslides, when combined with tall bank erosion at numerous locations there is a significant continuing sediment input into the Sutton mainstem channel.

**3.0 November 15, 2007 flood event**

From the evidence of channel disturbances, and sediment and LWD deposits, in the Sutton Creek watershed, a reconstruction of the likely series of events leading to the November 15 flood damage around Sutton Creek in Honeymoon Bay is possible.

Sustained heavy rain November 14 and 15, (preliminary data analysis reports Messachie Lake and nearby Harris Cr had over 50 yr return period rainfall) raised stream flows and saturated the soils in the Sutton watershed. Sometime in the P.M. a debris slide from a

steep slope by tributary N4 entered the stream approximately a kilometer upstream of its confluence with the Sutton mainstem. This would have temporarily blocked flow, initiating a debris torrent which ran the length of N4 and down the Sutton mainstem channel. This torrent, with entrained rock and wood debris, created numerous areas of bank erosion along the confined Sutton mainstem channel from tributary N4 downstream for around 1.5 km. Some larger rock settled out of the torrent in this confined transport reach, however much second growth deciduous LWD and eroded bank material was added to the flow.

An extended deposit of some of the torrent's debris, bedload and LWD, is seen on the first reach of unconfined channel, or floodplain, which was reached by the torrent run-out, between the Sutton confluences of tributaries S2 and N2, (approx Gordon River road markers km 7 and 8). Some of the torrent's flow of debris, LWD and finer bedload, continued down the now lower gradient (2%) channel, likely contributing to the bank erosion observed in the short final confined reach of the stream, downstream of tributary S1 and the bedrock canyon below Gordon River road marker km 6. As the attenuated debris torrent entered the lower valley, it continued to place extra erosive forces against outer banks of bends, and more bank material and LWD were accumulated. Gradients down this reach decrease gradually, and some large deposits of the sediment, and LWD, were dropped on bars where a slightly lower local gradient existed, or temporary blockages occurred.

LWD accumulated and obstructed flow through the opening of the logging bridge above the golf course, constraining flow enough that water ponded to approximately 6 m depth, high enough to flow over the logging road. A large deposit of bedload settled out in the over 200 m of channel which was ponded upstream of the logging bridge, with LWD. Approximately 5 m of the fill behind one concrete bridge abutment failed, which increased flow capacity enough to release the ponded waters. It is unknown what the exact mechanism of the release of the ponded waters was, or how rapidly they were released, but even if gradual it would have added a component of outburst or dam break flow to the flows which entered the populated lowest reach of the Sutton.

This water flow entering the village of Honeymoon Bay was higher than would have been experienced without the effect of the release of the ponded waters from upstream of the logging bridge. However, due to this ponding, and the trapping of LWD around the bridge opening, much less LWD and coarser bedload entered the stream channel through Honeymoon Bay than if the remaining entrained debris from the upstream torrent had carried through the village unimpeded.

The migration downstream of the meander pattern, in response to increasing deposits on gravel bars, has resulted in the outside of a bend, where erosive forces are greatest, now eroding just upstream of the golf bridge, in an area which lacks riparian vegetation. This erosion progressed Nov 15, and is threatening the left abutment of the golf bridge. At the downstream end of the golf course, a riprapped right bank directs flow into the end of an eroding riparian strip, creating turbulence and cross channel flow. Downstream of this

turbulence, accumulation of gravel and LWD in, and upstream of, the old channel has caused a side channel to be utilized and enlarged in the last few years, which has been progressively eroding the bank towards the residences which flooded during this event. Flow has split in two, with a large vegetated bar between channels, with flow in the more southern old main channel to the right, and in the new channel to flow left.

Splitting of the flow created less ability for the channel to carry bedload and LWD, and more LWD was deposited, upstream of the split of the two channels, and across much of the older southeast right channel, along with additional gravel bedload. This further constricted flow through the old aggraded main channel, causing channel build up, and back-watering enough to push some overbank flow into the golf course slightly upstream on the right bank, and most of the main flow into the newer left channel, and into the eroding bank behind the three residences which suffered flood damage. This relatively new channel is slightly higher than the old channel for much of its length, with bed height dropping at the downstream end, to meet the old channel bed height where flows join. Flow overtopped the eroding outer bank of the new channel, went through the residential properties, and crossed the highway into the trailer park. A further occurrence of overbank flow at this location, during the March 2007 flood event, (estimated to be in the range of the Mean Annual Flood), would indicate that the channel here no longer has the capacity to contain flow in most years.

*Highway Bridge (South Shore Road)*
The flow direction approaching the highway bridge has shifted, and is now parallel to South Shore Rd, a full 90 degrees from the most favorable direction of approach to the bridge opening, which is directly towards the opening. Flow begins to contact the highway fill upstream of the abutment riprap, however erosion there does not appear to be rapid. Flow through the bridge opening is at a sharp angle, impinging directly on the right, or SE side. Riprap on the downstream end of the SE abutment has begun to move, dropping in to the deeper erosion the impinging high flow has created. A large gravel accumulation has accumulated in the lee of the NW abutment. This gravel bar under the bridge does not appear to limit the capacity of the crossing significantly as flow is currently oriented. Should flow shift to a more direct approach to the opening, this material would be eroded to settle lower in the channel to the lake.

Flooding in the trailer park near the lake occurs many years, according to residents, with trailers being regularly moved to higher areas, as the pads near the lake flood from high lake levels. However, even higher areas than normal flooded in the November event, due to the cross highway flows into the trailer park. Residents report that the rip rapped channel downstream of the highway bridge did not overflow, until the point where lake levels and stream surface levels were close to the same. A larger than usual amount of silt was reported being deposited wherever overbank flows occurred. It is likely much of this silt originated in the debris torrent from tributary N4, and the increased bank erosion it aggravated in the Sutton mainstem.

It is difficult to estimate the frequency of occurrence of the November 15 peak flow in Sutton Creek through Honeymoon Bay. Without the trigger events of the debris torrent in tributary N4, and the flow obstruction by LWD, with ponding, above the logging bridge, it is likely that the return period of flows in Sutton Creek would have been similar to those experienced in many southern Vancouver Island streams on that date, as the heavy, sustained rains were widespread. This storm did not produce extreme record flows, as there was little snowmelt added to rainfall runoff. This is evidenced by nearby Jump Creek MOE snow pillow, which lost very little of its 200 mm Snow Water Equivalent snowpack in the 6 hours temperatures rose, and added snow before and after the 15$^{th}$. Gauged south and central Vancouver Island real-time WSC stations reported flows which were mostly in the 5 to 20 year return period range Nov 15. Nearby Harris Creek flows were estimated that day as slightly less than a 10 year return period flow. From reported flow levels, it is speculated that the November 15 flow would have been in the 10 to 20 year return period without obstruction of the logging bridge, where release of ponded waters may have increased the flows downstream to as much as the 20 to 25 year return period range.

### 3.1 Consultations

As well as consultations with the regional district and PEP representatives, the Sutton flooding problem and potential mitigating works have been discussed with DFO district officer Brad Rushton, and MOE habitat stewardship representative, John Baldwin. Their opinion was that work in the stream needs to be done, and if the works were under the auspices of the regional district only a notification, not the approval process, would be required under Section 9 for instream works, as the works would be channel maintenance by a municipality or local government. Most of the affected landowners have been contacted and consulted. Those consulted would support the works recommended. BC Parks has not been directly contacted regarding instream works through the ecological reserve. MOT has been contacted regarding the riprap movement and gravel bar under the bridge, and will investigate.

## 4.0 Risks to Public Safety

Risk is the product of likelihood of event occurrence, and the scale of the negative consequences if the event occurs. Risk assessment was done qualitatively, with professional judgment used in estimating the likelihood of occurrence of an event. Consequences would be considered to be high if the event in question would cause risk to health, public safety, and infrastructure, moderate if the consequence was significant property damage, low if flooding would not cause significant damage. Where likelihood of occurrence is moderate, and consequence low, risk would be rated as low. However, where likelihood of an event is low, but significant, with moderate or high consequences, risk should be rated as moderate, or even high if consequences are high enough.

A high risk location is the eroding bend behind the three residences which were inundated this last year, with flows then going across the highway. Unless some flood damage mitigation works are done, there is a high likelihood of overbank flow, and flood damage, at a Mean Annual Flood level, with occasional but less frequent cross highway

flows. There is a moderate likelihood that bank erosion will continue as far as one of the residences. There is a low, but significant, possibility that the stream will erode a new channel across the highway and through the upper trailer park.

The north golf bridge abutment has a high probability of failure within a few years, unless some protective work is done. Loss of use of this bridge is a property damage, not a public safety, issue. However, if the abutment fails, and even one end of the bridge falls into the stream, blocking or diverting flow, it could create downstream consequences which do create a risk to public safety. If the abutment fails and the bridge obstructs flow, there is a moderate likelihood that the channel could avulse and move to the west from the golf course bridge down, which would increase flood risks to the homes between the golf course and the highway bridge, including the residences which flooded this last year, and to the highway. Although uncertain, this should probably be considered a high risk location.

The high gravel bars and large amount of LWD upstream of the logging bridge, especially where ponding occurred due to bridge opening blockage by LWD, but also in the kilometer upstream, create at least a low probability that a blockage could again occur. However, the consequences are relatively high, from loss of that bridge, to outburst flows again increasing the flows, and flood damage experienced, downstream to the lake, so risk could be described as at least moderate.

There is a high likelihood that overbank flow will occur at two or three points along the right bank through the golf course. As there are no residences threatened, the consequence is relatively low, gravel and silt deposition on the golf course.

The probability of progressive riprap movement on the SE highway bridge abutment causing failure of the abutment is low, however the consequences are high. MOT is in the process of investigating the site, so no risk assignment will be given here.

A certain level of risk would be involved in working only at the above sites, and not stabilizing banks or increasing channel capacity between them, as the success of works at each site will be improved by an integrated approach.

**4.1 Recommendations:**

**4.2 Short Term Flood Risk Mitigation Works**

1. For flood mitigation for the inundated residences, and to reduce the likelihood of cross highway flow, the large gravel accumulation across nearly the entire channel width upstream of where the channel splits, and some of the side bar accumulation in the old channel, should be removed. As well, a weir field to protect the eroding bank along the residential properties is recommended, with a set-back berm to redirect any overbank flows back into the channel. Adding fill to the yard, and raising the house onto a higher foundation, should be considered by those residence owners where flood damage occurred. A preliminary conceptual

design of weirs, with locations of needed gravel removals, has been sketched onto the air photo of this site attached as in Appendix 3.

2. To reduce the probability of failure of the left (NW) golf bridge abutment, a weir field, as bank protection for the upstream bank and the abutment, and to lengthen the radius of curvature and shift the thalwag out from the eroding bank, is recommended. In conjunction with the weir field, gravel relocation to reduce the point bar on the opposite side of the stream, which is pushing flow into the eroding bank, is recommended. A preliminary conceptual design of weirs, with locations of needed gravel removals, has been sketched onto the air photo of this site attached in Appendix 3.
3. To reduce the likelihood of the logging bridge opening again being obstructed by LWD, and to prevent the large accumulations of LWD and bedload in the 200 meters upstream of the bridge from moving into the populated reach in the next few high flows, it is recommended that the gravel accumulations for around 200 m upstream of the logging bridge be removed, and the LWD relocated to locations favorable to slowing bank erosion. A photo of this location is in appendix 2.

The above works should be done in conjunction with overall flood mitigation works, comprising channel capacity improvement by reduction of bars, and bank protection in the worst of the eroding locations, utilizing combined LWD, larger sized available bar material, and partially buried willow clumps, excavated from some bar tops, to strengthen the banks. Relocated material from bar reduction can be used as fill (with willows) between weir bases, as set-back berms to confine future overbank flows through the golf course and by residences, or stockpiled. Treatment of the accumulations and local erosion for the entire length of river above the logging bridge to the highways bridge in this manner will maximize the length of time between stream channel maintenance cycles, and reduce the frequency of overbank flows. It also disrupts the gradient of the reach the least amount possible.

The large bedload and LWD deposits above the logging bridge create a significant disruption, or shift, of the old meander pattern. Flows impinge more directly, and are required to turn too rapidly, eroding a section of Ecological Reserve left bank. This meander disruption and erosion pattern continues through the reach downstream to the highway bridge. Removal of the depositions and LWD obstructions which create the first large disruption of the meanders would increase the likelihood of success of bank protection and channel works downstream

The Ministry of Transport is assessing the seriousness of the riprap movement at the downstream end of the SE abutment of the highway bridge. If works are being done in the channel upstream, removal of some of the high gravel bar from under the highway bridge would reduce any constriction it is causing, and prevent that material from eventually depositing lower in the channel, through the trailer park. Channel maintenance works upstream, if they are successful in shifting the meander pattern, may improve the angle of flow approach to the bridge opening.

While the bed level has risen from accumulated bedload deposition, it appears the riprapped channel through the trailer park accommodates high flows, with overbank flow not reported by residents to have occurred much above the level at which high lake waters were flooding the lower trailer court. This should be re-assessed at the time of the next stream maintenance assessments.

**4.3 Long Term Flood Risk Mitigation**

Where narrower riparian leave strips occur on private properties along Sutton Creek, through Honeymoon Bay, they should be enhanced and widened by property owners for their own protection.

To lessen the number of years for which lower Sutton Creek will continue to receive excess bedload, the first step, as recommended by the old Watershed Restoration Program, is reduction of sediment input from the uplands above the stream channel. Wherever possible, sediment and bedload sources, such as debris slides and erosion of high banks, which are depositing material into Sutton Creek or its tributaries, should be stabilized and revegetated.

The confined upper mainstem channel suffered extensive bank erosion, especially along the south stream bank side slope, from tributary N4 downstream. Air photos and observations show the portion of this south slope for the kilometer downstream of tributary N3 is sensitive, having historic and current landslide activity into the stream. Some of these bank erosion sites may progressively fail uphill, becoming debris slides. Slope stability assessments should be done prior to logging on and around these slopes.

Large sediment wedges in the stream channel can be stabilized, or at least slowed and partially removed from active yearly bedload movement, by active bar stabilization and revegetation works.

Management of the level of forest harvest, or ECA, should consider the disturbed and sensitive state of the stream channel, and manage for a low risk of increases to peak flows. Any increases created in the size and frequency of peak flows experienced in Sutton Creek will accelerate the rate of sediment transport from upstream bars and channels, and therefore of deposits into the lower populated reach. Some parts of the large sediment wedges and high bars in the upper unpopulated mainstem channel will naturally vegetate, or be stabilized by LWD. Increased peak flows which more actively move bedload would lessen the amount of bedload naturally stabilized. Riparian management of LWD controlled and functioning channel morphologies, which is the mainstem, and all tributary reaches where gradient is less than 12%, should assure a future supply of LWD input to those channels.

**4.4 Maintenance of Mitigation Works**
Excess bedload and plentiful LWD will continue to move down Sutton Creek, and will continue to accumulate in the populated lower reach. Periodic reduction of gravel accumulation on bars will be necessary until sediment sources are reduced, and the accumulated bedload throughout the lower four kilometers of the mainstem moves through to the lake, which will be decades. The length of time between bar reductions being required is probably in the range of 5 to 10 years, with severe events potentially shortening that time interval, or successive more moderate flow years increasing the interval. Active works to stabilize upstream bedload, and reduce sediment input, could increase the time interval between gravel removals within a few cycles.

Bank protection weir fields, even if properly constructed, need to be monitored, and may require minor repairs periodically for proper functioning, especially in the first few years as they 'settle in'. Landowners should assume responsibility for monitoring.

**4.5 Flood Watch**
During periods of very high flows, an excavator sitting by the logging bridge with an operator on call, combined with a periodic check by an observer that the bridge opening is clear, would decrease the likelihood of extensive ponding behind a full blockage of the bridge opening again occurring. LWD accumulations by the bridge could be cleared as they form, or a blockage cleared gradually to slowly release any ponded water. The operator would need to be knowledgeable of risks associated with work around high flows and a potentially weakened bridge, and should confine their works to removal of obstructing LWD at the bridge.

**5.0 Watershed Hydrology**
Sutton Creek, with a watershed area of 45 square kilometers, has a coastal hydrology, with highest flows during the higher precipitation months from October through to April, and low flows during the drier summer season. Peak flows occur from heavy rainfall during the wet winter months, with extremes of flow often coming from rain on snow events, when warm "Pineapple Express" Pacific weather systems, with heavy sustained rain, melt a relatively shallow snowpack, which adds to runoff. Spring snow runoff generally only produces flow increases which are significantly smaller than those from heavy rainfall or rain on snow events.

No flow records were found for Sutton Creek, however Harris Creek, whose upper basin is just over 3 km from Sutton Creek's upper basin, has a real-time Water Survey of Canada (WSC) stage gauge with 11 years of records. As a flow comparison for the November flow, Harris Creek, (basin size 27.9 sq km), is estimated to have had a Nov 15 peak flow 160 cubic meters per second, less than a 10 year return period (r.p.) flow. The March 11 peak measured at Harris Creek was 102 CMS, near the Mean Annual Flow. Design return period flows were estimated for Sutton Creek using MOE streamflow inventory mapping and graphs, a west coast extreme flows envelope curve, and comparison to Harris creek, assuming peak flows are proportional to area to the 0.4 power. Values given below are slightly conservative.

**5.1 Engineering Considerations**
**Design flood flows and velocities**

| Return Period | Flow (CMS) | Mean Velocity (meters/sec) |
|---|---|---|
| 2 yr (MAF) | 120 | |
| 10 yr r.p. | 205 | |
| 50 yr r.p. | 280 | 4.8 |
| 200 yr r.p. | 340 | 5.0 |

**Required rock size for weirs**
Weirs require larger rock sizes than riprap blankets. D50 for weirs should be over 1 m, with largest rock up to median dimension 2 m.

**6.0 Parks**
An Ecological Reserve is located on both sides of Sutton Creek, from the downstream side of the logging bridge to the golf course property. Concerns about bank erosion are reported to have been expressed by the Parks district representative. Any works done along the stream bank of the Ecological Reserve would require BC Parks permission.

**6.2 Fisheries Values**
Lower Sutton Creek is historically important as spawning and rearing habitat for both salmon and Trout, and has been traditionally fished for its salmon run. From local sources, last year no fish were taken, as the return was too small. A lack of adequate size and depth of pools throughout the system may be affecting successful coho rearing, and would severely limit the size and numbers of the resident trout population. Coho fry were observed in the deeper LWD related local scour holes in the lower reach, and in the relatively sparse larger pools of intermediate depth, from the lower reach to the lower end of tributary S2, seven km upstream.

Sutton Creek through Honeymoon Bay needs to be treated as a high value fish stream in any works instream. Solutions found for flood damage mitigation should consider, and if possible attempt to improve, fish habitat.

**6.3 Fisheries mitigation**
Much of the LWD in the channel of Sutton Creek through Honeymoon Bay is in locations which are providing little or no value, as either bank protection or fish habitat, and are creating flow obstructions which are in many cases increasing bank erosion and overbank flows. As well, the shift of the meander pattern downstream and away from enlarged bars is, in more than one location, eroding sections of the thin older riparian strip through the golf course, to the detriment of the fisheries values. Utilization of the available LWD as bank protection for eroding banks would place the LWD where scour holes are and will form, creating more deeper pool habitat with cover, which is the habitat element most lacking in Sutton Creek. Where possible, holes should be excavated where scour is predicted to form around relocated LWD, especially where shade also exists, to immediately replace any rearing habitat which may be impacted by moving LWD.

Some of the larger gravel bars are re-vegetating in willow, and removal of this vegetation to scalp the bar will result in the loss of leaf litter, and possibly in some locations shade, function for fisheries, although this revegetation is not generally associated with current pool locations. Excavation of the willow with a large bucket, and replanting of these clumps, behind the relocated LWD, with partially sorted larger diameter bar material from bar scalping, would provide an inexpensive method of increasing bank strength at eroded locations, from available materials. Vegetation would be relocated from where it increases flood risks, to where it can provide bank protection and direct cover and leaf litter to scour pools.

Work around existing scour locations may require fish salvage and sediment control, depending on operations to be performed, and on water levels at the time of any in-stream works which may occur.

PROFESSIONAL
PROVINCE OF
D. D. GOODING
BRITISH COLUMBIA
ENGINEER

Dave Gooding, P.Eng.

## Appendix 1: Terms of Reference

*Sutton Creek Contract*

Under take an investigation of Sutton Creek to determine the likely source of debris and significant gravel build-ups that are effecting public roads, bridges, and properties from approx. 800 meter west of the Gordon river mainline road bridge to the mouth of Sutton Creek on Lake Cowichan.

Report on the history of the watershed and stream channel changes, significant flooding, and on historic mitigation projects on Sutton Creek.

Report on any condition in stream that represents a significant public safety risk by the diversion of flow, the back up of water, the risk of sudden debris release or the erosion of banks.

Liaise with Department of Fisheries and Ocean, Regional District representatives, the Min. of Environment and the Provincial Emergency Program and other stakeholders as required.

Provide a final report of findings and recommendations that detail any significant public safety issue, that reports on occurrences and the size of significant debris accumulations or bank erosion and provide recommendations ( short and long term) to mitigate public safety related issues. Include recommendation for continued maintenance of recommended works.

**Appendix 2: Lower Sutton Stream Photos**

Photo 2a

South Shore Road highway bridge, trailer park to lower right, golf course upper center. Overbank flow path through residences, across highway, and into trailer park marked.

Photo 2b: Golf course on Sutton Creek, golf course bridge just left of center, flood damaged residences and trailer park to upper right.

Photo 2c
Looking downstream, at the large accumulation of bedload and LWD in the 250 m upstream of the logging bridge, where ponding occurred. Ecological Reserve is in the upper photo, downstream of the bridge.

Photo 2d: Logging bridge, Nov 15, 2006, after ponding release

**Appendix 3: Recommended flood mitigation works**

Photo 1. by residences flooded. Gravel removals, with weir field and LWD bank protection sites, and approximate locations where set-back berms would be benificial

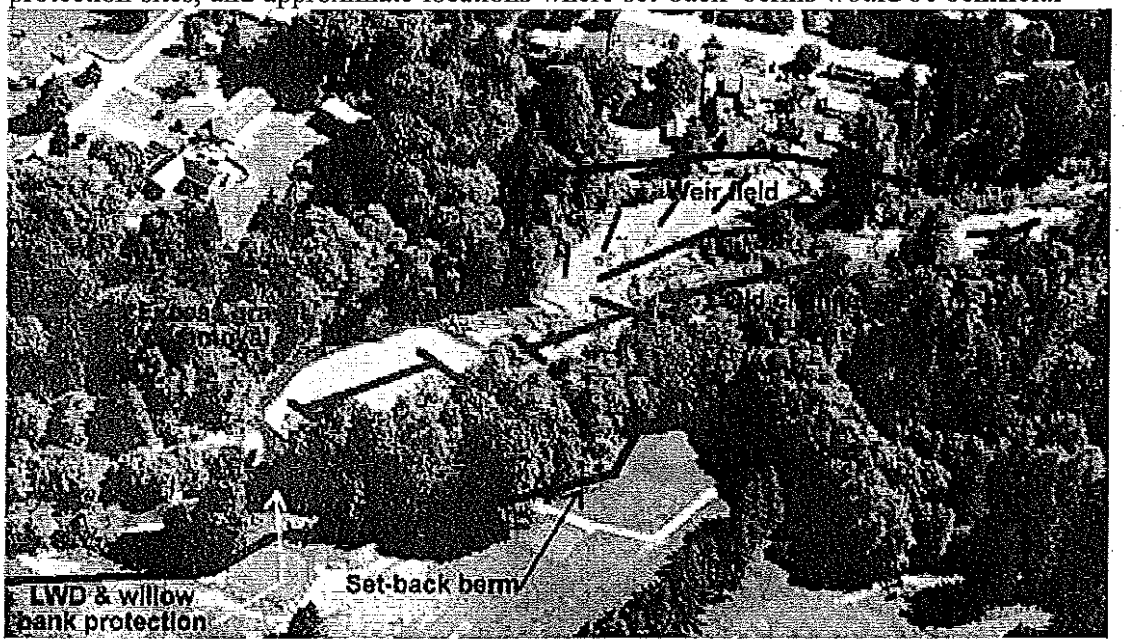
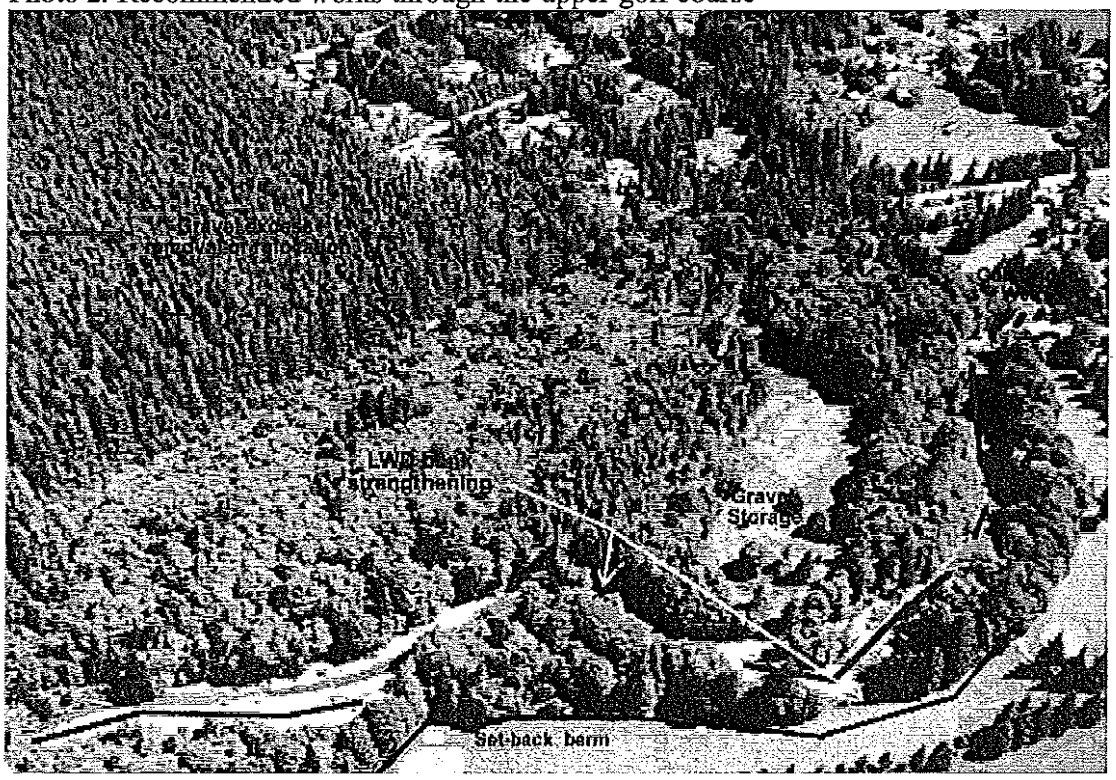
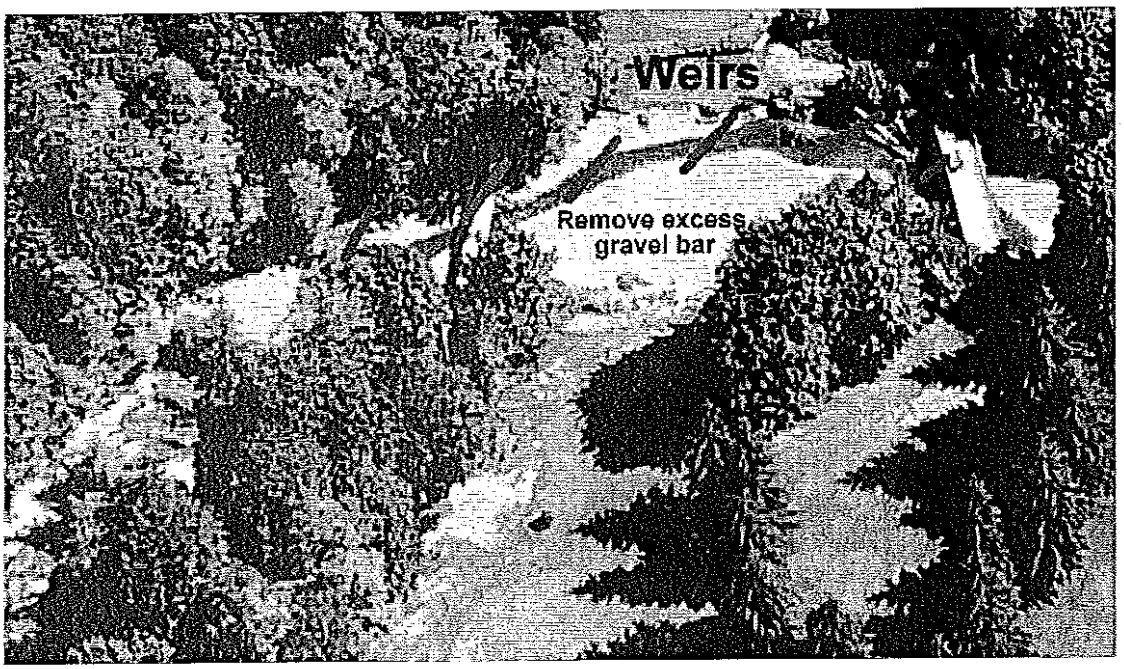



Photo 2. Recommended works through the upper golf course



*Recommended flood mitigation works*

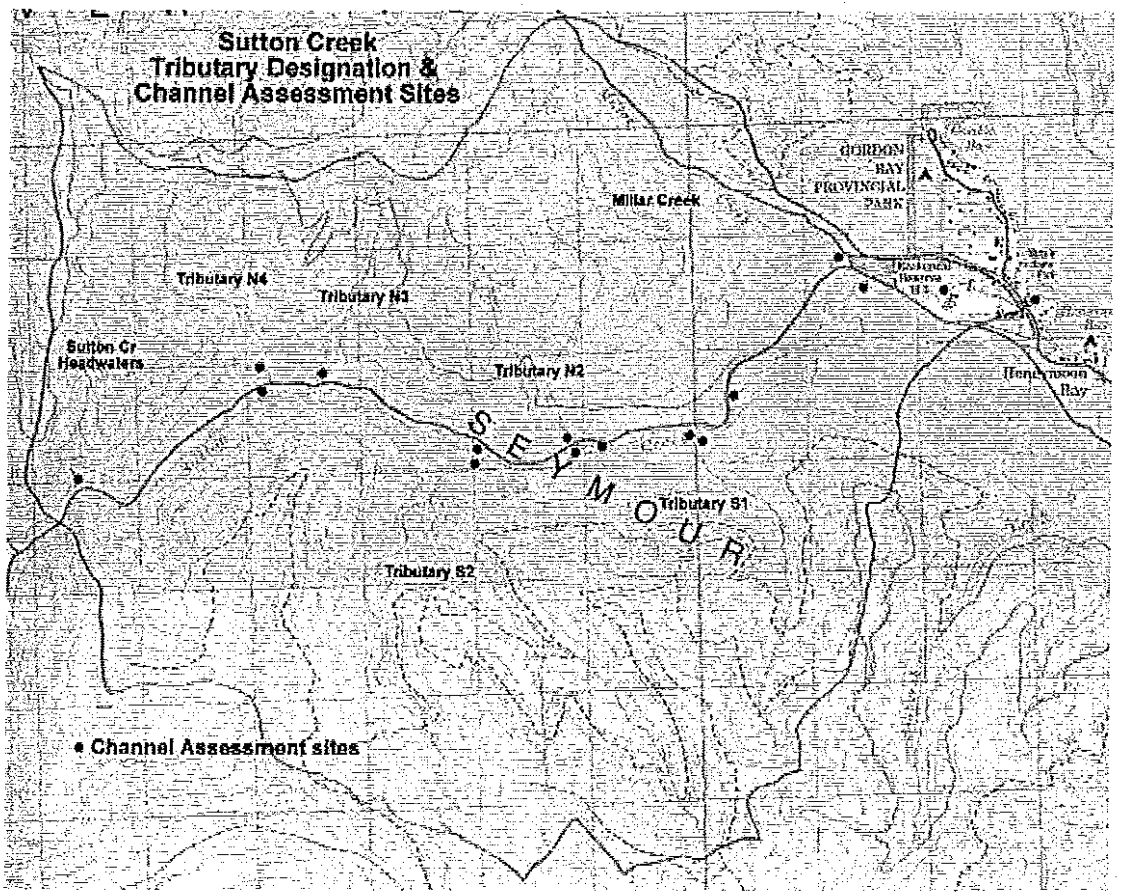
Photo 3.
Preliminary conceptual design for weir field bank protection upstream of the erosion threatened golf bridge abutment. Some fill and revegetation of the bank between weirs is required. It is recommended LWD and clumps of willows from bar removals, with larger excavated bar material, be utilized as fill.



**Appendix 4: Watershed Assessments**
**Limitations of Assessments**

Assessments done do not employ the full methodology and forms of the Forest Practices Code Watershed Assessment Procedure, or Channel Assessment Procedure, however methods used are based on these procedures. This is due to both the limitations of project time able to be allocated, and to limiting assessment to the level of detail necessary to gain the required understanding of processes occurring in the stream, for flood mitigation purposes at Honeymoon Bay. Assessment of historic condition is done from air photos.

Sub-basin and tributary designation




**Current watershed condition**

The harvest of older second growth in the lower elevation and eastern portions of the Sutton Creek watershed appears to have been proceeding for the last 10 to 15 years. At this date, a rough estimate of the proportion of the watershed which has been harvested during this pass is just over 10%. Some hydrologic recovery of the oldest of these blocks would mean the current Equivalent Clearcut Area is less than 10% of the total watershed area. This should not be creating any significant increases in peak flows in the watershed as a whole. Millar Creek sub-basin has a higher proportional cut, with a rough estimate

putting the sub-basin at just over 30% recently harvested, however, some hydrologic recovery has occurred. Current hydrologic practice would predict a low to moderate risk of peak flow increases in lower Millar Creek in the photo based estimated ECA range of 20 to 25% in the sub-basin.

Current harvest has occurred along the Sutton main channel, Millar Creek, and for short distances along tributaries S1 and N2. Along lower Sutton Creek, an adequate riparian reserve was left along the creek above the logging bridge, however in the upstream km it has eroded away at two locations due to channel shifting caused by growing gravel bars. The riparian reserve left for the bottom 0.5 km of Millar Creek is also adequate, however above the ravine it appears to become only a single row of trees. Riparian strips left along the tributaries S1 and N2, for the short length they are along the edge of a cutblock, also appear to be the relatively narrow.

No significant increased clearing of riparian areas is apparent on the lower settled reach of Sutton Creek between the 1968 air photos and current condition, where relatively narrow leave strips are seen through the March farm, (now the golf course), and along the bank behind the residences which experienced flooding this last year.

**Historic Watershed Development**
**Air photo analysis**
Historic air photos were compiled to determine the past history of land use, and natural disturbances, which may have had an impact on the stream channel of Sutton Creek. Disturbances which may affect the stream channel include large fires in the watershed, earthquakes initiating slope failures during saturated conditions, and forest harvesting activities. Obvious changes in channel morphology, such as conversion from a narrow single channel to wider braided flow can also often be perceived by historic airphoto analysis.

The BC Government Base Mapping and Geomatic Services database was researched for available flight lines across the Sutton Creek watershed. The airphoto flights available with coverage of the watershed, listed below, were analyzed both as stereo pairs and as mosaics.

| Year | Flight line | Photo numbers | Scale |
|---|---|---|---|
| 1968 | BC7109/7110 | 212-214/050-054,137-144 | 1:16,000 |
| 1979 | BCC204 | 025-028, 186-188 | 1:20,000 |
| 1984 | BC84026/84028 | 41,42/86-88, 152-155 | 1:20,000 |

More current airphoto flights of the watershed are not available. For current watershed condition, an early 2000's satellite photo from Google Earth was viewed, as well as 2007 photos of the watershed, taken from a plane by a local resident, and from the helicopter reconnaissance flight of July 2007.

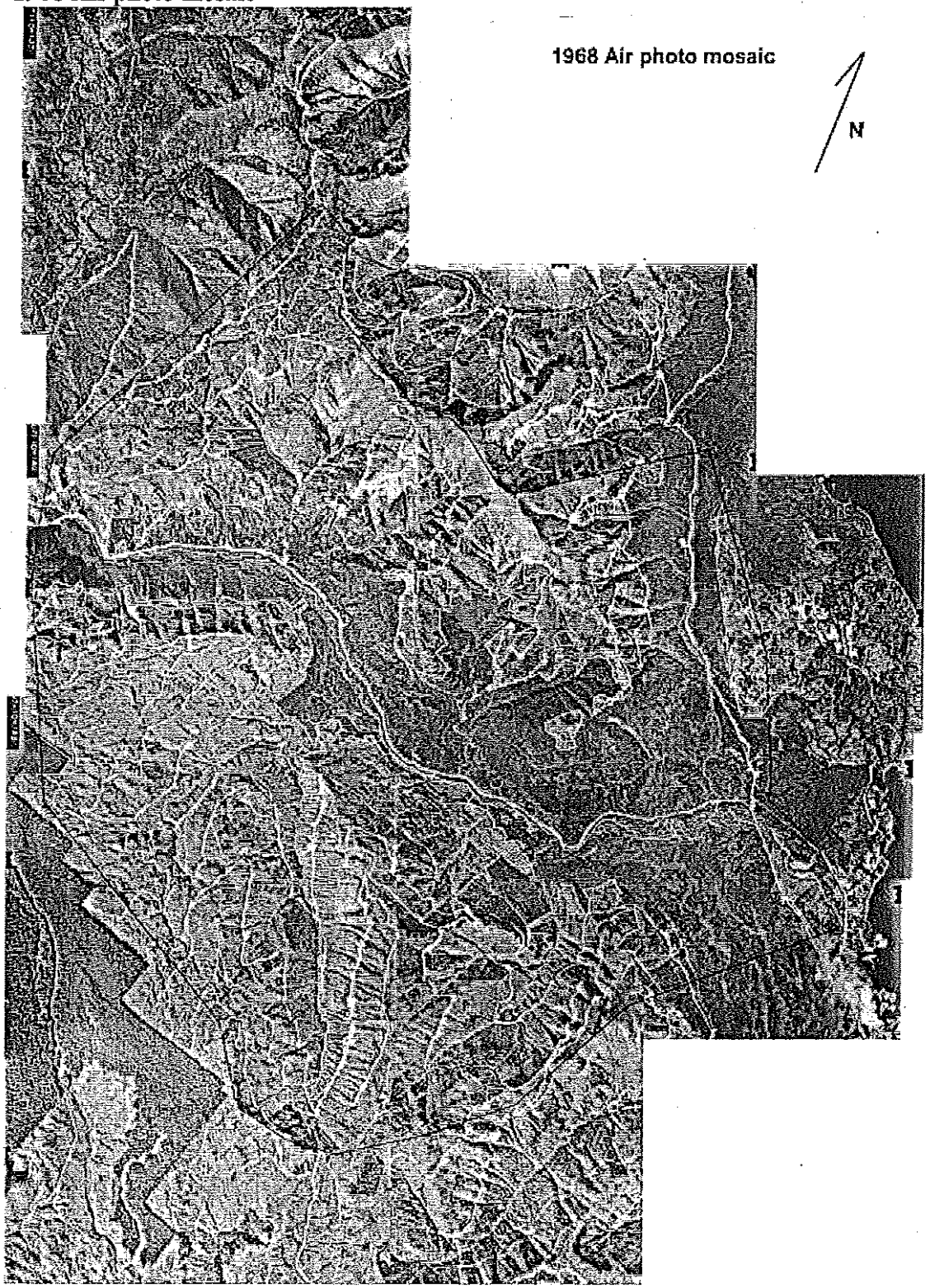
1968 Air photos:
The most significant year in the historic series is the 1968 series, which shows the watershed at approximately the time of the completion of the harvest of all the first growth forest. In the 1968 airphoto mosaic below it is seen that approximately the top 2/3 of the watershed, (delineated by yellow and red boundary lines), appears to be in a recently clearcut condition, with close to the entire sub-basins of the upper tributaries and headwaters of the watershed in a recent clearcut condition at that time. In these photos there does not appear to have been any riparian leave strip left on either the earlier mainstem logging, or on any of the tributaries. The steeper north side of the watershed was largely yarded from access along the ridge tops, with the south side having a more extensive road system along the mountainsides.

The lower elevation 1/3 of the watershed appears to be second growth, growing gradually older to the lower floodplain. It appears that no riparian trees have been left for stream buffer zones during the first full harvest of the watershed, during either the older, slower, valley bottom harvest, or on any tributaries during later, more rapid harvest. During viewing of air photos, note was made of areas which may be experiencing erosion or landslide activity for inspection on later flight lines.

The entire mainstem Sutton Creek, from the Sutton headwaters bridge near the Gordon River road summit to the lake, is of a size and gradient range which fits into the FPC Channel Assessment Procedure classification of its stream morphology as being LWD controlled. During the ongoing period of hydrologic recovery from this first full harvest, the tributaries and the mainstem of Sutton Creek would be predicted by current hydrologic knowledge to have experienced substantially increased risk of peak flows. The lack of mature (or any) riparian trees on the tributaries or mainstem has given the stream banks decreased bank strength during this period of predicted higher flows, resulting in predicted higher rates of bank erosion, and higher amounts of sediment and bedload input to the stream. If the 1960's logging was following the Fisheries policy requiring LWD to be all removed from channels, some bedload or sediment previously stored by the LWD would have been released in succeeding years.

1979 and 1984 photos show the re-growth of the harvested areas, with little forest harvest activity. Many of the possible eroding areas in the 1968 photos show re-growth, however the few which remain un-vegetated were again noted, and where possible observed during helicopter reconnaissance. A time series comparison of channel reaches was compiled, however the relatively small channels are largely obscured by revegetation, and few channel changes (i.e. a large fan by S2 in the 1984 series). Air photos were used for tracking recent historic debris slide activity along the channels.

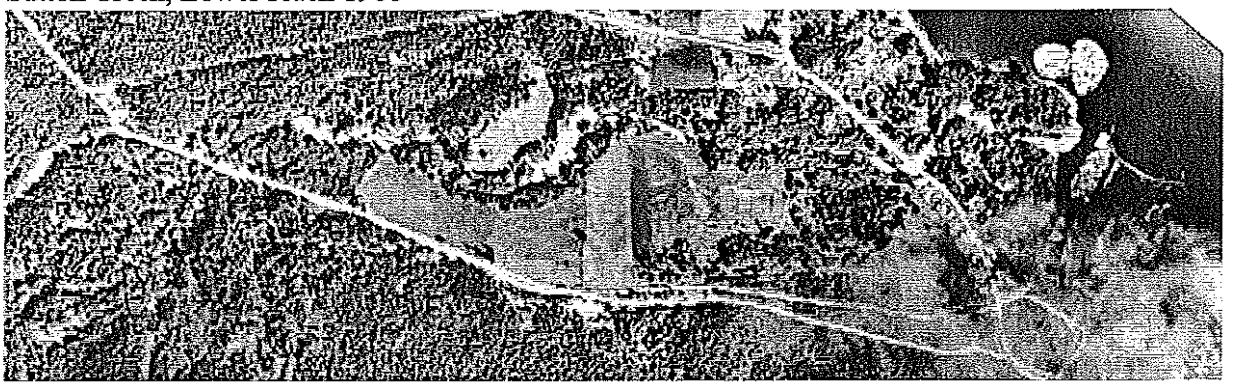
**1968 Air photo mosaic**



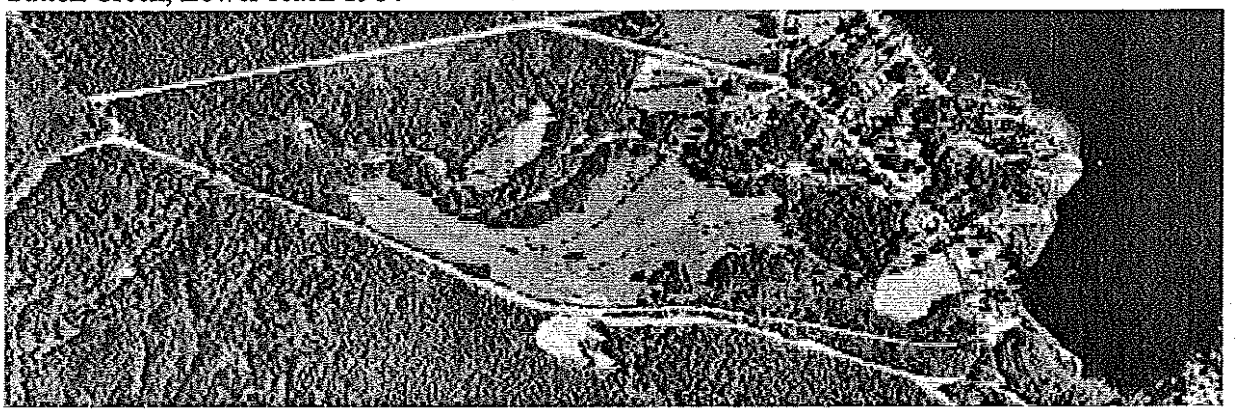
**Air photo channel reach time series samples:**
Time series comparisons of the 3 air photo flights on a reach or tributary basis were compiled to allow viewing of channel changes, progress of revegetation, and mass wasting activity into streams between 1968 and 1984. The time series were analyzed for 8 tributary reaches, the headwaters, and 6 main channel reaches. Samples of these series are shown below.

Stream Channel Time Series

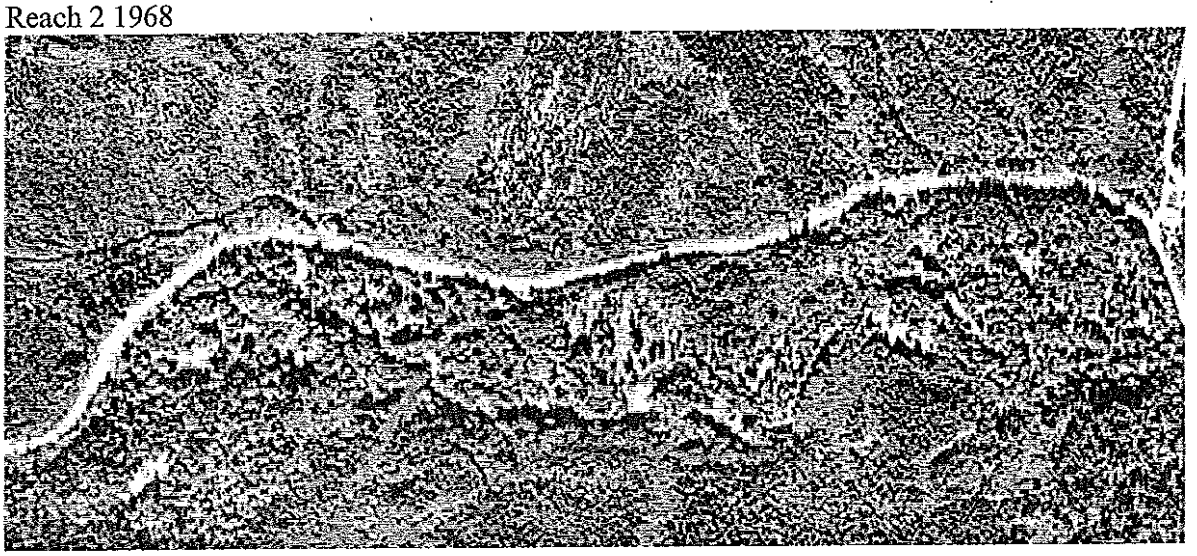
Sutton Creek, Lower reach 1968



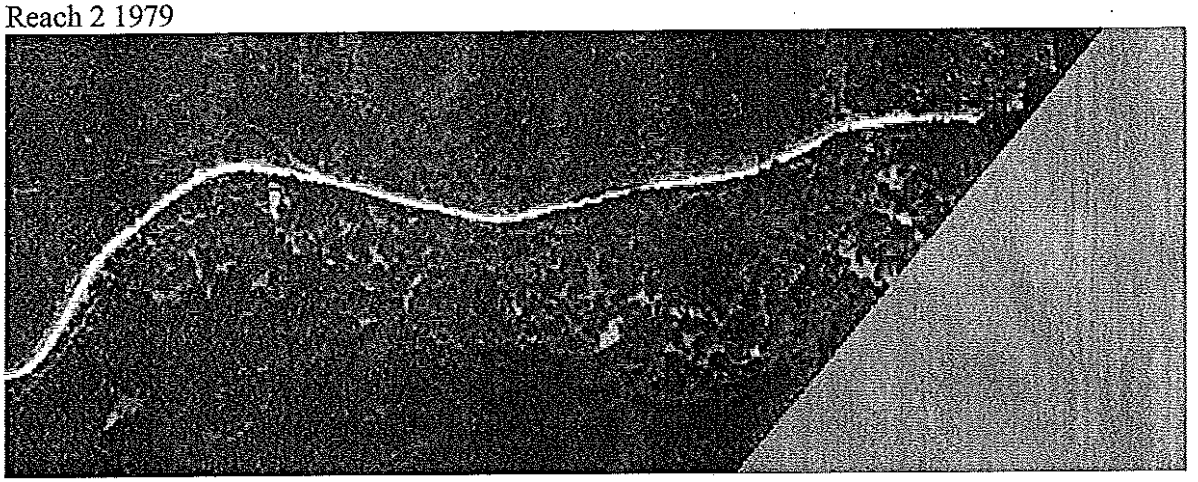
Sutton Creek, Lower reach 1984



Reach 2 1968



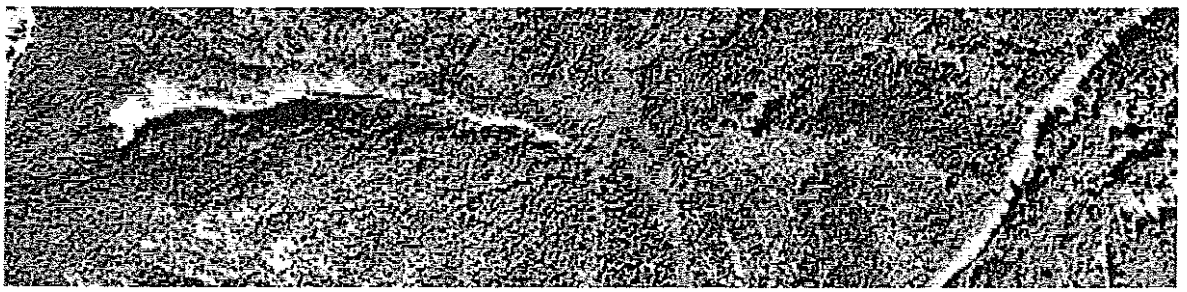
Reach 2 1979



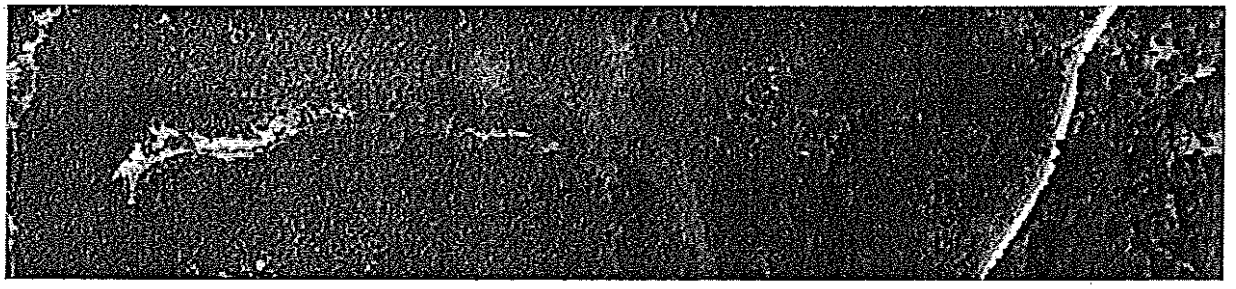
Reach 2 1984

*Tributary N1.5: Note erosion on left partially revegetated by 1984*

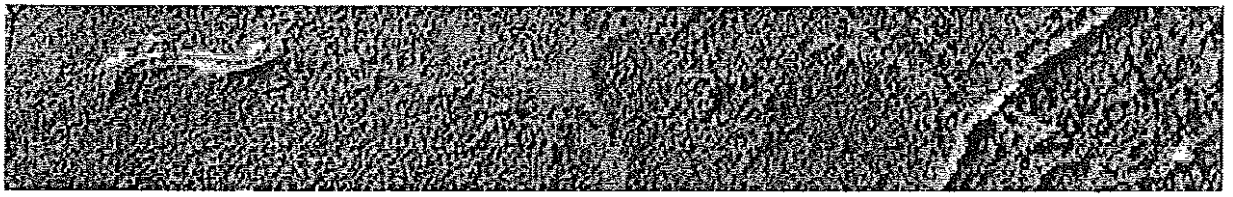
1968



1979

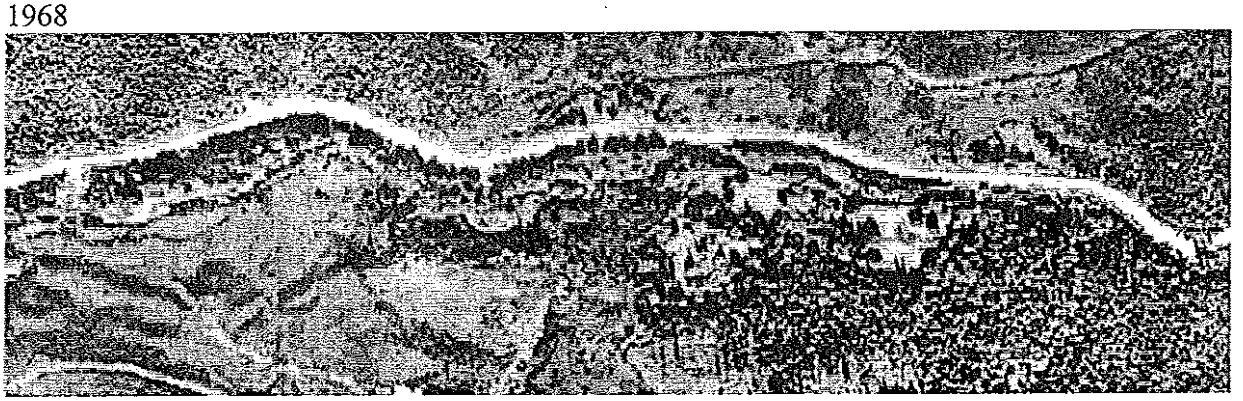


1984

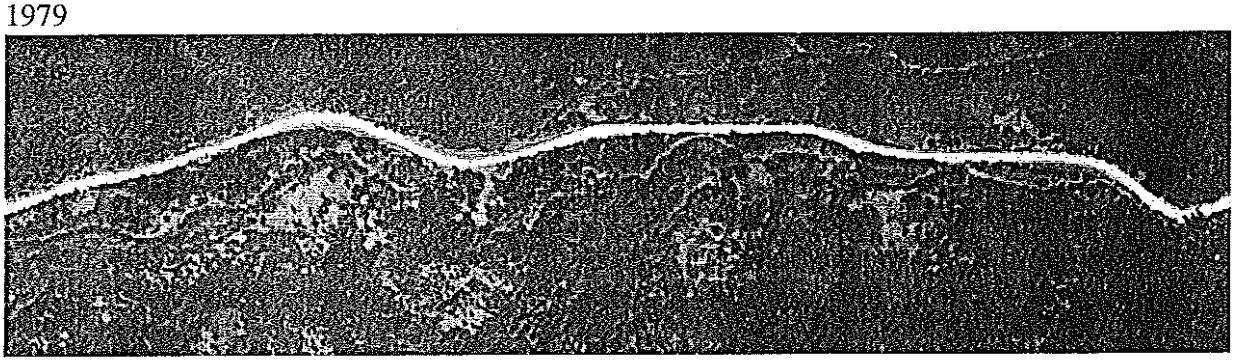


*Sutton main channel, Reach 3: Tributary S1 enters from bottom at far right.*
*Slide activity from Gordon River road at center left and far left?*

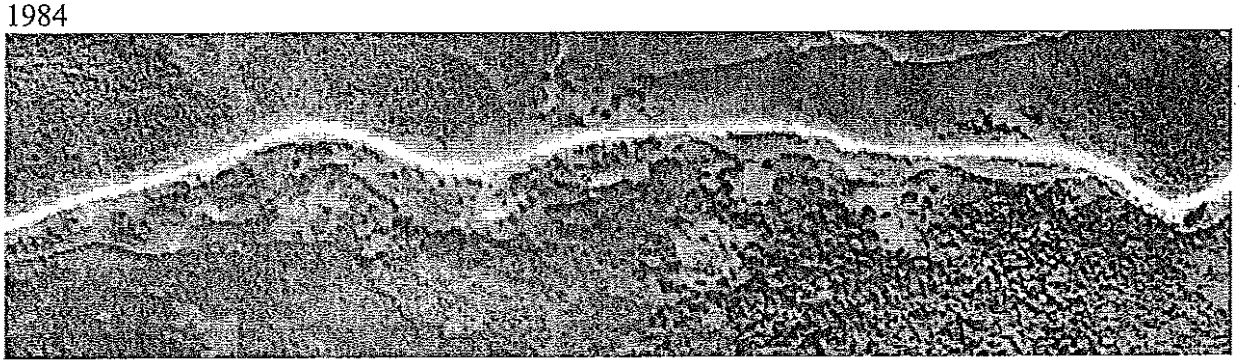
1968



1979



1984



**Appendix 5: Stream Channel Assessment:**
The main logging road from Honeymoon Bay to Gordon River, (GRR) which follows fairly closely along the Sutton Creek mainstem, was driven. Stops were made to walk into the river channel, and into the lower ends of all main tributary channels, to assess the channels.

Sutton Creek is moderately to severely aggraded from Cowichan Lake upstream for 3.5 km of its approximately 9 km mainstem length, with many gravel bars as high as the banks, and few pools of any depth and size. This extended reach of the channel runs through floodplain, at a gradient varying from 1% near the bottom, to 2% at the top end. With the short exception of the bedrock canyon just downstream of the Gordon River 6 km road marker, the channel is widening and shallow, with little remaining bank height to accommodate high flows along much of this lower reach, (up to around the 6.5 km on the Gordon River road markers). Increased general bank erosion is occurring at high flows due to the loss of flow capacity in the channel, which eroded material also adds to the excess bedload, and to the amount of LWD input to the stream from the still relatively weak second growth riparian areas. Sections of the stream around the 6.5 km mark of the GRR are only at a low level of aggradation, with some pool size, if somewhat shallow.

The main channel upstream of this point rises in gradient, varying from 2% to 4% over the next 3 km. The stream is confined by side slopes from around 0.2 km upstream of the 7 km road marker to the headwaters, with the exception of a small floodplain from road marker 7.8 km to road marker 8.5. The channel varies from a low to moderate level of aggradation (excess bed load) along this 3 km length, up to tributary N4. Above tributary N4, the channel is partially degraded, with the down-cutting becoming more severe in the higher gradient Sutton headwaters tributary north and upstream of the bridge just before the Gordon River road summit.

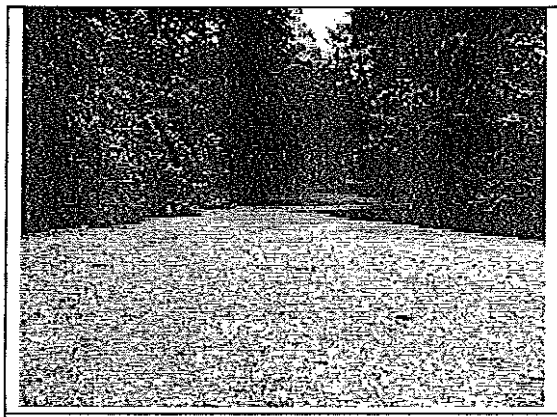
Tributary N4 appears to have very recently had a landside enter the channel a kilometer above the Sutton mainstem, resulting in a debris torrent running the length of the tributary to Sutton Creek, and down the mainstem. Photos of this tributary, and the mainstem below and above the Sutton confluence are given in appendix 6, the sediment source survey. Numerous areas of bank erosion of high steep banks, and at least one longer slide, are noted in the kilometer of Sutton downstream of tributary N4.

Channel conditions in the lower ends of the tributaries viewed vary from moderately degraded to moderately aggraded. However, most show at least a moderate level of disturbance at their lower ends. Most tributaries are still adding to, or in the recent past have added to, the excess bedload in the main channel. Millar Creek appears to be the least impacted of the tributaries, with only a low level of aggradation in the channel where viewed both above the confluence and in the ravine upstream of GRR.

**Channel Assessment Data**

| Site Desig-nation | Slope (%) | Width (m) | Depth (m) | Bank-full Depth (m) | Con-fined? | Channel type | Disturb-ance level | Indicators of Disturbance |
|---|---|---|---|---|---|---|---|---|
| bel hwy bridge | 2% | 18-20 | .35 | 2.5 | N | Riffle pool g | Mod aggrad | High but below bank ht bars most of ch |
| Ab hwy bridge | 1 to 1.5% | 20-30 | .3 | | N | Riffle Pool g | Severe aggrad | Bank high mid & side Bars, narrow thal, LWD |
| Ab log bridge | 1 to 1.5% | 20+ | 0.4 | 1.5 | N | Riffle Pool g | Severe aggrad | logjam pond sed high, narrow thal, LWD+ |
| Millar Cr | | 5 | 0.2 | 2 | N | | lo-mod degrad | Excavated channel? |
| Bel U bend | 1.5% | 15 to 20 | 0.2 | 0.6 | N | Riffle pool g | Mod-sev aggrad | Bank hi bars much of Channel, no LWD, wide |
| Canyon | | | | | Y | | | Bedrock |
| Trib S1 | 3 to-5% | 4 | 0.15 | 1.5 | N | Cascade pool | Mod aggrad | Cobble fan bel rock falls, lg grav fan by Sut |
| Sut 6 km-Ab S1 | 2% | 15-18 | 0.2 | 0.4 | N | Riffle Pool c | Mod aggrad | Wide shallow bed, hi bars |
| Sut 7 km | 2% | 15 to 20+ | 0.3 | 1.5 | N | Riffle pool | Lo-mod aggrad | Hi erod bank, local wide hi bars, x-LWD |
| Sut bel N2 | 1.5% | 14 | 0.3 | 0.8 | N | Riffle Pool c | Lo aggrad | Shallow wide bed |
| Trib N2 bel rd | 4% | 7 | 0.3 | 1.0 | N | Cascade pool | Lo-mod aggrad | shallow pools, some new lines, few w moss |
| Sut ab N2 | 2% | 14 | 0.3 | 1.6 | N | Cascade pool c | Lo aggrad | Widening, high cobble bars |
| Sut by S2 | 2% | 12 | 0.2 | 0.5 to 1.0 | N | Riffle Pool c | Mod aggrad | Lg high sediment wedge ab S2 |
| Trib S2 | 3% | 6 to 10 | 0.2 | 1.5 | Y/N | Cascade pool c | Mod aggrad | Varies lo agrad to erod banks, hi bars LWD |
| Trib N3 ab rd | 5%+ | 6 | 0.15 | 0.5 | Y | Cascade pool | Mod aggrad | Bedload accum between rd and falls |
| Sut bel N4 | 5% | 10 to 12 | 0.2 | 1.0+ | Y | Cascade pool c | Lo-mod aggrad | Debris wedge above erod LWD |
| Trib N4 11km br | 5 to 15% | 6 | 0.15 | 1.3 | Y | Casc to stp pool | | Debris torrent recently Silty water |
| Sut ab N4 | 5% | 9 | 0.25 | 1.5 | Y | Cascade pool c | Lo-mod degrad | Broken boulder lines Some lg mossy left |
| Sut Head-Waters | 10% | 8 | 0.2 | 1.5+ | Y | Step Pool b | Mod-sev degrad | Downcut ~1 m remn big boulders w moss by side |

**Channel Assessment Photos**

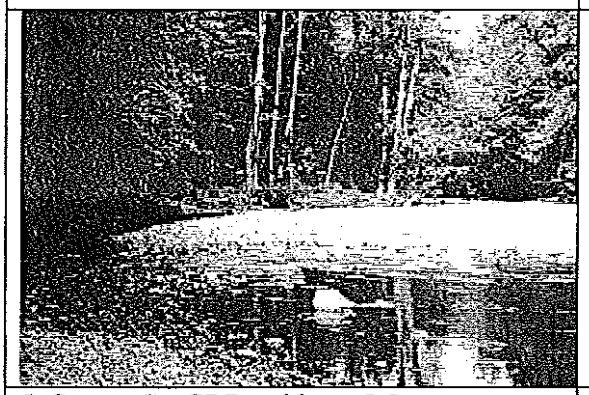


1. Sutton Cr below Hwy bridge

2. Above Hwy bridge and through golf course

3. Millar Creek above Sutton confluence

4. Sutton Cr above logging bridge

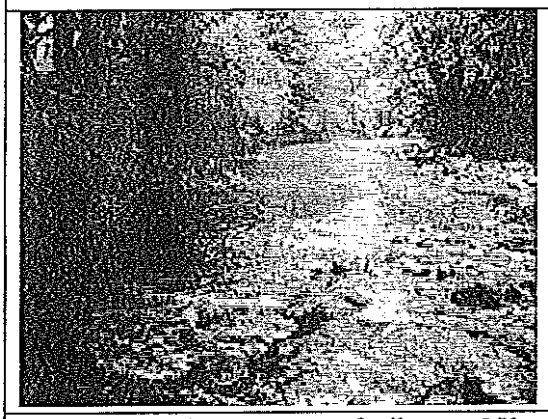


5. Sutton Cr, GRRoad km ~5.5, downstream of canyon

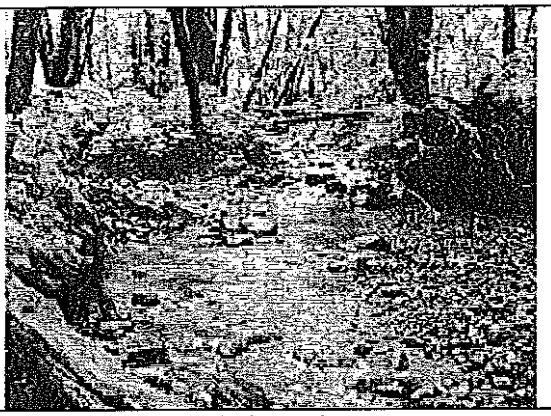
6. Old debris flow run-out, bottom of tributary S2

7. Fan on tributary S2 by Sutton confluence

8. Sutton Cr upstream of tributary S1- note lack of bank height



9. Sutton Cr downstream of tributary N2



10. Tributary N2 below rd

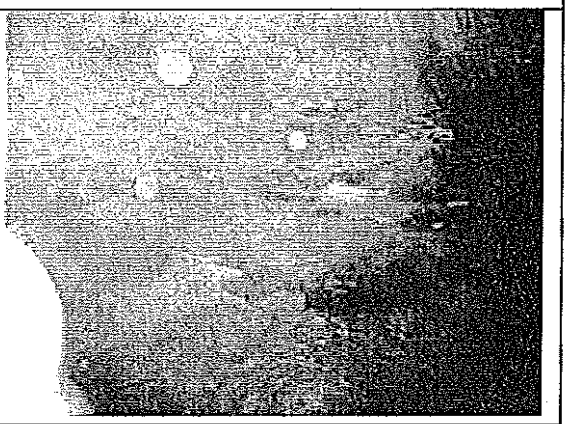
11. Tributary N2 above road
Stored sediment easily accessed

12. Sutton Cr downstream of S2

13. Large sediment wedge in Sutton Creek just upstream of S2

14. Tributary N4 downstream of km 11 bridge

15. Sutton Cr downstream of tributary N4

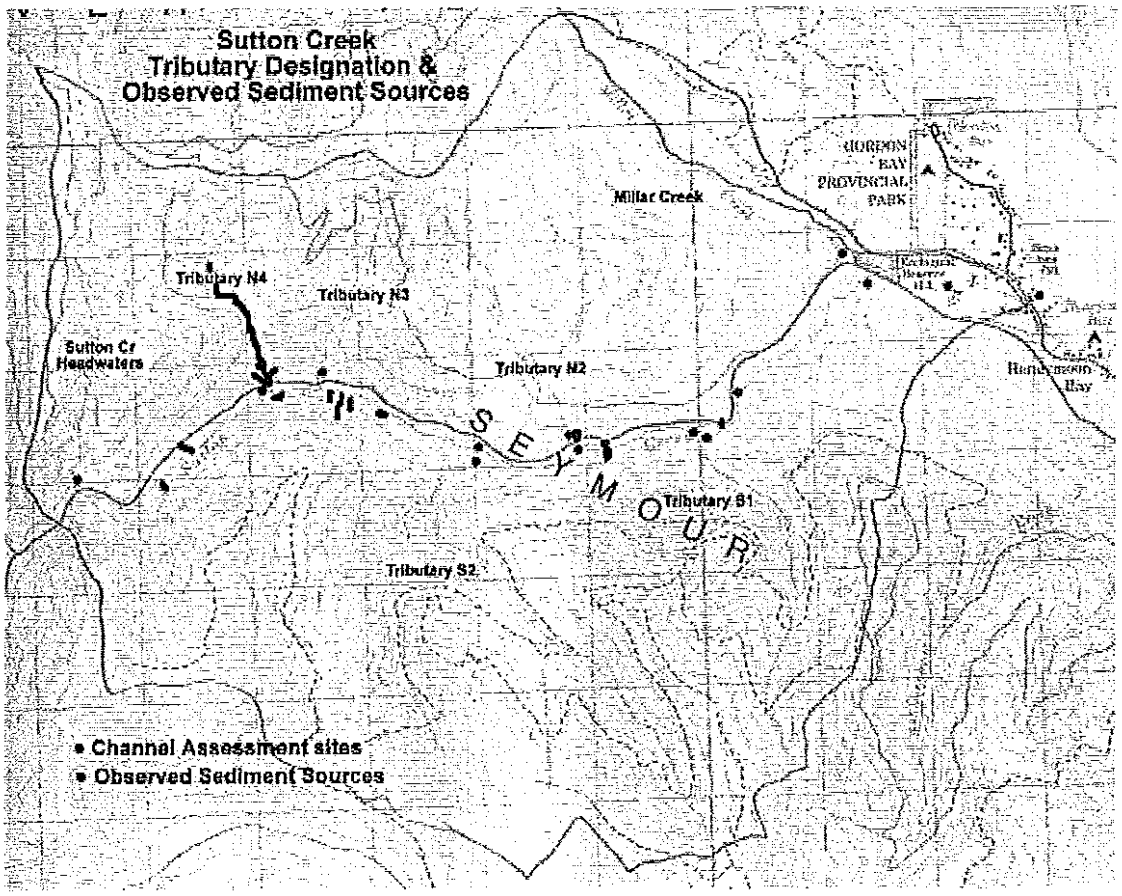


16. Sutton Creek upstream of tributary N4

17. Sutton Creek headwaters, upstream of bridge before GRR summit

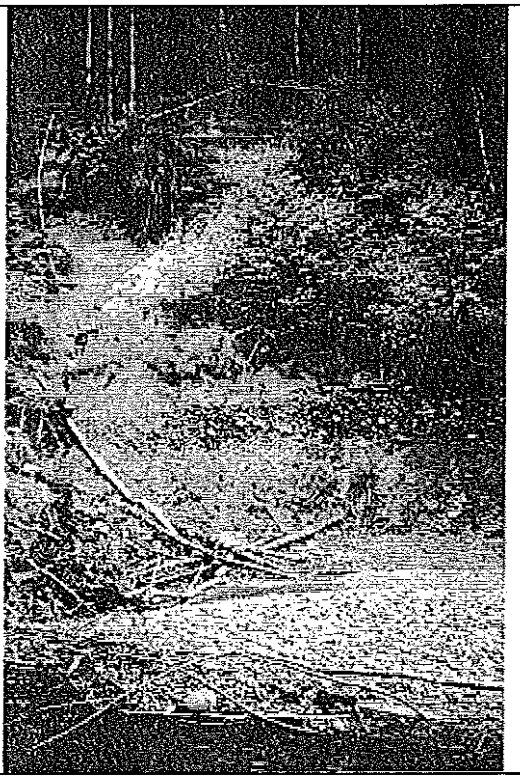
**Appendix 6: Sediment Source Survey**

As well as observations made of sediment sources during the channel assessment drive, a helicopter reconnaissance flight was made over the channels and watershed. Numerous sediment sources to Sutton Creek were observed. These included two slides from the Gordon River road shoulder, and a debris slide, (beside other historic slide tracks), from the steep south hillside downstream of tributary N3 into the Sutton mainstem channel. Evidence of a past debris torrent is seen at the bottom end of tributary S1, and tributary N4 appears to have recently had a debris torrent, initiated from a debris slide into N4 from a steep higher elevation slope, and running approximately a kilometer to the Sutton Creek main channel and downstream from there. This likely aggravated some of the numerous bank erosion sites noted in the kilometer downstream of N4.

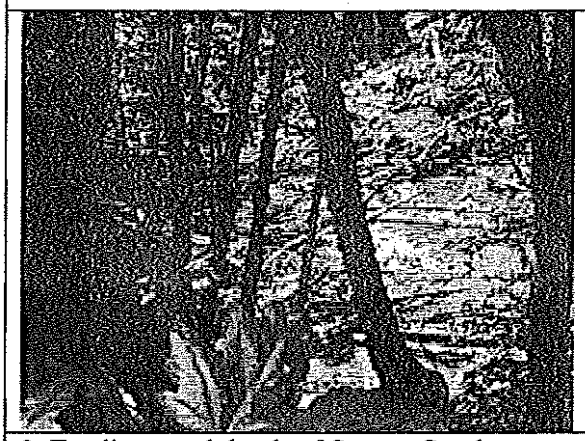


Photos of the sediment sources observed from Gordon River road, channel assessment reconnaissance, or helicopter flight as entering the mainstem of Sutton Creek, in order from downstream to upstream.

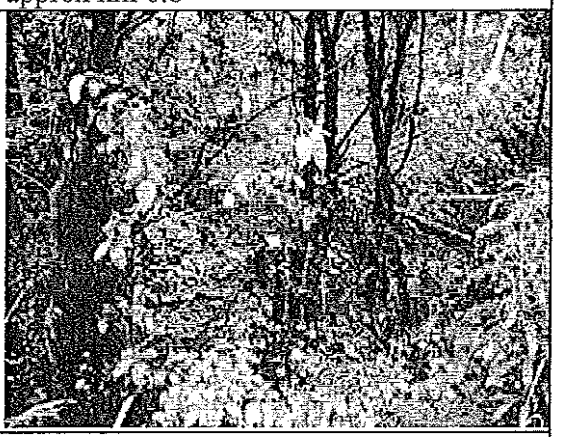
1. Failing shoulder of Gordon River rd just downstream of tributary S1.



2. Tall eroding south bank of Sutton Cr at approx km 6.8



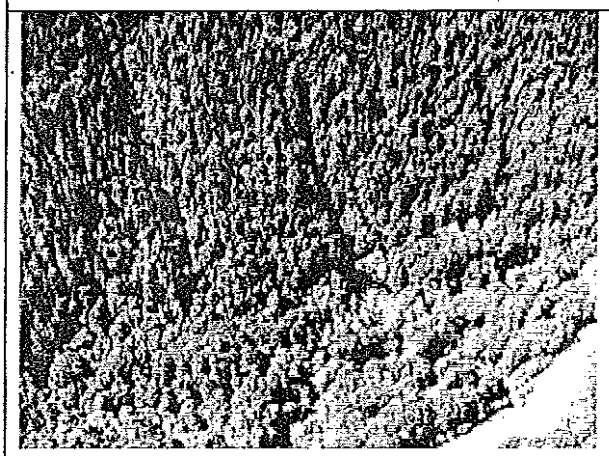
3. Eroding south bank of Sutton Creek Upstream of road marker km 7, widening bed



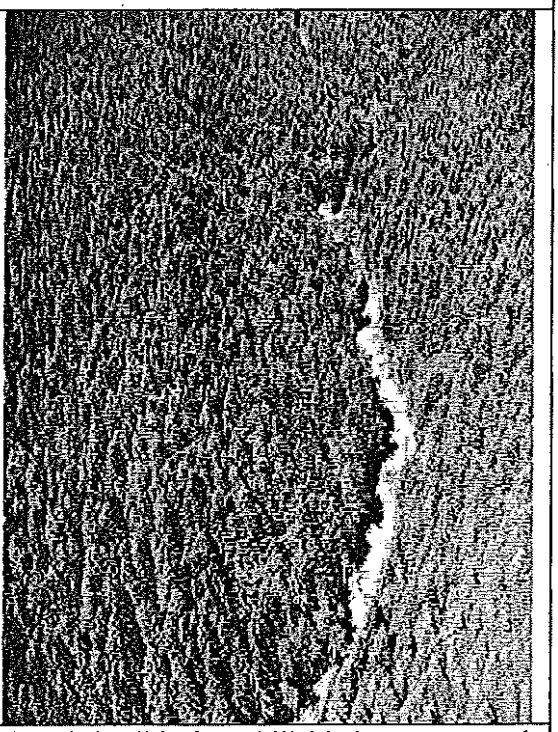
4. Slide or high bank erosion into south side of Sutton Cr near road marker km 8.

The above two photos' extensive bedload and LWD deposits may be settlement of some of the debris from the debris torrent in tributary N4 and resulting bank erosion on the Sutton channel below N4.

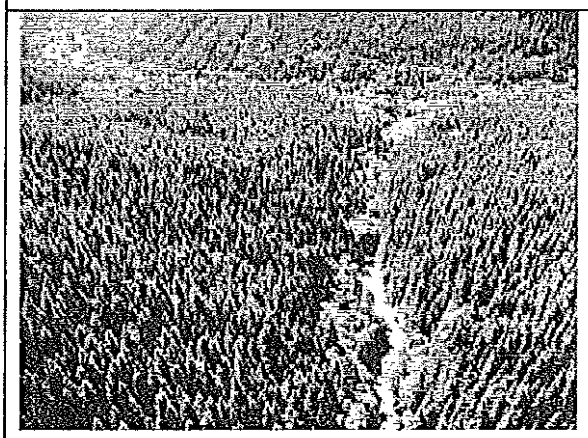
Sutton Creek Sediment Source Survey



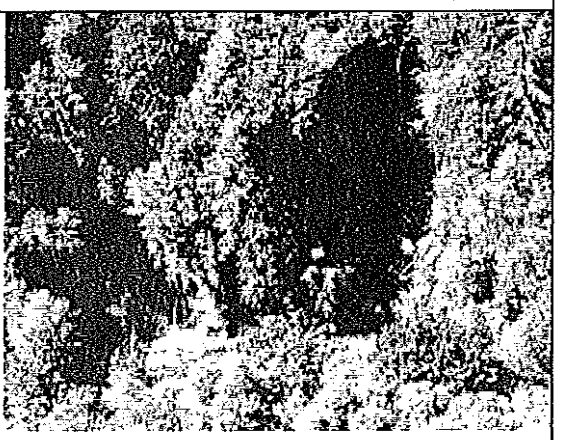
5. Debris slide into Sutton Cr and historic slide tracks downstream of tributary N3



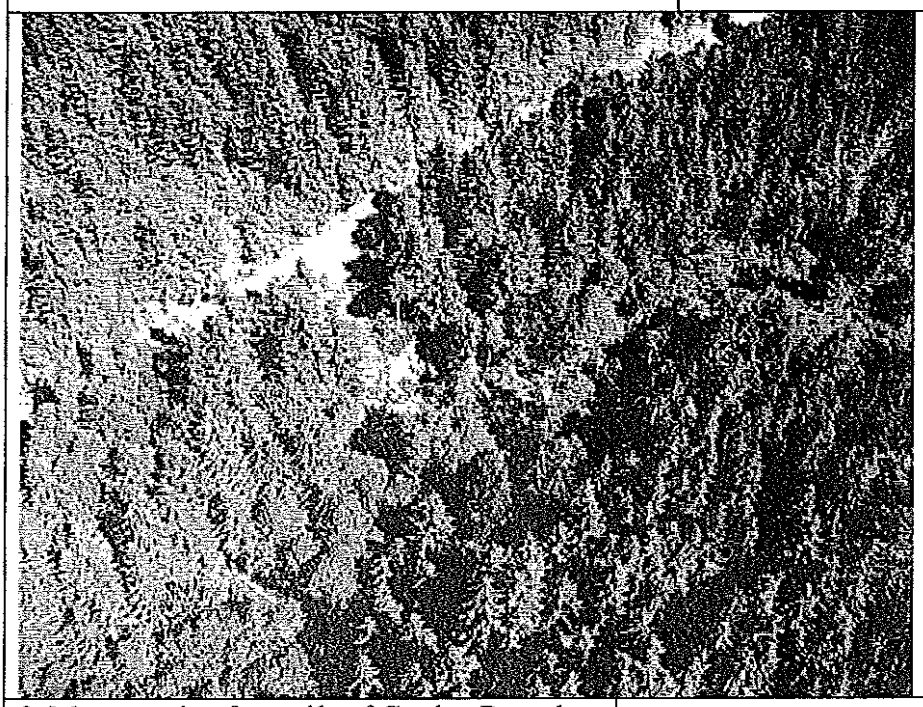
6. Debris slide from hillside into upper end of debris torrented tributary N4



7. Lower end of tributary N4 with debris torrent path to Sutton mainstem in upper photo.



8. Bank erosion from N4 debris torrent downstream of confluence with Sutton Creek

| Sutton Creek sediment source survey | |
|---|---|
|  | |
| 9. Mass wasting from side of Gordon R road at approx 11.3 km | |