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Channel and Debris Flow Risk Assessment

of

Ross Creek

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1.0 INTRODUCTION

A channel and debris flow risk assessment was undertaken in May 2002 on the Ross Creek mainstem, and East and North Tributary channels *[Overview Photomap – Appendix A]*. Objectives of the assessment were to:

- Review and summarize changes in channel morphology on Ross Creek and its two main tributaries over the period of record as provided by aerial photographs.
- Summarize existing channel conditions with respect to sediment input, storage, transport, and delivery to the Ross Creek fan.
- Determine the existing debris flow potential in the Ross Creek mainstem, and East and North Tributary channels, and document the risk of debris flow run out and deposition on the Ross Creek fan.
- Assess and summarize incremental effects on the debris flow potential and run out risk on the Ross Creek fan that may result from Forest Development Plan (FDP) proposed and previously approved cutblocks and roads in the lower watershed area.
- Identify opportunities for remedial action to reduce the debris flow and landslide risks within, adjacent to, or downslope of Salmon Arm Forest District, Small Business Forest Enterprise Program (SBFEP) FDP proposed and previously approved blocks.

2.0 BACKGROUND

Ross Creek is a fifth order channel (based on 1:20,000 maps) draining an area of 107 km^2 on the north side of Shuswap Lake. The Ross Creek drainage has been subject to extensive forest cover alteration resulting from the Magna Bay Fire in 1967, and forest harvesting prior to and after this event. Approximately 65% of the forested area within the watershed was burned in the Mag Fire, with an additional 5.0% harvested by August 1994[1]. Approximately 1.0% of the watershed has been harvested since 1994.

Coho, sockeye and kokanee salmon are known to use the Ross Creek system for spawning and rearing. Detailed habitat information with respect to salmonid returns or high value habitat areas is not available. Rainbow and bull trout use of the system is suspected.

Water from Ross Creek is used for irrigation on the fan. There are no domestic water licensees on Ross Creek.

[1] Dobson, D. 1994. Watershed Assessment for the Ross Creek Watershed near Anglemont, prepared for Federated Co-operatives Limited, Canoe, BC.

Chronic sedimentation, bank erosion, and flooding have been experienced on the Ross Creek fan for over 50 years[2]. Ongoing effort to manage sediment load and debris accumulation has been required to minimize damage to the Squilax-Anglemont highway and bridge at the toe of the fan, as well as private and public property adjacent to the fan channel. The three main causal mechanisms of sediment movement and flooding in the lower fan have been identified as: logjam formation with subsequent gravel accumulation in the lower channel, erosion through narrow dikes where natural ground is lower behind, and chronic gravel build-up with no intervention. The occurrence of a debris flow running out onto the Ross fan has also been suggested as a possible cause of future impacts, although there is no record of such an event.

It is suggested in a 1999 report to the Ministry of Transportation and Highways that sediment transport rates onto the fan have increased from 10,000 m^3/yr in the 1960's to 35,000 m^3/yr at present[3]. Reasons provided for the sediment load increase include: an increase in mass wasting throughout burned areas that can occur up to 20 years after large wildfire events; delayed sediment delivery to the fan via temporary storage behind logjams in channels upstream of the fan; and, increased peak flow magnitude following the fire. Peak flows are expected to trend back to pre-fire conditions with regenerating forest cover, but it has been suggested that decades may be required before sediment transport levels return to pre-fire conditions.

3.0 METHODS AND MATERIALS

Channel reaches were delineated for this assessment using standard *Channel Assessment Procedure*[4] guidelines with an emphasis on changes in gradient and channel confinement. Seven reaches were delineated on the mainstem, including the fan, with three on each of the tributary channels *[Appendix A]*. Longitudinal profiles were generated from 1:20,000 TRIM maps for the mainstem and tributaries, complete with average reach gradients and reference points such as road crossings *[Appendix B]*.

Good aerial photograph coverage is available for the Ross Creek area beginning with RCAF photos taken in 1928. All available coverage between 1928 and present was reviewed for the purpose of understanding changes in sediment supply and channel morphology over time. Specific attention was paid to the Ross fan and mainstem downstream of the East Tributary confluence, and lower reaches of the East Tributary (i.e. channels that could be affected by forest development planned in the lower watershed).

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[2] Costerton, B. 1999. Design Alternatives for Ross Creek Gravel Aggradation Problem, A letter report provided to the Ministry of Transportation and Highways, Okanagan/Shuswap District.
[3] Ibid.
[4] Ministry of Forests, 1996. *Channel Assessment Procedure Guidebook,* Victoria.

Field reconnaissance was completed on the lower four reaches of the Ross mainstem, and lower two reaches of the East Tributary. Sediment storage and transport characteristics, and evidence of any past debris flow occurrence was documented on all field-reviewed reaches. The remaining mainstem and tributary reaches were reviewed using aerial photographs and channel profiles.

The following criteria were used to determine debris flow initiation potential in channels, and the occurrence of debris flow run out and deposition activity on the Ross Creek fan:

Channel Gradient - Debris flow initiation has been found to occur locally with channel gradient in excess 14%[5]. This value should be considered conservative as initiation thresholds as high as 27% have been reported elsewhere in BC and Western Canada[6].

Fan Gradient - Low likelihood of debris flow run out and deposition on fans with gradients less than 7% at or near the apex. Gradients less than 7% near the apex imply fluvial deposition processes (i.e. fluvial fans).

Fan Morphology - Debris flow run out and deposition may have occurred if levees, lobes or single abnormally large boulders are located on the fan surface.

Fan Texture - Debris flow run out and deposition may have occurred if sediment deposits consisting of poorly sorted diamicton are encountered on the fan (i.e. a wide range of particle sizes – angular and/or rounded depending on source area and transport distance).

Riparian Areas - Scarring on the upstream side of riparian vegetation may indicate the occurrence of debris flows. Debris flows have likely occurred if a distinct change in vegetation age (i.e. trim line) is visible on lower slopes immediately above the channel. The absence of a trim line is not conclusive evidence that debris flows have not occurred.

Field reconnaissance was also completed within and downslope of SBFEP FDP approved and proposed development on the east side of Ross Creek. Particular attention was paid to water management and drainage configurations associated with old development and any cause and effect

[5] VanBuskirk, C. 2000. Office Review of Sicamous Creek Drainage IWAP With Respect to Cutblock TSL A46476. Salmon Arm Forest District, April 11, 2000.
[6] VanDine, D. 1985. Debris Flows and Debris Torrents in the Southern Canadian Cordillera, *Can. Geotech. J.* (22), 44-68.

relationships between altered drainage patterns and downslope landslide activity.

Materials used for the assessment include:

- SBFEP Forest Development Plan map - 1:30,000
- TRIM maps – 1:20,000
- Aerial photographs as follows:
  - 1928 A452 Nos. 72, 73 and A618 Nos. 24, 25 - 1:16,000
  - 1967 BC5246 Nos. 197, 198 - 1:18,000
  - 1974 BC7662 Nos. 19, 20, 21 and BC7649 Nos. 15, 16 - 1:20,000
  - 1988 30BCC 875 Nos. 1, 2, 23, 24, 25, 62, 63, 64 - 1:10,000
  - 1994 30BCC94089 Nos. 45, 46 and 30BCC94093 No. 45 - 1:15,000
  - 1997 BCB970 Nos. 22 22, 23 - 1:40,000
  - 2001 BCC01025 Nos. 112 to 114 - 1:30,000

4.0 ASSESSMENT

4.1 Overview

The Ross Creek fan channel has undergone a change in morphology (channel form) over the 70-year period of photographic record. The causes of morphologic change have been a significant increase in sediment and debris delivery from upstream areas, and to a lesser degree past harvesting in riparian areas on the fan and a likely increase in peak streamflow magnitude due to fire and harvesting in the watershed.

Small natural valley sidewall and gully failures are the main source of sediment and debris to upper Ross Creek (reach R5 and beyond) and its two main tributaries. The magnitude and frequency of these events increased significantly following Mag Fire occurrence, and appear to have further increased in the spring of 1997 in response to above average runoff. Movement of sediment and debris through the system has likely been episodic in nature relating to accumulation in and behind debris jams with subsequent release during high flow events. At this time, the North Tributary and smaller tributary streams along the west side of reach R5 are active sources of sediment and debris to the system. The East Tributary is not a significant source of sediment and debris at this time, based on aerial photograph review.

Between the East Tributary confluence and fan, Ross Creek is incised into glacio-fluvial terrace deposits and bedrock. Large historic debris slides in glacio-fluvial deposits (i.e. old scars) are visible in the 1928 photos. None of the slides appear active in 1928, but one large debris jam is visible on reach R4 at the base of an old slide scar. The presence of the jam in 1928, prior to any significant forest development or other disturbance in the area, implies the natural occurrence of jams on the lower Ross Creek system.

By 1967 several large old slides have been reactivated in terrace deposits along reaches R3 and R4. This precedes Mag Fire occurrence. The channel appears highly aggraded at this time from slide related sediment and debris. The debris jam on reach R4 visible in 1928 has released by 1967 and a larger jam has formed downstream. Large debris slides on steep coupled valley slopes, such as those present on reaches R3 and R4, can result from channel erosion in toe-slope areas, or alterations in upslope drainage that direct runoff into unconditioned areas. As mentioned in the 1999 report to the Ministry of Transportation and Highways[7], one notable high flow event occurred in 1948. It is likely that bank erosion during this event contributed to some slide activity. However, a considerable road and trail network had been built upslope of and within terrace areas by 1967 that may also have played a role in slide initiation. Very large volumes of sediment and debris were introduced to Ross Creek from reactivated failures on slopes adjacent to reaches R3 and R4, only a portion of which could have been retained in the large jam on reach R4.

Since 1967, most of the large slides on terrace slopes have remained active to some degree, and several other small slides have occurred. The cause of smaller slides on terrace slopes is unclear, but initiation points appear to correspond well with switchbacks on upslope roads and trails, or the presence of roads and trails along terrace edges. The large jam visible on lower reach R4 in 1967 has remained in place but episodic sediment release from this site may have occurred over time. Sediment transport through and over debris jams can also occur, particularly when sediment accumulation behind the jam exceeds jam height. Under these circumstances sediment introduced from upstream slides or other debris jam release can be delivered directly to the fan during high flow periods. The rate of sediment delivery to the fan may also have been exacerbated by an increase in peak flow magnitude following Mag Fire occurrence.

Ross Creek on the fan had a meandering pattern and average bankfull width of approximately 20 m in 1928. Several areas of active bank erosion are visible in 1928 associated with agricultural or other development related clearing in riparian areas. By 1967 channel width on the upper fan had

[7] Costerton, B. 1999. Design Alternatives for Ross Creek Gravel Aggradation Problem, A letter report provided to the Ministry of Transportation and Highways, Okanagan/Shuswap District.

increased to approximately 40 m, and selective harvesting in riparian areas had occurred along most of the left (east) bank. This increase in channel width corresponds with the reactivation of large slides along reaches R3 and R4, and precedes Mag Fire occurrence. In 1974 the fan channel has a braided pattern and average width of 60 m over its entire length. Partial re-vegetation on exposed bar materials occurred between 1974 and 1997, and channel width remained relatively constant. High flows in the spring of 1997 reactivated the entire floodplain on the fan channel, removing all vegetation from exposed bars and banks. Reach R1 on the fan was confined using riprap material between 1997 and 2001, but the width of reach R2 increased to 70 m in several locations.

Considering the volume of sediment and debris that has been introduced to Ross Creek between 1928 and present, and the fact that large and small sediment source areas remain active throughout the system, channel aggradation, bank erosion, and flooding should be anticipated on the fan for an indefinite period of time.

4.2 Debris Flow Risk and Channel Assessment

Existing channel conditions with respect to sediment input, storage, transport and delivery to the Ross fan are discussed by reach in the following section. Debris flow initiation potential is also discussed with reference to long profile derived stream gradient, and field observations where available. Debris flows that initiate within channels and those that may be triggered by landslide impact are accounted for in this discussion. A summary of channel reach length, average gradient, debris flow potential, and debris flow risk with respect to the Ross Creek fan is provided in Table 1.

4.2.1 Ross Creek Mainstem Channel

Reach R1 on the lower Ross fan is confined to approximately 15 m bankfull width by artificially constructed riprap levees *[Photo 1- Appendix C]*. The channel has a braided pattern within the riprapped margin and is aggrading in this location. The average gradient of reach R1 is approximately 2.3 % *[Appendix B]*, well below any threshold required for debris flow initiation. There is no evidence of recent or historic debris flow deposition on reach R1.

Reach R2 covers the remaining channel length on the Ross fan (1,700 m). The average gradient of reach R2 is 2.4% with a bankfull width ranging from 40 to 70 m. Fan gradient near the apex is approximately 3.0%. Debris flow initiation potential is low on reach R2, and no evidence of recent or historic debris flow deposition was noted in the middle and upper fan areas. Evidence of recent erosion and re-working by heavy

equipment is visible throughout reach R2 *[Photo 2]*. Approximately 90% of the reach is confined along its right (west) bank by a relic fan deposit composed of fluvial sand, gravel and cobble overlying lacustrine silt and clay deposits *[Photo 3]*. The left (east) bank is unconfined and has experienced significant erosion. The entire riparian zone along the left bank of reach R2 has been harvested and now consists of second growth vegetation ranging in seral stage from shrub-herb to young cedar dominated forest. Woody debris has been removed from reach R2, likely to prevent accumulation at the Squilax-Anglemont Bridge. Harvesting in riparian areas and removal of in-stream woody debris reduces natural bank protection and in-stream complexity, and can increase streamflow velocity. Increased velocity following debris removal would likely have been short-term, decreasing to natural levels or less as channel width increased with ongoing aggradation and bank erosion. While the role of natural bank protection and sediment regulation processes is small compared with the high level of sediment delivery to the Ross fan, their impairment has exacerbated long-term bank erosion, sediment transport, and deposition problems.

Table 1
Channel and Debris Flow Summary

Reach Number	Reach Length (m)	Average Reach Gradient (%)	Debris Flow Potential	Ross Creek Fan Debris Flow Risk
R1	440	2.27	Low	Low
R2	1,700	2.35	Low	Low
R3	1,120	3.57	Low	Low
R4	3,340	4.62	Low	Low
R5	4,920	4.47	Low	Low
R6	5,580	2.51	Low	Low
R7	1,280	10.42	Low	Low
ET1	350	25.71	Moderate	Low
ET2	2,780	17.99	Moderate	Low
ET3	1,020	13.73	Low	Low
NT1	160	5.00	Low	Low
NT2	910	13.19	Low	Low
NT3	3,300	9.09	Low	Low

Reach R3 is a short canyon section with an average gradient of 3.6 %. Sediment and debris transport processes dominate this section of the mainstem with no debris jams or other sediment storage mechanisms present. Mature vegetation exists to the water's edge along all of reach R3, and no evidence of scarring or trim line presence was noted. Debris flow initiation potential on reach R3 is low.

Steep glacio-fluvial terrace and bedrock slopes bound reach R4 over its entire length (3,400 m). Average channel gradient on reach R4 is 4.6%, mature vegetation is present to the water's edge *[Photo 4]*, and no debris flow trim line is visible. Some scarring was noted on the upstream side of riparian vegetation, attributable to large woody debris movement following debris jam release in upstream areas. Debris flow initiation potential on reach R4 is low. Numerous historic and active valley sidewall slides are present along reach R4, as noted in the overview. Several large debris jams with associated sediment deposits are present throughout the reach *[Photos 5 & 6]* derived from both valley sidewall slides and upstream post-fire related mass wasting. The channel has recently (last two to five years) eroded around the lowermost and largest jam releasing a significant volume of sediment, and re-activating an adjacent valley sidewall slide *[Photo 5]*. It is likely that the bulk of sediment released from this jam occurred during relatively high flows experienced in the spring of 1997. The volume of sediment released into the lower channel and onto the Ross Creek fan during this event would account for much of the aggradation and erosion problems experienced at that time. Monitoring of this jam during high flows may provide an early warning mechanism for future high bedload transport and delivery events. There is a high risk of flooding and channel avulsion on the Ross Creek fan from the future release of sediment and debris from the lowermost jam. It is unlikely that this jam will fail in a catastrophic manner based on its size, but future sediment release episodes are inevitable. Removal of this jam is not advisable as numerous others are acting in a similar manner upstream, and the complete removal of all jams on the system would release an unmanageable volume of sediment.

Reach R5 extends from the East Tributary confluence to approximately 1.2 km beyond the North Tributary confluence. Steep slopes consisting of bedrock, glacial till and colluvium bound reach R5. The average gradient of the channel is 4.5% and mature timber was noted to the water's edge near the East Tributary confluence *[Photo 7]*. Despite numerous valley sidewall slides and gully failures impacts on this reach following Mag Fire occurrence, no debris flows were initiated. Debris flow initiation potential on reach R5 is considered low. Although no large debris jams can be seen on reach R5 from aerial photographs at this time, it is likely that smaller

debris accumulations are present in the channel that also store sediment and debris for release during high flow events.

Reach R6 in the upper drainage is a meandering low gradient channel dominated by deposition processes. The average channel gradient is 2.5% and debris flow initiation potential is low. A narrow valley flat/floodplain complex separates reach R6 from adjacent valley slopes. The presence of this valley flat has buffered the channel from post-fire sediment and debris input.

Reach R7 has an average gradient of 10.4%. Based strictly on gradient, debris flow initiation potential on reach R7 is considered low. Bedload transport levels increased in reach R7 following Mag Fire occurrence based on a visible increase in deposition on upper reach R6. Increased deposition on reach R6 is confined to the upper 200-300 m of channel and should not affect downstream areas.

4.2.2 East Tributary Channel

The lowermost reach on the East Tributary (ET1) is 350 m long and has an average gradient of 25.7% *[Photo 8]*. Steep bedrock and colluvial slopes bound the channel, with glacio-fluvial sand and gravel deposits in upper slope areas. Several valley sidewall slides, initiated by upslope road and trail related drainage diversions *[refer to section 4.2.4]* have impacted on ET1, but debris flows have not occurred. Based on this, and the gradient and channel confinement, debris flow initiation potential from a valley sidewall landslide is considered moderate on ET1. Additional road drainage diversion related slides into ET1 should be expected until drainage issues have been addressed through restoration or road deactivation (refer to section 4.4). Mature vegetation is present to the water's edge on lower ET1 and no trim line or scarring is present *[Photo 9]*. If a debris flow were initiated in ET1 it would impact on Ross Creek but deposit in the channel a short distance downstream of the confluence. Such an event would increase sediment and debris accumulation in jams on lower Ross Creek, and likely impair water quality and fish habitat for a short period of time until fine sediment is washed through the system, but would not increase the low risk of debris flow run out or deposition on the fan.

Reach ET2 is 2,780 m long has an average gradient of 18.0% and has also been impacted by valley sidewall slides *[Photos 10 & 11]*. Debris flows were not initiated by the slides, but the potential for debris flow initiation from a valley sidewall landslide is considered moderate, based on stream gradient and confinement. If a debris flow were initiated in ET2 it would carry through ET1 and impact on the Ross mainstem. An event initiated in

ET2 would likely carry farther down the mainstem than an event initiated in ET1, but deposition would occur and the low risk of debris flow run out or deposition on the fan would not be affected. Sediment and debris from an event initiated in ET2 would also accumulate in jams on the mainstem and water quality and fish habitat would likely be impaired until fine sediment was washed through the system. Many of the slides that impacted on ET2 likely resulted from root strength deterioration following Mag Fire occurrence, but several have been initiated by road fillslope failure on steep slopes adjacent to the channel. Future fillslope slides should be anticipated along ET2 based on old road construction methods and evidence of road instability *[Photo 12]*(refer to section 4.4).

Reach ET 3 has an average gradient of 13.7%. No valley sidewall slides into ET3 are visible on aerial photographs. Debris flow initiation potential on ET3 is considered low.

4.2.3 North Tributary Channel

Debris flow initiation potential in reaches NT1, NT2, and NT3 of the North Tributary is considered low, based on the low channel gradients. Considerable sediment and debris loading has occurred throughout the North Tributary from post-fire related gully failures and valley sidewall slides. This tributary is a significant source of sediment to the upper Ross mainstem.

4.2.4 Debris Flow Risk and Channel Assessment Summary

There is a high risk of flooding and channel avulsion on the Ross Creek fan from the future release of sediment and debris from the lowermost jam on reach R4. Monitoring of this jam during high flows may provide an early warning mechanism for future high bedload transport and delivery events on the fan. It is unlikely that this jam will fail in a catastrophic manner based on its size, but future sediment release episodes are inevitable. Removal of this jam is not advisable as numerous others are acting in a similar manner upstream, and the complete removal of all jams on the system would release an unmanageable volume of sediment.

The debris flow risk on the Ross Creek fan is low based on low likelihood of debris flow initiation and propagation in the Ross Creek mainstem on and upstream of the fan. There is a moderate likelihood that debris flows could be initiated in two lower reaches of the East Tributary by valley sidewall slides. Debris flows that may be initiated in the East Tributary will deposit in the Ross mainstem before reaching the fan, and will not affect the low debris flow risk on the fan. Debris flow potential is low in the upper reach of the East Tributary and all reaches of the North Tributary.

Several valley sidewall slides into reaches ET1 and ET2 have been triggered by road fillslope failure and road drainage related diversions, but debris flows have not occurred. Additional slides from these sources should be expected until drainage and stability issues have been addressed through restoration and/or deactivation. The consequences of additional slides into, or a debris flow within the lower two reaches of the East Tributary include: increased sediment and debris input to the Ross mainstem, and fish habitat and water quality impairment that would result from a short-term increase in turbidity following the events. Fine sediment (silt and clay) that contributes to high turbidity would be washed through the lower Ross Creek system over one to two freshet periods. An increase in coarse sediment and debris input from events on the East Tributary is a concern, but considering the existing sediment load on Ross Creek, would likely not be detectable in jams or on the fan. Based on these considerations, the consequences of additional slides into, or debris flows within the East Tributary with respect to sediment and debris load, fish habitat, and water quality are considered low.

4.3 Overview of FDP Approved and Proposed Development

There are eight SBFEP blocks (A35168 1, 2, 3, A43170 1, 2, A68051, A68052 and A68053) and one Federated Co-operatives Limited (FCL) block (CP 930 Blk.1) planned in the lower Ross Creek drainage. Blocks are located on the east and west side of reach R4, and south side of tributary reaches ET1 and ET2 *[Detailed Photomap - Appendix D]*.

Forest Development in the Ross Creek drainage, approved, planned or otherwise, will not increase debris flow risk on the Ross Creek fan. As discussed previously, there is a low risk of debris flow initiation in the Ross Creek mainstem upstream of the fan, and debris flows that may be initiated in the East Tributary will deposit in the mainstem before reaching the fan.

From a runoff and streamflow perspective, all forest harvesting can be expected to increase localized runoff, but only that which is located above the H60 line can be expected to contribute to peak flow levels. The FCL block and six of eight SBFEP blocks are all located below the H60 elevation of 1,260 m. These blocks will be snow-free at the time of peak flow. The remaining two SBFEP blocks (A43170 – 1 and 2) are located on a northwest aspect immediately above the H60 line *[Appendix D]*. Snow accumulation in these clearcuts can be expected to increase by roughly 30 – 50%[8], as measured by snow water equivalent, and snowmelt should occur roughly 50% faster than

[8] Winkler, R. 2001. *The Effects of Forest Structure on Snow Accumulation and Melt in South-Central British Columbia,* Ph.D. Thesis, Department of Forest Resources Management, University of British Columbia, 163 p.

that in the adjacent forest[9]. With a combined area of only 40 ha, the net increase in runoff generated from these clearcuts would not be detectable in peak flows on Ross Creek and should not be a concern. It is also possible that harvesting in one or both of the SBFEP blocks located above the H60 line may advance snow-melt enough through increased melt rates, to render the area(s) snow-free at the time of peak flow on Ross Creek. Additional fieldwork would be required to confirm the likelihood of this scenario.

Aside from peak flow considerations, there are localized runoff concerns associated with approved and proposed SBFEP blocks located upslope of old trail related landslides into reaches R4, ET1 and ET2. These concerns are discussed in detail below.

4.4 Field Review of SBFEP FDP Approved and Proposed Development

An extensive network of old roads and trails is present within and downslope of SBFEP FDP approved and proposed development in Ross Creek. Natural hillslope drainage patterns have been altered by these road and trails, and several landslides into Ross Creek and the lower reaches of the East Tributary can be linked to the alterations. For the most part, altered drainage has stabilized in its present location, but two specific areas of concern remain. Additional forest harvesting upslope of these areas will increase localized runoff and may reduce stability in locations with existing drainage related stability problems.

The first area of concern is located to the northeast of A68053-1 *[Appendix D]*. In this area a small tributary to reach ET2 has been diverted on Trail 1, leading to a sequence of landslides (5 in total) into reaches R4, ET1 and ET2. There is a high existing landslide hazard associated with this diversion that will be exacerbated by increases in runoff associated with upslope harvesting. As discussed previously, the consequences of additional slides into the East Tributary are seen as low with respect to increased sediment and debris load, and fish habitat and water quality impairment. Following risk assessment methods outlined in the *Ministry of Forests - Road Engineering Guidebook*[10], there is a moderate risk of increased sediment and debris load, and/or water quality and fish habitat impairment on lower Ross Creek posed by additional landslides in this area. Restoration of this tributary into its natural course, and removal of two downstream crossings associated with Trails 2 and 3 in conjunction with upslope harvesting would reduce the landslide hazard and associated risk to low. To achieve a low risk in this situation, removal of fill material at the downstream crossings on Trails 2 and 3 would need to occur before flow is restored into the natural course. An

[9] Ibid.
[10] Ministry of Forests, 1995. Road Engineering Guidebook – Hazard, Consequence and Risk Assessment Procedures – Page 118.

effective way to address these concerns may be to upgrade Trail 1 for access into A68053-1, completing restoration work in conjunction with upgrade activities. A drainage restoration prescription would be required as part of the trail/road upgrade plan.

Additional landslides have also occurred from fillslope failure along Trails 2 and 3 within the East Tributary valley *[Photos 10, 11, 12]*. There is a high existing landslide hazard associated with portions of these trails that lie within the East Tributary valley. Upslope areas where SBFEP forest development is planned do not drain onto these sites and should not affect the current hazard level. There is a moderate risk of increased sediment input, and water quality and fish habitat impairment on lower Ross Creek from additional slides in this area. The existing hazard and risk on these roads could be reduced by deactivation.

The second area of concern is present on Trail 4 between blocks A68052-1 and A68051-1. Access into block A68051-1 is planned via this route. In this location Trail 4 is concentrating runoff and has the potential to divert flow north into two smaller tributaries if not upgraded properly. The volume of runoff currently being carried in ditchlines along Trail 4 is roughly equivalent to the discharge in each of the two tributary channels. There would be a high landslide hazard and moderate risk of downstream water quality and fish habitat impairment if this volume of flow were diverted into either of the two tributaries. This hazard and risk scenario could be avoided if a sufficient number of cross-drains (culverts) are installed on Trail 4 to disperse flow as evenly as possible across the slope below.

Drainage can be effectively managed using standard Forest Practices Code upgrade procedures on other roads and trails that may be required to access development. The main haul road (675) that will be required to access all SBFEP blocks has been semi-permanently deactivated. Metal culverts are present in the location of most cross-ditches, but there are some cross-ditches without. A culvert should be present in each cross-ditch location to maintain the current drainage configuration.

5.0 SUMMARY

- The debris flow risk on the Ross Creek fan is low based on a low debris flow potential in the Ross mainstem on and upstream of the fan.
- There is a moderate debris flow potential in the lower two reaches of the East Tributary channel. Debris flows that may be initiated in the East Tributary will deposit in the mainstem of Ross Creek a short distance downstream of their confluence, and will not affect the low debris flow risk on the fan.
- Approved and proposed road construction and forest harvesting, by both the SBFEP and FCL will not increase debris flow risk on the fan.
- The majority of development planned in lower Ross Creek is located below the H60 elevation of 1,260 m and will not contribute runoff to peak flows on the Ross mainstem. Two SBFEP blocks are located immediately above the H60 line on the east side of Ross Creek. With a combined area of only 40 ha, increases in runoff that will occur after harvesting in these areas will not make a significant contribution to peak flows on Ross Creek, and should not be a concern.
- There is site-specific drainage concerns associated with old road and trail related drainage diversions and the harvesting of blocks A68053-1, A35168-2, A68052-1, and A43170-1. There are also concerns with trail related drainage diversions between blocks A68052-1 and A68051-1. An effective way to address these concerns may be to utilize existing roads and trails where possible as outlined in section 4.4.
- There are concerns with old road and trail stability along reach ET2 that are unrelated to upslope development.
- The Ross Creek fan channel has undergone a change in morphology (channel form) over the period of photographic record (1928 to present). The causes of morphologic change have been a significant increase in sediment and debris delivery from upstream areas due to landslides following harvesting and fire, and to a lesser degree past harvesting in riparian areas on the fan and a likely increase in peak streamflow magnitude primarily due to the 1967 fire.
- There is a high risk of sediment delivery, channel avulsion, and flooding on the Ross Creek fan from episodic release of sediment and debris from the lowermost debris jam on reach R4. The release of sediment and debris from this jam is a natural process related to high flows and the deterioration of woody debris strength over time (i.e. rot). Sediment and debris accumulation in Ross Creek has been exacerbated by old road and trail related landslides, and extensive mass-wasting that occurred throughout the drainage following Mag Fire occurrence.
- Monitoring of the lowermost jam on reach R4 during high flow periods may provide an early warning mechanism for flooding on the fan.

6.0 RECOMMENDATIONS

- There is a high existing landslide hazard and moderate risk of increased sediment and debris load, and water quality and fish habitat impairment on lower Ross Creek associated with old trail related drainage diversions northwest of block A68053-1. Planned harvesting in upslope areas (A68053-1, A35168-2, A68052-1, and A43170-1) will increase localized runoff and may reduce stability in locations with existing drainage related stability problems. The landslide hazard in this area and associated risk could be reduced to low by implementing the following strategy:
    1. Plan to use Trail 1 for access into block A68053-1.
    2. Develop a road/trail upgrade and drainage restoration plan for Trail 1 and portions of Trails 2 and 3 that will be affected by upslope drainage restoration (i.e. stream crossings).
    3. Remove fill material from tributary crossings on Trails 2 and 3 then restore drainage on Trail 1 in upslope areas.
    4. Proceed with development in blocks A68053-1, A35168-2, A68052-1, and A43170-1.
- There would be a high landslide hazard and moderate risk of downstream water quality and fish habitat impairment if runoff currently flowing in ditchlines along Trail 4 were diverted during upgrade activity into either of the small tributary channels north of the area. This hazard and risk scenario could be avoided if a sufficient number of cross-drains (culverts) are used on Trail 4 to disperse flow as evenly as possible across the slope below.
- There is a high existing landslide hazard and moderate risk of downstream water quality and fish habitat impairment associated with portions of Trail 2 and 3 that lie within the East Tributary valley. Existing conditions should not be affected by development planned in upslope areas. If funding were available, the landslide hazard and associated risk in this area could be reduced by deactivation.
- The main access route for planned SBFEP development (695 Road) has been semi-permanently deactivated. Culverts are present at most of the cross-ditch locations but additional culverts should be installed where not present to maintain the current drainage configuration. This work could be undertaken in conjunction with road upgrade activity.

- The Ministry of Transportation and Highways and residents on the Ross Creek fan should be made aware of the risks associated with sediment release from the lowermost jam on reach R4, and opportunity for monitoring of the jam to serve as an early warning mechanism for future flooding.

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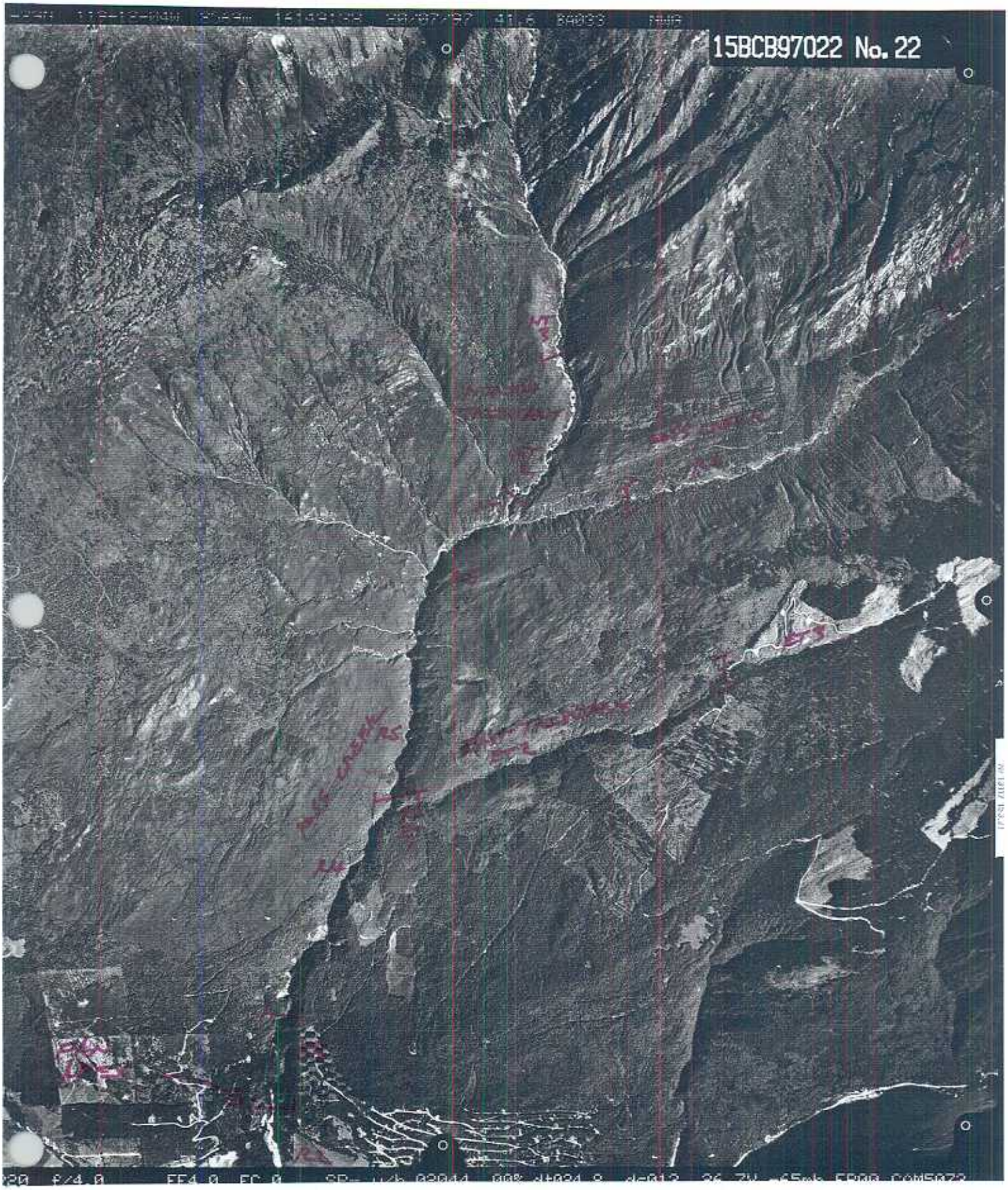
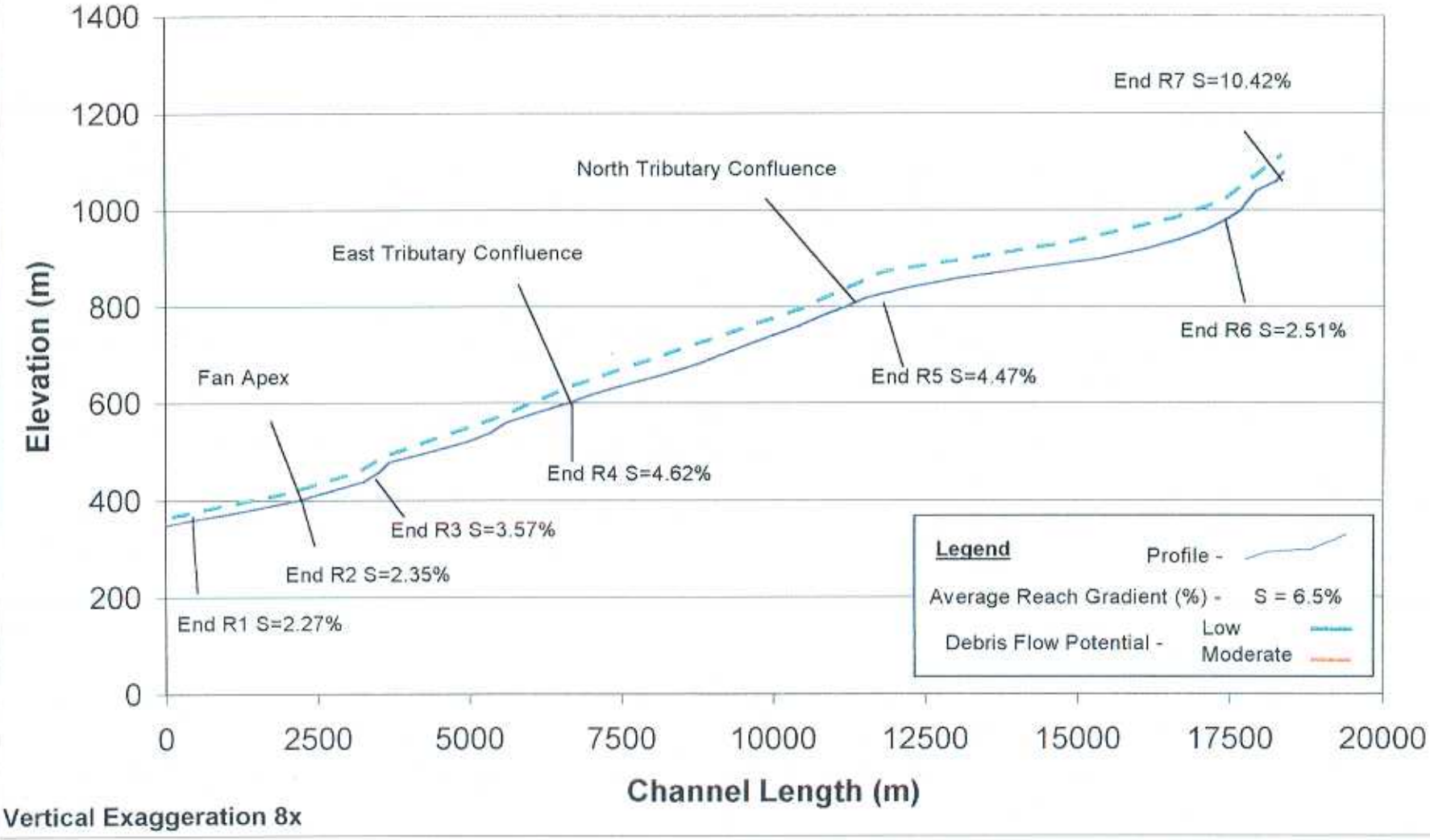


I REACH BREAK

SCALE 1:40,000

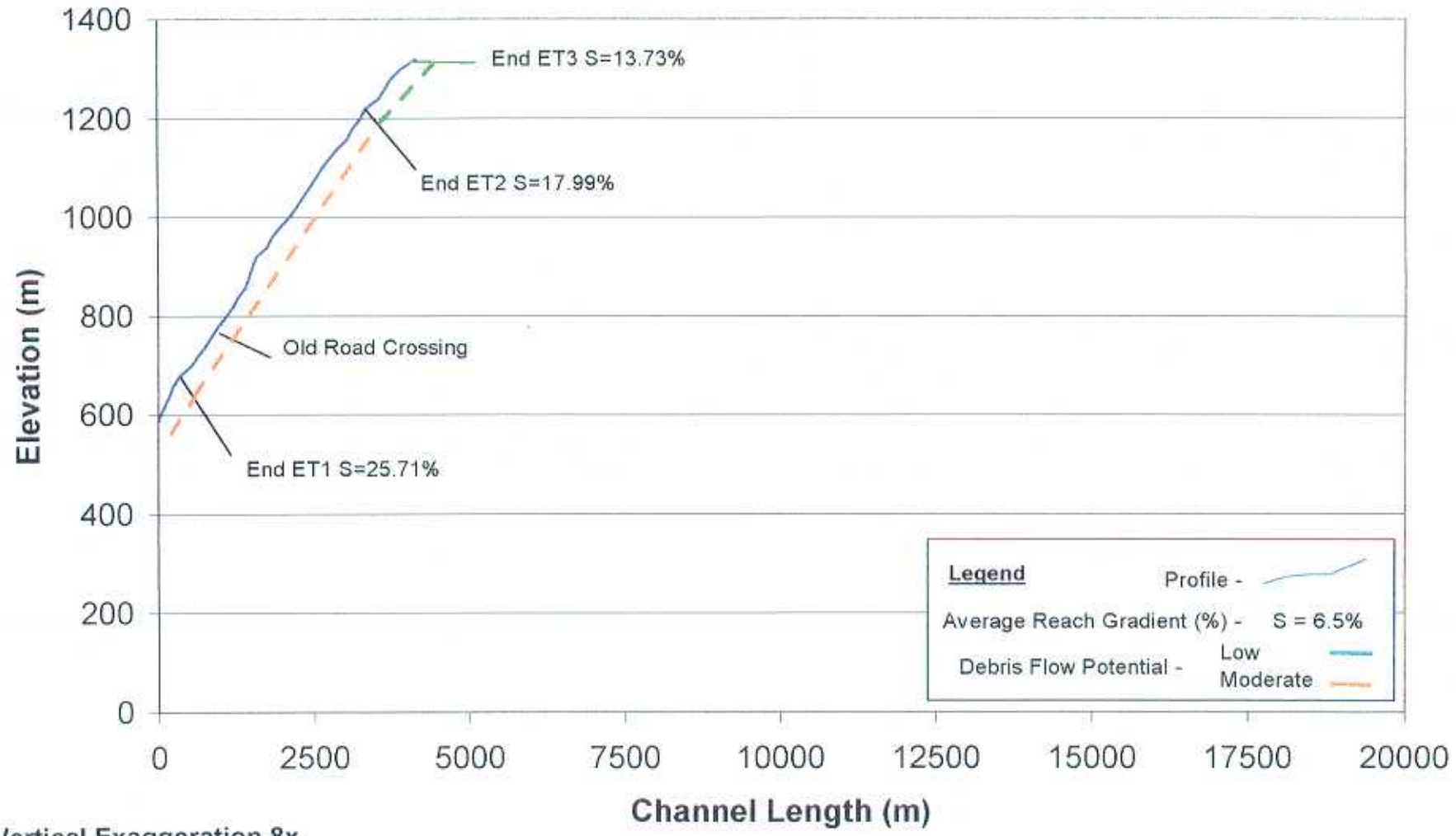
Ross Creek Mainstem Profile



Vertical Exaggeration 8x

6/10/02

Ross - East Tributary Profile



Vertical Exaggeration 8x

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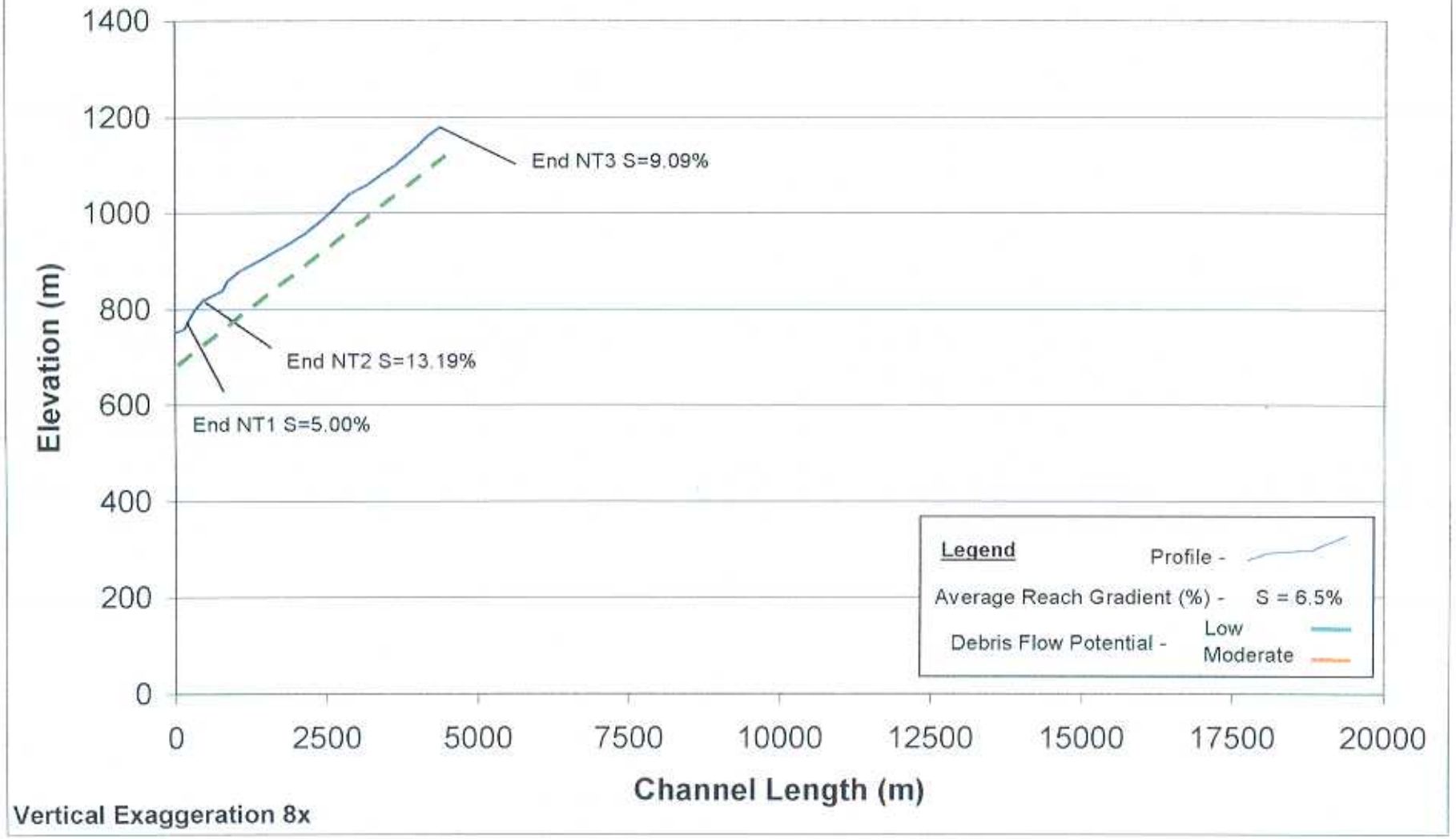
Ross - North Tributary Profile



Vertical Exaggeration 8x

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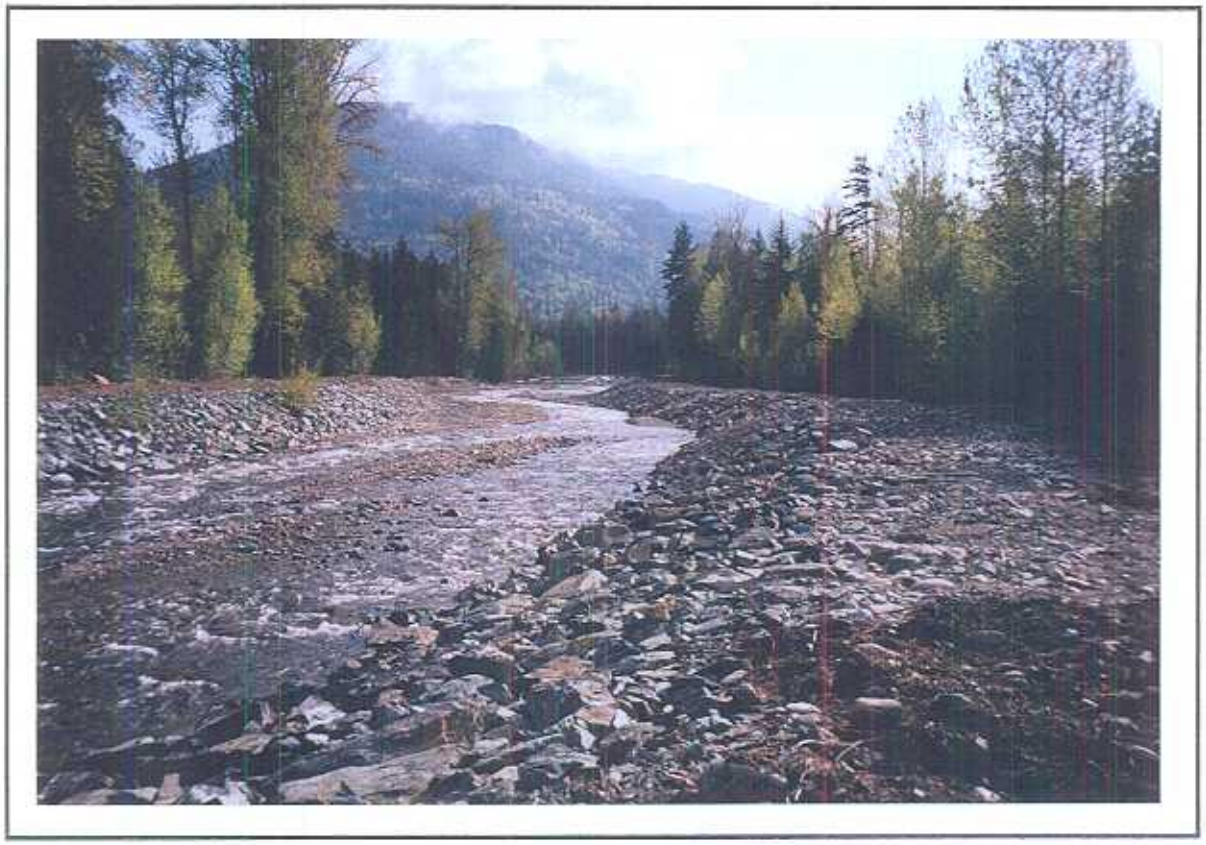

Photo 1. Reach R1 approximately 50 m upstream of Squilax-Anglemont Bridge. Note braided channel pattern within riprap banks.

Photo 2. Reach R2 showing unconfined fan channel, bankfull width ranging from 40 to 100 m, and gravel reworked by heavy equipment. Note absence of woody debris and young regenerating forest on both banks.

Photo 3. Historic delta and alluvial fan deposits on along right bank of reach R2. Note fluvial sand, gravel and cobble materials, overlying lacustrine silt and clay deposits at lower right of photo.

Photo 4. Mature vegetation present at water's edge on reach R4 with no debris flow related scarring.

Photo 5. Lowermost debris jam on reach R4. The channel has eroded around the jam on the left side of the photo re-activating a large slope failure in glacio-fluvial and lacustrine terrace deposits. This jam is approximately 75 m width and 3 m high.

Photo 6. Heavily aggraded section on upper reach R5. The entire floodplain is inundated in this location under approximately 3 m of gravel and cobble material. A downstream debris jam is the likely cause of sediment accumulation.

Photo 7. Reach R5 immediately upstream of the East Tributary confluence. Note mature timber to the water's edge and no evidence of a debris flow trim line.

Photo 8. Reach ET1 immediately upstream of confluence with Ross Creek. Note mature cedar vegetation to water's edge and no evidence of a debris flow trim line.

Photo 9. Mature cedar tree on right bank of reach ET1 at confluence with Ross Creek. No debris flow related scarring visible.

Photo 10. Recent (2001) road fillslope related landslide into reach ET2. Landslide material deposited within 50 m of the impact location and no debris flow was initiated.

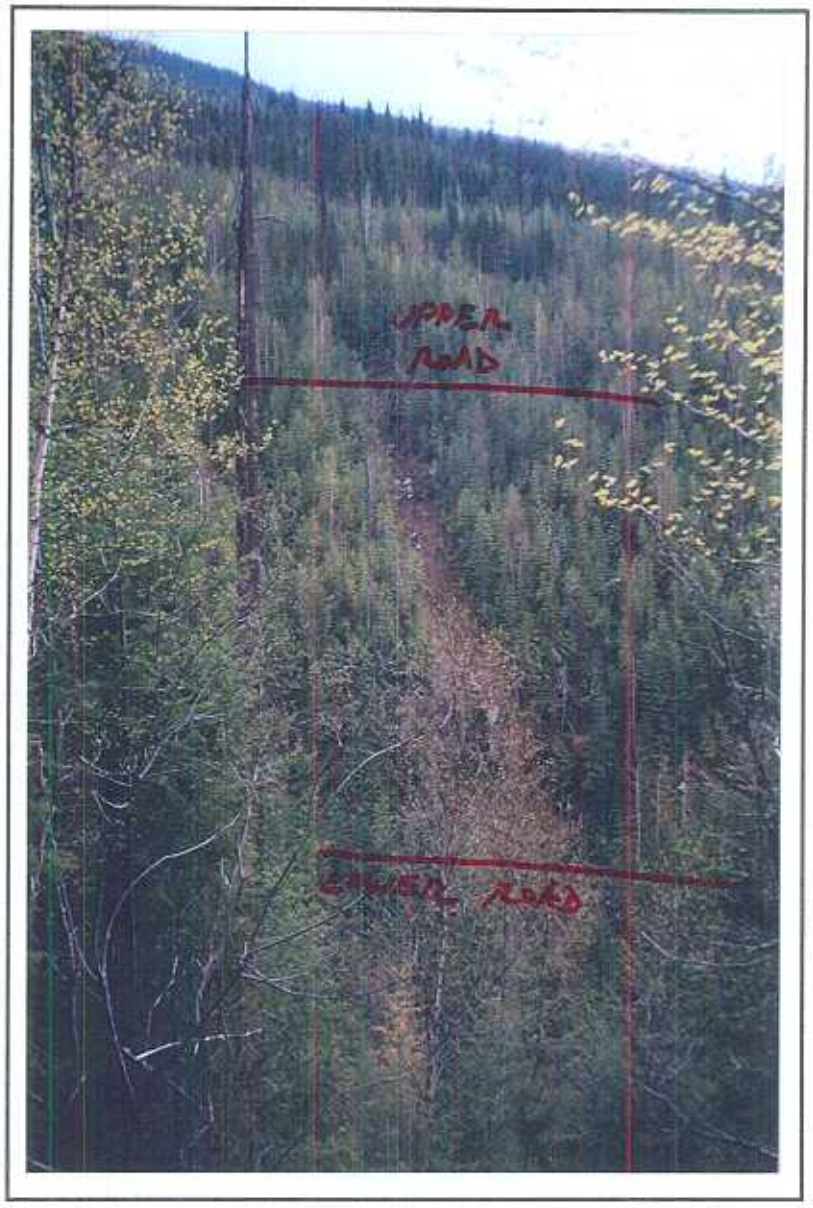

Photo 11. View across East Tributary valley at slide shown in photo 10. The slide initiated at an old road at the break in slope and carried through a lower slope road before impacting on the channel. Slope gradient ranges from 70 to 100% in the vicinity of the slide and lower slope road.

Photo 12. Old tension cracks with fillslope displacement on lower slope road shown in photo 11. Slope gradient is 90% in this location. Similar conditions exist along most of the lower slope road on both side of the East Tributary valley.