Copper Fox Metals Inc.

Geomorphic Channel Assessment and Channel Migration Hazard Mapping of Upper Mess Creek

submitted to:

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Summary

Mess Creek is a large, remote watershed located approximately 140 km southwest of Dease Lake in northwestern British Columbia. The watershed drains 2,306 km^2 of the Coast Mountains and Stikine Plateau before joining the Stikine River. Glaciers and glacial outwash channels dominate many of the high-elevation, mountainous headwater reaches of the watershed and these deliver relatively large volumes of sediment to the mainstem channel. Mess Creek is laterally unstable along some channel reaches and often flows in an irregular wandering or anastomosing channel pattern. Avulsions are common along the floodplain, and the channel has experienced major flow path changes. Mess Creek hosts a variety of fish species and thus the whole river and its floodplain are considered fish habitat as per the Fisheries Act. Copper Fox Metals Inc. (Copper Fox) has proposed construction of a haul-road (including a causeway and bridge crossings) along the upper 30-35 km of Mess Creek (above Mess Lake). Selecting the most stable location along the river and floodplain for the causeway and bridges will help minimize any potential disturbance to fish habitat and allow the river to naturally change course over time (in less stable areas). This will also minimize future maintenance costs by reducing potential erosion of the causeway following lateral river migration and adjustment.

The morphological character, stability and associated erosion hazard of upper Mess Creek was assessed from both historical airphoto and field investigations. The assessment included approximately 40 km of mainstem river channel extending from the outlet of the study area to the headwater reaches of the watershed and adjacent to the proposed haul-road. An overview airphoto assessment was undertaken for the entire mainstem length of channel, while the channel migration hazard was mapped for two separate 5 km sections of river (10 km in total), each centered near one of two proposed channel crossings. In general, the two proposed channel crossings investigated in this report occur over relatively stable channel types. However, channel change and lateral adjustment is expected in these reaches, and the channel migration hazard has been mapped in the vicinity of the proposed crossings. The channel migration hazard was based on separate assessments of the bank erosion hazard and the avulsion hazard. The bank erosion hazard was assessed by measuring both the rate and spatial distribution of bank erosion across the floodplain or valley bottom, while the avulsion hazard was assessed by delineating the width of the meander belt and considering the past location(s) of a given channel on the floodplain.

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Preface

Terms of reference

Fluvial Systems Research Inc. has completed this report upon the request of Shane Uren of Copper Fox. The report was initiated to address the potential impact(s) of a proposed haul-road and causeway on fish habitat in Mess Creek (located in northwestern British Columbia). The purpose of this report is to provide guidelines for locating relatively stable portions of the Mess Creek floodplain and/or valley bottom to help minimize any potential disturbance to fish habitat and allow the river to naturally change course over time (in less stable areas). The guidelines are also intended to help minimize future maintenance costs by reducing potential erosion of the causeway following lateral river migration and adjustment.

The channel assessment was limited to the mainstem of upper Mess Creek (starting approximately 6 km upstream of Mess Lake) to the upper reaches of the sub-basin (herein named sub-basin D) that parallels the proposed haul-road before crossing into More Creek. The channel migration hazard mapping was restricted to a 5 km section of river in the vicinity of the proposed causeway and 5 km section of river in sub-basin D (near a second proposed crossing). The mapping was based on a historical series of airphotos available for 1965, 1974, 1982, 2006, and 2007. Imagery prior to 1965 was not available. Copper Fox provided imagery for 2006 and 2007 in an orthorectified format. The entirety of this report has been completed by Fluvial Systems Research Inc. in accordance with the working plan submitted to Copper Fox entitled Mess Creek Geomorphic Channel Assessment and dated June 6, 2008.

Statement of limitations

This report has been prepared for use by Copper Fox for the specific objectives under which it was commissioned. Fluvial Systems Research Inc. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report. Any such unauthorized use of this report is at the sole risk of the user. This report is based on current conditions and information made available at the time the report was prepared and as appropriate for the project scope of work. The report is intended to be read as a whole and sections of the report should not be read or relied upon out of context.

This report has been carried out in accordance with generally accepted geoscience practice. Geoscience judgment has been applied both in interpreting the results and developing the conclusions and recommendations presented in this report. No other warranty is made, either expressed or implied.

Certification

This report entitled *Geomorphic Chanel Assessment and Channel Migration Hazard Mapping of Upper* Mess *Creek* has been prepared by:

(Original signed and sealed hardcopy held on file)

Stephen Bird, M.Sc., P.Geo.

Fluvial Geomorphologist

Citation

Bird, S.A. 2010. Geomorphic channel assessment and channel migration hazard mapping of upper Mess Creek. Unpublished report prepared for Copper Fox Metals Inc. by Fluvial Systems Research Inc., White Rock, BC.

1.0 Introduction

Mess Creek is a large, remote watershed located approximately 140 km southwest of Dease Lake in northwestern British Columbia (Figure 1). The watershed drains a mountainous terrain and several high-elevation, tributary valleys host glaciers with outwash channels that deliver relatively large volumes of sediment to the mainstem channel. Mess Creek is laterally unstable along some mainstem channel reaches and often flows in an irregular wandering or anastomosing channel pattern. The high sediment supply causes the channel to braid along reaches proximal to glaciated tributary valleys. Channel avulsions are common along the floodplain, and the channel has experienced major flow-path changes along a relatively unconfined valley

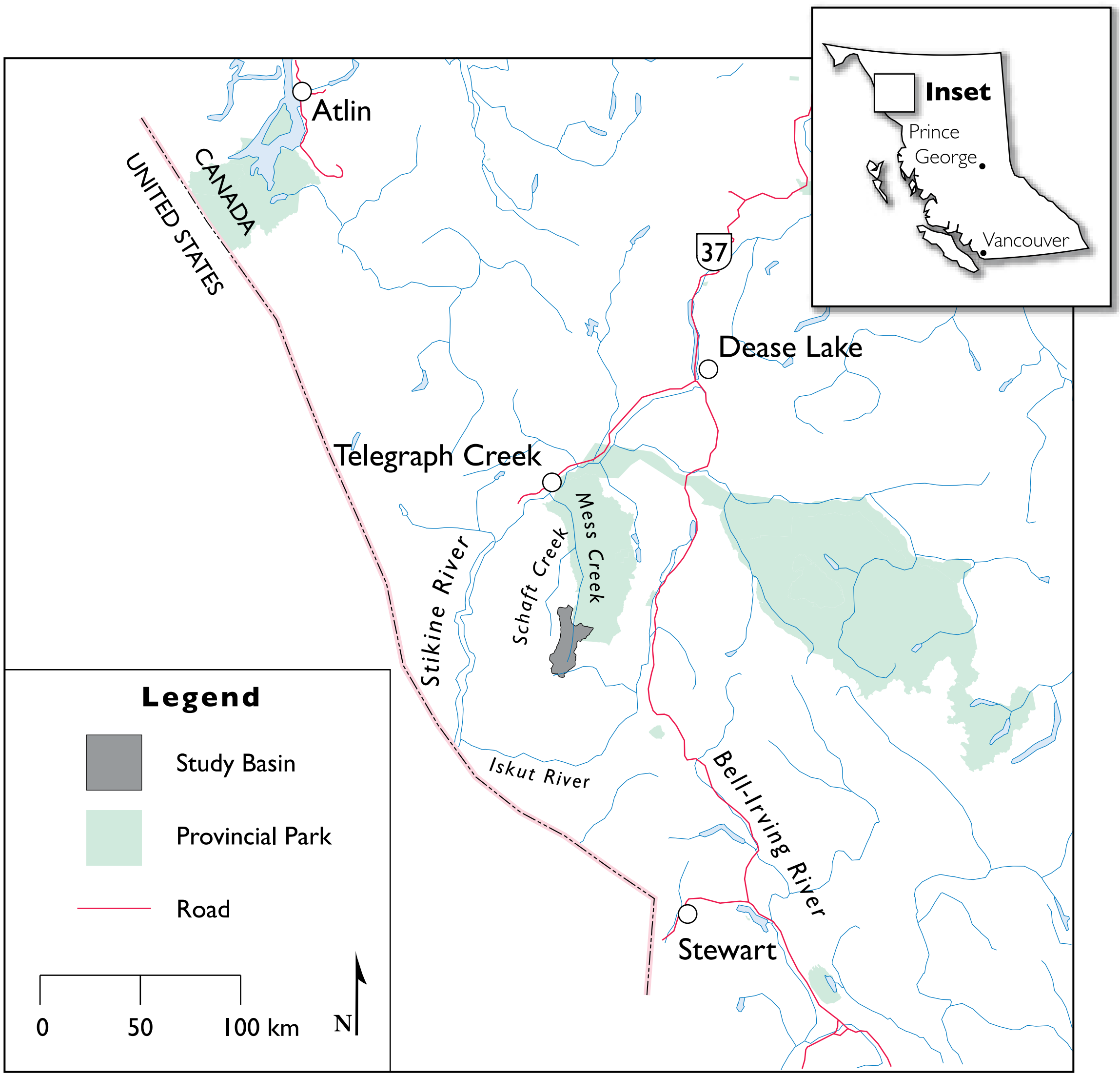

Figure 1. Map showing the location of Mess Creek and the watershed boundary assessed as part of this report.

bottom and floodplain. Mess Creek hosts a variety of fish species, including Chinook Salmon, Mountain Whitefish, and Steelhead (FISS, 2009). However, several barriers to fish passage limit the distribution of these species from the upper reaches, and Rainbow trout is the dominant species found in various lakes, wetlands, and active channels upstream of Mess Lake (Rescan, 2008a).

Copper Fox Metals Inc. (Copper Fox) is a Canadian mineral exploration and development company currently in development of the Schaft Creek copper-gold-molybdenum deposit (Schaft Creek is a major tributary to Mess Creek). The property is located on a remote, greenfield site and access to the minesite requires construction of a haul-road. Following a review of technical feasibility, operational constraints, existing geo-hazards, and the proximity of Mount Edziza Provincial Park, two options have been prioritized for further consideration, both of which require construction of a causeway and two bridges across the floodplain and main channels of upper Mess Creek (Rescan, 2008b). The proposed causeway and bridge crossings are located from about km 6.5 to 8.0 of the proposed haul-road. Once across Mess Creek, the proposed haul-road continues up valley to km 25.5 where the proposed route either a) continues southward (up valley) to the headwaters of Mess Creek before crossing into the More Creek drainage, or b) ascends the relatively steep slopes of Mess Creek valley and traverses a high elevation plateau to the east of Mess Creek. Construction of a rock-fill causeway is required across approximately 500 m of wetlands and each bridge must span about 30 to 40 m of the main channel (Rescan, 2008b).

The proposed causeway is located along an anastomosed reach of Mess Creek, and multiple channels flow across the floodplain and amongst numerous wetlands. An anastomosed river is defined here partly after Makaske (2001) as a river with multiple, coexisting channel belts bound by floodbasins or the floodplain margin. Individual channel belts may host channels with a range of channel patterns (meandering, wandering, etc.), channel bars (including braids), abandoned channel segments, crevasse splays and levees. In this sense, the terms "anastomosing" and "braided" are not synonymous, with the latter referring to bifurcation of the flow (water and/or sediment) within the active channel and around relatively stable portions of the bed (Ashmore, 1991). Floodbasins are "saucer-shaped" islands that separate individual channel belts and are bound by levees or the floodplain margin, are typically poorly drained, and often support extensive wetlands (Makaske, 2001).

Anastomosed channels such as Mess Creek (near the proposed causeway) form when an avulsion diverts the channel onto its floodplain while maintaining the existing channel for some period (i.e., a partial avulsion), and the diverted flow scours a new channel(s) on the floodplain surface (Makaske, 2001; Slingerland and Smith, 2004). An avulsion may occur following aggradation of the channel bed and the incision of a crevasse channel in a levee (or exploitation of an existing crevasse or other weak -point in a levee) that enlargers until flow is permanently diverted away from the parent channel (Slingerland and Smith, 2004). Avulsions may occur gradually or in rapid fashion, ranging from a period defined by several floods to a period of several centuries (Slingerland and Smith, 2004). An anastomosed channel pattern persists through either relatively frequent avulsion and/or slow abandonment of the old channels (Makaske, 2001). Given the dynamic nature of upper Mess Creek, selection of a relatively stable location along the river and floodplain for the causeway and bridges will help minimize any potential disturbance to fish habitat and allow the river to naturally change course over time (in less stable areas). This will also minimize future maintenance costs by reducing potential erosion of the causeway following lateral river migration and adjustment (in addition to the avoidance of other geo-hazards not considered by this report).

1.1 Objectives

The objectives of this report are to first identify sensitive river reaches and/or geomorphic watershed units in upper Mess Creek where river management efforts may be prioritized, and then create a channel migration hazard map that rates the probability of a given portion of floodplain being eroded into the active channel in a given period. The results can be used to identify the most stable portions of the river and floodplain with respect to expected patterns of future river erosion. The channel migration hazard map will be based on the position of the channel as mapped from airphotos acquired in 1965, 1974, 1982, 2006, and 2007. The airphoto series will be rectified and georeferenced to an orthophoto (supplied by Copper Fox) so that changes in channel position reflect actual changes and not distortions in the imagery and/or mapping. The erosion hazard will be mapped on a reach-by-reach basis (as determined above). Planimetric channel maps will be generated from the airphotos and will include line-work showing the banks of all active channels flowing across the floodplain and visible on the airphotos (dependent on image resolution, tree cover, shadows, etc., relative to channel width). The position of the channel(s) will be compared through time following methods adapted from Graf (1984), Schwab et al. (2002) and Piegay et al. (2005) to generate an erosion hazard rating along each reach. The map will describe the probability of a raster cell (located on the valley bottom/floodplain) being eroded into the active channel in a given period.

1.2 Report organization

Section 2 of this report describes the environmental setting of upper Mess Creek and the geomorphic character of the watershed. Emphasis is placed on the processes that transfer sediment from throughout the watershed and influence the morphology of the mainstem of Mess Creek. Section 3 describes the methods used to map and assess the stability of select channel reaches. Section 4 describes the character of sub-basins and the reach stability, while the channel migration hazard mapping is presented in Section 5. Section 6 discusses the results while conclusion are given in section 7. Large-scale channel migration hazard maps are included in the pocket.

2.0 Environmental setting

Mess Creek flows through a large, remote watershed located approximately 140 km southwest of Dease Lake in northwestern British Columbia (Figure 1). The watershed drains approximately 2,306 km^2 of the Coast Mountains and Stikine Plateau before joining the Stikine River near the town of Telegraph Creek. The study area is located 6 km upstream of Mess Lake and includes 344.1 km^2 of the upper Mess Creek watershed.

2.1 Physiography

Mess Creek flows along a north-trending fault zone (Logan et al., 1992) that generally marks the border between the Boundary Ranges (a physiographic subzone of the Coast Mountains) to the west and the Tahltan Highland (a physiographic subzone of the Stikine Plateau) to the east (Holland, 1964). The watershed drains both terrains. Generally, the western slopes within the Boundary Ranges are characterized by rugged, high mountains with peaks that reach elevations of up to 2,400 m (relief in the study area is approximately 1,700 m). These slopes are underlain with rock associated with the Stikine Assemblage (mostly Lower Permian basaltic rock and Pennsylvanian dolomitic carbonate rock) and the Stuhini Group (mostly Upper Triassic volcaniclastic rock) amongst others (BC Geological Survey, 1997). In contrast, the eastern slopes within the Tahltan Highland are relatively subdued and reach a maximum elevation of about 2,100 m. The highland is the remnant of a late Tertiary erosion surface dissected by Mess Creek and its tributaries (as well as by surrounding drainages), and forms a transitional zone between mountainous regions to the west and the relatively large plateaus to the east (Holland, 1964). The highland is underlain by rock from the Mt. Edziza Group (Pliocene and Pleistocene to Recent volcanics) and rock from the Stikine Assemblage (Lower Permian and Devonian volcanics and limestone, marble and calcareous sedimentary) amongst others (BC Geological Survey, 1997). Mt Edziza is a composite, shield volcano of Tertiary and younger age, located on the highland about 35 km northeast of the study area, and large lava surfaces slope westward into Mess Creek valley (Holland, 1964).

Cordilleran ice during Pleistocene glaciations reached elevations in the area of about 2,000 to 2,100 m valley (Holland, 1964). During Fraser Glaciation (ca. 25-10 ka), ice flowed across the region in a southwesterly direction and crossed valleys such as Mess Creek at an oblique angle and did not follow local topography until the ice thinned, sometime after the climax of the glaciation (McCuaig and Roberts, 2002). Once sufficient thinning had occurred, ice was channeled along Mess Creek valley where terrain features were further modified and straightened (Holland, 1964). In general, peaks and ridges below the ice level are rounded, slopes are oversteepened, and the main valleys are U-shaped (Figure 2). There were two advances of

Figure 2. Photomosaic of upper Mess Creek looking upstream along reach M1-D with the Boundary Ranges on the right and the Tahltan Highland on the left. The surface texture of the bar in the foreground is dominated by silty sand. A floodbasin and associated wetland are seen along the right of the image.

Cordilleran ice in the region but it is unknown if these were two stades of Fraser Glaciation or two distinct glaciations (Ryder and Maynard, 1991).

Deglaciation throughout the region occurred as both frontal retreat and downwasting of glacial ice, with Stikine River serving as a major subglacial drainage system to the area (Ryder and Maynard, 1991). Alpine glaciers persist in some western tributaries of Mess Creek and form part of a relatively large ice field southwest of the watershed (Figure 3). Ryder (1987) investigated the Neoglacial advance of ice throughout the Stikine-Iskut area, and suggests that the advance of glacial ice during this period (and for sites nearby Mess Creek) reached a maximum by the late nineteenth or early twentieth centuries. Overall, subsequent ice retreat has been relatively rapid and the alpine glaciers of Mess Creek (and surrounding areas) are likely smaller at present than at any other time in the past 4,000 years (Ryder, 1987).

The surficial geology of the study area is relatively complex, and includes occurrences of colluvium, glacial till (morainal), glaciofluvial and fluvial sediments. Volcanic ash and pyroclastic sediments (silty to sandy) transported by wind are also found in the area, most commonly near Mt. Edziza (Rescan, 2008c). The upper slopes are steep and gullied with a thin layer of rubble colluvium over rock (BGC Engineering, 2008), while bedrock outcrops are common at higher elevations (Rescan, 2008c). Lower valley slopes are more subdued and overlain with glacial till and colluvium, although bedrock is exposed on steeper slopes and in areas of stream channel incision (BGC Engineering, 2008). The mainstem floodplain of Mess Creek consists of glacial, glaciofluvial, and fluvial deposits (Fenger and Kowall, 1992; BGC Engineering, 2008; Rescan, 2008c).

2.2 Climate and hydrology

Climatic normals for the study area during the period 1971-2000 are and summarized below after Wang et al., (2006) using the ClimateBC (2006) data model. Generally, Mess Creek is characterized by long and cold winters and cool, short summers. The mean winter and summer temperatures are -11.9 and 11.5° C, respectively, and the frost-free period is brief, extending from May 17 to August 24. Total annual precipitation averages 688 mm, with 195 mm arriving over the summer months and 393 mm falling as snow. However, the results of a short term, low density climatic network established and monitored in the Stikine-Iskut region by Fenger and Kowall (1992) suggest that the regional normals presented above may actually underestimate local precipitation. In fact, the greatest amount of precipitation in the region may occur south and southwest of the upper reaches of Mess Creek. Additional base-line meteorological data is currently being collected in the watershed. Initial results (although preliminary in nature) from the Schaft Saddle station also indicate that annual precipitation exceeds that predicted from regional normals (Rescan, 2008d).

Mess Creek is an ungauged watershed although several hydrometric stations are located nearby. Baseline hydrometric data have been captured in the area beginning in the spring of 2006 (Rescan, 2008e). Two stations (Sk-1, Mess-1) are located in the study area with the remaining four in Shaft Creek. A typical hydrological year based on regional data is summarized here after Rescan (2008e). Generally, streamflow discharge during the winter months is negligible as channels are covered in snow and ice (depending on elevation) with annual peak flows occurring in the spring driven by snow melt and/or rain-on-snow events. The discharge recedes to low flow conditions over the summer months with water yields

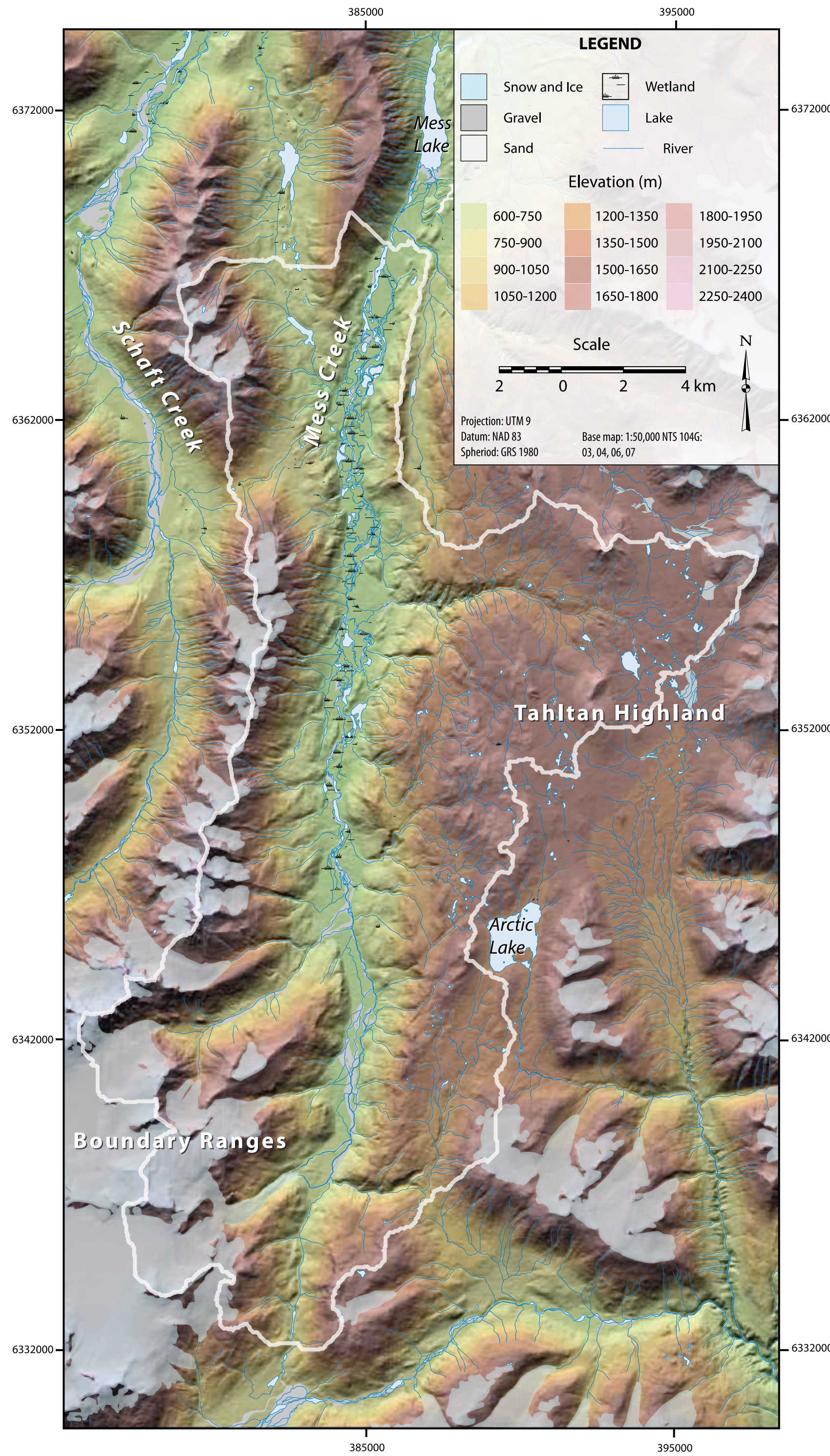

Figure 3. Shaded relief map of upper Mess Creek watershed.

supplemented by glacial meltwater. Discharge remains relatively low during the fall, although the hydrograph may be punctuated by higher flows associated with individual rainstorms and/or rain-on-snow events. Results from the monitoring program suggest that, generally, water yield is greatest in the high elevation and highly glacierized catchments. Annual instantaneous peak flows of 74.1 and 120 m^3/s were estimated for the Mess-1 station in 2006 and 2007, respectively (see Rescan, 2008e for additional details). The mean annual flood (Q_{maf}) at the outlet of the study are was estimated here as 181 m^3/s using the scale relation for British Columbia given by Eaton et al. (2002)

$$Q_{maf} = k\,A_d^{\;0.75} \qquad \text{Eq. [1]}$$

where A_d is the drainage basin area and k is a factor describing regional run-off response (taken here as 2.26). (For a general comparison, Equation 1 suggests Q_{maf} = 126 m^3/s for the Mess-1 station given A_d = 212.7 km^2 upstream of the gauge.)

Two hydrometric stations operated by Water Survey of Canada and comparable to Mess Creek (see Rescan, 2007) have relatively long-term records available for analysis. A gauge on Stikine River at Telegraph Creek (and upstream of the confluence with Mess Creek) has operated since 1955, while a gauge on Iskut River below Johnson River has operated since 1959. A cumulative departure plot of the annual peak instantaneous discharge for each site (to 2007) is given in Figure 4. Cumulative departure plots

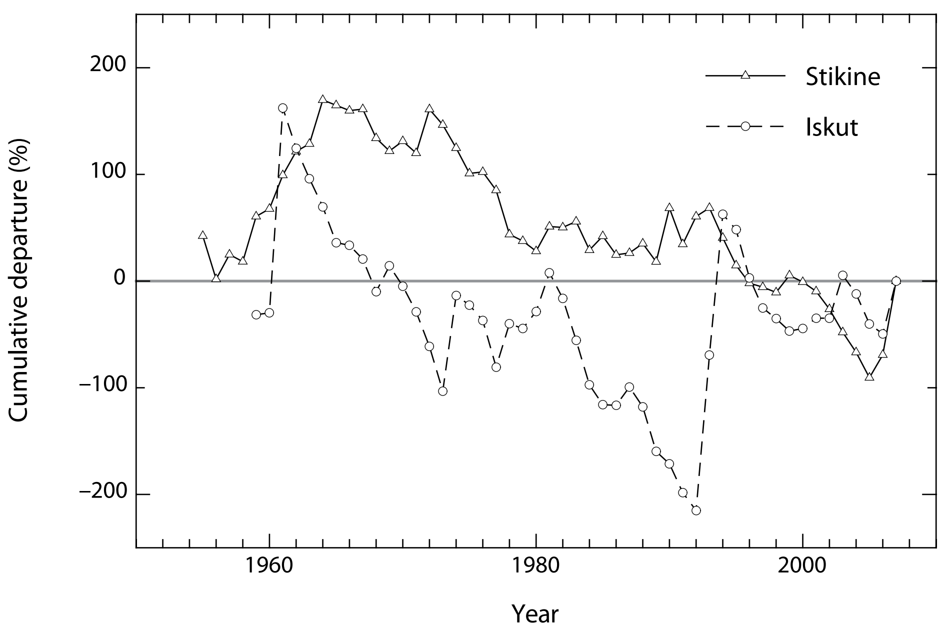

Figure 4. Cumulative departure (from the mean) plots of the annual maximum instantaneous discharge for Water Survey of Canada gauges nearby to Mess Creek, located on Stikine River (station no. 08CE001) and Iskut River (station no. 08CG001).

can be used to identify periods of above and below average discharge (up-trending and down-trending, respectively) relative to the long-term mean. For the gauges deemed similar to Mess Creek, peak flows have generally been below average since the early 1960s and through until 2007, albeit with some fluctuations. In particular, Stikine River maintained an average discharge from about 1980 through until the early 1990s, while Iskut River had a relatively large increase above the average in 1993 and 1994 given the occurrence of relatively large floods in each of these years.

2.3 Sediment transfer

Both chronic and episodic processes characterize sediment transfer throughout the watershed. Chronic processes include soil and (potentially) deep seated rock creep (Samuel Engineering Inc., 2007), glacial, nival, and fluvial erosion. Extensive post-glacial colluvial and fluvial deposits have accumulated along many of the relatively steep tributary channels (Rescan, 2008c), especially those coupled to adjacent hillslopes. These sediments may be remobilized by fluvial erosion during relatively high flows and transferred downstream. Generally, the banks of the mainstem channel flowing through the main valley of Mess Creek are alluvial and may be eroded by the channel at high flow.

Evidence of episodic processes such as landslide, rock fall, rock slide, debris flow, and debris flood have been observed in either Mess Creek or in neighbouring Shaft Creek (BGC Engineering, 2008; Samuel Engineering Inc., 2007). In general, hillslope failures can transfer sediment directly into Mess Creek from residual watershed areas or from sub-basin tributaries (BGC Engineering, 2008), while snow avalanches deliver small woody debris to lower slope tributaries along avalanche chutes (Rescan, 2008a). Sediment transfer throughout the drainage basin is relatively active, especially in sub-basins that have experienced recent glacial retreat and lack substantive vegetation on newly exposed sediments. In particular, rock falls and rock slides from glacially over-steepened slopes deliver sediment to steep tributary channels where the material may become remobilized in a debris flow, debris flood, or flood and delivered to the mainstem of Mess Creek or stored in fans prograding onto the valley bottom (BGC Engineering, 2008).

Although Mess Lake is outside of the study area, it is considered here as it serves as a sediment sink to upper Mess Creek and limits the transfer of coarse, bedload sediments from transfer to downstream reaches. The lake has a surface area of 1.7 km^2 and a mean depth of 9.6 m (BC Ministry of Environment, 1985). The lake forms a delta upstream as distributary channels of Mess Creek deposit fine sand on the bed and floodplain, while the outlet channel of the lake is characterized by boulders before entering a section of canyon (Rescan, 2008a).

2.4 Vegetation and soils

The distribution of biogeoclimatic zones within the watershed is summarized here after BC Ministry of Forests and Range (2006a). The floodplain and lower slopes of the Mess Creek watersheds (up to elevations of 1850 m) are dominated by the very wet and cold subzone of the Engelmann Spruce–Subalpine Fir (ESSFwv) biogeoclimatic zone. The undifferentiated parkland subzone of the Boreal Altai Fescue Alpine (BAFAunp) biogeoclimatic zone occurs at elevations ranging from 950 to 2400 m located on plateaus, mountainous slopes and steep, confined valleys. A relatively small portion of western slopes within the watershed is located in the undifferentiated parkland subzone Coastal Mountain-heather Alpine Zone (CMAunp) and ranges in elevation from 1850 to 2150 m.

Forest cover mapping of the watershed prepared in 1970 show most stands are dominated by mature subalpine fir with some mixed stands of subalpine fir and lodgepole pine (BC Ministry of Forests and Range, 2006b). These stands were established about 250 years before present and generally range from 20 to 25 m in canopy height. Mixed stands of spruce and balsam poplar were also found in the watershed. Results from Rescan (2008f) suggest that stands dominated by subalpine fir interspersed with lodgepole pine and hybrid white spruce in the ESSFwv are likely Drier forests with a shrub layer of black huckleberry and black gooseberry. Mature, coniferous forests dominate relatively stable, lower slope tributaries. However, some mixed deciduous forests with stand ages ranging from absent, initial, shrub/herb, pole sapling, and young forest are found along the banks of some tributaries (Rescan, 2008a) and this can indicate an occurrence of relatively recent channel disturbance (although not invariably).

Wetlands and riparian flood ecosystems are common along the Mess Creek floodplain (summarized here after Rescan, 2008g). Swamps and marshes are common (at least within 100 m of the proposed causeway), although fens and open water wetlands also occur (amongst others). Generally, these wetlands are comprised of silt (33 to 64%) and clay (6 to 54%) with smaller proportions of sand and very little gravel. The hydrology is dominated by spring snowmelt. Common marsh species include willow, water sedge, horsetail, and some spruce. In addition to these pure wetland ecosystems, a transitional shrub-carr ecosystem of Barclay's willow – Arrow-leaved groundsel is common along imperfectly drained, moist to very wet mineral soils (e.g., streambanks and levees), while various flood associations (usually dominated by willow) often occur in association with swamps and/or upland forests.

Podzolization is the dominant soil forming process in the study area (Rescan, 2008c). Orthic Humo-Ferric Podzols are found on most low elevation, morainal slopes throughout the ESSFvw biogeoclimatic zone and adjacent to the mainstem floodplain of Mess Creek (Fenger and Kowall, 1992; Rescan, 2008c). Both Melanic and Sombric Brunisols are typical of the BAFAunp biogeoclimatic zone across the Tahltan Highland, although Humo-Ferric Podzols are also found throughout this area (Fenger and Kowall, 1992). Alpine areas of the Boundary Ranges are more rugged and soils consist of Sombric Humo-Ferric Podzols and Sombric Brunisols or may be lacking entirely (Fenger and Kowall, 1992). Generally, alpine soils found throughout the area are both shallow and sensitive to disturbance (Rescan, 2008c).

Organic soils (Mesisols, Humisols) are found in poorly drained sites or depressions along the mainstem floodplain of Mess Creek (Fenger and Kowall, 1992; Rescan, 2008c). Generally, these sites occur at relatively low slope positions within an individual floodbasin and these are found along anastomosed reaches of the river. Orthic Gleysols are found on poorly drained sites (i.e., a permanent water table is < 1 m below the surface) while Orthic Dystric Brunisols and Orthic Melanic Brunisols on well drained sites (Fenger and Kowall, 1992). Generally, these sites are found throughout a floodbasin (poorly drained) and/or along levees and streambanks (imperfectly drained). Orthic Regosols occur on recent fluvial deposits (Rescan, 2008c), such as recently abandoned channels, accreting portions of the floodplain, vegetated channel bars, and splays. Regosols dominate the upper reaches of the mainstem floodplain (Fenger and Kowall, 1992), partly in response to a decrease in lateral channel stability (relative to the lower reaches) given relatively high amounts of sediment transfer from upstream and upslope areas of the watershed (generally, the frequency of fluvial disturbance prevents the soil from weathering and maintains it as a Regosol).

3.0 Methods

The morphological character, stability and associated erosion hazard of upper Mess Creek was assessed from both airphoto and field investigations. The assessment included approximately 40 km of mainstem river channel extending from the outlet of the study area to headwater reaches of the watershed and adjacent to the proposed haul-road (Figure 5). An overview airphoto assessment was undertaken for the entire mainstem length of channel, while the erosion hazard was assessed for two separate 5 km sections of river (10 km in total), each centered near one of two proposed channel crossings (Figure 5).

3.1 Airphoto analysis

Mess Creek was assessed from airphotos acquired in 1965, 1974, 1982, 2006, and 2007. Neither provincial nor federal imagery prior to 1965 was available for this analysis. Imagery acquired in 2006 and 2007 was commissioned by Copper Fox and covered the lower and upper reaches of the watershed, respectively. Diapositives of the 1965, 1974, and 1982 imagery were digitized with a photogrammetric scanner at a resolution of 10 μm (imagery acquired by Copper Fox was provided in digital format). Copper Fox also provided orthomosaics of the 2006 and 2007 imagery with a ground resolution of 0.5 and 0.2 m, respectively. An inventory and description of all images used in the analysis is given in Table 1.

Planimetric channel maps were generated for the erosion hazard assessment by triangulating the historical imagery relative to the respective orthomosaics. (Generally, the triangulation process establishes the relation amongst images in a project, the camera(s) used to acquire the imagery, and the position of the imagery relative to the ground, and is a required step before accurate planimetric maps can be generated from overlapping airphotos). Imagery from 1965, 1974, and 1982 imagery was triangulated in a single image block using Leica Photogrammetry Suite (LPS) software. A separate image block triangulation was completed for the upper and lower proposed channel crossings. Ground control was derived from the appropriate orthoimage by bridging stable, discrete points (e.g., rock outcrops, local topographic peaks,

Table 1. Inventory of airphotos reviewed in this report. Imagery from 2006 was provided in orthomosaic format only.

Year	Flight line	Frames	Nominal scale
1965	15BC05157	153-168	1:31,860
1974	15BC5607	228-229; 249-251; 269-271	1:60,000
1974	15BC5612	10-11	1:60,000
1982	15BC82016	118-120; 141-143; 176-178; 199-201; 240-242	1:60,000
2007	11	274-279	1:10,000

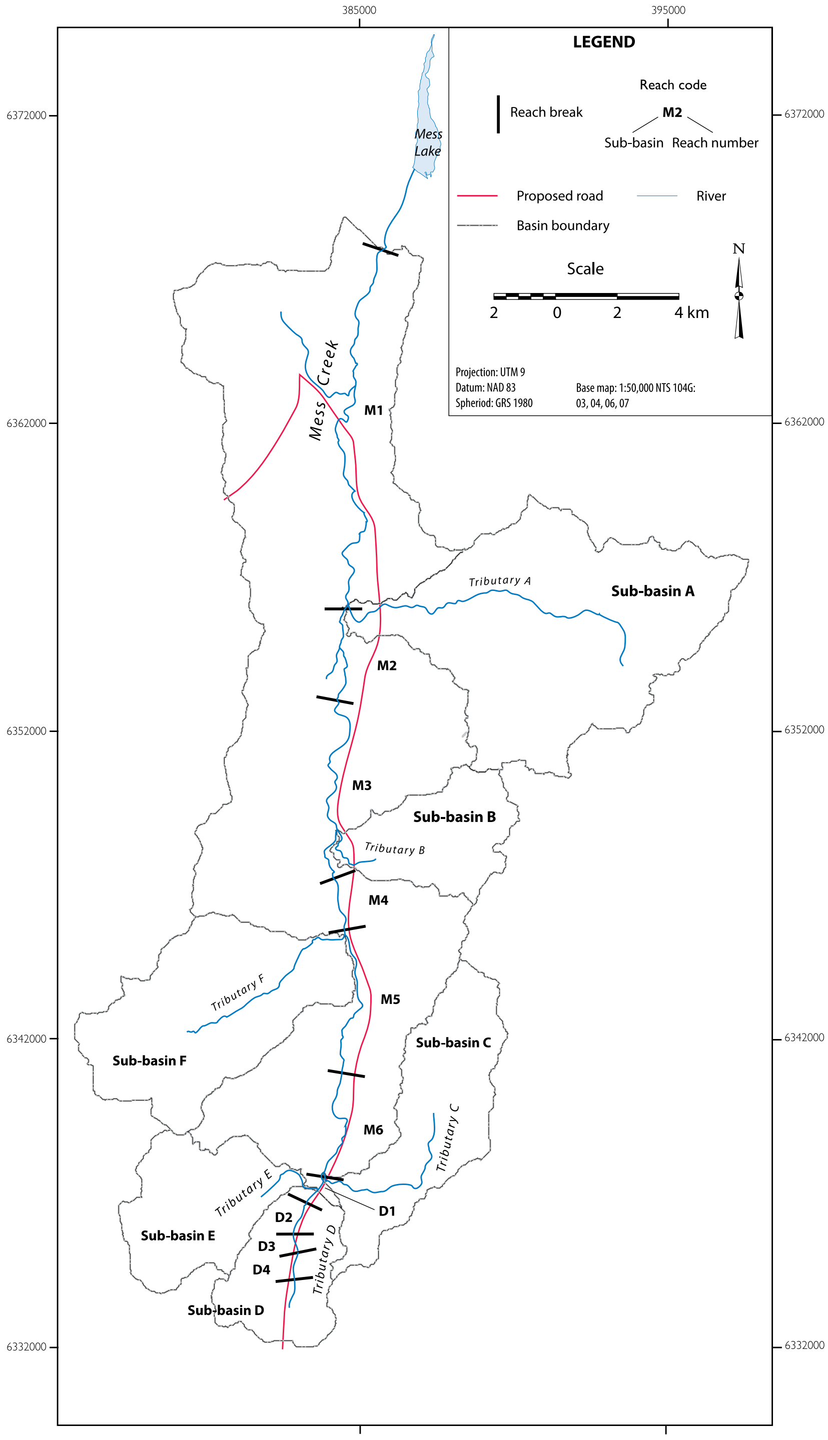

Figure 5. Map of upper Mess Creek watershed showing the location of the major sub-basins and the mainstem channel reaches assessed in this report.

tributary confluence, etc.) common to both the orthomosaic and the historical imagery (or at least one year of the historical imagery). The orthomosaics had a horizontal precision of ±1 m (F. Leggiadro, McElhanney Consulting Services Ltd., pers. comm.). The final root mean square (RMS) error for the upper and lower image blocks were +/- 0.0053 and 0.0063 mm, respectively, measured in image space (the RMS error gives the overall quality of the triangulation). Additional ground control points were withheld from the triangulation process and used as independent check points to assess the horizontal precision of any planimetric measurements made from the image blocks. The results of the check point analysis are given in Table 2.

Once the images were triangulated, planimetric maps of the active channel were generated for 1965, 1974, and 1982 with a digital stereoplotter (ERDAS Stereo Analyst), while the active channel was mapped directly from the respective orthoimage for 2006 and 2007. The active channel included the water surface, any active or partially vegetated channel bars, active overbank scour and/or deposition, and any woody debris accumulations within the channel boundary. These data were mapped as a single map coverage (i.e., bars were not distinguished from the water surface, etc.). Channel banks were often obscured by riparian vegetation and not mapped by direct observation. In these instances, bank positions were instead interpolated between points where the banks were visible and/or were mapped along the vegetation trim line adjacent to the active channel. The extent of the Holocene floodplain and/or valley bottom was mapped from the 1982 stereo imagery. The position of any abandoned channels and/or flood channels was mapped as indefinite features and their position and can only be regarded here as approximate. Often these features were recognized as sinuous, linear depressions in floodplain vegetation connected to the active channel. Wetlands and other features on the floodplain or valley bottom were not mapped as part of this analysis.

3.2 Field work

A reconnaissance field inspection of the channel was undertaken in the vicinity of the upper and lower proposed channel crossings on June 24 and 25, 2008. Observations made from these field sites were supplemented by a helicopter traverse of the mainstem channel and several tributary valleys. The objective of the field work was to verify observations made from airphotos, and to describe the bed and bank materials and any bed forms not visible on the airphotos. However, field work preceded much of the airphoto interpretation required for this report (due to delays encountered in the airphoto purchasing process) and not all relevant field sites could be identified

Table 2. Check point errors for the upper and lower triangulated image blocks.

Year	Nominal pixel size (m)	Lower image block		Upper image block	
		Frames	Check point error (± m)	Frames	Check point error (± m)
1965	0.32	163-165	2.8	153-155	3.0
1974	0.60	228-229	3.3	10-11	2.7
1982	0.60	200-201	2.9	119-120	2.8

in advance. In addition, access was limited by high flow and unsafe wading conditions along the lower proposed crossing, and suitable footing was generally restricted to stable streambanks and levees.

4.0 Channel stability

This section describes the relative stability of the mainstem channel adjacent to the proposed haul-road. The assessment is based on both the characteristics of reach-scale channel morphology and the relation of each reach to upstream and upslope sediment sources. Although the focus here is on the lateral dimension of channel adjustment (given the proximity of the channel to the proposed causeway), other channel characteristics and adjustments are also considered.

4.1 Potential sediment yield

Mess Creek is a relatively large watershed that comprises several different biophysical terrain types. Each contributes to the morphology of the floodplain and mainstem river channel. The watershed was thus divided into six sub-basins and a residual watershed to provide a framework for describing expected sediment transfer routes and the relative magnitude of sediment yield from different parts of the watershed (Figure 5). Sub-basins were created here based on an objective assessment of stream order, and delineated for all channels one stream order lower than the main channel as it flowed along Mess Creek floodplain. The assessment was based on the drainage network as depicted on 1:20,000 TRIM maps. Given the mainstem river changes from a 4^{th} order channel as it emerges from its tributary valleys in the upper reaches of the floodplain to a 6^{th} order channel at the outlet of the basin, progressively larger sub-basins are considered in the lower reaches of Mess Creek. This scales the assessment so that focus is on sub-basins with the potential to influence the mainstem channel and not on relatively small channels or sub-basins that do not influence the overall character of Mess Creek. The intent here is to provide an overview of the dominant watershed-scale processes that influence the mainstem channel and not on localized conditions. Given the tributaries in the study area of Mess Creek are unnamed (as depicted on 1:50,000 topographic maps), sub-basins and their channels were named here A through F starting clockwise from the outlet of the watershed (Figure 5).

The general morphometric properties of each sub-basin are given in Table 3 and discussed below. Examples of channels along the drainage network are given in Figure 6. Sub-basins A through C drain the Tahltan Highland, while sub-basins D through F drain the Boundary Ranges. Generally, the potential sediment yield to the mainstem of Mess Creek is greatest in sub-basins E and F. Both sub-basins contain relatively high proportions of ice, and recent glacial retreat has exposed large areas of morainal sediments. Glacial outwash and slope processes transfer sediment directly to the respective channels (i.e., the hillslopes are coupled to the channel network), while unvegetated, proximal sediments may be readily mobilized by the channels during high streamflow events (see section 2). In addition, both sub-basins contain relatively high amounts of steepland and a steep main channel, and these provide a route for sediment transfer from distill portions of the sub-basins and leading to the mainstem channel. Both sub-basins have built relatively large fans that prograde onto the Mess Creek floodplain.

In contrast, sub-basins A through C contain little to no glacial ice and the drainage network is buffered from sediment transfer by numerous

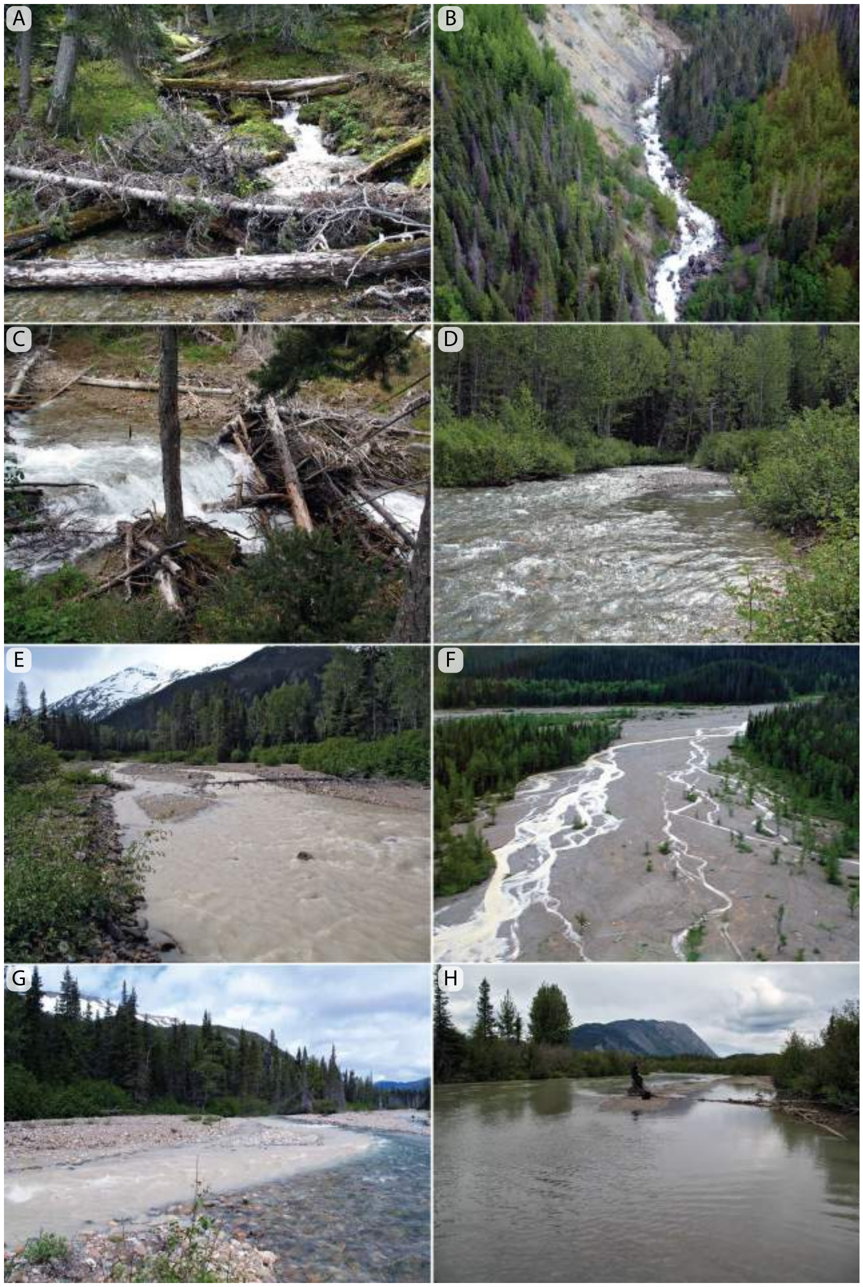

Figure 6. Photographic examples of channels that form part of the drainage network. a and b) Step-pool channels in sub-basins D and A, respectively. c) Large woody debris jam in a riffle-pool channel in sub-basin D. d) Riffle-pool channel near outlet of sub-basin C. e and f) Aggraded channels on fans of sub-basins E and F, respectively. g) Looking downstream at reach M-6 at the confluence of tributaries E and C (on left and right of the frame, respectively). h) Large, low gradient channel near the outlet of study basin (reach M-1).

Table 3. Morphometric parameters of each sub-basin and for the entire upper Mess Creek watershed. Data were derived from 1:50,000 NTS maps (see Figure 3 for source information) and a 25 m gridded DEM.

	Watershed unit						
Morphometric parameter	**A**	**B**	**C**	**D**	**E**	**F**	**Mess**
Basin area (km^2)	60.5	15.8	25.2	16.0	19.4	35.9	344.1
Ice area (%)	0.0	0.0	3.1	0.0	61.6	25.3	8.5
Lake area (%)	2.3	1.3	0.8	0.3	0.0	0.0	1.1
Steepland area (%)[a]	5.3	7.5	9.6	27.3	18.3	34.3	18.1
Flatland area (%)[b]	20.7	9.1	7.4	2.1	0.4	2.8	11.9
Mean gradient (m/m)[c]	0.22	0.31	0.31	0.52	0.39	0.52	0.36
Mean elevation (m asl)	1504	1402	1413	1255	1661	1493	1314
Stream magnitude	95	39	36	7	1	13	325
Drainage density (km/km^2)	2.1	2.5	1.9	0.9	0.0	0.7	1.0
Relief (m)	1380	1030	1027	959	1310	1653	1708
Main channel gradient (m/m)[d]	0.07	0.11	0.05	0.08	0.05	0.12	0.01

[a] Slopes > 60%

[b] Slopes < 7% and adjacent to a stream channel

[c] Mean gradient of all terrain in a given watershed unit

[d] The "main channel" is defined here as the longest, highest-ordered channel (i.e., series of links) from the basin outlet to the headwaters

small lakes and relatively high amounts of flatland adjacent to the channel network. The amount of dissection in the highland is indicated by both the magnitude of the drainage network (i.e., the number of first order links) and the relatively high drainage density. As a result, sediment yield per unit area may increase in the downstream direction in these sub-basins, especially along channels where the highland is being actively incised. However, overall sediment yield is likely relatively low in comparison to sub-basins E and F.

Sub-basin D is located near the boundary between the two physiographic sub-zones considered in this report and shares characteristics of both terrains. For example, the sub-basin contains relatively high amounts of steepland with the hillslopes directly coupled to the channels (similar to sub-basins E and F), while in contrast, there is a relatively small amount of lake cover, some flatland to buffer sediment transfer, and no ice cover (similar to sub-basins A through C). As such, the sub-basin is likely transitional in terms of sediment yield per unit area between sub-basins A through C (in the highlands) and sub-basins E through F (in the mountains).

4.2 Channel assessment

The mainstem channel was divided into a series of channel reaches (see Figure 5) based on interpretation of airphotos, maps, and a longitudinal channel profile (Figure 7). A reach is defined here as a section of channel characterized by relatively homogeneous hydrologic

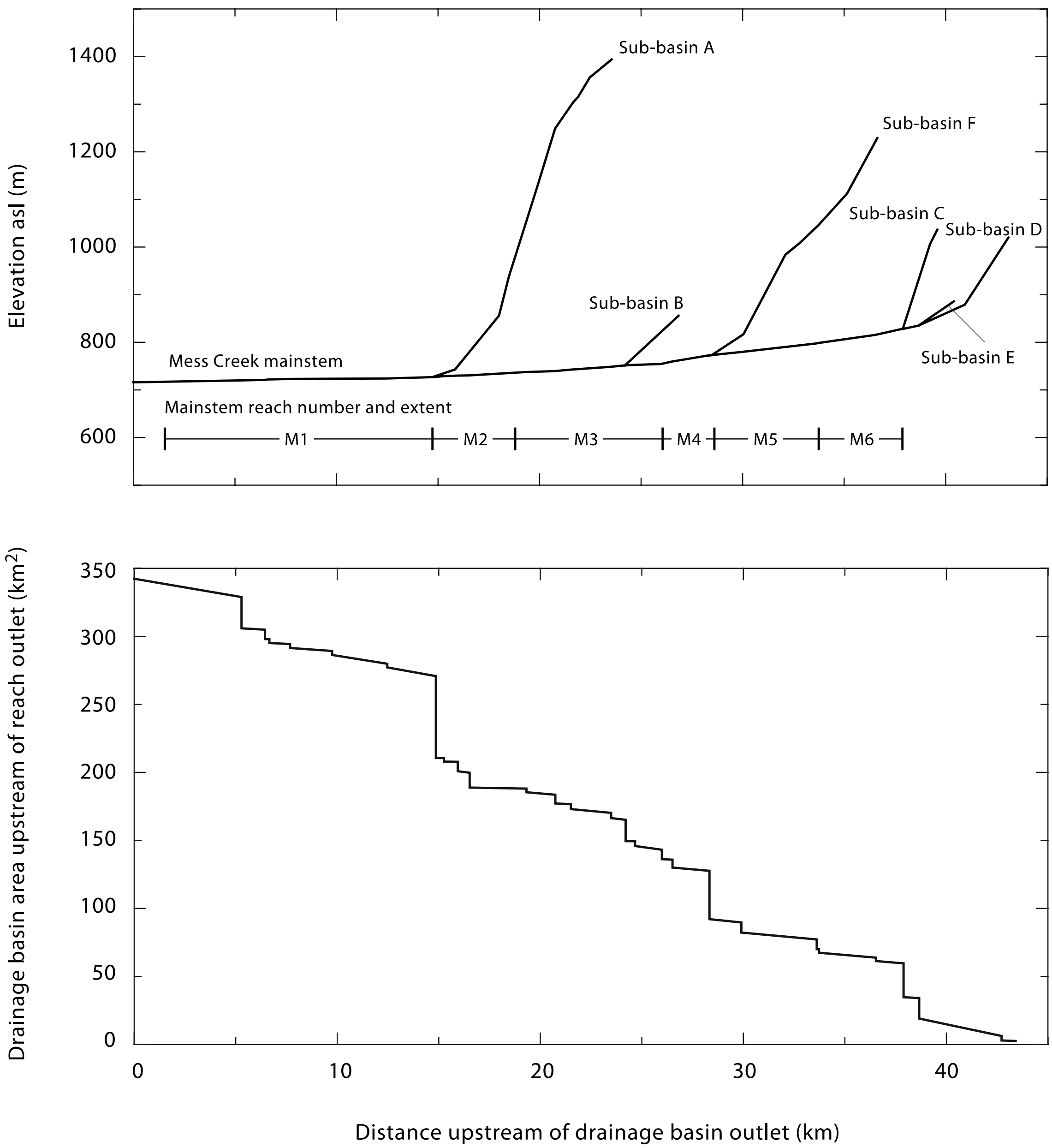

Figure 7. Longitudinal characteristics of Mess Creek. a) Longitudinal profile of the mainstem channel and the highest-ordered channel in each sub-basin. Channel slope along the mainstem and the main tributary channels average 0.3 and 10 %, respectively. b) Change in drainage basin area along the mainstem channel and sub-basin D. Steps in the distribution occur at tributary confluences. The magnitude of a step scales to the relative amount of water and sediment transferred to the mainstem at a discrete point along the longitudinal profile (assuming these variables are a function of drainage basin area). Relatively large steps indicated zones of potential channel instability in the system.

and physical processes that produce a relatively consistent channel form. Reach breaks were generally identified at major tributary confluences, changes in channel gradient, and/or changes in the hillslope-valley flat relation (Kellerhals et al., 1976).

The descriptions of channel bars, pattern, and island development follows the terminology and definitions of Kellerhals et al. (1976), while the descriptions of hillslope-channel coupling follows the terminology and definitions of Church (1983). Interpretations presented here are based primarily on observations made from 1:60,000 airphotos flown in 1974 (generally, the best quality small-scale imagery available, although other imagery described above was also reviewed including the large-scale orthomosaics) and a brief field reconnaissance and helicopter overflight of select reaches.

4.2.1 Reach M1

Reach M1 flows across an alluvial floodplain in a relatively wide (approximately 750 m) and continuous valley bottom (Figure 8a; Table 4) with an anastomosed channel pattern. The reach extends upstream from the outlet of the study watershed to the confluence with tributary A. Individual channel belts within the anastomosed channel pattern generally wander across the floodplain in a series of irregular meanders, and are often partially confined by the valley walls (i.e., confined on one bank). The reach

Table 4. General mainstem channel and valley geometry (data was derived from topographic maps, digital elevation model, and an orthoimage). Note that the valley width includes both the width of the floodplain and the active channel.

Reach	Length (m)	Slope (%)	Bankfull width (m)	Valley width (m)
M1	14,900	0.07	80	750
M2	3,400	0.23	60	900
M3	3,200	0.24	60	480
M4	6,800	0.44	110	600
M5	5,300	0.47	120	670
M6	4,300	0.73	170	280
D1	1,100	1.3	8.8	80
D2	1,200	1.9	8.1	60
D3	400	8.8	7.0	20
D4	700	6.1	9.0	40

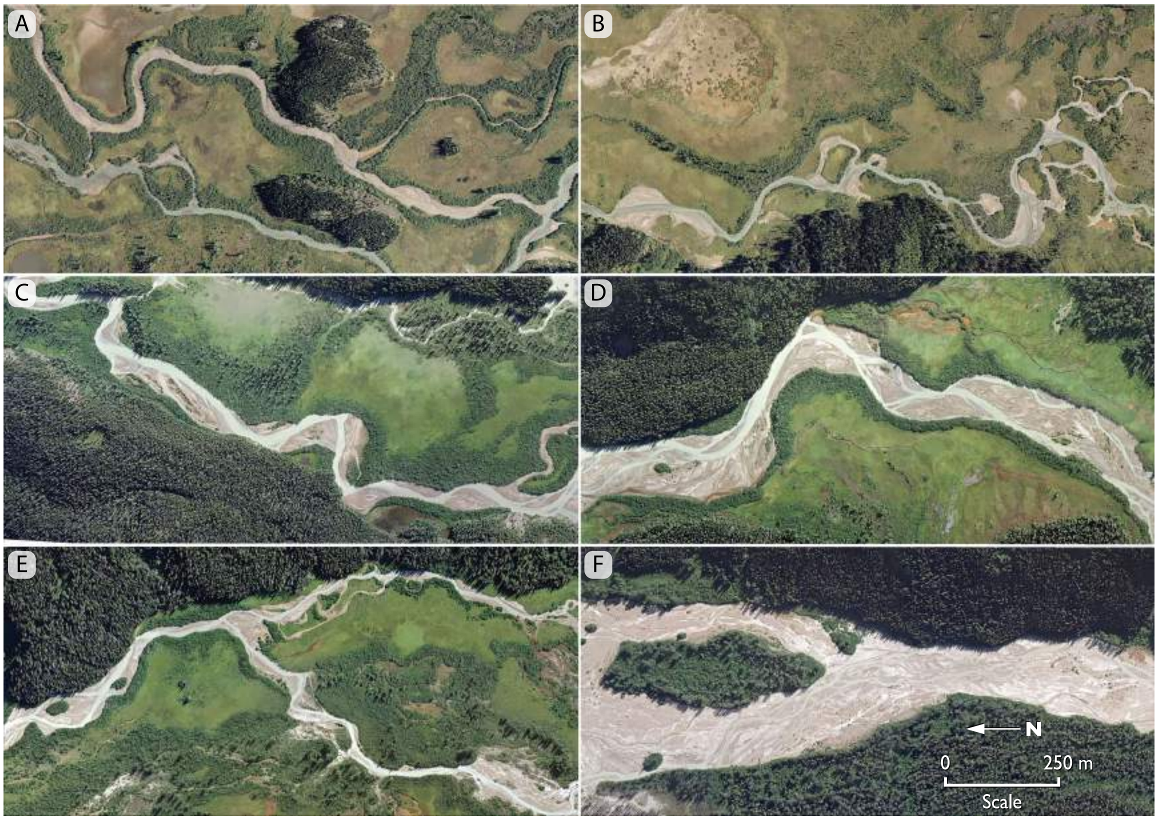

Figure 8. Pictorial illustration of channel reaches along the mainstem channel of Mess Creek, including a) M1, b) M2, c) M3, d) M4, e) M5, and f) M6. Flow is from right to left. Imagery was subset from orthoimages acquired in 2006 by Copper Fox. Note that the images do not show the entire reach but highlight differences in channel morphology that characterize each reach (refer to text for discussion).

is generally decoupled from direct sediment transfer from both the hillslopes and tributary channels (i.e., buffered by the wide valley bottom), except in locations where a given channel branch flows near the base of the valley walls (avalanche tracks are visible at the upstream end of the reach and appear to enter the channel, while colluvial fans prograde onto the valley bottom in several locations throughout the reach). The valley bottom is sparsely forested with a shrub-carr association (Barclay's willow – Arrow-leaved groundsel) common along streambanks and levees (Figure 9a). Floodbasins between channel belts host extensive wetlands. Conifers are infrequent.

The channels within an individual channel belt flow in a series of riffles and pools amongst infrequent and irregularly spaced islands (Figure 9b). Sediment storage throughout the reach is relatively high, with most sediment stored in side bars, although point bars and mid-channel

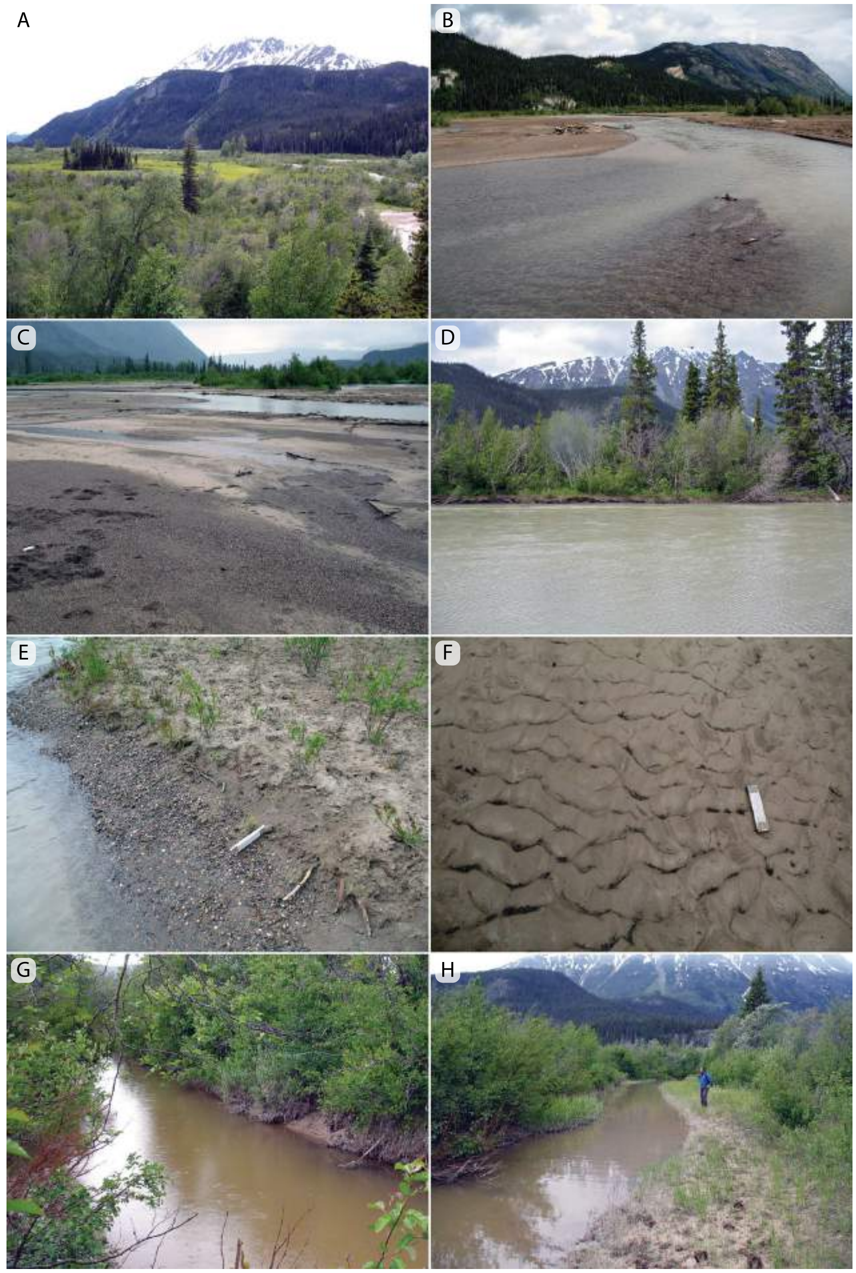

Figure 9. Pictorial illustration of reach M1 in the vicinity of the proposed lower crossing. a) Floodplain vegetation and a floodbasin—wetland complex adjacent to belts M1-A and M1-B. b and c) Gravel bed channel and sedimentation zone along belt M1-D. d) Bank materials and vegetation along belt M1-B. e and f) A layer of fine sediment covers coarse gravel bed materials, while ripples have formed along some surfaces of belt M1-D. g and h) Relatively low energy channel dominated by storage of fine sediments along belt M1-A.

bars are also present (Figure 9c). The channel is moderately unstable in the lateral dimension and exhibits irregular lateral activity given the presence of secondary channels that split amongst larger-scale islands (within a given channel belt). Avulsions have occurred as crevasse splay formations, some of which have initiated new channels and/or new channel belts, while others have been abandoned once the floodbasin had aggraded and the flow returned to the old channel.

Bank materials are generally cohesive (silt and sandy silt) and streambanks are vegetated with a willow shrub-carr (Figure 9d). Two main belts dominate the anastomosed pattern and bed material in these channels generally consists of gravel with local sand deposits. A layer of silt and mud covers gravel on the bar tops (Figure 9ef). Bed material in the smaller, secondary belts generally consists of silt and mud, although these observations were limited by high water at the time of the field survey (Figure 9gh). Channel gradient is relatively low (~ 0.07%) and sediment transport through the reach is likely dominated by the supply of wash material. The reach is likely laterally unstable over medium timescales (e.g., > 100 years) and relatively stable during shorter timescales (although local changes in planimetric geometry are still expected).

4.2.2 Reach M2

Reach M2 is similar in most respects to reach M1 and flows in an anastomosed pattern with two main channel belts and several secondary belts, although the channel is narrower given the smaller drainage area upstream of sub-basin A (Figure 8b; Table 4). Individual channel belts are also less sinuous and generally flow in an irregular-wandering pattern with only infrequent meanders. Several sedimentation zones exist in the reach (approximately 100 – 150 m in width). Snow avalanches are common along the left valley wall and enter the channel where a given channel branch flows at the base of the slope. The channel is confined at the downstream end of the reach by a fan building onto the floodplain from tributary A and a cone building onto the floodplain from the opposite valley wall.

4.2.3 Reach M3

Reach M3 flows across the floodplain in a single-threaded, irregular-wandering channel pattern and is frequently confined by the valley walls, usually along one channel bank (Figure 8c; Table 4). The channel is partially coupled to the hillslopes as the channel flows along the base of relatively steep valley walls and around fans that prograde onto the valley bottom for most of the reach (see BGC Engineering Inc. 2008). The valley bottom is moderately forested with a shrub-carr growing on solid dry ground, interspersed with wetlands along the margin of the floodplain. Conifers are infrequent. Note that although sub-basin B enters the mainstem channel near the upstream end of the reach, the morphology of the channel remains relatively consistent and did not warrant subdivision of the reach at this scale of analysis (i.e., the dominant influence on the character of the reach is from upstream, mainstem reaches and not from the sub-basin).

The channel flows in a series of riffles and pools amongst occasional islands. Sediment storage along the channel is relatively high, with most sediment stored in side and point bars, although mid-channel bars are also present throughout the reach. The channel is slightly unstable in the lateral dimension and exhibits some irregular lateral activity, although the channel flows in one main channel with only infrequent and relatively short secondary channels as the result of avulsion (in contrast to reaches M1 and M2). However, the channel is relatively aggraded (vertically unstable) given the increased sediment supply to the reach from upstream (as evidenced by relatively high sediment storage in channel bars) and likely transports a mixed load of wash and bed load sediment. The channel banks are likely cohesive (silt and sandy silt material) with localized sections of coarse bed material where the channel has avulsed, and are vegetated with a shrub-carr. Wetlands are present along the valley margin. Bed material in the main channel likely consists of gravel. Overall, the reach is moderately unstable.

4.2.4 Reach M4

Reach M4 flows across the floodplain in an irregular-wandering channel pattern, and is frequently confined by the valley walls, usually along one channel bank (Figure 8d; Table 4). The reach extends upstream to the confluence with tributary F (and its active fan) and flows in a series of riffles and pools amongst occasional islands. Sediment storage along the channel is relatively high, with most sediment stored in a series of braided channel bars. The reach is directly coupled to sub-basin F and sediment supply to the channel is dominated by sediment transferred from tributary F (given the glaciated headwaters and active sediment transfer processes that characterize the sub-basin). The reach is subject to at least some irregular lateral activity as the channel flows in one main channel with infrequent and relatively short secondary channels (tributary channels also flow along the valley bottom before entering the mainstem), and subject to avulsions given both the relatively high sediment supply to the reach and storage within the channel. Note the increased channel and valley gradient along the reach (as compared to downstream reaches) as shown in Figure 7, indicating long-term (i.e., post-glacial) aggradation of the valley bottom and the importance of sub-basin F as a sediment source (at the watershed scale).

Sediment transport through the reach is likely dominated by bedload material, although the wash load remains an important sediment source given the proximity of the reach to glacial outwash sources. As such, the channel banks are likely moderately cohesive (gravel overlain by silt) with localized sections of coarse bed material where the channel has avulsed, and are vegetated with willow. Wetlands are present along the valley margin. Bed material in the main channel likely consists of coarse gravel. Overall, the reach is considered here relatively unstable and subject to episodes of lateral adjustment and avulsions in response to sediment transfer from sub-basin F.

4.2.5 Reach M5

Reach M5 flows in an anastomosed channel comprised of sinuous to wandering individual channel belts and is frequently (almost continuously) confined by the right valley wall, although the channel remains free to wander across the relatively wide valley bottom (Figure 8e; Table 4). The reach is partially coupled the hillslopes given the position of the channel in relation to the hillslopes and several avalanche paths along the valley wall, however; the dominant sediment supply to the reach is from upstream channel sources.

Individual channel belts flow in a series of riffles and pools amongst occasional islands. Sediment storage along the channel is relatively high, with most sediment stored in side and mid-channel bars. The channel is unstable in the lateral dimension and exhibits irregular lateral activity as the channel flows in one to two main channel belts with several secondary belts (at least five channel belts were observed in some portions of the reach). In addition, the channel has avulsed in multiple locations with active sedimentation zones throughout the upper portion of the reach. Wetlands are generally absent from the reach (with the exception of a wetland on the left bank at the upstream of the reach break), and both the streambanks and valley bottom support a shrub-carr. Sediment transport through the reach is dominated by bedload material. The streambanks appear unconsolidated (likely gravel overlain by silt) and bed materials consist of gravel. Overall, the reach is relatively unstable with active sedimentation of the channel and valley bottom, and frequent adjustment of planimetric channel geometry.

4.2.6 Reach M6

Reach M6 flows within a fragmentary, narrow valley bottom in a sinuous channel pattern, partially confined in frequent locations by the valley walls (i.e., confined on at least one bank) (Figure 8f; Table 4). The reach extends upstream to the confluence with tributaries C, D, and E and flows in a series of riffles and pools amongst infrequent and irregularly spaced islands. Sediment storage along the channel is relatively high, with most sediment stored in bars that form a series of braids. The reach is directly coupled to sub-basin E and sediment supply to the channel is dominated by sediment transfer from tributary E (given the glaciated headwaters and active sediment transfer processes that characterize the sub-basin). The channel is also coupled to the hillslopes as the channel flows along the base of relatively steep valley walls with both snow avalanches and landslides, although sub-basin E is the dominant sediment source to the reach. Given the relatively high sediment load, the channel is prone to avulsions and is laterally unstable. A partial and poorly defined fluvial terrace along the upper left bank of the reach indicates cyclical aggradation and erosion of the channel bed as the channel responds to fluctuations in sediment supply. Sediment transport through the reach is dominated by bedload material (although the wash supply from sub-basin E is relatively high given the glacial outwash source). The streambanks appear unconsolidated (likely gravel overlain by silt) and bed materials consist of gravel and cobbles. Overall, the reach is relatively unstable.

4.2.7 Reach D1

Reach D1 flows within a fragmentary, narrow valley bottom in a sinuous channel pattern (Figure 10a; Table 4). The reach extends upstream from the outlet of Sub-basin D and adjacent to a debris flow fan emerging from Sub-basin E (the fan progrades onto the mainstem Mess Creek floodplain). The channel is frequently confined by both the valley wall and and/or the margin of the fan, and is coupled to the surrounding hillslopes (in particular, to the fan and any potential avulsions that may occur as Tributary E adjusts its flow-path).

The channel flows in a series of riffles and pools amongst sediment stored in side channel bars. The channel is moderately unstable in the lateral dimension given the presence of channel avulsions along the upstream portion of the reach. Bed materials are dominated by gravels while the banks are relatively stable (although shallow) and consist of gravels overlain by silty-sand. Sediment transport through the reach is dominated by bedload transport. The valley bottom is heavily forested with willow. Conifers grow on the fan and adjacent hillslopes and provide a

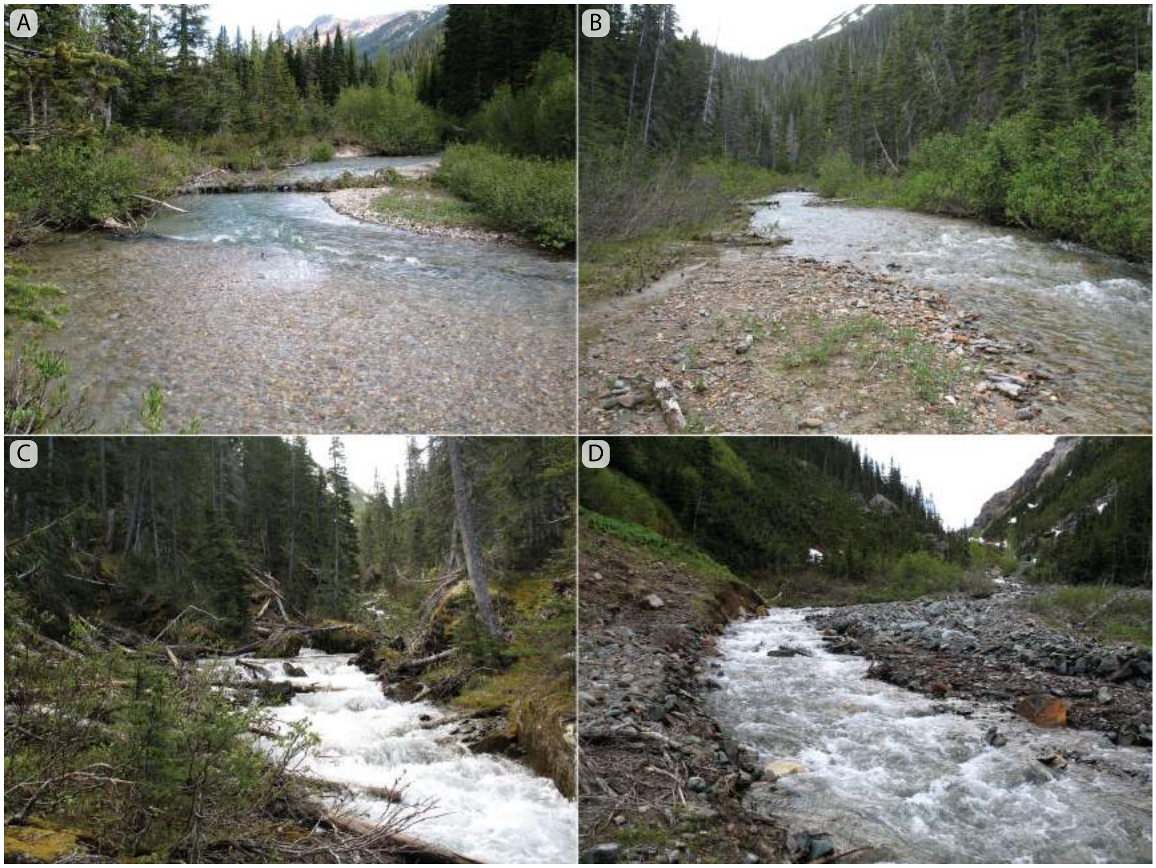

Figure 10. Photographic examples of the general morphology of the reaches assessed in Sub-basin D, including a) reach D1, b) reach D2, c) reach D3, and d) reach D4.

source of functional woody debris to the channel. Generally, the reach is aggrading to the base level set by the main valley fill of Mess Creek and is moderately unstable.

4.2.8 Reach D2

Reach D2 flows within a continuous, narrow valley bottom in a sinuous to irregular-wandering channel pattern (Figure 10b; Table 4). The channel is frequently confined by at least one valley wall and is coupled to both the surrounding hillslopes and to upstream channel reaches. The channel flows in a series of riffles and pools amongst infrequent and irregularly spaced islands, with sediment stored in side channel bars. The channel is moderately unstable in the lateral dimension, exhibiting irregular lateral activity given the presence of secondary channels and off-channel wetlands (the latter formed in association with multiple beaver dams). Bed materials are dominated by gravels while banks are relatively stable and consist of gravels. Sediment transport through the reach is dominated by bed material transport. The valley bottom is heavily forested with willow, and patches of cottonwood grow on solid dry ground. Given the lack of conifers in the riparian area, functional woody debris in the channel is infrequent. Generally, the reach is aggrading to the base level set by the main valley fill of Mess Creek (similar to reach D1) and is moderately unstable in the lateral dimension.

4.2.9 Reach D3

Reach D3 flows within a narrow, indefinite valley bottom in a straight to sinuous channel pattern (Figure 10c; Table 4). The channel is confined by the valley walls and is coupled to the surrounding hillslopes and partially coupled to upstream channel reaches. The channel flows in a stable series of steps and pools over relatively coarse bed materials (generally, steps and pools consist of boulders and gravels, respectively) and amongst occasional large, lag boulders. Channel-spanning steps represent the dominant bed form and intervening pools are relatively deep (~ 1 m at the thalweg). Sediment transport through the reach is dominated by bedload transport, although the boulders and step-forming clasts are likely stable under most flows and up to floods with about a 50 year return period (Grant et al., 1990). The channel banks are relatively stable and consist of cobbles and boulders in a sandy-silt matrix. Functional woody debris is limited but present in the reach and forms the occasional log step. Overall, the reach is relatively stable in both the lateral and vertical dimensions.

4.2.10 Reach D4

Reach D4 flows within a fragmentary, narrow valley bottom in a straight to sinuous channel pattern (Figure 10d; Table 4). The channel is frequently confined by at least one valley wall and is coupled to both the surrounding hillslopes and to upstream channel reaches. Multiple landslide paths enter the reach from the left bank (BGC Engineering Inc. 2008) while a snow avalanche(s) path enters the channel from the right bank. Woody debris delivered to the channel during the snow avalanche(s) has accumulated at the downstream boundary of the reach and forms a relatively large log jam (5 to 10 m^3 of wood) as individual logs have anchored against standing conifers along the channel margin. Buried woody debris and root wads with soil in the root ball at the downstream and upstream extent of the jam suggest the jam has been built by multiple, episodic events (e.g., Hogan et al., 1998).

Generally, the channel flows in a series of cascades (separated by relatively infrequent pools) amongst occasional and small islands. Localized portions of the reach are vertically unstable (i.e., alternating zones of erosion and deposition), and have either aggraded (with most sediment stored in mid- and side-channel and bars), or have incised into the valley bottom (generally, by 1 to 1 ½ m). Bed materials vary from cobbly-boulder where the channel is incised, to gravelly-cobble where the channel is aggraded. The stream banks are vertical to sloping in profile and consist of cobble-gravel in a clay-silt matrix with minor, localized erosion. The valley bottom supports willow along the banks and valley bottom. Generally, the reach is laterally stable (especially when confined by the valley walls), although the log jam at the downstream reach boundary has aggraded the valley bottom and forced the flow into multiple channels.

4.3 Reach sensitivity rank

The section provides a qualitative ranking of reach sensitivity as it relates to the potential for lateral channel adjustment (Table 5). The

Table 5. Reach sensitivity rank (refer to sections 4.1 and 4.2 for details).

Reach	Stable	Comments
M1	Stable	Tributary A may initiate localized channel instability in the mainstem channel along the upper 1 km of the reach, although sub-basin A does not generally dominate the sediment regime of the mainstem (given similar channel types upstream and downstream of the confluence).
M2	Stable	Several sedimentation zones exist in the reach and initiate localized instability as the channel deposits sediment on the floodplain.
M3	Moderately unstable	Sediment supply to the reach from upstream sources is relatively high and may initiate episodes of channel instability.
M4	Unstable	High sediment supply to this reach from reach M5 and from tributary F (a steep, glaciated sub-basin), especially along the upper 1 km of the reach.
M5	Unstable	High sediment supply to this reach from reach M6.
M6	Unstable	High sediment supply to this reach from tributary E (a steep, glaciated sub-basin), especially along the upper 1 km of the reach.
D1	Moderately unstable	Depositional reach with channel avulsions along the upstream portion of the reach. The channel is directly coupled to the debris flow fan of sub-basin E.
D2	Moderately unstable	Depositional reach coupled to sediment supply from reach D3. Beaver activity in off-channel areas of the valley bottom.
D3	Stable	Transport reach with stable step-pool morphology. Potential localized channel instability in the vicinity immediately downstream of the large log jam located at the upstream reach break.
D4	Moderately unstable	High sediment supply to reach from both upstream and upslope sources. Large log jam forcing valley bottom to aggrade at downstream end of reach.

assessment is based on the preceding discussion of general reach characteristics given changes to the sediment and/or water regime (natural or otherwise), and the environmental setting of the reach within the watershed (see section 2). The assessment does not take into account any additional geohazards but does consider the location of a reach in relation to discrete inputs of water and sediment from tributary channels and their respective sub-basins (see Figure 7).

5.0 Erosion hazard

This section describes the potential erosion hazard associated with sections of the mainstem channel near the two proposed channel crossings. The lower and upper proposed crossings are located midway along reaches M1 and D3, respectively. Approximately 5 km of the mainstem channel centered near each proposed crossing are considered here. As such, the assessment of the lower crossing considers only a portion of reach M1 (the reach is approximately 15 km in total length), while the assessment of the upper crossing considers reaches D1 through D4. Both processes of bank erosion and channel avulsion are considered in the assessment.

5.1 Bank erosion rates

Bank erosion rates were determined here from an analysis of channel changes depicted on the planimetric channel maps. Reach M1 was divided into five individual channel belts (given the anastomosed channel pattern) and named M1-A though M1-E, and separate erosion rates were calculated for each belt. Belts M1-B and M1-D represent the dominant channels through this portion of the reach (see section 4). The upstream portion of reach D2 could not be reliably mapped from the 1982 imagery given the relatively low channel width and the presence of shadows cast from the riparian forest canopy. As such, reach D2 was subdivided into two sections named D2-A and D2-B in the lower and upper portion of the reach, respectively. Imagery representing section D2-B in 1982 was then omitted from the analysis. In addition, Reach D3 was obscured by the riparian forest canopy and shadows throughout the entire period of observation and could not be reliably mapped from airphotos. Generally, step-pool channels similar to that found in reach D3 are laterally stable (Church, 1992) and are unlikely to migrate across the valley bottom, especially over relatively short timescales such as that consider by this report. Generally, confinement by valley walls, incision of the channel into the valley bottom, and the presence of relatively large lag boulders present in the bank material limit the ability of step-pool channels to adjust their lateral dimension (Montgomery and Buffington, 1997). In fact, most research on step-pool morphology focuses on adjustment by the vertical dimension (e.g., Church and Zimmermann, 2007). Regardless, the approximate centerline of the reach was mapped for each year of data and is presented here for descriptive purposes.

The net rate of bank erosion for each period was calculated by overlaying successive polygon map layers of both the active channel and floodplain (and/or valley bottom). A change from active channel to floodplain was considered here to represent an area of net deposition, while the opposite change was considered here to represent net erosion. These areal data were converted into a net amount of linear bank erosion by dividing the data by the centerline length of the main channel, and then into a bank erosion rate by dividing the result by the length of the period under consideration. Finally, since the polygon analysis considered data from both banks, the rate was divided in half to estimate the net rate of bank erosion for a single bank.

The historical sequence of orthoimages for reaches M1 and select reaches in sub-basin D are given in Figures 11 and 12, respectively. The historical sequence of channel maps for reaches M1 and select reaches in sub-basin D are given in Appendix A, respectively, with results summarized in Tables 6 and 7. Generally, both erosion and deposition rates have been in decline over the period of observation. Examination of the 1965 airphotos shows relatively frequent and active channel disturbance near both proposed crossings. In particular, multiple avulsions are active along reach M1 during this time, with both crevasse-splay formations in several floodbasins and a relatively large sedimentation zone in the M1-D channel belt (Figure 13). Similarly, near the upper proposed crossing, reaches D1 and D2 were impacted by an avulsion on the fan of Tributary E as a distributary channel flowed into Tributary D at the break between reaches D1 and D2. This event caused aggradation of

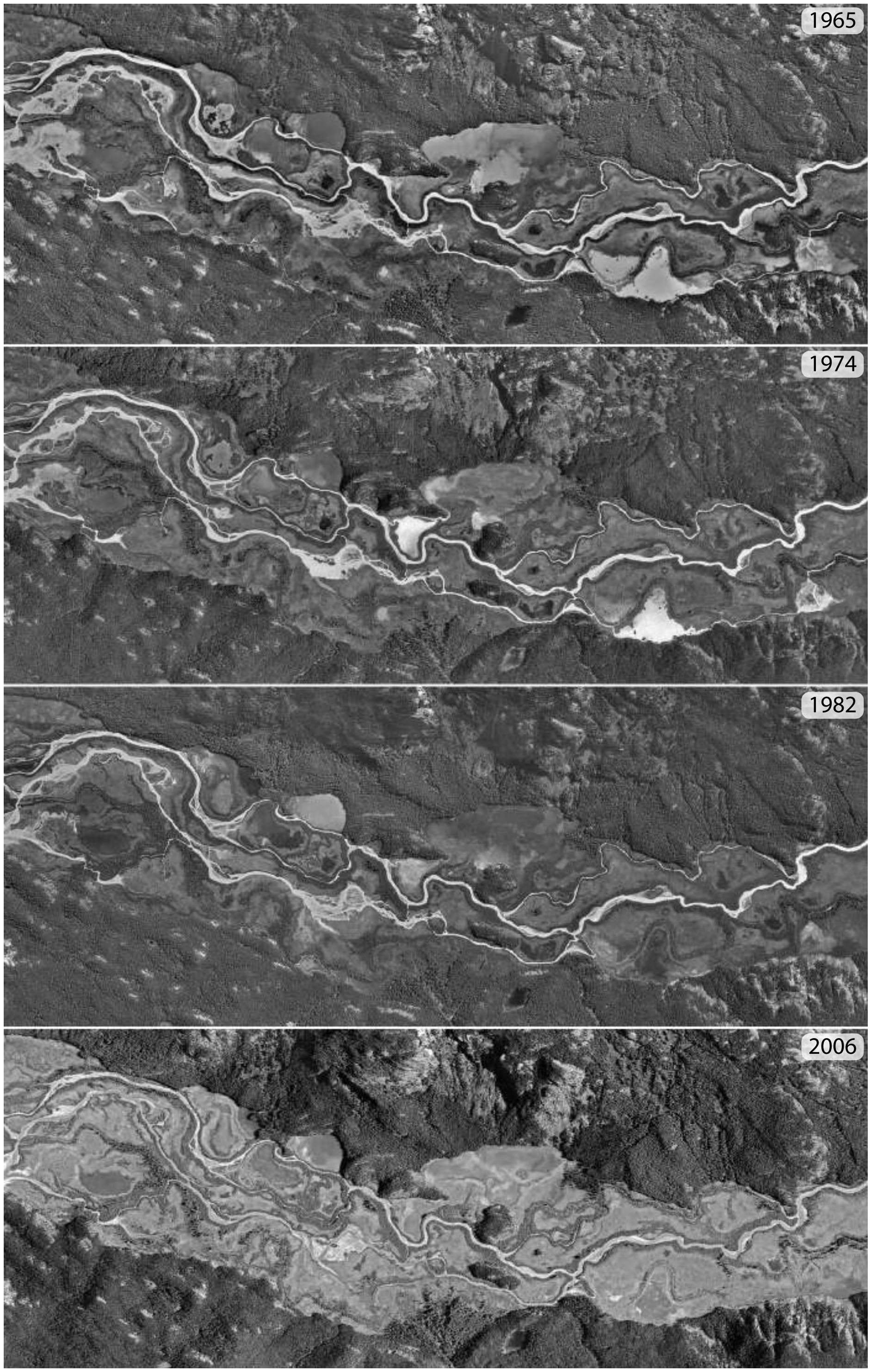

Figure 11. Historical orthoimage sequence of reach M1 from 1965 to 2006.

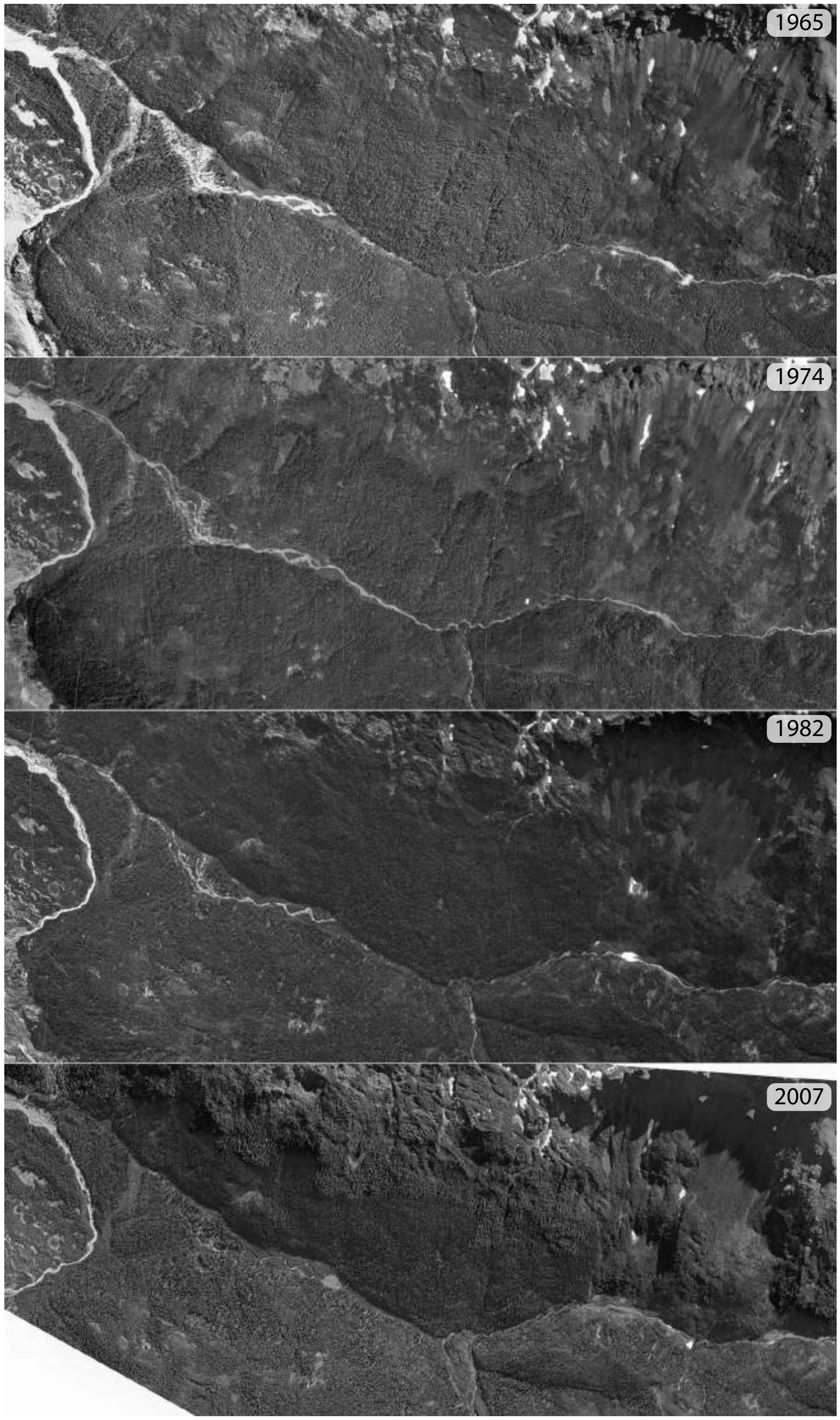

Figure 12. Historical orthoimage sequence of reaches in sub-basin D from 1965 to 2007.

Table 6. Net rate of bank erosion and deposition by period in reach M1. The period 1965-2006 gives the weighted mean rate of change for all three periods mapped from airphotos. The sum gives the total of all five channel belts for a reach-based estimate of overall erosion and deposition rates.

		Erosion and deposition rate by period (m/yr)			
Channel belt	**Process**	**1965-1974**	**1974-1982**	**1982-2006**	**1965-2006**
A	Erosion	0.11	0.10	0.03	0.06
	Deposition	0.15	0.12	0.15	0.14
B	Erosion	0.14	0.11	0.04	0.08
	Deposition	0.15	0.22	0.16	0.17
C	Erosion	0.18	0.04	0.02	0.06
	Deposition	0.50	0.78	0.19	0.37
D	Erosion	0.39	0.13	0.08	0.16
	Deposition	0.53	0.41	0.13	0.27
E	Erosion	0.16	0.11	0.08	0.10
	Deposition	1.34	0.26	0.08	0.39
Sum	Erosion	0.98	0.50	0.25	0.46
	Deposition	2.67	1.79	0.71	1.35

Table 7. Net rate of bank erosion and deposition by period in reaches D1 through D4. The period 1965-2007 gives the weighted mean rate of change for all three periods mapped from airphotos.

		Erosion and deposition rate by period (m/yr)			
Reach	**Process**	**1965-1974**	**1974-1982**	**1982-2006**	**1965-2007**
D1	Erosion	0.25	0.33	0.05	0.15
	Deposition	0.69	0.71	0.35	0.49
D2-A	Erosion	0.13	0.10	0.01	0.05
	Deposition	0.35	0.33	0.15	0.23
D2-B	Erosion	0.23	NA	0.07*	0.10
	Deposition	0.12	NA	0.02*	0.04
D3	Erosion	NA	NA	NA	NA
	Deposition	NA	NA	NA	NA
D4	Erosion	0.07	0.12	0.05	0.07
	Deposition	0.17	0.16	0.05	0.09

* Computed over the period 1974-2006 as data for 1982 was not available (see text for details)

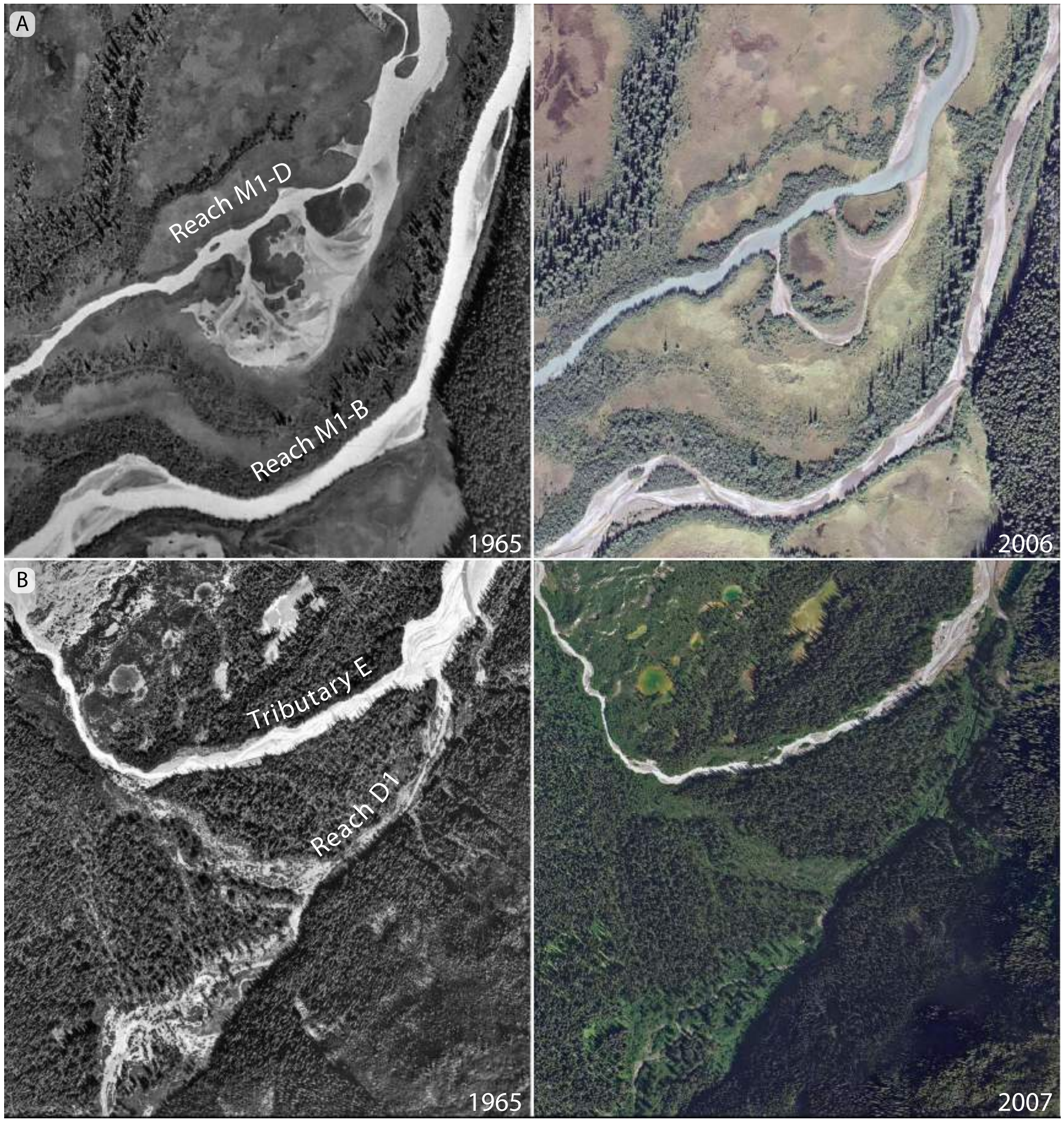

Figure 13. Photographic examples of channel changes in upper Mess Creek. *a)* Active channel avulsions along reach M1-D were present in 1965 and then were stabilized by 2006. Note the associated splay crevasse formations on the floodplain that coalesce downstream before rejoining the main channel. *b)* Active channel avulsion on the fan of tributary E in 1965 entered tributary D and the boundary between reach D1 and D2.

both reaches, as sediment from tributary E was deposited into reach D1 while reach D2 aggraded to a new local base level (given aggradation in reach D1). By 2006 and 2007, these portions of Mess Creek had stabilized (relatively) and many of the overbank avulsion deposits had been revegetated (Figure 13).

5.2 Turnover rates

The turnover rate describes the time required for the progressive migration of the channel across the entire floodplain or valley bottom. The turnover rate can be used to estimate the residence time of stored sediment and the relative stability of any floodplain or valley bottom features. The data were derived from the polygon analysis used above to generate an estimate of bank erosion. However, the bank erosion rate considers the erosion of both old and new deposits, while the turnover rate considers only the erosion of a surface not previously deposited within the period of observation (i.e., either 1965-2006 or 1965-2007).

The turnover rate was calculated here after O'Conner et al., (2003) and assumed an exponential decay in floodplain or valley bottom area with time given the analysis of Everitt (1968) and O'Conner et al., (2003). The results are given in Table 8 and Figure 14. Generally, the residence time of valley bottom sediments found in reaches along sub-basin D are on the order of a century, while the residence time of floodplain sediments along reach M-1 are on the order of a millennium. Note, however, that these residence times present an average period of sediment storage and floodplain stability for the entire feature considered in the analysis, and proximal deposits are likely eroded over shorter periods than distill deposits. The analysis also assumes current erosion rates and channel behavior will persist for the entire period denoted by a complete cycle of floodplain turnover.

5.3 Bank erosion hazard

The bank erosion hazard was determined here for a 50-year period based on the proximity of a

Table 8. Turnover rates of floodplain and valley bottoms of select reaches in upper Mess Creek. Ranges are based on the standard error of the estimate.

Reach	Valley area (km^2)	Residence time (yrs)
M-1	5.08	2,300 ± 800
D1	0.0813	200 ± 100
D2a	0.0481	900 ± 600
D2b	0.0174	-
D3	-	-
D4	0.0285	400 ± 200

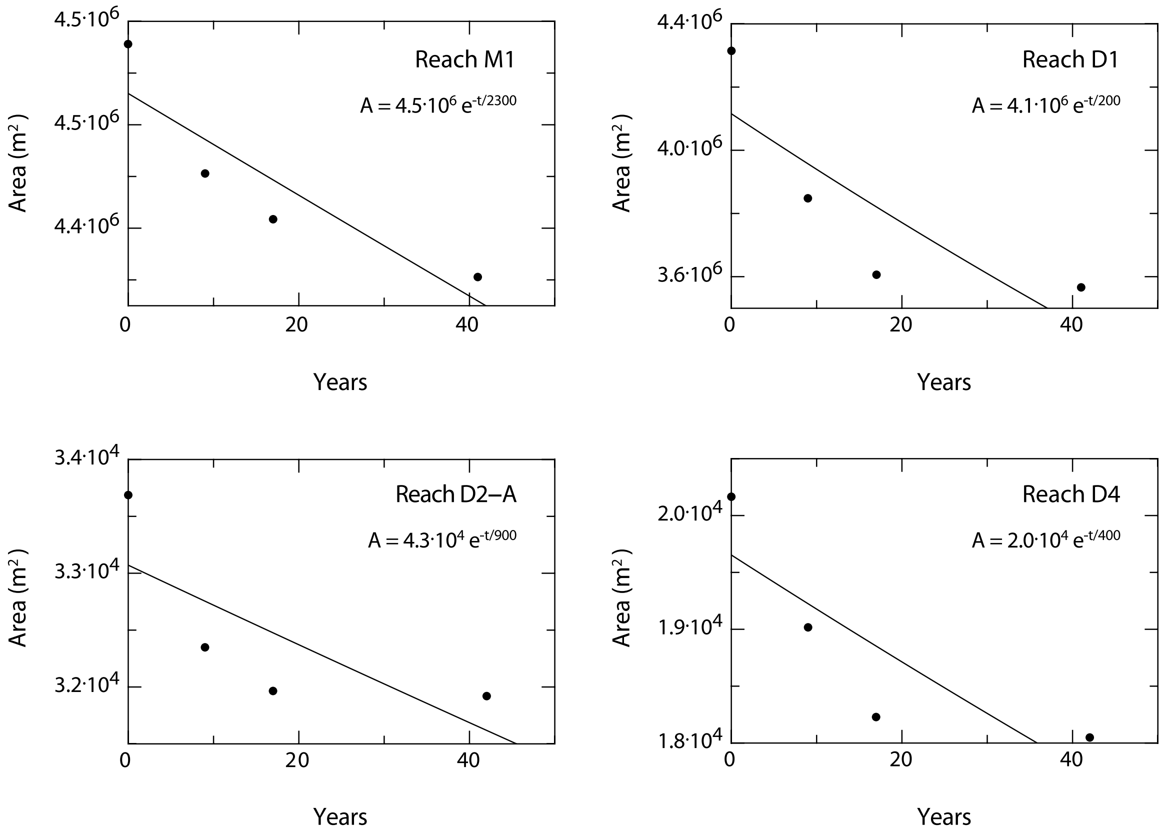

Figure 14. Floodplain and valley bottom turnover rates. Although the estimates are based on four data points per reach (and should therefore be interpreted with caution), they give at least some indication as to the order of magnitude of the actual rates.

given location on the floodplain relative to the active channel. Polygons representing the active channel, floodplain and valley bottom were first converted to a raster grid with a cell resolution of 1 m. The distance of a given raster cell on the floodplain or valley bottom to the active channel (as mapped from the 1965 imagery) was determined for each of the five channel belts in reach M1 and for reaches D1, D2, and D4 in sub-basin D. The number of floodplain cells occupied by the channel in subsequent imagery was summed by 1 m wide distance intervals constructed parallel to the banks. These data were treated as Poisson counts with a mean count equivalent to the observed count. To enable a more conservative estimate, the 95th percentile of the Poisson distribution was determined from each mean count to account for any random fluctuations not observed in the field and establishes an estimate of the upper limit of the number of expected erosion cells over the period of observation. Data representing the 95th percentile of the distribution was then used in subsequent analysis.

The number of cells observed in each distance interval was standardized by the length of the period to establish a rate and then prorated and extrapolated to the number of cells expected over a 50-year period. These data were further standardized by the total number of cells in each 1 m distance interval, converting the data into erosion probabilities. Floodplain stability was estimated from these data by plotting the reciprocal probabilities against distance on log-Weibull paper and extracting the parameters of the Weibull distribution using least squares analysis (Figures 15 and 16). The expected value and variance of each distribution was estimated from Equations 2 and 3, respectively

$$E(X) = \alpha\Gamma(1+1/\beta) \qquad \text{Eq. [2]}$$

$$Var(X) = \alpha^2 (\Gamma(1+2/\beta) - \Gamma(1+1/\beta)) \qquad \text{Eq. [3]}$$

where α and β are the shape and scale parameters of the Weibull distribution, respectively, and Γ is the Gamma function. The standard deviation was calculated as the positive square root of Equation 3. The expected value of the distribution gives the average distance from the streambanks to the location of a grid cell expected to remain stable in the forthcoming 50-year period for a given reach (i.e., the area between the streambanks and the expected grid cell distance is expected to erode). These estimates were then used to establish erosion hazard zones on the floodplain or valley bottom (Table 9). Note that the raw probabilities were not used in this analysis given the non-normal distribution of data. Hazard classes were constructed as follows:

High Erosion Hazard—area between the active channel banks and the expected distance to a stable floodplain grid cell (defined by Equation 2). Erosion is expected in most of this area over the next 50 years (on average).

Moderate Erosion Hazard—area beyond the zone of High Erosion Hazard defined by one standard deviation above the expected distance to a stable floodplain grid cell (defined by Equations 2 and 3). Erosion is expected in some of this area over the next 50 years (on average).

Low Erosion Hazard—area beyond the zone of Moderate Erosion Hazard to the maximum distance of observed erosion relative to the streambanks over the observed 41 or 42 year period (and prorated to 50 years). Erosion is possible in some of this area over the next 50 years, although limited in areal extent (on average).

Very Low Erosion Hazard—area beyond the zone of Low Erosion Hazard where no erosion cells were predicted (as defined above). Erosion remains possible in this area (given the grid cells are located on a floodplain or valley bottom), although unlikely over the next 50 years (on average).

5.4 Avulsion hazard

The avulsion hazard zone is defined here as the area of the floodplain or valley bottom that may be occupied by the channel following incision of a new channel or a reoccupation of an existing, relic channel. The analysis was restricted to areas previously occupied by the active channel over the period of the airphoto record (areas likely to contain relic channels and preferred flow paths), the existing meander belt of the active channel, and along any other identifiable, relic channel(s).

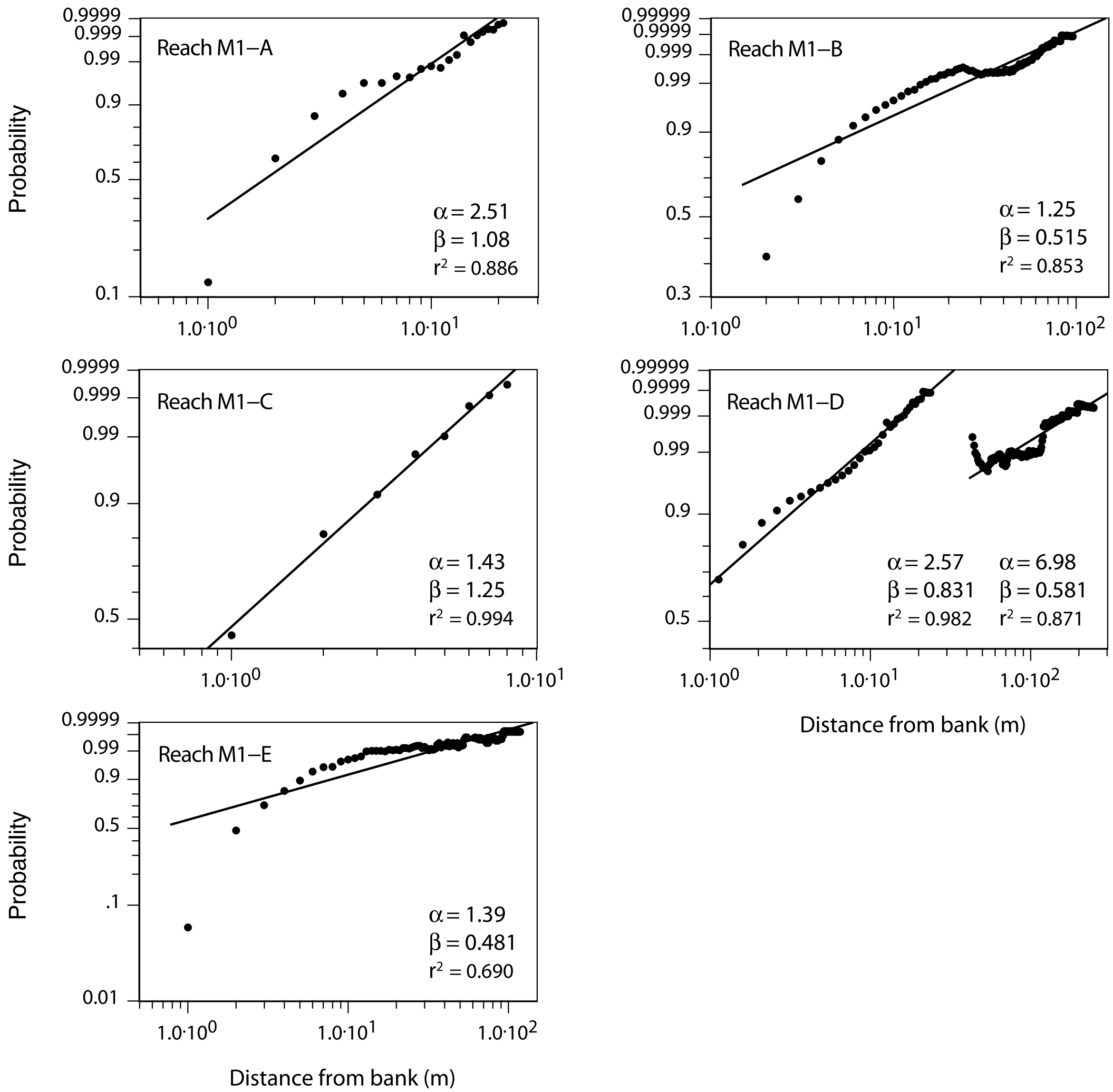

Figure 15. Weibull probability plots describing floodplain stability in a portion of reach M1 over the next 50 years. Generally, the distributions show the probability that a grid cell on the floodplain remaining stable as a function of distance from the active channel banks. The symbols α and β give the shape and scale parameters, respectively, of the Weibull distribution.

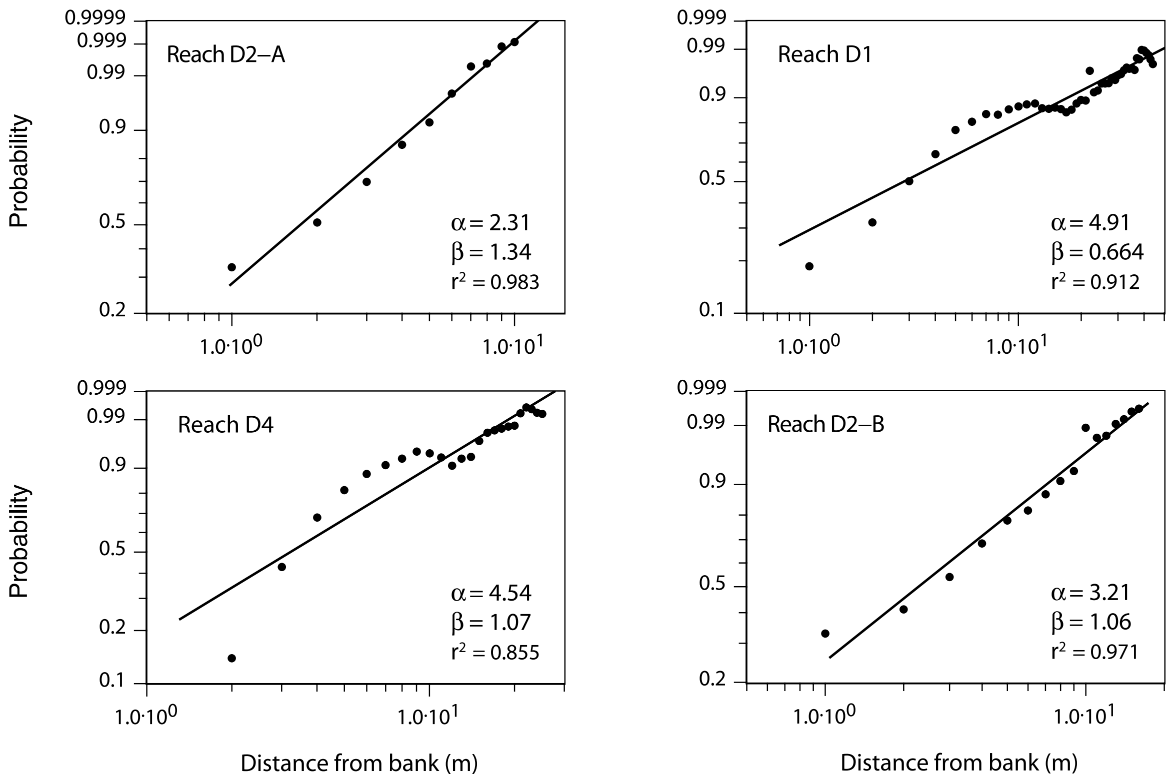

Figure 16. Weibull probability plots describing floodplain stability for select reaches in sub-basin D over the next 50 years.

The latter included any channels mapped as indefinite features (see section 3.1) connected to the active channel and/or through a series of wetlands. The meander belt describes the reach-scale corridor defined by the lateral extent of the largest meander bends in the reach, and is used here to identify the location of any potential, local channel avulsions. Regional avulsions are not considered by this analysis (see Slingerland and Smith, 2004).

The meander belt was defined on a reach-by-reach basis by first generalizing the channel centerline with a node every two to five times the bankfull width to give the channel belt axis. In reach M1, the belt width (B) was objectively established using the empirical relation of Williams (1986)

$$B = 4.3W^{1.12} \qquad \text{Eq. [4]}$$

where W is the bankfull width. In reaches D1 through D4, the meander belt was delineated manually based on visual observation of both the existing and past extent of channel bends and

Table 9. Bank erosion hazard classes based on the distance of a grid cell on the floodplain or valley bottom surface from the active channel banks (mapped from imagery acquired in either 2006 or 2007). The avulsion hazard is given as "present" within a zone given by a distance from the active channel banks and is considered "absent" beyond this distance.

	Bank erosion hazard class by distance (m)				Avulsion hazard by distance (m)
Reach	High	Moderate	Low	Very Low	
M1-A	≤5	5-7	7-21	≥21	42
M1-B	≤7	7-16	16-96	≥96	115
M1-C	≤2	2-4	4-8	≥8	48
M1-D	≤30	30-44	44-256	≥256	159
M1-E	≤9	9-22	22-118	≥118	58
D1	≤15	16-24	24-44	≥44	85
D2-A	≤4	4-5	5-10	≥10	56
D2-B	≤6	6-8	8-16	≥16	11
D4	≤9	9-11	11-25	≥25	21

fitting tangential lines to the largest bends along each reach. (The manual method was preferred in sub-basin D due to the predominance of non-alluvial influences on channel morphology in the reaches considered).

Channels mapped as linear, indefinite features (typically flood and/or relic channels) were considered in this analyses by assuming a channel width based on the width of the active, connected channel that would flow along the indefinite feature if the active channel were to avulse (and assuming it would maintain an average width similar to the parent channel). The meander belt axis was defined by the existing axis of the indefinite feature, and the potential avulsed channel was assumed to flow along the same meander belt axis.

5.5 Channel hazard mapping

Bank erosion and avulsion hazards were combined into a single channel migration hazard map that illustrates areas of the floodplain along a portion of reach M1 and areas of the valley bottom along reaches D1, D2, and D4 susceptible to erosion over the next 50 years (relative to the relevant imagery acquired in either 2006 or 2007). Small-scale versions of the maps are presented in Figures 17 and 18, while large-scale

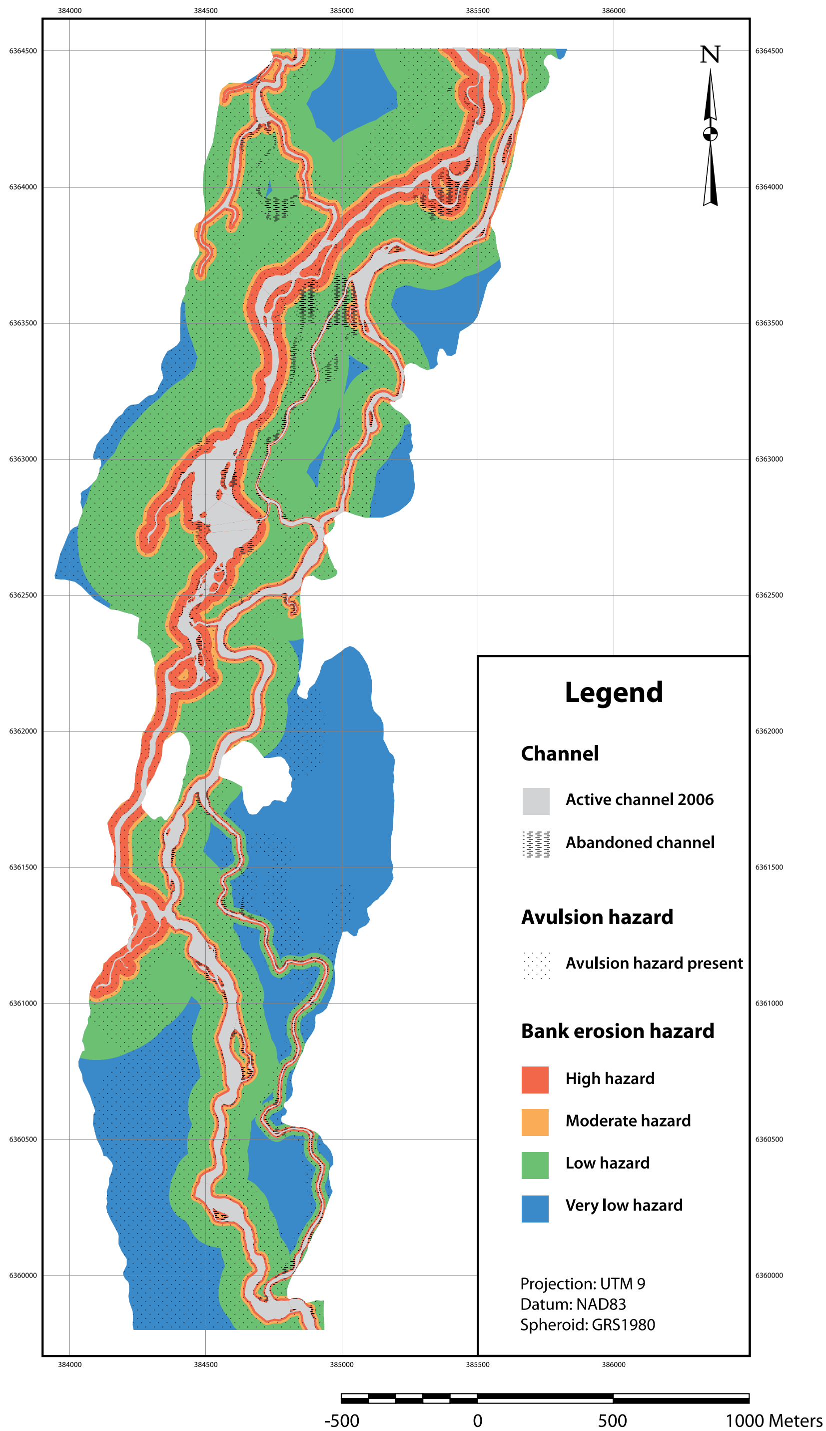

Figure 17. Channel migration hazard map for reach M1 (location of the channel belts is given in Appendix A). Refer to the pocket for a large-scale version of this figure.

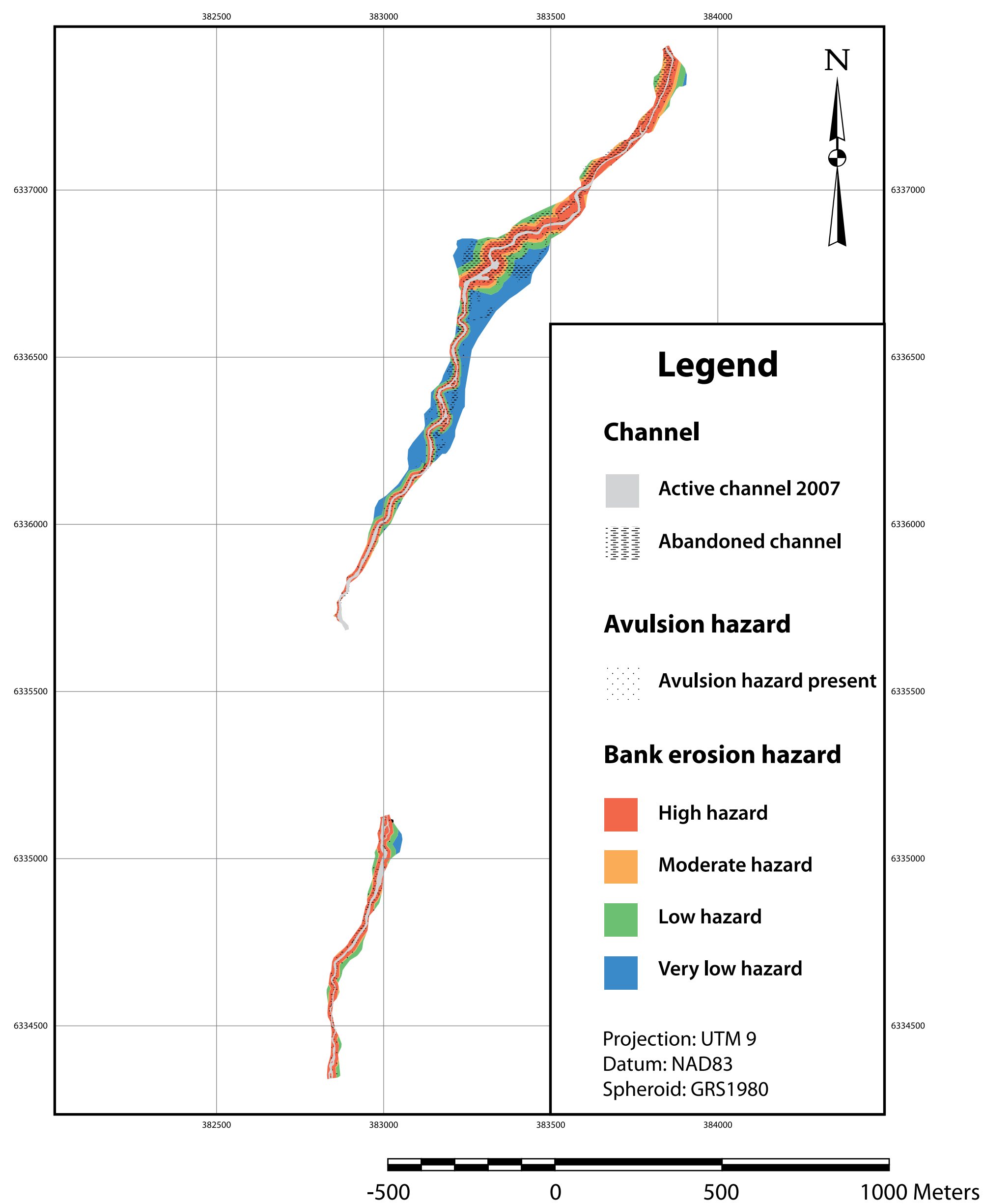

Figure 18. Channel migration hazard map for sub-basin D (location of the reach breaks is given in Appendix A). Refer to the pocket for a large-scale version of this figure.

versions are included in the pocket. The channel migration zone is bound by the projected extent of bank erosion and/or the avulsion hazard zone and is relative to the current location of the channel banks and meander belt axis (again, as depicted in the relevant imagery acquired in either 2006 or 2007). The bank erosion hazard is ranked as very low, low, moderate, or high based on a quantitative assessment of bank erosion rates (see section 5.3), while the avulsion hazard is identified as a singular zone where avulsions are most likely to occur based a qualitative assessment of channel geometry and past locations of the channel on the floodplain or valley bottom (see section 5.4). The avulsion hazard is otherwise not ranked (e.g., low, moderate, high, etc.) given our inherent inability to predict the occurrence and characteristics of avulsions (Slingerland and Smith, 2004).

The boundaries on the channel migration hazard map are intended to help guide management decisions along upper Mess Creek and are not intended to provide regulatory boundaries or override site-specific assessments. The map identifies a 50-year channel migration corridor for specific reaches of upper Mess Creek based on current migration rates, measured either between 1965 and 2006 or 1965 and 2007. The map includes the present location of the channel (mapped from imagery acquired in either 2006 and 2007), historic channel locations since 1965, and an erosion buffer based on measured rates of lateral channel migration and potential locations of channel avulsion. The hazard classes are based on current channel and watershed conditions and are only valid for the period under which these conditions may persist. Any changes to conditions described in section 2 (e.g., changes in the supply and quality of water and/or sediment to the channel, vegetation along the channel banks, direct modification to the channel, etc.) are not accounted for in the hazard assessment.

6.0 Discussion

Sediment supply to the mainstem of upper Mess Creek is dominated by relatively high sediment yields from sub-basins E and F. Both sub-basins contain alpine glaciers that likely advanced to their Neoglacial maxima sometime before the early 20th century. Newly exposed and unvegetated sediments (following glacial retreat) have since been transferred episodically to their respective, steep tributary channels that, in turn, supply relatively large quintiles of sediment to the mainstem. Channel instability along the mainstem is greatest in the reaches M4 through M6, immediately downstream of the respective confluences with tributaries E and F, largely in response to this relatively high sediment supply. The valley gradient through these reaches is ~ 0.6% and the channel is generally braided and/or flows in multiple channel belts. Lateral channel instability (avulsions in particular) have resulted in active sedimentation of the floodplain and, in response, floodplain soils are dominated by Regosols. The lower mainstem reaches (M1 through M3) are relatively stable by comparison. Valley gradient decreases to ~ 0.1% and the channel follows a generally anastomosed pattern. Floodbasins between channel belts generally support wetlands and the development of organic soils. Reaches M1 and M2 are aggrading in response to the high sediment supply from upstream and the local base level set by Mess Lake. The persistence of partial avulsions along the main channel belts have maintained the current channel pattern along the section of reach M1 near the proposed lower channel crossing since at least 1965.

In general, both bank erosion and deposition rates have been in decline since 1965 (at least in the reaches mapped near the upper and lower proposed causeway crossings). In addition, there has also been an apparent decline in the number of active avulsions along these reaches, with multiple active crevasse-splay formations observed along reach M1 in 1965 and an avulsion along the fan of tributary E (diverting the channel into tributary D) prior to 1965, and these features are now largely abandoned and stabilized (as observed on the given the relevant 2006/07 imagery). Generally, changes to the frequency of avulsion can be linked to changes in aggradation rates, that in turn, reflect changes in sediment load, peak discharge, and local base level (Slingerland and Smith, 2004), the later being linked to the relative elevation of Mess Lake. Although a thorough reconstruction of the disturbance history of the watershed is beyond the scope of this report, it is speculated here that this decrease in lateral channel activity is likely in response to fluctuations in sediment transfer rates from sub-basins E and F to the mainstem channel, and/or the predominance of below average peak flows experienced in nearby watersheds (and likely in Mess Creek) since the early 1960s (Figure 4). The former may be in response to a relaxation of sediment production from the glacierized sub-basins following an initial pulse of sediment transfer following the relatively rapid retreat of glacial ice experienced in the watershed. The latter may have reduced both the transport potential of the mainstem channel and its ability to erode the streambanks and, in turn, reduced the potential for episodes of lateral channel instability (i.e., bank erosion/deposition and avulsion).

The airphoto record was too short to fully explore the styles of avulsion present on the floodplain and in the vicinity of the proposed causeway, but observations suggest that avulsion by progradation is most common (especially given the relatively low floodplain slope, high water table, slow drainage, and fine-textured sediments present in a given floodbasin). Generally, this process involves an initial diversion of flow through a crevasse in a levee and into an adjacent floodbasin where competence is reduced and relatively coarse sediment is deposited into a splay, eventually forming a sediment wedge that progrades downslope (Slingerland and Smith, 2004). A crevasse may eventually heal after several decades, especially if the gradient advantage gained by flowing through the new floodbasin is lost after prolonged aggradation of the splay (Makaske, 2001; Slingerland and Smith, 2004). If the avulsion persists, however, the flow may eventually coalesce into a single thread and incise a new channel into the floodplain that will continue to flow downslope until it is able to rejoin another, preexisting channel (Slingerland and Smith, 2004). Although not observed near the causeway, avulsion by annexation of an abandoned channel (mapped here as an indefinite feature—see section 5) remains a possibility given the relatively large number of available (and apparently abandoned) channels connected to active channels along the main channel belt (the latter point requires confirmation in the field during low flow conditions).

7.0 Conclusions

Channel reaches along the mainstem of Mess Creek and in sub-basin D exhibit a variety of channel types, each with a characteristic lateral stability. In general, the two proposed channel crossing investigated in this report occur over relatively stable channel types (at least in the lateral dimension and over the timescale considered here). Channel change and lateral adjustment is expected in these reaches (particularly in reach M1), and the channel migration hazard has been mapped in the vicinity of the proposed crossings. The hazard maps were developed here based on airphoto imagery available over the period 1965 to 2006 and 1965 to 2007 for the lower and upper proposed crossings, respectively. The channel migration hazard was based on separate assessments of the bank erosion hazard and the avulsion hazard. The bank erosion hazard was assessed by measuring both the rate and spatial distribution of bank erosion across the floodplain or valley bottom, while the avulsion hazard was assessed by delineating the width of the meander belt and considering the past location(s) of a given channel on the floodplain. Generally, the floodplain area outside of the avulsion hazard zone was coincident with the "low" and "very low" bank erosion hazard zone.

The channel migration hazard maps are based on channel and watershed conditions observed over the periods of airphoto coverage described above. The analysis was projected forward for a period of 50 years, however; the hazard classes are only valid if current watershed conditions (as observed since 1965) persist during this period. In particular, any changes to the supply and quality of sediment and/or water to the channel, the condition of vegetation along the channel banks, and/or direct modification of the channel (for example) are not accounted for in this hazard assessment. Generally, the temporal span of available imagery was coincident with a period of (potentially) below average geomorphic activity along the mainstem channel. As such, the width of a given channel migration hazard zone (relative to the position of the channel banks) should be considered here as a minimum value. Further refinement of these hazard classes would require a more detailed examination of watershed history and an estimation of the magnitude and frequency of past disturbance events that have influenced channel and floodplain morphology.

8.0 Acknowledgements

Sean Dennis of Rescan Tahltan Environmental Consultants provided field assistance for this project. Photogrammetric scanning of the airphoto diapositives was undertaken by Bernard Poirier of Delta Aerial Surveys Ltd.

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Appendicies

A. Channel change maps

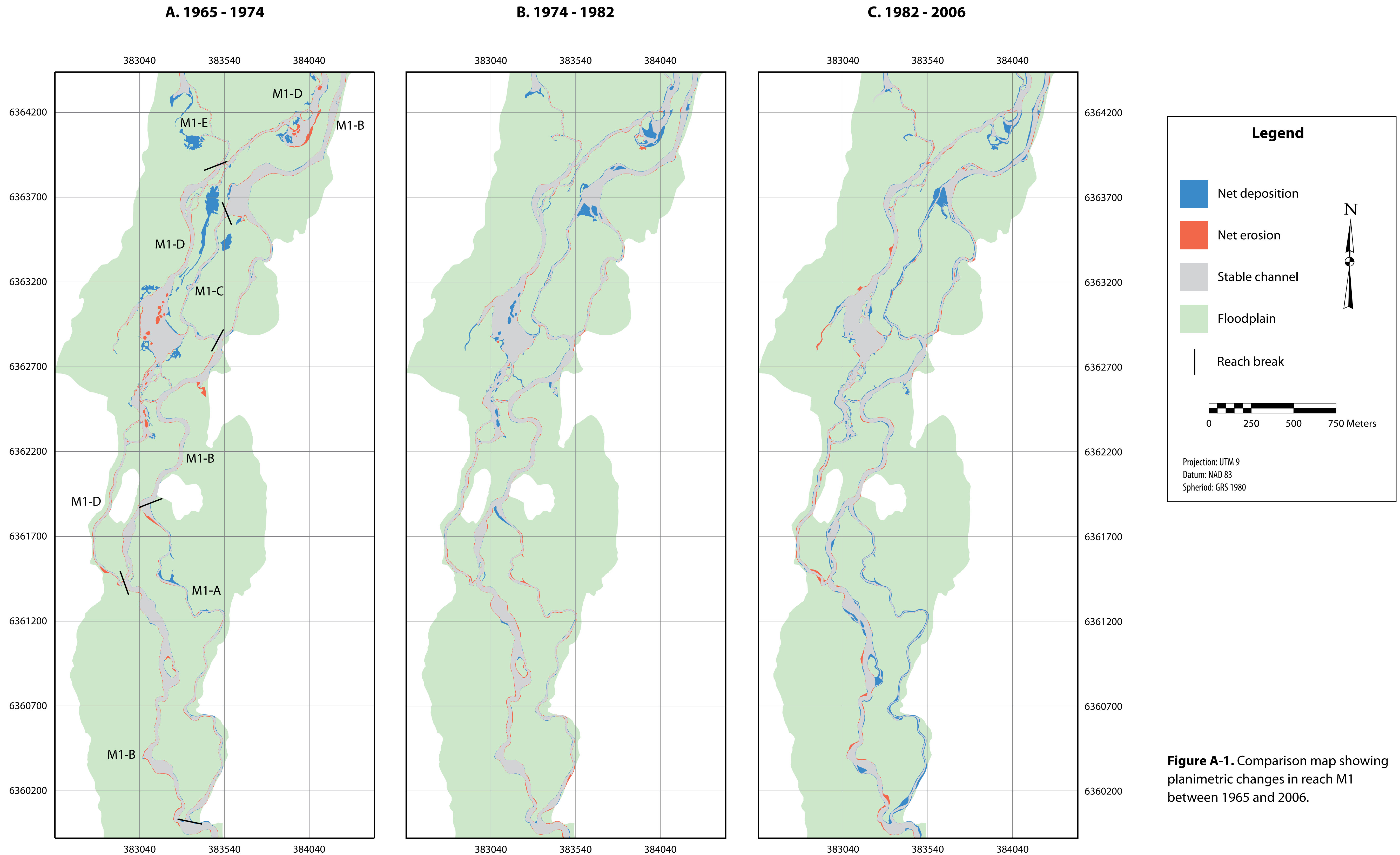

Figure A-1. Comparison map showing planimetric changes in reach M1 between 1965 and 2006.

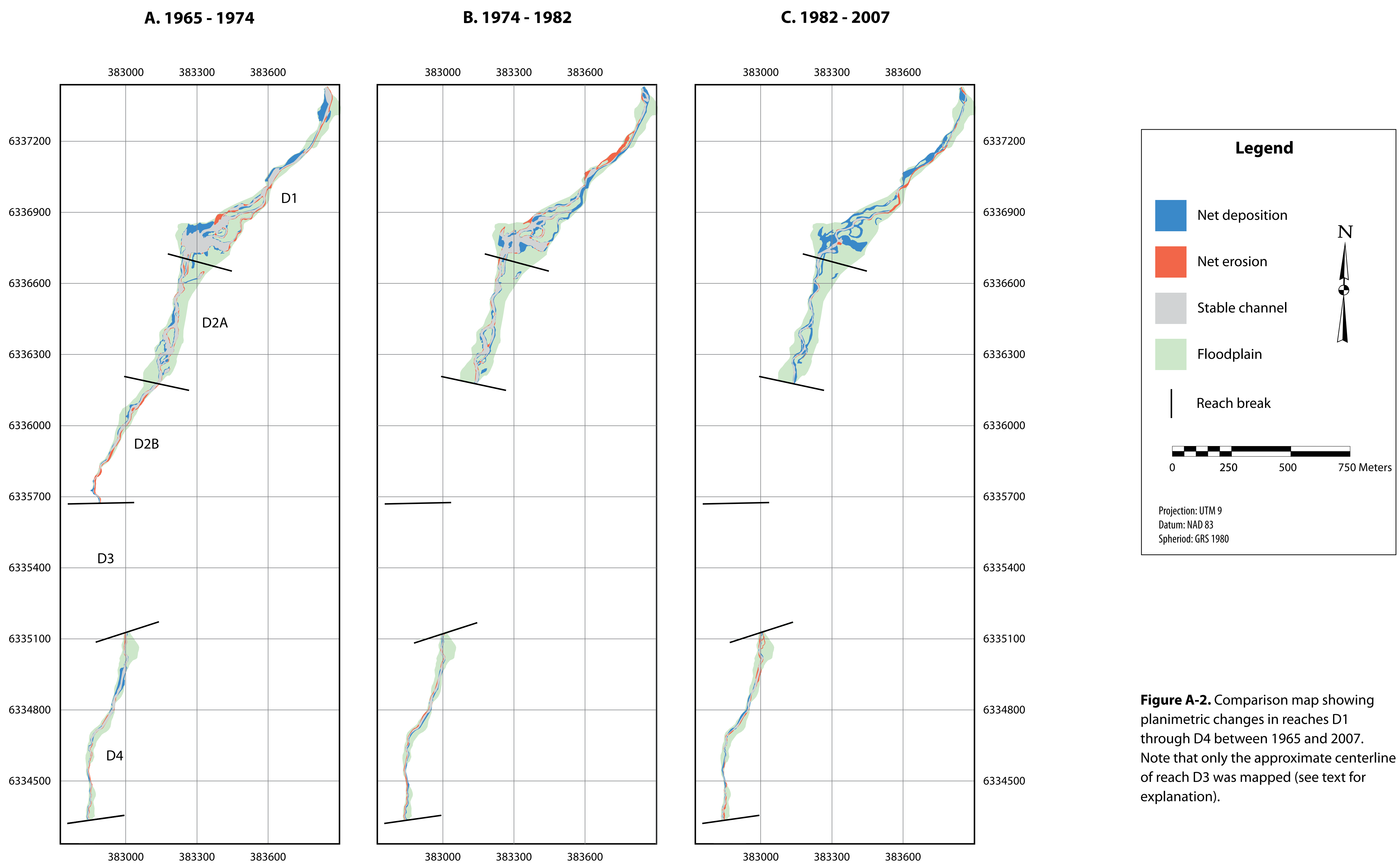

Figure A-2. Comparison map showing planimetric changes in reaches D1 through D4 between 1965 and 2007. Note that only the approximate centerline of reach D3 was mapped (see text for explanation).