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Englishman River Claybank Stabilization Geomorphic Impact Assessment

Englishman River Claybank Stabilization

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The following McQuarrie Geotechnical Consultants Ltd. personnel participated in the study:

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EXECUTIVE SUMMARY

The British Columbia Conservation Foundation (BCCF) is planning to implement engineering solutions to stabilize eroding claybanks in the lower Englishman River, Vancouver Island. The claybanks are known to input silt and clay directly to the channel which can negatively impact fish and fish habitat. BCCF retained Northwest Hydraulic Consultants (NHC) to evaluate how the Englishman River estuary would be affected if the claybanks along the river were stabilized. One major concern that BCCF has is that a reduction in sediment flowing into the estuary may cause lower accretion rates. This is a concern given the anticipated rise in sea level due to climate change, which could result in the loss of crucial estuarine habitat. This study aims to determine if sediment from the claybanks plays a meaningful role in sediment accretion rates within the estuary.

This study includes a field assessment of two claybank sites and the estuary; a high-level estimate of the watershed and claybank sediment yields; an air photo review to identify major sediment sources and changes in river morphology; a review of turbidity monitoring data; and a discussion of estuary morphodynamics.

Based on regional data, the estimated annual suspended sediment yield for the Englishman River watershed is in the range of 4,700 to 26,200 m^3/yr, while the volume of sediment supplied from the upstream claybank may be in the range of 3,000 to 4,500 m^3/yr, representing 11% to 96% of the overall basin yield. However, both the basin and claybank sediment yields represent crude estimates due to the inherent uncertainties associated with regional sediment yields and estimating bank erosion volumes from aerial imagery. Due to the highly dynamic nature of sediment transport processes, a more continuous record of sediment monitoring over a longer-time period that includes various flow conditions is required to better understand the watershed sediment regime. As part of this monitoring program, topographic surveying of the claybanks could help provide more robust estimates of bank erosion volumes.

The air photo review revealed numerous sediment sources throughout the lower watershed and a low-gradient alluvial reach in the upper watershed. Sediment supply in the upper watershed is dominated by bank erosion and channel avulsions, while input from mass wasting events on unstable hillslopes appears very low. High sediment supply to the lower watershed (downstream of the South Englishman River) drives periods of high bank erosion throughout the alluvial channel reach extending downstream to Allsbrook Canyon. The claybanks have the potential to input large volumes of sediment to the river, as was the case during a 2021 bank failure. However, on average over the long term, sediment input through erosion of the claybanks appears to be relatively minor relative to the high volumes of sediment that have historically been generated throughout the lower watershed during periods of rapid bank erosion, channel avulsions, and meander cutoffs in alluvial sediments.

The results from the turbidity monitoring at the upstream claybank show that for the observed flow conditions, there is very little difference in turbidity at high flow upstream and downstream of the claybank. The interpretation of this result is that the claybank sediment supply is negligible in comparison to the suspended sediment supply from upstream in the watershed, at least during the observed high flows.

The claybanks are almost predominantly supplying fine material (clay, silt) to the river which is transported downstream as wash load. Most of this sediment appears to get deposited offshore and is flushed through to the Strait of Georgia. As such, the potential reduced sediment supply from the stabilization of the upstream claybank is unlikely to have a meaningful impact on the estuary morphodynamics.

Protecting the toe of the upstream claybank should reduce the frequency and magnitude of fluvial erosion at the toe of the slope and allow the slope to stabilize over time. Reducing fine sediment inputs to the river from the claybanks may improve salmon spawning habitat downstream of the sites. Groynes could be constructed at selected locations to redirect the river channel away from the toe of the bank.

A simple mitigation option for the downstream claybank would be to redirect the channel through the adjacent gravel bar, similar to its natural course prior to 2006. Large trees could also be placed along the toe of the claybank to protect it from further erosion. These trees could be buried using the material excavated from the bar.

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ABBREVIATIONS

Acronym / Abbreviation	Definition
BCCF	British Columbia Conservation Foundation
DEM	Digital elevation model
LiDAR	Light detection and ranging
LWD	Large woody debris
MAF	Mean annual flood
RK	River kilometre
SLR	Sea level rise
UAV	Unmanned Aerial Vehicle
WSC	Water Survey of Canada

1 INTRODUCTION

The British Columbia Conservation Foundation (BCCF) is considering implementing engineering solutions to stabilize the toe of eroding claybanks in the lower Englishman River, Vancouver Island. The claybanks are known to input silt and clay directly to the channel; these sediments can negatively impact fish and fish habitat by directly smothering salmonid eggs or by forming a cementitious layer that traps salmonid alevins and emergent fry in their redds.

BCCF retained Northwest Hydraulic Consultants (NHC) to evaluate how the Englishman River estuary would be affected if the claybanks along the river were stabilized. One major concern that BCCF has is that a reduction in sediment flowing into the estuary may cause lower accretion rates. This is a concern given the anticipated rise in sea level due to climate change, which could result in the loss of crucial estuarine habitat. This study aims to determine if sediment from the claybanks plays a meaningful role in sediment accretion rates within the estuary.

During the course of the study NHC recommended that BCCF undertake a slope hazard assessment of the sites. BCCF retained McQuarrie Geotechnical Consultants Ltd. NHC incorporated some of the slope hazard assessment in this report. The full *Englishman River "Claybanks" Slope Hazard Assessment* (McQuarrie, 2023) is included in Appendix A.

1.1 Scope of Work

The scope of work for this assessment is as follows:

- Background review of the watershed and study reach history and physical properties.
- Field assessment of the two claybank sites and the estuary to make observations of geomorphic processes, bank composition, substrate grain size and to collect field photos.
- High-level estimate of the watershed sediment yield, including an assessment of the relative importance of the upstream claybank site as a sediment point source. The downstream claybank was not included in this assessment.
- Review of historical air photos to identify major sediment sources and changes in river morphology.
- Review of available turbidity data to evaluate the relative concentration of sediment generated by the upstream claybank site.
- Discussion of estuary morphodynamics including the potential effects of reducing sediment input from the stabilization of the upstream claybank on sediment deposition and accretion in the estuary.

The assessment does not involve a geotechnical assessment of claybank stability, nor does it address the engineering design of potential stabilization options.

1.2 Available Datasets

In addition to the data collected during the field assessment, the following datasets were available for this study:

- Discharge and sediment data from the Water Survey of Canada (WSC) hydrometric station 08HB002.
- 2019 GeoBC lidar Digital Elevation Model (DEM)
- UAV videos and photos of the claybank
- Satellite imagery including: ESRI, Google Earth, and Sentinel 2
- Historical air photos courtesy of the UBC Geographic Information Centre
- Turbidity data collected by BCCF
- Laboratory sieve analysis of the claybank soil grain size

2 PHYSICAL SETTING

This section provides an overview description of the Englishman River watershed including the geology and glacial history, climate and hydrology, wildfire history, and landuse and infrastructure.

2.1 Watershed Overview

The Englishman River watershed drains an area of 316 km^2 on the central east coast of Vancouver Island, British Columbia (Figure 2.1). The headwaters begin at Mount Arrowsmith within the Vancouver Island Ranges, from here, the river flows along an east-to-northeast trajectory before eventually discharging to the Strait of Georgia downstream of the Town of Parksville. The lower half of the watershed, including the project study area, resides within the Nanaimo Lowland physiographic region, a relatively flat, low-lying coastal plain extending about 10 km inland from the coast (Holland, 1976). Within the lower watershed, the Englishman River flows along a gentle gradient (< 1%), with local increases in gradient coinciding with the location of bedrock confinements (e.g., Allsbrook Canyon) and crossings (e.g., Hwy 19 and 19a Bridges) (Figure 2.2). Major tributaries within the watershed include Marshall, Moriarty, Morison Creeks, and the South Englishman River (Figure 2.1).

In the upper watershed the river flows primarily over bedrock and till, and is characterized by typically narrow, stable channels with sediment supply primarily generated by bank erosion in isolated lower-gradient alluvial reaches. In contrast, the river transitions to an alluvial channel in the lower watershed, flowing within a 1 km wide floodplain. The river is laterally unstable through this reach and is prone to downstream progression, meander cutoffs, and channel avulsions. This is explored further in Section 3.4. As the river approaches the Strait of Georgia, the gradient declines, and the river branches into multiple channels in its estuary. The river deposits much of its coarse sediment load at and upstream of the estuary in the form of lateral and mid-channel bars that are frequently re-worked by annual peak flows.

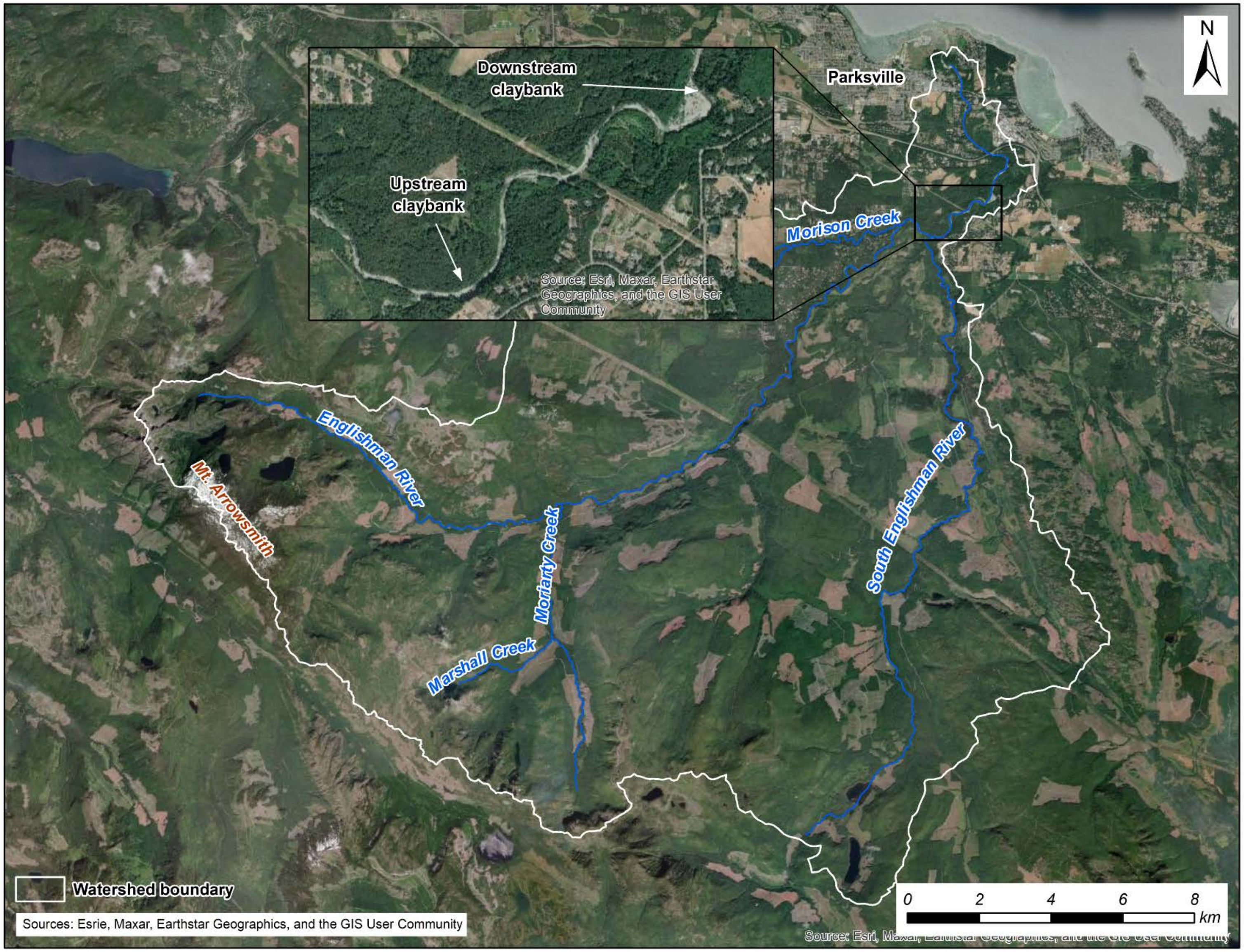

Figure 2.1 The Englishman River watershed. Inset shows the study area encompassing the eroding claybanks.

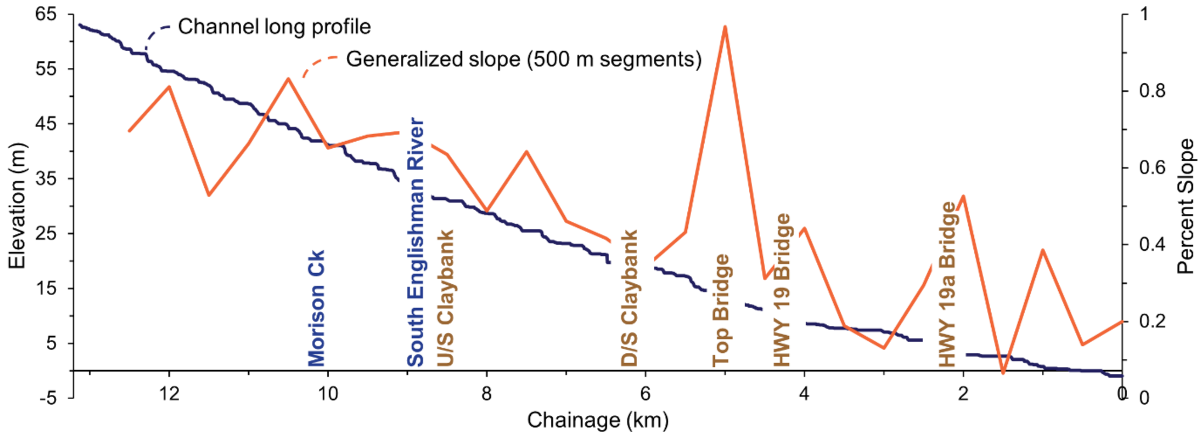

Figure 2.2 Longitudinal profile of the Englishman River based on 2019 GeoBC Lidar elevations. River chainage is measured upstream from the estuary. River chainage is referred to in this report using the notation RK (river kilometre).

2.2 Geology and Glacial History

The lower Englishman River watershed is underlain by sedimentary bedrock of the Upper Cretaceous Nanaimo Group. Broadly, this unit includes conglomerates, sandstones, siltstone, shale, and coal (BCGS, 2019). Exposed bedrock near Top Bridge (Figure 2.2) provides local confinement on the Englishman River, forcing the river to flow with a narrow (10 m wide) steep channel, named Allsbrook Canyon.

Throughout much of the watershed, bedrock is overlain by sediments of the Vashon Drift, which includes surface till and ice-proximal deposits from the last glaciation around 14,500 years ago (Hicock and Armstrong, 1985). At this time, the Cordilleran Ice Sheet covered most of the Vancouver Island Ranges with an estimated thickness of 1,500 m (Clague, 1981).

Over the next few thousand years, ice retreated from its maximum extent, with deglaciation complete around 10,000 years ago. As the ice melted away, relative sea levels declined due to the isostatic rebound of ice-free land areas. During this time, the Capilano sediments were deposited. Glaciomarine sediments were deposited in low-lying coastal areas, while in areas where sediment supply was high, such as the Englishman River valley, fluvial terraces formed and deltas prograded into the sea (Russell and Benoit, 2016). The Capilano Sediments are technically considered postglacial but were still affected by the influx of meltwater from late deglaciation. Following the initial isostatic uplift after deglaciation, relative land levels declined and the Laurentian Ice Sheet added meltwater to the sea (Earle, 2002). By around 6,000 years ago relative sea level was within a few metres of what it is today.

The Englishman River has since cut into older glacial and postglacial sediments, with modern alluvium (Salish Sediments) covering the valley floor (Figure 2.3). At the two claybank sites, the river has eroded across the modern valley bottom and into the bounding valley wall composed of glacial sediment. Here, the exposed claybanks are composed largely of till from the Vashon Drift, overlain by a glaciofluvial delta terrace deposited during the onset of deglaciation (Figure 2.3). Claybanks are described in further detail in Section 3.1.

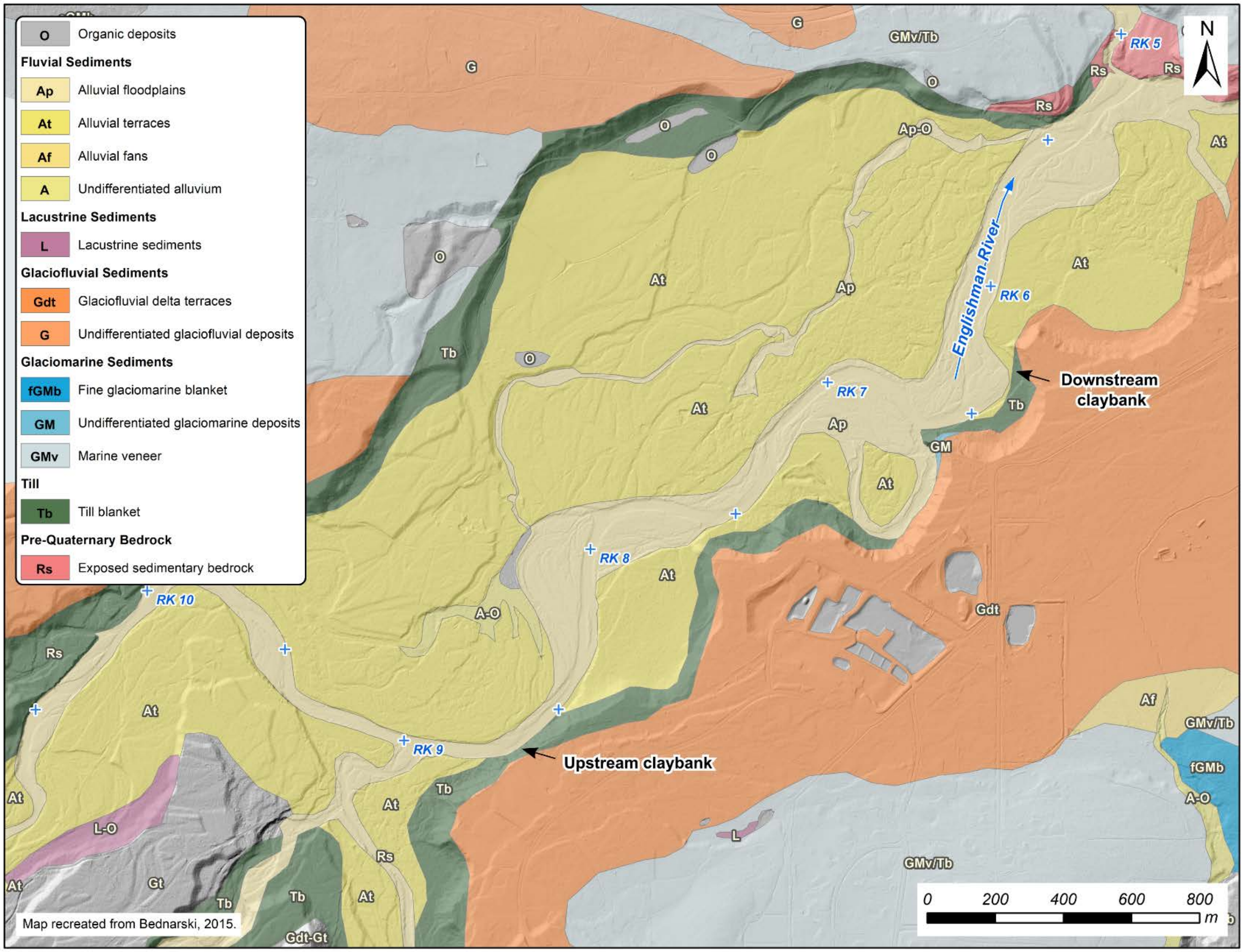

Figure 2.3 Surficial geology of the lower Englishman River study reach.

2.3 Climate and Hydrology

The lower Englishman River watershed resides within the Coastal Douglas-fir biogeoclimatic zone (MFLNRO, 2020). This area is located within the rainshadow of the Vancouver Island Ranges and is warmed by air from the Pacific Ocean. The climate is characterized by mild, wet winters and warm, dry summers. In contrast, the upper watershed resides with the Coastal Western Hemlock zone, which sits at a higher elevation, where mountains force moisture to drop from warm Pacific air, creating a particularly wet environment with moderate temperatures.

The Englishman River discharge regime is largely rainfall driven. Floods tend to occur between October and March, generated by rainstorms combined with snowmelt from higher elevations in the watershed. The Water Survey of Canada (WSC) hydrometric station 08HB002, installed at the Highway 19a Bridge (RK 2.2), has a continuous discharge record dating back to 1986, with more intermittent records prior. Based on this record, the largest peak flows occurred in 2020 (538 m^3/s), 2006 (535 m^3/s), and 2018 (491 m^3/s) (Figure 2.4a). From 1986 to 2017, maximum daily flows were generally below the long-term average (Figure 2.4b). Since 2017, maximum daily flows have exceeded the long-term average, representing a hydrologically more intensive period.

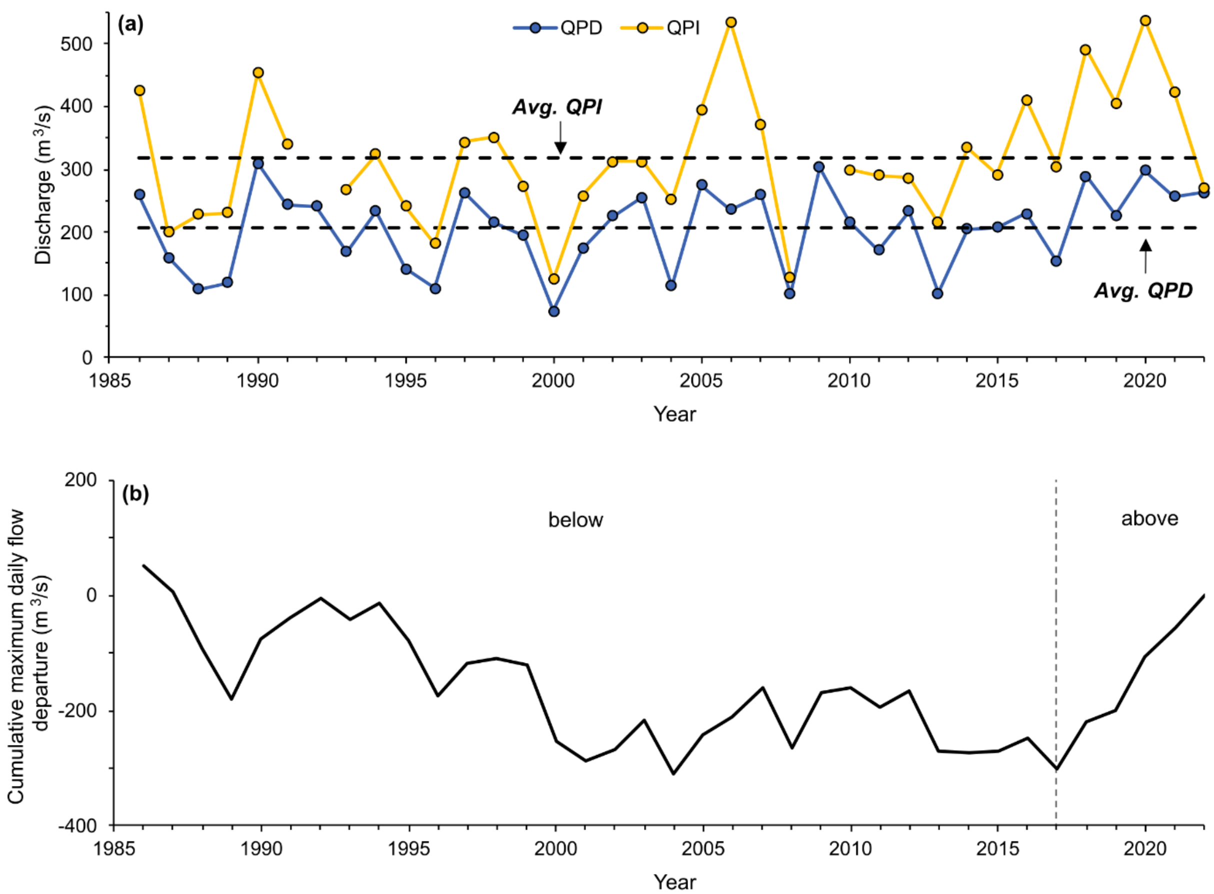

Figure 2.4 **(a) Historical flood flow sequence ; QPD = maximum daily discharge; QPI = peak instantaneous discharge. (b) Cumulative flood flow departures from the mean QPD. A rising trend indicates a period of above-average floods, whilst a falling graph indicates a period of below-average floods.**

2.4 Wildfire Activity

The removal of vegetation by wildfires can lead to increased runoff on hillslopes and greater peak flows; it can also increase the probability of slope failures (Geertsma et al., 2010). The Government of BC's historical wildfire inventory shows three human-induced wildfires occurred in 1920 and 1922 (areas of 476, 619, and 761 ha) within the lower Englishman River and South Englishman River basins, and more recently, a lightning-induced wildfire that occurred in the steep headwaters of Moriarty Creek in 1978 (area of 687 ha). Much of the remaining watershed area has remained undisturbed by wildfire activity, so the sediment supply regime is not likely to have been strongly influenced by post-wildfire landslides or other mass wasting events.

2.5 Landuse and Infrastructure

The primary landuse within the Englishman River watershed is logging, with over 70% of the watershed area owned by private forestry companies (Bocking and Gaboury, 2001). Much of the Englishman River watershed was harvested in the early 1900s, with a significant second cut in the 1950s and 1960s since then, logging activities have been greatly reduced and are primarily restricted to headwater areas (Bocking and Gaboury, 2001). The loss of old-growth riparian trees within the watershed has undoubtedly had an impact on the morphology of the alluvial channel. Based upon a review of air photos (described in further detail in Section 3.4), a high delivery of sediment from upstream in the watershed caused major changes to alluvial channel morphology between Allsbrook Canyon and the South Englishman River confluence during the mid twentieth century. This higher-than-normal sediment delivery may be associated with riparian harvesting in the upstream portions of the watershed.

There is very little urban development within the Englishman River watershed, except for a small area of Parksville located along the downstream-most section of the river. More commonly, rural residential development has occurred within the lower Englishman River and Morison Creek basins.

The study area falls within the Englishman River Regional Park, which extends from Top Bridge upstream to the Morison Creek confluence. Here, a sparse network of trails cut through the floodplain north of the river following an old secondary channel, with a campsite located near Englishman River Falls at Top Bridge.

Historical anthropogenic modifications to the landscape have had a profound impact on the form and function of the estuary. The estuary was originally cleared for farming in 1873, and has more recently been modified for logging, then urban development (Clough, 2013). A comparison of the estuary between 1949 and 2016, shows urban development has occurred on both the east margin of the estuary, and along a western breakwater (Figure 2.5). During the 1950s, the estuary was diked, and subsequently dredged to accommodate the development of a resort (Clough, 2013). In aggregate, these modifications have reduced the available area that the estuary's distributary channel network can access, limiting the area in which erosional and depositional processes can occur. In its current configuration, the estuary occupies a single main channel with several side channels active during high flows and by backwatering during high tides.

Figure 2.5 Comparison of the Englishman River estuary between 1949 and 2016.

3 GEOMORPHIC ASSESSMENT

This section presents the results of the geomorphic assessment, beginning with a description of observations collected during the field assessment, and summarizing key findings form a geotechnical assessment completed after NHC's initial assessment (McQuarrie, 2023). The following sections focus on the basin sediment yield, identified sediment sources, and the results from turbidity monitoring (RK 8.6), before concluding with a review of controls on estuary morphodynamics and the potential effects on sedimentation in the estuary resulting from the stabilization of the claybanks.

3.1 Field Assessment

NHC conducted a field assessment on November 23, 2022, along with the client (BCCF), to evaluate the current condition of the claybanks. The assessment focused primarily on the claybank located near the confluence with the South Englishman River (RK 8.6) but also included a visit to the second downstream eroding claybank site (RK 6.3) and the upstream portions of the estuary.

3.1.1 Upstream Claybank (RK 8.6)

The upstream claybank (RK 8.6) is approximately 30 to 35 m high, extending about 100 m downstream before the river moves north and transitions into 5 m high alluvial banks. The claybank is composed of three distinct units. The top layer is approximately 2 to 3 m thick, composed of sand and gravel, below which is a 3 to 5 m thick layer of orange sandy material, mapped as a glaciofluvial delta deposit (Figure 2.3). The lower 25 m of the bank is composed of Vashon Drift till (Photo 3.1). Two samples of this unit were collected by BCCF in August 2022 and sent to Bureau Veritas lab for sieve analysis. The results of this analysis show that the till is composed of 19-22% clay, 29-30% silt, 49-52% sand, and < 2% gravel (Table 3.1). The high clay content makes this unit particularly cohesive, and compression from overriding ice during deposition has made the sediment particularly compact.

Photo 3.1 Photograph of the upstream eroding claybank (RK 8.6).

Table 3.1 Sieve analysis results for the upstream claybank (RK 8.6).

Physical Properties	Sample #1	Sample #2
Sand (by hydrometer)	52%	49%
Silt (by hydrometer)	29%	30%
Clay content	19%	22%
Gravel	< 2%	< 2%

Field observations indicate the toe of the claybank at RK 8.6 is being eroded by the Englishman River. Exposed roots are visible along trees lining the top of the bank, and several trees have recently been undermined and fallen downslope (Photo 3.1). The lower bank appears to be contributing soil directly into the channel, perhaps by block failures when the river erodes the toe of the slope, as well as during freeze-thaw and other weathering events (Photo 3.2). Failed material and debris input to the channel is likely flushed downstream relatively quickly by the river. Jeramy Damborg (BCCF) noted that small-scale inputs from the claybank are mobilized during moderate flows and tend to be deposited in the downstream sections of channel, negatively impacting habitat quality (pers. comm. April 14, 2023, email).

Photo 3.2 Conglomerate of bank material deposited in the channel near RK 8.5.

Across from the claybank, a coarse cobble-boulder bar has formed (Photo 3.3). A Wolman count collected at this location shows that the median size of surficial bed material (D_{50}) is 173 mm (cobble) and that the coarse fraction of the bed, as represented by the D_{84}, is 300 mm (boulder). The coarse sediment imparts a degree of stability to the bed, as these particles are likely only mobilized during extreme flood events. The increased resistance to flow provided by this bar may be deflecting higher velocity flows towards the claybank, contributing to the observed bank erosion.

Photo 3.3 Photo is looking upstream at the head of a cobble-boulder bar across from the upstream claybank (RK 8.6).

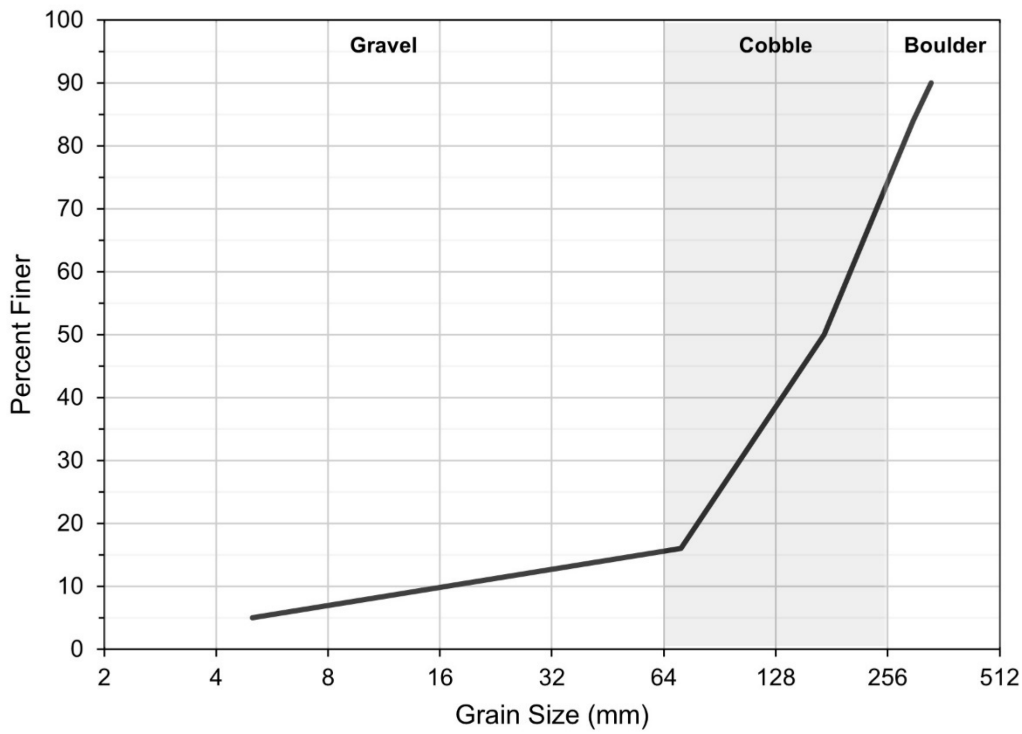

Figure 3.1 Wolman count collected at the head of the cobble bar across from the upstream claybank (RK 8.6).

3.1.2 Downstream Claybank (RK 6.3)

A secondary claybank, located at RK 6.3, was identified by BCCF as an area that had recently become exposed due to rapid bank erosion over the past few years. Here, the bank is about 25 m high, consisting of the same sequence of glaciofluvial delta terrace sediment overlying glacial till as observed at the upstream claybank (Photo 3.4). In contrast to the upstream site, the sandy glaciofluvial sediment is approximately 10 m thick, and the underlying till is just 15 m thick. Sieve analysis of samples collected from each unit by BCCF, and processed by Bureau Veritas, reveal that the glaciofluvial upper layer is 79% sand, 20% silt, < 2% clay and < 2% gravel (Table 3.2). The glacial till is composed of 12% sand, 70% silt, 19% clay, and < 2% gravel, a similar composition as observed at the upstream site.

Table 3.2 Sieve analysis results for the downstream claybank (RK 6.3).

Physical Properties	Glaciofluvial delta terrace sediment	Glacial till
Sand (by hydrometer)	79%	12%
Silt (by hydrometer)	20%	70%
Clay content	< 2%	19%
Gravel	< 2%	< 2%

Due to the rapid bank erosion, numerous trees, previously lining the top of bank, have raveled downslope, and accumulated along the slope and toe of the bank. During future flood events, the river is likely to mobilize much of the debris accumulation along the toe of this slope and transport it downstream.

Immediately upstream of the eroding bank is a cobble-gravel bar, the largest bar featured in this reach of the river. The interior and upstream portions of the bar are partially covered by immature vegetation, while pieces of large woody debris (LWD) floated from upstream have been deposited at the bar margin, closer to the channel thalweg. A coarse bedload sheet appears to be migrating downstream at the tail of the bar (Photo 3.5), indicating that there is a high volume of sediment being deposited at this location, and potentially driving the high rates of bank erosion. This is explored in more detail, along with a review of other sediment sources in the watershed, in Section 3.4.

Photo 3.4 Photograph of the downstream eroding claybank (RK 6.3).

Photo 3.5 Photo looking upstream at the slip face of a migrating bedload sheet on the bar tail near RK 6.3.

3.1.3 Estuary

The field assessment included an inspection of the upstream portion of the estuary and the tidally influenced portion of the river upstream of the estuary. Surficial sediment in the upstream portion of the estuary is dominated by medium to coarse gravels, with a higher proportion of sand found below the surface. Due to the reduced channel gradient upstream of and within the estuary, the river is prone to bed aggradation and channel avulsions (Photo 3.6). Sediment accumulates at side-channel and mid-channel bars, which appear to be frequently re-shaped and re-organized during peak flood events.

Photo 3.6 Photo looking upstream at the site of a recent channel avulsion upstream of the estuary (RK 1).

3.2 Geotechnical Assessment

Following the field and desktop assessment completed by NHC and documented in this report, a slope hazard assessment of both the upstream and downstream claybanks was completed by McQuarrie (2023). The following paragraphs summarize the key findings from this report.

Erosion at the toe of the slope over-steepens the upstream claybanks. The till remains temporarily intact due to its high density and negative pore pressures. Small failures occur where the bank is steepest or has been undercut. Periodically, large sections of till fail as slabs, retrogressing up the bank. This over-steepening undermines the fluvial deposits overlying the till. This material ravels more frequently with much less volume. The main consequence of continuing bank failures is related to sediment in the river and the loss of private land above the slope crest.

River migration has caused extensive erosion along the downstream claybank. Here, the till bank tends to fail periodically in slabs, while the upper bank ravels much more frequently. The average rate of erosion since 2006 has been 8.5 m/year. This bank poses a risk of high sediment loads to the river. Compared to the upper claybank, this slope exposes less till and more sand and gravel from the Capilano sediments. The till here contains more silt and less fine sand, which, when deposited in downstream channel reaches, may negatively impact habitat quality.

McQuarrie also noted that during the dry season the pore pressure can decrease due to drying of the face, which can lead to small failures.

3.3 Basin Sediment Yield

The sediment that is transported in a river is commonly classified as wash load or bed material load (Figure 3.2). Wash load is the fine sediment (typically silt and clay sized particles) that can be maintained in suspension by the turbulence of the flow and consequently is not found in appreciable quantities in the river channel bed material. Wash load sediments may deposit in local slack water areas such as back channels and sloughs, in low energy mudflat and marsh environments or be transported offshore. The fine sediments can also migrate vertically through the coarser surface layer of the river bed and eventually become trapped in the voids of the underlying sediments. The rate of wash load transport is mainly governed by the supply of fine sediment from erosion in the watershed, not by the local hydraulic conditions in the river channel. The banks at the two erosion sites consist almost entirely of wash load sized sediment.

The coarser bed material load (typically cobbles, gravel and coarse sand) is derived from entrainment and erosion of bed material deposits in the channel. The bed material load can be transported both as bedload (sediment moving in direct contact with the bed) and in intermittent suspension or saltation.

Sediment transport is commonly measured with suspended sediment samplers and bed load samplers. On steep coarse-grained rivers such as the Englishman, the suspended load consists mainly of wash load, although a small amount of bed material sediment moving in suspension near the bed may also be included.

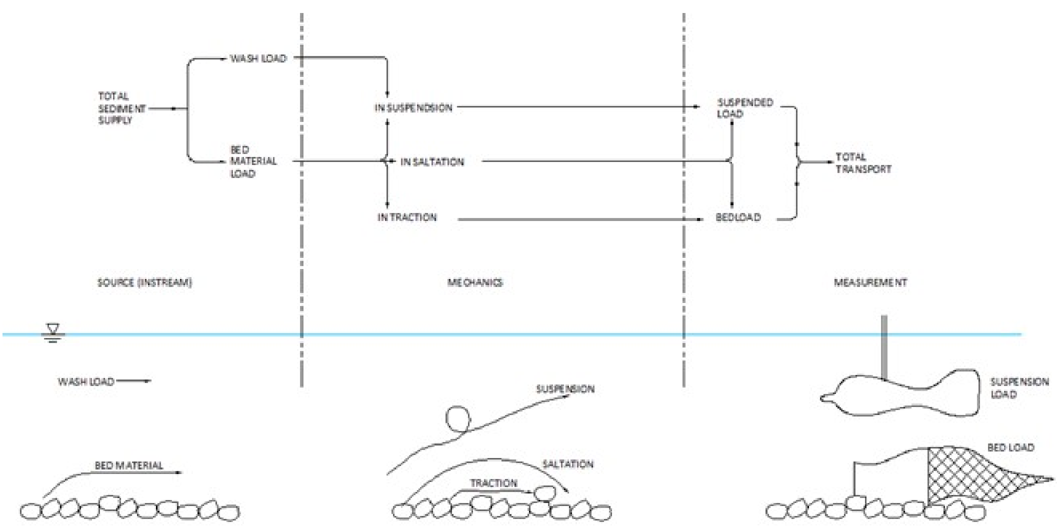

Figure 3.2 Classification of sediment transported in rivers (modified from Church et al, 1990).

Estimating the long-term suspended sediment load on a river requires conducting suspended sediment samples over a period of several years. Water Survey of Canada maintained a network of sediment stations in BC over the period 1965 to 1992, including some intermittent samples from the Englishman River at the Highway 19A bridge (hydrometric station 08HB002). While most sampling over this period was completed during low-flow conditions, depth-averaged samples were collected with a DH-49 sampler at five verticals in the gauging cross section during a high-flow event on November 23, 1990 (Table 3.3). The daily discharge on this date reached 310 m^3/s and the peak instantaneous discharge was 454 m^3/s. The suspended load was computed from the measured concentration and discharges in each sub-section of the channel using the following equation:

$$Q_s = C_s Q_w k$$

Where Q_s is the suspended sediment discharge (tonnes per day), C_s is the suspended sediment concentration (mg/L), Q_w is the instantaneous streamflow (m^3/s), and k is a unit conversion factor (0.0864). Based on this equation, the total daily sediment load was 34,518 tonnes. Grain size analysis was carried out for each of the samples. The analysis showed 60% of the suspended load consisted of silt and clay sediment (less than 0.063 mm). The corresponding fine sediment load was approximately 21,000 tonnes. The equivalent in-situ volume of deposited sediment (sand, silt and clay) from this one day of transport is in the range of 12,000 to 13,000 m^3, assuming void ratio of between 0.40 to 0.35.

A review of the 1990 flood season (Oct 1, 1990 to March 1, 1991) indicated there were 15 days that exceeded 100 m^3/s and only two that exceed 200 m^3/s. Therefore, it is expected that the amount of sediment transported on November 23 represented a substantial percentage of the annual load. However, the measurements are too limited to estimate long-term sediment loads at the station.

Table 3.3 WSC suspended sediment data collected on November 23, 1990.

Vertical	Discharge (m^3/s)	Concentration (mg/L)	Load (T/day)
7.5	32.5	1,021	2,867
13	105.2	998	9,071
21.5	111.1	1,314	12,613
27	55.1	1,292	6,151
32	42.8	1,032	3,816
Total	347		34,518

Regional estimates of basin sediment yield have been developed from long-term suspended sediment stations on other rivers in BC. These studies provide a basis for comparing sediment yield in different climate zones and physiographic regions. The results can also be used to provide crude “order of magnitude” estimates in ungauged basins. This approach was used for the Englishman River using the relationship between specific sediment yield and drainage area presented by Church and Slaymaker (1989) for catchments in BC:

$$Y \propto A_d L$$

Where Y is the total sediment yield, A_d is the drainage area, and L is the mainstream length. The upper and lower envelopes of Church and Slaymaker’s plot (Figure 1 in Church and Slaymaker, 1989) are given by $Y = 36 \times 10^{-4} A_d L$ and $Y = 6.5 \times 10^{-4} A_d L$ respectively. For the Englishman River watershed, this equates to an annual suspended sediment yield in the range of 8,100 to 45,100 T/yr. Assuming a unit weight of 1.7 T/m^3, this represents a volume of 4,700 to 26,200 m^3/yr, with a central estimate of 15,500 m^3/yr (average of upper and lower bounds). However, actual year-to-year rates are highly volatile and will respond to differences in the magnitude, duration, and timing of peak flood events (McLean et al., 2013).

3.4 Sediment Sources

To evaluate the relative importance of the claybanks as sediment sources, a review of historical imagery was completed to inventory sediment sources within the Englishman River watershed. Historical air photos from 1949, 1954, 1962, 1968, 1975, 1984, and 1998 were reviewed for the lower watershed, and Google Earth imagery from 2005 to 2021 was reviewed for the entire watershed. This analysis highlights numerous episodic sediment point sources in the watershed such as slumps, channel avulsions, and rapid bank erosion, but does not include areas where more gradual erosion of channel banks occurred, though these may also contribute a substantial volume of sediment to the overall basin yield over the long-term. A summary of this analysis, including the location, year, and description of the type of disturbance is summarized in Table 3.4 and shown on Figure 3.3.

Table 3.4 Summary of historical sediment sources in the Englishman River watershed.

Image/Source	Year(s) Active	Location	Description
BC814:100 BC1667:41 Google Earth	1949 – 1954, 2021	Upper watershed (403514 E, 5458488 N)	Slumping 30 m high bank. Failure occurring in till with glaciofluvial sediment overtop, similar to claybanks. Slump reactivated in 2021.
BC1667:41	1954	Lower watershed (406468 E, 5459861 N)	Avulsion cuts through meander bend immediately downstream of the upstream claybank.
BC1667:41	1954	Lower watershed (407287 E, 5460180 N)	Substantial bank erosion at high-amplitude meander bend.
BC5047:93	1962	Lower watershed (407083 E, 5460249 N)	Major meander cutoff downstream of powerlines.
BC5047:40	1962	Upper watershed (402820 E, 5457501 N)	Avulsion through inside of meander bend.
BC7076-270	1968	Lower watershed (407855 E, 5461229 N)	Major meander cutoff upstream of Allsbrook Canyon.
BC7079-179	1968	Upper watershed (404244 E, 5458612 N)	Small-scale channel avulsion at meander bend.
BC7760:173	1975	Lower watershed (407706 E, 5461055 N)	Major meander cutoff upstream of Allsbrook canyon.
BC84029:006	1984	Lower watershed (406212 E, 5459777 E)	Substantial channel widening and bank erosion downstream of upstream claybank.
BC84027:225 30BCC98038:093	1984-1998	Upper watershed (403072 E, 5457978 N)	Substantial bank erosion on outer bank of meander bend.
BC84027:226	1984	Upper watershed (405409 E, 5459552 N)	Bank erosion upstream of upstream claybank.
30BCC98038:109	1998 – 2021	Lower watershed (407495 E, 5460413 N)	Major bank erosion and channel widening first observed in 1998 air photo. This is the downstream claybank site, but the claybank only becomes exposed

Image/Source	Year(s) Active	Location	Description
			after 15-20 years of continued bank erosion into alluvium.
Google Earth	2005	Upper watershed (392394 E, 5451243 N)	Major meander cutoff avulsion.
Google Earth	2005	Upper watershed (406309 E, 5459937 N)	Slumping bank at outside of meander bend.
Google Earth	2011	Upper watershed (392065 E, 5451335 N)	Major meander cutoff with substantial downstream channel erosion and widening.
Google Earth	2016	Upper watershed (401839, 5456437 N)	Bank erosion between bedrock outcrops.
Google Earth	2019	South Englishman River (406291 E, 5457494 N)	Channel avulsion with downstream channel widening.
Google Earth	2008-2015	Upper watershed (391807 E, 5451563 N)	Bank erosion adjacent to road. Revetments installed around 2015 have since reduced erosion.

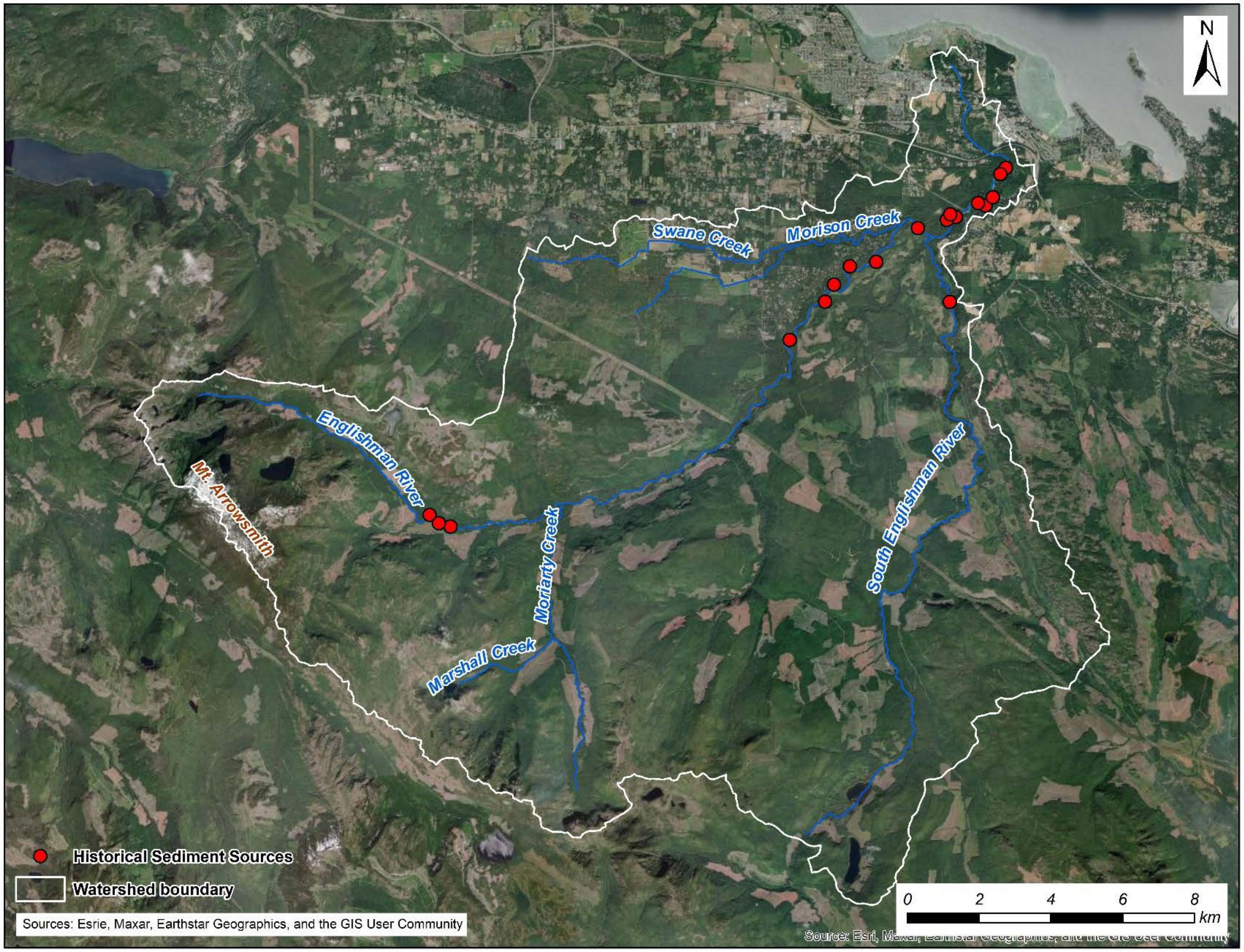

Figure 3.3 Historical sediment sources in the Englishman River watershed identified from air photos and satellite imagery.

In the upper watershed, the Englishman River and its major tributaries largely flow through bedrock covered be a veneer of glacial till. Here, steep narrow channels dominate, with relatively low lateral instability or fluvial erosion of sediment. The hillslopes in the upper watershed also appear to be relatively stable, with no observed mass wasting failures or debris flows inputting large volumes of sediment into the headwater channels. The most significant sediment sources in the upper watershed appears to occur at the confluence with an unnamed tributary approximately 3 to 4 km upstream of the Moriarty Creek confluence (Figure 3.3). Here, the channel gradient decreases and there is a 2-3 km reach of alluvial channel where the river is prone to rapid bank erosion and meander cutoffs. The lateral instability at this location may have been exacerbated by historical riparian logging (Higman et al., 2003).

In the middle of the watershed, upstream of the Morison Creek confluence, the Englishman River flows through a semi-alluvial channel, often confined by bedrock outcrops. Through this reach several meander bends have historically been susceptible to rapid erosion or meander cutoffs, generating a large source of sediment to the downstream channel. At one bend, there was a large slump or rotational failure that occurred between 1949 and 1954, where the river eroded into glacial till, similar to the claybank study sites in the lower watershed.

However, the most abundant sediment sources in the watershed have historically occurred within the channel reach extending from the confluence with the South Englishman River through to Allsbrook Canyon (Top Bridge). This reach encompasses both claybank study sites as the river exits confinement and flows onto a 1 km wide floodplain. The reduced confinement and channel gradient through this reach allows the river to migrate more freely across its floodplain and deposit sediment supplied from upstream in the watershed. Here, the river is prone to periods of rapid bank erosion and lateral instability, with major cutoffs of high-amplitude meander bends. From 1949 to 1968, there appears to have been a high sediment load delivered to this reach, possibly related to logging activities, and as a result there was substantial channel straightening and steepening (Gaboury, 2005). In recent years, the river may be moving towards a more sinuous channel planform through this reach, in main part due to the rapid bank erosion at the downstream claybank (RK 6.3). From 2019 to 2021, the channel bank retreated by 40 m at this location (Figure 3.4), which has caused the river to impinge upon the glacial till unit forming the valley wall. This period of high bank erosion coincides with a period of high peak flows on the river (Figure 2.4a).

Figure 3.4 Rapid bank erosion at the downstream claybank (RK 6.3) from 2019 to 2021.

The upstream claybank (RK 8.6) actively contributes sediment to the river channel through both gradual erosion during moderate flows and episodic events during high flows, as well as smaller episodic events during dry periods when there is low pore pressure in the face. One recent example of a large claybank failure occurred in 2021, resulting in the deposition of a substantial volume of fine sediment into the Englishman River. This event can be observed in Figure 3.5, where pre- and post-failure images illustrate the infilling of the pool at slope's base and partial blocking of the channel. By using the 2019 Lidar DEM to model the pre-failure bank topography, we estimate that the failed material covered an area of approximately 69 m^2 for a given cross-section. Extrapolating this over the 100 m length of bank, we estimate a total volume of 6,900 m^3, or 11,700 T. Comparing this to the long-term average sediment yield estimated from regional data (ranging from 4,700 to 26,200 m^3), suggests that the sediment input from the 2021 bank failure may have constituted an appreciable portion of the total sediment yield for that year. It is important to note that the deposition of fine sediment during such large events poses potential risks to downstream water quality and fish habitat, as emphasized in communication with J. Damborg (email, April 24, 2023).

Another recent failure occurred August 26/27, 2023 during low river flow conditions and a dry weather period. This failure was caused by low pore pressure in the face, which decreases cohesion. The over-steepened slope failed contributing clay, silt, sand, and gravel to the river. This episode caused visible siltation in the river in downstream reaches. Photo 3.7 shows the slope failure.

In other years, erosion at the upstream claybank has generally been less pronounced, such that on average, the bank has eroded by just 1 to 1.5 m/yr since 2005, as observed through examination of Google Earth imagery. However, this rate still exceeds the historical average of 0.6 m/yr reported by Gaboury (2005). Given the bank dimensions (approximately 30 m high by 100 m in length), this represents a volume of 1,800 m^3/yr historically and more recently falls within the range of 3,000 to 4,500 m^3/yr. These estimates should be treated with a high degree of caution due to the large uncertainties associated with estimating bank retreat from aerial imagery. The presence of overhanging vegetation obscuring the top of bank in imagery, as well as the lack of consideration of the vertical bank profile, contribute to the uncertainties in this erosion estimate. More detailed topographic surveying of the bank over time is needed to refine the rate of retreat and volume of sediment being eroded.

Given the high uncertainties in both the basin sediment yield and the volume of bank erosion from the upstream claybank (RK 8.6), accurately quantifying the relative proportion of sediment supplied by the claybank becomes challenging. The erosion volume from the claybank may represent anywhere from 11% to 96% of the total basin yield (based upon the upper and lower bound estimates for both parameters). Furthermore, erosion volumes from the claybank likely exhibit appreciable year-to-year variation, potentially differing by an order of magnitude in any given year. Taking into account the abundance of other sediment sources identified in the air photo review, it appears that, on average over the long term, the claybank typically represents a relatively minor proportion of the overall sediment yield. Supporting this interpretation, the analysis of WSC sediment data indicated that the river can mobilize at least 12,000 to 13,000 m^3 of sediment in a single day.

In summary, numerous sediment sources were identified throughout the watershed. In the upper watershed, the primary sediment sources appear to come from an alluvial reach 3 to 4 km upstream of the Moriarty Creek confluence. There also appears to be episodic erosion of meander bends upstream of the Morison Creek confluence, that in one location led to a mass failure of a 30 m high bank composed of till. In the lower watershed, the entire channel reach from the South Englishman confluence through to Allsbrook canyon has been laterally unstable with numerous meander cutoffs and periods of rapid bank erosion leading to large volumes of sediment input directly to the channel. Overall, the basin sediment yield is controlled by the aggregate sum of various sediment sources throughout the upper and lower watershed, rather than by a small number of individual point sources. Because of this, it appears unlikely that stabilizing the claybanks would meaningfully impact the overall watershed sediment yield.

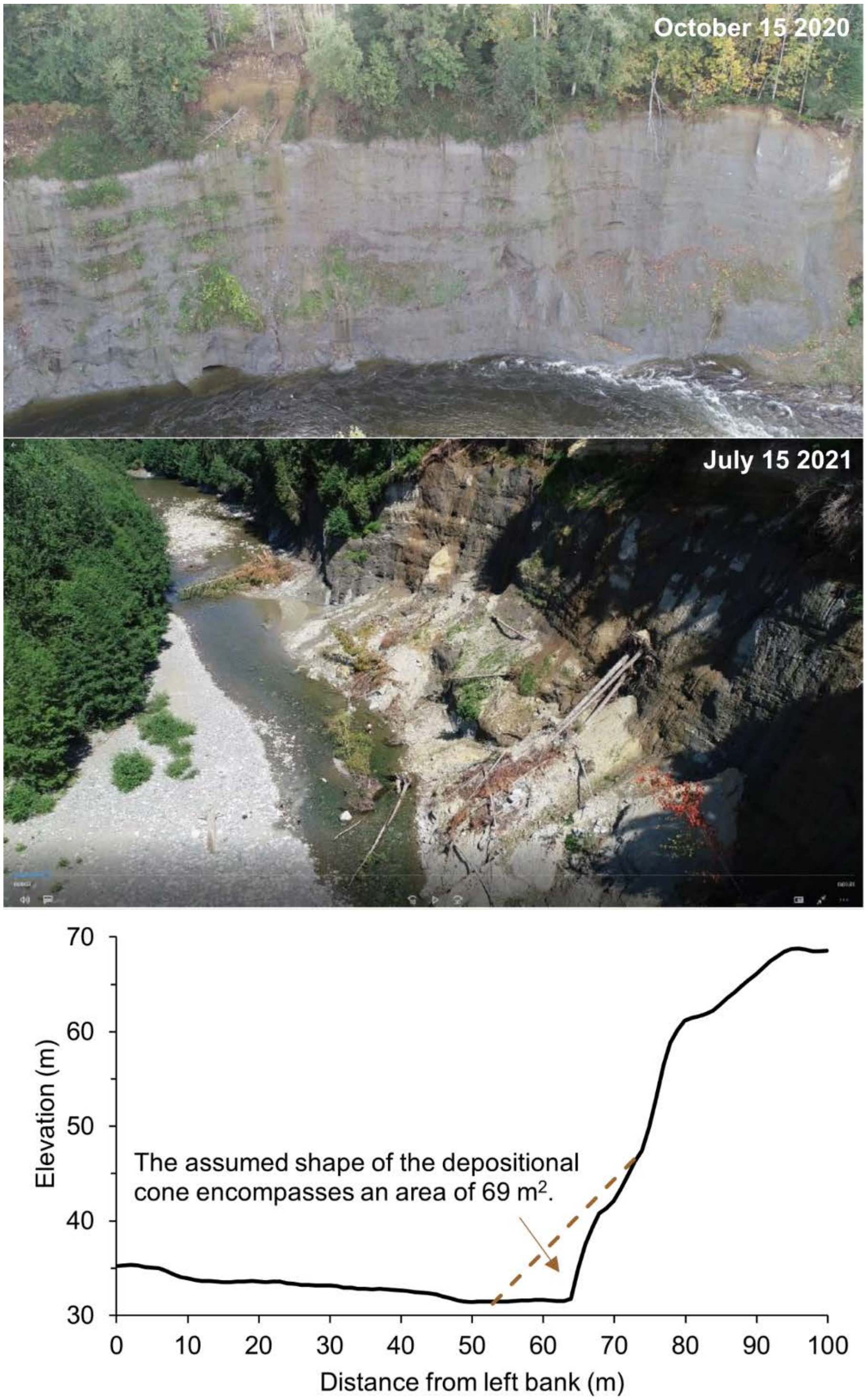

Figure 3.5 Example of an episodic large-scale failure at the upstream claybank . Upper panel shows the claybanks prior to failure in 2020 while the middle panel shows the claybanks in July 2021 post-failure. The lower panel shows a cross-section profile of the claybank based on the 2019 Lidar DEM, with an assumed shape and area of the depositional cone.

Photo 3.7 A slope failure occurred on August 26/27, 2023 during a dry, low flow period (Photo credit: Mid Vancouver Island Enhancement Society).

3.5 Turbidity Monitoring

In November 2022, BCCF installed turbidity sensors upstream and downstream of the claybank (RK 8.6) to further evaluate its relative contribution of sediment to the river (Figure 3.6). In this report, the upstream turbidity sensor is referred to as 'upstream of claybank' and the downstream sensor is referred to as 'powerlines' (as it was installed nearby the powerline crossing). For the purposes of this analysis, turbidity was used as a proxy for sediment concentration, as insufficient sediment data was collected to directly correlate turbidity and sediment concentration. Turbidity data was collected for the two-month period between November 21, 2022 and January 24, 2023, in which there were three high-flow events (> 50 m^3/s): December 24, December 26, January 13. The assumption being made in this analysis is that increased turbidity recorded at the powerlines sensor is attributed to sediment input from the claybank.

The following turbidity sensor metadata was provided by BCCF (J. Damborg, pers. comm. November 24, 2022, email):

- Type of sensor: Eureka turbidity sensors with anti-fouling wiper.
- Data collection: Logging was collected at 1-hr intervals and calibrated at 0 and 100 NTU.
- Installation method: Sensors were installed in 2" galvanized metal electrical conduit, with an open bottom with twenty-four 9 mm holes drilled in the lower 20 cm.
- Location: The 'upstream of claybank' sensor was installed at an elevation of 33 m, fastened to boulders on the left bank (when looking downstream), such that the sensor was wetted at

winter base flows (RK 8.7). The 'powerlines' sensor was installed at an elevation of 28 m, fastened to a 60 cm diameter log along a right bank large woody debris (LWD) structure (RK 7.5). This sensor is wetted at all flows.

After the December 26 flood event, the upstream turbidity logger housing was filled with sand above the sonde unit. The unit was cleared of sand and recalibrated on January 13, but no meaningful data was collected at this site between December 26 and January 13. Because of this issue, data between the two turbidity sensors was only compared from November 21 to December 26 and from January 13 to January 24.

Figure 3.6 Location map of BCCF turbidity sensors . Unlabeled chainage markers represent 500 m increments.

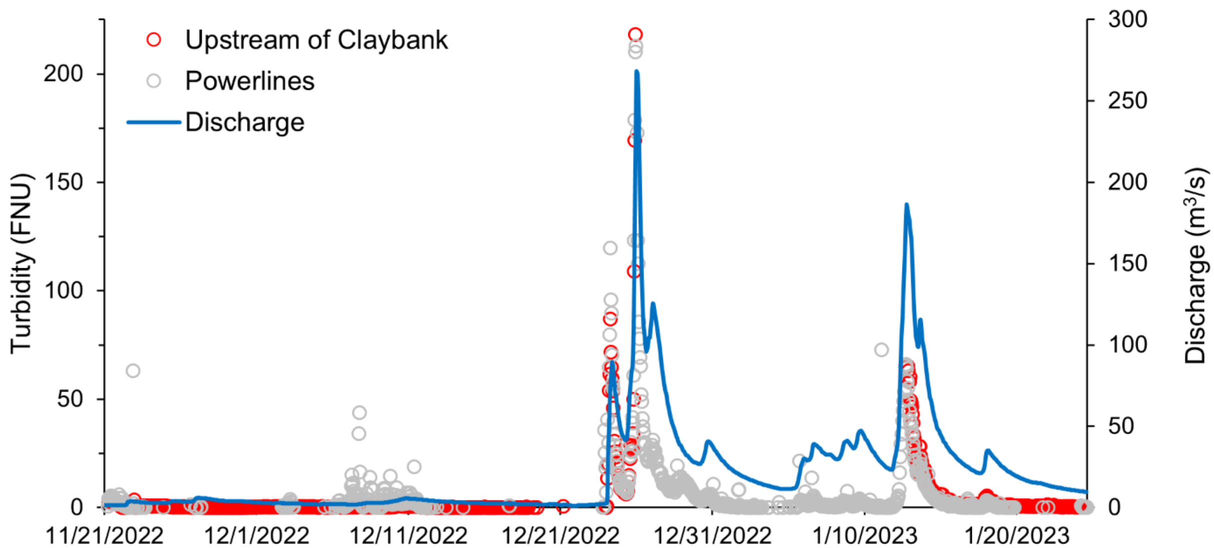

Figure 3.7 Turbidity and discharge hydrographs from November 21, 2022 to January 24, 2023 . Turbidity data provided by BCCF; preliminary discharge data downloaded from WSC website for gauge 0HB002 (at the Hwy 19a bridge). The results from turbidity monitoring at the claybank (RK 8.6) show very little difference in turbidity between the two stations during the observed high flow events (Figure 3.7). This is interpreted to mean that during these events, sediment input from the claybank (and any other part of the river channel between the two sensors) was negligible compared to the upstream sediment supply. The greatest difference in turbidity between sensors occurred in early to mid-December, where the powerlines sensor exhibits a spike in turbidity absent from the upstream sensor (Figure 3.7). During this time, the river was at winter base flow conditions, so it is unlikely that streamflow velocities were high enough to cause significant erosion. The spike in turbidity may be related to slope failures at the claybank, though this cannot be confirmed.

The results from this analysis provide supporting evidence that the claybank is unlikely to be a significant sediment source in the context of the basin-scale sediment load, at least for the observed flow conditions. However, due to the short monitoring period, which encompassed just three high-flow events, these results should be interpreted cautiously. Erosion of the claybank can occur episodically, such that its relative contribution to the basin sediment yield will be highly variable from one flood to another. More extensive monitoring over a longer-time period would be required to better characterize the relative magnitude and frequency of sediment input at this site.

3.6 Englishman River Estuary Morphodynamics

A primary stakeholder concern identified by BCCF was that the stabilization of the claybank could reduce sediment accretion in the Englishman River estuary, negatively impacting the estuary's resiliency to predicted sea level rise (SLR) associated with climate change. Remotely sensed images of the estuary during peak floods can provide insight to sediment transport and deposition through the estuary. A near infrared (NIR) image collected by the Sentinel 2 satellite shows that during the December 26, 2022 flood

(267 m^3/s), the sediment plume at the estuary extended several kilometres into the Strait of Georgia (Figure 3.8). We can infer from this that much of the fine wash load sediment (clay and silt) that is supplied from the upstream watershed, including the claybanks, is flushed through to the ocean during peak flood events capable of mobilizing the highest volume of sediment. Therefore, it seems unlikely that stabilizing the claybanks would have a meaningful impact on accretion rates in the estuary because much of the sediment sourced from the claybanks is wash load and does not appear to get deposited in the estuary.

This finding aligns with the typical patterns of sediment deposition observed in deltas. A schematic figure of the Fraser River delta from Mosher et al. (2003) shows a stratigraphic sequence of sediment facies (Figure 3.9). Mosher et al. (2003) describe the delta topsets as being composed of distributary channel sediments, which for the Englishman River is typically medium to coarse gravel and sand. The foreset beds are formed by sand and silt deposition, while the bottomset facies, which extends into the ocean, consist of clay, silt, and fine sand. On the Englishman River, while some of the wash load material may get trapped in backwater sloughs in the estuary, it is likely that most wash load sediment is deposited in the delta bottomsets and gets remobilized offshore by waves and tidal currents.

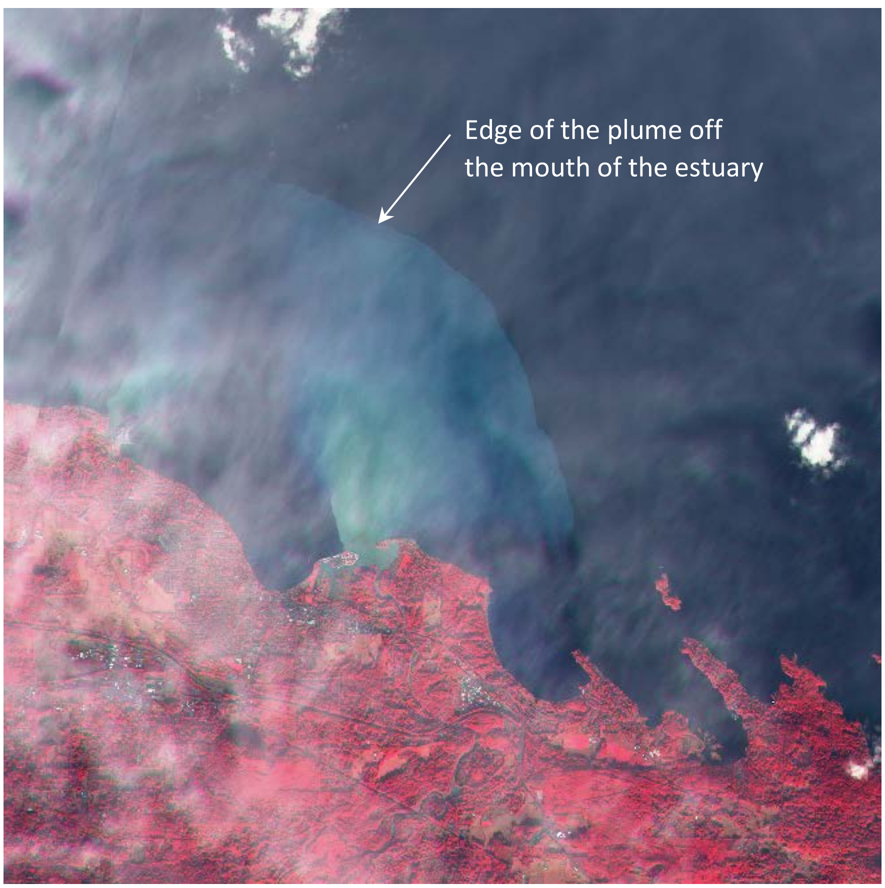

Figure 3.8 Near infrared (NIR) Sentinel 2 satellite image of the Englishman River estuary from December 26, 2022.

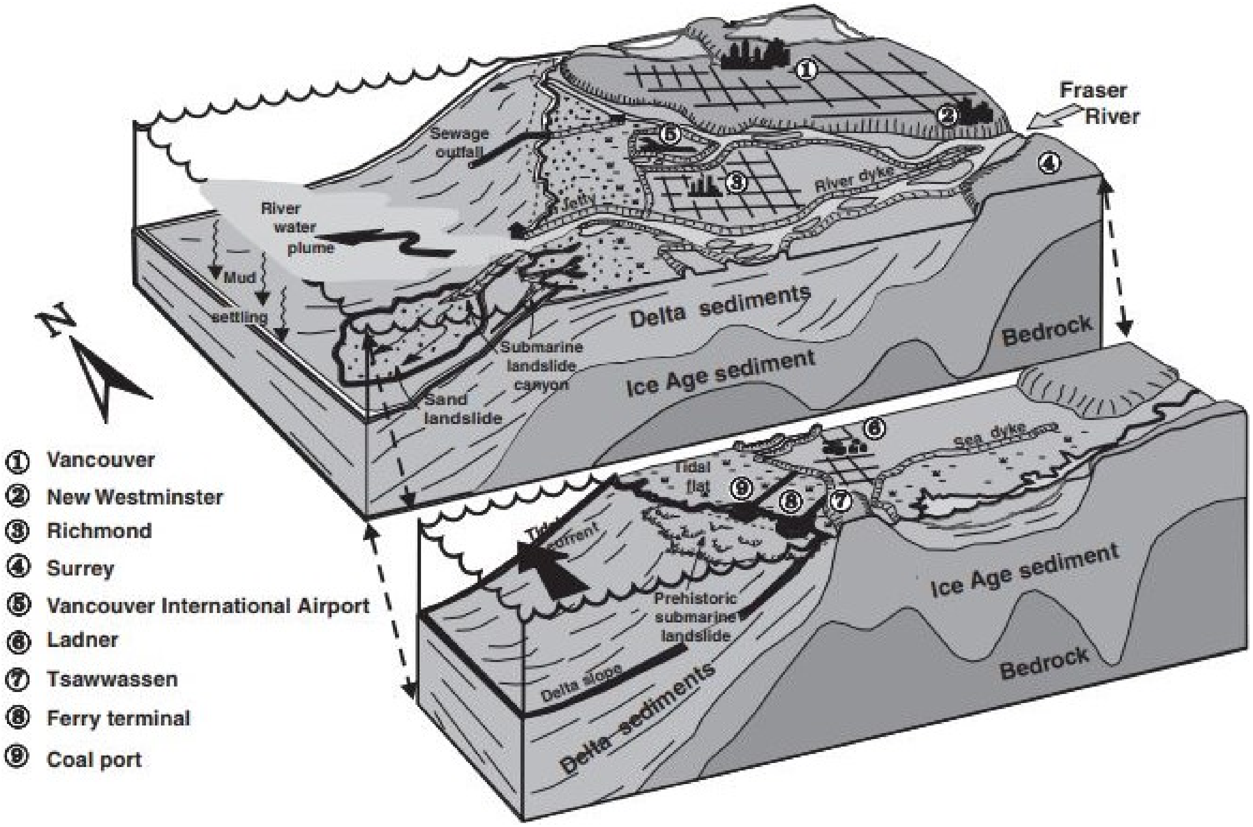

Figure 3.9 Schematic diagram of the Fraser River delta stratigraphy and sediment facies originally from Mosher et al. (2003).

The primary controls on estuary morphodynamics (the change in shape or form of the estuary) are the river-borne sediment supply and base level conditions (Parker and Muto, 2003). During increasing base level conditions (i.e., sea-level rise), Muto (2001) showed through physical experiments that a delta shoreline may initially prograde seaward, but in time, will transgress (move landward) due to the increasing accommodation space that needs to be filled with sediment. Conversely, when the base level is held constant, the delta always progrades seaward.

For the Nanaimo region of Vancouver Island, sea level is projected to rise by 80 cm in the next 100 years (Bornhold, 2008). Over this period, we can expect the Englishman River estuary to transgress unless there is a commensurate increase in the supply of sediment from the upstream watershed. In the future, there is generally expected to be an increase in the frequency and magnitude of peak flows for rivers in BC due to increased storm precipitation intensity (EGBC, 2018) which will likely lead to an increased sediment supply, as most sediment is mobilized during these high-flow events. Estimating the relative magnitude by which sediment supply will increase in the future is a complex problem that is beyond the scope of this study. Ultimately, future morphodynamics in the estuary will be governed by the future basin sediment supply, of which the claybanks appear to be one relatively minor component, compared to the rate of SLR. Further anthropogenic modifications made to the landscape may also affect sediment transport and deposition processes in the estuary.

4 CONCLUSIONS AND RECOMMENDATIONS

This section provides a summary of the key findings of this report and outlines some recommendations for future monitoring and management of the claybanks.

4.1 Conclusions

- **Relative sediment yields.** Based on regional data, the estimated annual suspended sediment yield for the Englishman River watershed is in the range of 4,700 to 26,200 m^3/s, with a central estimate of 15,500 m^3/s. Based upon a review of available imagery, the volume of sediment supplied from the upstream claybank may be in the range of 3,000 to 4,500 m^3/yr, representing 11% to 96% of the overall basin yield. However, both the basin and claybank sediment yields represent crude estimates that require longer-term monitoring to better refine. Annual sediment loads are highly variable, with large changes occurring between years related to the timing, magnitude, and duration of sediment-mobilizing flood events.
- **Basin sediment sources.** The basin sediment yield is comprised of numerous point sources throughout the lower watershed and a low-gradient alluvial reach in the upper watershed. Sediment supply in the upper watershed is dominated by bank erosion and channel avulsions, while input from mass wasting events on unstable hillslopes appears very low. High sediment supply to the lower watershed (downstream of the South Englishman River) drives periods of high bank erosion throughout the alluvial channel reach extending downstream to Allsbrook Canyon, which in turn supplies sediment to the lower channel reaches and estuary. Sediment input through erosion of the claybanks appears to be relatively minor compared to the high volumes of sediment that have historically been generated throughout the lower watershed during periods of rapid bank erosion, channel avulsions, and meander cutoffs in alluvial sediments. Periods of high instability and morphologic change are driven by high peak flows and may historically have been exacerbated by riparian forest harvesting.
- **Turbidity monitoring.** The results from the turbidity monitoring at the upstream claybank show that for the observed flow conditions, there is very little difference in turbidity at high flow upstream and downstream of the claybank. The interpretation of this result is that the claybank sediment supply is negligible in comparison to the suspended sediment supply from upstream in the watershed, at least during the observed high flows. Spikes in turbidity downstream of the claybank occurred between floods, potentially representing pieces of the bank falling into the river via freeze-thaw processes. Sediment mobilized during these more moderate flows may get deposited in downstream sections of channel, negatively impacting habitat quality.
- **Morphological response of the estuary**. Changes to the morphology of the estuary will be driven by the rate and duration of sea level rise, relative to the rate of upstream sediment supply. Based on climate change projections, the sea level in this region is predicted to increase by 80 cm over the next 100 years (8 mm/yr). Under conditions where the sea level rises but the sediment supply is held constant, we can expect the estuary to transgress (move landward). For the estuary to maintain its current configuration or even prograde seaward, the sediment supply must increase substantially. Based on the results from turbidity monitoring at the claybank, and the estimated relative sediment yield, the potential reduced sediment supply from the stabilization of the upstream claybank is unlikely to have a meaningful impact on the estuary

morphodynamics. Sediment supplied by the claybanks is moved as wash load and is mostly deposited offshore and mobilized into the ocean. The long-term fate of the estuary will be governed by the relative increase in watershed sediment supply that occurs as the frequency and magnitude of peak flows increase, as well as the rate and duration of sea level rise.

4.2 Recommendations

- Protecting the toe of the upstream claybank should reduce the frequency and magnitude of fluvial erosion at the toe of the slope and allow the slope to stabilize over time. Reducing fine sediment inputs to the river from the claybanks may improve water quality and salmon spawning habitat downstream of the sites. Groynes could be constructed at selected locations to redirect the river channel away from the toe of the bank.
- A potential mitigation option for the downstream claybank would be to redirect the channel through the gravel bar away from the toe of the claybank, similar to its natural course prior to 2006. Large trees could also be placed along the toe of the claybank to protect it from further erosion. These trees could be buried using the material excavated from the bar.
- A long-term sediment monitoring program is required to better refine the basin sediment yield and to help characterize the relative input of sediment from the claybank sites. Currently, the only available sediment data on the river was collected by the WSC from 1988 to 1992, capturing just one high flow event. Due to the highly dynamic nature of sediment transport processes, a more continuous record of sediment monitoring over a longer-time period that includes various flow conditions is required to better understand the watershed sediment regime. As part of this monitoring program, topographic surveying of the claybanks could help provide more robust estimates of bank erosion volumes.

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Appendix A

ENGLISHMAN RIVER "CLAYBANKS"

SLOPE HAZARD ASSESSMENT

McQuarrie Geotechnical Consultants Ltd.

Geotechnical Engineering
Slope Stabilization
Landslide Hazard Management

ENGLISHMAN RIVER
"CLAYBANKS"
SLOPE HAZARD ASSESSMENT

Prepared For

BC Conservation Foundation

Prepared by:

E.J. McQuarrie, PEng, PGeo
Senior Geotechnical Engineer

Date July 12, 2023

Project #132-1
Permit #1001716

1. INTRODUCTION

This report summarizes slope hazard assessments of two over-steepened banks along the southeast side of the Englishman River, locally referred to as the "Claybanks". The two slopes assessed are approximately 1.8 and 4.0 km upstream of Highway 19, near Parksville, BC, and are shown on Figure 1.

The objectives of this assessment are to assess the general stability of the banks and the potential risks associated with the bank failures, and to comment on possible mitigation plans. The assessment is in support of the broader "Geomorphic Impact Assessment" conducted by Northwest Hydraulics Consultants Ltd. (NHC).

This report is subject to the attached Statement of General Conditions, which should be read carefully and understood by all users of this report.

2. SCOPE OF WORK

The assessment included a review of both the bedrock[1] and surficial geology maps[2] for the area, and a half-day field review conducted on May 5, 2023 by Eric McQuarrie PEng, PGeo with McQuarrie Geotechnical, Jeramy Damborg with BC Conservation Foundation (BCCF), and Graham Hill PEng with Northwest Hydraulics Consultants (NHC). Both of the claybanks were viewed from the opposite side of the river while the upstream bank was also viewed from the crest of the slope.

3. GEOLOGY

3.1 Bedrock Geology

Bedrock has not been mapped in the immediate vicinity of the study area; however, the bedrock geology in the general vicinity of the site consists of the Nanaimo Group of formations, comprised of upward fining sequences of conglomerate, sandstone, shale and coal. These are upper Cretaceous sedimentary formations commonly found along the east side of Vancouver Island between Ladysmith and Courtenay. The field assessment did not find any exposed bedrock in either of the assessed river banks.

3.2 Surficial Geology

The southeast river bank, including the Claybanks, is mapped as terraced fluvial deposits overlying "ground moraine" or glacial till. The terraced fluvial deposits belong to the Capilano Formation and are comprised of deltaic silt, sand and gravel deposits often overlying silt and clay. This deposit formed during deglaciation when sea levels were significantly higher than at present, and were deposited by the proto-Englishman River prior to isostatic rebound. As the ground level rose relative to the sea level, the river

[1] Geological Survey of Canada Open File 463, Geology of Vancouver Island (1977), scale 1:250,000.
[2] Geological Survey of Canada Map 1112A, *Surficial Geology, Parksville*, (1962) scale 1:63,360 (1"-1 mile).

gradually down-cut through the Capilano deposits and then through the till, until reaching its current level. The steep bank was formed by this down-cutting.

The gentle terrain along the northwest side of the river is mapped as a wide fluvial deposit extending to the southeast edge of the Englishman River at the toe of the Claybanks. This is the youngest deposit in this area, deposited by the existing river. The extent of this recent deposit narrows immediately upstream of the Claybanks as the river valley becomes more confined.

4. UPSTREAM CLAYBANK

4.1 Slope Conditions

The bank is 30 to 35 m high and located on the outside of a broad meander. The exposed geology is shown on Photo 1 and summarized on Table 1.

Table 1: Surficial Geology Exposed in the Upstream Clay Bank

Unit	Soil Type	Approximate Thickness	Description
Capilano	Fluvial sand & gravel	2 to 3 m	Coarsely bedded, some sand seams
	Silty sand	3 to 4 m	Thinly bedded, fine to medium sand
Vashon	Till	~ 25 m	Poorly sorted mixture of silt, sand, gravel with some cobbles and boulder

Grain size tests previously conducted on the till deposit measured: 19 to 22% clay, 29 to 30% silt, 49 to 52% sand, and <2% gravel. The till deposit varies both longitudinally along the bank and vertically up the bank, but is not bedded. Some layers contain a higher gravel content than others, but continuous sand and/or gravel seams were not apparent.

The bank is wet but groundwater discharge appears to be broadly distributed throughout the till. More concentrated groundwater discharge was observed from the overlying silty sand deposit or at the base of the fluvial sand and gravel deposit. These more concentrated seepage zones have low discharge and have caused only minor erosion as the seepage flowed down the bank.

The overall slope angle of the upstream Claybank is roughly 60° or steeper. The till exposure is nearly vertical with one or two minor benches while the overlying granular deposits range between 40 and 60°. Overall, the bank is highly over-steepened.

The fluvial deposits along the upper bank are actively raveling. Some of this material is depositing on the minor benches, creating small wedges of loose colluvium. Some isolated pockets of accumulated sediment have naturally seeded with grass. However, a vast majority of the bank is bare, without any vegetation.

The erosion has undermined several trees along the slope crest, causing them to uproot and fall down the bank. Some trees undoubtedly washed downstream but a few currently rest precariously along the minor benches, as seen in Photo 1. One of these trees still has green foliage, indicating it has only recently been uprooted.

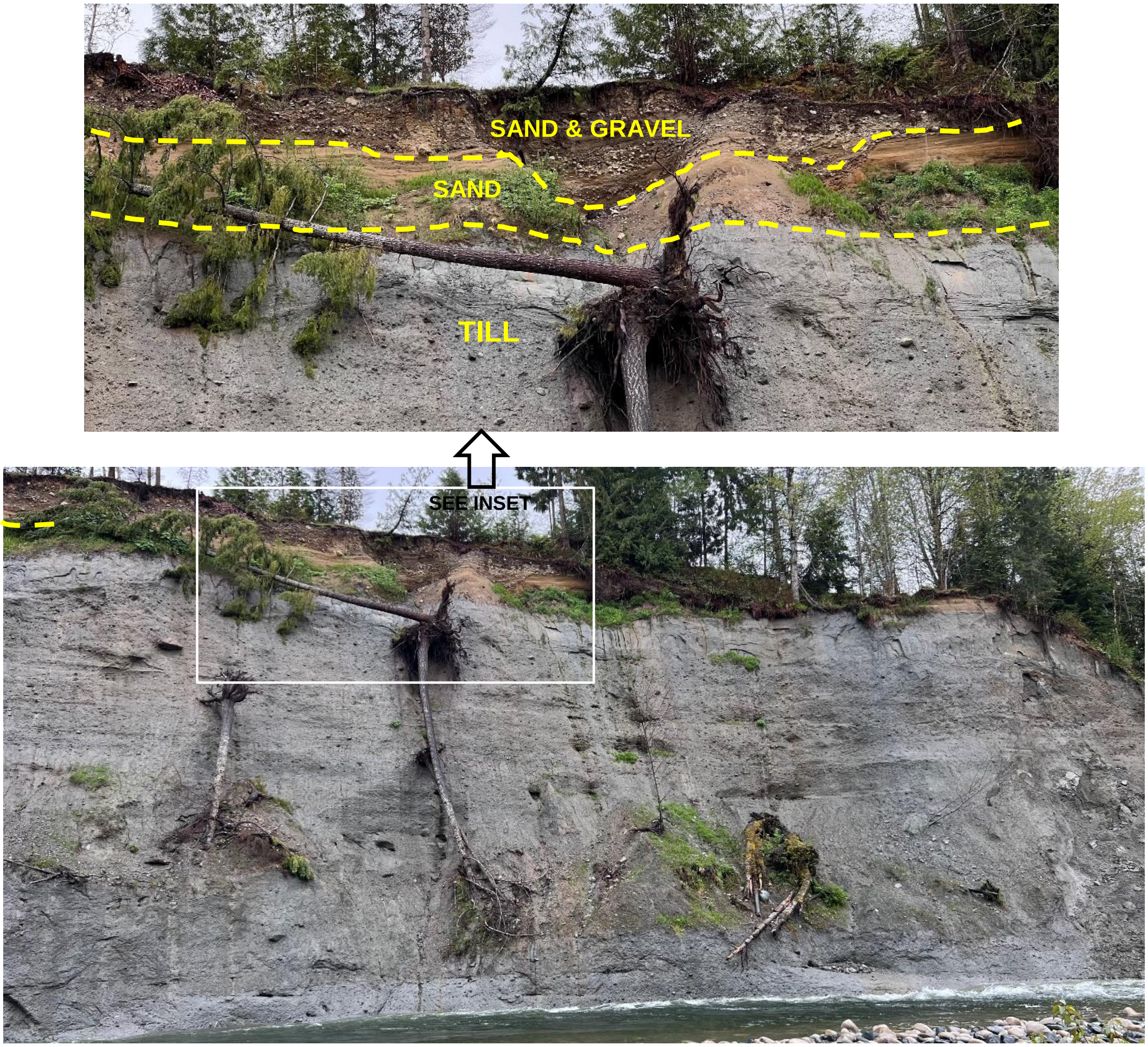


Photo 1: Upstream Claybank, exposing Capilano sediments overlying till.

4.2 River Channel

The river channel cross-section is asymmetrical, with the deeper channel along the outside, directly along the toe of the Claybank (southeast side of the river).

4.3 Upland Terrain

The terrain above the bank is gently sloping to flat, and used for agricultural purposes. The area is well drained without any streams or ponded water.

The farm adjacent to the middle of the bank had previously cleared the trees and placed a windrow of soil very close to the slope crest. Some of the remaining trees along the crest have subsequently been undercut and fallen onto the bank or into the river below.

The nearest occupied structure is set back 85 to 90 m from the slope crest.

4.4 Adjacent Terrain

The steep slopes adjacent to the Claybank, both upstream and downstream, provide an indication of the terrain that previously existed along the Claybank before it was eroded by the river and failed.

These slopes are generally 35 to 40° and forested. The remnants of an old logging road crosses the upper slope, leading both in to and out of the failed bank. The upper slope is wet with significant groundwater discharge. Water ponds along the former logging road, creating poorly drained conditions vegetated with skunk cabbage and horsetail. The slope upstream of the failed bank has a few concave features forested with alder. These appear to be small landslide scars. The wet ground and apparent landslide scars indicate that this section of slope was prone to localized slumps or small-scale slides associated with shallow groundwater discharge.

4.5 Slope Hazards

The southeast bank of the Englishman River is naturally over-steepened by the processes that formed it. Down-cutting of the river would have caused natural landslides and bank failures until the slope reached a more stable angle. Its marginal stability is evident by the more recent landslide scars visible just upstream of the Claybank.

The Claybank is a mostly bare section of slope situated on the outside of a large meander, where it has been subject to ongoing fluvial erosion causing frequent bank failures of various magnitudes. The process generally consists of:

i. Erosion over-steepens the toe of the slope.
ii. The highly over-steepened till remains intact temporarily due to its very dense nature and negative pore pressures. Small-scale failures occur where the bank is steepest or has been undercut. Eventually, larger sections of the till bank fail as slabs comprising several cubic metres of soil (up to tens of cubic metres).
iii. These slab failures occur periodically, retrogressing farther up the bank.
iv. Over-steepening of the upper part of the till undercuts the fluvial deposits. These deposits are not as dense as the till and contain less fines; therefore, they are less able to stand over-steepened and tend to ravel much more frequently but with much less volume.

This process has been occurring at this particular section of the bank for as long as the meander has been eroding the toe. The rate of slope retrogression depends on the rate of toe erosion, but lags behind because it may take several years for the slope to over-steepen and decades for the slope to respond and naturally stabilize.

NHC has estimated that the upstream Claybank has eroded 1 to 1.5 m/year since 2005, based on airphotos. Estimations of slope retrogression using airphotos has limited accuracy depending on the airphotos' scale and control points. A rate of 1 to 1.5 m/year would mean 18 to 27 m of retrogression since 2005. The river channel or toe of the bank may have migrated that much but that value seems too high for retrogression of the slope crest. If the adjacent slope directly upstream is extrapolated across the eroded slope, recent retrogression seems to be in the order of 10 m maximum. Accordingly, the average rate of 0.6 m/year seems more consistent with site observations. Whether the current rate of retrogression continues depends on several factors, most notably the continued migration of the river channel and the resulting toe erosion.

If the slope crest continues to retrogress at a rate of 0.6 m/year for the next 50 years, total retrogression would reach 30 m. The retrogression would directly affect the adjacent properties, reducing the size of the farm land. The closest house is set back 85 m; therefore, the risk to residential structures should remain low over this period. Therefore, the main consequences of the continuing bank failures would be related to sediment in the river, and the loss of private land above the slope crest.

4.6 Mitigation

The 35 m high bank is too high to effectively stability without significant expense. Without at least one structure at risk, the costs far exceed the benefits. However, the risks to the river can be partially mitigated by reducing the frequency and magnitude of the slope failures. The first critical step is to reduce or halt erosion along the toe of the over-steepened slope.

NHC discussed construction of groynes at selected locations to redirect the river channel away from the toe of the bank. If successful, erosion along the base of the over-steepened bank should be significantly reduced. The 35 m high bank would remain over-steepened, highly unstable, and would continue to fail and introduce sediment into the river for several decades. However, the frequency and magnitude of the bank failures should gradually reduce, thereby also reducing the total volume of sediment reaching the river.

5. DOWNSTREAM CLAYBANK

5.1 Slope Conditions

The downstream Claybank, shown on Photo 2, is estimated to be 25 m high and located on the outside of another broad meander. The exposed geology is similar to that described for the upstream Claybank, except the Capilano sediments are approximately 10 m thick with greater bedding, particularly in the upper sand and gravel unit.

A grain size tests previously conducted on the fluvial deposit yielded the following gradation: <2% clay, 20% silt, 79% sand and <2% gravel. The grain size test indicates that the sample was taken from the lower sand unit because the upper unit contains significantly more gravel and less silt.

The till deposit is similar to that found at the upstream Claybank, but is mostly buried beneath a colluvial apron of granular material that has recently failed from the upper slope. Grain size tests previously conducted on the till deposit yielded the following gradations: 19% clay, 70% silt, 12% sand, and <2% gravel. Compared to the till exposed in the upstream Claybank, this exposure contains more silt and less fine sand.

The upland area was not viewed in the field but no streams or concentrated surface water were visibly flowing over the slope. Given the thickness of granular soils, the upland area is likely well drained.

The upper slope is highly over-steepened at 60° or steeper, bare or unvegetated, and actively failing. The slope crest has undermined the thick mat of forest soil, causing several trees to uproot and fall onto the lower slope.

Localized steeper sections along the lower slope expose till at the surface; however, most of the lower slope is covered by the granular colluvium that has failed from the upper slope. This lower slope is at its angle of repose estimated to be roughly 36°, and is lightly vegetated with grasses, sedges, and horsetail.

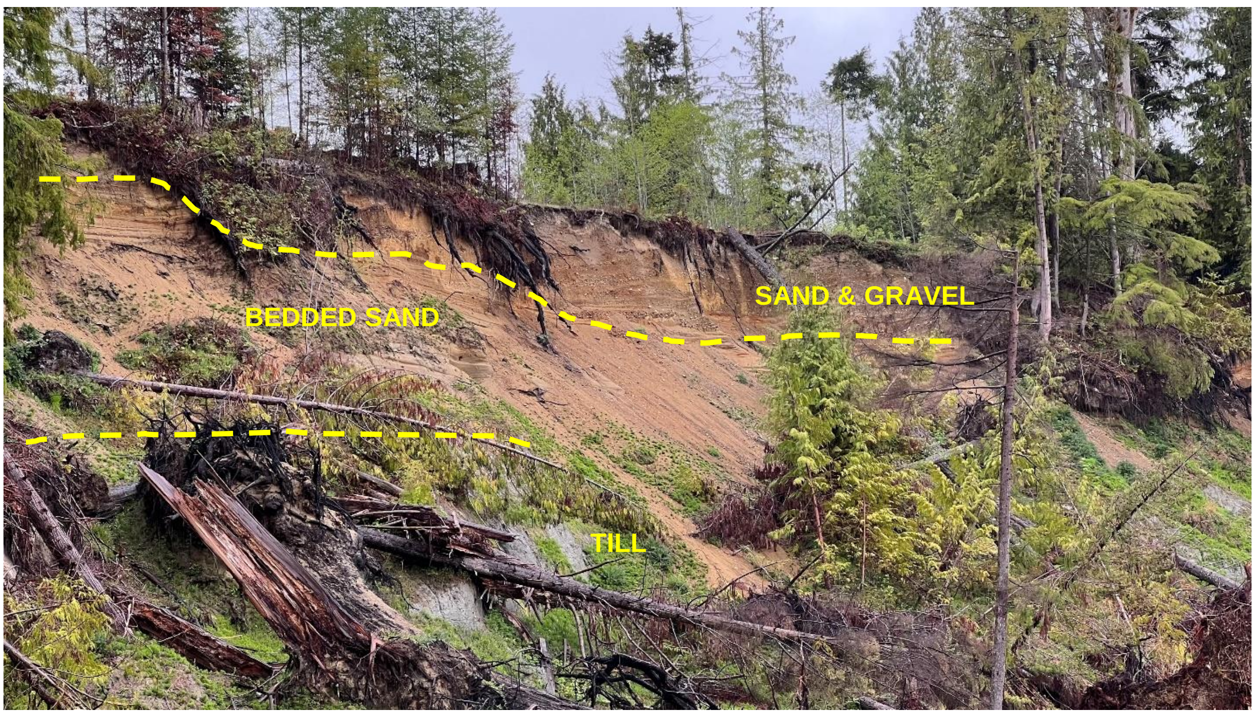


Photo 2: Downstream Claybank exposing thicker Capilano sediments over till.

5.2 Adjacent Terrain

The adjacent slopes both upstream and downstream of the exposed Claybank are roughly 35°, have a thick topsoil layer, and are forested. The river has not yet affected stability of either slope; only the approximately 100 m long section of exposed slope is actively unstable.

The nearest residential structure is located approximately 75 m back from the slope crest based on the 2023 Google Earth image.

5.3 River Channel

The gravel bar on the west side of the river has increased in width by approximately 75 m as the river channel has migrated roughly 145 m to the east since 2006, eroding a naturally forested area. As shown on Figure 2 and based on Google Earth satellite imagery, at least 100 m of this channel migration occurred between 2006 and 2012, with much less erosion between 2012 and 2017, and then another 40 m of migration between 2017 and 2021. Based on the naturally forested slopes both upstream and downstream of the scoured bank, the area eroded during the channel migration up to 2012 and possibly even 2017 was likely flood plain, with a bank just a few metres high. Most of the erosion and failure of the 25 m high bank likely occurred since 2017.

5.4 Slope Hazards

Like the upstream Claybank, the downstream Claybank was formed by post-glacial erosion as the river down-cut to its current elevation and was just marginally stable prior to toe erosion. River migration has caused extensive erosion along a 100 m section of bank, creating highly unstable conditions. Like the upstream Claybank, the till deposit tends to fail periodically in slabs up to several tens of cubic metres, while the granular soils on the upper bank tend to ravel much more frequently.

Based on the extensive grass growth on the colluvial apron covering the till, there seems to have been much less erosion in the past 1 to 2 years. However, based on 145 m of channel migration over 17 years, the average rate of migration since 2006 has been 8.5 m/year. With 30 m of migration in 4 years (2017 to 2021), even the most recent episode of erosion has been in the range of 7.5 m/year.

If toe erosion ceased immediately, the current over-steepened and highly unstable slope would continue to retrogress at a rate that gradually reduced over the next few decades. Ultimately, the crest of the slope would retrogress at least 20 m back from its current location. With the nearest structure set back approximately 75 m from the slope, no structures are currently at risk. On the other hand, if this rate of channel migration, toe erosion, and slope retrogression were to continue, the nearest structure above the bank could be at risk in less than 10 years.

The 25 m high bank also poses a risk of high sediment loads in the river. Compared to the upper Claybank, this slope exposes less till and more sand and gravel from the upper Capilano sediments; however, the till contains more silt and less fine sand.

5.5 Mitigation

Based on the recent rate of slope retrogression and the proximity of the nearest residential structure, the lower Claybank poses a higher risk than the upper Claybank. Mitigation works are not urgent but could become urgent within a few years if the channel continues to migrate eastward.

NHC discussed a simple mitigation option of redirecting the channel back through the gravel bar similar to its natural course up to 2006. The toe of the failing bank would be protected by placing large trees against the toe of the bank and allowing it to be buried by the ravelling material from the upper slope. Excavated material from the redirected channel should also be used to bury the trees and support the lower slope.

After toe erosion is halted, the 25 m high bank would remain over-steepened, highly unstable, and would continue to ravel. But the objective should be that the failed material does not reach the redirected river channel. Depending on how well the toe of the slope can be buttressed, the continued ravelling could result in another 5 to 10 m of retrogression at the slope crest.

STATEMENT OF GENERAL CONDITIONS

1. STANDARD OF CARE

This study and Report have been prepared in accordance with generally accepted engineering consulting practices at described in the Engineers and Geoscientists British Columbia's professional practice guidelines *"Landslide Assessments in British Columbia"* , Version 4.0, dated September 29, 2022. No other warranty, expressed or implied, is made.

2. COMPLETE REPORT

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment are a part of the Report which is of a summary nature and is not intended to stand alone without reference to the instructions given to us by the Client, communications between us and the Client, and to any other reports, writings, proposals or documents prepared by us for the Client relative to the specific site described herein, all of which constitute the Report.

In order to properly understand the recommendations and opinions expressed herein, reference must be made to the whole of the report. We are not responsible for use by any party of portions of the report without reference to the whole report.

3. BASIS OF REPORT

The Report has been prepared for the specific site, development, design objectives and purpose that were described to us by the Client. The applicability and reliability of any of the findings, recommendations, suggestions, or opinions expressed in the document are only valid to the extent that there has been no material alteration to or variation from any of the said descriptions provided to us unless we are specifically requested by the Client to review and revise the Report in light of such alteration or variation.

4. USE OF THE REPORT

The information and opinions expressed in the Report, or any document forming part of the Report, are for the sole benefit of the Client. NO OTHER PARTY MAY USE OR RELY UPON THE REPORT OR ANY PORTION THEREOF WITHOUT OUR WRITTEN CONSENT. We will consent to any reasonable request by the client to approve the use of this report by other parties as "approved users. Any use that a third party makes of the Report, or any portion of the Report, are the sole responsibility of such third parties. We accept no responsibility for damages suffered by any third party resulting from unauthorized use of the Report.

5. INTERPRETATION OF THE REPORT

a) Nature and Exactness of Terrain Description: Identification of soils, rocks, terrain and geological units have been based on assessments performed in accordance with the standards set out in Paragraph 1. The field reconnaissance cannot practically cover the entire area and will only identify surface features and existing soil exposures. This type of assessment does not include subsurface investigation or measurement of soil strength properties. This assessment is qualitative, based on observed conditions and cannot be relied upon to identify conditions that may not be visible or instabilities caused by poor logging or road construction practices. Actual conditions may vary significantly between the points observed and all persons making use of such documents or records should be aware of, and accept, this risk. Some conditions change over time and those making use of the Report should be aware of this possibility and understand that the Report only presents the conditions at the time of assessment.

b) Reliance on Provided Information: The evaluation and conclusions contained in the Report have been prepared on the basis of conditions in evidence at the time of site inspections and on the basis of information provided to us. We have relied in good faith upon representations, information and instructions provided by the Client and others concerning the site. Accordingly, we cannot accept responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of misstatements, omissions, misrepresentations, or fraudulent acts of persons providing information.

6. CONSTRUCTION INSPECTIONS

Our scope of work may include inspections of the work during construction or after completion. Such field reviews do not replace the need for appropriate construction inspection and supervision on the part of the client or his agents. We accept no responsibility for damages caused by unforeseen conditions unless we are on site during construction.

7. INHERENT RISKS

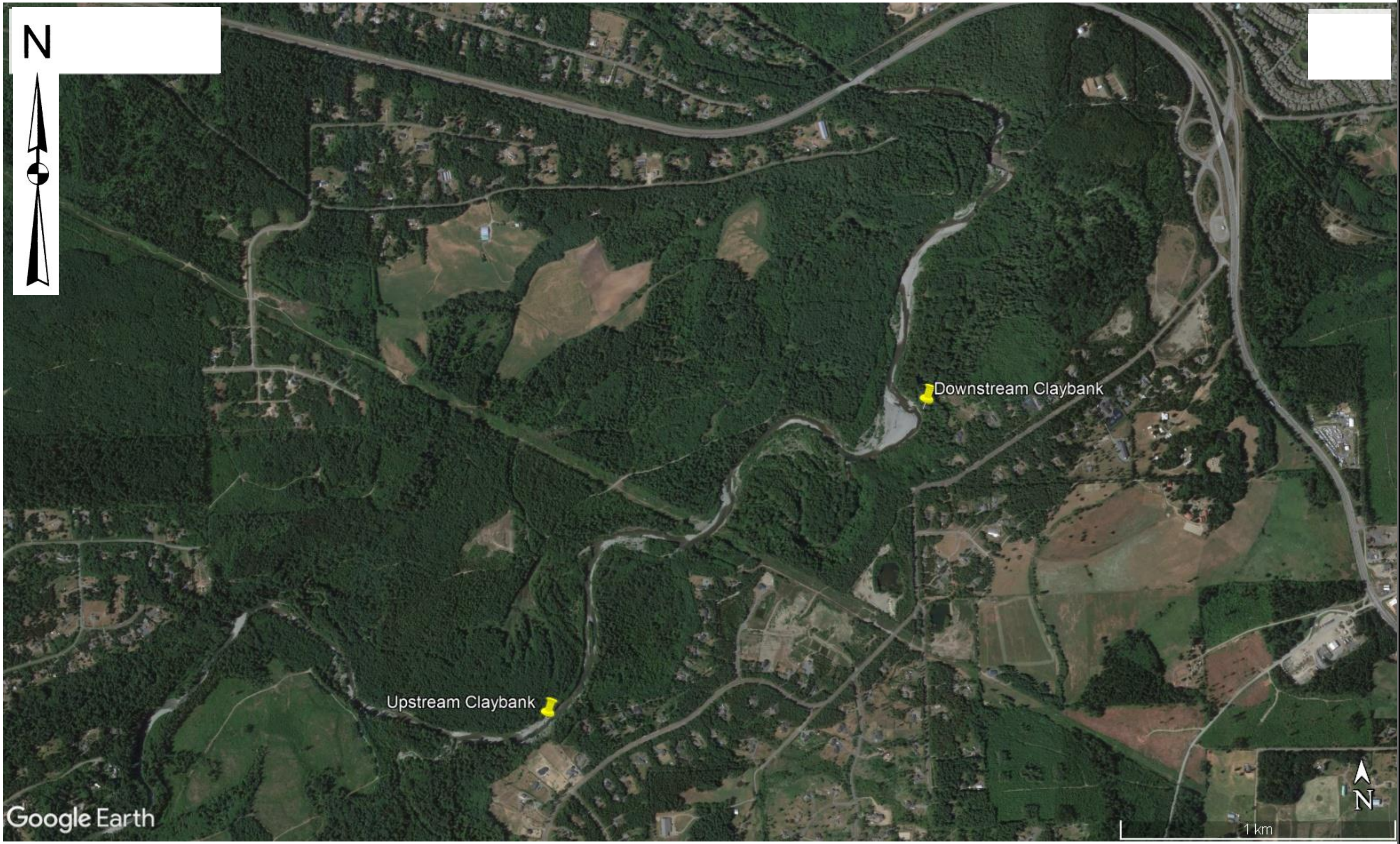
Landslide hazard assessments typically occur where there are risks of landslides. As such, inherent risks exist and landslides can occur even where the likelihood of instability has been identified as low. The client must operate with an understanding of this risk.

8. CONTROL OF WORK AND JOBSITE SAFETY

We are responsible only for the activities of our employees on the jobsite. The presence of our personnel on the site shall not be construed in any way to relieve the Client or any contractors on site from their responsibilities for site safety. The Client acknowledges that he, his representatives, contractors or others retain control of the site and that we never occupy a position of control of the site. The Client undertakes to inform us of all hazardous conditions, or other relevant conditions of which the Client is aware. The Client also recognizes that our activities may uncover previously unknown hazardous conditions and that such a discovery may require that certain regulatory bodies be informed and the Client agrees that notification to such bodies by us will not be a cause of action or dispute.

9. INDEPENDENT JUDGEMENTS OF CLIENT

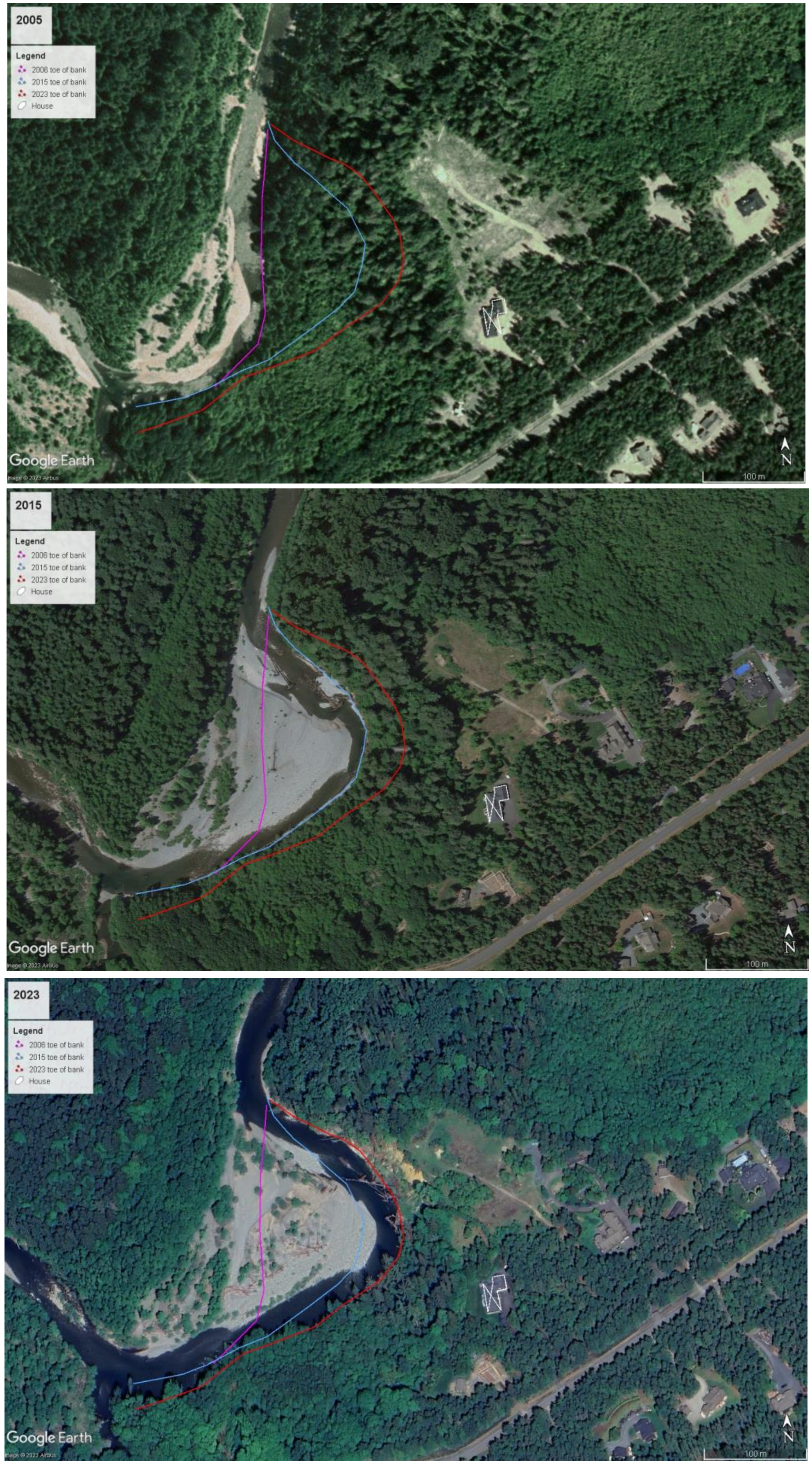
The information, interpretations and conclusions in the Report are based on our interpretation of conditions revealed through limited assessment conducted within a defined scope of services. We cannot accept responsibility for independent conclusions, interpretations, interpolations and/or decisions of the Client, or others who may come into possession of the Report, or any part thereof, which may be based on information contained in the Report. This restriction of liability includes decisions made to either purchase or sell land.



McQuarrie Geotechnical Consultants Ltd.	Scale 1:20,000 (Approx)	Englishman River "Claybanks" Slope Hazard Assessment	**Figure 1**
	Project: 132-1	**LOCATION PLAN**	

Google Earth images showing the approximate edge of the river bank at selected years.

Location of slope crest adjacent to house is unknown.
Set back was not measured.



McQuarrie Geotechnical Consultants Ltd.	Scale 1:6,000 (Approx)	Englishman River "Claybanks" Slope Hazard Assessment	**Figure 2**
	Project: 132-1	**DOWNSTREAM BANK CHANNEL MIGRATION**	