TECHNICAL MEMORANDUM

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ASSESSMENT OF AVULSION RISK ON MCNAB CREEK, BC

1.0 INTRODUCTION

BURNCO Rock Products Ltd. (BURNCO) and 0819042 BC Ltd. are proposing to develop a sand and gravel pit, processing facility and marine barge load-out marine facility as components of the McNab Creek valley Aggregate Project (the Project). The McNab Creek valley is located on the western shore of Howe Sound immediately north of Gambier Island, and northeast of Gibsons, BC (Figure 1). See the McNab Creek Valley Aggregate Project Description for additional details (Golder 2010).

This technical memorandum summarizes the findings of an assessment of the potential avulsion risk in the lower reaches of McNab Creek.

2.0 OBJECTIVES

The objective of this work was to assess the potential risk of avulsion in the lower reaches of McNab Creek.

For reference, avulsion is defined as a rapid change in location of stream channel that typically occurs during one storm event, i.e., over a period of a few hours. This is distinct from lateral migration, which is a natural, slow, ongoing process by which a stream channel alters its location within a stream valley over geologic time, i.e., over a period ranging from centuries to millennia.

This work also assesses the potential for lateral migration in the lower reaches of McNab Creek.

3.0 METHODS

The avulsion assessment of McNab Creek was undertaken through a preliminary review of the available information and a one day field reconnaissance.

The field reconnaissance included a helicopter overflight of the McNab Creek valley and foot traverse of the lower McNab Creek valley and McNab Creek channel.

For the purposes of this assessment the risk of avulsion, the definition of risk being the product of hazard and consequence was adopted. This definition of risk is the accepted method used in BC for natural hazards. Avulsion is a natural hazard. The hazard was determined as the likelihood of occurrence of an avulsion. The consequence was determined as the effect of an event on McNab Creek and the fan-delta area.

3.1 Information Review

The information review included historic air photos, charts and LiDAR (Light Detection and Ranging) topography data obtained from McElhanney Land Surveys Ltd. Historic vertical air photos were acquired from the University of British Columbia (UBC) air photo library. The air photos reviewed are listed in Table 1. Two oblique images for 1938 were also acquired from UBC (BC 399, Frames 115 and 116). Historical charts of the area were obtained from online searches as well as the British Admiralty Office.

The contour plot generated using the LiDAR data and the available air photos were reviewed for evidence of historic channel avulsions.

Table 1: Air Photos Reviewed

Air Photo Number	Frame Number	Year
30BCC05026	144, 145	2005
30BCC03039	139	2003
30BCC3040	18, 19	2003
15BCB96037	160, 161, 178	1996
15BCB95067	38	1995
30BCC92033	134, 153	1992
30BCB90046	2, 72	1990
30BCB90113	1	1990
15BC87098	220, 221	1987
30BC87048	54	1987
30BC86058	185	1986
15BC85013	85, 86	1985
15BC82010	202	1982
30BC79194	197	1979
15BC5760	167, 218	1976
15BC5601	179	1974
BC5497	194, 195	1972
A30339	29, 30	1971
15BC5279	129	1968
30BC4426	86, 100, 101, 170	1967
BC5175	82, 83	1966
BC1634	89, 90	1953

3.2 Field Reconnaissance

A one day field reconnaissance was carried out on September 8th, 2010 by Rowland Atkins and Neil Goeller of Golder, and consisted of a helicopter overflight and foot traverse. The helicopter overflight of McNab Creek, its larger tributaries and the McNab Creek valley was conducted from a Bell 206L Long Ranger helicopter supplied by Helijet International Inc. Observations of general channel morphology of McNab Creek and its tributaries were observed along with the general geomorphology and topography of the valley.

Following the helicopter reconnaissance a foot traverse was conducted. The foot traverse involved walking one of the accessible logging roads on the east side of McNab Creek to observe a tributary channel and the quaternary sediments exposed in road cuts and borrow pits. A foot traverse along the channel was conducted for approximately the lower 3.5 km of McNab Creek to the estuary to observe channel bed and bank material and channel morphology.

4.0 RESULTS

The results of the information review and the field reconnaissance are outlined below. For the purposes of this analysis, McNab Creek was divided into three reaches exhibiting similar characteristics based on the available information and observations (Figure 2). The three reaches cover the length of McNab Creek from the upstream limit of forest harvesting to the mouth of McNab Creek on Thornbrough Channel (Figure 1), a distance of approximately 10.5 km. Stream reaches upstream of the harvested area were situated on steep terrain where avulsion risk and lateral migration risk were negligible and were therefore excluded from the assessment.

Reach 1 is 7.0 km long and extends from the upstream limit of harvesting to a point approximately 3.5 km upstream of the mouth of McNab Creek. This reach has an incised and confined channel flowing through the harvested area of the valley floor.

Reach 2 is 1.9 km long and is situated between approximately 3.5 km and 1.6 km upstream of the mouth. This Reach has an incised and partly confined channel flowing through an area of old stream terraces. Reach 2 was subdivided into two (Sub-Reaches 2.1 and 2.2, Figure 3) on the basis of the foot traverse.

Reach 3 is approximately 1.6 km long and includes the remaining stream channel to the mouth. This Reach includes the fan-delta area of McNab Creek and has an incised but unconfined channel. Reach 3 was subdivided into 4 (Sub-Reaches 3.1, 3.2, 3.3 and 3.4, Figure 4) on the basis of the air photo interpretation and subsequent field checking during the foot traverse.

Each of these reaches and sub-reaches is presented in more detail below.

4.1 Information Review

4.1.1 LiDAR Topography

The LiDAR survey extended to approximately 3 km upstream of the mouth of McNab Creek and covers Reaches 2 and 3. Reach 1 is not covered by the LiDAR dataset. The topographic plan produced using the LiDAR data was reviewed to identify observable features which may indicate historic channel alignments.

Between approximately 3 km and 1.6 km upstream of its mouth (Reach 2), McNab Creek flows through a section of the valley where the existing stream channel is flanked by a series of terraces (Figure 5). These terraces are between approximately 10 and 25 m high. The presence of the terraces indicates that the stream has previously migrated laterally back and forth across the floor of the valley and downcut to its present position. The lateral migration and downcutting has likely occurred since the recession of the glaciers over the past several thousand years.

Between its mouth and a point approximately 1.6 km upstream (Reach 3), McNab Creek flows across a relatively low gradient fan-delta. Throughout this reach a number of side channels are visible adjacent to the existing channel (Figure 5). The side channels may be active during episodes of higher flow, but were mostly dry at the time of the field visit. Isolated shallow pools of standing water were observed in some of the side channels. No visible indications of historic main channels (e.g., oxbow lakes, abandoned chutes, channel-like depressions) were observed in the central and western parts of the fan-delta. The LiDAR dataset does not record terraced evidence of lateral migration in this reach. However, it is reasonable to assume that lateral migration of the channel in Reach 2 would have resulted in lateral migration of the channel in Reach 3 in order to maintain continuity of flow between reaches.

4.1.2 Air Photos

The available vertical air photos span the 52-year interval between 1953 and 2005. These photos cover only Reach 3. Portions of Reaches 1 and 2 were covered by the 1938 oblique air photos.

A review of these air photos suggests that the main alignment of the McNab Creek channel has remained relatively stable since 1953 and has been situated against the eastern flank of the valley. The two oblique air photos from 1938 also indicate that Reach 3 was situated against the eastern flank of the valley at that time. The channel width and presence of side channels has, however, varied over this time interval. The channel widths in Reach 3 have varied between about 60 and 300 m due to episodic flooding and sediment deposition. This flooding is likely a result of higher flow events which can be expected during extreme precipitation events, spring snowmelt and in particular rain-on-snow events. Additionally, forest harvesting in the upper watershed over the last few decades may have resulted in higher volumes of runoff leading to more frequent flooding.

In all the air photos reviewed, the active channel of McNab Creek is narrow and situated within a wider channel system. This is likely due to the photos being taken during drier (low flow) periods when the flowing stream is restricted to a narrow channel. The absence of vegetation and exposed bedrock within the wider channel system suggests that flows in the stream are highly variable preventing the establishment of vegetation.

No indications of historic abrupt changes in channel alignments (avulsions) were observed in the air photo record. This suggests that no major avulsions have occurred between 1953 and 2005. However, the tidal channels observed at the mouth of the valley may indicate past locations of the channel mouth as the stream migrated laterally across the floor of the valley over geologic time (e.g., several thousand years) (Figure 2). A stream survey conducted in 1994 for Canfor on the McNab property, indicated the presence of watercourses connected to tidal channels, which now no longer exist. A separate tidal channel memo has been created for McNab Valley Aggregate Project as part of this report series.

A clear patch of ground is visible in the 1938 air photos in Reach 1 (Figure 2). This clear patch of ground is estimated to be about 25 acres in area and is located downslope of several steep gullies; the fan-like shape is reminiscent of landslide deposit(s). A linear feature on the west side of the valley is interpreted to be a road. This feature appears to link to the clear patch of ground and suggests the area may be a harvested area. The colour and texture of the terrain in this area in the 1953 photos suggests that the interpretation of the area being a clearcut is more likely to be correct.

The lower 1.6 km of McNab Creek was divided into four sub-reaches. The four sub-reaches are described below (Figure 4). The approximate maximum extents of the channel margins observed in the air photo record for the lower 1.6 km are indicated in Figure 4.

4.1.2.1 Sub-Reach 3.1 (1.6 km to 1.2 km upstream of the mouth)

In 1953, McNab Creek appears to occupy a single channel through Sub-Reach 3.1 including the large left-hand bend in the stream (Figure 4). By 1985 a secondary channel appears to have established to the north of the main channel, resulting in the formation of a vegetated island between the main channel and the north channel. The north channel is still present at the time of writing, based on foot traverse observations. The pair of channels appear to vary between 40 m and 60 m in width.

Evidence for channel avulsion was not observed in this sub-reach over the period 1938-2005. Borehole data from subsurface investigations suggest that bedrock is close to the surface here. Near to surface bedrock may play a role in stabilizing the channel bend at this location.

4.1.2.2 Sub-Reach 3.2 (1.2 km to 0.9 km upstream of the mouth)

In Sub-Reach 3.2, the bend of McNab Creek appears to be eroding the toe of an escarpment as the creek migrates laterally to the northeast (Figure 4). This sub-reach includes the large right-hand bend in the stream. The active portion of the channel does not appear to be in contact with the escarpment at low flows, and erosion is likely limited to periods of higher flows.

A tributary is visible on the left bank in this reach (Figure 4). The tributary appears to have cut down through the terrace and be depositing material in the McNab Creek channel.

The width of the channel at this location appears to fluctuate between approximately 60 m and 180 m in width between 1953 and 2005. The width of the channel appears to increase by activating channels (chutes) located on the inside of the meander loop (Figure 4). The air photo record indicates these chutes episodically support vegetation, suggesting that flooding of these channels is not an ongoing and frequent event (i.e., flooded on an annual to once every 5 years basis). The chutes are located up to approximately 75 m from the present channel alignment.

4.1.2.3 Sub-Reach 3.3 (0.9 km to 0.4 km upstream of the mouth)

In Sub-Reach 3.3, McNab Creek appears to have a number of inactive side channels in an area near the BC Hydro right-of-way (ROW). Between 1966 and 1968, the establishment of a side channel to the east of the main channel created an island (Figure 4). This side channel appears to have re-vegetated since 1968 and did not appear to have been reactivated between 1985 and 2005. Between 1953 and 1968, a side channel to the west of the main channel appears to extend onto the floodplain (Figure 4). The scar resulting from the deposition of material at this location remained visible in 2005; however, no evidence of additional deposition was observed after 1968. The channel width in Sub-Reach 3.3 appears to vary between 150 m and 270 m in width, depending on the activation or abandonment of these various side channels.

4.1.2.4 Sub-Reach 3.4 (0.4 km to the mouth)

In Sub-Reach 3.4, McNab Creek appears to vary between approximately 50 m and 100 m in channel width. An inactive side channel is visible on the west side of the existing channel. This side channel appears to have been active between 1966 and 1985.

4.1.3 Historical Charts

A range of historical charts from 1798 to 1913 were reviewed. Unfortunately, these charts did not contain adequate detail to resolve the location of McNab Creek. An historical chart from 1860, obtained from the British Admiralty Office, indicated that McNab Creek was located on the east side of the valley at that time. The chart appears to show the large west-east bend that crosses the top of the project site. This bend appears to be a similar location to the modern channel. This similarity would suggest that the channel of McNab Creek has been relatively stable for at least 150 years and that avulsion of the channel between the west-east bend and the mouth has not occurred at least since 1860.

4.2 Field Reconnaissance

A summary of the observations made during the field reconnaissance are presented below.

4.2.1 Aerial Observations

The helicopter reconnaissance of the McNab Creek valley covered McNab Creek to approximately 10 km north of the mouth, Box Canyon Creek, a tributary to the north of Box Canyon Creek and three tributaries on the east side of the valley (Figure 2).

The McNab Creek valley is a broad U-shaped valley with steep upper slopes and a broad flat floor near the mouth. The flat valley floor narrows northwards from the valley mouth, becoming terraced approximately 1 km north and continuing to narrow and steepen up to the headwaters of McNab Creek.

A number of small landslides were observed during the helicopter flight. These landslides originated on the steeper upper valley walls in the McNab Creek valley and in Box Canyon valley. The landslides were observed to terminate on the lower, shallower slopes, terraces and valley floor without reaching the main channel. The flatter lower slopes appear to cause the landslide sediment to lose momentum and be deposited before reaching the main channel.

In Reach 1, more than approximately 3.5 km upstream of the mouth, the stream tends to be deeply incised into the valley floor sediments (Figure 3). Channel migration is constrained by the narrower valley. Downstream, McNab Creek flows across an increasingly broad, terraced valley floor (Figure 3, Reach 2) before flowing across the relatively flat McNab Creek fan-delta. The fan-delta appears to encompass the lower 1.6 km of McNab Creek (Figure 3, Reach 3).

Bed material in McNab Creek channel appears to be generally composed of coarse sediments and bedrock, with in-channel sediments ranging between coarse gravel to boulders. The stream was observed to be eroding the toe of several terrace scarps in the lower reaches (Figure 3). Where bedrock was observed, the stream channel was generally constrained against the bedrock. Minor accumulations of large woody debris (LWD) were observed along the length of the channel; however, no extensive accumulations of LWD or sediment were observed along the McNab Creek channel.

Two different types of tributary channels were observed. One type of tributary has lower gradient headwaters in a hanging valley with steep gradient mid channel sections where the tributary emerges into the McNab Creek valley wall (e.g., Box Canyon Creek). The second type of tributary had steep bedrock headwaters and flows down the side of the McNab Creek valley wall with shallower stream gradients at lower elevations. No extensive accumulations of sediment or woody debris were observed in the tributary channels during the helicopter reconnaissance.

Large volume sediment delivery in Reaches 1 and 2 tends to occur as a result of landslide or slumping into the channel. The landslides observed in the McNab Creek valley along Reach 1 did not appear to attain the channel and large scale slumps were not observed in the eroding terraces. It is possible that the cohesion within the eroding terraces is sufficient that delivery of large volumes of sediment by slumps or slides is infrequent. In addition, the self armouring of the channel banks by the accumulation of coarse cobbles and boulders likely reduces the rate of erosion of the channel margins. Thus sediment available for transport in McNab Creek is likely generated by erosion of channel banks, erosion of terraces and discharge from tributaries.

4.2.2 Ground Observations

4.2.2.1 Quaternary Sediments

Exposures of Quaternary (i.e., last 10,000 years) sediments were observed at several locations including road cuts, borrow pits and eroded terraces. The exposed sediments consisted primarily of interbedded sands and gravels, indicative of deposition by flowing water. Exposures of till were observed in several locations to overlie the sands and gravels. Exposures of unsorted cobbles and gravels were observed adjacent to steep tributary streams where debris flow materials would be likely to be deposited. Sediments observed in the lower reaches of McNab Creek consisted of laminar deposits of gravelly sands. Exposures of sediments along the channel margins of McNab Creek included boulder to cobble-sized material that were similar in size range to the bed material of McNab Creek.

4.2.2.2 Tributary Channels

Two tributary channels to Reach 1 of McNab Creek were observed during the foot traverse (Figure 3). The tributaries had been re-routed by the construction of berms along a logging road, training the channels. The sediments in these channels ranged in size from coarse gravel (~ 0.04 m) to boulders (~ 0.5 m)[1]. The channel margins were observed to undercut by the channel with occasional slumps. It appears that the channel margins may supply a portion of the coarse sediments observed in the channel. No water was present in the channel during the field visit.

4.2.2.3 McNab Creek Channel

The field traverse of McNab Creek covered approximately the lower 3.5 km of the channel alignment (Figure 4, Reaches 2 and 3). The channel varied from a narrow, deeply incised cobble and boulder bed stream with bedrock outcrops to a broader, mildly incised, cobble bed stream. A general scarcity of fine grained sediment

[1] Sediment sizes in this memo are reported as the length of the median axis in metres. This is not a “diameter” since gravel sized sediments and larger are not typically spherical. The median axis is determined by establishing the longest axis of an individual piece of gravel/cobble/boulder as well as the shortest axis. The median axis is typically taken at right angles to these other two axes.

(sand and gravel) was observed along the length of the channel upstream of the tidal influenced reaches of the channel (e.g., Sub-Reaches 3.3 and 3.4), although the sediments in the McNab Creek channel were observed to become finer (more cobbles, less boulders) with distance downstream.

Sub-Reach 2.1 (3.5 km to 2.8 km upstream of the mouth)

Sub-Reach 2.1 is located between approximately 3.5 km and 2.8 km upstream of the mouth (Figure 4). The channel in this reach is deeply incised into valley fill sediments. The channel margins are steep to near vertical banks of over-consolidated sediments approximately 10 m high. The stream bank sediments were primarily composed of unsorted glacial material (Photos 1 and 2). It is likely that the stream bed material is partially sourced from the stream banks. The finer material has been carried away, leaving the cobbles and boulders. The channel bed sediments were primarily coarse ranging between small cobbles (~0.1 m) to large boulders (~ 2 m) (Photo 1). The median grain size was approximately 0.5 m. The coarse stream bed material has accumulated in a series of longitudinal bars and large scale dune-type accumulations of coarse material. During the field visit, stream flow was low and was conducted via smaller channels within the stream channel deposits. No extensive accumulations of LWD or sediment were observed in this segment.

The coarse channel sediments observed during the field traverse would require relatively high velocity flows for transport, likely being transported along the bottom by rolling or bouncing. The absence of finer sediment in the upper reaches suggests more frequent moderate flows sufficient to winnow the finer grained material but not sufficient to move the larger cobbles and boulders.

Sub-Reach 2.2 (2.8 km to 1.6 km upstream of the mouth)

In Sub-Reach 2.2, the channel is moderately incised into valley fill sediments flanked by terraces with stream banks ranging in height from 2 to 4 m (Figure 3). The composition of the bed material at the upper end of Sub-Reach 2.2 is similarly coarse to the bed material observed in Sub-Reach 2.1; however, near the lower part of Sub-Reach 2.2, the typical boulder sizes have decreased to less than 0.5 m, with occasional larger (up to 1 m) boulders. In places the erosion of the stream bank material has resulted in an armouring effect by removal of the finer sediment where the coarser boulders and cobbles are left behind. This coarse material remains against the stream bank, producing a natural armouring effect, likely reducing the erosive effect of higher flows on the stream banks (Photo 3). The formation of longitudinal bars is more pronounced through this sub-reach than in Sub-Reach 2.1. A bar-like feature was observed to support some vegetation with an elevated bar surface approximately 1 to 1.5 m above the channel floor (Photo4). This bar may also be an erosional remnant of the valley-fill floodplain that is presently being reworked by the stream channel.

Outcrops of bedrock were observed intermittently along this sub-reach in the channel banks and floor. A relatively sharp corner in the channel was observed towards the upper end of this sub-reach (Figure 3). The channel is constrained by the bedrock outcrop which has forced the channel to turn sharply south. The snout of an accumulation of coarse sediment was observed just upstream of the corner (Photo 5). This sediment has likely stalled here before being carried around the corner under high flows; during waning flow, it is likely that that the velocity of water just before the corner is not sufficient to move this material.

Further downstream the confluence of McNab Creek and Box Canyon Creek was observed (Figure 3). The sediments discharged by Box Canyon Creek appear to be finer than those of McNab Creek. Box Canyon Creek sediments tended to range from gravel (~ 0.025 m) to small boulders (0.3 m). The snout of sediment deposited at the confluence by Box Canyon Creek was truncated, suggesting erosion by McNab Creek.

Reach 3 (1.6 km to the mouth)

In Reach 3 the channel is mildly incised into fan-delta sediments, with banks generally less than 1 m high (Figure 3). The size of the bed material is smaller, ranging from coarse gravel (~ 0.05 m) to small boulders (~ 0.4 m) with sand and gravel deposits observed on the bars. Several longitudinal bars were observed with established vegetation (Photo 7).

Downstream of the confluence with Box Canyon Creek an accumulation of LWD is present on the right hand bank of McNab Creek in conjunction with a small side channel (Photo 6, Figure 3). This LWD jam is located at approximately the upstream end of Sub-Reach 3.1 (Figure 4). The sediments in the side channel were mainly sand with some cobbles and gravel. Flow was observed in the side channel during the field visit. The presence of fine grained sediments (sand) in this side channel suggests that flow velocities are lower behind the accumulated LWD, resulting in the deposition of finer sediments under moderate flow. This sediment is likely eroded under higher flow and replaced during waning flow.

Evidence of avulsion was not observed through Sub-Reach 3.1and the area of the creek left handed bend during the ground traverse.

On the outside of the large right-handed bend in Sub-Reach 3.2 (Figure 4), the stream channel was observed to impinge on the tow of an escarpment (Figure 3). The stream was not observed to be in contact with the escarpment during the field visit. On the inside of the bend, several chutes were observed (Figures 3 and 4). Just downstream of the bend, a groundwater seep was observed emerging on the west side of the channel (Figure 3).

As the channel broadens towards the mouth through Sub-Reaches 3.3 and 3.4, sediment was observed to have been deposited over the banks of the channel (Figures 3 and 4). These over-bank deposits were composed mostly of sand and coarse gravel, and some shrub vegetation has established on these deposits (Photo 8). Sparse LWD was observed to be deposited along these sub-reaches and near the mouth (Photo 8).

Indicators of large-scale, historic channel avulsions in Reach 3 would include relict channel scars, oxbow lakes, meander scars or channel-shaped marshes. These indicators were not observed in the air photo record, LiDAR topography, helicopter or foot traverse; however, it is possible that evidence of historic channels have been obscured by logging and subsequent re-growth of vegetation or construction activities on the fan-delta surface.

The potential for an avulsion may also be increased by low channel margins (i.e., banks) which may be easily overtopped. Frequent bank overtopping flows would likely contribute to the risk of avulsion. However, overbank deposits were not observed in McNab Creek Sub-Reaches 3.1 and 3.2. Overbank deposits were observed in Sub-Reaches 3.3 and 3.4, near the mouth of McNab Creek, but these were not observed to be extensive. An avulsion near the mouth would likely not significantly alter the channel alignment, as it would likely be limited to the reactivation of one of the numerous side-channels present in these sub-reaches. This suggests that bank overtopping flows are only frequent in Sub-Reaches 3.3 and 3.4.

Avulsion hazard, and consequently risk, may also be increased by the presence of unconsolidated or easily erodible channel banks. During the field traverse the channel margins appeared to be generally resilient to the flows occurring in the channel and somewhat self armouring as discussed above (section 4.2.2.3). No significant areas of channel bank erosion were observed.

Evidence of limited avulsion was observed in the shifting pattern of channels within Sub-Reaches 3.2, 3.3 and 3.4. These appear to be related to in-channel deposition of sediments derived from the upper reaches (e.g., Reaches 1 and 2) and appear to be confined to a corridor along the eastern margin of the fan-delta (Figure 4). This corridor is defined by the boundaries of the historically active channel and varies in width between 50 m and 270 m. The typical lateral extent of reactivation of these side channels appears to be approximately 75 m.

4.2.3 Groundwater Assessment

A groundwater characterization is also being carried out on McNab Creek for this project. Preliminary data from the characterization indicates that the groundwater contours slope from McNab Creek into the groundwater fish channel that was constructed on the site in the 1990s by DFO. Due to their coarse sediment texture, the sands and gravels of the valley fill are typically porous. The presence of the groundwater channel appears to depress the groundwater surface within approximately 150 m of the channel.

5.0 DISCUSSION

5.1 Avulsion

The avulsion hazard of McNab Creek in the vicinity of the project is estimated to be 1:100 year to 1:500 year (Moderate) in Sub-Reaches 3.1 and 3.2 (left and right-handed bends). The consequence of an avulsion under existing conditions is considered to be Very Low as the stream will re-establish a mainstem across the existing fan-delta with the same characteristics as the existing channel and that this is a natural process in stream development. Therefore the present avulsion risk is estimated to be Low.

The consequences of an avulsion after development of a pit is rated as Moderate, based on the potential to flood the pit and develop an outlet channel from the pit with different characteristics to the existing mainstem. Therefore avulsion risk is rated to be Moderate in Sub-Reaches 3.1 and 3.2; however, this risk can be mitigated and reduced to Very Low (see Section 5.1.2 below).

The avulsion hazard of McNab Creek is estimated to be more frequent than 1:20 year (Very High[2]) in Reach 3.3 (the BC Hydro power lines). The consequences are the same as for Sub-Reaches 3.1 and 3.2 above. This combination of hazard and consequence results in a risk rating of Moderate under present conditions and High after development of the pit; However the Moderate and High risks in Sub-Reach 3.3 appear to be limited to small-scale reactivations of side channels. As with Sub-Reaches 3.1 and 3.2, the risk rating can be mitigated and reduced to Very Low (see Section 5.1.2 below).

The absence of extensive accumulations of sediment within the channel in Reaches 1 and 2 suggests that large scale deliveries of sediments to Reach 3 of the main channel are limited. This limited sediment delivery and stable single-thread channel suggests that progressive channel destabilization through downstream migration of excessive sediments from Reaches 1 and 2 is not a concern on McNab Creek.

[2] The terms “Moderate” and “Very High” relate to probabilities of occurrence of “between once every 500 years and once every 100 years” and “more frequently than once every 20 years” respectively, in accordance with the terms used for rating natural hazards that has been adopted in BC.

5.1.1 Fisheries Habitat Implications

In Reach 3, the McNab Creek channel varies in width between approximately 40 m and 270 m, the size of the main channel expanding and establishing side channels when higher flows occur. Some of these side channels may behave like small-scale avulsions, capturing flow during storm events, before being abandoned several years later.

These small-scale avulsions and activation and abandonment of the side channels in Reach 3 likely limit the habitat value of the stream due to instability of substrates, trend in seasonal drying in side channels used as potential salmon spawning habitats. The lack of stability of flow and substrate in these side channels would typically preclude or hamper the natural development of stable fish habitat during seasonally sensitive fall / winter spawning / incubation periods. Available fish data seem to support this hypothesis over time demonstrating highly variable salmon escapement over the period of record and correspondence with past forest harvesting in the watershed. Potential improvements to habitat could be engineered by developing more stable flow and substrate environments in these side channel areas. Biological, geomorphological and engineering expertise would be required to develop sustainable and successful habitat improvements in these channels and approaches are identified in an accompanying technical memorandum on salmon habitat restoration and enhancement options in the McNab Creek valley.

5.1.2 Avulsion Risk Management

The small-scale avulsions in Reaches 3.3 and 3.4 can be accommodated by maintaining a setback from the right hand bank (looking downstream) of McNab Creek. Based on available information, this setback should be no less than 75 m from the present active channel boundary. Additionally, flood management in the form of an adequately engineered training berm constructed along the right bank (existing road) of the channel would serve to reduce the risk of avulsion by preventing the development of new side channels as a result of overland flow and lowering the consequence of an event. Appropriate engineering and careful construction of a training berm can reduce the risk of avulsion in sensitive portion of the creek to a rating of Very Low[3].

5.2 Lateral Migration Risk

Lateral migration will occur. Since lateral migration occurs slowly and is an ongoing, natural process, the likelihood of the occurrence of lateral migration of McNab Creek in the vicinity of the project (e.g., Reach 3) does not lend itself to the same risk rating method as channel avulsion. What can be hazard rated is the likely magnitude of lateral migration and the consequences of that migration. The likelihood of accumulating a large lateral shift in the channel is low over a short time frame (operational life of project) and high over several centuries to millennia. Similar to avulsion, the consequences of a lateral shift in the channel is rated to be low. Therefore, the risk that the magnitude of lateral channel migration is sufficient to impinge on the proposed project is Low[4] over the design life of the project and Moderate over timescales of centuries to millennia.

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[3] The term “Very Low” applies to a probability of occurrence of less frequently than once every 2,500 years, in accordance with the terms used for rating natural hazards that has been adopted in BC.

[4] The term “Low” applies to a probability of occurrence of between once every 500 years and once every 2,500 years, in accordance with the terms used for rating natural hazards that has been adopted in BC

In all reaches, the channel of McNab Creek has migrated laterally (back and forth) across the floor of the McNab Creek valley since the last ice age (i.e., approximately the last 10,000 years). The modern channel in Reach 1 is presently confined by terraces. The presence of terraces in all reaches indicates a succession of lateral migration and downcutting. The terraces are also indicators of the historic channel margins. The tidal channels near the mouth of the valley also suggest that the mouth of McNab Creek has migrated laterally over geologic time. These historical markers indicate that the stream may occupy any portion of the valley floor as the result of slow, natural, lateral migration over geologic time; however, the present alignment of the channel does not appear to have changed in the last 150 years, based on air photo and historical chart observations. This apparent stability even includes changes in the flow regime associated with watershed harvesting in recent decades. The operational life of the gravel extraction operation is likely less than 40 years. Thus, lateral migration of McNab Creek into the pit is not anticipated over the life of the operation.

5.2.1 Lateral Migration Risk Management

For longer periods of time, e.g., several centuries, lateral migration may be expected and will occur to some magnitude. Detailed engineering and careful construction of a training berm can reduce the risk of lateral migration to a rating of Very Low.

6.0 CONCLUSIONS

Based on the available information and the field reconnaissance that we conducted, the:

Risk of avulsion of McNab Creek in the vicinity of the project is Low to Moderate in Sub-Reaches 3.1 and 3.2 to the north of the project and Moderate to High in Reach 3.3 which is situated downstream and to the east of the project. The Moderate to High risk in Sub-Reach 3.3 appears to be limited to small-scale reactivations of side channels. Appropriate engineering and careful construction of a training berm can reduce the risk of avulsion of McNab Creek into the proposed gravel pit to a rating of Very Low

To accommodate the natural variability in the existing channel, a minimum setback for construction of no less than 75 m should be established from the right bank for McNab Creek. This setback would allow the modern channel to occupy and abandon existing side channels. The proposed training berm should be constructed no closer to the stream than this setback. The side channels left on the stream-side of the training berm could be used to develop habitat enhancements on McNab Creek.

Risk that the magnitude of lateral channel migration is sufficient to carry the main channel westwards across the valley and impinge on the proposed project is Low over the design life of the project and Moderate over timescales of centuries to millennia. Detailed engineering and careful construction of a training berm can reduce the risk of lateral migration of McNab Creek into the proposed gravel pit to a rating of Very Low; however, the berm will need to be maintained in order to retain the reduction in risk over geologic time.

Should additional protective measures be considered necessary or desirable to further reduce the potential risk of avulsion, refinement of a suitable setback and/or provision of training measures such as armoured earthfill berms are anticipated to be both feasible and effective, subject to more detailed investigations and assessments as part of detailed design of the project.

7.0 CLOSURE

We trust that this information is sufficient for your immediate requirements.

GOLDER ASSOCIATES LTD.

PROFESSIONAL
PROVINCE OF
R. J. ATKINS
BRITISH COLUMBIA
GEOSCIENTIST
March 27, 2013

Neil Goeller, M.Sc., GIT
Geoscientist

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Associate / Senior Geomorphologist

NG/RA/alq

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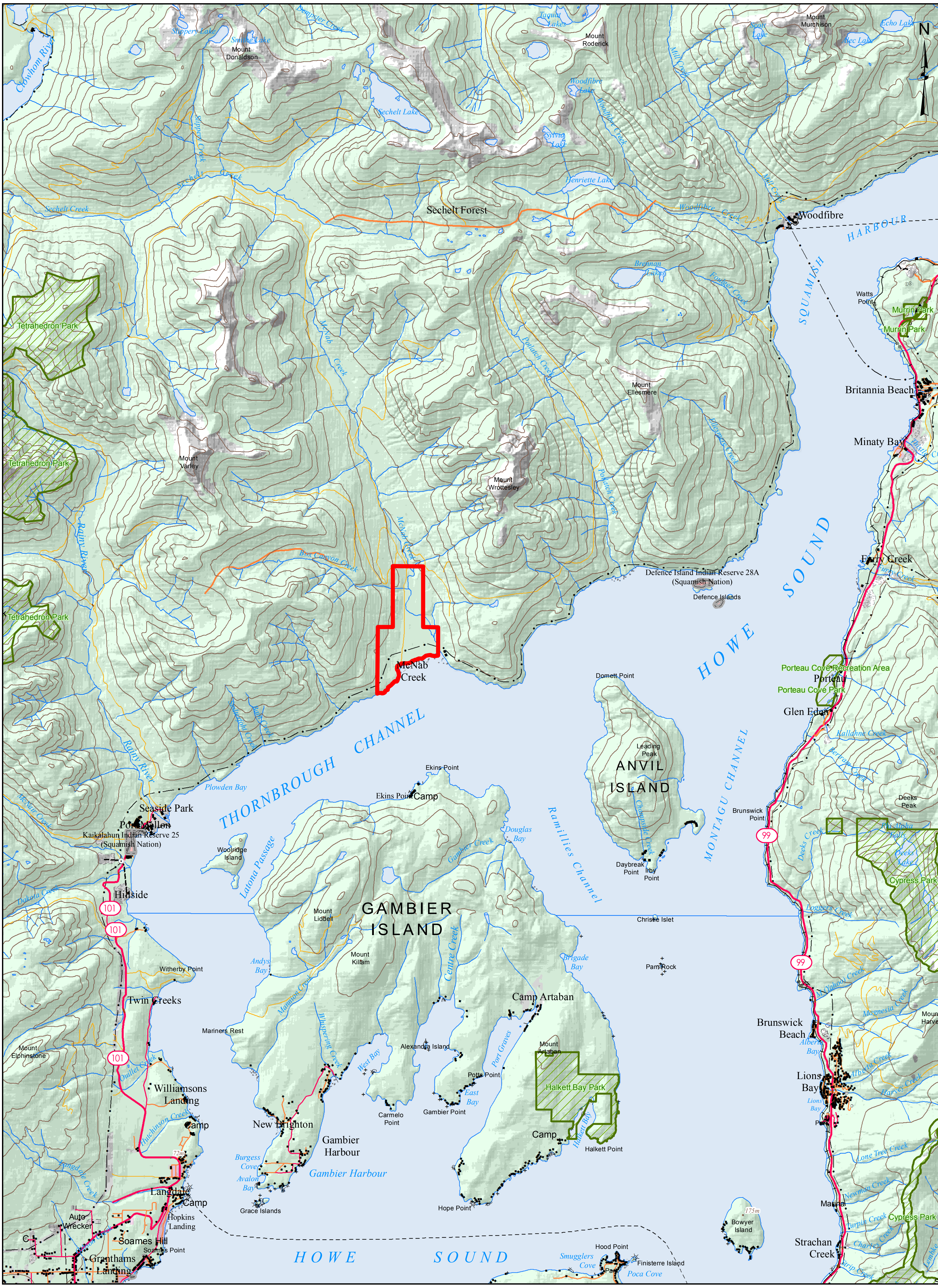
Attachments: Figures

8.0 REFERENCES

Golder 2010. McNab Creek valley Aggregate Project, Howe Sound, BC, Project Description. October 6, 2010. Submitted to BC Environmental Assessment Office, Victoria, BC. 17p. Appendices A, B and C.



LEGEND

- Project Area (Approximate)
- Building
- Elevation Point
- Hazard to Navigation
- Historic Site
- Navigation Aid
- Picnic Area
- Tank
- Communication Tower
- Other Infrastructure
- Contour - Index (500 ft)
- Dam
- Cable
- Transmission Line
- Railway
- Bridge
- Highway
- Major Road
- Local Road
- Limited Use Road
- Ferry Route
- Tunnel
- Watercourse
- Conduit
- Wharf
- Facility
- Rocky Ledge
- Mining Area
- Sand
- Waterbody
- Built-up Area
- Vegetation
- Aboriginal Title Area
- Park/Protected Area

2,500 0 2,500

SCALE 1:100,000 METRES

REFERENCE

Parks, and protected areas provided by B.C. LRDW. Aboriginal Areas provided by Geobase. Base features from geogratis.ca NTDB data.
For map symbology not included in legend, see http://cartes.rncan-nrcan.gc.ca/cartospecs/mainindex50_e.php.
Projection: UTM Zone 10 Datum: NAD 83

PROJECT

BURNCO ROCK PRODUCTS LTD.
MCNAB VALLEY AGGREGATE PROJECT
HOWE SOUND, B.C.

TITLE

KEYPLAN

Golder Associates
Greater Vancouver Office, B.C.

PROJECT No. 09-1416-0004			PHASE No. 6000	
DESIGN	MJ	06OCT10	SCALE AS SHOWN	REV. 0
GIS	KG	06OCT10	FIGURE 1	
CHECK	NG	27MAR13		
REVIEW	RA	27MAR13		

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LEGEND

- Reach 1
- Reach 2
- Reach 3
- Area of Interest

1,000 0 1,000

SCALE 1:50,000 METRES

REFERENCE

Areas of Interest provided by Golder. Orthophoto provided by B.C. Open Maps WMS.
Projection: UTM Zone 10 Datum: NAD 83

PROJECT
BURNCO ROCK PRODUCTS LTD.
MCNAB VALLEY AGGREGATE PROJECT
HOWE SOUND, B.C.

TITLE
GEOMORPHOLOGICAL OBSERVATIONS

Golder Associates
Greater Vancouver Office, B.C.

PROJECT No. 09-1416-0004			PHASE No. 3100	
DESIGN	NG	08OCT10	SCALE AS SHOWN	REV. 0
GIS	KG	08OCT10	FIGURE 2	
CHECK	NG	27MAR13		
REVIEW	RA	27MAR13		

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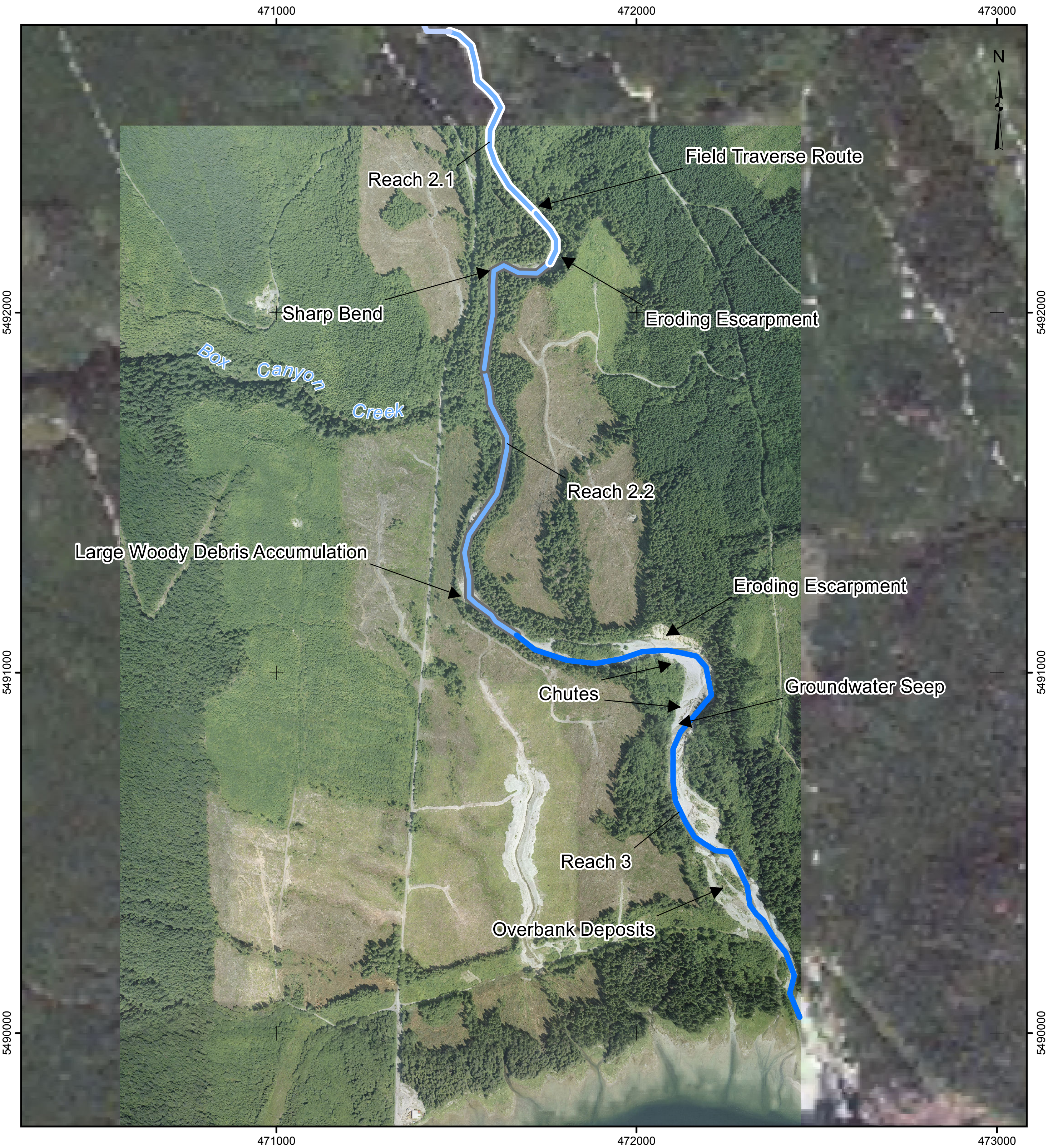

LEGEND

- Reach 1
- Reach 2.1
- Reach 2.2
- Reach 3

250 0 250

SCALE 1:15,000 METRES

REFERENCE

Areas of Interest provided by Golder. Orthophoto provided by B.C. Open Maps WMS.
Projection: UTM Zone 10 Datum: NAD 83

PROJECT

BURNCO ROCK PRODUCTS LTD.
MCNAB VALLEY AGGREGATE PROJECT
HOWE SOUND, B.C.

TITLE

LOWER MCNAB CREEK VALLEY

Golder Associates
Greater Vancouver Office, B.C.

PROJECT No. 09-1416-0004			PHASE No. 3100	
DESIGN	NG	08OCT10	SCALE AS SHOWN	REV. 0
GIS	KG	12OCT10	**FIGURE 3**	
CHECK	NG	27MAR13		
REVIEW	RA	27MAR13		

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472000

LEGEND

- Reach 2
- Reach 3.1
- Reach 3.2
- Reach 3.3
- Reach 3.4
- Boundary of Historically Active Channel (1953-2010)
- Inactive Channel

REFERENCE

Areas of Interest provided by Golder. Orthophoto provided by McElhanney.
Projection: UTM Zone 10 Datum: NAD 83

200 0 200
SCALE 1:10,000 METRES

PROJECT
BURNCO ROCK PRODUCTS LTD.
MCNAB VALLEY AGGREGATE PROJECT
HOWE SOUND, B.C.

TITLE
LOWER MCNAB CREEK

Golder Associates
Greater Vancouver Office, B.C.

PROJECT No. 09-1416-0004			PHASE No. 3100	
DESIGN	NG	08OCT10	SCALE AS SHOWN	REV. 0
GIS	KG	12OCT10	**FIGURE 4**	
CHECK	NG	27MAR13		
REVIEW	RA	27MAR13		

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LEGEND

Contour - Index	Ditch
Contour - Index - Depression	River Shore
Contour - Intermediate	Bridge
Contour - Intermediate - Depression	Gravel Road
Canal	Rough Road
Creek - Indefinite	

REFERENCE

Areas of Interest provided by Golder Associates. Orthophoto and LIDAR data provided by McElhanney.
Projection: UTM Zone 10 Datum: NAD 83

200 0 200
SCALE 1:7,500 METRES

PROJECT
BURNCO ROCK PRODUCTS LTD.
MCNAB VALLEY AGGREGATE PROJECT
HOWE SOUND, B.C.

TITLE
MCNAB VALLEY LIDAR SURVEY

Golder Associates
Greater Vancouver Office, B.C.

PROJECT No. 09-1416-0004			PHASE No. 6100	
DESIGN	NG	08OCT10	SCALE AS SHOWN	REV. 0
GIS	KG	11OCT10		
CHECK	NG	27MAR13	**FIGURE 5**	
REVIEW	RA	27MAR13		

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