TETRA TECH EBA

OQM | Organizational Quality Management Program

Powell River Regional District Landslide and Fluvial Hazards Study Electoral Areas B and C




PRESENTED TO

POWELL RIVER REGIONAL DISTRICT

SEPTEMBER 4, 2015
ISSUED FOR USE
FILE: V13103482-01 DOCUMENT NO. 002

Tetra Tech EBA Inc.
Suite 1000 – 10th Floor, 885 Dunsmuir Street
Vancouver, BC V6C 1N5 CANADA
Tel 604.685.0275 Fax 604.684.6241

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LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of Powell River Regional District and their agents. Tetra Tech EBA Inc. (Tetra Tech EBA) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than Powell River Regional District, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this report is subject to the terms and conditions stated in Tetra Tech EBA's Services Agreement. Tetra Tech EBA's General Conditions are provided in Appendix A of this report.

1.0 INTRODUCTION

Tetra Tech EBA Inc. (Tetra Tech EBA) has been retained by the Powell River Regional District (the PRRD) to carry out a study to delineate landslide and fluvial hazard areas within the coastal portion of Electoral Areas B and C of the PRRD. This study was carried out under the terms of a Tetra Tech EBA Services Agreement dated April 15 2015.

Disclaimer: This report and the attached figures are intended to be used by the PRRD for development planning, and provide limited overview mapping of landslide and fluvial hazards. Proposed developments located within the hazard areas shown on the attached figures should, as a condition of development, be required to complete a site-specific assessment of these hazard(s) by a qualified professional engineer or geoscientist. These assessments should be carried out in accordance with the following provincial guidelines:

- **Association of Engineers and Geoscientists of British Columbia. 2010. Guidelines for Legislated Landslide Assessment for Proposed Residential Developments in BC. Revised May 2010.**
- **Association of Engineers and Geoscientists of British Columbia. 2012. Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC. June 2012.**

1.1 Objective

The objective of this study is to identify areas within the coastal portion of Electoral Areas B and C which may be vulnerable to landslide and/or fluvial hazards. The results of this study will provide the PRRD with a technical basis for reviewing the adequacy of the existing Development Permit Area (DPA) polygons, and the potential need to integrate these hazard areas into DPAs for future developments.

1.2 Scope of Services

As outlined in our March 2015 proposal to the PRRD, our scope of work for this study was limited to the following:

- Desktop study of: existing information provided by the PRRD; readily available geotechnical reports; Tetra Tech EBA project archives; documents, records and web-based information relating to site setting, topography, geology, terrain, bedrock and soil deposits; and water well records.
- Comparative review of the slope development policies of other, nearby municipalities and regional districts.
- Review and interpretation of available aerial imagery and topographic data in order to identify landforms and geomorphological processes to facilitate the identification of landslide and fluvial hazards within the study area.
- Site reconnaissance fieldwork in key areas identified from the above tasks, in order to assess the terrain and slope features, soil and bedrock conditions as well as landslide and fluvial hazard processes.
- Regional hydrological analysis and modeling of flood flows along the major creeks and watercourses.
- Delineation of landslide and fluvial hazard areas based on the topography of the study area and additional engineering criteria established from the results of the above.
- Presentation of the results of the above in a summary report (this report), including details of the methods used to delineate landslide and fluvial hazard areas.

1.2.1 Exclusions

The following items are excluded from our scope, as previously discussed and agreed to with the PRRD:

- Assessment of coastal hazards including sea level rise, storm surges, wave hazards and coastal erosion.
- Assessment of Tsunami hazards, which are addressed in a 2007 study completed for the PRRD.
- Assessment of seismic (earthquake) hazards or related phenomena.
- Assessment of wildfire hazards.
- Assessment of snow avalanche hazards.

2.0 INFORMATION REVIEWED

2.1 General

The following information was reviewed as part of this study and/or is referenced in the report:

Data and Imagery:

- 2 m topographic contours (derived from 2006 aerial imagery), provided by the PRRD.
- Available 1:20,000 scale TRIM topography and watercourse mapping.
- Available water well logs from the BC Water Resources Atlas (http://maps.gov.bc.ca/ess/sv/wrbc/).
- Available 1:50,000 scale terrain mapping, completed by June Ryder & Associates in 2001.
- BC Ministry of Forests Biogeoclimatic Ecosystem Classification Mapping.
- Environment Canada Climate Normals and Averages (period 1981-2010).
- Meteorological Services of Canada (MSC) Hourly Climate Data for all stations in the vicinity.
- Water Survey of Canada (WSC) streamflow information for all gauged watercourses in the vicinity.
- Historic aerial photographs of the area from the UBC Air Photo Library (only select years were reviewed, based on the scale, coverage and overall quality of the photos):
  - BC4319 (1965), Photos 5-7 and 10-17, black and white.
  - BC4428 (1967), Photos 100-108, 111-113 and 222-224, black and white.
  - BC5586 (1974), Photos 40-44, 49-52, 54-60, 146-152 and 154-158, black and white.
  - BC5587 (1974), Photos 5-7, black and white.
  - BC82004 (1982), Photos 43-57, 72-74, and 149-161, black and white.
  - 30BCC03037 (2003), Photos 83-197, 163-180 and 226-228, colour.

- Massey, N.W.D., MacIntyre, D.G., Desjardins, P.J. and Cooney, R.T. (2005): Digital Map of British Columbia: Tile NM10 Southwest B.C., B.C. Ministry of Energy and Mines, GeoFile 2005-3.
- Orthophotographs of the study area (2006 and 2012), provided by the PRRD.
- Other GIS datasets and line work for the study area, provided by the PRRD.
- Relevant archival photographs obtained from the Powell River Historical Museum & Archives.

Publications:

- Bichler, A.J., Brooks, E.D., and Bobrowsky, P.T. 2002. Sunshine Coast Aggregate Potential Mapping Project. BC Geological Survey Open File 2002-14.
- Holland, S.S. 1976. Landforms of British Columbia, a physiographic outline; B.C. Ministry of Energy, Mines and Petroleum Resources, Bulletin 48.
- Hungr. O., Corominas, J. and Eberhardt, E. 2005. Estimating landslide motion mechanism, travel distance and velocity. In Procs., Landslide Risk Management. Taylor and Francis, London. pp. 99-128.
- McCammon, J.W. 1977. Surficial Geology and Sand and Gravel Deposits of Sunshine Coast, Powell River, and Campbell River Areas. BC Ministry of Mines and Petroleum Resources, Bulletin No. 65 (1977).
- Powell River Regional District Official Community Plan (2013), Electoral Areas B and C, Bylaw Nos. 465 & 467.

Previous Reports:

- Email correspondence and photos related to the December 2014 landslide events, provided by the PRRD.
- Golder Associates Ltd. 2004. Texada Island Shoreline Hazards Study, Van Anda and Gillies Bay. Report to Powell River Regional District dated April 26, 2004.
- Landworks Consultants Inc. 2008. Powell River Regional District RAR Implementation Report. Report to Powell River Regional District dated February, 2008.
- Planterra Environmental Consulting. 2013. Identification of Natural Hazard Areas, Malaspina Peninsula / Okeover Inlet. Report to Powell River Regional District dated September, 2013.
- Planterra Environmental Consulting 2014. Landslide Assessment Report, Stittle Road Landslide Event. Report to Powell River Regional District dated December 19, 2014.
- Tetra Tech EBA Inc. 2014. Atrevida Road – Geotechnical Assessment. Letter report to BC Ministry of Transportation & Infrastructure dated January 14, 2015.
- Thurber Engineering Ltd. 2003. Savary Island Dune and Shoreline Study. Report to Powell River Regional District dated March 12, 2003.

2.2 Review of Slope Development Policies in other Jurisdictions

Tetra Tech EBA reviewed the current slope development policies of other nearby municipalities and regional districts, including, the Sunshine Coast Regional District, the Comox Valley Regional District, the District of North Vancouver, the City of West Vancouver, the City of Nanaimo, the Regional District of Nanaimo, the Town of Qualicum Beach, the Capital Regional District, and the Cowichan Valley Regional District. These are discussed in more detail below.

2.2.1 Sunshine Coast Regional District

The Sunshine Coast Regional District (SCRD) has seven electoral areas, each of which has an individual Official Community Plan (OCP). These OCPs include Geotechnical Development Permit Areas (DPAs) adjacent to shorelines, ravines, steep slopes and other potentially hazardous areas, although the type and number of Geotechnical DPAs (and the criteria/rationale which was used to develop the DPAs) varies by electoral area.

According to the SCRD website, *"all Development Permits within a geotechnical hazard area must include a report completed by a qualified geotechnical engineer. The assessment report on the proposed development is required that meets the SCRD's risk assessment and liability standards prior to the SCRD issuing a Development Permit:*

- *Minimum acceptable risk threshold for flooding is 1:200 years.*
- *Minimum probability for other geotechnical occurrences must be less than 2% in 50 years (or 1:2475 years).*
- *The report must state that the proposed development is safe for the use intended".*

2.2.2 Comox Valley Regional District

The Comox Valley Regional District (CVRD) has established a DPA for steep slope areas which applies to slopes greater than 3 m in height with a gradient exceeding 30%, slopes designated as hazard lands by a professional engineer with experience in geotechnical engineering, as well as areas within 7.5 m of the top or bottom of the aforementioned slopes. Proposed developments within the DPA require a geotechnical report submitted by a professional engineer with experience in geotechnical engineering.

2.2.3 District of North Vancouver

The District of North Vancouver (DNV) has established DPAs for potentially hazardous areas including creek hazards, slope hazards, and wildfire hazards. The DPA for slope hazards applies to slopes greater than 10 m in height which are inclined at a gradient exceeding 20 degrees (36%), including an additional 20 m buffer (setback) from the top and bottom of these slopes. According to the DNV's website, proposed developments within these DPAs generally require a report prepared by one or more Qualified Professionals (QPs), which *"should reference the DNV's Risk Tolerance Criteria, be safe for the use intended, and reference applicable APEGBC guidelines".*

2.2.4 City of West Vancouver

The City of West Vancouver requires delineation of all land with slopes of 20% or greater, with slopes of 35% or greater identified separately. Slopes with a gradient of more than 35% are considered "Difficult Terrain". Requirements for development on slopes deemed Difficult Terrain are reviewed by the council on a site specific basis.

2.2.5 City of Nanaimo

The City of Nanaimo (CoN) specifies requirements for steep slope development in the document *Steep Slope Development Permit Area Guidelines*. These guidelines define steep slopes as “lands in their natural state that have a slope angle of 20% or greater for a minimum horizontal distance of 10 metres.” This definition is used to identify all properties 0.5 hectares or greater with a 10% or greater portion of the parent property having sloped land 20% or greater. Identified properties are mapped and included in the above referenced document. Properties identified require a Steep Slope Development Permit. A report submitted by a professional engineer with experience in geotechnical engineering may also be required regarding the suitability and safety of the site.

2.2.6 Regional District of Nanaimo

The Regional District of Nanaimo (RDN) has seven electoral areas. Most of the electoral areas have an individual OCP. Some of these OCPs include DPAs for “Hazardous Land”, which apply to steep, unstable slopes along watercourses and along the coastal shoreline. The Hazardous Land DPAs stipulate that a report prepared by a professional geotechnical engineer may be required when slope gradients exceed 30%.

2.2.7 Town of Qualicum Beach

The OCP for the Town of Qualicum Beach (Bylaw No. 590) includes a DPA for “Hazardous Lands” that are defined as flood prone lands, coastal properties that are susceptible to storm damage, and all lands with a natural grade greater than 30% where the land may potentially be further subdivided or developed and environmental degradation is likely. Development Permits are required, and a geotechnical assessment may be required.

2.2.8 Capital Regional District

The Capital Regional District (CRD) defines steep slopes as all areas having slopes exceeding 20% gradient over a minimum 6 m horizontal distance. These steep slopes are designated as Development Permit Areas and are mapped to identify properties that require development permits. Requirements for development permits are similar to the CoN’s requirements.

2.2.9 Cowichan Valley Regional District

The Cowichan Valley Regional District has nine electoral areas, each of which has an individual OCP. Some of the OCPs do not include steep slope development requirements. Some of the OCPs identify DPAs which are based on a set of objectives including protection of life and property from hazardous conditions and protection of environmentally sensitive areas. These DPAs do not specifically identify areas with hazardous slopes. Application for a development permit requires submission of detailed site mapping which includes the location of hazardous slopes exceeding 25% gradient. A report submitted by a professional engineer with experience in geotechnical engineering may also be required regarding the suitability and safety of the site.

2.2.10 Summary

A comparative summary of geotechnical development permit areas for each of the above jurisdictions is provided in Table 1:

Table 1: Summary of Geotechnical Development Permit Areas

Local Government	DPA Criteria
Sunshine Coast Regional District	DPAs defined based on broad criteria, which vary by electoral area, but generally include steep slope areas, ravines and shorelines.
Comox Valley Regional District	Slopes 30% or greater with minimum vertical height of 3 m, other hazardous slopes as designated by a professional geotechnical engineer, including areas within 7.5 m of the top or bottom of these slopes.
District of North Vancouver	Slopes 36% or greater with a minimum vertical height of 10 m, including areas within 20 m of the top or bottom of these slopes.
City of West Vancouver	Requires review of proposed development when slope exceeds 35%.
City of Nanaimo	Slopes 20% or greater for a minimum horizontal distance of 10 m.
Regional District of Nanaimo	DPAs defined based on broad criteria. Some DPAs require submission of a report by a professional geotechnical engineer when slopes exceed 30%.
Town of Qualicum Beach	Slopes 30% or greater.
Capital Regional District	Slopes 20% or greater for a minimum horizontal distance of 6 m.
Cowichan Valley Regional District	DPAs defined based on broad criteria including protection from hazardous conditions. Lands within some DPAs require identification of slopes exceeding 25% when applying for permit.

3.0 STUDY AREA

3.1 General

The study area stretches approximately 25 km from the southern boundary of the City of Powell River to Saltery Bay along the coastline of Malaspina Strait and Jervis Inlet. The area is generally sparsely populated with most of the existing residential development located in close proximity to the Highway 101 corridor, which generally parallels the coastline. The extent of the study area from a base map provided by the PRRD is shown on Figure 1, below.

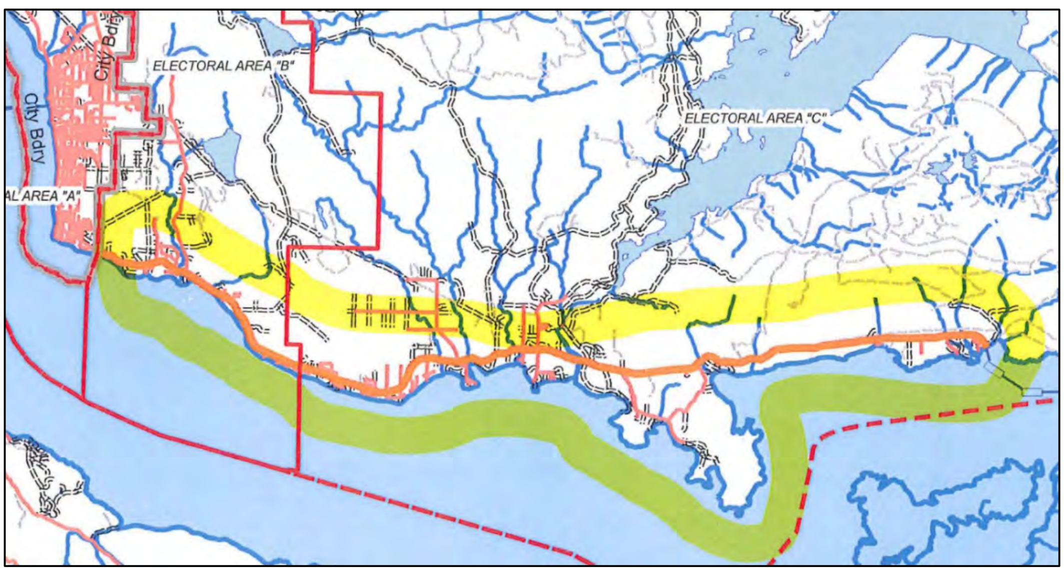

Figure 1: Extent of study area (yellow line) delineated by the PRRD, extending from the southern boundary of the City of Powell River to Saltery Bay.

3.2 Physiography

The study area ranges in elevation from sea level to about 400 m above sea level (asl) upslope of Highway 101 near Saltery Bay, with the terrain being generally steeper and more rugged east of Lois River compared to the area to the west. The study area is contained within a larger physiographic region known as the Georgia Lowland, which extends along much of the BC mainland coast. According to Holland (1976), these lowlands rise eastward, away from the Strait of Georgia, merging with the Coast Mountain Range at an elevation of approximately 1300 m asl.

3.3 Climate and Vegetation

The study area is contained almost entirely within the Coastal Western Hemlock biogeoclimatic zone and experiences relatively cool summers and mild winters. Environment Canada weather records from the nearest station at the Stillwater Powerhouse (period 1980 to 2010) indicate that mean annual rainfall is about 1440 mm and mean annual snowfall is about 30 cm.

Watercourses within the study area will typically experience their annual peak flow between October and February, coinciding with the autumn and winter rain and/or rain-on-snow storm events. Low flow occurs in late summer or early autumn, depending on the year and the arrival of the autumn rains.

3.4 Bedrock Geology

According to Massey et al. (2005) bedrock within the study area mainly comprises granitic rocks, including quartz diorite, granodiorite, and diorite of the Coast Plutonic Complex. These rocks are locally overlain by sedimentary rocks including sandstone, conglomerate, and siltstone of the Nanaimo Group Extension - Protection Formation.

3.5 Surficial Geology and Soils

The surficial geology of the Powell River area is described in detail by McCammon (1977) and Bichler et al. (2002). Like much of British Columbia, the terrain in this area has been largely shaped by the repeated advance and retreat of glaciers over the Quaternary Period (2.6 Million years ago to present). However, the current landscape of the area and the underlying soil stratigraphy were largely formed during the last (Fraser) glaciation, which ended approximately 12,000 years ago. Glacial ice flowed out of the Coast Mountains, then moved southward and southeastward over the Georgia Lowland, depositing a complex assemblage of glacial sediments (till) overlying a thick sequence of older marine and glaciofluvial sediments known locally as the Quadra Sediments. At the time when the area was de-glaciated, relative sea levels were approximately 200 m above the present datum due to glacio-isostatic depression of the earth's crust by the weight of the ice sheet that covered most of British Columbia. Glaciomarine, marine, and glaciofluvial sediments were deposited into the high-level sea, forming an irregular surficial mantle over the till at present day elevations below about 200 m asl. These sediments have been subsequently reworked in post-glacial time by fluvial downcutting and mass-wasting processes (for example, in the form of modern stream channel and beach deposits) as the earth's crust rebounded and sea levels fell to the current datum. Above 200 m asl, the terrain becomes more rugged and generally comprises veneers to blankets of till and/or colluvial (gravity transported) sediments over bedrock.

Available water well logs for the study area indicate that the soils comprise up to 35 m of glacial till (mantled by variable post-glacial sediments), underlain by up to 90 m of Quadra Sediments. The latter consists of interbedded layers of fine to coarse sand and silty sand with scattered gravel, commonly grading with depth into beds of silt and clay. Quadra Sediments are found in abundance throughout the Strait of Georgia at elevations up to 100 m asl, most notably along the eastern coastline of Vancouver Island and on several islands in the Strait including Cortes, Denman, Harwood, Hernando, Marina, Quadra, Savary and Thormanby (Clague, 1977).

3.6 Groundwater

Available water well logs for the study area indicate that groundwater is typically present at a depth of approximately 15 to 30 m below the crest of the coastal escarpment, within the Quadra Sediments. These deposits form an important aquifer and have been extensively tapped for domestic water use in the PRRD. Groundwater discharges in springs and seeps on the slope near the contact with the lower-permeability beds of silt and clay.

4.0 LANDSLIDE HAZARD ASSESSMENT

4.1 Background

The southwest coast of British Columbia is subject to high volumes of precipitation and runoff, which can trigger a number of mass-wasting (landslide) hazards that have the potential to impact developed areas in addition to the general environment. As described below, these hazards may originate in bedrock or soil, and exhibit various modes of movement including falls, slides and flows.

The southwest coast of British Columbia is also situated in a seismically active area. A seismic event may trigger debris slides/slumps, rock falls/slides or other landslide processes; however, in general, the seismic hazard for a specific property must be considered on a site-specific basis. In the case of a proposed development, this is generally captured under the jurisdiction of the British Columbia Building Code (BCBC) 2012.

4.2 Terminology

Landslide hazard terminology referenced in the following sections of the report is summarized in Table 2, below. Diagrams of typical landslide processes are also shown on the accompanying figure from Varnes (1978).

Table 2: Landslide Hazard Terminology

Mode of Movement		Landslide Process / Material Type (1)	
		Bedrock	**Soil ("Debris") (2)**
Falls		Rock fall	Debris fall
Slides	Rotational	Rock slump	Debris slump
	Translational	Rock slide	Debris slide
Flows		Rock flow	Debris flow
		Rock avalanche	Debris avalanche
Lateral Spreads		Rock spread	Debris spread
Topples		Rock topple	Debris topple
Creep		Slope creep	
Complex and compound		Combination in time and/or space of two or more principal types of movement.	

1. Table modified from Varnes 1978 and Cruden and Varnes (1996). Terminology also based on Hutchinson (1988) and Hungr et al. (2001).
2. The term "Debris" refers to coarser soils with at least 20% of particles greater than 2 mm in diameter. Finer soils which do not satisfy this criteria are referred to as "Earth". Most of the soils within the study area are comprised of Debris.

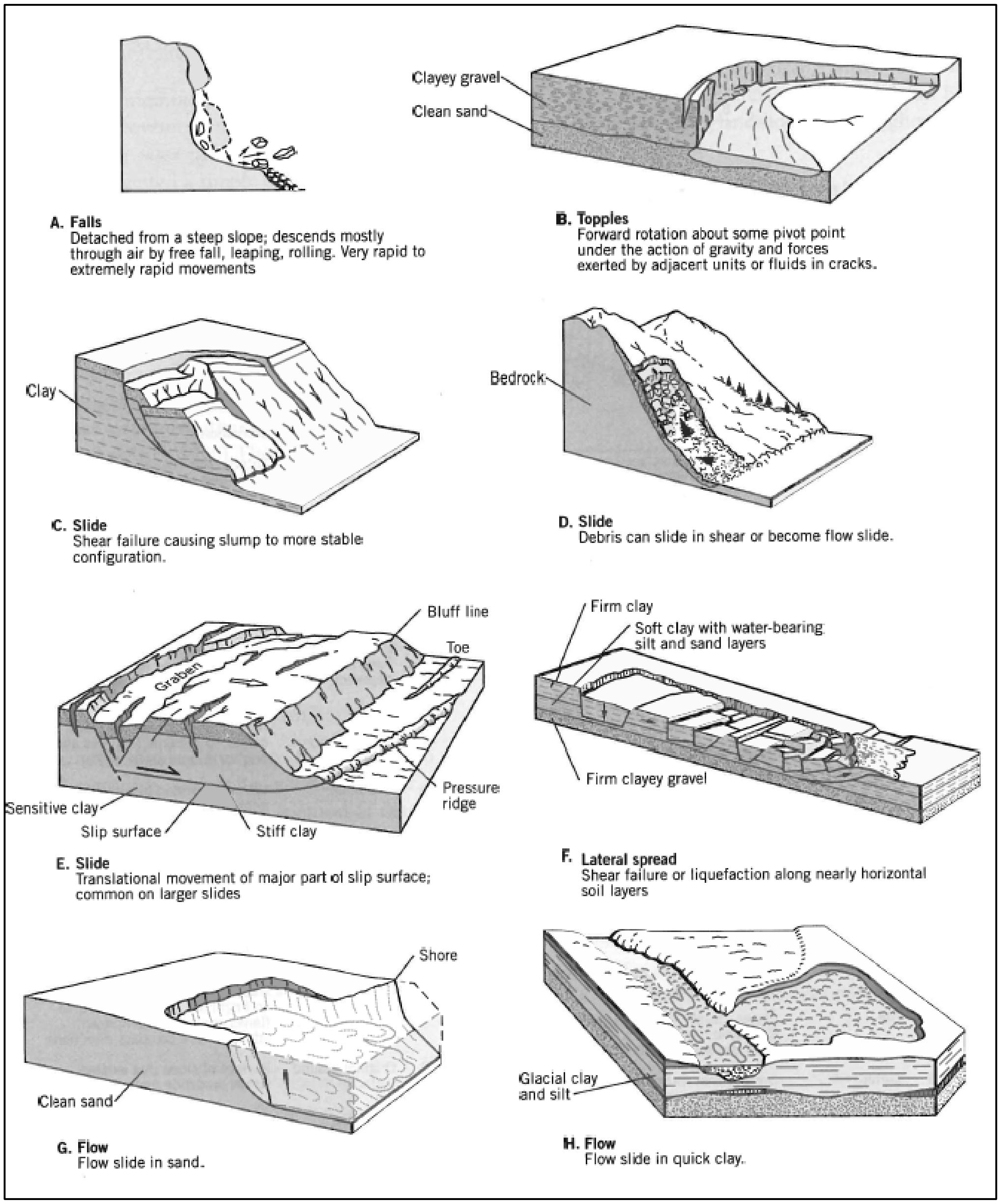

Figure 2: Examples of landslide processes (after Varnes, 1978)

4.3 Methods

4.3.1 Desktop Mapping

A digital elevation model (DEM) and slope gradient map of the study area were created using ArcGIS software based on the 2 m topographic contour information provided by the PRRD. These maps were augmented with the results of the air photo interpretation and desktop review of other information sources (see Section 2.1) to assist in the interpretation of the terrain conditions and slope stability in the study area. The slope gradient mapping and landslide hazards identified from the desktop review are shown on the attached figures in Appendix B.

December 2014 Landslide Events

A number of landslide events occurred in the study area during the week of December 8, 2014 following several days of very heavy rainfall. According to information provided by the PRRD, we understand that the Powell River area received approximately 202 mm of rain between December 5 and December 12. For comparison, the mean/average rainfall at Powell River for the entire month of December is about 139 mm. Table 3 provides a brief summary of these failures based on our review of the available information. From this table, it can be seen that the December 2014 events generally occurred in areas which have experienced historic slope instability.

Table 3: December 2014 Landslide Events in Study Area

Location	Description of Event	Notes
2977 / 2981 Stevenson Road	▪ Failure of coastal escarpment with associated erosion by surface runoff / ditch discharge	▪ Previous failures documented by homeowner in January 2010 and October 2014
Highway 101 Cut Slope	▪ Failure of highway cut slope between Maris Road and Deighton Creek	▪ Previous slumping evident from 1974 air photo
9441 / 9449 Stittle Road	▪ Large failure (slump); slide debris reached the shoreline	▪ Historic air photos show existing slide scarps / shallow swales in this area ▪ Previous slope failure (30+ years old) noted by homeowner (Planterra, 2014).
Pine Tree Road	▪ Failure of coastal escarpment with associated erosion by surface runoff / culvert discharge	▪ Previous slope failure evident from 1982 air photo
9661 Random Road	▪ Large failure (slump); slide debris reached the shoreline	▪ Historic air photos show existing slide scarps / shallow swales in this area
Victory Road	▪ No information available	▪ Previous slope failure evident from 1974 air photo

4.3.2 Site Reconnaissance

A total of three days of ground reconnaissance fieldwork were completed during the first week of June 2015 in order to verify the terrain features and landslide processes identified from the desktop mapping. No aerial reconnaissance or subsurface investigations were carried out. Tetra Tech EBA field staff were accompanied in the field by Mr. Jason Gow of the PRRD, who contacted local residents and arranged access to private property at select locations within the study area. Fieldwork consisted of short foot traverses at selected stopping points along the coastal escarpment and other areas of interest, and included visual assessment of the general topography, slope gradients, landforms, soil and bedrock exposures, hydrologic conditions, and vegetation. Detailed field notes and photographs were collected on a georeferenced map of the study area using a tablet computer. Areas which have experienced recent landslide activity were also assessed, including discussions with the affected landowner(s) where this could be arranged. The location of field observation waypoints are shown on the attached figures in Appendix B and the key findings are discussed in the following sections of the report.

4.4 Hazards Identified

4.4.1 Debris Slides and Slumps

Debris slides and slumps are the dominant landslide process within the study area. In general, these events range from shallow failures of weathered soil and topsoil, to deeper failures in dense glacial soils along steep slopes. Debris slide/slump hazards were identified at the following locations (see Photos 1 to 8, attached):

- Along the section of coastal escarpment located west of Albion (Black) Point, where several historic landslides, including the December 2014 events, have occurred. These failures were identified by the presence of arcuate (bowl-shaped) scarps, tilted/curved tree trunks, and hummocky ground within the failed mass. Abundant groundwater seepages and/or the presence of "wet site" vegetation such as horsetail and blackberry were also commonly observed. Many of these failures are located downslope of shallow natural depressions (swales) or at the discharge point of culverts and roadside ditches, indicating that surficial runoff and groundwater discharge are important causal mechanisms. Land use changes upslope of the coastal escarpment, such as logging, gravel quarrying, residential development, road construction, ditching, etc. may also be exacerbating the problem, as these activities can disrupt natural drainage patterns and increase both surface runoff and groundwater discharge. The thickness of the glacial till capping along the crest of these slopes also appears to be highly variable; areas were the till is fairly thin, such as in the vicinity of Stittle Road, are more susceptible to slope instability due to the relatively weaker nature of the Quadra Sediments compared to the glacial till.
- Along the steep slopes adjacent to Myrtle Creek, upslope of Highway 101. Overturned trees and shallow bowl-shaped slumps were observed in damp, silty soils.
- Along the steep slopes adjacent to Lang Creek, upslope of Highway 101. Shallow failures of topsoil and weathered sandstone bedrock were observed in this area; these failures appear relatively recent and may have been triggered by the December 2014 storm event.
- Along the steep slopes adjacent to Lois River, upslope of Highway 101. This area was not visited during the site reconnaissance; however, historic landslides were identified from the aerial photos and archival imagery obtained from the Powell River Historical Museum & Archives.

No evidence of large-scale landslides was identified in the study area from the desktop mapping or site reconnaissance. In north Nanaimo, the silt and clay beds forming the base of the Quadra Sediments (see Section 3.5) contain a weak layer known as a pre-shear; slope movements have occurred preferentially along this weak layer in the form of large block slides.

4.4.2 Slope Creep

Slope creep is a common hillslope process which involves the slow, downslope movement of rock and soil particles due to gravity; this process can occur in localized areas, or over a broad area. Slope creep is generally an indicator of slope instability, and can be a precursor to landslide activity. Slope creep is often identified by the presence of mature trees with tilted or curved trunks, tilted fence lines and retaining walls, or by the cracking of roadways and building foundations located near slopes.

Evidence of slope creep was observed at several locations in the study area, most notably along the coastal escarpment as well as inland areas such as along the steep slopes adjacent to Myrtle Creek and Lang Creek; refer to Photos 9 and 10, attached.

4.4.3 Rock Fall

Rock fall hazards were identified at the following locations within the study area (see Photos 11 and 12):

- Along the rock canyon section of Lois River located downstream of the Highway 101 bridge. Angular wedge-shaped masses of granitic bedrock up to about 300 m^3 in volume have locally detached from the high rock bluffs above the river, with individual block sizes up to 2 m in diameter.

- Along the peninsula / headland area between Stillwater Bay and Thunder Bay. The terrain in this portion of the study area is fairly rugged and includes sections of high rock bluffs as well as several smaller rock ledges and promontories comprised of granitic bedrock. Localized areas of rock fall were observed at the base of these bluffs, along the coastline, and in some inland areas, with fallen blocks up to several metres in diameter.
- Along the steep forested slopes above Highway 101 near Thunder Bay. Aprons of rock fall debris (talus) are present upslope of the highway, although some deposition was observed within the adjacent transmission line right-of-way near the Malaspina Viewpoint. The talus ranges in size up to 1.5 m diameter and generally appears old with heavy moss cover, although localized areas of loose rock were observed along the bluffs upslope.
- Other portions of the study area in proximity to bedrock bluffs may be potentially susceptible to rock fall hazards, in addition to the locations described above. Likely causal mechanisms for rock fall include blasting or other significant construction disturbance, freeze-thaw events, heavy rainfall and seismic loading.

4.4.4 Rock Slides

A potential rock slide hazard was identified along the peninsula / headland area between Stillwater Bay and Thunder Bay. Large masses of fractured bedrock are locally present on the high bluffs forming the western coastline of this peninsula, with adversely oriented joint surfaces (fracture planes) dipping out of the face of the slope. During a major earthquake, it is possible that these bedrock masses could detach from the bluffs. See Photo 13, attached.

4.4.5 Debris Flows

No evidence of debris flow hazards was identified from the desktop mapping and site reconnaissance; however, the watercourses draining the steep mountainous terrain to the east of Thunder Bay may be subject to debris flood activity. Refer to Section 5.0 for more information.

4.4.6 Coastline Erosion

A detailed assessment of coastal hazards is outside the scope of this study; however, no evidence of significant coastline erosion was identified from the desktop review or site reconnaissance.

4.5 Landslide Hazard Polygons

Based on the findings of the desktop mapping and site reconnaissance, and in keeping with the slope development policies adopted by most other local jurisdictions (Table 1), landslide hazard areas have been mapped using a slope gradient-based approach. Table 4 summarizes the criteria used to delineate the landslide hazard polygons, which include an additional setback distance from the top and bottom of the slope to account for the potential runout of landslide debris and/or the retrogression of unstable slopes over time. These criteria were developed from the results of the following:

- Field observations and engineering judgment.
- Generic, limit-equilibrium slope stability analyses of the coastal escarpment, based on the approximate soil stratigraphy and depth to groundwater.
- A review of published literature to estimate landslide travel distances using empirical methods.

As shown in Table 4, more stringent criteria were adopted for the section of the coastal escarpment located west of Albion (Black) Point where the majority of historic landslides have occurred, including the December 2014 events.

The landslide hazard polygons are presented on Figures 3 to 13, which include separate overview maps of Electoral Areas B and C as well as 1:10,000 scale maps of the entire study area.

Table 4: Landslide Hazard Polygon Criteria

Location	Mapping Criteria
Coastal Escarpment west of Albion (Black) Point	▪ Slope gradient ≥ 35% ▪ Slope height ≥ 3 m ▪ Additional 15 m setback from crest of slope; slopes greater than 15 m in height have a setback equivalent to the slope height (e.g. 20 m setback from a 20 m high slope) ▪ Additional setback from toe of slope extends to the shoreline of Malaspina Strait
All other areas	▪ Slope gradient ≥ 35% ▪ Slope height ≥ 3 m ▪ Additional 15 m setback from the perimeter of all polygons meeting the above criteria

4.5.1 Limitations

The landslide hazard study is intended to be a preliminary guide for development planning. Limitations to the study include the age and low resolution of the available contour data, the brief nature of the site reconnaissance, and uncertainties inherent to the geotechnical assessment of subsurface conditions and the stability of slopes.

The landslide hazard polygons were derived from the 2 m topographic contour data provided by the PRRD. We understand these contours were produced by Integrated Mapping Technologies in 2007-2008 from photogrammetric interpolation of 20 cm (1:20,000 scale) aerial imagery flown in 2006. As such, the accuracy of these contours, and the associated polygons, is uncertain due to the age of this imagery and the technical limitations of photogrammetric techniques.

5.0 FLUVIAL HAZARD ASSESSMENT

5.1 General

Rivers, creeks and streams can experience different water flow (fluvial) processes, ranging from floods to debris floods to debris flows. Debris flows are normally treated as a landslide process (Table 2); however, they are discussed here as a continuum of fluvial processes.

5.2 Terminology

Distinction between these processes is important as they differ in flow mechanics and potential consequences. Transitions between processes are common within space and time during an event, with floods transitioning into debris floods and eventually debris flows through progressive sediment entrainment. Conversely, dilution of a debris flow through partial sediment deposition and tributary injection of water can lead to a transition towards debris floods and eventually floods. Definitions of these processes are listed below:

- ***Flood:*** For the practical purposes of this study, floods are defined as water flows with sediment concentrations up to 10% by volume. Sediment in floods is transported as suspended load and bed load.

- ***Debris Flood:*** Debris floods can be defined as "a very rapid, surging flow of water, heavily charged with debris in a steep channel" (Hungr et al., 2001). Debris floods typically occur on creeks with channel gradients between 3% and 30%. The term "debris flood" is similar to the term "hyperconcentrated flow", defined by Pierson (2005) on the basis of sediment concentration as "a type of two-phase, non-Newtonian flow of sediment and water that operates between normal streamflow (water flow) and debris flow (or mudflow)". Transitions from water to debris flood/hyperconcentrated flow and vice versa occur at minimum volumetric sediment concentrations of 3% to 10%. Debris floods (as defined by Hungr) have slightly lower sediment concentrations than hyperconcentrated flows (as defined by Pierson), but this range depends on overall grain size distribution and the ability to acquire yield strength (Pierson, 2005).
- ***Debris Flow***: A debris flow can be defined as: "a very rapid to extremely rapid flow of saturated non-plastic debris in a steep channel" (Hungr et al., 2001). Debris-flow material is typically saturated; however, unlike debris floods, the movement is colluvial (gravity transported) rather than fluvial (water transported). As such, debris flows typically require slopes between 45% and 60% gradient to mobilize (Iverson, 2014). To maintain material transport, flows require an established channel or confined path. When debris flows exit the lateral confines of canyons, significant deposition occurs at the apex of their fans. Boulder lobes often observed at the front of debris flows may create levees that channelize the flow and lead to greater run-out distances on the fan surface. Often, debris flows occur in multiple surges with flood dominated transport mechanisms in between, which can lead to multiple types of deposits in the channel and on the fan surface. Hungr et al. (2001) suggest the use of peak discharge as the most reliable criterion to distinguish between debris flows and debris floods. For debris floods, typical peak discharges are two to three times that of a (water) flood; by contrast, debris flows may have a peak discharge up to 40 times higher than a flood due to the surging behaviour of these events. Debris flows also typically require a channel gradient in excess of some 25% for transport over long distances and have volumetric sediment concentrations typically in excess of 50% to 60%.

5.3 Methods

5.3.1 Process Mapping

As a preliminary measure to predict which regime (flood, debris flood or debris flow) is likely to be the predominate process in a watershed, we have calculated the Melton Ratio (R) for the identified watersheds in the study area. The Melton Ratio is used to distinguish between watersheds that are prone to debris flows, as opposed to debris floods (Jackson et al. 1987, Wilford et al. 2004). Overall, the Melton Ratio has shown to be one of the more robust parameters used to classify these processes based on the watershed morphometry (size and shape), with a number of studies identifying similar critical threshold values of R for hydro-geomorphic phenomena in different regions (e.g. Jackson et al., 1987; Bovis and Jakob, 1999; de Scally and Owens, 2004; Wilford et al., 2004).

The Melton Ratio is defined as the relative relief of a catchment area divided by the square root of the catchment area. Melton Ratios between 0 and 0.3 suggest the watershed is flood-dominated; between 0.3 and 0.6 indicate that the catchment may be prone to debris floods; and greater than 0.6 indicates the catchment may be prone to debris flows. However, debris floods and debris flows can also occur in flatter (flood-dominated) watersheds as a result of extreme events, such as outburst flooding generated by the failure of old dams or other water retention structures (Tannant and Skermer, 2013).

Table 5 presents the watershed area and Melton Ratio as a measure to identify the predominant process for each watershed considered in this study. This information was compiled from the 2 m topographic contours provided by the PRRD and from province-wide 1:20,000 scale TRIM topographic data.

Table 5: Morphometric Characteristics of Watersheds included in this Study

Watershed (1,2,3)	Area (km^2)	Min Elevation (m)	Max Elevation (m)	Melton Ratio (R)	Fluvial Hazard(s)
Bishop Creek	4.45	6	1301	0.61	Floods, Debris Floods
Deighton Creek	11.74	4	269	0.08	Floods
Jefferd Creek	3.80	8	439	0.22	Floods
Kelly Creek	7.08	7	171	0.06	Floods
Lang Creek	131.35	7	1104	0.10	Floods
Myrtle Creek	16.61	1	311	0.08	Floods
Park Creek	3.02	13	1038	0.59	Floods, Debris Floods
Whittall Creek	9.40	7	586	0.19	Floods
Unnamed Creek 1	0.55	7	420	0.56	Floods, Debris Floods
Unnamed Creek 2	1.57	7	664	0.52	Floods, Debris Floods

1. Lois River is dam-controlled for hydroelectric power generation, and as such is not included in the fluvial hazards study.
2. Unnamed Creek 1 is located approximately 1.7 km west of Park Creek.
3. Unnamed Creek 2 is located approximately 1.3 km east of Jefferd Creek.

5.3.2 Regional Hydrological Analysis

To estimate the flow in a subject watercourse for a given return period, we have completed a regional hydrologic analysis. A regional hydrologic analysis uses flow data from WSC stream gauging stations near the study area and applies that information to the ungauged watercourses within the study area.

The process for conducting a regional hydrologic analysis is as follows:

- Identify WSC stations near the project area, with similar physiographic characteristics and with sufficient period of record;
- Delineate the WSC stations catchment and determine physiographic properties (GIS analysis);
- For annual peak instantaneous flow data, perform flood frequency analysis to predict flows for various return periods;
- Plot estimated flow vs. watershed area and perform a regression analysis to derive a regional curve for each return period; and
- Apply the regression curve equation to each watershed to predict flows for specified return periods.

We identified nine WSC stations near the study area that we used for the regional analysis. These watersheds were selected based on the availability of historical data, watershed size, and the proximity to the study area.

A flood frequency analysis was performed on the flow data from each station and the 100-year and 200-year peak flows were estimated for each of the gauged stations. Figure 14 presents the relationship between watershed area and estimated flow for each return period for the nine stations analysed.

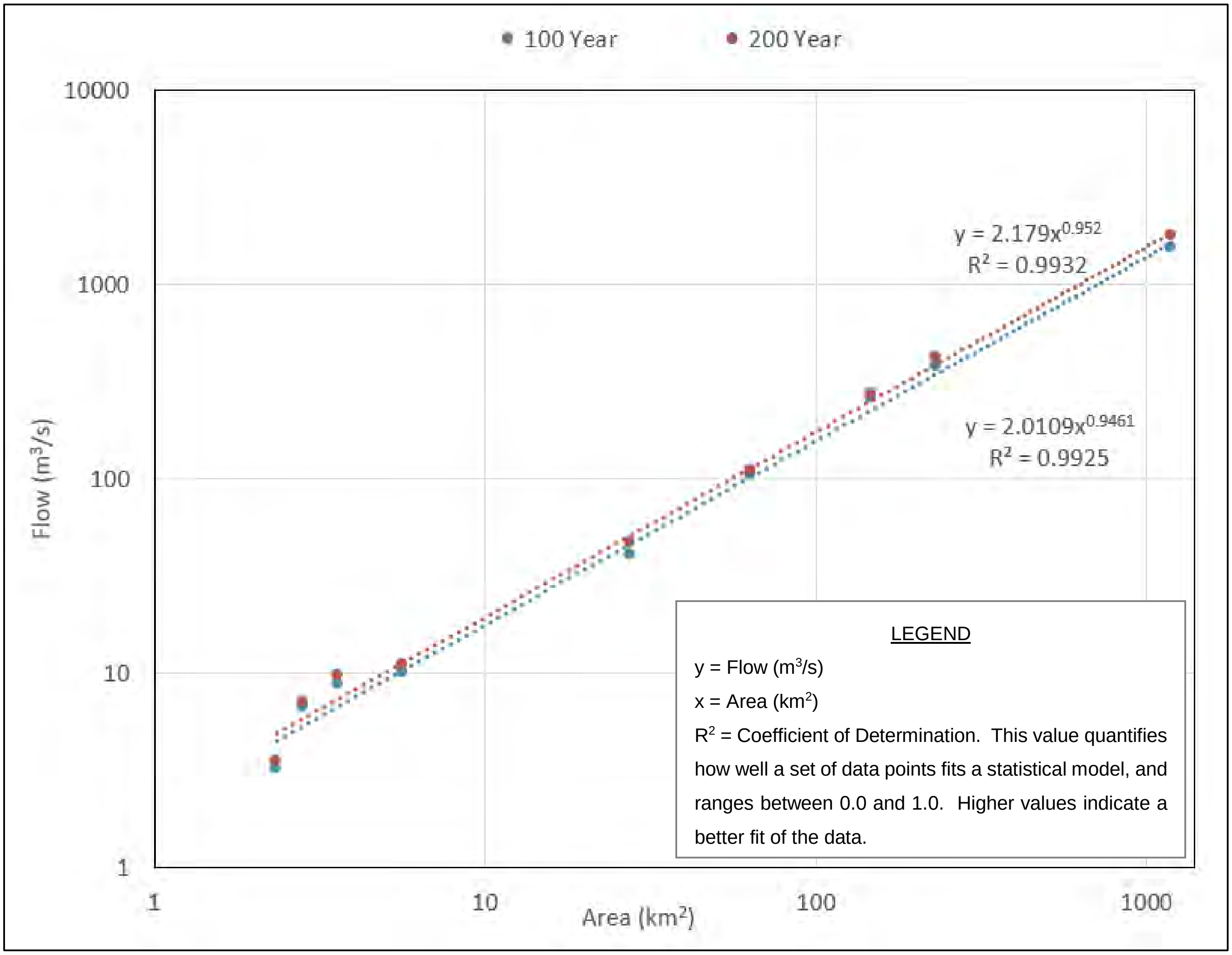

Figure 14: Relationship between peak flow and watershed area for nine WSC stations adjacent to study area for the 100-year and 200-year return periods.

Regression analysis was performed to develop relationship between the peak flow values and the watershed area. This relationship was then applied to the watersheds within the study area to predict the peak flows for each watercourse. The predicted peak daily flows for each watercourse are presented in Table 6, below.

Table 6: Predicted Peak Daily Flow for 100 year and 200 year return

Watershed	Flow (m^3/s)	
	100-year Return Period	200-year Return Period
Bishop Creek	8.25	9.02
Deighton Creek	20.67	22.72
Jefferd Creek	7.12	7.78
Kelly Creek	12.81	14.04
Lang Creek	66.70	73.90
Myrtle Creek	28.71	31.63
Park Creek	5.73	6.25
Whittall Creek	16.75	18.40
Unnamed Creek 1	1.14	1.23
Unnamed Creek 2	3.09	3.36

5.4 Flood Inundation Modelling

The purpose of the flood inundation modeling is to route the flood flows estimated from the regional analysis along each of the creeks within the study area and, subsequently, to map the predicted inundation extents associated with each flood flow. By their very nature, extreme flood flows will not be confined to their established channels; they will overtop the banks and occupy the floodplain adjacent to the watercourse. To assess this condition, we employed a 2D flood model which can simultaneously simulate channel flows and floodplain flows.

5.4.1 Modeling Software

FLO-2D software was used to model the flood flows. The estimated 200 year peak flows from Table 6 were individually input to the FLO-2D model and were routed through the corresponding creek. FLO-2D is a model approved by the U.S Federal Emergency Management Agency (FEMA) with the capabilities of modelling:

- Levee and dam breach.
- Channel, floodplain, reservoir and hydraulic structures flood routing.
- Watershed analysis and rainfall-runoff-infiltration.
- Sediment transport.
- Hazard mapping.
- Coastal flooding.

The modelling algorithm is based on a depth averaged volume conservation method, and has the ability to simulate non-Newtonian (viscous) flows such as mud flows, debris flows and tailings run-out over three-dimensional terrain. Non-Newtonian flows are differentiated from Newtonian (water-like) flows in that the viscosity of the fluid medium, unlike water, varies depending on the rate of the applied shear stress or the shear rate history.

A composite channel roughness (Manning's) coefficient of 0.04 was selected for the modeling area. The topography of the model was based on a DEM surface generated from the 2 m topographic contours provided by the PRRD.

The flood was routed within each creek for a period of between 10 to 20 hours based on the catchment size and flood magnitude.

Bishop Creek, Park Creek, Unnamed Creek 1 and Unnamed Creek 2 are also potentially subject to debris flood hazards based on their Melton Ratios and field observations of these creek channels. Evidence of a possible debris flood channel scar was identified along Unnamed Creek 1; available water well logs drilled near the mouth of this creek at Saltery Bay Provincial Park encountered layers of sand, gravel and boulders mixed with wood debris, which is consistent with typical debris flood deposits.

Debris floods were modelled in FLO-2D by increasing (bulking) the design flow for these watercourses by 30%. This represents the typical upper sediment concentration of debris floods.

5.5 Inundation Results

The results of the inundation modeling are presented on the attached figures in Appendix C and are summarized in Table 7, below. The figures in Appendix C include an overview map of the study area as well as 1:10,000 scale maps showing the inundation extents along each of the creeks.

For the creeks located east of Thunder Bay, specifically Bishop Creek, Park Creek, Unnamed Creek 1 and Unnamed Creek 2, the model predicts a wider inundation area relative to the flow and watershed area. A possible explanation is the fact that the resolution of the surface modeled (3 m x 3 m) will not reproduce a smaller, defined channel as is present in these watercourses. For the larger channels, this resolution will more accurately model the channel.

Jefferd Creek exhibits an incised and narrow geometry within the study area. The flood flow is sufficiently contained within the main channel with inundation extending only immediately adjacent to the top of bank.

For the creeks located west of Thunder Bay, including Whittall Creek, Lang Creek, Kelly Creek, Deighton Creek and Myrtle Creek, the flood flows are generally contained within the channel. Specific sections of these watercourses will be inundated.

Table 7: FLO-2D Predicted Flood Depths

Watershed	Flood Depth (m)	
	Channel Centerline	Floodplain
Bishop Creek	0.6 - 1.4	0.25 - 0.5
Deighton Creek	0.7 - 1	0.3 - 0.5
Jefferd Creek	0.5 - 1	0.2 - 0.7
Kelly Creek	0.5 - 1	0.25 - 0.5
Lang Creek	3 - 4	1 - 2
Myrtle Creek	2 - 2.5	0.5 - 1.5
Park Creek	0.5 – 1.2	0.25 - 0.5
Whittall Creek	0.7 - 1	0.2 - 0.5
Unnamed Creek 1	0.2 - 0.3	0.05 - 0.1
Unnamed Creek 2	0.3 - 0.5	0.1- 0.2

5.6 Fluvial Hazard Polygons

The fluvial hazard polygons are presented on Figures 15 to 25, which include separate overview maps of Electoral Areas B and C as well as 1:10,000 scale maps of the entire study area. For the purposes of this assignment, the fluvial hazard polygons correspond to all areas that are predicted to have some level of inundation.

5.6.1 Limitations

The fluvial hazard study is intended to be a preliminary guide for development planning. Limitations to the study include the low resolution of the topographic data, limited hydrometric data for the subject watercourses, and the uncertainty inherent with the frequency analysis and flood routing modeling. In addition, no infrastructure, such as roads, bridges and culverts were included in the model.

Lois River, within the study area, is downstream of Lois Lake. The outlet of Lois Lake is dam controlled for hydroelectric power generation, with flood levels influenced by operations of the dam. Fluvial hazards in this watershed, including outburst floods in the event of a dam failure fall under the purview of a Dam Safety Review, and are outside the scope of this study.

6.0 RECOMMENDATIONS

6.1 General

Based on the above discussion, Tetra Tech EBA recommends the following:

1. The PRRD should consider adopting the landslide and fluvial hazard areas into DPAs for the lands within PRRD's jurisdiction, given the potential impacts of these hazards to the general public, land base and the environment. This includes:
    a. The landslide hazard areas in Electoral Area B (Figures 3, 5 and 6).
    b. The fluvial hazard areas in Electoral Area B (Figures 15, 17 and 18).
    c. The landslide hazard areas in Electoral Area C (Figures 4 and 6 to 13).
    d. The fluvial hazard areas in Electoral Area C (Figures 16 and 18 to 25).
2. The PRRD should develop an education or public awareness program about landslide and fluvial hazards and how residents can manage their slopes to mitigate potential impacts to the public, property and the environment.
3. The PRRD should hold a public meeting or information session(s) to inform residents of any upcoming policy changes and for general awareness of landslide and fluvial hazard issues in the area.
4. If the PRRD decides to adopt the landslide and fluvial hazard areas into DPAs, Tetra Tech EBA should be provided the opportunity to review the proposed amendments to the OCPs in order to comment on whether the contents of this report have been appropriately understood and applied.
5. This study should be repeated at least every 10 years in order to update the hazard maps based on then-current knowledge and data.

6.2 Suggested Future Work

Tetra Tech EBA suggests that the PRRD also consider the following future work in order to supplement and expand upon the results of this study:

1. Develop a comprehensive plan for drainage control and stormwater management in coordination with other key stakeholders including the BC Ministry of Transportation and Infrastructure (BC MoT), the City of Powell River, local businesses and residents. One of the key outcomes of this plan would be to develop inspection, maintenance and rehabilitation protocols for local watercourses, ditches and culverts.

2. The study area for this assignment only covers the coastal portion of Electoral Areas B and C. Landslide and fluvial hazards should be assessed within the remaining, inland areas of the PRRD in proximity to existing or potential future developments.

3. Obtain more detailed geotechnical information of soil and bedrock conditions at key locations along the coastal escarpment and complete detailed stability analyses, seismic slope assessments and slope deformation analysis using numerical modeling techniques for the refinement of slope setbacks.

4. Complete an airborne LiDAR survey of the area, in conjunction with more detailed terrain stability mapping of Electoral Areas B and C, in order to enhance the landslide and fluvial hazard maps which have been provided to the PRRD as a preliminary planning tool. As part of this work, a watershed-scale study of the creeks located east of Thunder Bay should also be undertaken to assess potential debris flow and debris flood hazards in more detail.

5. Assess coastal hazards including sea level rise, storm surges, wave hazards and coastal erosion within Electoral Areas B and C.

6. Commission a study to assess the potential effects of climate change and related impacts to slopes, watercourses and coastlines in the PRRD.

7.0 CLOSURE

We trust this report meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech EBA Inc.

ORIGINAL SIGNED BY:

Prepared by:
Jason Pellett, P.Eng./P.Geo.
Senior Geotechnical Engineer
Geotechnical Engineering Group
Direct Line: 778.945.5841
Jason.Pellett@tetratech.com

ORIGINAL SIGNED BY:

Prepared by:
Doug Johnston, P.Eng.
Senior Hydrotechnical Engineer
Water and Marine Engineering
Direct Line: 778.945.5808
Doug.Johnston@tetratech.com

ORIGINAL SIGNED BY:

Reviewed by:
Nigel Skermer, P.Eng.
Independent Reviewer
Direct Line: 604.562.2375
nskermer@shaw.ca

ORIGINAL SIGNED BY:

Reviewed by:
Bob Patrick, P.Eng.
Principal Engineer
Nanaimo Geotechnical Group
Direct Line: 250.756.2256 x243
Bob.Patrick@tetratech.com

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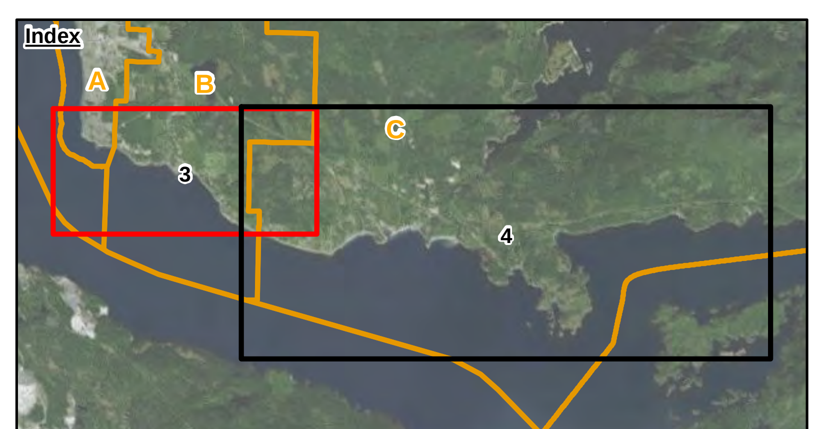
FIGURES

LEGEND

- Coastline
- Watercourse
- Limit of Study Area
- PRRD Electoral Area Boundary
- Provincial Park
- Indian Reserve
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Unclassified Road

Landslide Hazard Polygons

- Slopes ≥ 3 m High and ≥ 35% Gradient
- Recommended Additional Setback



NOTES

1. Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas; CanVec
2. Slope gradients derived from 2 m topographic contours provided by PRRD.

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Landslide Hazard Polygons Electoral Area B Overview

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:25,000

500 250 0 500
Metres

FILE NO.
V13103482-01_Figure03_AreaB_HazOverview.mxd

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V13103482-01	MEZ	YL	JP	0

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Tt EBA-VANC	September 1, 2015

Figure 3

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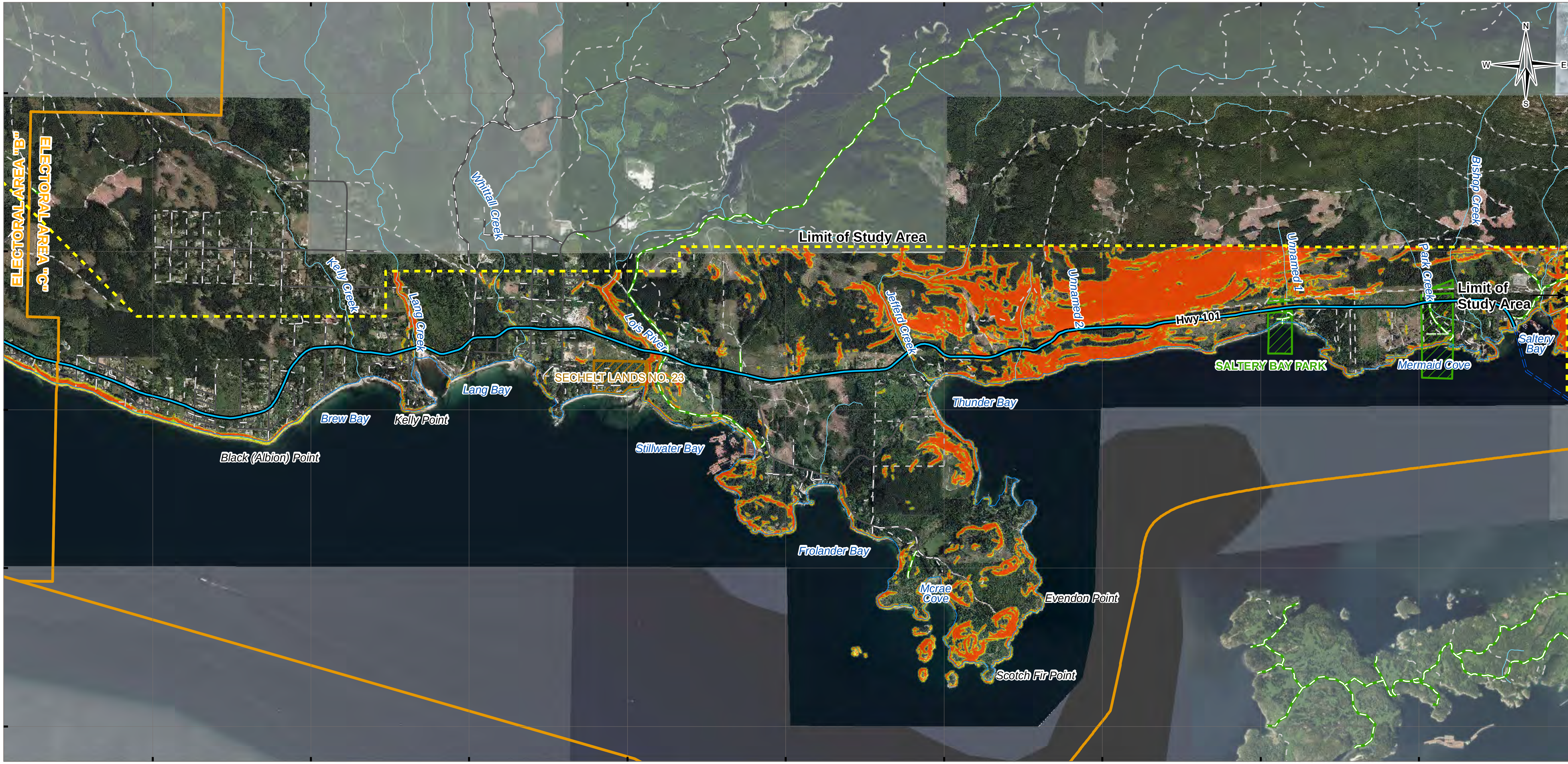
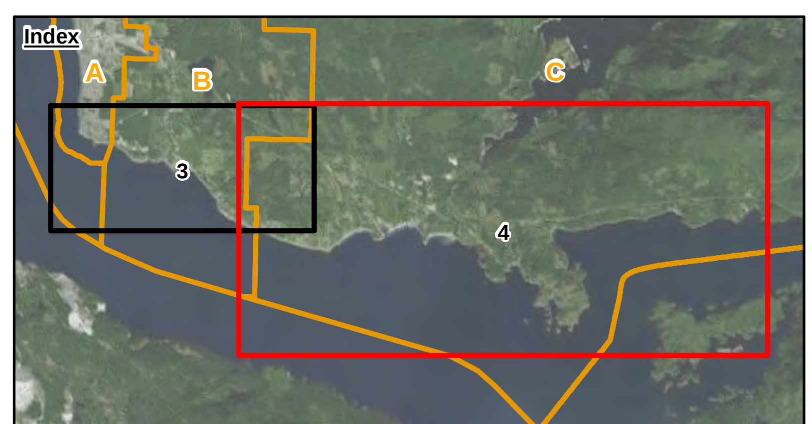


LEGEND

- Coastline
- Watercourse
- Limit of Study Area
- PRRD Electoral Area Boundary
- Provincial Park
- Indian Reserve
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry

Landslide Hazard Polygons

- Slopes ≥ 3 m High and ≥ 35% Gradient
- Recommended Additional Setback



NOTES

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2. Slope gradients derived from 2 m topographic contours provided by PRRD.

STATUS
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LANDSLIDE AND FLUVIAL HAZARDS STUDY

Landslide Hazard Polygons Electoral Area C Overview

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:50,000 — 1 0.5 0 1 Kilometres

FILE NO.
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Figure 4

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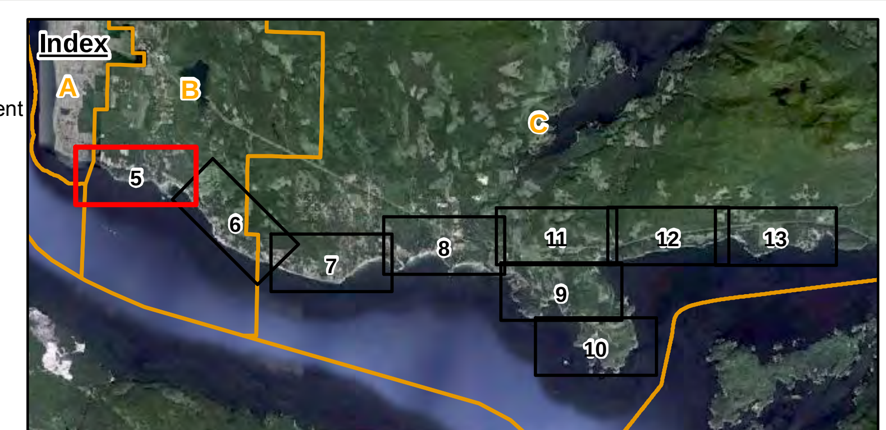
LEGEND

- Coastline
- Watercourse
- Contour (10 m)
- PRRD Electoral Area Boundary
- Indian Reserve
- Provincial Park
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry

Landslide Hazard Polygons

- Slopes ≥ 3 m High and ≥ 35% Gradient
- Recommended Additional Setback



NOTES
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2. Slope gradients derived from 2 m topographic contours provided by PRRD.

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Landslide Hazard Polygons

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000
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Metres

TETRA TECH EBA

FILE NO.
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Tt EBA-VANC	September 1, 2015

Figure 5

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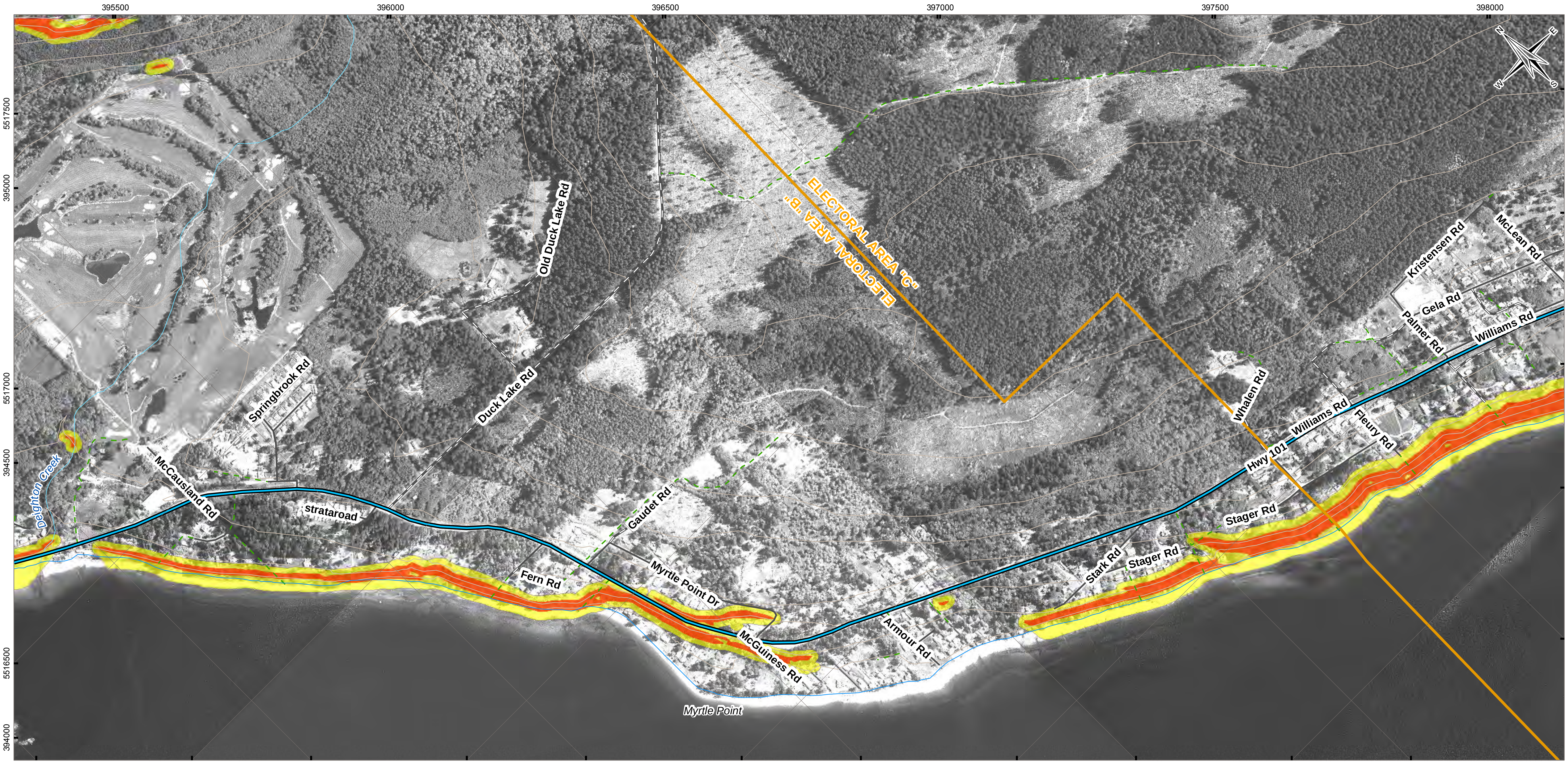

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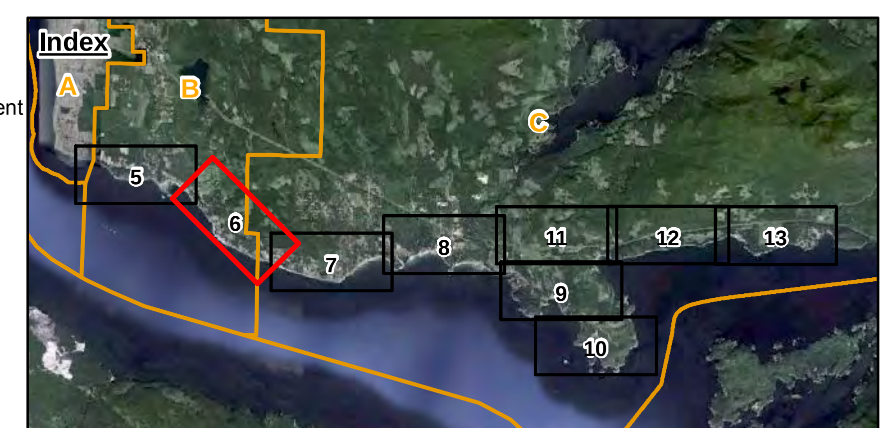
LEGEND

- Coastline
- Watercourse
- Contour (10 m)
- PRRD Electoral Area Boundary
- Indian Reserve
- Provincial Park
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry

Landslide Hazard Polygons

- Slopes ≥ 3 m High and ≥ 35% Gradient
- Recommended Additional Setback



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2. Slope gradients derived from 2 m topographic contours provided by PRRD.

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Landslide Hazard Polygons

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000
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Metres

TETRA TECH EBA

FILE NO.
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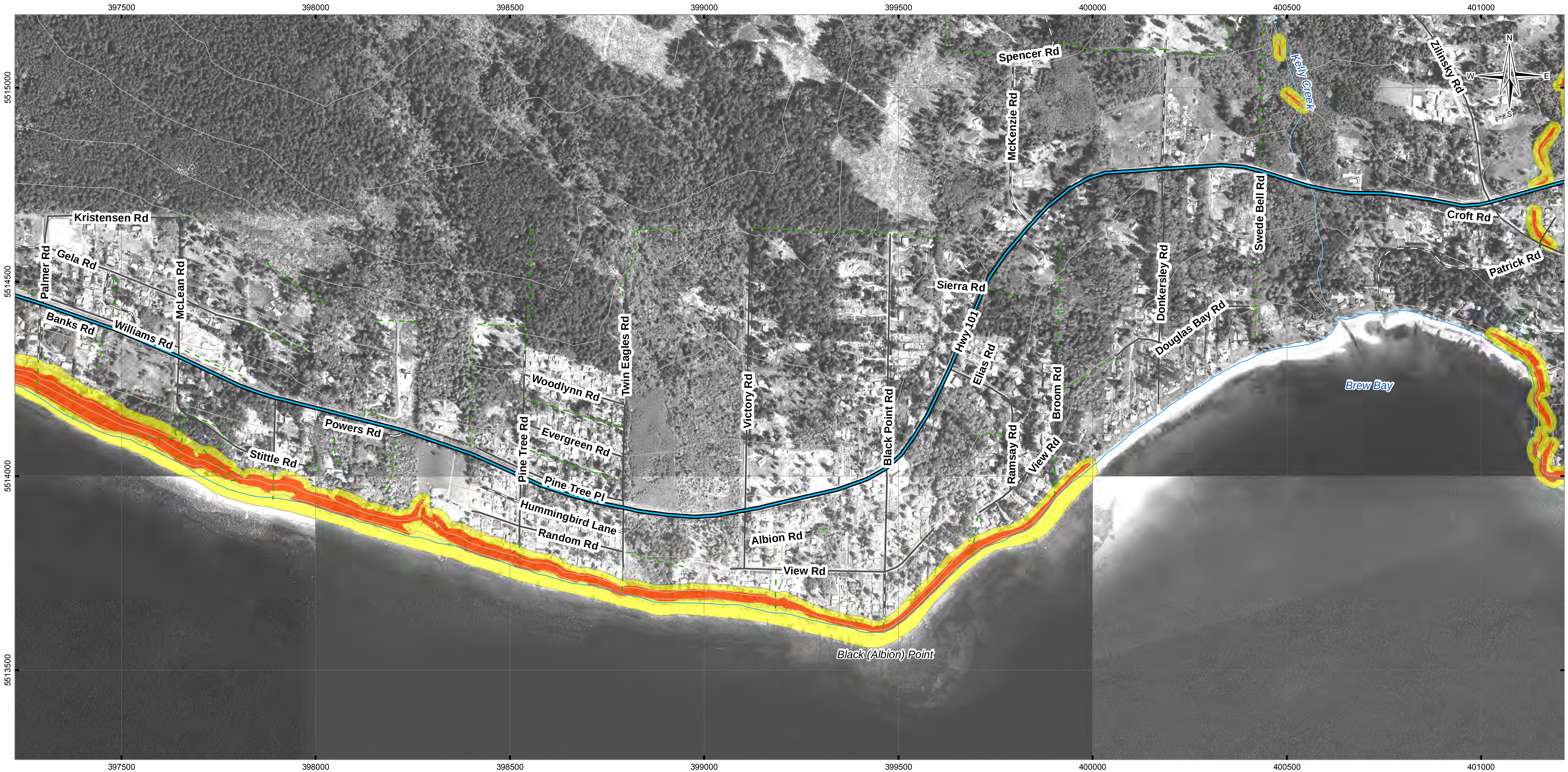
V13103482-01	SL	MEZ	JP	0

OFFICE	DATE
Tt EBA-VANC	September 1, 2015

Figure 6

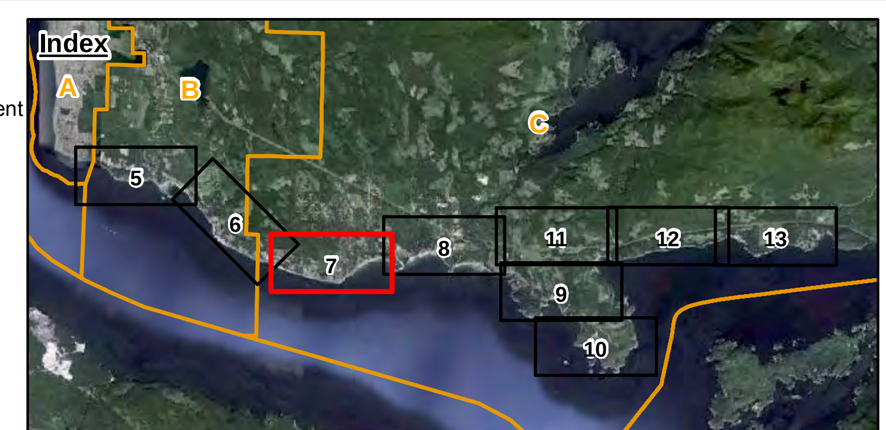


LEGEND

- Coastline
- Watercourse
- Contour (10 m)
- PRRD Electoral Area Boundary
- Indian Reserve
- Provincial Park
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry

Landslide Hazard Polygons

- Slopes ≥ 3 m High and ≥ 35% Gradient
- Recommended Additional Setback



NOTES

1. Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas; CanVec
2. Slope gradients derived from 2 m topographic contours provided by PRRD.

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Landslide Hazard Polygons

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	POWELL RIVER REGIONAL DISTRICT

Scale: 1:10,000
200 100 0 200
Metres

TETRA TECH EBA

FILE NO.
V13103482-01_Figure05-13_LandslidePolys.mxd

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	SL	MEZ	JP	0

OFFICE	DATE
Tt EBA-VANC	September 1, 2015

Figure 7

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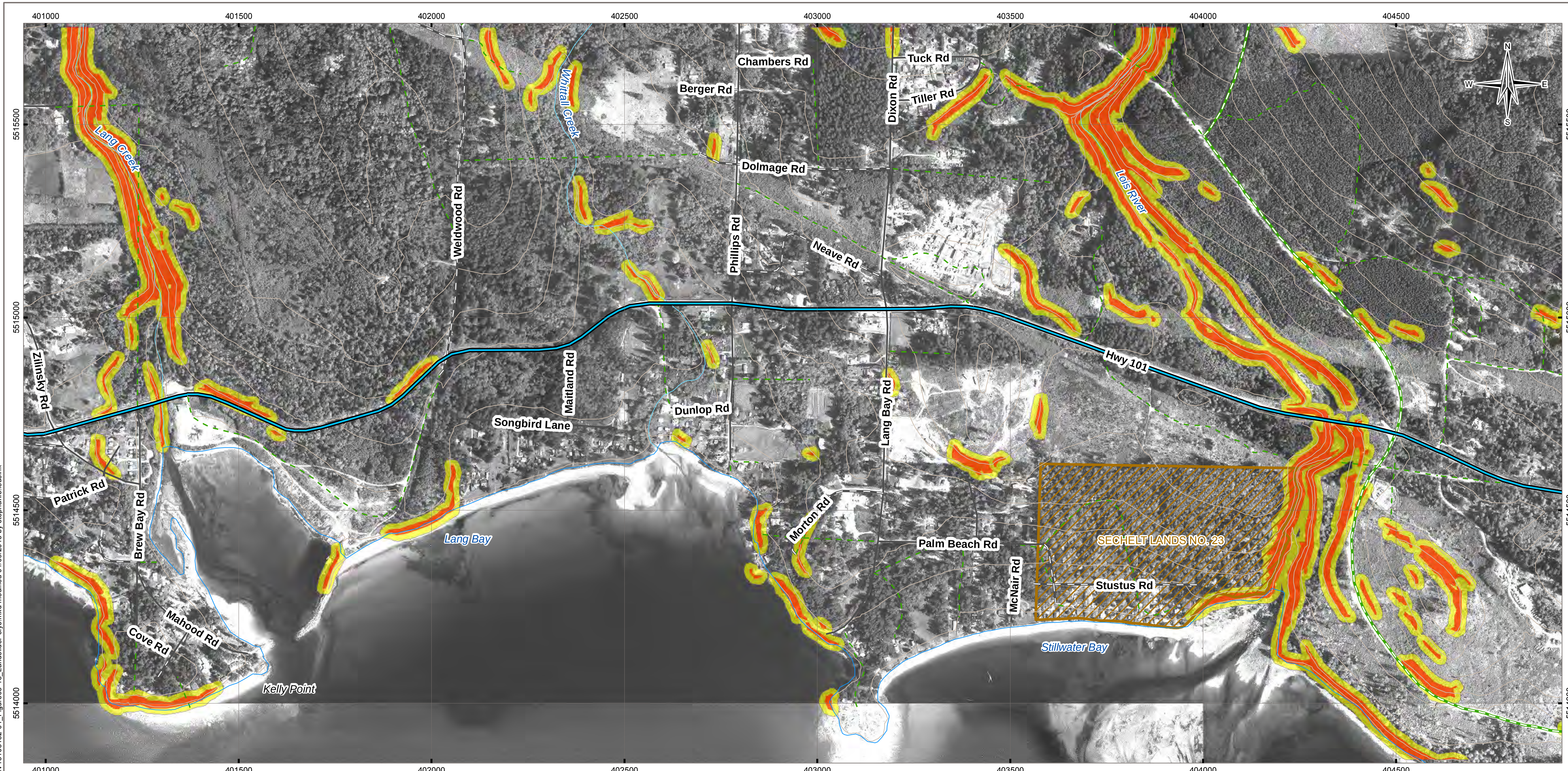

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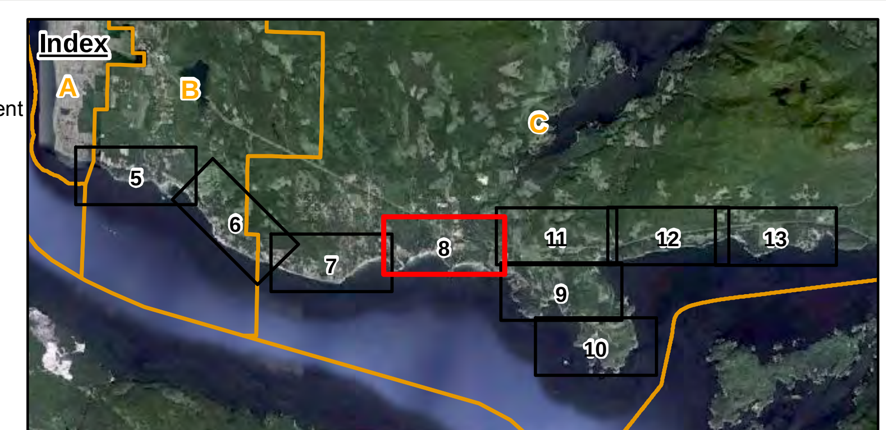
LEGEND

- Coastline
- Watercourse
- Contour (10 m)
- PRRD Electoral Area Boundary
- Indian Reserve
- Provincial Park
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry

Landslide Hazard Polygons

- Slopes ≥ 3 m High and ≥ 35% Gradient
- Recommended Additional Setback



NOTES

1. Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas; CanVec
2. Slope gradients derived from 2 m topographic contours provided by PRRD.

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Landslide Hazard Polygons

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	POWELL RIVER REGIONAL DISTRICT

Scale: 1:10,000
200 100 0 200
Metres

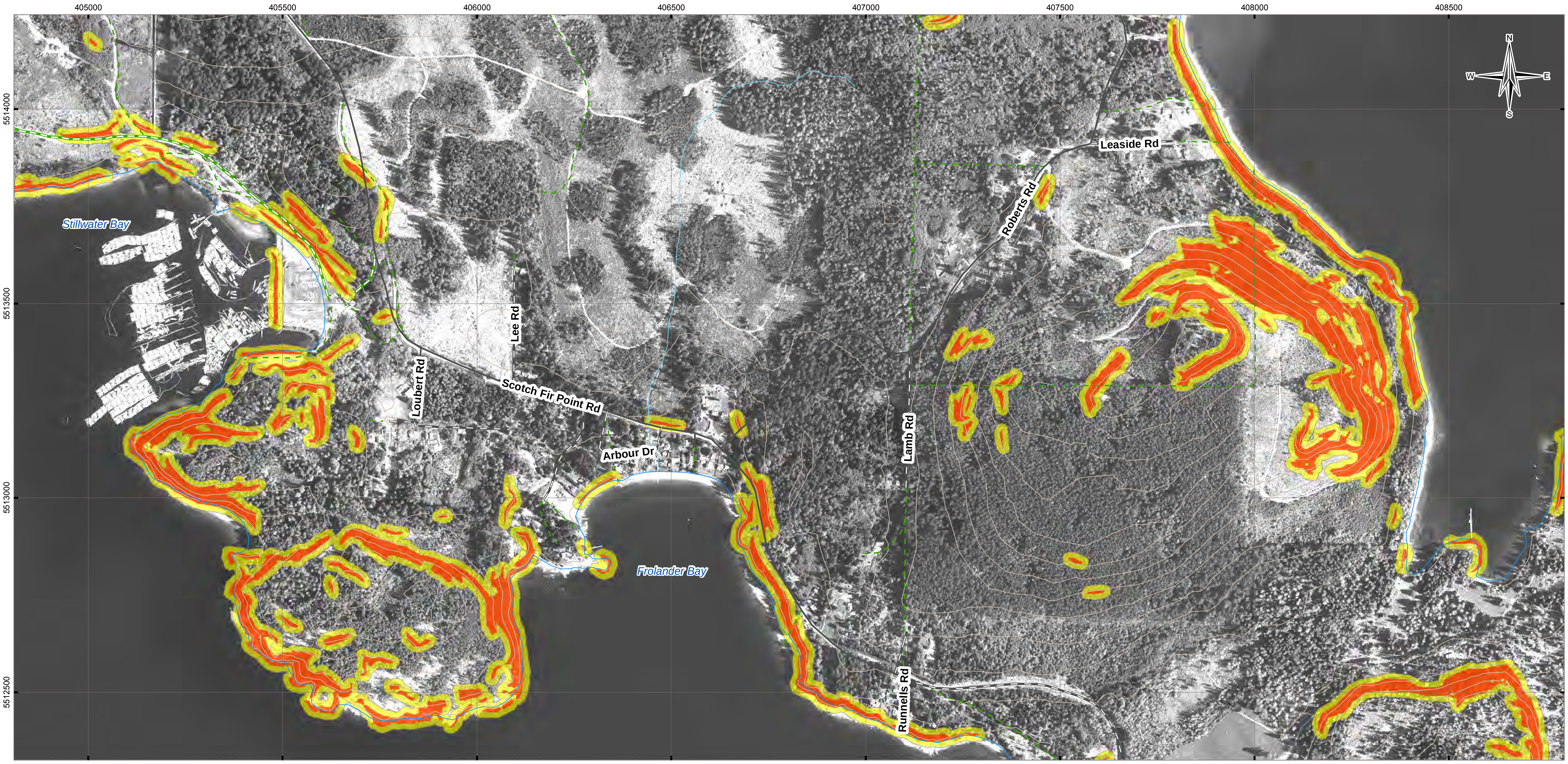
FILE NO.
V13103482-01_Figure05-13_LandslidePolys.mxd

TETRA TECH EBA

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	SL	MEZ	JP	0

OFFICE	DATE
Tt EBA-VANC	September 1, 2015

Figure 8

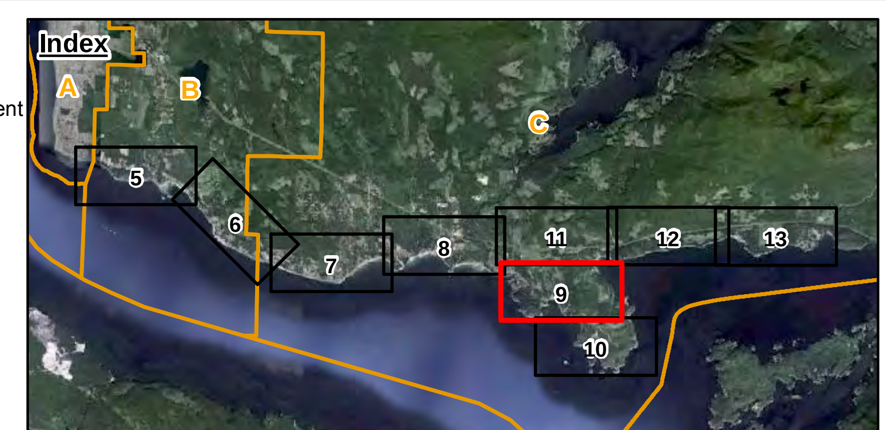


LEGEND

- Coastline
- Watercourse
- Contour (10 m)
- PRRD Electoral Area Boundary
- Indian Reserve
- Provincial Park
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry

Landslide Hazard Polygons

- Slopes ≥ 3 m High and ≥ 35% Gradient
- Recommended Additional Setback



NOTES

1. Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas; CanVec
2. Slope gradients derived from 2 m topographic contours provided by PRRD.

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Landslide Hazard Polygons

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000

200 100 0 200

Metres

TETRA TECH EBA

FILE NO.
V13103482-01_Figure05-13_LandslidePolys.mxd

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	SL	MEZ	JP	0

OFFICE	DATE
Tt EBA-VANC	September 1, 2015

Figure 9

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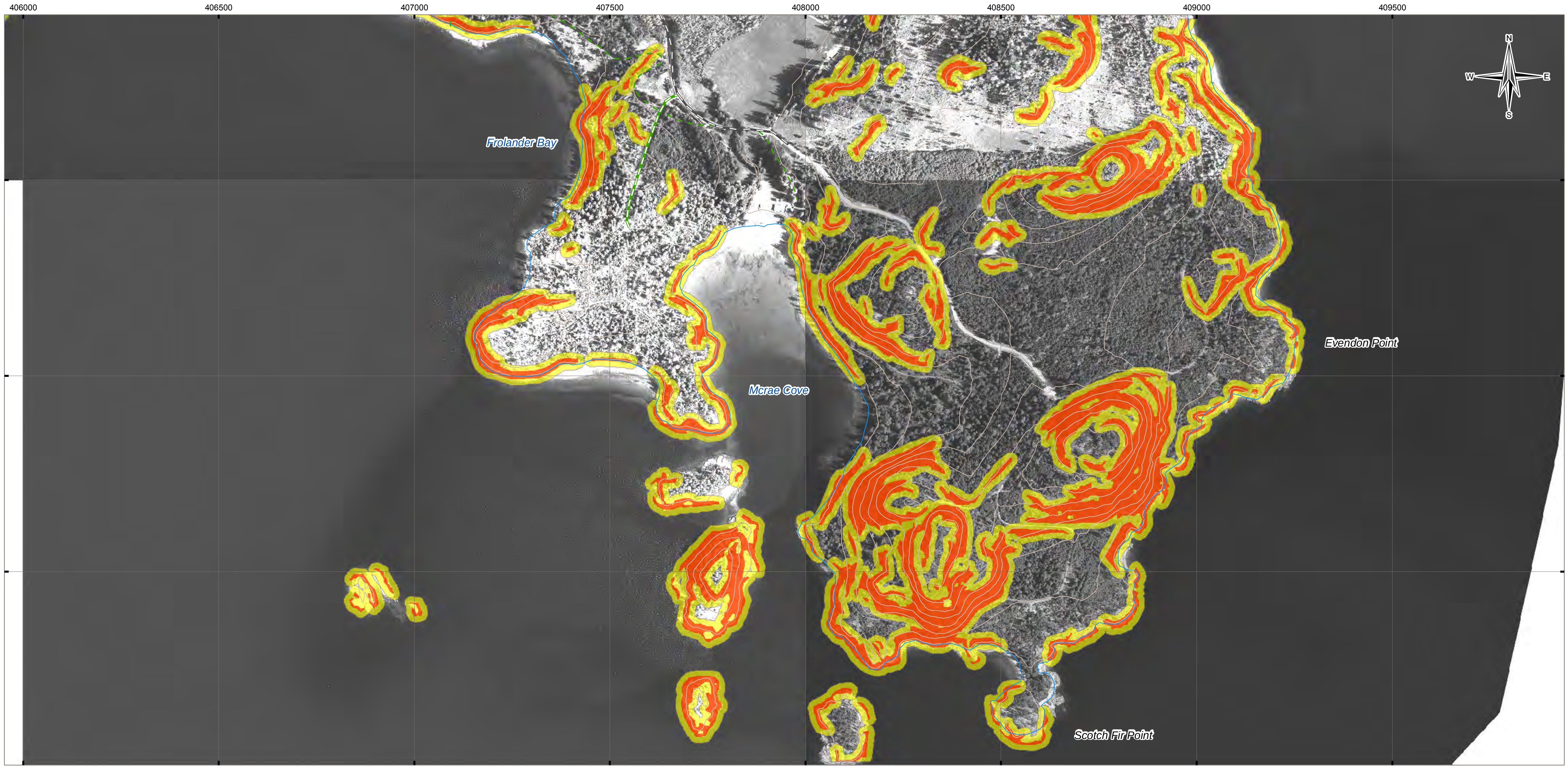
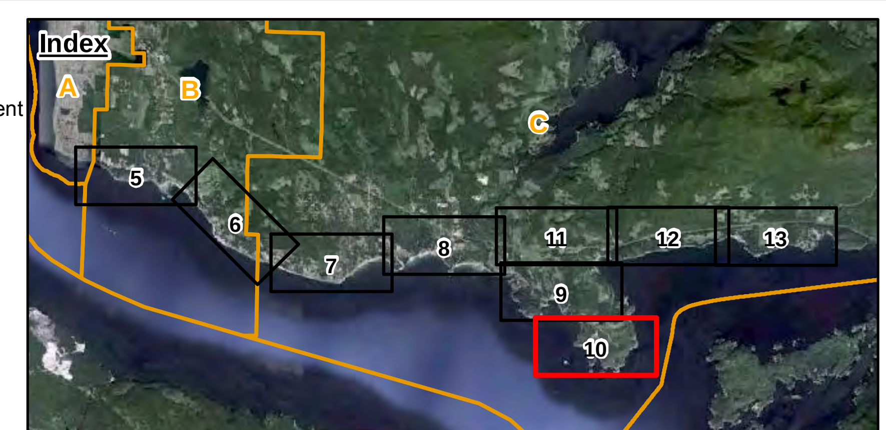


LEGEND

- Coastline
- Watercourse
- Contour (10 m)
- PRRD Electoral Area Boundary
- Indian Reserve
- Provincial Park
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry

Landslide Hazard Polygons

- Slopes ≥ 3 m High and ≥ 35% Gradient
- Recommended Additional Setback



NOTES

1. Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas; CanVec
2. Slope gradients derived from 2 m topographic contours provided by PRRD.

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Landslide Hazard Polygons

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000
200 100 0 200
Metres

FILE NO.
V13103482-01_Figure05-13_LandslidePolys.mxd

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PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	SL	MEZ	JP	0

OFFICE	DATE
Tt EBA-VANC	September 1, 2015

Figure 10

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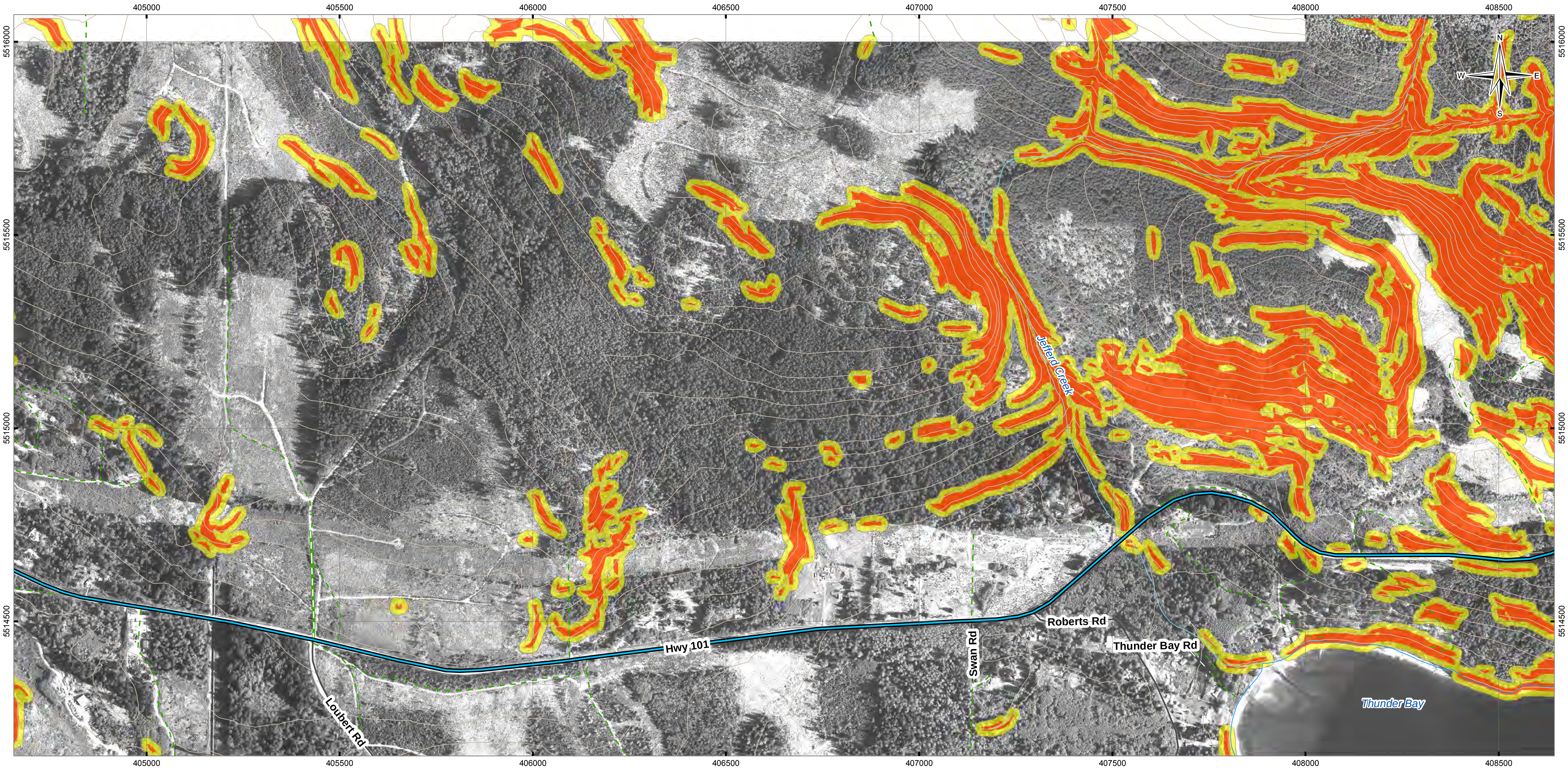
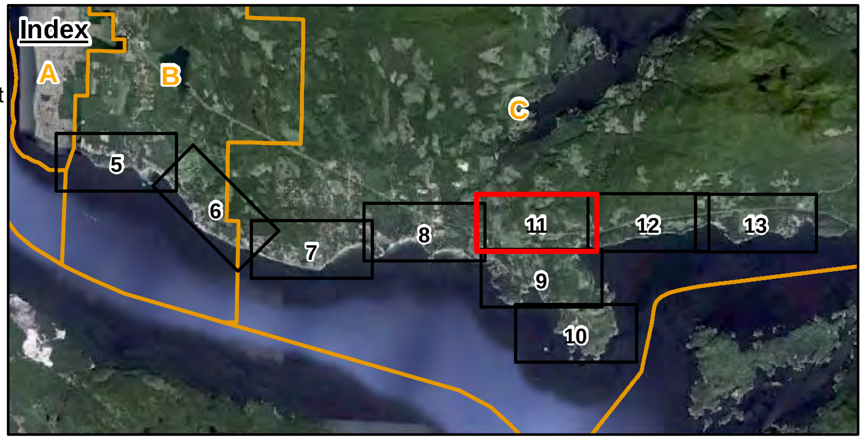


LEGEND

- Coastline
- Watercourse
- Contour (10 m)
- PRRD Electoral Area Boundary
- Indian Reserve
- Provincial Park
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry

Landslide Hazard Polygons

- Slopes ≥ 3 m High and ≥ 35% Gradient
- Recommended Additional Setback



NOTES
1. Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas; CanVec
2. Slope gradients derived from 2 m topographic contours provided by PRRD.

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Landslide Hazard Polygons

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000

200 100 0 200
Metres

Tetra Tech EBA

FILE NO.
V13103482-01_Figure05-13_LandslidePolys.mxd

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	SL	MEZ	JP	0

OFFICE	DATE
Tt EBA-VANC	September 1, 2015

Figure 11

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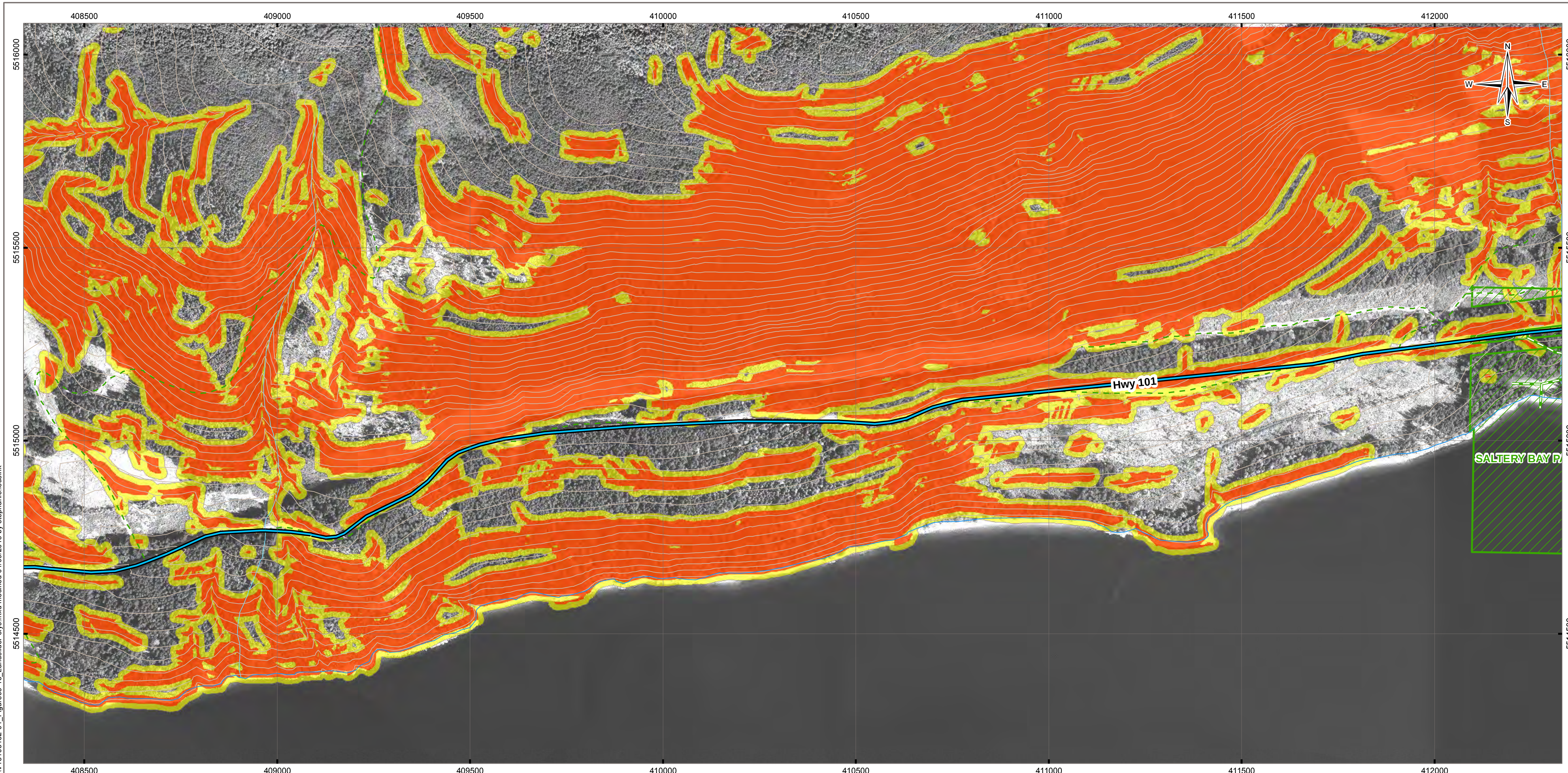
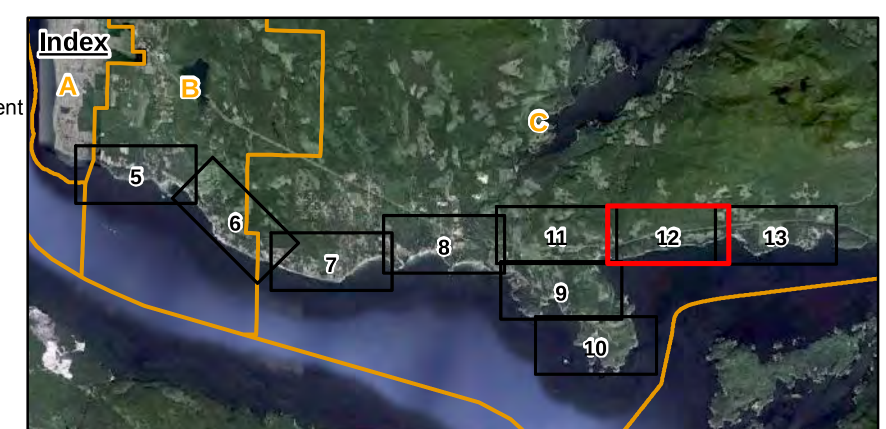


LEGEND

- Coastline
- Watercourse
- Contour (10 m)
- PRRD Electoral Area Boundary
- Indian Reserve
- Provincial Park
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry

Landslide Hazard Polygons

- Slopes ≥ 3 m High and ≥ 35% Gradient
- Recommended Additional Setback



NOTES

1. Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas; CanVec
2. Slope gradients derived from 2 m topographic contours provided by PRRD.

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Landslide Hazard Polygons

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000

200 100 0 200

Metres

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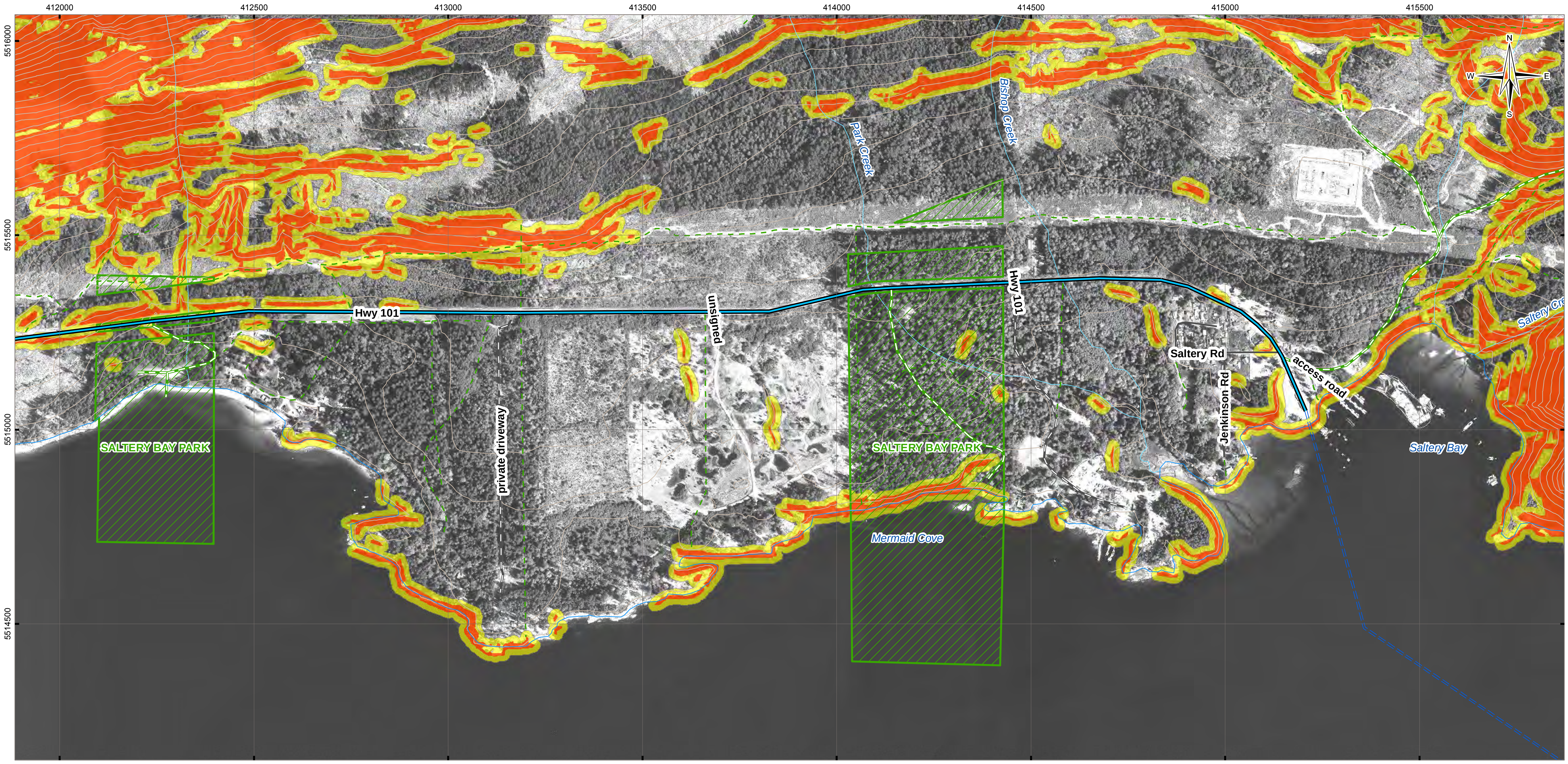
FILE NO.
V13103482-01_Figure05-13_LandslidePolys.mxd

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	SL	MEZ	JP	0

OFFICE	DATE
Tt EBA-VANC	September 1, 2015

Figure 12

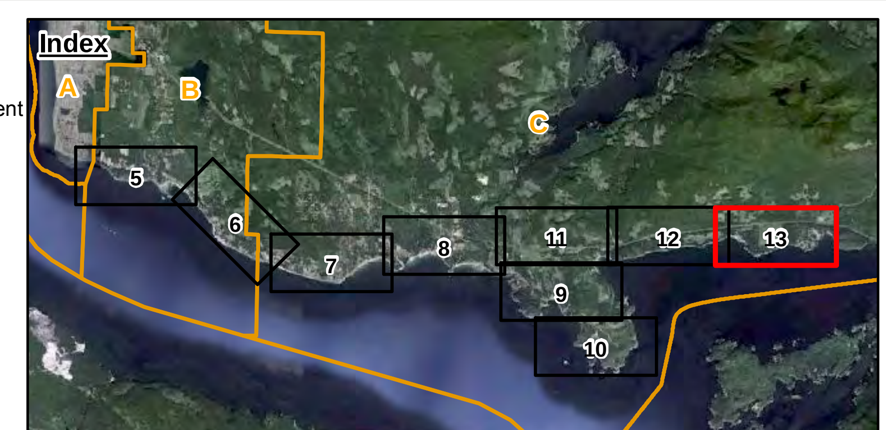


LEGEND

- Coastline
- Watercourse
- Contour (10 m)
- PRRD Electoral Area Boundary
- Indian Reserve
- Provincial Park
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry

Landslide Hazard Polygons

- Slopes ≥ 3 m High and ≥ 35% Gradient
- Recommended Additional Setback



NOTES

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2. Slope gradients derived from 2 m topographic contours provided by PRRD.

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Landslide Hazard Polygons

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000

200 100 0 200

Metres

Tetra Tech EBA

FILE NO.
V13103482-01_Figure05-13_LandslidePolys.mxd

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	SL	MEZ	JP	0

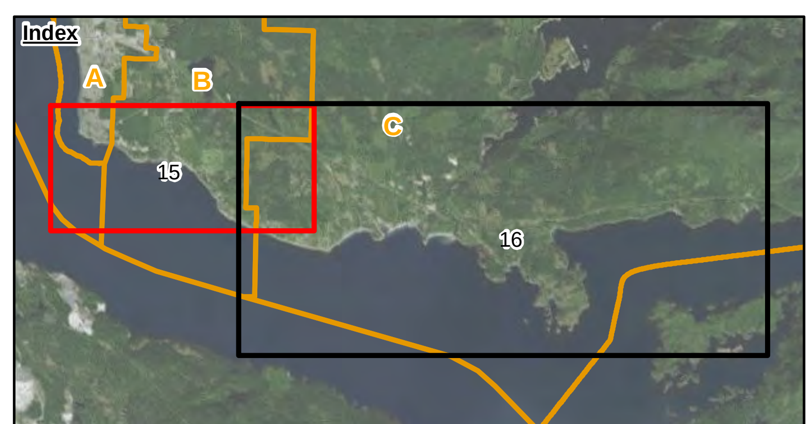
OFFICE	DATE
Tt EBA-VANC	September 1, 2015

Figure 13

Q:\Vancouver\GIS\ENGINEERING\V131\V13103482-01_PowellRiver\Maps\V13103482-01_Figure15_AreaB_FluvialHaz.mxd modified 01/09/2015 by stephanie.leusink

LEGEND

- Fluvial Hazard Polygon
- Coastline
- Limit of Study Area
- PRRD Electoral Area Boundary
- Provincial Park
- Indian Reserve
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Unclassified Road



NOTES

1. Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas; CanVec

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Fluvial Hazard Polygons Electoral Area B Overview

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	POWELL RIVER REGIONAL DISTRICT

Scale: 1:25,000
500 250 0 500
Metres

FILE NO.
V13103482-01_Figure15_AreaB_FluvialHaz.mxd

TETRA TECH EBA

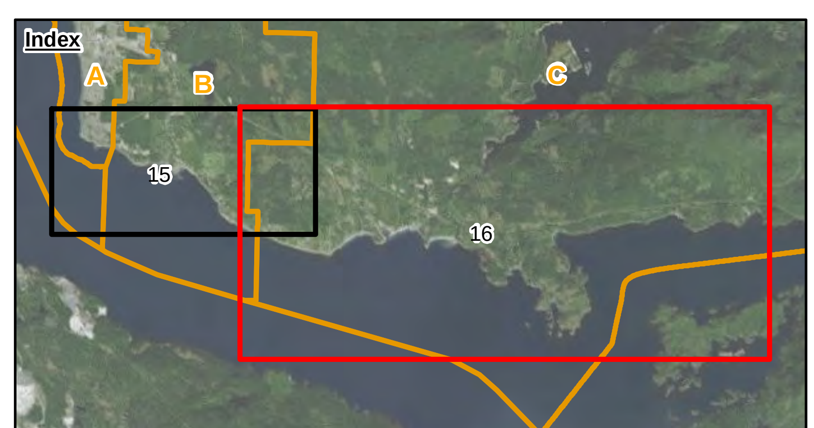
PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	MEZ	YL	JP	0

OFFICE: Tt EBA-VANC
DATE: September 1, 2015

Figure 15

LEGEND

- Fluvial Hazard Polygon
- Coastline
- Limit of Study Area
- PRRD Electoral Area Boundary
- Provincial Park
- Indian Reserve
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry



NOTES

1. Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas; CanVec
2. Slope gradients derived from 2 m topographic contours provided by PRRD.

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Fluvial Hazard Polygons Electoral Area C Overview

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	POWELL RIVER REGIONAL DISTRICT

Scale: 1:50,000

1 0.5 0 1

Kilometres

FILE NO.
V13103482-01_Figure16_AreaC_FluvialHaz.mxd

TETRA TECH EBA

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	MEZ	YL	JP	0

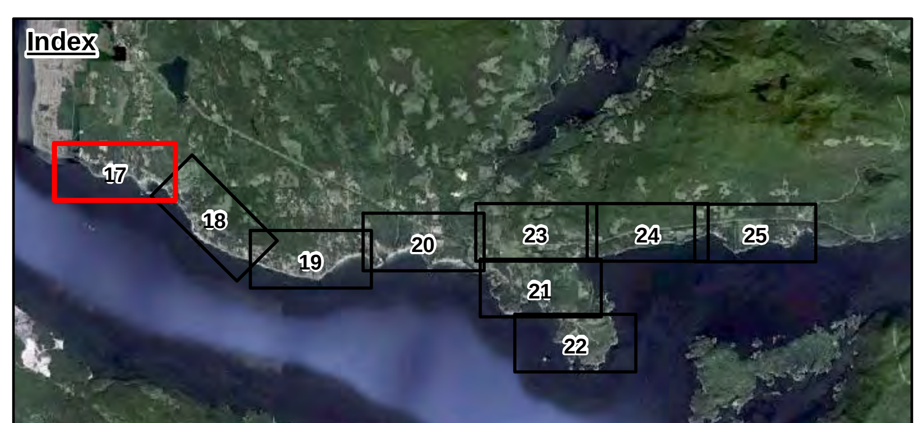
OFFICE	DATE
Tt EBA-VANC	September 1, 2015

Figure 16

Q:\Vancouver\GIS\ENGINEERING\V131\V13103482-01_PowellRiver\Maps\V13103482-01_Figure16_AreaC_FluvialHaz.mxd modified 01/09/2015 by stephanie.leusink

LEGEND

- Fluvial Hazard Polygon
- Coastline
- Contour (10 m)
- PRRD Electoral Area Boundary
- Provincial Park
- Indian Reserve
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry



NOTES

Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Fluvial Hazard Polygons

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000

200 100 0 200

Metres

FILE NO.
V13103482-01_Figure17-25_HazardPolys.mxd

TETRA TECH EBA

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	MEZ	YL	DJ	0

OFFICE	DATE
Tt EBA-VANC	September 1, 2015

Figure 17

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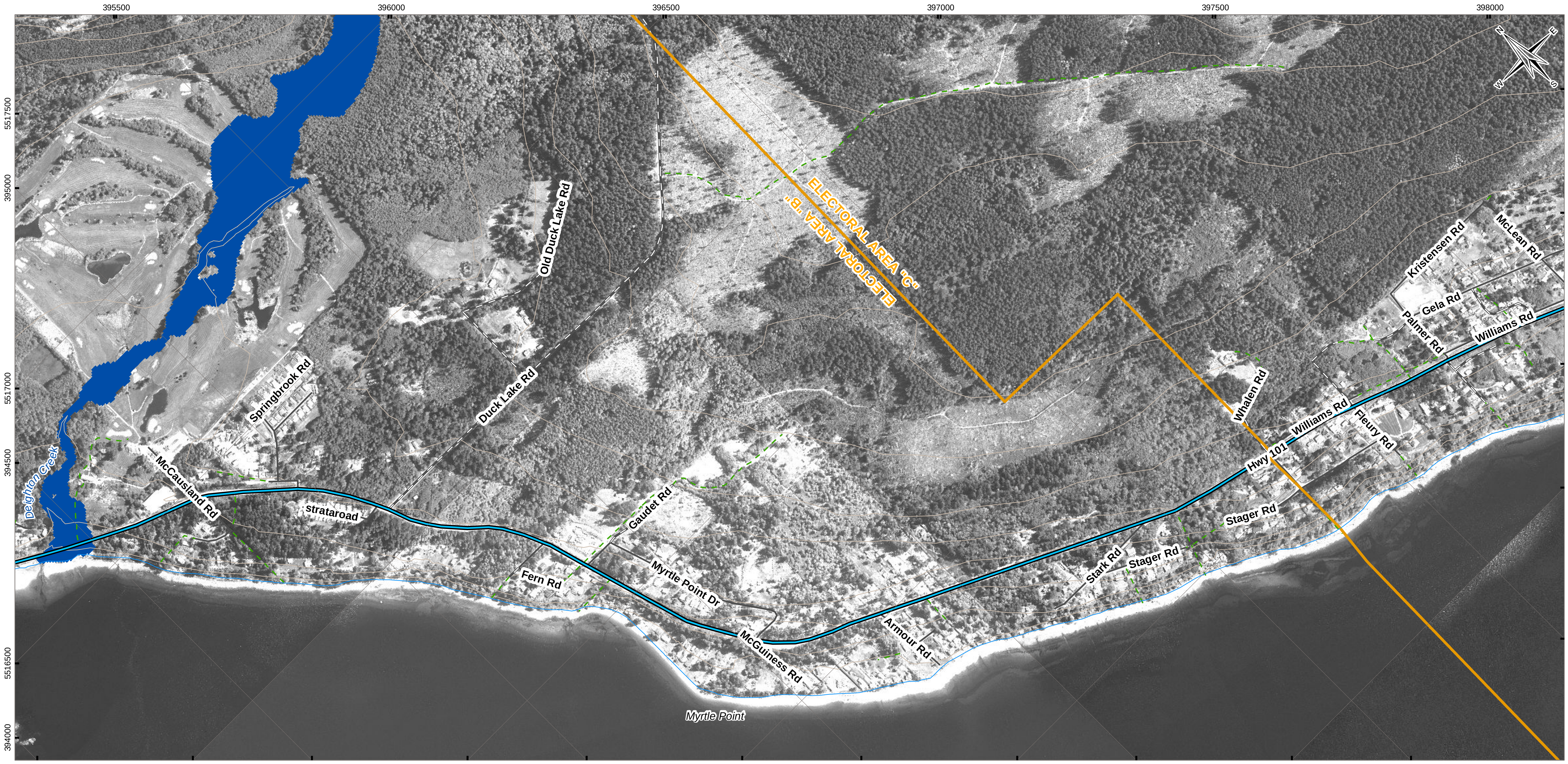

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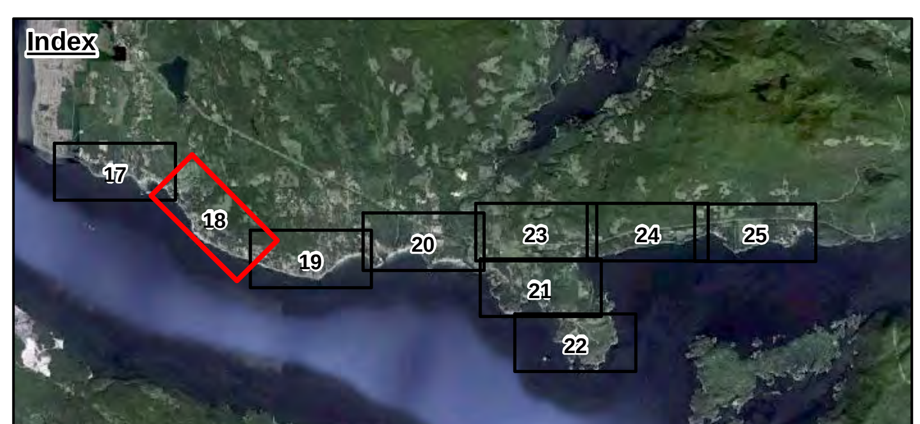
LEGEND

- Fluvial Hazard Polygon
- Coastline
- Contour (10 m)
- PRRD Electoral Area Boundary
- Provincial Park
- Indian Reserve
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry

Index



NOTES

Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Fluvial Hazard Polygons

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000
200 100 0 200
Metres

Tetra Tech EBA

FILE NO.
V13103482-01_Figure17-25_HazardPolys.mxd

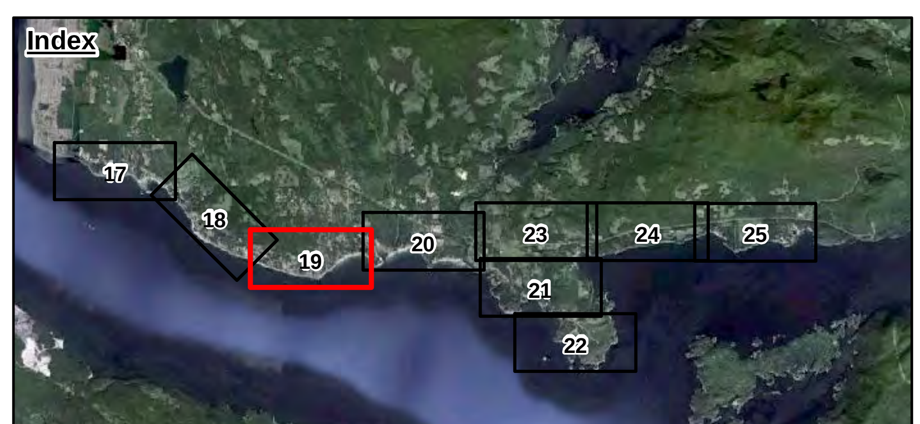
PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	MEZ	YL	DJ	0

OFFICE	DATE
Tt EBA-VANC	September 1, 2015

Figure 18

LEGEND

- Fluvial Hazard Polygon
- Coastline
- Contour (10 m)
- PRRD Electoral Area Boundary
- Provincial Park
- Indian Reserve
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry



NOTES
Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Fluvial Hazard Polygons

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000
200 100 0 200
Metres

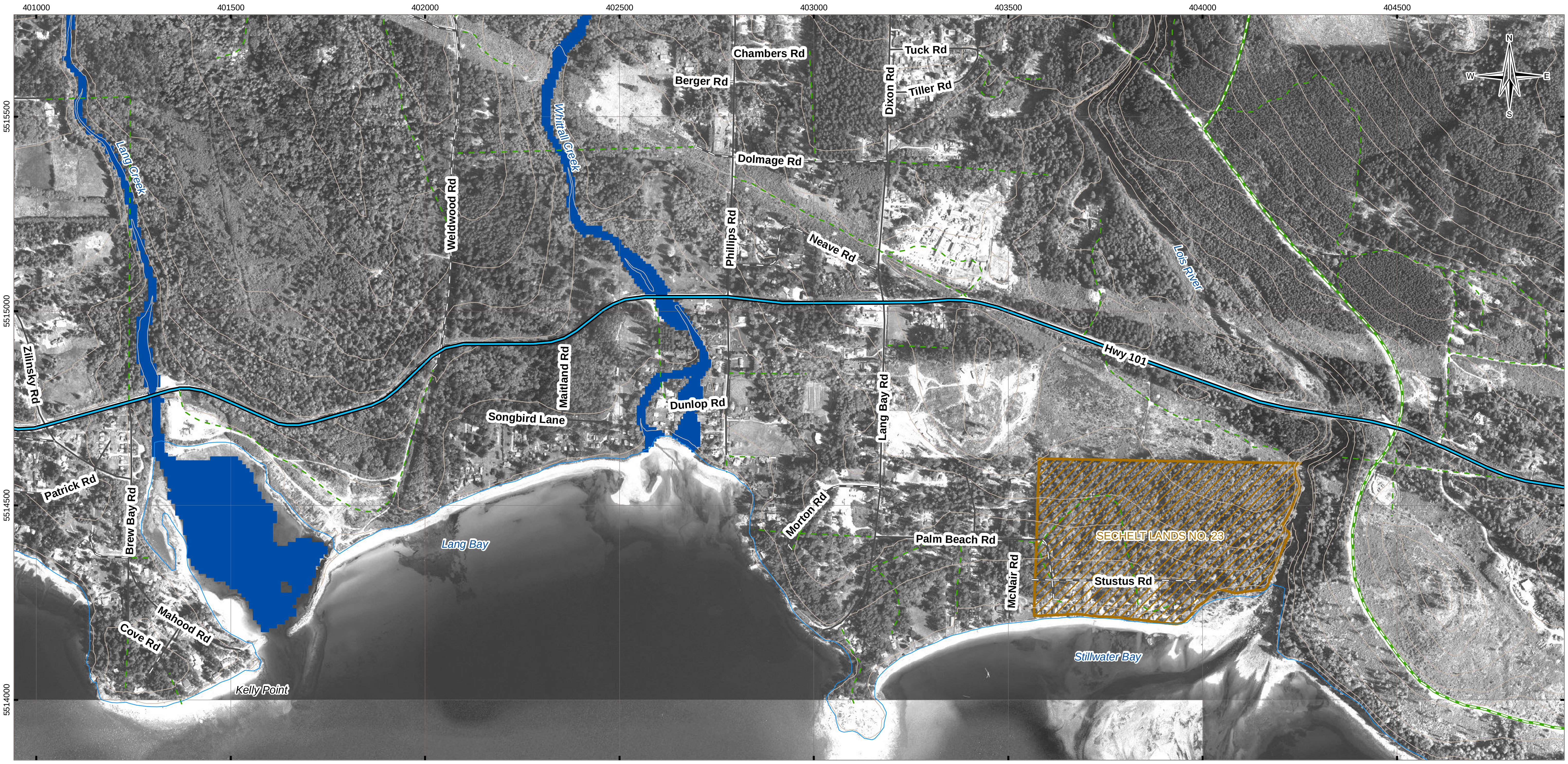
FILE NO.
V13103482-01_Figure17-25_HazardPolys.mxd

TETRA TECH EBA

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	MEZ	YL	DJ	0

OFFICE	DATE
Tt EBA-VANC	September 1, 2015

Figure 19



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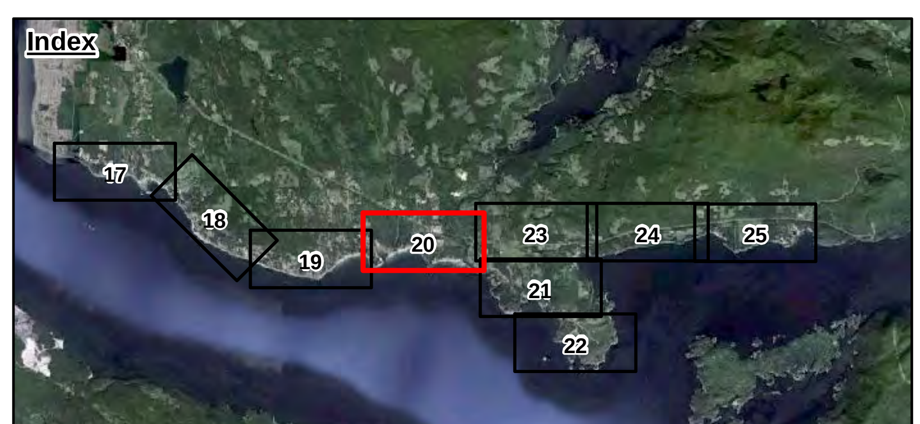
LEGEND

- Fluvial Hazard Polygon
- Coastline
- Contour (10 m)
- PRRD Electoral Area Boundary
- Provincial Park
- Indian Reserve
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry



NOTES

Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Fluvial Hazard Polygons

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000

200 100 0 200

Metres

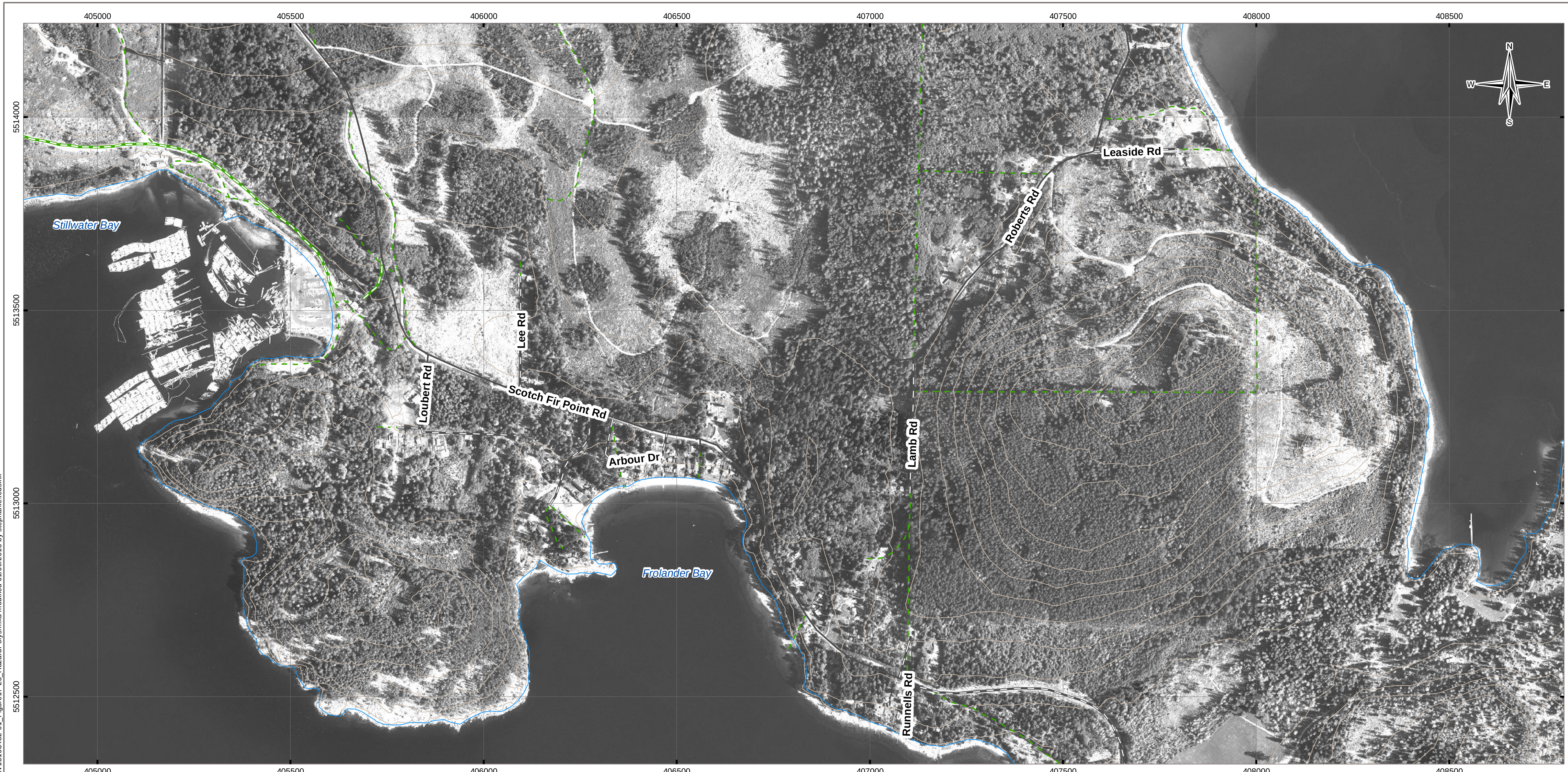
FILE NO.
V13103482-01_Figure17-25_HazardPolys.mxd

TETRA TECH EBA

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	MEZ	YL	DJ	0

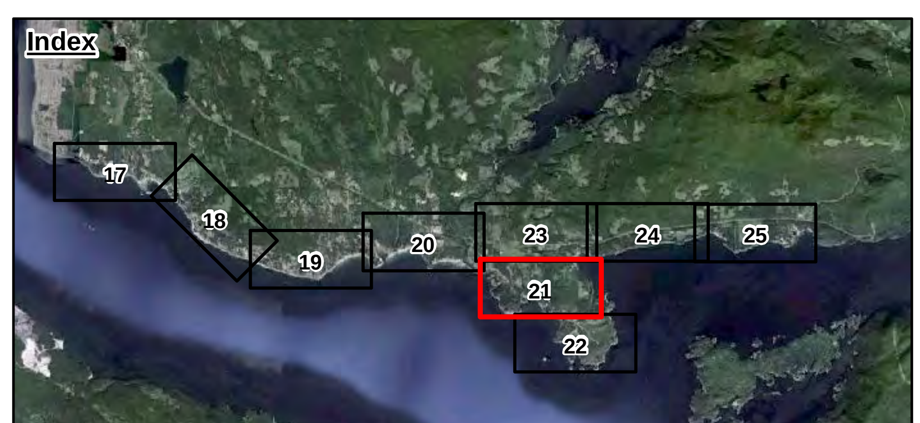
OFFICE	DATE
Tt EBA-VANC	September 1, 2015

Figure 20



LEGEND

- Fluvial Hazard Polygon
- Coastline
- Contour (10 m)
- PRRD Electoral Area Boundary
- Provincial Park
- Indian Reserve
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry



NOTES

Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Fluvial Hazard Polygons

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000

200 100 0 200

Metres

FILE NO.
V13103482-01_Figure17-25_HazardPolys.mxd

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	MEZ	YL	DJ	0

OFFICE	DATE
Tt EBA-VANC	September 1, 2015

TETRA TECH EBA

Figure 21

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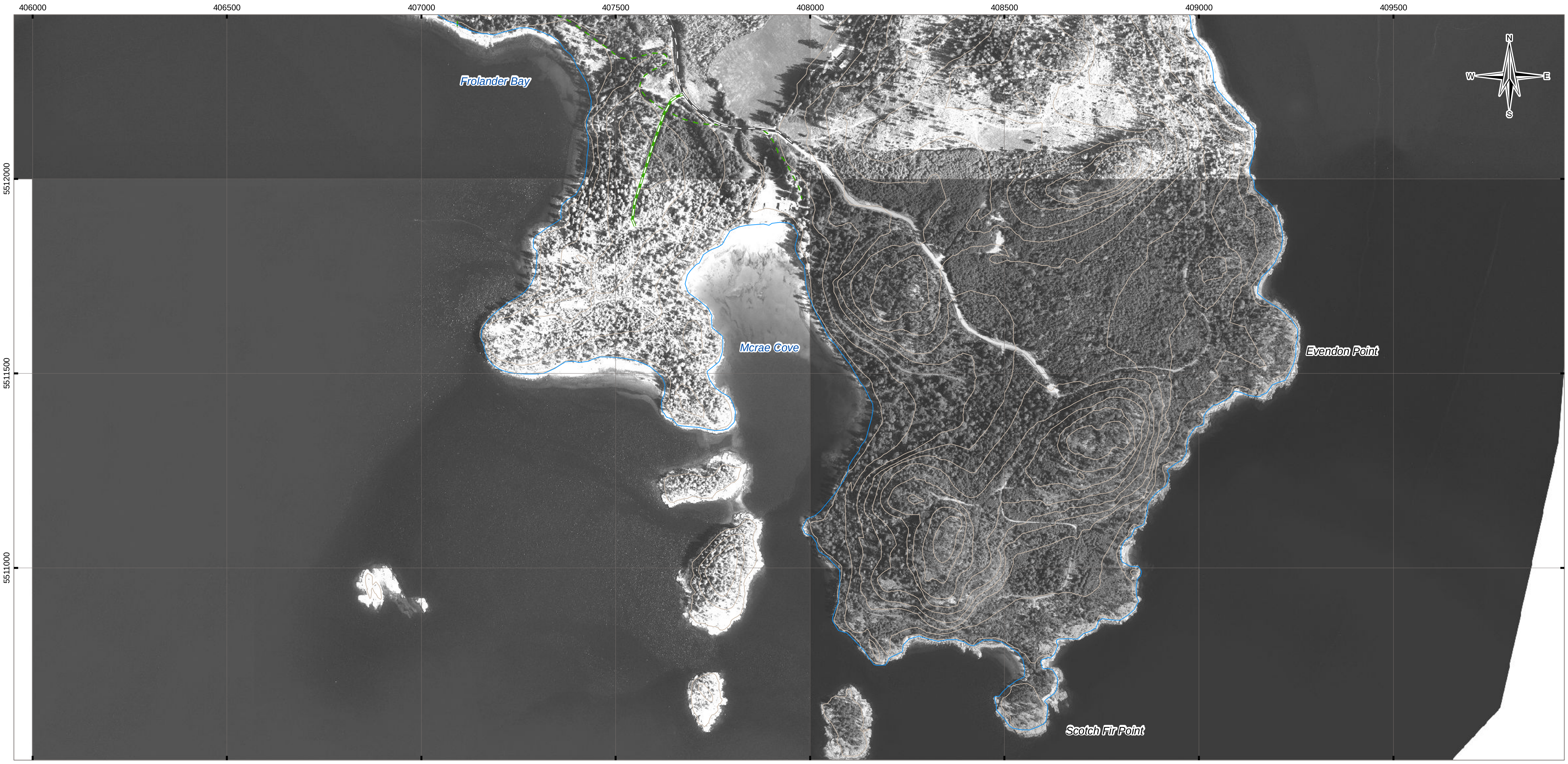
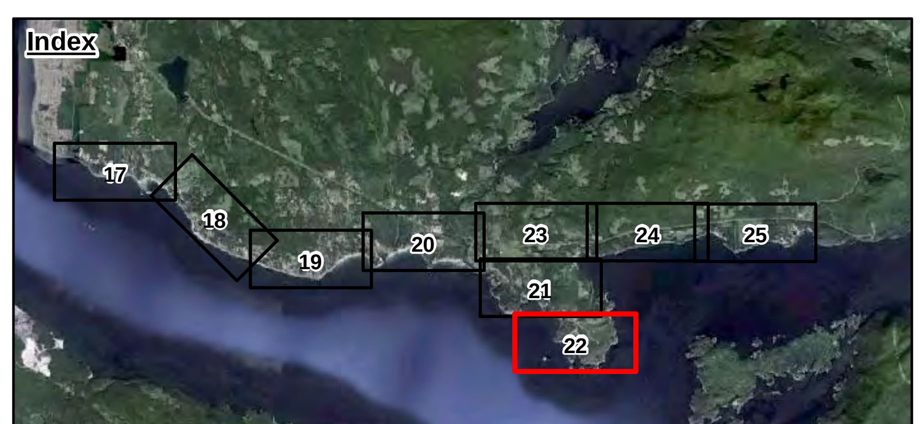


LEGEND

- Fluvial Hazard Polygon
- Coastline
- Contour (10 m)
- PRRD Electoral Area Boundary
- Provincial Park
- Indian Reserve
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry



NOTES

Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Fluvial Hazard Polygons

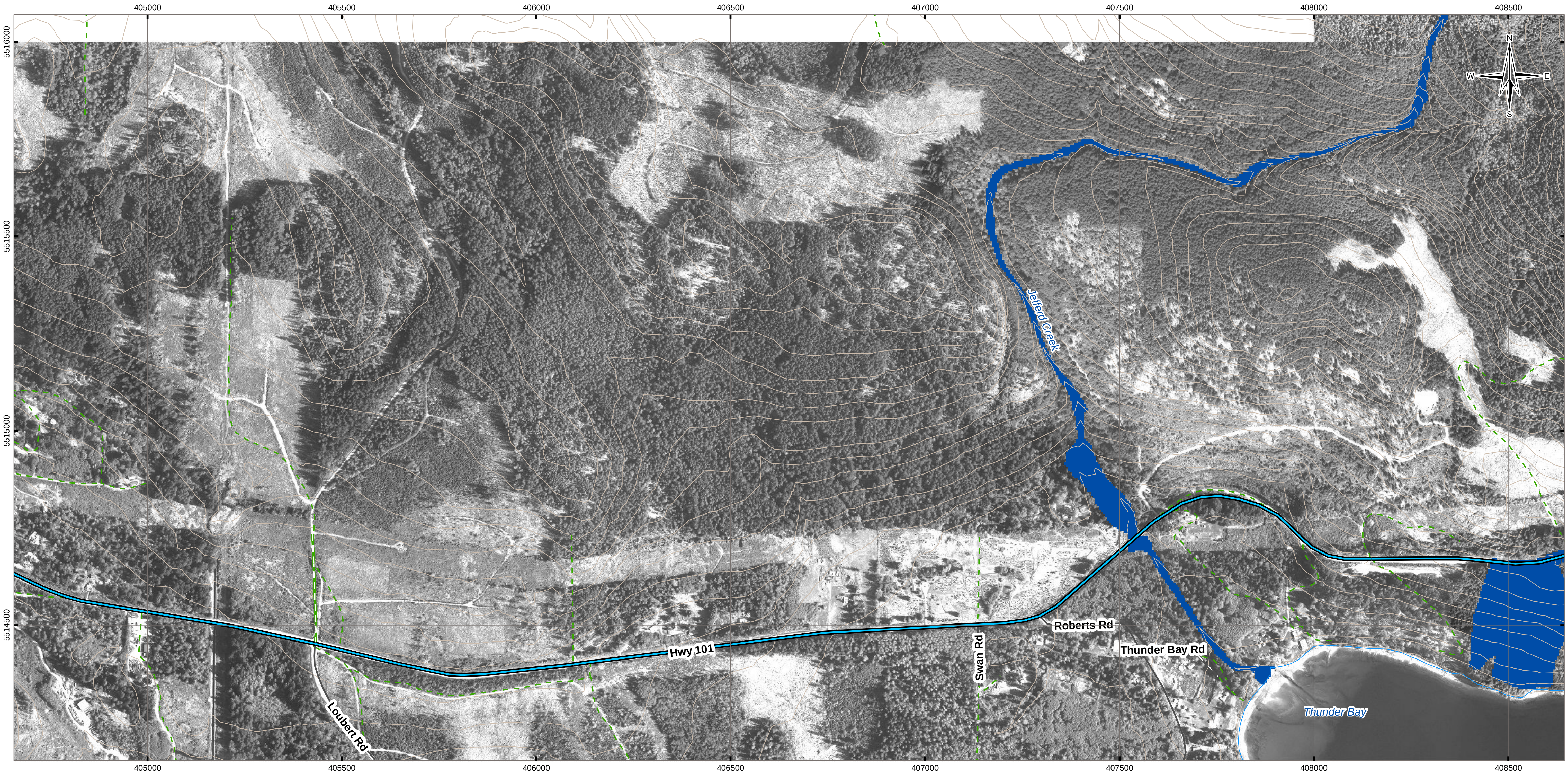
PROJECTION: UTM Zone 10	DATUM: NAD83
Scale: 1:10,000 (200 100 0 200 Metres)	
FILE NO.: V13103482-01_Figure17-25_HazardPolys.mxd	
PROJECT NO.: V13103482-01	DWN: MEZ · CKD: YL · APVD: DJ · REV: 0
OFFICE: Tt EBA-VANC	DATE: September 1, 2015

CLIENT: Powell River Regional District

TETRA TECH EBA

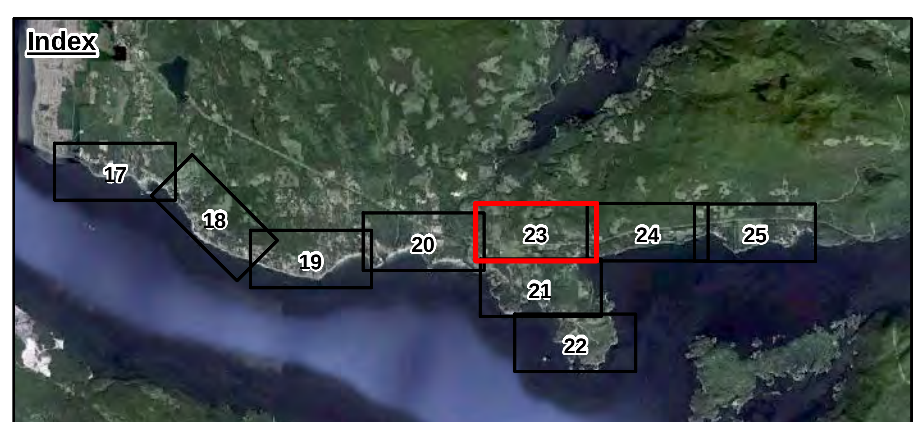
Figure 22

Q:\Vancouver\GIS\ENGINEERING\V131\V13103482-01_PowellRiver\Maps\V13103482-01_Figure17-25_HazardPolys.mxd modified 01/09/2015 by stephanie.leusink



LEGEND

- Fluvial Hazard Polygon
- Coastline
- Contour (10 m)
- PRRD Electoral Area Boundary
- Provincial Park
- Indian Reserve
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry



NOTES

Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Fluvial Hazard Polygons

PROJECTION: UTM Zone 10	DATUM: NAD83

Scale: 1:10,000

200 100 0 200

Metres

CLIENT: Powell River Regional District

TETRA TECH EBA

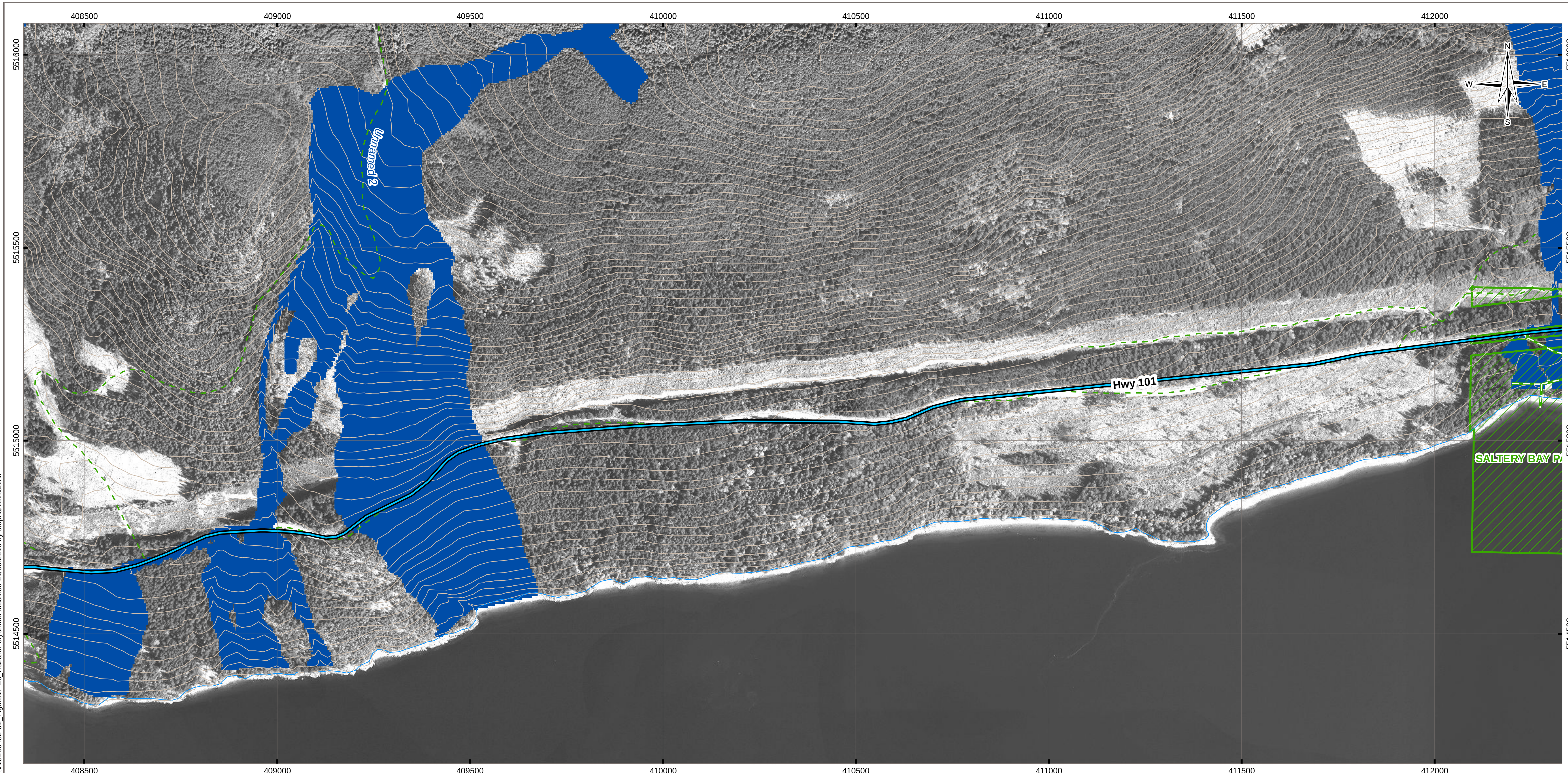
FILE NO.: V13103482-01_Figure17-25_HazardPolys.mxd

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	MEZ	YL	DJ	0

OFFICE	DATE
Tt EBA-VANC	September 1, 2015

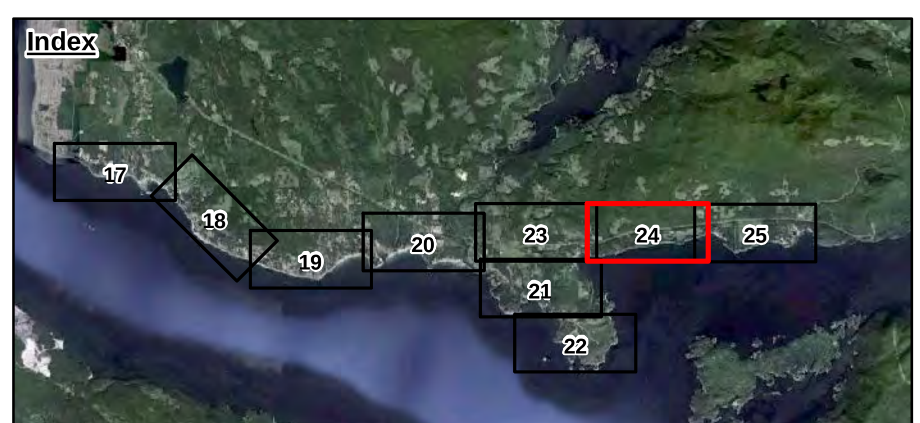
Figure 23

Q:\Vancouver\GIS\ENGINEERING\V131\V13103482-01_PowellRiver\Maps\V13103482-01_Figure17-25_HazardPolys.mxd modified 01/09/2015 by stephanie.leusink



LEGEND

- Fluvial Hazard Polygon
- Coastline
- Contour (10 m)
- PRRD Electoral Area Boundary
- Provincial Park
- Indian Reserve
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry



NOTES

Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Fluvial Hazard Polygons

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	POWELL RIVER REGIONAL DISTRICT

Scale: 1:10,000

200 100 0 200

Metres

FILE NO.
V13103482-01_Figure17-25_HazardPolys.mxd

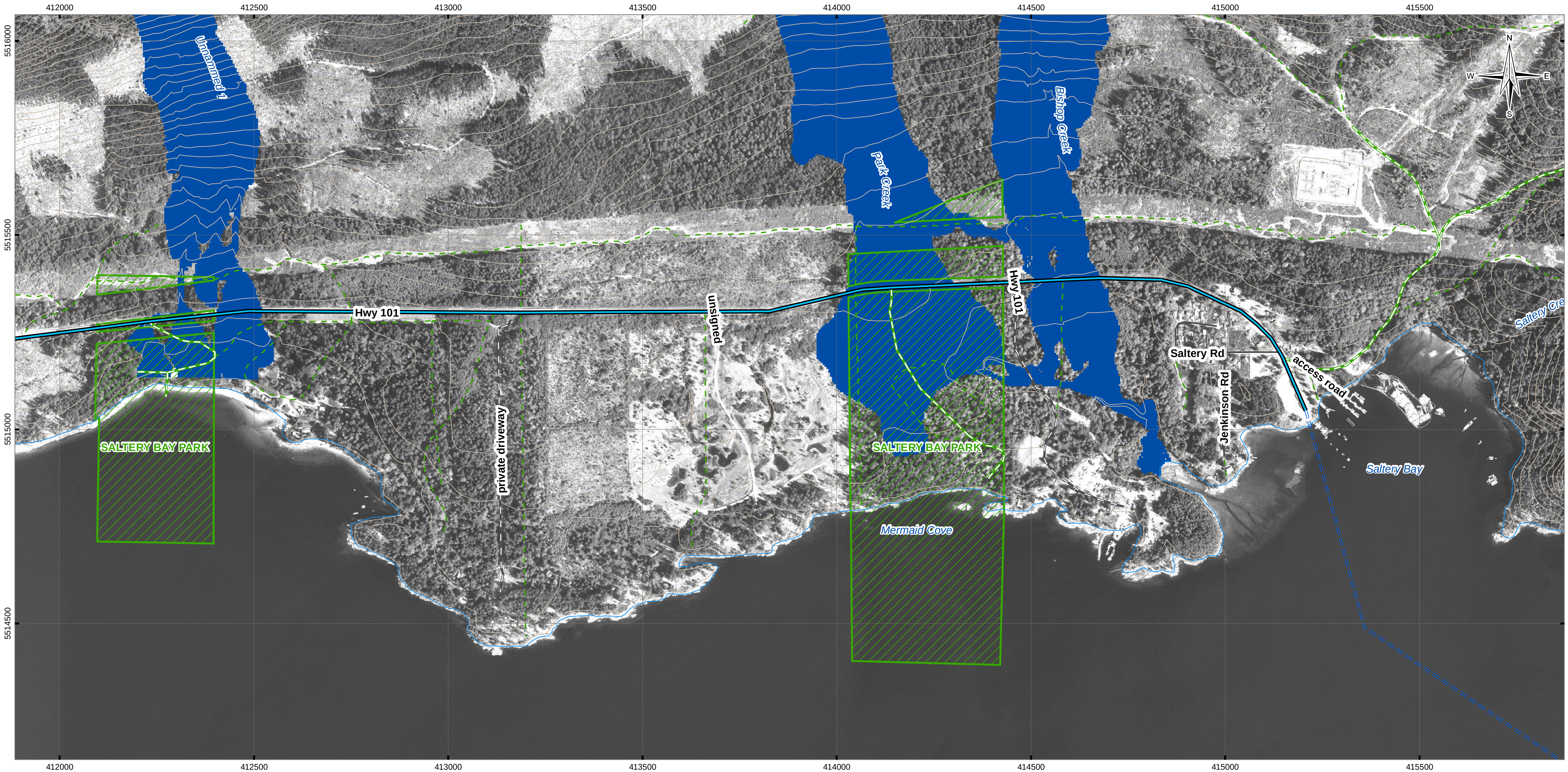
TETRA TECH EBA

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	MEZ	YL	DJ	0

OFFICE	DATE
Tt EBA-VANC	September 1, 2015

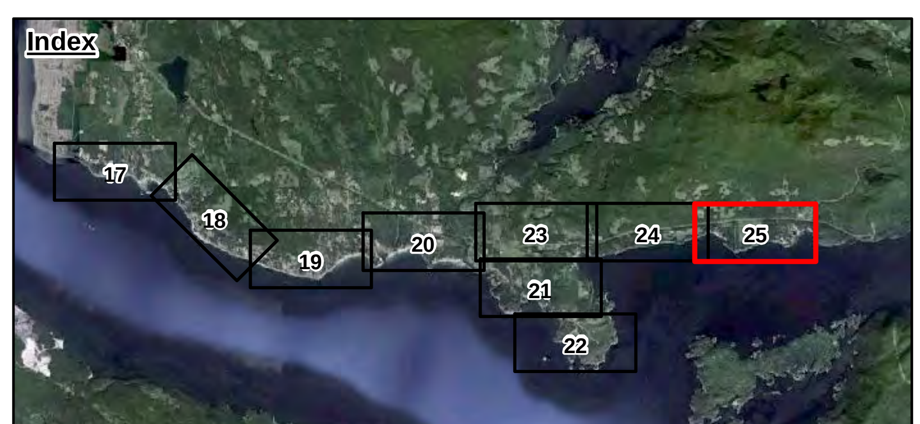
Figure 24

Q:\Vancouver\GIS\ENGINEERING\V131\V13103482-01_PowellRiver\Maps\V13103482-01_Figure17-25_HazardPolys.mxd modified 01/09/2015 by stephanie.leusink



LEGEND

- Fluvial Hazard Polygon
- Coastline
- Contour (10 m)
- PRRD Electoral Area Boundary
- Provincial Park
- Indian Reserve
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry



NOTES

Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Fluvial Hazard Polygons

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	POWELL RIVER REGIONAL DISTRICT

Scale: 1:10,000
200 100 0 200
Metres

TETRA TECH EBA

FILE NO.
V13103482-01_Figure17-25_HazardPolys.mxd

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	MEZ	YL	DJ	0

OFFICE	DATE
Tt EBA-VANC	September 1, 2015

Figure 25

PHOTOGRAPHS

Photos 1 to 13

Photo 1: View of near-vertical eroding slope located along the crest of the coastal escarpment near Rifle Range Road. Note highway culvert in centre of photo. (Photo taken June 2015).

Photo 2: View of recent landslides along the coastal escarpment at Stevenson Road. Note slide debris at the bottom of the photo. Larger slide in the centre of the photo has been subsequently blanketed with riprap. (Photo taken June 2015).

Photo 3: View of December 2014 landslide scarp along the coastal escarpment at Stittle Road. (Photo taken June 2015).

Photo 4: View of older landslide scarps (bowl-shaped depressions) along the coastal escarpment near Fleury Road. (Photo taken June 2015).

Photo 5: View of landslide scarp at Stittle Road, taken shortly after the failure occurred in December 2014. (Photo provided by PRRD).

Photo 6: View of landslide debris along the coastal escarpment at Random Road, taken shortly after the failure occurred in December 2014. (Photo provided by PRRD).

Photo 7: View of December 2014 landslide along Highway 101 near Deighton Creek. Failure has been subsequently blanketed with riprap with drainage pipe extended to the base of the slope. (Photo taken June 2015).

Photo 8: View of recent landslide on steep forested slopes near Myrtle Creek. Note overturned tree in centre of photo. (Photo taken June 2015).

Photo 9: View of coastal escarpment near McCausland Road. Curved tree trunk indicative of slope creep and potential landslide activity. (Photo taken June 2015).

Photo 10: View of steep forested slopes near Myrtle Creek. Curved / tilted tree trunks indicative of slope creep and potential landslide activity. (Photo taken June 2015).

Photo 11: View of rock fall debris within the transmission line right-of-way near Highway 101 at the Malaspina Viewpoint. (Photo taken June 2015).

Photo 12: View of rock fall debris near Stillwater Bay, sourced from an approximately 8 m high bedrock bluff located to the left of the photo.

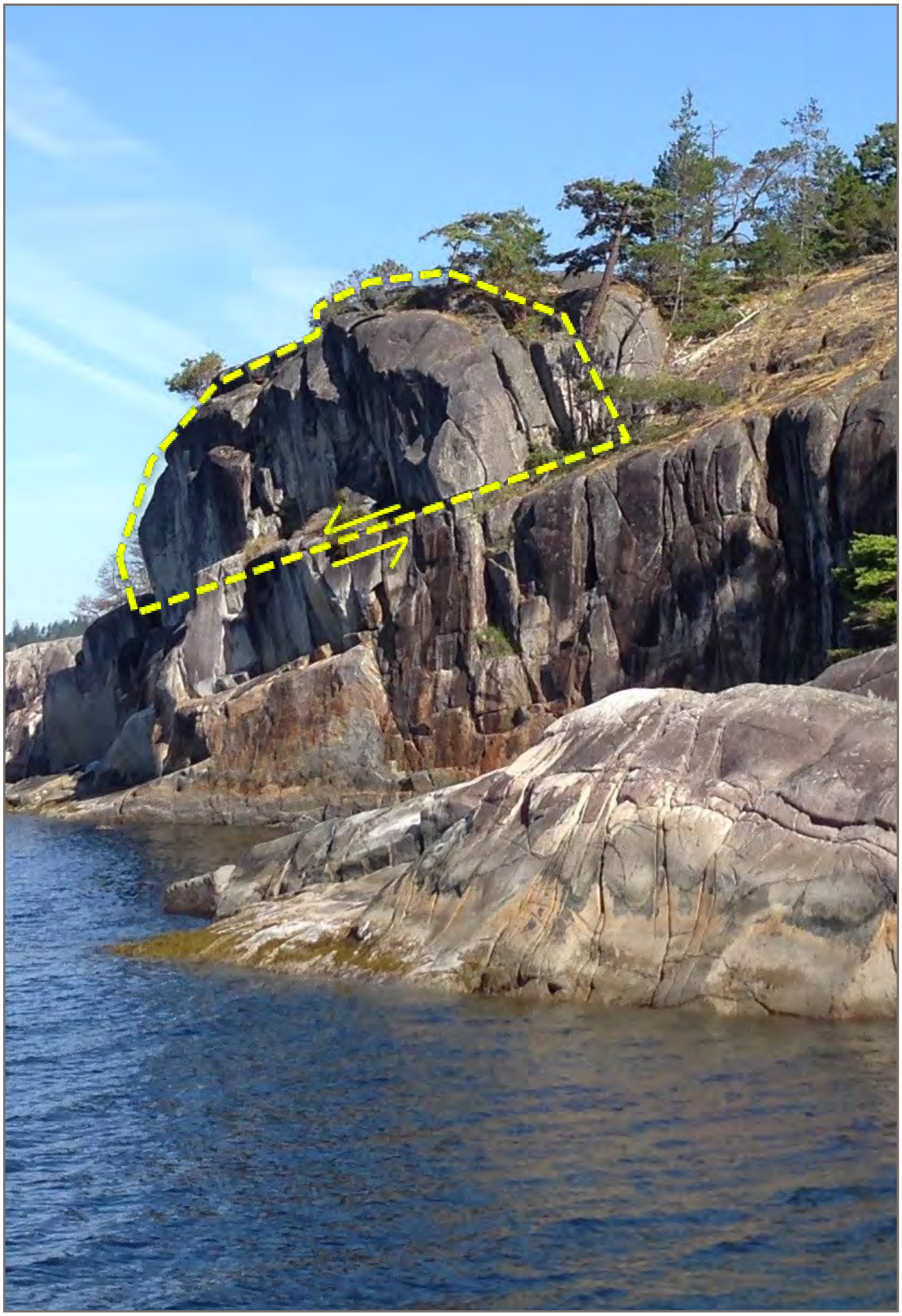


Photo 13: View of potentially unstable bedrock bluff (area circled in yellow), located near Stillwater Bay. (Photo taken June 2015).

APPENDIX A
TETRA TECH EBA'S GENERAL CONDITIONS

GENERAL CONDITIONS

GEOTECHNICAL REPORT

This report incorporates and is subject to these “General Conditions”.

1.0 USE OF REPORT AND OWNERSHIP

This geotechnical report pertains to a specific site, a specific development and a specific scope of work. It is not applicable to any other sites nor should it be relied upon for types of development other than that to which it refers. Any variation from the site or development would necessitate a supplementary geotechnical assessment.

This report and the recommendations contained in it are intended for the sole use of Tetra Tech EBA’s Client. Tetra Tech EBA does not accept any responsibility for the accuracy of any of the data, the analyses or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than Tetra Tech EBA’s Client unless otherwise authorized in writing by Tetra Tech EBA. Any unauthorized use of the report is at the sole risk of the user.

This report is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of Tetra Tech EBA. Additional copies of the report, if required, may be obtained upon request.

2.0 ALTERNATE REPORT FORMAT

Where Tetra Tech EBA submits both electronic file and hard copy versions of reports, drawings and other project-related documents and deliverables (collectively termed Tetra Tech EBA’s instruments of professional service), only the signed and/or sealed versions shall be considered final and legally binding. The original signed and/or sealed version archived by Tetra Tech EBA shall be deemed to be the original for the Project.

Both electronic file and hard copy versions of Tetra Tech EBA’s instruments of professional service shall not, under any circumstances, no matter who owns or uses them, be altered by any party except Tetra Tech EBA. Tetra Tech EBA’s instruments of professional service will be used only and exactly as submitted by Tetra Tech EBA.

Electronic files submitted by Tetra Tech EBA have been prepared and submitted using specific software and hardware systems. Tetra Tech EBA makes no representation about the compatibility of these files with the Client’s current or future software and hardware systems.

3.0 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, Tetra Tech EBA has not been retained to investigate, address or consider and has not investigated, addressed or considered any environmental or regulatory issues associated with development on the subject site.

4.0 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems and methods employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Where deviations from the system or method prevail, they are specifically mentioned.

Classification and identification of geological units are judgmental in nature as to both type and condition. Tetra Tech EBA does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Where subsurface conditions encountered during development are different from those described in this report, qualified geotechnical personnel should revisit the site and review recommendations in light of the actual conditions encountered.

5.0 LOGS OF TESTHOLES

The testhole logs are a compilation of conditions and classification of soils and rocks as obtained from field observations and laboratory testing of selected samples. Soil and rock zones have been interpreted. Change from one geological zone to the other, indicated on the logs as a distinct line, can be, in fact, transitional. The extent of transition is interpretive. Any circumstance which requires precise definition of soil or rock zone transition elevations may require further investigation and review.

6.0 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of testholes and/or soil/rock exposures. Stratigraphy is known only at the locations of the testhole or exposure. Actual geology and stratigraphy between testholes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historic environment. Tetra Tech EBA does not represent the conditions illustrated as exact but recognizes that variations will exist. Where knowledge of more precise locations of geological units is necessary, additional investigation and review may be necessary.

7.0 PROTECTION OF EXPOSED GROUND

Excavation and construction operations expose geological materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations must be protected from the elements, particularly moisture, desiccation, frost action and construction traffic.

8.0 SUPPORT OF ADJACENT GROUND AND STRUCTURES

Unless otherwise specifically advised, support of ground and structures adjacent to the anticipated construction and preservation of adjacent ground and structures from the adverse impact of construction activity is required.

9.0 INFLUENCE OF CONSTRUCTION ACTIVITY

There is a direct correlation between construction activity and structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques are known.

10.0 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, as well as the potential of adverse circumstances arising from construction activity, observations during site preparation, excavation and construction should be carried out by a geotechnical engineer. These observations may then serve as the basis for confirmation and/or alteration of geotechnical recommendations or design guidelines presented herein.

11.0 DRAINAGE SYSTEMS

Where temporary or permanent drainage systems are installed within or around a structure, the systems which will be installed must protect the structure from loss of ground due to internal erosion and must be designed so as to assure continued performance of the drains. Specific design detail of such systems should be developed or reviewed by the geotechnical engineer. Unless otherwise specified, it is a condition of this report that effective temporary and permanent drainage systems are required and that they must be considered in relation to project purpose and function.

12.0 BEARING CAPACITY

Design bearing capacities, loads and allowable stresses quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition assumed. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions assumed in this report in fact exist at the site.

13.0 SAMPLES

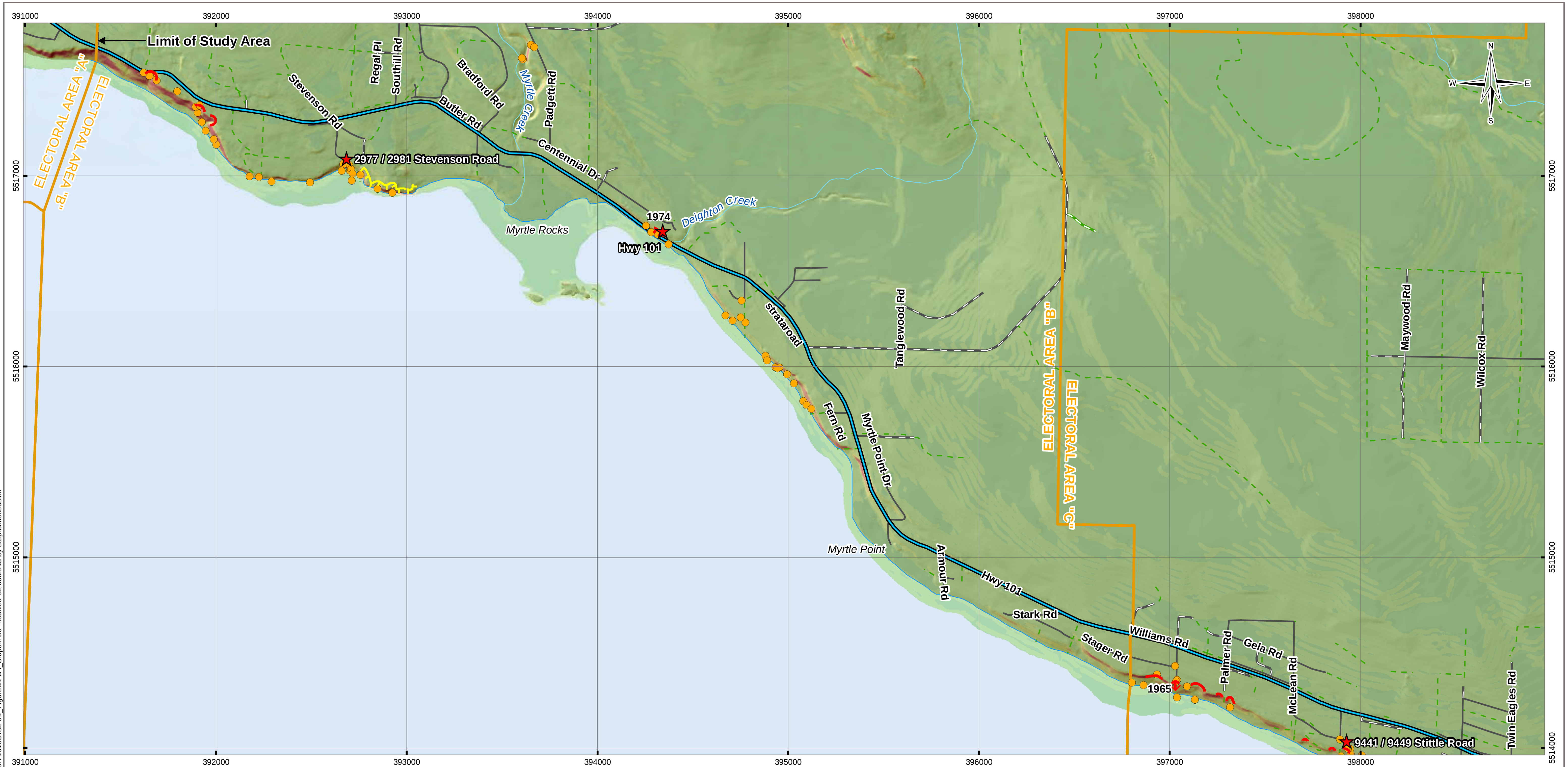
Tetra Tech EBA will retain all soil and rock samples for 30 days after this report is issued. Further storage or transfer of samples can be made at the Client’s expense upon written request, otherwise samples will be discarded.

14.0 INFORMATION PROVIDED TO TETRA TECH EBA BY OTHERS

During the performance of the work and the preparation of the report, Tetra Tech EBA may rely on information provided by persons other than the Client. While Tetra Tech EBA endeavours to verify the accuracy of such information when instructed to do so by the Client, Tetra Tech EBA accepts no responsibility for the accuracy or the reliability of such information which may affect the report.

APPENDIX B

SLOPE GRADIENT AND LANDSLIDE INVENTORY MAPPING

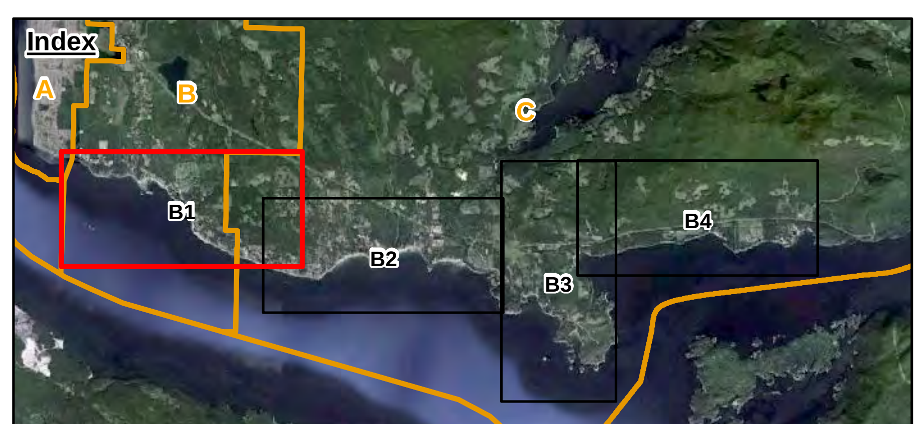


LEGEND

- December 2014 Landslide Event
- Waypoint
- Visible Scarp
- Historic Erosion/Landslide Events
- Rock Bluff
- Gullied Terrain
- Coastline
- Contour (10 m)
- PRRD Electoral Area Boundary
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry
- Watercourse
- Provincial Park
- Indian Reserve

Slope Gradient (%)

- < 5%
- 5% - 27%
- 27% - 50%
- 50% - 60%
- 60% - 70%
- 70% - 80%
- > 80%



NOTES

1. The terrain features noted on the figures are based on desktop review of the available imagery and limited field checking.
2. The years noted on the figures correspond to the year of the air photo where this feature was observed.
3. Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas; CanVec.
4. Slope gradients derived from 2 m contours provided by PRRD.

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Slope Gradient and Landslide Inventory Mapping

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:20,000
400 200 0 400
Metres

Tetra Tech EBA

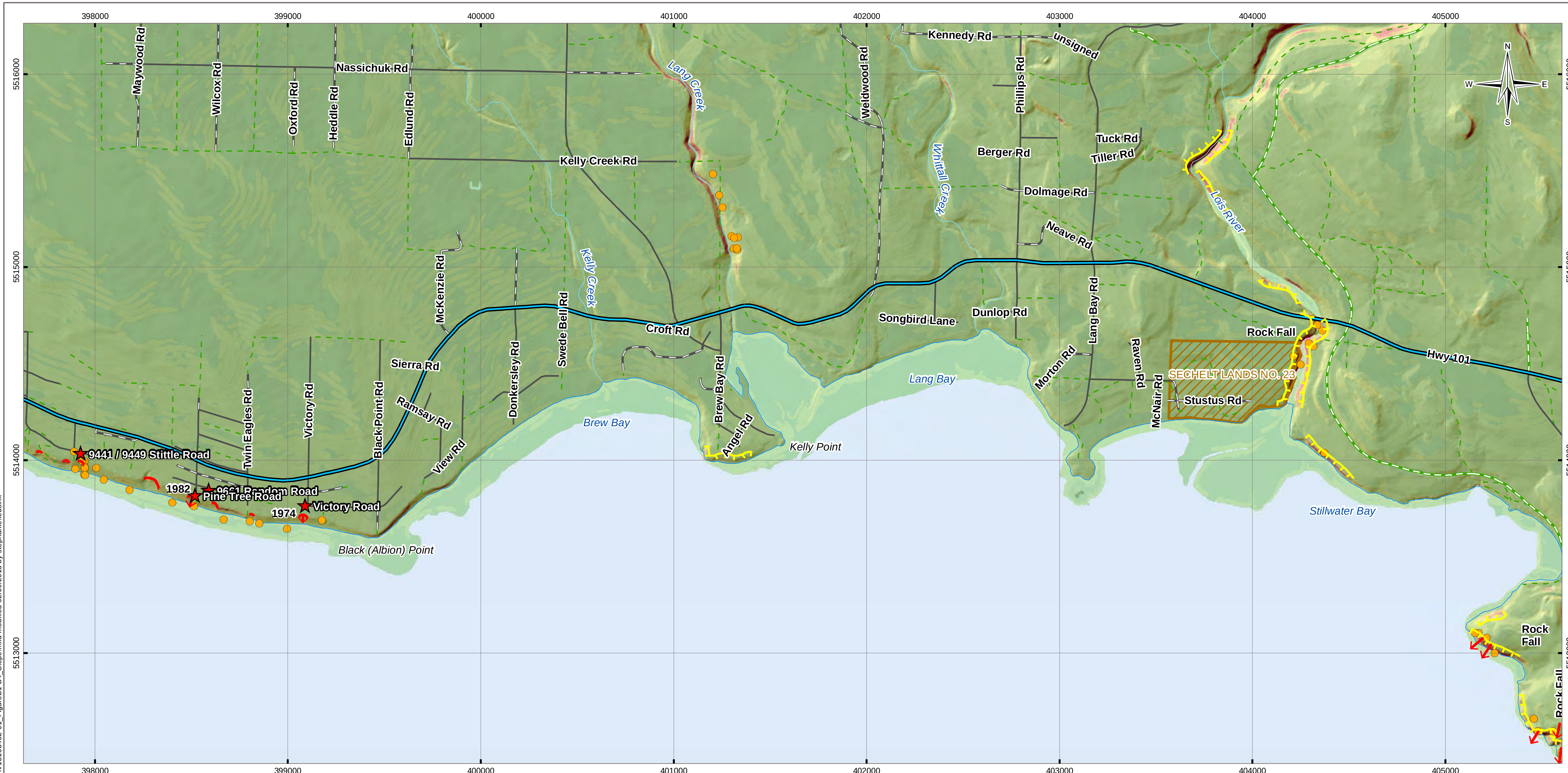
FILE NO.
V13103482-01_FigureB1-B4_Slope.mxd

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	MEZ	SL	JP	0

OFFICE	DATE
Tt EBA-VANC	September 2, 2015

Figure B1

Q:\Vancouver\GIS\ENGINEERING\V131\V13103482-01_PowellRiver\Maps\V13103482-01_FigureB1-B4_Slope.mxd modified 02/09/2015 by stephanie.leusink

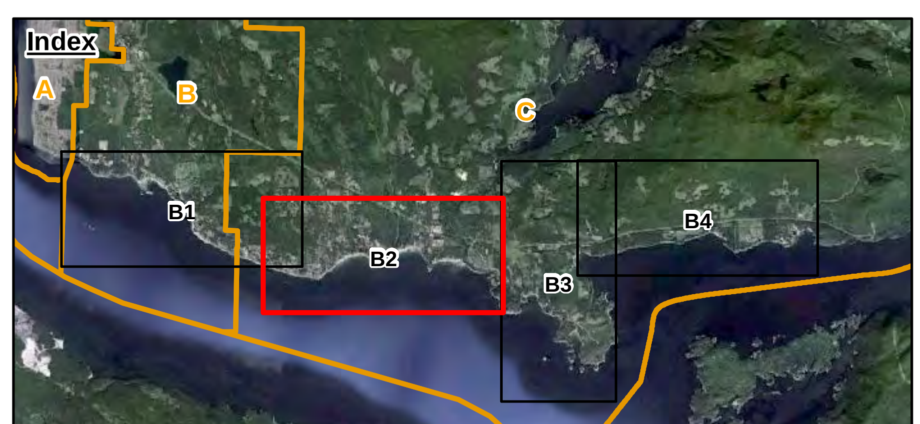


LEGEND

- December 2014 Landslide Event
- Waypoint
- Visible Scarp
- Historic Erosion/Landslide Events
- Rock Bluff
- Gullied Terrain
- Coastline
- Contour (10 m)
- PRRD Electoral Area Boundary
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry
- Watercourse
- Provincial Park
- Indian Reserve

Slope Gradient (%)

- < 5%
- 5% - 27%
- 27% - 50%
- 50% - 60%
- 60% - 70%
- 70% - 80%
- > 80%



NOTES

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4. Slope gradients derived from 2 m contours provided by PRRD.

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Slope Gradient and Landslide Inventory Mapping

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:20,000
400 200 0 400
Metres

TETRA TECH EBA

FILE NO.
V13103482-01_FigureB1-B4_Slope.mxd

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	MEZ	SL	JP	0

OFFICE	DATE
Tt EBA-VANC	September 2, 2015

Figure B2

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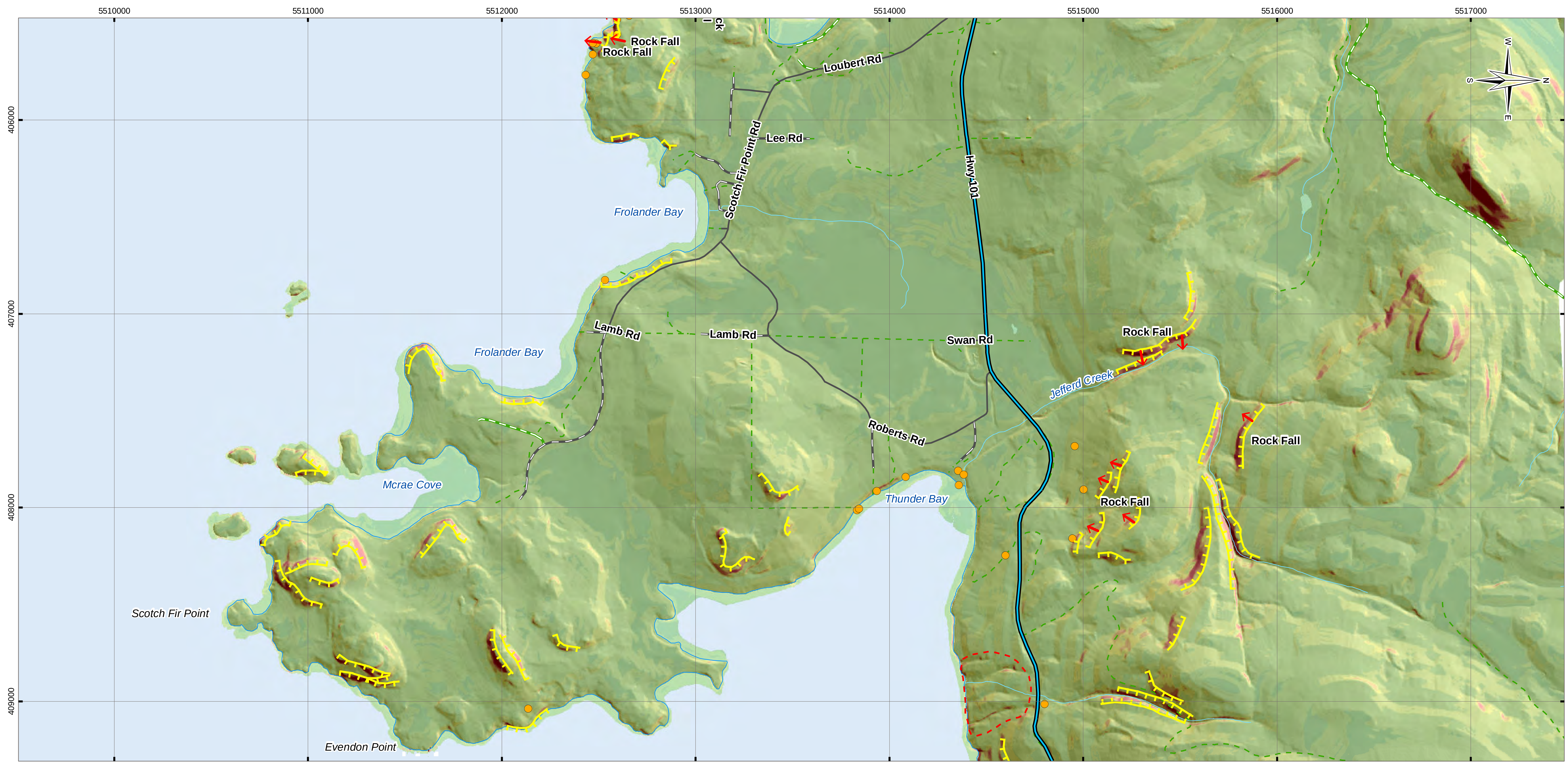
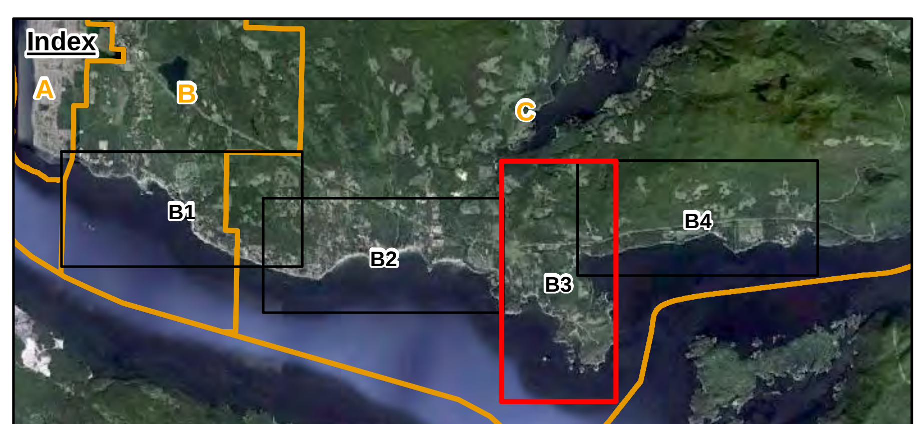


LEGEND

- December 2014 Landslide Event
- Waypoint
- Visible Scarp
- Historic Erosion/Landslide Events
- Rock Bluff
- Gullied Terrain
- Coastline
- Contour (10 m)
- PRRD Electoral Area Boundary
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry
- Watercourse
- Provincial Park
- Indian Reserve

Slope Gradient (%)

- < 5%
- 5% - 27%
- 27% - 50%
- 50% - 60%
- 60% - 70%
- 70% - 80%
- > 80%



NOTES

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3. Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas; CanVec.
4. Slope gradients derived from 2 m contours provided by PRRD.

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Slope Gradient and Landslide Inventory Mapping

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District
Scale: 1:20,000 (400 200 0 400 Metres)		TETRA TECH EBA

FILE NO.
V13103482-01_FigureB1-B4_Slope.mxd

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	MEZ	SL	JP	0

OFFICE	DATE
Tt EBA-VANC	September 2, 2015

Figure B3

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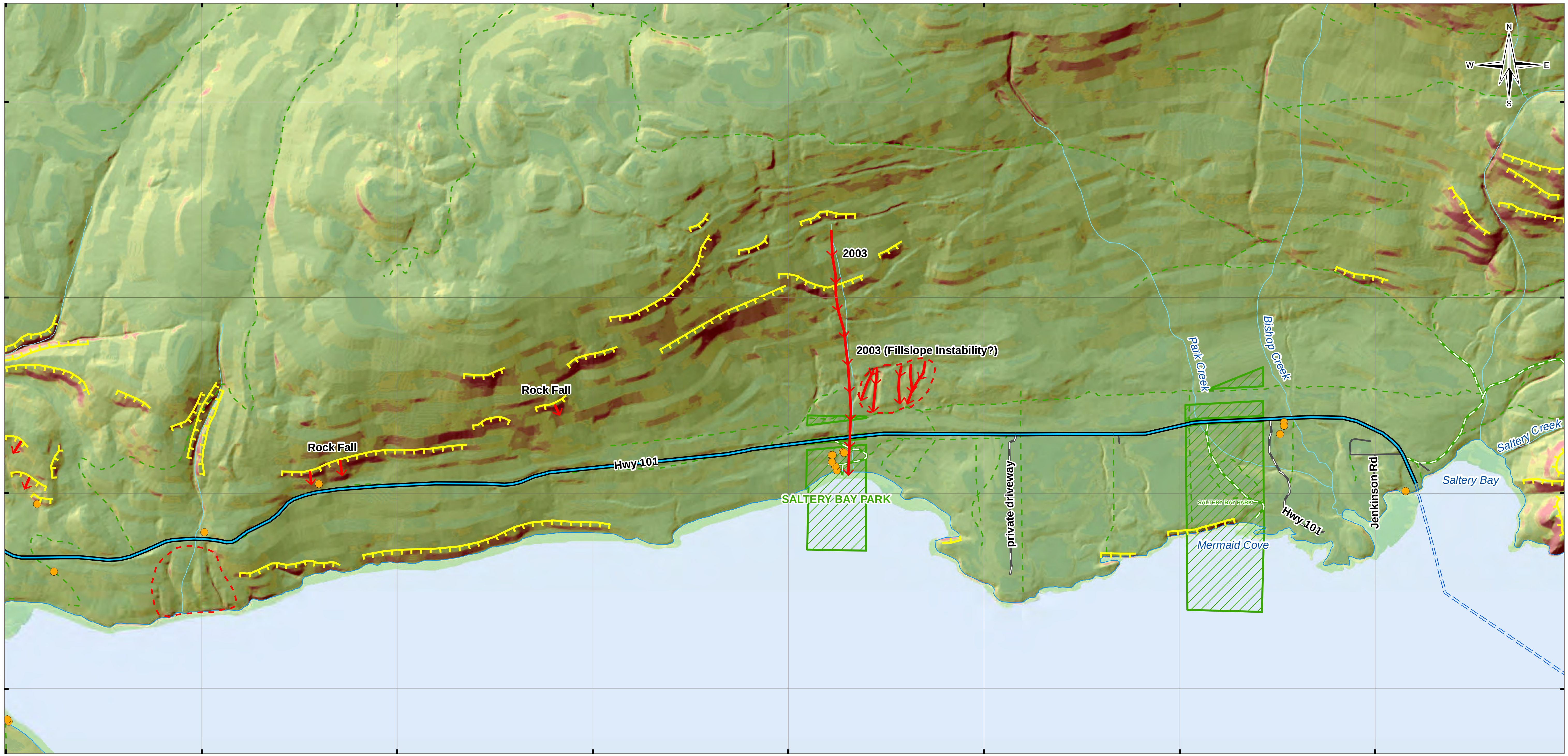

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LEGEND

- ★ December 2014 Landslide Event
- Waypoint
- Visible Scarp
- Historic Erosion/Landslide Events
- Rock Bluff
- Gullied Terrain
- Coastline
- Contour (10 m)
- PRRD Electoral Area Boundary
- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry
- Watercourse
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- Indian Reserve

Slope Gradient (%)

- < 5%
- 5% - 27%
- 27% - 50%
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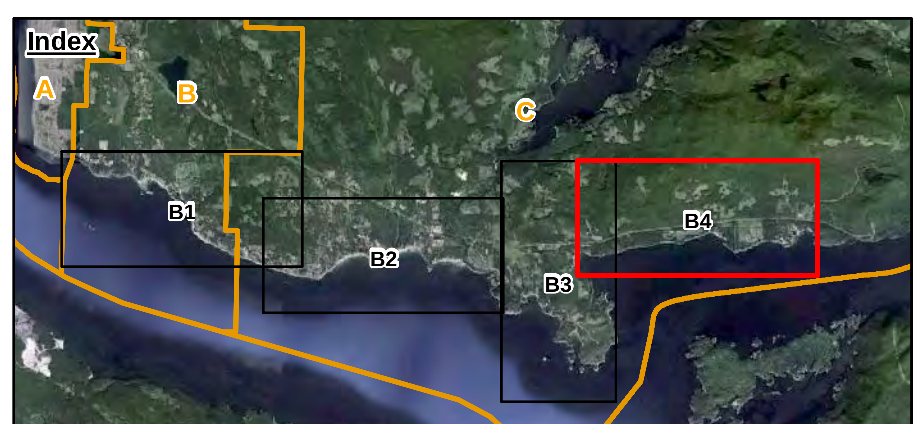

NOTES

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2. The years noted on the figures correspond to the year of the air photo where this feature was observed.
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4. Slope gradients derived from 2 m contours provided by PRRD.

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Slope Gradient and Landslide Inventory Mapping

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:20,000
400 200 0 400
Metres

FILE NO.
V13103482-01_FigureB1-B4_Slope.mxd

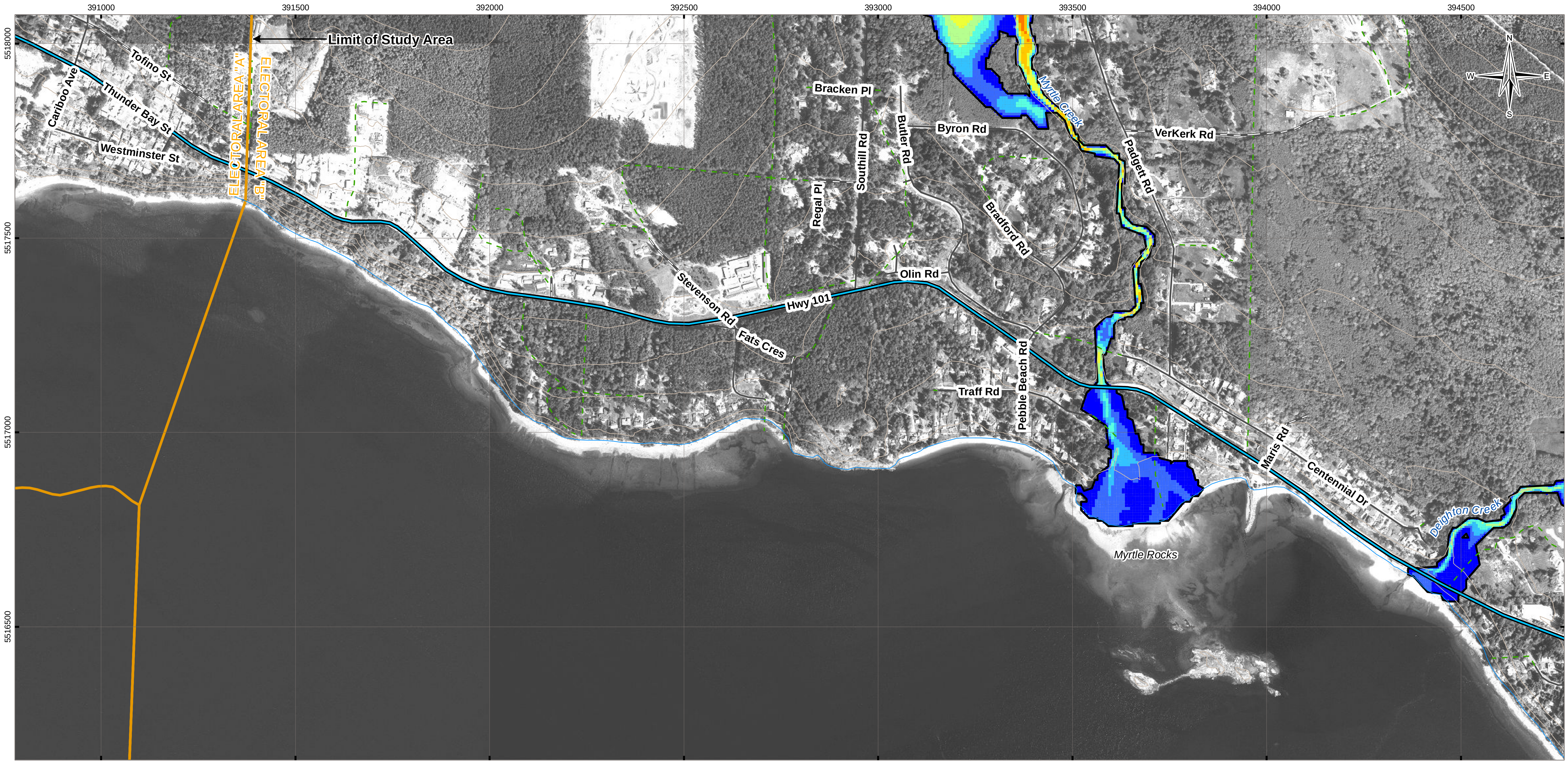
TETRA TECH EBA

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	MEZ	SL	JP	0

OFFICE	DATE
Tt EBA-VANC	September 2, 2015

Figure B4

APPENDIX C
FLOOD INUNDATION MODELS



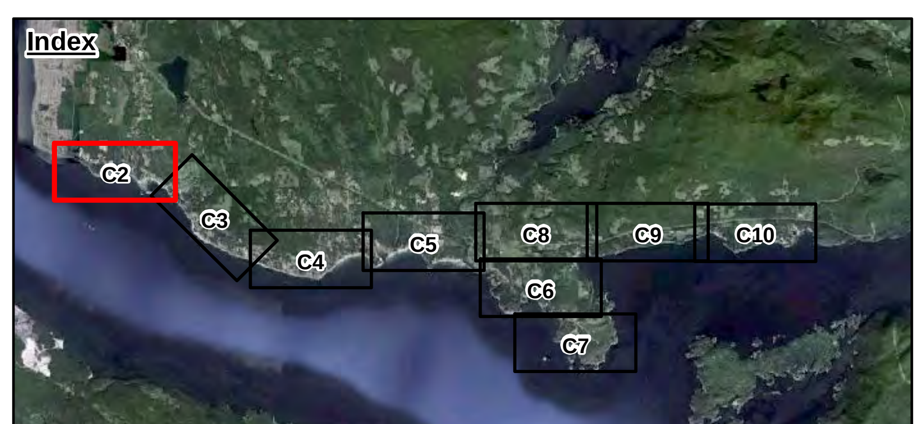
LEGEND

Maximum Flow Depth (m)

- 0.00 - 0.14
- 0.15 - 0.34
- 0.35 - 0.62
- 0.63 - 0.96
- 0.97 - 1.36
- 1.37 - 1.90
- 1.91 - 2.61
- 2.62 - 3.71
- 3.71 - 6.69

- Coastline
- Contour (10 m)
- PRRD Electoral Area Boundary
- Provincial Park
- Indian Reserve

- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry



NOTES

Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Maximum Flow Depth (m)

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	POWELL RIVER REGIONAL DISTRICT

Scale: 1:10,000

200 100 0 200

Metres

TETRA TECH EBA

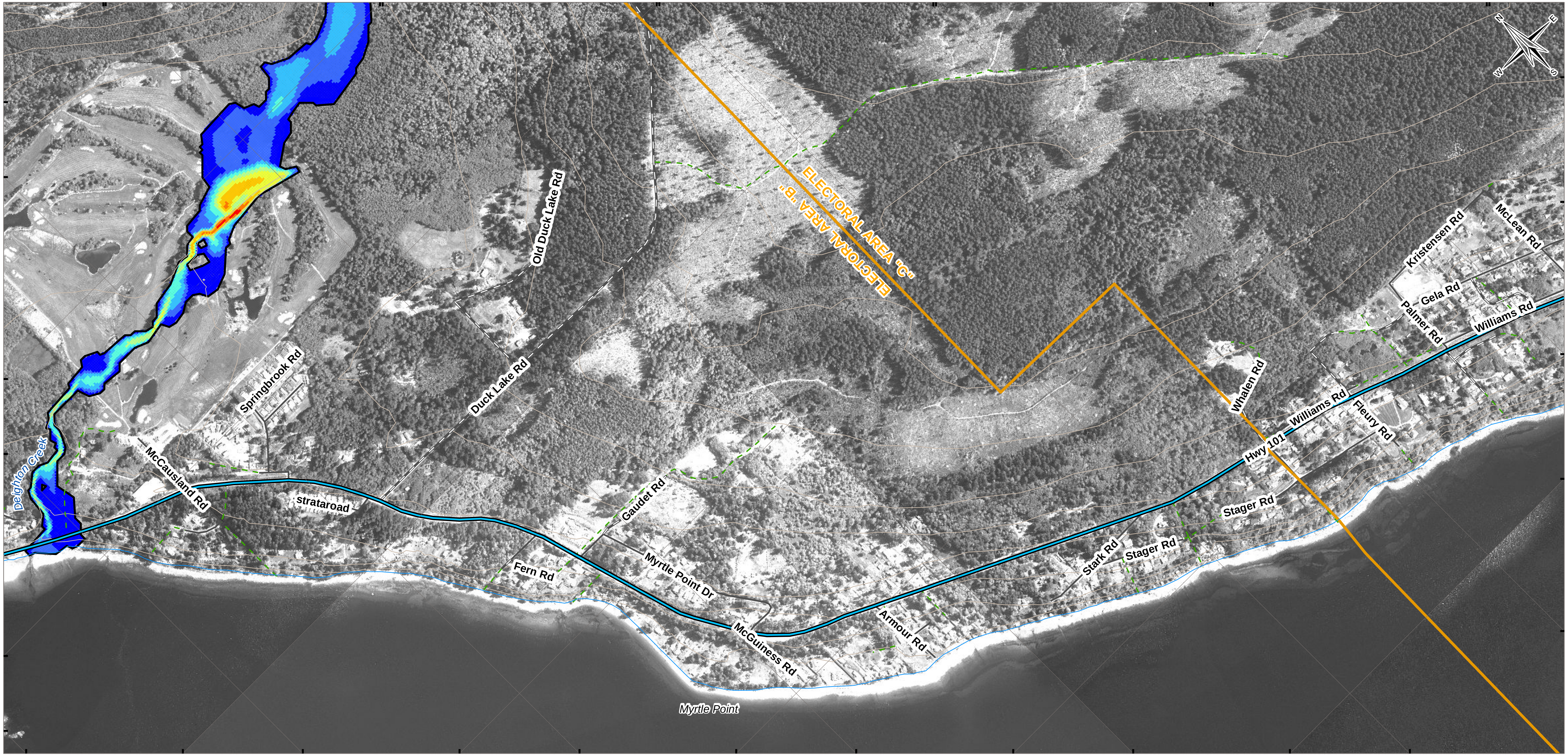
FILE NO.
V13103482-01_FigureC2-C10_Max_Flow_Depth.mxd

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	YL	MEZ	DJ	0

OFFICE	DATE
Tt EBA-VANC	September 2, 2015

Figure C2

Q:\Vancouver\GIS\ENGINEERING\V131\V13103482-01_PowellRiver\Maps\V13103482-01_FigureC2-C10_Max_Flow_Depth.mxd modified 02/09/2015 by stephanie.leusink



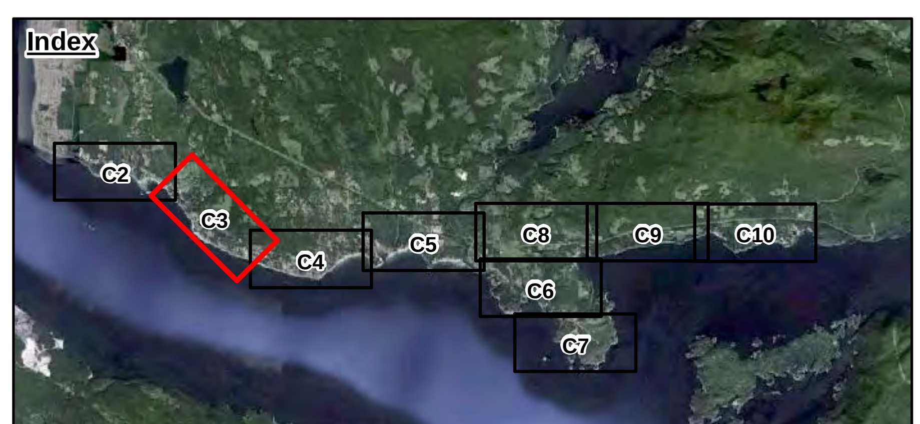
LEGEND

Maximum Flow Depth (m)

- 0.00 - 0.14
- 0.15 - 0.34
- 0.35 - 0.62
- 0.63 - 0.96
- 0.97 - 1.36
- 1.37 - 1.90
- 1.91 - 2.61
- 2.62 - 3.71
- 3.71 - 6.69

- Coastline
- Contour (10 m)
- PRRD Electoral Area Boundary
- Provincial Park
- Indian Reserve

- Major Road - Paved
- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry



NOTES

Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Maximum Flow Depth (m)

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000
200 100 0 200
Metres

TETRA TECH EBA

FILE NO.
V13103482-01_FigureC2-C10_Max_Flow_Depth.mxd

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	YL	MEZ	DJ	0

OFFICE	DATE
Tt EBA-VANC	September 2, 2015

Figure C3

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LEGEND

Maximum Flow Depth (m)

- 0.00 - 0.14
- 0.15 - 0.34
- 0.35 - 0.62
- 0.63 - 0.96
- 0.97 - 1.36
- 1.37 - 1.90
- 1.91 - 2.61
- 2.62 - 3.71
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- Major Road - Loose surface
- Minor Road - Paved
- Minor Road - Loose surface
- Resource Road
- Unclassified Road
- Ferry

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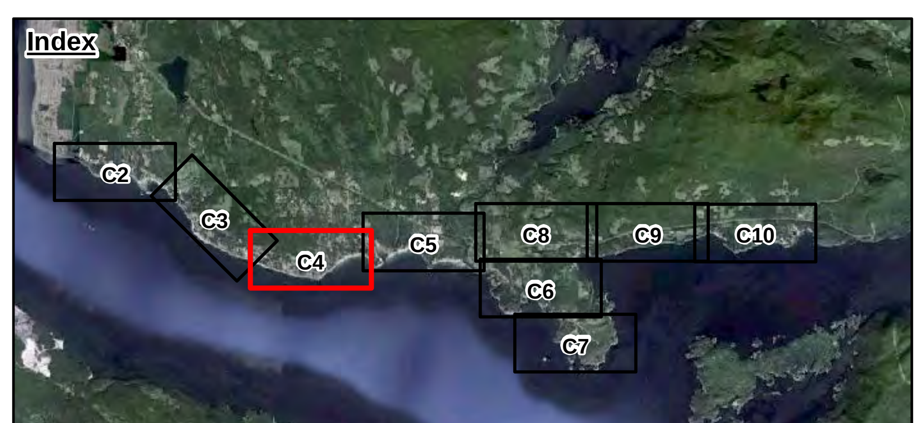

NOTES

Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Maximum Flow Depth (m)

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000
200 100 0 200
Metres

FILE NO.
V13103482-01_FigureC2-C10_Max_Flow_Depth.mxd

TETRA TECH EBA

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	YL	MEZ	DJ	0

OFFICE	DATE
Tt EBA-VANC	September 2, 2015

Figure C4

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LEGEND

Maximum Flow Depth (m)

- 0.00 - 0.14
- 0.15 - 0.34
- 0.35 - 0.62
- 0.63 - 0.96
- 0.97 - 1.36
- 1.37 - 1.90
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- 3.71 - 6.69

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NOTES

Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Maximum Flow Depth (m)

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000

200 100 0 200

Metres

TETRA TECH EBA

FILE NO.
V13103482-01_FigureC2-C10_Max_Flow_Depth.mxd

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	YL	MEZ	DJ	0

OFFICE	DATE
Tt EBA-VANC	September 2, 2015

Figure C5

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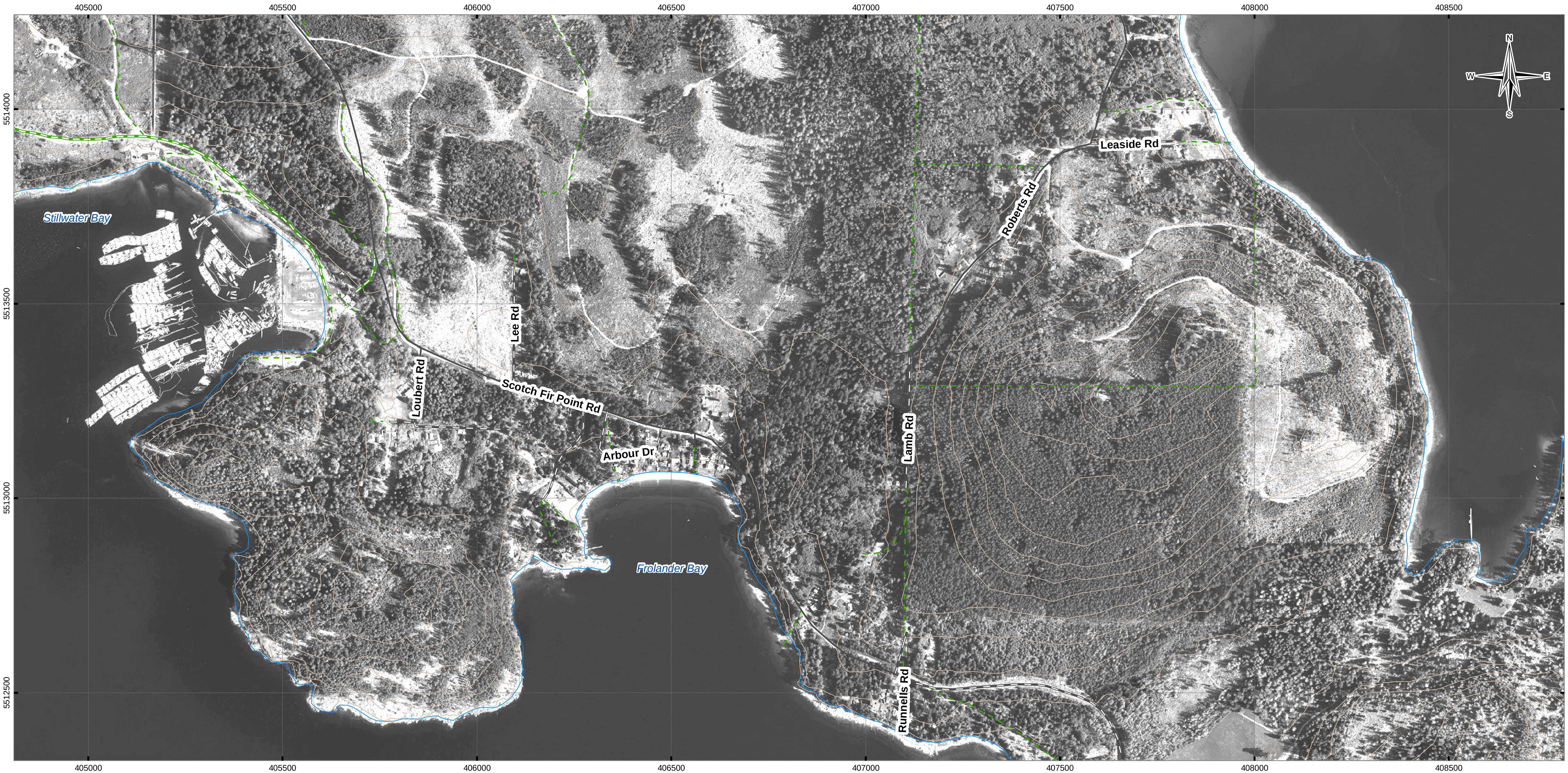

LEGEND

Maximum Flow Depth (m)

- 0.00 - 0.14
- 0.15 - 0.34
- 0.35 - 0.62
- 0.63 - 0.96
- 0.97 - 1.36
- 1.37 - 1.90
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- 2.62 - 3.71
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- Minor Road - Loose surface
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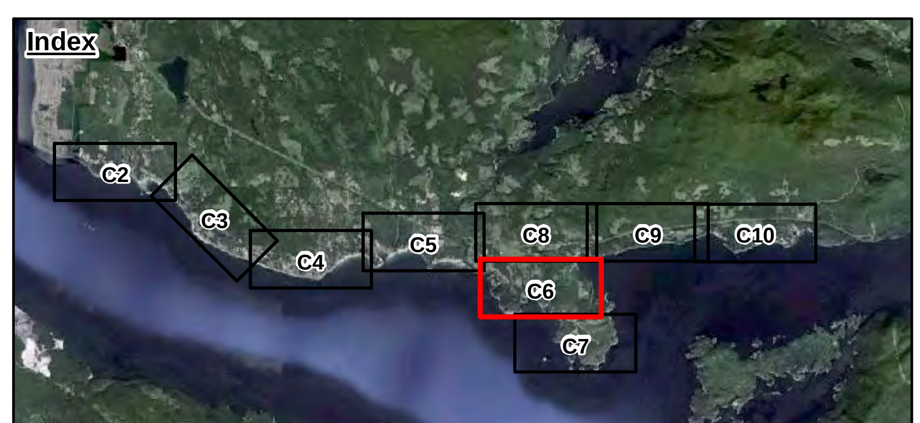
- Ferry



NOTES

Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Maximum Flow Depth (m)

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000

200 100 0 200

Metres

FILE NO.
V13103482-01_FigureC2-C10_Max_Flow_Depth.mxd

TETRA TECH EBA

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	YL	MEZ	DJ	0

OFFICE	DATE
Tt EBA-VANC	September 2, 2015

Figure C6

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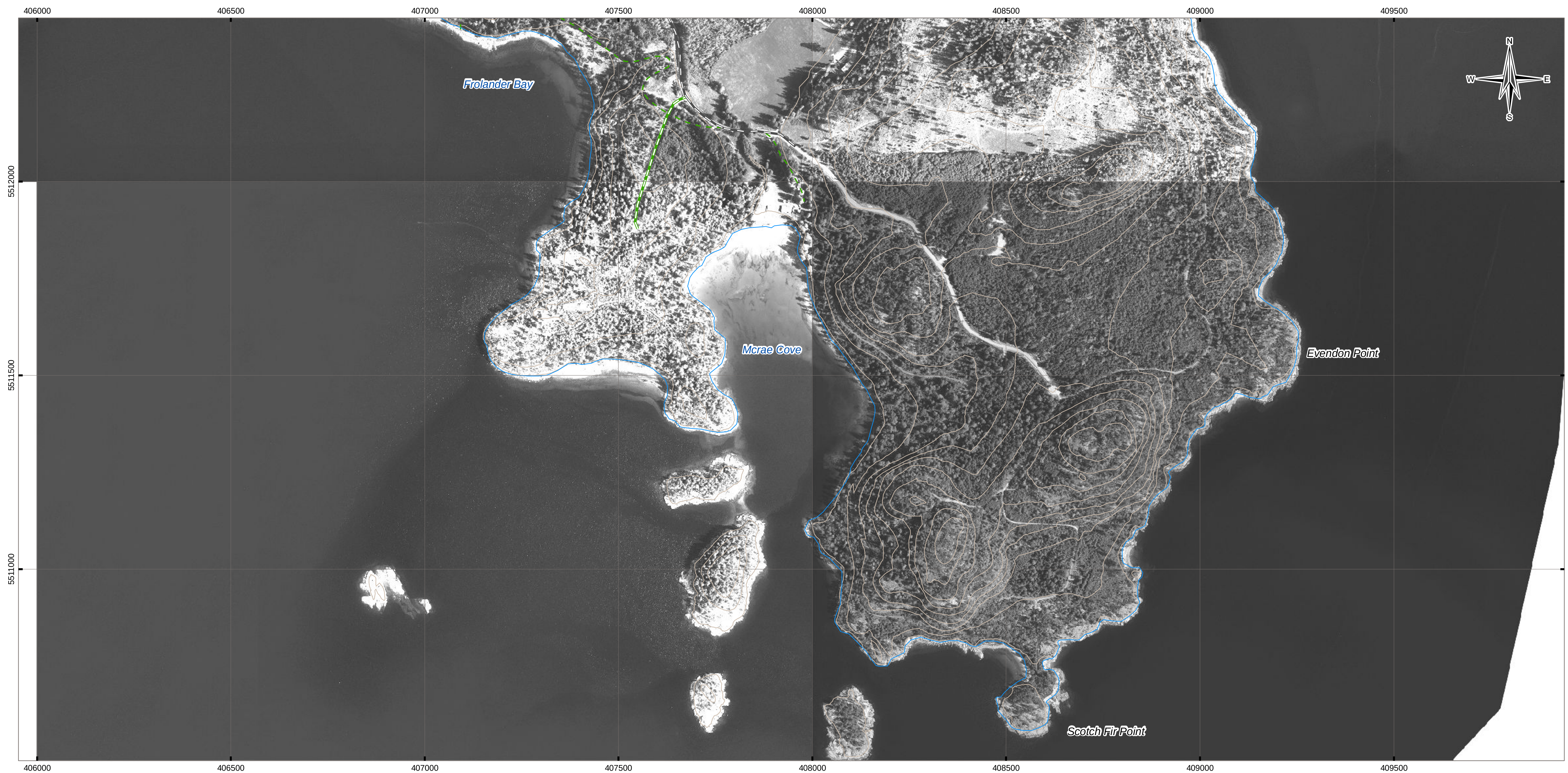

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LEGEND

Maximum Flow Depth (m)

- 0.00 - 0.14
- 0.15 - 0.34
- 0.35 - 0.62
- 0.63 - 0.96
- 0.97 - 1.36
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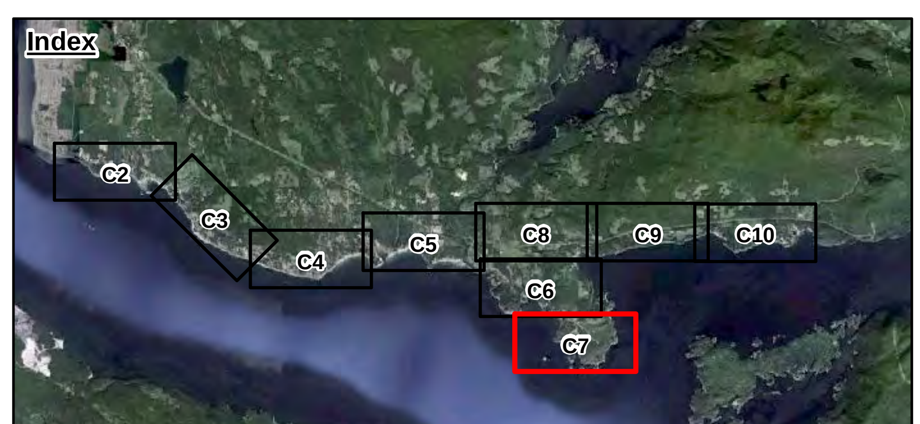


NOTES

Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Maximum Flow Depth (m)

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000
200 100 0 200
Metres

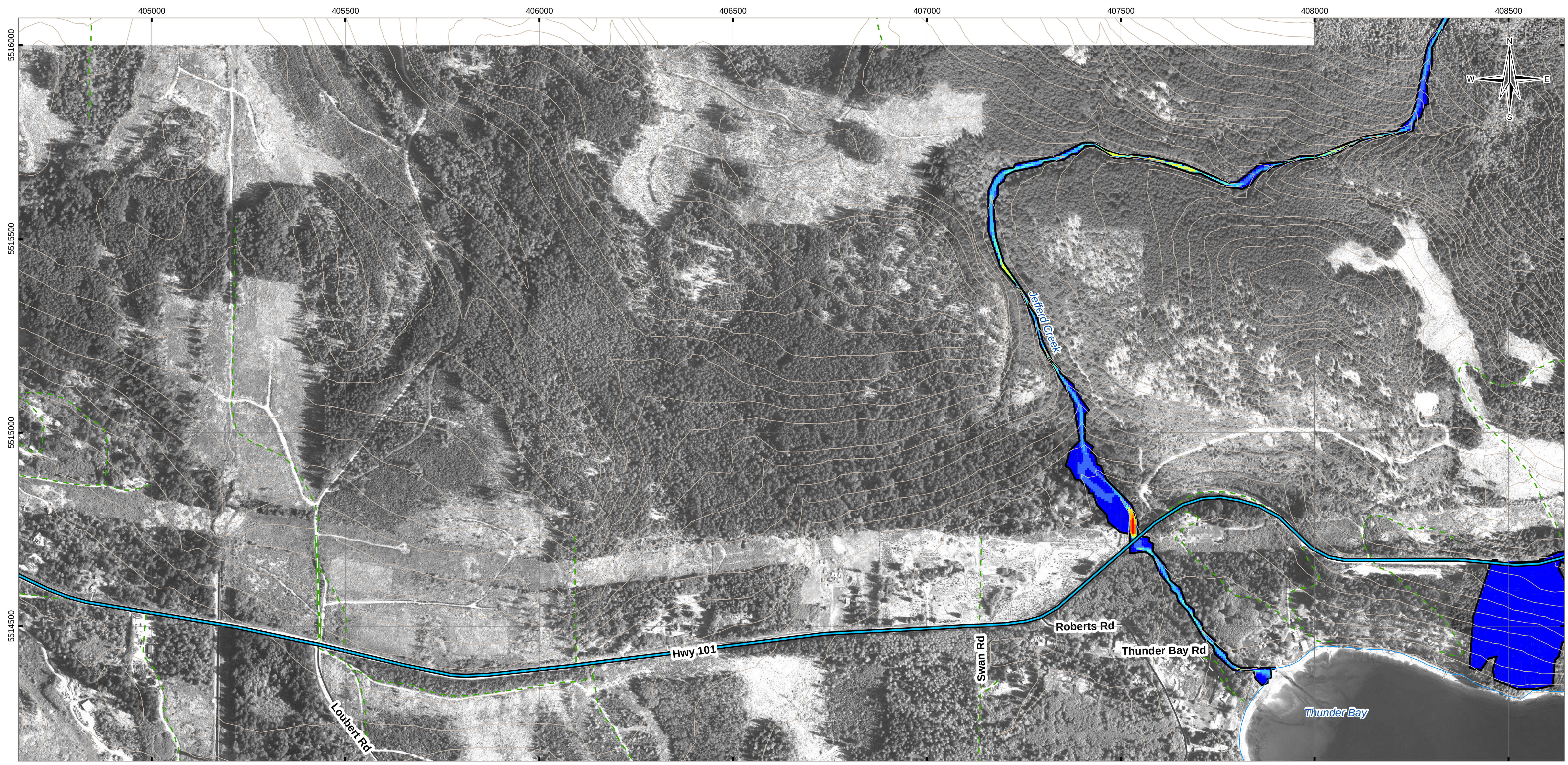
TETRA TECH EBA

FILE NO.
V13103482-01_FigureC2-C10_Max_Flow_Depth.mxd

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	YL	MEZ	DJ	0

OFFICE	DATE
Tt EBA-VANC	September 2, 2015

Figure C7



LEGEND

Maximum Flow Depth (m)

- 0.00 - 0.14
- 0.15 - 0.34
- 0.35 - 0.62
- 0.63 - 0.96
- 0.97 - 1.36
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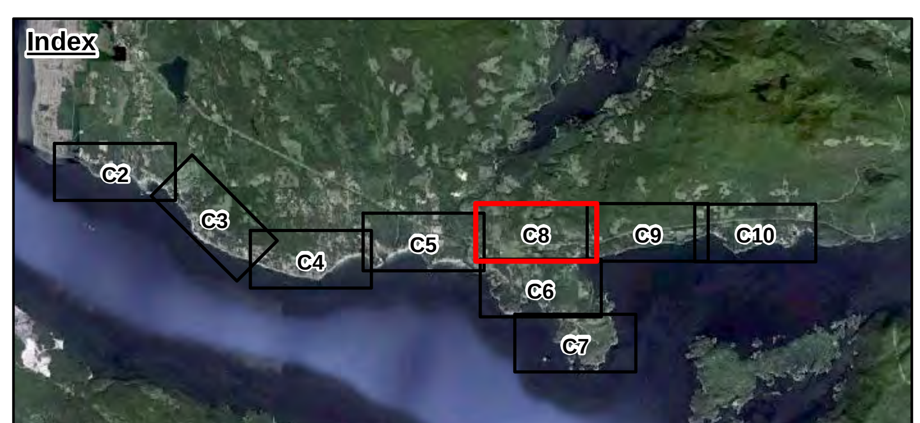

NOTES

Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Maximum Flow Depth (m)

PROJECTION	DATUM
UTM Zone 10	NAD83

Scale: 1:10,000

200 100 0 200

Metres

CLIENT: Powell River Regional District

TETRA TECH EBA

FILE NO.
V13103482-01_FigureC2-C10_Max_Flow_Depth.mxd

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	YL	MEZ	DJ	0

OFFICE	DATE
Tt EBA-VANC	September 2, 2015

Figure C8

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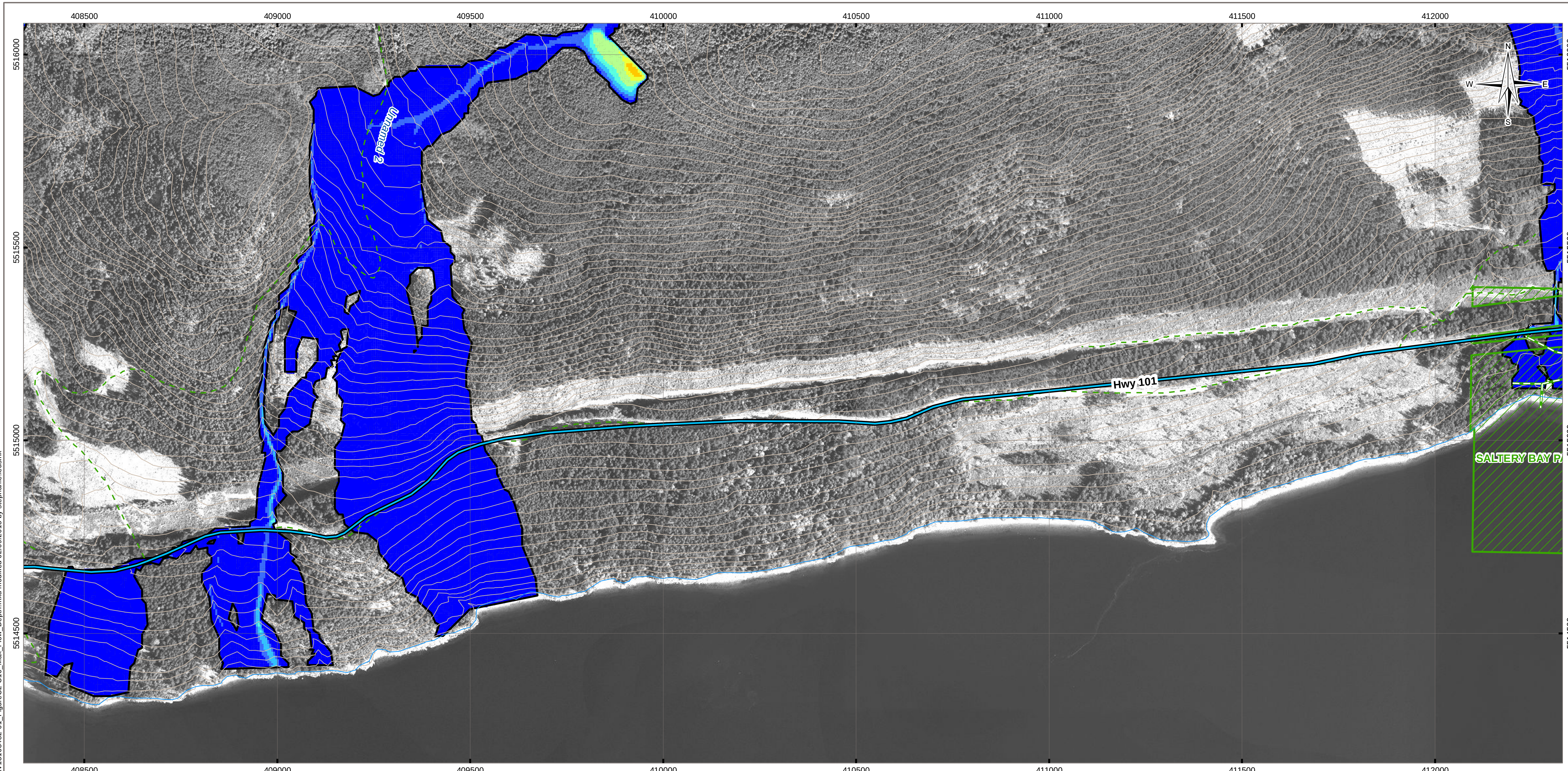

LEGEND

Maximum Flow Depth (m)

- 0.00 - 0.14
- 0.15 - 0.34
- 0.35 - 0.62
- 0.63 - 0.96
- 0.97 - 1.36
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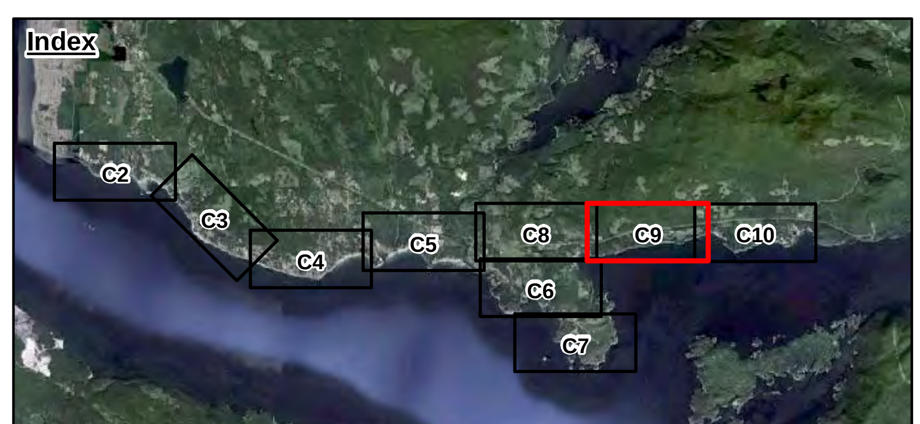


NOTES

Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Maximum Flow Depth (m)

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000
200 100 0 200
Metres

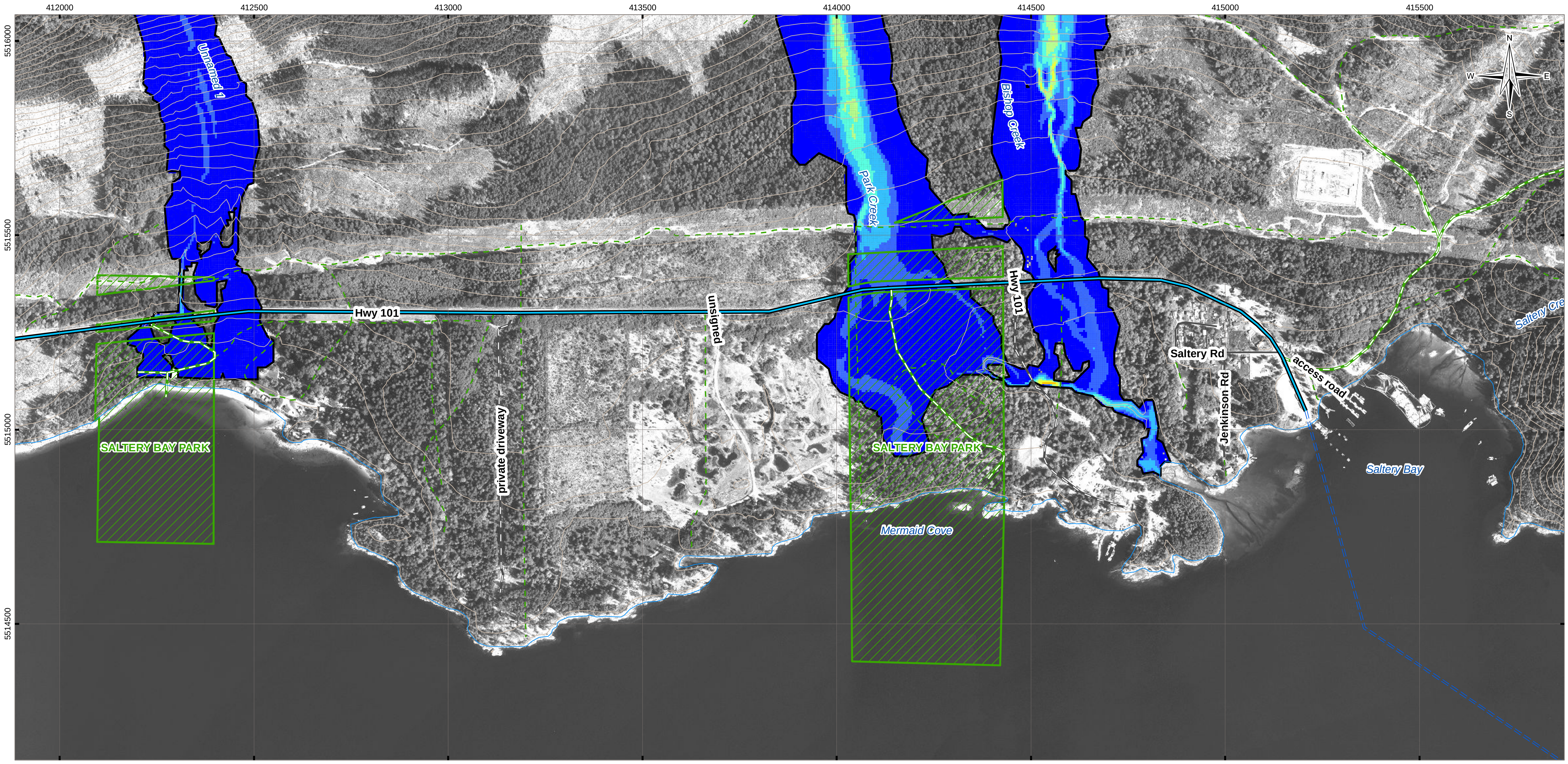
FILE NO.
V13103482-01_FigureC2-C10_Max_Flow_Depth.mxd

TETRA TECH EBA

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	YL	MEZ	DJ	0

OFFICE	DATE
Tt EBA-VANC	September 2, 2015

Figure C9



LEGEND

Maximum Flow Depth (m)

- 0.00 - 0.14
- 0.15 - 0.34
- 0.35 - 0.62
- 0.63 - 0.96
- 0.97 - 1.36
- 1.37 - 1.90
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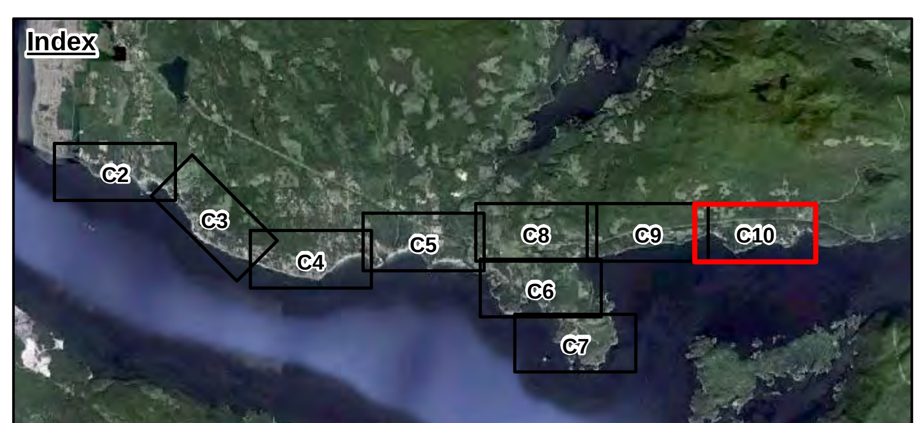

NOTES

Base data source: Imagery and base layers from PRRD; BC Digital Road Atlas

STATUS
ISSUED FOR USE

LANDSLIDE AND FLUVIAL HAZARDS STUDY

Maximum Flow Depth (m)

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Powell River Regional District

Scale: 1:10,000
200 100 0 200
Metres

TETRA TECH EBA

FILE NO.
V13103482-01_FigureC2-C10_Max_Flow_Depth.mxd

PROJECT NO.	DWN	CKD	APVD	REV
V13103482-01	YL	MEZ	DJ	0

OFFICE	DATE
Tt EBA-VANC	September 2, 2015

Figure C10

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