District of Sechelt

Chapman Creek Flood Assessment

Draft Report
August 2010

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

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KWL File No. 551.010

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REVISION HISTORY

Revision #	Date	Status	Revision	Author
0	August 31, 2010	Draft	Draft for Review	DR / DTM

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Section 1

Introduction

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1. INTRODUCTION

1.1 BACKGROUND

Chapman Creek drains a multi-use watershed on BC's Sunshine Coast, supporting a diverse range of values that includes forestry, recreation, anadromous and resident fisheries resources, and community water supply. At the mouth, the creek passes through the community of Sechelt, BC and the Sechelt First Nation – Tsawcome I.R. No 1 lands. Figure 1-1 shows the location of the watershed.

Historically, steep slopes in the Chapman Creek watershed have produced landslides capable of reaching and impounding the creek. Such conditions create the potential for "debris floods", a type of flood that is transitional to debris flow and in which flood discharge is heavily charged with sediment, mud, boulders, and woody debris. Debris floods often result from the overtopping and failure of a landslide that temporarily dams the creek. Two large historical discharges recorded on Chapman Creek in the 1960s may have been the result of debris floods.

Chapman Creek has formed a large alluvial fan a short distance upstream from the Strait of Georgia. A number of developed and vacant residential properties are located on the fan. The District of Sechelt (the District) has also received a number of land development proposals for the creek fan. The District's Official Community Plan identifies the Chapman Creek Alluvial Fan as part of an Environmental and Geotechnical Development Permit area. The fan has been recognized as a flood hazard area by Golder (1993), the Ministry of Environment and the Ministry of Transportation.

1.2 PURPOSE

As a result of increasing development pressure, the District of Sechelt wishes to develop floodplain management guidelines for the Chapman Creek alluvial fan. The previous land-use planning document was produced in 1993 as an overview document, and does not investigate the hazards quantitatively. The District requires a refinement of the existing flood hazard area, and flood construction levels and intensities within the flood hazard area.

The District of Sechelt retained Kerr Wood Leidal Associates Ltd. (KWL) to study Chapman Creek and provide guidance with respect to hazard levels and appropriate conditions of development. This report includes:

- a summary of past studies (Section 2);
- an overview of watershed geomorphology and hydrology (Section 3);
- a description of debris flood design event characteristics (Section 4);
- hydraulic modelling of flood inundation on the Chapman Creek fan (Section 5); and

- flood-related considerations for land use and community planning (Section 6).

The basis for the study is a hydraulic modelling tool coupled with the GIS database to allow quantitative floodplain analyses. This tool can provide a basis for evaluation of future flood protection measures and development proposal assessments, as construction of dykes, and large changes to lot grading can effect water levels on other parts of the floodplain.

1.3 SCOPE

The scope of work for this project is outlined in Table 1-1.

Table 1-1: Work Program

Task	Description
1. Project Initiation	▪ Meet with the Project Team ▪ Confirm reporting and communication protocols ▪ Review proposed work program and project goals ▪ Review schedule and identify important milestones and dates ▪ Finalize purchasing and agreements
2. Data Review and Base Mapping	▪ Obtain data from Sechelt, including: o Reports o LiDAR and topographic data o Orthophotos and air photos o GIS data (Cadastral, zoning, archaeological sites, streams, roads, district lots, easements, Hydro ROW, Municipal Geo-Spatial Reference Survey Monuments) ▪ Review reports provided by District of Sechelt o Golder 1993; Ministry of Environment 1991; etc. ▪ Assemble up-to-date Water Survey of Canada hydrometric information ▪ Review air photos provided by District of Sechelt for channel changes and potential historical geohazards ▪ Develop base mapping to be used in the project from available topographic data, orthophotos and cadastral information
3. Hydrologic Assessment	▪ Review flood history ▪ Examine regional gauges (1921 to present) ▪ Conduct hydrological homogeneity review ▪ Conduct peak flow analysis (local and regional as data permit) ▪ Estimate clear-water peak flow design event

Task	Description
4. Field Reconnaissance	▪ Delineate present day creek fan from available mapping ▪ Conduct channel traverse along fan reach to identify possible sediment sources along the creek channel and potential avulsion locations ▪ Examine fan and nearby features to identify hazard landforms ▪ Detail highway bridge crossing **Additional Work:** ▪ Collect cross-section data to improve LiDAR data set (if req'd)
5. Hazard Assessment	▪ Prepare debris flow / debris flood likelihood assessment based on review of air photos and field reconnaissance ▪ Provide a qualitative estimate for a debris flood multiplier to be applied to the 200-year debris flood, if applicable ▪ Prepare a one-dimensional HEC-RAS model of Chapman Creek within the District boundary ▪ Simulate peak flows (clear-water flood and debris flood) ▪ Identify up to three key parameters and perform sensitivity analysis ▪ Create flood profile plots based on HEC-RAS model results ▪ Extrapolate flood profile plots to create flood profile mapping (if possible) or identify key additional tasks necessary to produce maps ▪ Prepare hazard Assessment Report and provide to District for review ▪ Incorporate District feedback and finalize report

As part of Task 4, KWL and Cordilleran Geoscience conducted an extensive foot traverse of the Chapman Creek fan and vehicle reconnaissance of the middle watershed reaches on April 7 and 8, 2010.

1.4 TEAM

This study was carried out by KWL with assistance from Cordilleran Geoscience. The KWL project team includes:

- David Matsubara, M.Eng., P.Eng. – Project Manager;
- Mike V. Currie, M.Eng., P.Eng. – Technical Reviewer;
- David Roche, M.A.Sc., P.Eng. – Project Engineer; and
- Jason Miller, P.Eng. – Modelling Engineer.

Input from Cordilleran Geoscience was provided by Pierre Friele, M.Sc., P.Geo., PG (WA).

Input and assistance on behalf of the District of Sechelt was provided by:

- Ray Parfitt – Project Manager; and
- Sandra Brown – GIS Co-ordinator.

Additional digital resources were provided by various staff at the BC Ministry of Environment and by Trevor Fawcett, GIS Co-ordinator for the Sunshine Coast Regional District.

Chapman Creek
Flood Hazard Assessment

Legend

- Chapman Creek Watershed
- Sechelt Municipal Boundary

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Location Plan for Chapman Creek Watershed

Figure 1-1

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Section 2

Summary of Previous Work

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2. SUMMARY OF BACKGROUND INFORMATION

2.1 PREVIOUS REPORTS

Given the importance of Chapman Creek as a multi-use watershed, it is not surprising that the watershed has been the subject of a number of studies. A number of past studies were reviewed for this report. These studies are listed below with brief descriptions provided.

Reksten, D.E., 1974. Chapman Creek Hydrology Study

This report documents an early hydrologic study carried out by the BC Ministry of Environment for Chapman Creek. At the time the available streamflow record was limited. The Ministry of Environment produced a comprehensive update to the hydrology study in 1991.

Chapman, A.R. & D. E. Reksten, 1991. Chapman Creek Hydrology – Data Summary and Analysis

This hydrology analysis, published by the BC Ministry of Environment, examines precipitation normals and extremes, temperature normals, annual and monthly runoff, peak flows, and low flows. The report also provides advice on estimating design flows for bridges and culverts using the rational method. Estimates of bankfull discharge (assumed 1.5-year return period) on Chapman Creek compare well with the results of flood frequency analysis. Of note, the two largest peak flows on record (1961 and 1968) are excluded on the basis that they are not supported by comparison to published precipitation data and streamflow data recorded at the nearby hydrometric gauge on Roberts Creek.

While now somewhat dated, the Chapman and Reksten report is still considered a key study for Chapman Creek. It is our understanding that there is no comprehensive update to this study.

Golder Associates, 1993. Geotechnical and Environmental Reconnaissance Study of the District of Sechelt Official Community Plan Area

In this document, Golder provides a comprehensive reconnaissance-level review of geotechnical and environmental conditions in the District of Sechelt and makes recommendations for establishing Development Permit Areas (DPAs) under the Official Community Plan. The recommendations were developed based on a desktop study, air photo review, field visits and stakeholder meetings. The report recommends the implementation of four DPAs for environmental sensitivity (natural coniferous forests, gravel pits, watercourse habitat, and shoreline / foreshore) and five DPAs for natural hazards (beachfront / upland slopes, beach front escarpments, rockfall, watercourse – minor streams, and watercourse – Chapman Creek / Gray Creek). The final DPA (DPA 9

– Watercourse Hazards Along Gray and Chapman Creeks) requires that the DPA boundary be set at the most restrictive of:

- 30 m setback from the natural boundary of the creek at high water;
- 15 m setback from ravine crest or top of eroded slope above a creek or tributary; or
- no less than 3 m vertically above the creek high water level.

BC Environment, 1994. Restoration Streams in the Lower Mainland Region

This document, prepared by the Ministry of Environment's Integrated Management Committee, reviews a wide-ranging list of watershed restoration candidate projects throughout the Lower Mainland Region. The report addresses only the "more obvious" [*sic*] projects and notes that a comprehensive assessment has not been undertaken. Specific challenges and/or restoration opportunities in the Sechelt area are identified on Chapman Creek, Gray Creek, Vancouver River, and McNab Creek / McNair Creek. For Chapman Creek, the issues noted include extensive slides and water quality problems. The report identifies need for a high level of road rehabilitation / deactivation is required.

Dayton & Knight, 1996. Sunshine Coast Regional District Aquifer Protection Plan

This document describes the need for groundwater protection on the Sunshine Coast, summarizes available data on groundwater resources and protection, and lays out a program for moving forward with a groundwater protection initiative. The report is of limited applicability for a flood hazard study on Chapman Creek.

Newbury Hydraulics, 1997. Lower Chapman Creek Re-Alignment Project

In this document, Newbury Hydraulics provides a brief review of some flood and erosion hazards on lower Chapman Creek. Design solutions are proposed to reduce bank erosion and re-establish fish habitat. Of note, Newbury identifies the bridge at Highway 101 as a channel constriction at high flow and recommends that the responsible authorities consider replacing the bridge with a wider span.

Summit Environmental Consultants, 1997. Hydrologic Analysis for the Chapman / Gray Chart Area

Summit Environmental prepared this document on behalf of International Forest Products (Interfor) as a "Level 2" analysis under the Coastal Watershed Assessment Procedure (CWAP). The Summit study makes recommendations for ongoing forestry practices aiming to maintain an acceptable degree of hydrologic risk, particularly with regard to potential increases in peak flows due to deforestation. Maximum Equivalent Clearcut Area (ECA) percentages are defined for a number of sub-basins and elevation bands based on a subjective assessment of hydrologic risk. Only the Executive Summary was available for download and review via the Ministry of Environment EcoCat online catalogue. The report does not include a detailed description of the hydrologic assessment.

EVS Environment Consultants, 1999. Overview Fish Habitat and Riparian Assessment

This document includes two main parts: a desktop assessment of factors that could potentially limit fish production; and a two-level desktop / field assessment of riparian habitat. The desktop assessment focuses on identifying fish species at risk, evaluating habitat conditions, and identifying opportunities for rehabilitation. The main deliverable of the fish habitat assessment is a listing of sites recommended for a more detailed Level 1 (field-based) assessment. The riparian assessment begins at the watershed scale and ultimately provides detailed recommendations and cost estimates for rehabilitation using revegetation, silviculture practices, and slope bioengineering. Prescriptions are proposed for 10 sites on Chapman Creek included nine prescriptions developed by Interfor and one by the Sechelt Indian Band.

EBA, 2000. Watershed Assessment for Chapman Creek and Gray Creek, Sechelt BC

This document presents an update to the 1997 hydrologic analysis carried out by Summit Environmental (see Summit Environmental, 1997). Like the Summit report, EBA implements the Coastal Watershed Assessment Procedure (CWAP) to assess the impacts of forestry on the watershed and provide recommendations for further development. Specifically, the report examines potential forestry impacts on peak flows, landslides, erosion, channel morphology, and water quality. The report provides a “watershed report card” for Chapman Creek and makes recommendations to adapt forestry practices for hazard mitigation.

The report provides a detailed reach by reach description of the channel including hillslope-channel coupling. Of note, the report finds that 224 (or 82%) of the 274 total landslides historically observed in the Chapman Creek watershed initiated within a clearcut or along a road, with 78 of these landslides directly or indirectly impacting a stream. The report also suggests that the high peak flows recorded in 1962 and 1968 may have been associated with the failure of landslide debris dams.

Triton Environmental Consultants, 2006. Chapman Creek Watershed Drinking Water Source Assessment

This document details a Source to Tap watershed assessment for Chapman Creek, undertaken in compliance with the provincial *Drinking Water Protection Act*. The report is primarily a review of information created by others with the goal of developing a comprehensive understanding of risks to the water supply system. Ten watershed-level hazards are identified, including human access to the intake works, high precipitation and runoff, decaying vegetation, wildlife and birds, high water demand / natural low flows, destratification of Chapman Lake in the upper watershed, lake drawdown, infrastructure damage from falling trees and natural disasters, wildfires, and climate change. The hazards are evaluated qualitatively and assigned relative likelihoods. Recommendations to mitigate risk to the water supply system are provided.

2.2 DATA SOURCES

Data for the geohazard assessment and hydraulic modelling was obtained from a number of sources. These are described below.

Air Photos

Air photos for the Chapman Creek watershed were obtained from UBC's Geographic Information Centre. Years examined include 1971, 1976, 1987, and 1996.

LiDAR / Topographic Data

LiDAR data for the lower part of the Chapman Creek watershed was provided by both the District of Sechelt and the Sunshine Coast Regional District. Buildings and dense vegetation were excluded from the LiDAR data through a filtering process applied by the supplier. Filtered ground elevation data were synthesized into a raster-based Digital Elevation Model for use in GIS analysis. Topographic information upstream of the LiDAR data boundary at the SCRD water intake was obtained from the provincial TRIM dataset.

Other GIS Data

The District of Sechelt provided a variety of additional data for this study, including cadastral, contours, orthophotos, archaeology sites, and legal boundaries.

Terrain Stability Mapping

During the course of this study, extensive efforts were made by the project team and the District to obtain Terrain Stability Mapping (TSM) for the Chapman Creek watershed. Parties contacted include Interfor (Campbell River and Sechelt offices), the Sunshine Coast Regional District, BC Ministry of Environment, and BC Ministry of Forests and Range. The Ministry of Environment provided baseline Terrain Mapping for Chapman Creek. The Ministry also confirmed that Interfor produced 1:20,000 scale TSM in 1995. The project team reviewed the TSM produced by Interfor for their chart area on the north side of Chapman Creek, but was unable to obtain any further TSM from MoE. The available TSM provided a useful supplement to the field assessment.

Streamflow Data

The Water Survey of Canada collected hydrometric data on Chapman Creek between 1959 and 2003. Over this period, the hydrometric station was moved and recommissioned twice in response to the installation and relocation of the SCRD water intake. The composite record for the WSC gauges is outlined in Table 2-1.

Table 2-1: Water Survey of Canada Records for Chapman Creek

Gauge	Name	Drainage Area (km^2)	Period of Record
08GA046	Chapman Creek near Wilson Creek	71.5	1959 - 1970
08GA060	Chapman Creek above Sechelt Diversion	64.5	1970 - 1988
08GA078	Chapman Creek below Sechelt Diversion	65.8	1993 - 2003

The presence of the intake and its variable location complicates an analysis of mean annual discharge; however, SCRD water demand reaches a maximum of approximately 0.25 m^3/s in late summer (Triton, 2006) and is therefore largely irrelevant when considering peak flows.

Section 3

Geomorphology and Hydrology

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3. GEOMORPHOLOGY AND HYDROLOGY

3.1 WATERSHED PHYSIOGRAPHY

Chapman Creek is a 20-km long, SSW-facing watershed draining an upland surface on the eastern margin of the Georgia Depression (Holland 1976). Peaks in the headwaters such as Tetrahedron reach up to 1,700 m. The watershed has an area of approximately 56 km² upstream from the SCRD drinking water intake, 66 km² above the discontinued Water Survey of Canada (WSC) hydrometric station, and 72 km² at the fan apex. The Chapman Creek Watershed is shown in Figure 3-1.

The headwaters of Chapman Creek rise in Tetrahedron Park, flowing down to the lake-dotted plateau where they feed into the SCRD reservoir at Chapman Lake (elevation 976 m). At 34 ha surface area, Chapman Lake is the largest lake in the watershed.

The creek becomes deeply incised along its middle reaches. The average gradient for the mainstem creek channel is about 4%. Tributary streams can be significantly steeper, with gradients in excess of 60% (EBA, 2000). There is a significant waterfall (> 10 m height) located at the SCRD drinking water intake (elevation 175 m). Chapman Creek meets the sea near Wilson Creek south of Sechelt. The Chapman Creek mainstem channel is described with typical valley cross-sections and historic air photographs in Figure 3-2.

Bedrock underlying the watershed consists of almost entirely of granodiorite and quartz diorite, part of the Coast Plutonic Complex (Roddick et al., 1976). The bedrock is competent, and coarsely jointed yielding blocky debris. No large deep-seated bedrock landslide scars or deposits have been identified in the watershed (Thomson, 1987).

The entire watershed was ice covered during the last and previous glaciations (McCammon, 1977). Upper Chapman Creek watershed supports organic soils on veneers of till and bedrock. The middle portion of the valley is incised up to 600 m in the plateau. In this section the upslope sidewalls are steep (>70%) and rocky, while mid and lower slopes are steep (>70%) to moderately steep (50-70%) and support till and glaciofluvial blankets, and local blocky colluvium (see terrain mapping in Thomson, 1987). The till is a compact, poorly sorted sediment with a sandy matrix. The glaciofluvial sediments are typically moderately sorted sandy gravel (Waypoint 507 on Figure 3-2), but due to the ice contact setting, they may be complex, containing beds of till-like material and glaciolacustrine mud (Waypoints 509, 512 on Figure 3-2). Lower Chapman Creek extends from the mouth of the incised valley, defined approximately by the 300 m contour, to the sea. Along this section the creek is incised in a thick complex of glacial deposits and bedrock. Creek sidewalls are typically 40m tall and may be undermined by the creek, creating active sediment sources (Waypoint 515 on Figure 3-2).

3.2 CLIMATE AND PEAK FLOW HYDROLOGY

The Chapman Creek watershed is located in the Sunshine Coast region of southwestern British Columbia. The area is called the Sunshine Coast for its climate, which is clearer and drier than areas to both east and west. The climate results from the presence of the Georgia Depression between the mountains of Vancouver Island and the higher Coastal mountains of the mainland. Temperatures throughout the region are moderated by the presence of the Pacific Ocean, resulting in wet, relatively mild winters and warm, dry summers.

Annual precipitation in the watershed increases substantially with elevation and is subject to a strong seasonal distribution. Chapman and Reksten (1991) estimate mean annual precipitation for the watershed of about 2,700 mm, with about 75% of total annual precipitation occurring in the October to March period. Winter precipitation can fall as snow throughout the watershed; while only a small fraction of precipitation (<5%) falls as snow at sea level, a significant snowpack (as much as 1,700 mm snow-water equivalent) can accumulate at higher elevations (Triton, 2006). A transitional range between about 300 m and 800 m elevation can experience periodic accumulation and rapid melt during intense winter storms (Summit, 1997).

The steep valley-side and headwater slopes of the watershed result in the quick conversion of rainfall to runoff. Although annual peak flows can result from the spring freshet or summer rainstorms, the dominant flood-inducing process for Chapman Creek involves rain-on-snow events during the fall and early winter (**Error! Reference source not found.**). These autumn events involve heavy precipitation inducing rapid melt of a thin and immature, fully-saturated higher-elevation snowpack. Annual Chapman Creek peak flows recorded by WSC show that the peak occurred in October, November or December in 26 of 39 years of record.

The combination of a high-flow freshet season with a dominant period of fall/winter floods classifies Chapman Creek watershed as a "pluvial hybrid" system (Wade et al., 2001). An average annual hydrograph for Chapman Creek is provided as Figure 3-3

3.3 LAKE STORAGE AND RESERVOIR OPERATIONS

Chapman Lake is a main water supply reservoir for the Sunshine Coast Regional District. The Chapman Lake reservoir is drawn down during the summer months to support SCRD withdrawals. The reservoir refills over the winter period.

At the present time, the capacity of the reservoir is about 750,000 m³ (750 ML), or approximately 8.7 cms-days[1] (D. Crosby, pers. comm.). This volume of water must be recharged before the watershed upstream of the lake begins to spill past the dam and

[1] One cms-day is a volume of water equal to a flow rate of 1 m³/s (cms) flowing for one full 24-hr period. 1 cms-day = 86,400 m³.

contribute to downstream runoff. Current storage operations at Chapman Lake may therefore provide a degree of buffering and attenuation for fall peak flow events not fully reflected in the historical record, which corresponds to a period of lower SCRD water use. KWL understands that the SCRD may at some point consider raising the dam at Chapman Lake, increasing the storage capacity typically available at the onset of the flood season.

There are several factors that reduce the expected significance of Chapman Lake storage on the design event. These factors include:

- the relatively small volume of the lake with respect to runoff associated with an extreme flood;
- the relatively small contributing watershed area upstream of the lake;
- the elevation of the lake, which some studies place above the classic transitional rain-on-snow elevation band (e.g., Summit, 1997); and
- the nature of a rain-on-snow event, which is typically seasonally preceded by some degree of melt or runoff.
- the occurrence of landslide-channel impacts along reaches downstream of the lake (see section 3.5)

The above factors suggest that a flood analysis neglecting reservoir operations at Chapman Lake is a potentially conservative but not unreasonable approach. The potential impacts of reservoir operations should be reconsidered if storage is expanded significantly.

Relative to the controlled storage at Chapman Lake, the smaller natural lake systems are expected to provide a lesser degree of attenuation that is fully reflected in the historical record.

3.4 FORESTRY

Commercial forestry operations have been active in the Chapman Creek watershed since the 1930s, reaching over 36% of the watershed area. Forestry operations reached their maximum during the 1970s, and Equivalent Clearcut Area (ECA) peaked at 15% in the 1980s. In recent years, forestry operations have been scaled back with periods of little to no logging (e.g., late 1990s per EBA, 2000).

Past forest practices, particularly poor road construction, led to increased landslide frequencies in BC (e.g., Rollerson et al., 1997, 2001, 2005), with direct landslide-river impacts in areas of steep terrain, and increased erosion and sedimentation from road surfaces (Megahan and Kidd 1972). In response to these types of impacts, several road deactivation and watershed restoration initiatives have been undertaken in Chapman Creek (EVS, 1999). Furthermore, forestry operations may result in higher water yield (i.e., more precipitation becoming runoff) and can generate earlier and higher peak flows (Jones and Grant 1996; Grant et al 2008). Looking forward, harvesting is expected to continue at a reduced pace from that seen in the 1970-1990s, continuing a trend of recovery toward a more sustainable ECA and reduced watershed impacts.

3.5 LANDSLIDES AND HILLSLOPE-CHANNEL COUPLING

This section describes past and present landslide hazards observed in Chapman Creek and outlines their potential impact on the mainstem channel of Chapman Creek.

History

Landslides referred to in the following sections involve slides and avalanching of shallow soils on hillslopes (e.g., open slope landslides) and/or slides that become channelized, often in gullies (e.g., channelized debris flows). Large deep-seated landslides have not been described in the Chapman Creek watershed; their occurrence is uncertain and their potential impacts are not considered in the context of this review. Such deep-seated landslides could result from bedrock failures in the middle watershed or rotational failures in Quaternary sediments along the lower watershed. The absence of deep-seated rotational failures in these thick Quaternary sediments could be related to overconsolidation during glacial periods.

The 1960s and 1970s era logging resulted in a dramatic increase in landslide activity along middle Chapman Creek (Figure 3-2), with many landslides having direct channel impacts (Table 3-1). Of 274 landslides occurring, 225 (85%) were logging-related, 49 (15%) were natural. Of the 225 logging-related landslides, 78 resulted in channel impacts. These impacts all occurred throughout middle Chapman Creek where channel aggradation (infilling) and widening are evident on the 1970s era airphotos (Figure 3-2). There is no data as to whether any of the landslides originating in undisturbed areas resulted in channel impacts.

Table 3-1: Summary of Landslides in the Chapman Creek Watershed: 1946-2000*

Total number of landslides	274
Total number related to forestry activities	225 (85%)
Total number of forestry related slides that have impacted a stream	78 (28%)
*Source: Table 5.6 in EBA (2000).	

It is important to note that landslide occurrence is typically not evenly distributed in time and space. Landslides generally cluster, often being triggered by localized, intense rain cells embedded in larger cyclonic storms (Guthrie and Evans 2004a). Thus, in any given year the watershed may experience more or less than the reported average. Landslide rates in British Columbia are expected to increase (from historic natural background levels) given future climate change scenarios (Jakob and Lambert 2009).

Landslide-Channel Impact Potential

Rekston (1974) mapped the entire lower and middle portions of Chapman Creek as having direct hillslope-channel coupling (see also Table 5.9 in EBA 2000). Maynard (1995) conducted terrain stability and channel sedimentation potential mapping within Interfor's chart area in middle Chapman Creek (west sidewall). About 40-50% of his mid to upslope polygons were rated as having moderate to high potential for post logging instability and moderate to high potential for direct impact to Chapman Creek.

In this report, valley cross sections plotted from 1:20,000 scale TRIM maps (Figure 3-2) were used to assess landslide-channel impact using the concept of landslide travel angle (Corominas 1996). The travel angle (H/L) is expressed as height from the landslide crown to the landslide toe (H) divided by the distance from the landslide crown to the landslide toe (L). Landslide travel is related to landslide volume, with steep travel angles for small volume landslides and shallower angles for larger landslides.

Valley cross-sections (Figure 3-2) are typically broadly U-shaped reflecting the glacial history. The steep (>70%) to moderately steep (50-70%) mid and upper slopes represent potential landslide initiation sites. Slope distance from potential initiation sites to the channel ranges from 400-1,500 m. Landslides in the Coast Mountains are typically 20-50 m wide involving soil thickness of 1m on veneered mid and upper slopes. Thus, rough estimates of landslide volume would range from 8,000-75,000 m³. These are considered Class 3-4 landslides (Table 3-2), a typical size in the Coast Mountains (Guthrie and Evans 2004a, b).

Applying a valley slope angle of 40%, representative of Class 3 landslides (Table 3-2), to mid and upper slope potential initiation zones (Figure 3-2), it is apparent that landslides can readily impact Chapman Creek.

Table 3-2: Channelized Landslide Classes and Consequences

Class	Volume (m^3)	Peak Discharge (m^3/s)	Innudation Area (m^2)	Potential Consequences[1]
1	$< 10^2$	< 5	< 500	Very localised damage, known to have killed forestry workers in small gullies, and damaged small buildings
2	10^2-10^3	5 - 30	500 - 2,000	Could bury cars, destroy small wooden buildings, break trees, block culverts, damage heavy machinery
3	10^3-10^4	30 - 200	2,000 - 9,000	Could destroy larger buildings, damage concrete bridge piers, block or damage main roads and pipelines
4	10^4-10^5	200 - 1,500	9,000 - 40,000	Could destroy camps, destroy sections of infrastructure corridor, bridges, and block creeks

Class	Volume (m^3)	Peak Discharge (m^3/s)	Innudation Area (m^2)	Potential Consequences[1]
5	10^5-10^6	1,500 - 12,000	40,000 - $2x10^6$	Could destroy parts of towns, destroy forests of up to 2 km^2 in area, block creeks and small rivers
[1]After Jakob (2005)				

3.6 FIELD EVIDENCE FOR GEOMORPHIC FLOODS

Based on observations in Chapman and Rekston (1991) and EBA (2000), the middle valley may have been affected by geomorphic floods and may record some evidence of these events such as trimlines or flood terrace deposits. On April 8, 2010, KWL and Cordilleran Geoscience accessed this reach of Chapman Creek via the mainline logging road on the west side of the valley. The purpose of the field reconnaissance was to search out field evidence for geomorphic floods. The road was blocked by debris (Waypoint 507 on Figure 3-2) about 5 km upvalley from the gate, and field reconnaissance was limited to channel reaches between this point and the SCRD water intake. The assessment consisted of familiarization with terrain characteristics and hillslope/channel linkage, and documenting evidence and potential for landslide channel impacts.

Several sites along the middle reach of the river were examined (Waypoints 506, 508, 510 & 511 on Figure 3-2). Because of the heavy logging disturbance including removal of riparian vegetation, it was not possible to conclusively identify trimlines (e.g., scarred trees) associated with large historic floods. One suspected site was at Waypoint 511 where the original valley flat was 44 m wide with the right bank filled by a 4 m tall terrace 14 m wide, leaving a 30m wide active channel area. The terrace was colonized by immature conifer less than 40 years old (post-logging regenerative forest). An old 45-gallon drum was partially buried in the terrace sediment along the west margin of the deposit. The nature of burial was inconclusive but appeared related to terrace rather than hillslope sediments. The size of the terrace at this point in the valley was consistent with the size of a geomorphic flood expected from a Class 3-4 landslide-channel impact.

3.7 DEBRIS FLOOD POTENTIAL

Overall basin slope, or ruggedness, of Chapman Creek, measured from Tetrahedron Peak to the fan apex is 20%, suggesting at first glance that only normal hydrologic floods would affect the fan (Wilford et al 2005).

However, review of background reports shows that many authors believe the high peak flows recorded in October 1962 and January 1968 are distinct from the other hydrologic peak flows and may have been associated with the failure of landslide debris dams. The above discussion of landslide hazards and impact potential for the mainstem of Chapman Creek offer a strong degree of support for this hypothesis; however, specific landslides were not identified for either of the floods and the connection, while likely, remains uncertain.

Based on the landslide hazard assessment, it is reasonable to conclude that heavy rainfall and high runoff could initiate a landslide capable of direct impact to Chapman Creek. The formation of a landslide barrier within the creek channel could cause water to build up behind the obstruction before ultimately overtopping and washing out the landslide barrier. This process would result in an outburst flood.. The time taken for a landslide dam to fail can be as rapid as seconds to a few minutes. As the landslide dam fails, there is a sudden release of water down the creek. The water is often highly charged with sediment, boulders, and woody debris from the dam failure, and the dynamic energy of the flood wave can mobilize additional debris within the creek channel.

A water flood enriched with a very high concentration of sediment is often termed a “hyperconcentrated flow” or “debris flood”, and is considered an intermediate process between a channelized landslide (“debris flow”) and a clear-water hydrologic flood. It is appropriate to adopt a debris flood scenario as the design event for Chapman Creek. The design event is addressed further in the next section.

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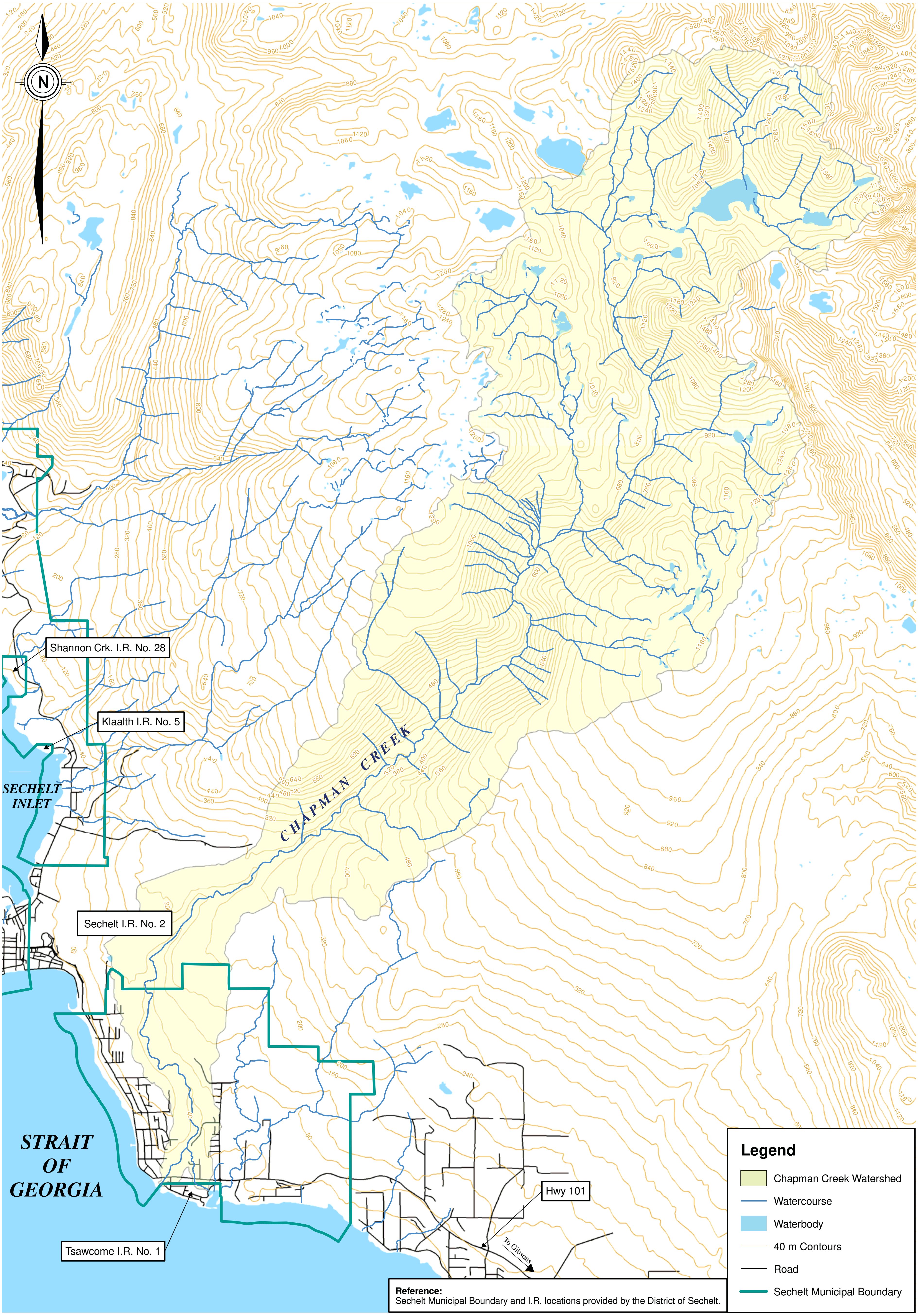

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Chapman Creek Flood Hazard Assessment

Project No.	Date
551-010	August 2010

0 500 1,000 2,000 Meters
Scale in Metres 1:60,000

Chapman Creek Watershed

Figure 3-1

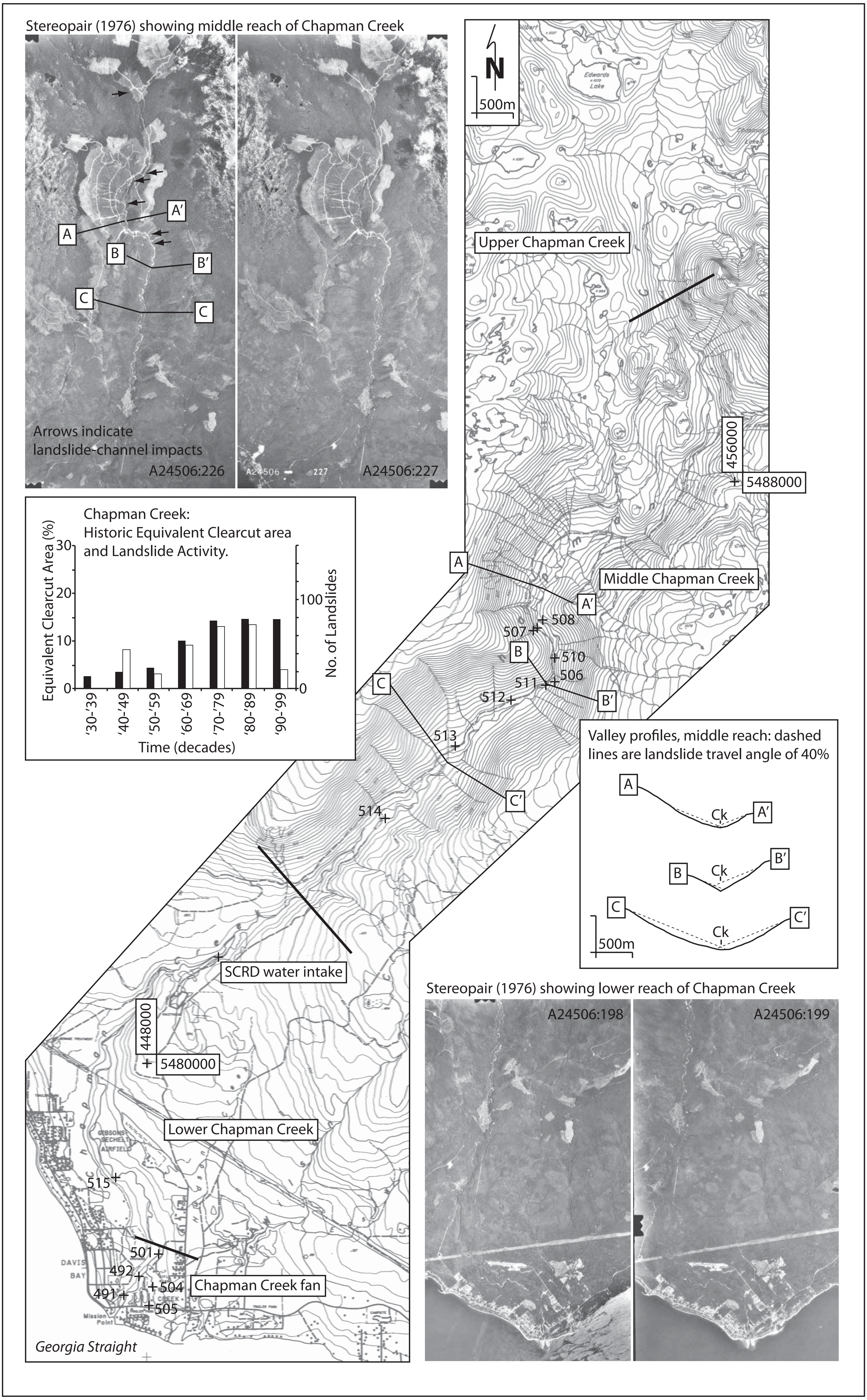

FIGURE 3-2: Geohazard Overview for Lower Chapman Creek Watershed

Overview of watershed geohazards showing TRIM mapping, cross-sections, landslide runout angles, landslide occurrences, aerial photo stereo pairs, and GPS waypoints (+) identified during the field visit of April 7-8, 2010.

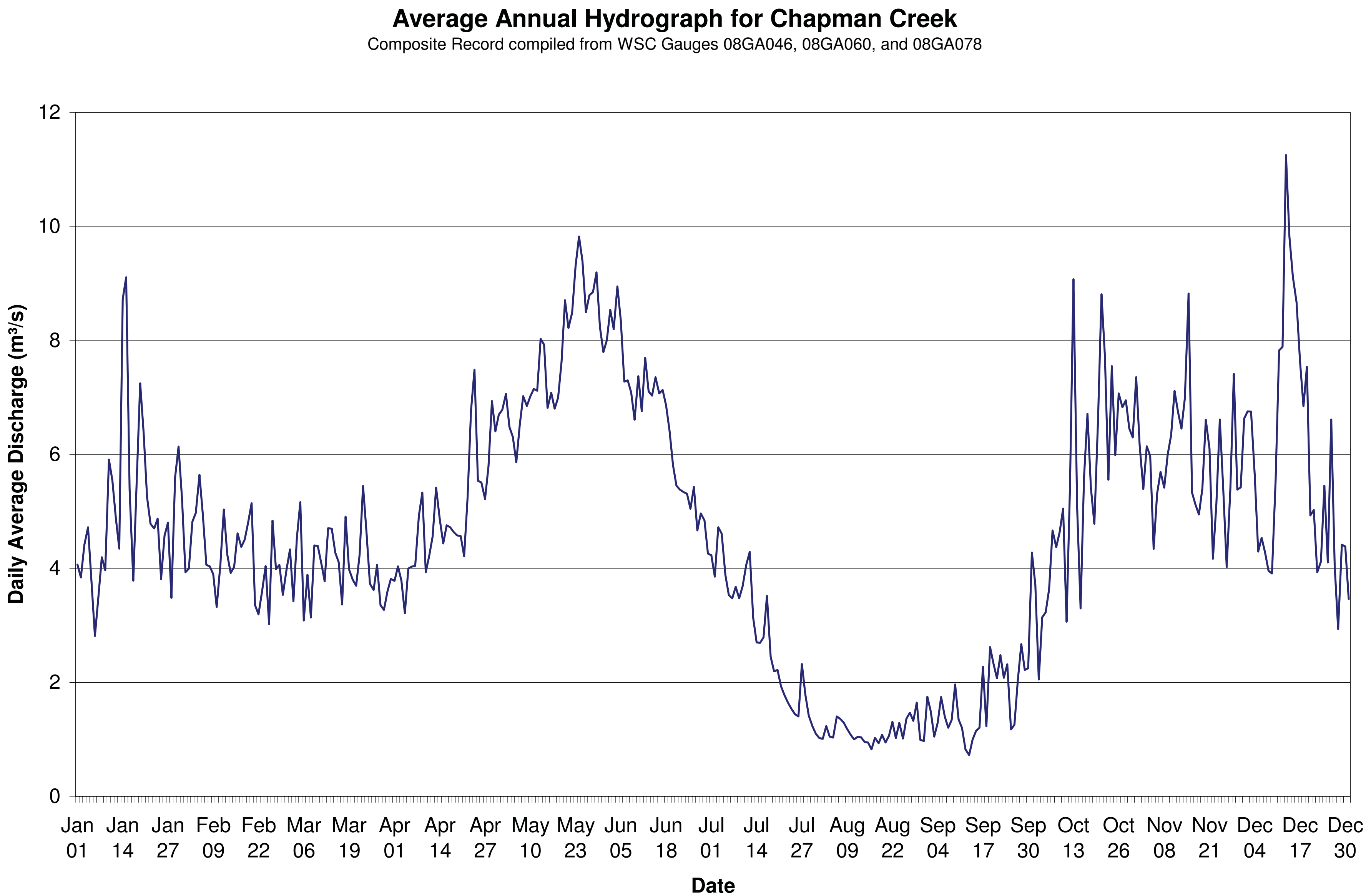

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Figure 3-3

Section 4

Design Flood

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4. DESIGN FLOOD

The standard clear-water design event for flood protection in British Columbia is a flood that occurs, on average, once every 200 years. This is referred to as the “200-year return period flood”.

In contrast, there is no standard design flood for creeks where geomorphic processes are known to play a role in flood recurrence. A return period of less than 200 years (the provincial standard for clear-water floods) would normally not be considered. There are some guidelines for the selection of a design debris flood event (typically the 500-year return period) for some purposes. Some recent seismic design standards are based on the 2,500-year return period event. For planning new communities in BC, there has been some discussion about whether a 10,000-year event should apply.

For the present study, it is understood that the District does not wish to exceed a nominal 200-year return period for assessing hazards to existing development along Chapman Creek. Examining debris flood hazards at levels significantly exceeding the 200-year return period would require a more extensive study that includes a much more intensive field investigation.

This section describes the process undertaken to quantitatively define an appropriate design flood scenario for Chapman Creek. The analysis is based on past hydrometric and geomorphic observations.

4.1 FLOOD FREQUENCY ANALYSIS

This section describes the application of a flood frequency analysis to the available Water Survey of Canada data for Chapman Creek.

Creating a Composite Peak Flow Series

In composite, the three WSC gauges described in Section 2.2 provide annual maximum daily average and instantaneous streamflow series consisting of 39 and 24 data points, respectively. The combined series of daily average annual maxima for the three gauges is shown in Figure 4-1. The daily series in particular provides a relatively strong basis for flood frequency analysis, assuming the three series of annual maxima can be normalized to the same location.

Flood quantiles (peak flows) can be scaled within a single river system using a general relationship of the form:

$$Q_1 = Q_2 (A_1/A_2)^n \qquad [4\text{-}1]$$

where the subscripts 1 and 2 represent the target and reference locations, respectively. The exponent *n* is usually determined based on a log-log regression between two gauging stations having concurrent records on the river. Where concurrent records do not exist, a number of guidelines are available for estimating *n* (e.g., Watt et al., 1989). Coulson and Obedkoff (1998) examined peak flows across BC and estimated a representative value of n = 0.785. In the absence of data to support a local estimate, KWL has adopted the Coulson and Obedkoff value for combining the WSC hydrologic records.

The applicability of the scaling exponent must be considered in the context of the flood response of a given watershed. In this case, the scaling exponent was applied to both instantaneous and daily flows within the watershed to allow in part for the strong precipitation and runoff gradients through the watershed.

The series of annual maximum daily average streamflow data includes two peak flows (1962 and 1968) excluded in previous studies and noted as possible debris floods (e.g., Chapman and Reksten, 1991; EBA, 2000).

Flood Frequency Analyses

The more complete composite streamflow record of daily average maxima was analyzed using Environment Canada's Consolidated Frequency Analysis software package. Average flood quantiles are presented in Table 4-1 below, both with and without the 1962/1968 events.

Table 4-1: Frequency Analysis Results at 08GA078 (A = 65.8 km²)

Return Period	Without Debris Flood Events	With Debris Flood Events
Years of Data	**37**	**39**
2	46.7	47.3
5	62.6	69.9
10	74.3	90.0
20	86.2	114.0
50	102.7	153.3
100	116.3	190.3
200	130.0	234.7

The above FFA results compare well with the FFA results presented by Chapman and Reksten (1991), which were obtained using a historical subset of the same data.

The results clearly show the strong influence of the two potential 1960s debris floods on flood frequency extrapolation. The series of lower values represents what KWL believes to be a "clear-water" (i.e., purely hydrologic) flood series on Chapman Creek. These values are subsequently used as background conditions for a landslide outburst condition (described in Section 4.2). If the two events of 1962 and 1968 are taken as historic debris floods, including these events makes the series of higher values more representative of the full range of hazards on Chapman Creek (i.e., including debris floods). It is not reasonable to combine the higher FFA results with a landslide dam failure simulation.

Peaking Factor

Peaking factors represent the ratio of an instantaneous peak flow to the corresponding daily average flow. In determining a peaking factor for the design flood, two different approaches were adopted:

- calculation of the I/D for the largest daily discharge on record; and
- comparison of the daily average and instantaneous Q200 estimates.

In both cases the results suggest a peaking factor of approximately 1.5. A synthetic flood hydrograph was constructed for use in the hydraulic modelling described in Section 5. The synthetic hydrograph is based on the Q200 daily average flood estimate, a peaking factor of 1.5, and assumed baseflow conditions.

Comparing FFA Results to Other Regional Hydrometric Stations

Frequency analysis suggests that the 200-year unit runoff for Chapman Creek is significantly higher than corresponding estimates for the nearby watershed at Roberts Creek (08GA047); however, this is to be expected given the strong orographic precipitation gradient and significantly higher mean basin elevation (1,007 m for Chapman Creek vs. 697 m for Roberts Creek).

In contrast, predicted 200-year return period unit runoff for Capliano River above Intake (08GA010), located in the North Shore mountains near Vancouver, is significantly greater than that recorded for Chapman Creek. Capilano River has a similar mean basin elevation (976 m) and hypsometry to Chapman Creek; however, Capilano River lacks the headwater lakes of Chapman Creek. In addition, the aspect of the watershed is more exposed to southwesterly flows that typically bring storms from the Pacific Ocean; comparison of mean annual unit runoff for the recent record shows that Capilano River exceeds Chapman Creek by as much as 80%.

The 200-year unit runoff estimated for Chapman Creek approximates the average of estimates for Roberts Creek and Capilano River. This is considered good validation of the independent Chapman Creek flood frequency analysis due to the topographic and orographic differences between the watersheds.

FFA Limitations

As might be expected when extrapolating a 40-year record to the 200-year threshold, Flood Frequency Analysis is subject to uncertainties and limitations. For this study, there are two specific sources of uncertainty that should be noted by users.

Firstly, although some of the flood events may have resulted from processes other than rain-on-snow, separate analyses of distinct flood-producing mechanisms is beyond the scope of this study. Therefore, the hydrologic series was conservatively treated as a homogeneous population.

Secondly, climate change and land cover changes were neglected in the frequency analysis as these factors are also beyond scope of the present study. To account for this uncertainty, the design scenarios presented in Section 5 include some more conservative alternatives.

4.2 GEOMORPHIC FLOOD FREQUENCY

The landslide inventory provided by Thomson (1987), as updated by EBA (2000), and the geomorphic flood inference by Chapman and Rekston (1991) provide an opportunity to assess the potential for geomorphic floods to affect the Chapman Creek alluvial fan. This method follows a conditional probability approach, as advocated by Wise et al. (2004; and others). The application of the conditional probability approach to landslide-channel impacts and outburst flooding has been applied by Korup (2005). The following analysis is similar to Korup (2005), but differs in detail due to the constraints of the available data.

In this analysis, estimates for the landslide rate (P_H) and likelihood of consequent geomorphic flood at the fan given a landslide occurrence ($P_{GF:H}$) will be determined. The product of these probabilities yields the probability of a geomorphic flood affecting the fan, on a per annum basis (P_{GFA}).

The rate of landslide activity (P_H) in Chapman Creek increased proportionally with the clearcut equivalent area in the period from 1960-1990 (Fig. 1). However, in response to forestry-related landslide activity, the Forest Practices Code and the FRBC watershed restoration program was implemented BC-wide in the 1990s. A significant amount of road deactivation and landslide and channel restoration work was conducted in Chapman Creek at this time (EBA 2000). As a result the landslide rate appears to have subsided in the 1990s (Fig. 1). From 1960-1990, the landslide rate rose as high as 70 landslides per decade, but dropped to 20 landslides per decade in the 1990s.

In the future, the landslide rate (P_H) is not expected to be as high as in the 1960-1990 period. This is because the watershed restoration that has occurred has reduced landslide risk as described above, and, future logging activity will be subject to closer scrutiny (e.g., EBA 2000). Thus, future landslide rates may be more similar to historic natural background rates. Consideration of climate change impacts is beyond the scope of this study.

The landslide inventory (Table 1; EBA 2000) suggests 49 natural landslides in a 70-year period (1930-2000), or an average of 0.7 landslides per year. For the Brooks Peninsula, an unlogged landscape on the west coast of Vancouver Island, Guthrie and Evans (2004b) report a natural landslide rate of three landslides per year. Brooks Peninsula is a hypermaritime area, and its landslide rate is 1.2 - 9.5 times higher than other sites on Vancouver Island. Thus, landslide rates in drier areas might be in the range of 0.3 – 2.5 landslides per year. Based on these numbers, a landslide rate (P_H) of 0.7 landslides per year for Chapman Creek seems reasonable.

As indicated in Table 1, not all landslides impact the channel, and not all channel impacts result in geomorphic floods. Of the 225 historic logging-related landslides, 78 impacted the stream, but only two are thought to have resulted in significant geomorphic floods affecting the Chapman Creek alluvial fan (natural events are not used because the number of natural events impacting a stream was not reported by EBA 2000). Using these statistics, the probability of geomorphic flooding at the fan should a landslide occur ($P_{GF:H}$) is 0.009.

Finally, using the available data the probability of geomorphic flooding affecting the fan in any given year (P_{GFA}), under natural conditions, appears to be 0.7 times 0.009, or 0.006 per annum (1/160 year return interval). This could rise to a much larger rate under poor landuse practices, where up to 70 landslides per decade have been recorded (e.g., 7.0 times 0.009 = 0.063 per annum, or 1/15 year return interval).

4.3 POTENTIAL GEOMORPHIC FLOOD MAGNITUDE

Peak discharge immediately downstream of the channel impact site is related to the size of the landslide dam, the volume of the impounded water body, and the rate of breach (Costa and Schuster, 1988). As the flood progresses downvalley, factors such as channel roughness and constrictions or bends will attenuate the flood, reducing its potential impact at the point of interest, in this case the Chapman Creek fan.

Estimating potential geomorphic flood discharge at the apex of Chapman Creek fan requires a general idea of reasonable landslide barrier geometry and material type, and the associated impoundment volume. The dambreak may then be simulated and propagated downstream using a hydraulic model.

Two landslide-channel impact sites were examined in the field. Waypoint 508 (shown on Figure 3-2) is located at the toe of an historic logging related landslide. At the location of Waypoint 508, the valley flat is about 30 m wide with the opposing valley side a vertical rock wall. The channel gradient is approximately 6% and the bed composed of large (2-5 m sized) blocks. The most probable barrier height related to the historic landslide was about 5 m tall at the upstream end of the deposit. Projecting a level surface upstream, the potential impoundment may have extended some 50-80m upstream. Based on a simple geometric estimate the potential impoundment may have been about 6,000 m^3. Materials forming the barrier were derived from sandy glaciofluvial deposits and would have failed rapidly.

Waypoint 510 is a blocky deposit on the west bank assumed to represent a prehistoric rockfall. The valley flat, cross-section, channel gradient, and bed composition are similar to those observed at Waypoint 508. The most probable barrier height related to the prehistoric landslide was about 10m tall at upstream end of the deposit. Again using a simple geometric estimate the potential impoundment may have been about 25,000 m^3. Materials forming the barrier were derived from blocky rockfall and would have failed slowly.

Assuming deposit lengths of 50 m and the previously-noted channel width and barrier heights, the barrier volumes ranged from 7,500 to 15,000 m^3. Given some unknown loss to the channel, these volumes are consistent with Class 3-4 size (Table 3-2) landslides expected to impact this reach.

4.4 TIDAL CONDITIONS

The lower reaches of the Chapman Creek channel are tidally influenced, and flooding may be caused or affected by high tides and storm surge. Such a condition is reported for a significant flood event on lower Chapman Creek in 1980 (Golder 1993).

Some consideration must be given to prevailing tidal conditions during a design flood. A rain-on-snow event will typically occur in the late fall or early winter. This period includes the largest tidal cycles of the year. It is also possible for a storm system to be accompanied by storm surge as it reaches the Chapman Creek watershed. On the west coast of British Columbia, storm surge can add 0.9 m to normal water levels, as was experienced in the December 1982 storm surge or record for at Point Atkinson (Thompson and Crawford, 1996). A flood could occur at high or low tides.

The “extreme” tide reported for Point Atkinson, when transferred to Roberts Creek, has a geodetic elevation of 2.5 m. The “extreme” tide as defined by the Canadian Hydrographic Service is the highest value recorded for a particular gauge. The foreshore area along the Sechelt Indian Band’s Tsawcome I.R. No. 1 was not part of the KWL / Cordilleran Geoscience field review, as the First Nation lands are outside the scope of this study. A brief analysis of LiDAR data provided by the SCRD shows a continuous belt of land at minimum elevation 2.5 m along the foreshore, with lower elevations within the “protected” area. The 2.5 m “high ground” line extends from Chapman Creek to the Wilson Creek estuary.

A dynamic tide series with a peak water level of 2.5 m was therefore adopted as a conservative downstream boundary condition for the design event.

KWL’s analysis did not explicitly consider storm surge or wave runup. These factors could result in transient water levels exceeding elevation 2.5 m during an extreme storm event. KWL also did not provide a detailed review of whether 2.5 m is an appropriate "design tide" condition for the purposes of flood assessment. As such, this report does not provide a conclusive analysis of tidal-induced inundation on the Chapman Creek fan.

4.5 SELECTION OF BACKGROUND FLOOD FOR A GEOMORPHIC EVENT

In most cases a geomorphic debris flood is initiated under conditions of high antecedent soil moisture, intense precipitation and high runoff (e.g., Jakob and Weatherly, 2003). While the likelihood of a landslide increases with rainfall / runoff intensity, landslide initiation processes are complex at a local scale and it is impossible to explicitly quantify the magnitude of a triggering event.

For the purposes of this study, it is assumed that the triggering event would be a rain-on-snow event with saturated surface conditions, and that the accompanying runoff would be toward the more extreme end of the range. Given the uncertainty associated with the design event, a range of scenarios is considered in the hazard analysis described in Section 5. These scenarios include:

Scenario 1: landslide debris dam failure with the 50-year clear-water flood hydrograph;
Scenario 2: landslide debris dam failure with the 100-year clear-water flood hydrograph;
Scenario 3: landslide debris dam failure with the 200-year clear-water flood hydrograph; and
Scenario 4: 200-yr "debris flood" hydrograph from FFA using complete peak flow series.

The 200-year clear water design flood (Scenario 5) is also presented for comparison purposes.

In all cases, the flood scenario is combined with an astronomic tide signal scaled up to peak at 2.5 m geodetic elevation. A scenario where the dam break flood wave is intentionally timed to arrive at high tide would represent the most conservative interpretation of downstream boundary conditions. This scenario is briefly considered as a sensitivity analysis parameter. These events are summarized in the following table.

Table 4-2: Background Floods for Chapman Creek Flood Analysis

ID	Flood	Debris Flood	Tide Peak	Attenuation	Peak Flow (m^3/s)	Volume ($x10^3$ m^3)
1	50-yr	Dam Breach	Nominal	Nominal	267	150
2	100-yr	Dam Breach	Nominal	Nominal	291	159
3	200-yr	Dam Breach	Nominal	Nominal	316	170
4	200-yr	FFA	Nominal	Nominal	380	141
5	200-yr	None	Nominal	Nominal	210	218

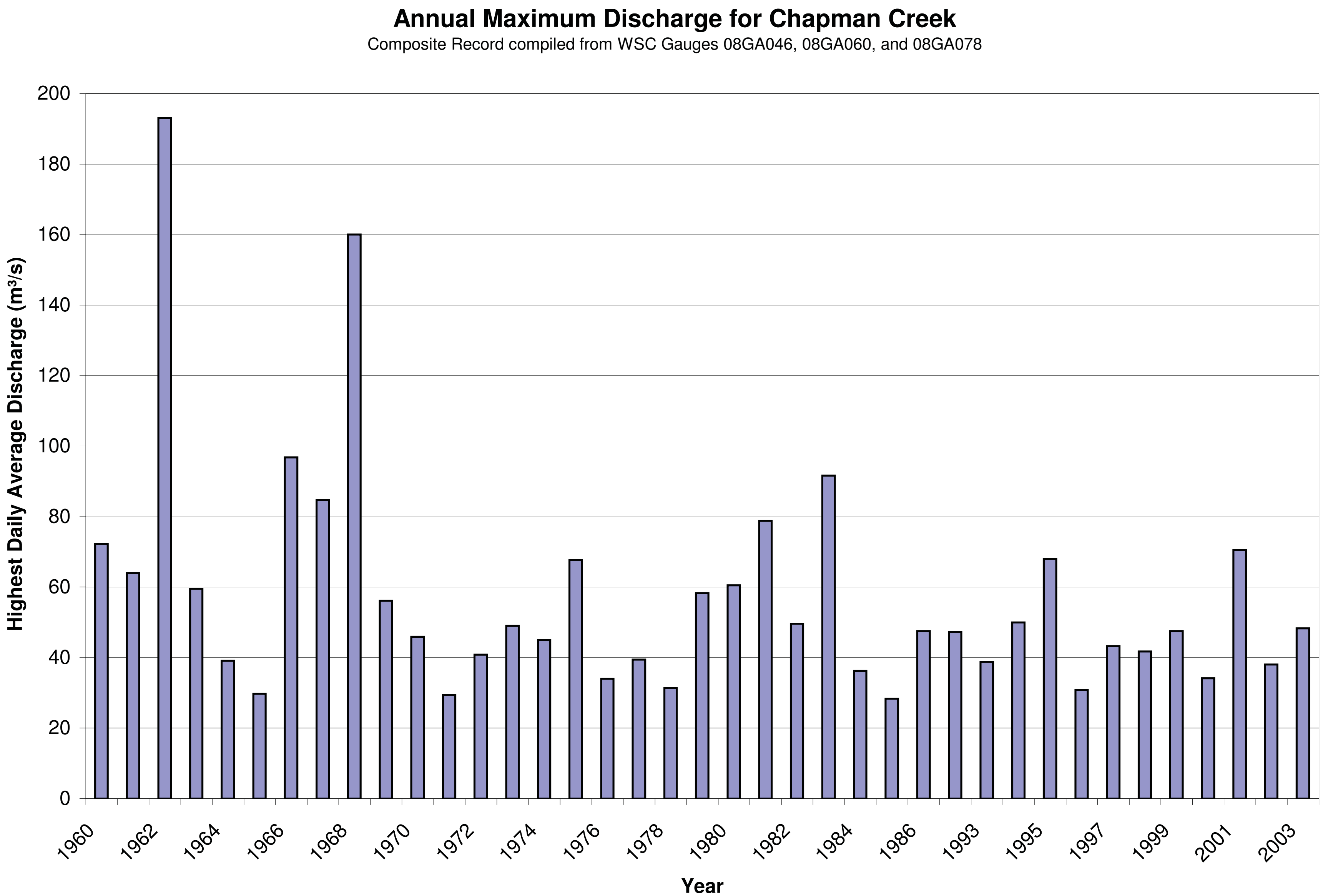

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Figure 4-1

Section 5

Flood Hazard Assessment

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5. FLOOD HAZARD ASSESSMENT

5.1 CHAPMAN CREEK FAN

The Chapman Creek fan was formed by deposition of sediment at the mouth of Chapman Creek where it meets the sea, near the town of Sechelt, BC (Figure 5-1). The fan is designated as part of Development Permit Area 9 (DPA9) in the 1993 hazard mapping (Golder, 1993). The term creek fan shall be synonymous with floodplain for the purposes of this discussion.

The DPA 9 area includes escarpment slopes, watercourses, and active and inactive alluvial fan deposits, and as such does not precisely define the active fan area. The management recommendations from the 1993 report are based on a high-level assessment, and follow from provincial guidance for “large watercourses” (e.g., WLAP, 2004) rather than a watershed/landform specific analysis.

This section describes the evolution of the Chapman Creek fan as it pertains to the hazard area, outlines the modern active fan area, and summarizes KWL’s hydraulic modelling.

Chapman Creek Fan Morphology

Chapman Creek flows into the sea, and as a result, the history of the fan and modern creek/fan processes are linked to sea-level fluctuation. Figure 5-2 shows relative sea-level change in the central Strait of Georgia for the period from 15,000 to 5,000 years before present (adapted from Hutchinson et al., 2004).

During glaciation the land surface was depressed by the weight of the ice, and upon deglaciation the sea inundated the depressed land surface. In the Sechelt area the maximum inundation level stood at about 160-200 m elevation above current sea level (Clague et al., 1982). At that time, meltwater transported abundant volumes of sediment to outwash deltas forming along the mouths of meltwater channels. Today these sediments are widespread in the Sechelt area and are extensively mined.

Following deglaciation, the land rebounded rapidly and relative sea level fell. By about 11,500 years ago relative sea level was approximately 10 m lower than today. At this time rebound had more or less ceased, and sea level began to rise slowly. By about 8,000 years ago, sea-level reached and slightly surpassed modern level, then began to fall. Mean relative sea-level has essentially been constant over the last several thousand years.

When sea level was falling rapidly in the early post-glacial period, Chapman Creek downcut, or incised, into the thick glacial deposits along lower Chapman Creek watershed. The creek would have been laterally unstable at this time, sweeping north and south and gradually abandoning former floodplain surfaces as sea level continued to fall.

These abandoned surfaces now appear as raised terraces to the north and south of the active fan area.

During the sea-level lowstand, Chapman Creek would have created an incised channel graded to the lowest sea-level, some 10 m below present. This channel then became filled in by stream and shoreline sedimentary processes as sea-level rose to its maximum position (several metres higher than present) some 8,000 years ago. The last phase of emergence would have resulted in another phase of terrace abandonment, leading to the formation of the modern active fan.

The Chapman Creek fan has been developed through a complex sequence of erosional and depositional cycles that have created features that do not reflect the current hydrological and sea level regime.

Current Geometry and Topography

The modern active fan apex is located just upstream of the Shooting Range (Waypoint 501 on Figure 3-2). The fan margins are defined by a ±10 m tall scarp bounding the western side of the present channel and by a variable scarp (from several metres high to 20 m plus) on the eastern side of the fan, passing near the Canadian Tire site at Wilson Creek. The fan is roughly triangular in plan, measuring about 1 km from its apex near the fish hatchery to the ocean foreshore along Tsawcome I.R. No. 1. From west to east, the fan extends about 800 m from Chapman Creek to the Wilson Creek estuary. The extents of the fan are shown on Figure 5-1.

Lower Chapman Creek flows along the west side of the fan and occupies an active channel up to about 30 m wide. A small side channel on the south side of the creek branches and rejoins the main channel (Waypoints 496, 497 and 498). The active channel is contained by a bank several metres high to the west and 1.5-2 m high to the east.

Highway 101 crosses the fan from east to west about 200 m upstream from the channel mouth and forms a flood barrier up to 2 m tall. The highway crosses the creek channel via a two-lane bridge skewed at ±40° to the direction of flow, giving it a projected effective width of about 25 m at flood stage. The bridge forms a constriction in the lower reaches of the creek. Local drainage of the fluvial fan surface is passed under the highway via a 1.5 m dia. CSP culvert at Waypoint 505.

The Chapman Creek fan shows a distinct east-west elevation gradient, with the channel occupying the western fan margin as the lowest point. Along the upstream side of Highway 101, land elevation generally increases from about 4 m at the top of the creek bank to ±8 m near the Canadian Tire retail lot. On most fans, the land surface slopes away from the apex in all directions; the difference at Chapman Creek is a result of the evolving geologic history described above.

Historic Secondary Channel

Historic mapping of the Chapman Creek fan shows a second channel branching off the existing main channel near the fan apex and flowing across the eastern portion of the fan; however, the channel is not apparent in recent orthophotos or on LiDAR-derived topography. Newbury (1997) reports that this eastern channel was re-directed into the present-day main channel in the 1950s. This status of this channel was investigated on foot during the April 7/8 field visit carried out by KWL and Cordilleran Geoscience.

Field traverse indicates that the upstream half of this feature has been obliterated by land development, including development of the fish hatchery, the shooting range and private properties. Remnant portions of a relic channel were traced from north of Hazelnut Lane to Highway 101. Based on field observations of discontinuous channel sections, the channel appears to have been 10-15 m wide with 1.5-2 m tall banks (e.g., Waypoint 495 on Figure 3-2). Immediately north of the highway, a local resident appears to have reclaimed a portion of the relic channel as habitat ponds.

Anecdotal information from local residents and the District of Sechelt indicates that the Ministry of Transportation removed the culverts conveying the secondary channel beneath Highway 101 and did not replace them. SCRD orthophotos show that a defined channel resumes about 200-300 m upstream from the ocean. KWL was unable to trace a surface channel connection upstream to the present-day highway culvert.

Exposed sections of the former creek channel may locally convey and pond water if overland flow occurs on the creek fan; however, it is no longer effective as a significant secondary channel during high flows.

5.2 MODEL DESCRIPTION

KWL constructed an uncalibrated hydraulic model to explore the nature and extent of inundation on the Chapman Creek fan that could result from the design event described in Section 4. Limitations on available data and scope did not allow a complete two-dimensional analysis; therefore, a pseudo-2D model was constructed using a linked channel Mike11 one-dimensional hydrodynamic model.

Model Structure

The pseudo-2D representation was achieved by dividing the channel and fan into a number of conveyance channels connected by storage-independent link channels (Figure 5-3). The main components of the model include:

- Upper Chapman Creek, from the potential landslide zone to the upstream limit of SCRD LiDAR;
- Chapman Creek, from the upstream limit of SCRD LiDAR to tidewater; and

- three main north-south overflow channels on the fan.

Significant structures within the model include:

- Highway 101 bridge (modelled as a closed culvert skewed at an angle to the flow);
- Highway 101 bridge weir (for bridge overtopping);
- weirs at Highway 101 on each of the three main overflow channels;
- 1.5 m dia. CSP drainage culvert beneath Highway 1;
- outlet control structure at the Wilson Creek marina; and
- weirs to control artefacts caused by applying a 1D flow network to 2D topography.

Proper development of a pseudo-2D modelling framework is key to achieving reasonable output, and requires a thorough knowledge of the limitations of one-dimensional modelling. Even so, the results of such a process should be used as guidance for engineering and planning decisions rather than as definitive definitions of flood levels at a specific location. For the present study, the level of uncertainty associated with the model is considered acceptable with regard to the uncertainty inherent in quantifying the magnitude and likelihood of the design event.

Topographic data

As described in Section 2 m, available LiDAR topographic data covers the Chapman Creek fan and extends upstream approximately 8 km beyond the fan apex. Cross-sections were obtained by overlaying LiDAR with the Mike11 model network in ArcGIS, then sampling cross-sections at defined chainage intervals. Once copied into Mike11, the ends of each cross-section were georeferenced to facilitate inundation mapping.

For this study, the creek reach from approximately 8 km to 15 km upstream from the fan apex is referred to as the Upper Chapman Creek model branch. Cross-sections for Upper Chapman Creek model branch were obtained from provincial TRIM contours at 20 m resolution. Sections were cut slightly downstream from the intersection of contour and creek alignment to maximize descriptive information.

The topographic information available from TRIM contour mapping is coarse and is not a good representation of any particular channel section; however, the data provide a reasonable characterization of reach-scale channel characteristics. The Upper Chapman Creek branch is included to allow simulation of dam breach flood wave attenuation from the landslide dam location to the fan apex rather than to provide direct modelling results.

Design Event Boundary Conditions

Boundary conditions for this study include an inflow hydrograph at the upstream limit of the model and a tide series at the downstream end.

The inflow hydrograph was based on an areal transposition of the synthetic hydrograph described in Section 4.1. A distributed hydrograph was applied along the channel mainsteam to represent local inflows between the upstream boundary condition and fan apex.

The tidal boundary condition was an astronomic tide series produced for Roberts Creek using the WXTide generator and scaled up to a maximum sea level of 2.5 m geodetic as described in Section 4.4. The tide series boundary condition utilized the nominal times and dates generated by WXTide.

Landslide Dam Breach Parameters

For scenarios involving a landslide dam breach, a 10 m high dam was specified 750 m below the upstream end of the model. The resulting backwater curve remains fully contained within the model space, thereby preserving the maximum storage volume.

Time series for dam failure base elevation (incision), breach base width, and side slopes were selected by KWL in consultation with Cordilleran Geoscience assuming a 60-second failure period for the unconsolidated dam. Ultimate breach dimensions approximate the full channel cross-section.

Mike11 does not account for sediment and debris bulking of dam failure flows; however, this process can have a significant effect on peak discharge. To approximate sediment and debris bulking, a constant point source inflow of 150 m^3/s was selected by dividing a representative volume for the landslide dam (9,000 m^3) by the breach duration (60 s). The 150 m^3/s is applied as inflow for a 60 s period concurrent with the dam breach.

Peak discharge is computed by the model and the flood wave is allowed to propagate dynamically downstream.

Simulation Parameters

The Mike11 model was applied with stabilized initial conditions for a 24-hour simulation beginning at the arbitrary date of 04:30 AM on May 17, 2010. The complex nature of the flow network required a 2 s timestep for stability. The time-centering parameter delta was set to 0.7.

Hydraulic Parameters

No calibration data was available for this model, and the scope of this study did not allow for a data collection program. Roughness values (Manning's *n*) were assumed based on engineering judgement and field review. Values for the Chapman Creek mainstem ranged from a low of 0.03 for the lower gravel/cobble reach of the creek up to 0.08 for vegetated overbank areas in the higher watershed. It is noted that Manning's n can decrease with discharge; the magnitude of the design flood peak flows was considered in making these selections.

Under the current project scope, a detailed assessment of flow resistance on the fan was not possible. For simplicity, cross-sections for overland flow conveyance were assigned a Manning's n value of 0.08.

Future calibration of the model would permit a more strict interpretation of results. If more detailed analysis is required, the District could consider expanding the sensitivity analysis described below to further explore the effects of floodplain and channel roughness.

Sensitivity Analysis

For this study, sensitivity analyses were carried out to examine impacts on inundation extent for the following parameters:

- design flood magnitude;
- flood wave attenuation; and
- relative timing of tide and flood peaks.

Each of these analyses is presented as a separate scenario.

Design flood magnitude is explored by assuming a variety of hydrologic and geo-hydrologic conditions for the flood event, as described in Section 4. These include:

Scenario 1: 50-year clear-water flood with landslide debris dam failure;
Scenario 2: 100-year clear-water flood with landslide debris dam failure;
Scenario 3: 200-year clear-water flood with landslide debris dam failure;
Scenario 4: 200-year "debris flood" peak flow obtained from FFA; and
Scenario 5: 200-year clear-water flood, no debris flood component

To explore sensitivity of flood wave attenuation, roughness values were decreased to plausible minimum values between the landslide dam location and the fan apex. By decreasing channel roughness upstream of the fan, a more conservative estimate of flood wave could be investigated.

Scenario 6: 200-year flood with landslide dam failure, minimum channel roughness

Finally, the tidal series was shifted such that the extreme peak of 2.5 m geodetic occurred concurrently with arrival of the dam failure flood wave. This would provide the highest combination of water levels.

Scenario 7: 200-year flood with landslide dam failure and concurrent extreme tide

Many other sensitivity analyses are possible but are beyond the scope of this analysis. The District is encouraged to explore additional sensitivity analyses as required to support risk management and/or controversial decisions.

5.3 SCENARIO RESULTS

Key results for each scenario include the following parameters:

- simulated instantaneous peak discharge at the fan apex;
- maximum water surface elevation at the upstream side of the Highway 101 bridge;
- inundation mapping; and
- volume of water represented by the inundation mapping.

The first two items in the above list are straightforward parameters calculated by the Mike11 hydraulic model. The inundation mapping is produced through ArcGIS, which utilizes Mike11 results through an interface program called Mike11GIS. Water volumes are provided as a numeric measure of relative inundation, and are calculated by summing the water depths for each raster cell in the inundation mapping and multiplying by the GIS cell area.

Numerical results are summarized in Table 5-1 below. Inundation maps are presented in Figure 5-4 through Figure 5-10 with each figure representing its corresponding scenario. Simulated 24-hour flood hydrographs for Scenarios 1-5 are shown in Figure 5-11.

Table 5-1: Debris Flood Modelling Scenario Results for Chapman Creek

ID	Flood	Debris Flood	Tide Peak	Attenuation	Peak Flow (m^3/s)	Max WS Elev (m)	Volume ($x10^3$ m^3)
1	50-yr	Dam Breach	Nominal	Nominal	267	5.0	150
2	100-yr	Dam Breach	Nominal	Nominal	291	5.2	159
3	200-yr	Dam Breach	Nominal	Nominal	316	5.4	170
4	200-yr	FFA	Nominal	Nominal	380	5.8	141
5	200-yr	None	Nominal	Nominal	210	4.8	**218**
6	200-yr	Dam Breach	Nominal	Minimum	325	5.4	171
7	200-yr	Dam Breach	Concurrent	Nominal	316	5.4	177

All inundated areas shown on the figures have been included in the volume calculation, including ocean, beach and foreshore coastal inundation. However, since the high tide level is constant across all scenarios, the inclusion of purely coastal inundation will not affect relative results.

The flood wave resulting from the debris dam breach in Scenarios 1, 2, 3, and 7 has a time base (i.e., time between first arrival and recession to background conditions) of approximately 15 minutes at the fan apex.

Of note, the largest peak discharge and water levels were experienced in the debris flood estimated by frequency analysis of recorded events. This surpassed all of the peak discharges developed by numerical analysis. The clear water flood, had the lowest peak flow, but the largest total discharge (volume) of all the floods.

5.4 DISCUSSION

This section discusses the results of the hydraulic modelling and their implication for land-use planning decisions.

Peak Discharge

As expected, all of the debris flood scenarios yield instantaneous peak flows significantly larger than the 200-year clear-water flood. This confirms that formation and breaching of a landslide debris dam in the middle reaches of Chapman Creek can generate debris flood discharges in excess of the typical 200-year design flood. As such, a debris flood design scenario should be adopted for Chapman Creek.

Flood Wave Characteristics and Timing

The peak magnitude (roughly +105 m^3/s) and time base (±15 min) of the floodwave are relatively consistent across all dam breach scenarios (i.e., 50-year, 100-year and 200-year background floods). When channel roughness is reduced to a realistic minimum (Scenario 6), the relative magnitude of the flood wave increases slightly (roughly +115 m^3/s) and the time base decreases by 1-2 minutes. Figure 5-12 compares simulated flood waves for the base scenario (Scenario 3) and the sensitivity analysis scenario (Scenario 6).

The sensitivity check provided in Scenario 6 demonstrates that the flood wave timing and magnitude is much more dependent on debris dam storage, breach characteristics, and flow bulking during dam failure than on channel roughness.

Peak discharges from the outburst event were validated against field observations of a presumed paleoflood terrace in the middle reach of the model and found reasonable.

Inundation of Chapman Creek Fan – Fan Apex to Ponderosa Pines

Maximum water surface elevations on the Chapman Creek fan are observed to occur from the interaction of one or more processes:

- dynamic flood routing of peak flows (e.g., through the fish hatchery reach);
- backwater conditions imposed by the constriction at the Highway 101 bridge; and/or
- tidal inundation and backwatering in the lower reaches of the creek.

Modelled peak flows associated with Scenarios 1-3 and 5-7 remain relatively well confined within the creek channel from the fan apex to the north end of the Ponderosa Pines Mobile Home Park. Notable exceptions at higher discharge include:

- low-lying areas at the fish hatchery, which the model suggests will be subject to inundation and ponding but provide little to no conveyance; and

- the active side channel adjacent to the north portion of Big Maple Mobile Home Park, which will convey significant flow. Some overtopping and shallow flow through the mobile home park should be expected for events approaching the 200-year threshold.

Scenario 4 ("debris flood" peak flow based on Flood Frequency Analysis) has much higher peak and average discharges and therefore results in much more significant flooding. Ponding is more extensive at the fish hatchery and conveyance through the Big Maple Mobile Home Park becomes more significant.

Inundation of Chapman Creek Fan – Ponderosa Pines to Highway 101

The hydraulic model clearly demonstrates the potential effects of the Highway 101 bridge during a large flood on Chapman Creek. Figure 5-13 shows a water surface profile along the main channel from below the highway bridge to the north end of Big Maple Mobile Home Park.

The induced backwater condition and acceleration-induced hydraulic drop through the bridge opening are readily apparent in Figure 5-13. The hydraulic drop across the bridge opening of up to 2 m is associated with energy losses at the constriction and considerable acceleration. Average cross-sectional velocities could approach 5 m/s, creating potentially significant scour conditions. The model suggests that 200-year clear-water flood would have essentially no freeboard at the upstream side of the bridge, and that all debris flood scenarios could impinge on the bridge superstructure.

Inundation extents resulting from the Highway 101 bridge backwater can be significant, as shown on the various inundation maps. Inundation extents range from limited for the 200-year clear-water flood to extensive for the largest debris flood. For the 200-year clear-water flood (Scenario 5), inundation is largely confined to the small corner of parkland north of Highway 101, the northern extension of the Mission Road right-of-way, and the currently-undeveloped Lot 1 property. Backwater inundation reaches a maximum elevation of about 4.8 m geodetic with depths generally ranging from negligible to well over 1 m across the inundated area. All flow is conveyed downstream via the main channel (i.e., beneath the Highway 101 bridge) and the model indicates essentially no overtopping of Highway 101 across the fan.

In contrast, the largest debris flood scenario (Scenario 4) results in widespread inundation upstream of Highway 101, extending about 400 m west from the main channel beyond the east side of the Big Maple Mobile Home Park. Inundation depths over much of the Ponderosa Pines / Big Maple area range from 0.1 m to about 1.0 m, depending on local topography. Inundation depths approach 2.0 m in the undeveloped areas closer to the creek. Backwater inundation reaches a maximum elevation of about 5.8 m geodetic, a full metre higher than the 200-year clear-water flood scenario. Chapman Creek overtops Highway 101 at the highway bridge and across most of the mobile home park frontage.

Scenarios 1, 2, and 3 result in progressively increasing levels of inundation falling between the limited inundation of the clear-water flood (Scenario 5) and the significant inundation of the largest debris flood (Scenario 4). Inundation is generally proportional to the magnitude of the background event (i.e., 50 year < 100 year < 200 year).

The high-flow hydraulics of a skewed constriction such as the Highway 101 bridge can be complex and difficult to represent in a one-dimensional model. Nonetheless, the nature and scale of bridge effects are usually well represented. Hydraulic uncertainty is considered much less significant than the geo-hydrologic uncertainty of the design event hydrograph. Improving the hydraulic capacity of the Highway 101 bridge could significantly reduce the depth and extent of backwater inundation on the upstream side of Highway 101.

A more complex hydraulic model could be developed if policy decisions are found to be extremely sensitive to water levels upstream of the Highway 101 bridge.

Inundation of Chapman Creek Fan – Highway 101 to Tidewater

Although KWL's modelling efforts focussed on the area upstream of Highway 101, the model provides some insight on the flood risk to areas downstream of the highway, including areas of both the District of Sechelt and Sechelt Band's Tsawcome I.R. No. 1.

Low-lying areas downstream of Highway 101 are potentially susceptible to backwater flooding during an extreme tide event from both the Chapman Creek estuary and the remnant secondary channel at the Wilson Creek marina. This flood risk is independent of (but may be exacerbated by) high flow conditions on Chapman Creek.

KWL's model indicates that the bank topography of the secondary channel at Wilson Creek marina is sufficient to confine an extreme high tide of 2.5 m GSC. The model also suggests that there is limited coherent flood drainage to this channel.

At the Chapman Creek channel, some overtopping of the creek banks may be possible a short distance upstream from the channel mouth under the extreme tide. Purely coastal flood hazards were not examined in detail.

The hydraulic model suggests that some flooding would occur in areas adjacent to Chapman Creek during the 200-year clear-water event, even during a period of normal tidal oscillation. Flooding would be somewhat more extensive on the east side of the channel than on the west.

Combination of a flood or debris flood event on Chapman Creek with an extreme tide significantly exacerbates potential inundation in areas downstream of the Highway 101 bridge. This is shown through the progression of inundation maps for the 200-year clear-water scenario (Scenario 5, Figure 5-8), 200-year debris flood scenario (Scenario 3,

Figure 5-6), and the 200-year debris flood with concurrent high tide (Scenario 7, Figure 5-10).

The inundation hazard in this area therefore varies with flood magnitude, tidal range, and most importantly, with timing of respective flood and tidal peaks. As shown in Scenario 7 (Figure 5-10), inundation from a very large flood occurring concurrently with an extreme tide could be extensive.

Historic Secondary Channel

It is reasonable to conclude that abandonment and infill of the historic secondary channel likely reduced discharge capacity downstream of the Chapman Creek fan apex. This becomes particularly important if bridge blockage or sedimentation further reduces the capacity of the main channel. Nonetheless, in the absence of a bridge blockage, avulsion, or significant sediment deposition, the model confirms that the Highway 101 bridge imposes a more restrictive control on discharge capacity than the natural channel itself.

Potential Internal Drainage Issues

After the flood has receded, some ponding may persist in low-lying areas separated by elevation from the drainage network. High water table conditions in the alluvial deposits forming the fan may extend the time required for ponded water to infiltrate. Internal drainage concerns may be of particular importance along remnant sections of the historic secondary channel, where the only relief drainage is via the 1.5 m CSP culvert under Highway 101.

KWL's hydraulic model should permit a more detailed assessment of potential internal drainage issues; however, such an assessment is beyond the scope of the present study.

5.5 SELECTION OF A DESIGN EVENT

This report confirms that a debris flood scenario is an appropriate design event for evaluating flood protection on the Chapman Creek fan. As discussed in Section 4, other jurisdictions have adopted a variety of standards from the 500-year to 10,000-year return period, depending on the nature and extent of the risk to the community. In keeping with the District's preference to not exceed the 200-year level for the present study, this report focuses on a number of scenarios that could potentially be interpreted as a 200-year event.

The range of modelling scenarios presented reflects the inherent uncertainty in defining complex geo-hydrologic processes for Chapman Creek in the absence of a more comprehensive field investigation. For a debris flood to affect the Chapman Creek fan (estimated return interval 160 years), it must be combined with a background hydrologic flood (estimated return interval 50-200+ years). The constituent assumptions for these two processes further complicate the definition of a 200-year event.

This section provides guidance to assist the District of Sechelt in making an appropriate policy decision as to which of the scenarios presented herein should be adopted for land use planning, permitting, and design of flood protection works. Based on engineering judgement, two scenarios (Scenario 3 and Scenario 4) were selected for consideration as potential design events.

Scenario 4 – Most Conservative Scenario

In many cases, a local authority will employ the precautionary principle and select the most conservative design event. For Chapman Creek, KWL's modelling analysis clearly shows that Scenario 4 yields the most conservative results. However, for reasons described below, Scenario 4 is subject to a much higher degree of uncertainty than other scenarios and as such may not be an appropriate design event.

As discussed in Section 4, Scenario 4 is based on a flood frequency analysis that includes the 1962 and 1968 floods recorded at WSC hydrometric station 08GA046. These flows are both daily average values. WSC does not report peak instantaneous discharge for 08GA046.

As originally noted by Chapman and Reksten (1991), rainfall and adjacent flow records for the 1962 and 1968 floods are not consistent with background conditions necessary for a flood of the recorded magnitude.

It should also be noted that daily average discharge recorded for the day *following* the 1968 flood (92.9 m^3/s) is larger than all annual maximum peak flows reported between 1971 and 2003. In fact, the historical record for WSC hydrometric station 08GA046 (1959-1970) reports a total of eight days where flow was approximately equal to or larger than the largest daily average discharge reported between 1971 and 2003.

In response to the concerns raised by Chapman and Reksten (1991), others have proposed that the events reported in 1962 and 1968 may represent debris floods.

KWL concurs that debris floods may have been responsible for elevated discharge on Chapman Creek in 1962 and 1968. However, KWL's model suggests that a debris flood wave would be transient in nature (±15 min) and would therefore not have a major impact on the daily average discharge. Even if the 1962 and 1968 peak flows occurred under debris flood conditions, the background hydrologic event required to produce the reported peak flows would have to exceed the 200-year clear-water flood.

In summary, a number of factors suggest that Scenario 4 may not be realistic, including:

- regional climatic inconsistencies noted by Chapman and Reksten (1991);
- apparent inconsistencies between WSC records at 08GA046 and successor stations;
- the limited impact of a debris flood wave on daily average discharge values; and
- scale of differences between physically-based (dam breach) and FFA-derived results.

For the above reasons, KWL does not recommend Scenario 4 as a design scenario; however, the inundation mapping can still provide valuable insight into inundation that may result from a larger event.

Scenario 3 – Most Realistic Scenario

Scenario 3 presents a combination of a 200-year clear-water flood with a landslide dam breach debris flood. The results are less extreme than Scenario 4; however, it still represents a conservative interpretation of the 200-year return period condition as described below.

Section 4.2 concludes that the likelihood of a debris flood affecting the Chapman Creek fan is approximately 1/160 per year, equivalent to a 160-year return period. The assessment does not consider the magnitude of the resulting debris flood event, only that the debris flood reaches the fan apex. The modelled sediment flood is consistent with the size of landslide that would be expected in the landscape, and with observed landslide barrier dimensions.

It is reasonable to expect that a major debris flood would be initiated by a significant hydrologic event; however, the relationship between the two processes is not straightforward. In general, it is reasonable to assume that a debris flood will be:

- less likely than the least likely of any assumed contributing process (P1 *or* P2); and
- more likely than the combined probability (P1 x P2) of all contributing processes.

The above axioms reflect the definitions of fully dependent and independent probabilities, respectively. For Scenario 3, the actual likelihood will be closer to the first case than the second.

KWL concludes that Scenario 3 provides a reasonable basis for use as a 200-year design event for the Chapman Creek fan. Taking a conservative approach to defining the 200-year event is appropriate with respect to the larger design events typically adopted in other jurisdictions. Scenarios 2 and 1, respectively, present less conservative options.

Some consideration should be given to the potential use of Scenario 7 (concurrent tide and flood waves) as a design event downstream of the Highway 101 bridge; however, incorporating a concurrent tide peak further reduces probability. If a less extreme event is preferred, the District may wish to further investigate the effects of combining Scenario 1 or Scenario 2 with a concurrent extreme tide peak.

5.6 CONSIDERATIONS FOR FURTHER WORK

As noted, KWL has applied a pseudo-2D model to assess of flood hazards on the Chapman Creek fan. This information is provided to the District to assist in decision-making and development policy review. If decisions are found to be highly sensitive to the results, additional modelling could be performed to refine some of the key assumptions. In particular, more detailed analysis could be considered for the following areas:

- **Highway 101 bridge**: the existing bridge strongly affects upstream inundation depths and extents. The District (or other authorities like the BC Ministry of Transportation) may wish to consider further study, including the potential effects of bridge blockage, two-dimensional hydraulics arising from the narrow opening and skewed alignment, and the possibility for bridge capacity upgrades to mitigate potential inundation.

- **Potential for deposition or avulsion**: This study does not attempt to predict deposition or avulsion (rapid changes in channel alignment) processes that could occur during a debris flood. A qualitative review of potential deposition within the Chapman Creek channel could provide some guidance on the magnitude of deposition required to initiate blockage and/or avulsion (channel movement).

- **Coastal inundation**: While this study provides some comment for areas downstream of Highway 101, additional consideration should ultimately be given to potential interactions between floods and tidal interaction and the resulting impacts on the community. In particular, further study could include probabilistic consideration of coastal flooding hazards (e.g., 200-year tide) instead of transposed recorded extreme values as used herein.

- **Flood protection studies**: This study does not provide a design-level assessment of specific areas where protective works (e.g., dykes, berms, erosion protection) could mitigate flood hazards. However, this report should provide a key starting point for any such work in the future.

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Chapman Creek Flood Hazard Assessment

Project No. 551-010

Date August 2010

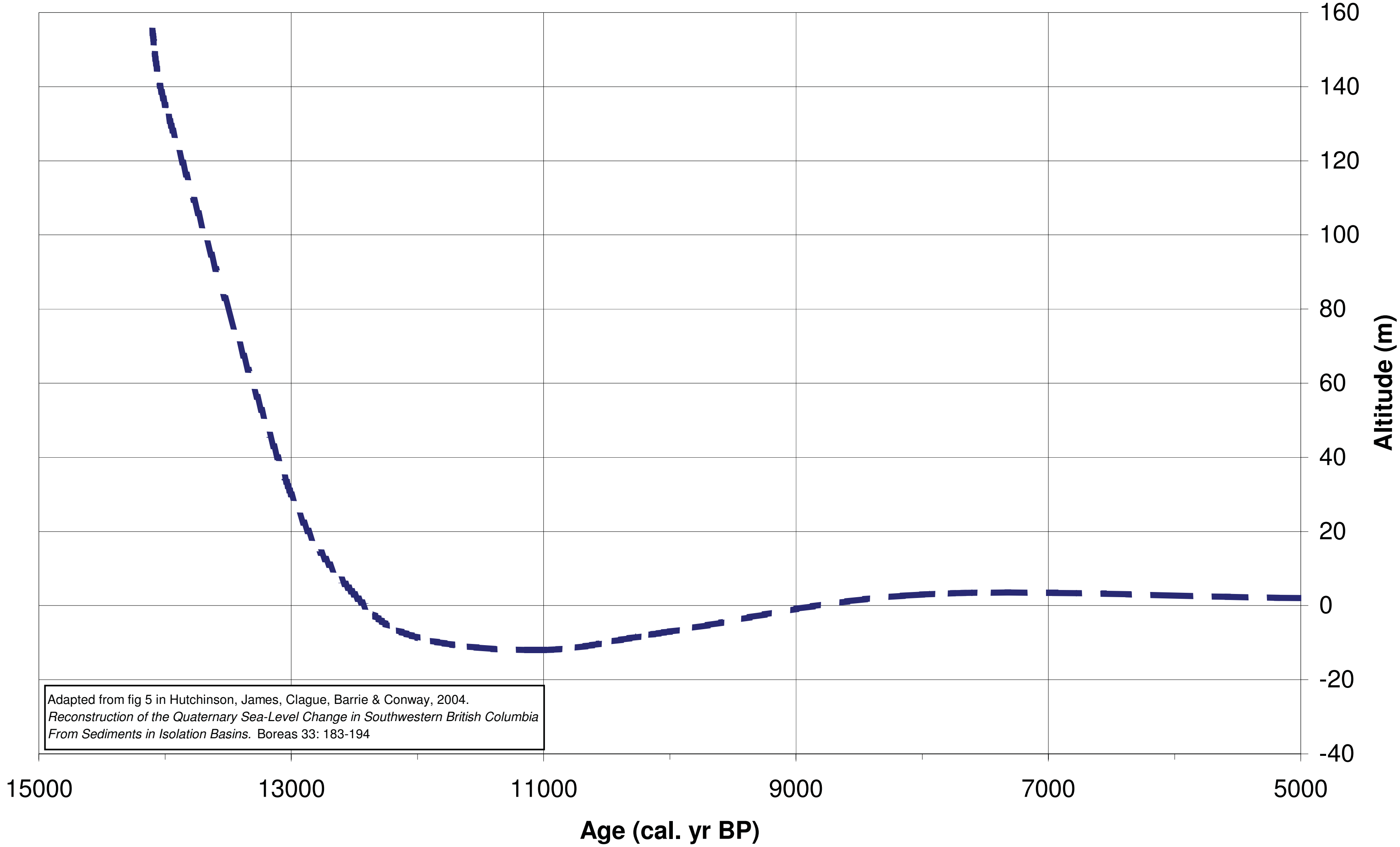
100 0 100

Scale in Metres 1:5,000

Chapman Creek Fan

Figure 5-1

Historic Changes in Relative Sea Level for the Georgia Strait



Adapted from fig 5 in Hutchinson, James, Clague, Barrie & Conway, 2004. *Reconstruction of the Quaternary Sea-Level Change in Southwestern British Columbia From Sediments in Isolation Basins.* Boreas 33: 183-194

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Figure 5-2

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Reference:
Tsawcome I.R. No.1 Boundary data provided by the District of Sechelt.
Orthophoto taken March 2009 and provided by the SCRD.

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Scale in Metres 1:4,000

Pseudo-2D Channel Network for Mike 11 Model of Chapman Creek Fan

Figure 5-3

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551-010	August 2010

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Scale in Metres 1:4,000

Scenario 1 Flood Inundation Map - 50-Year Return Period
Clear Water Flood Plus Landslide Dam Breach

Figure 5-4

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551-010	August 2010

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Scale in Metres 1:4,000

Scenario 2 Flood Inundation Map - 100-Year Return Period
Clear Water Flood Plus Landslide Dam Breach

Figure 5-5

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Scale in Metres 1:4,000

Scenario 3 Flood Inundation Map - 200-Year Return Period
Clear Water Flood Plus Landslide Dam Breach

Figure 5-6

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Reference:
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Orthophoto taken March 2009 and provided by the SCRD.

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Scale in Metres 1:4,000

Scenario 4 Flood Inundation Map - 200-Year Return Period Debris Flood - Based on Flood Frequency Analysis

Figure 5-7

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Reference:
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Orthophoto taken March 2009 and provided by the SCRD.

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Scale in Metres 1:4,000

Scenario 5 Flood Inundation Map - 200-Year Return Period Clear Water Flood and no Landslide Dam Breach

Figure 5-8

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Reference:
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Orthophoto taken March 2009 and provided by the SCRD.

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Scale in Metres 1:4,000

Scenario 6 Flood Inundation Map - 200-Year Return Period
Clear Water Flood Plus Landslide Dam Breach
with Decreased Manning's n Values

Figure 5-9

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Reference:
Topographic and Tsawcome I.R. No.1 Boundary data provided by the District of Sechelt.
Orthophoto taken March 2009 and provided by the SCRD.

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Project No.	Date
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100 0 100
Scale in Metres 1:4,000

Scenario 7 Flood Inundation Map - 200-Year Return Period Debris Flood and Shitfted Tidal Boundary Condition

Figure 5-10

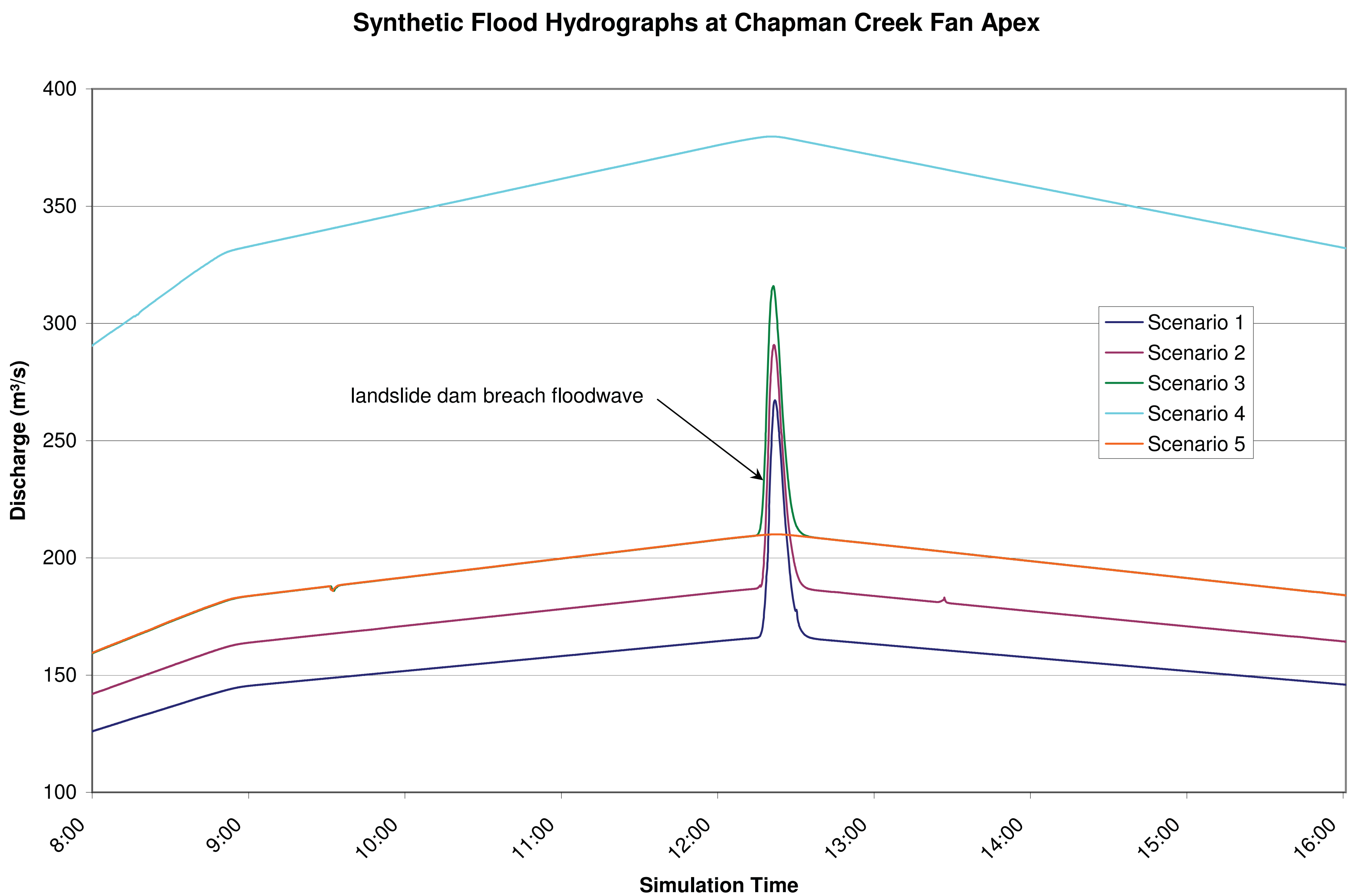

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Figure 5-11

Comparison of Flood Wave Attenuation at Chapman Creek Fan Apex

for Scenario 3 (nominal channel roughness) & Scenario 6 (reduced channel roughness)

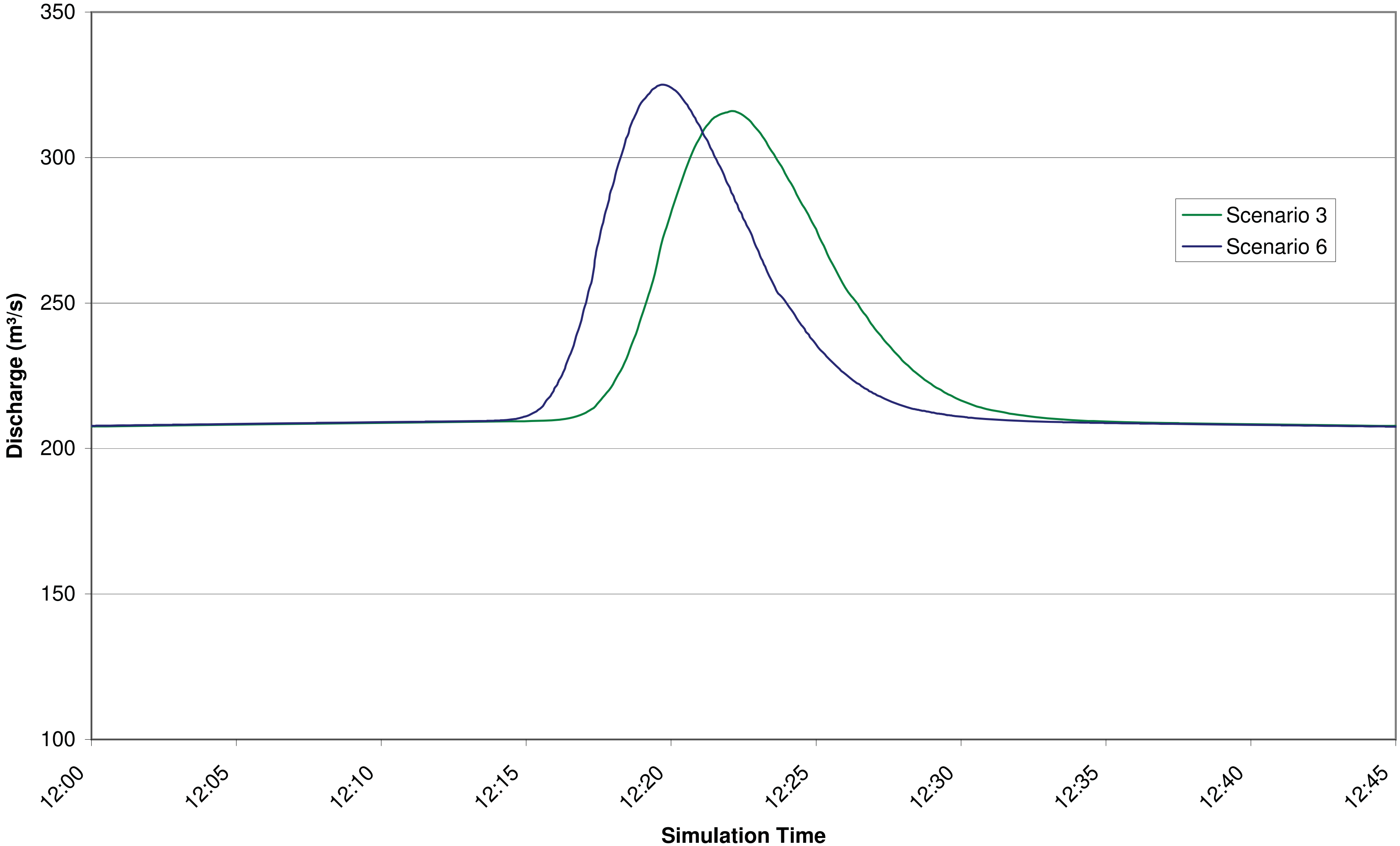

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Figure 5-12

Peak Water Levels along Main Channel above Hwy 101 Bridge (Scenario 3)

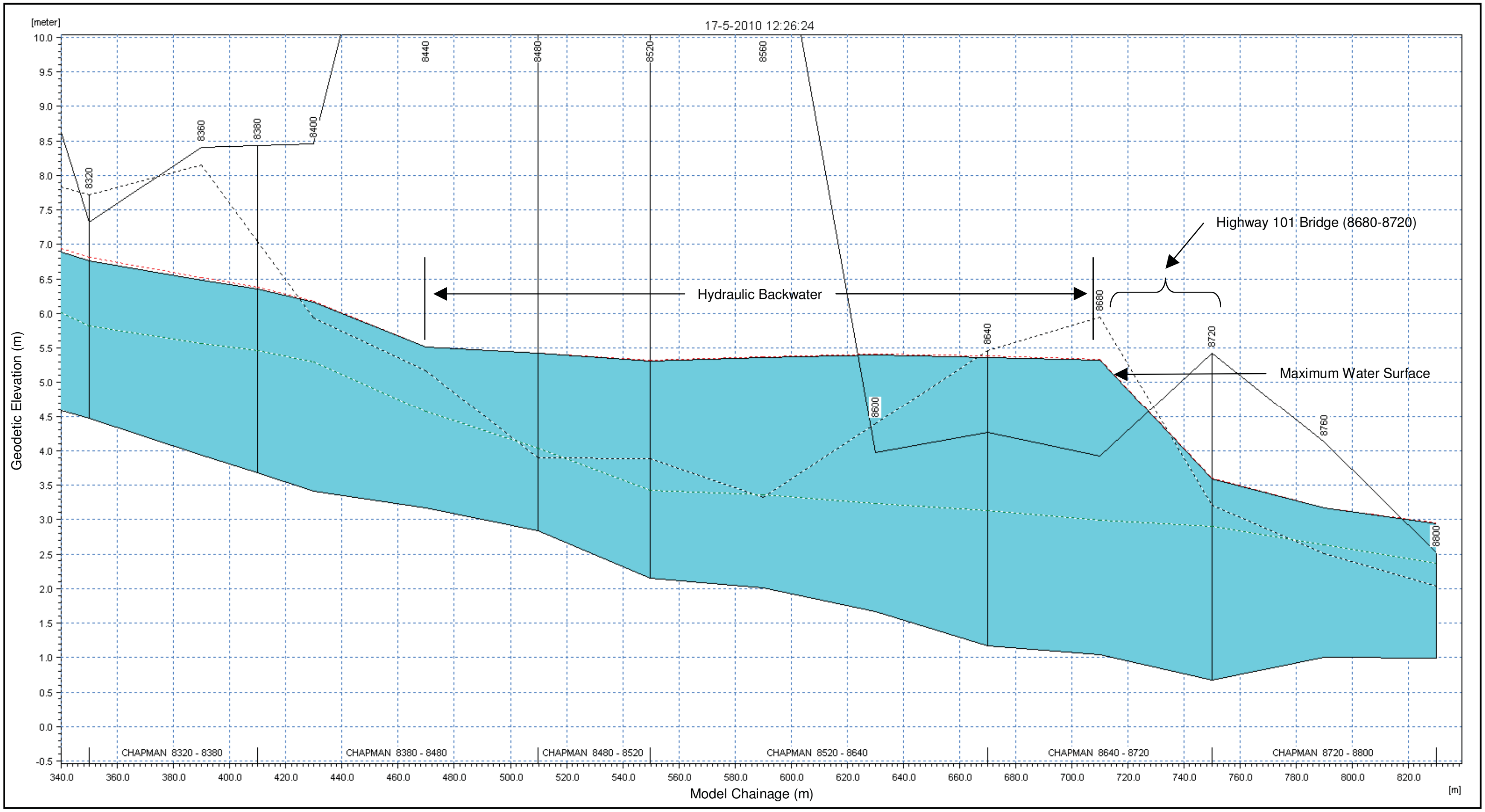

Figure 5-13

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Sensitivity of Main Channel Water Levels to Flood / Tide Peak Timing

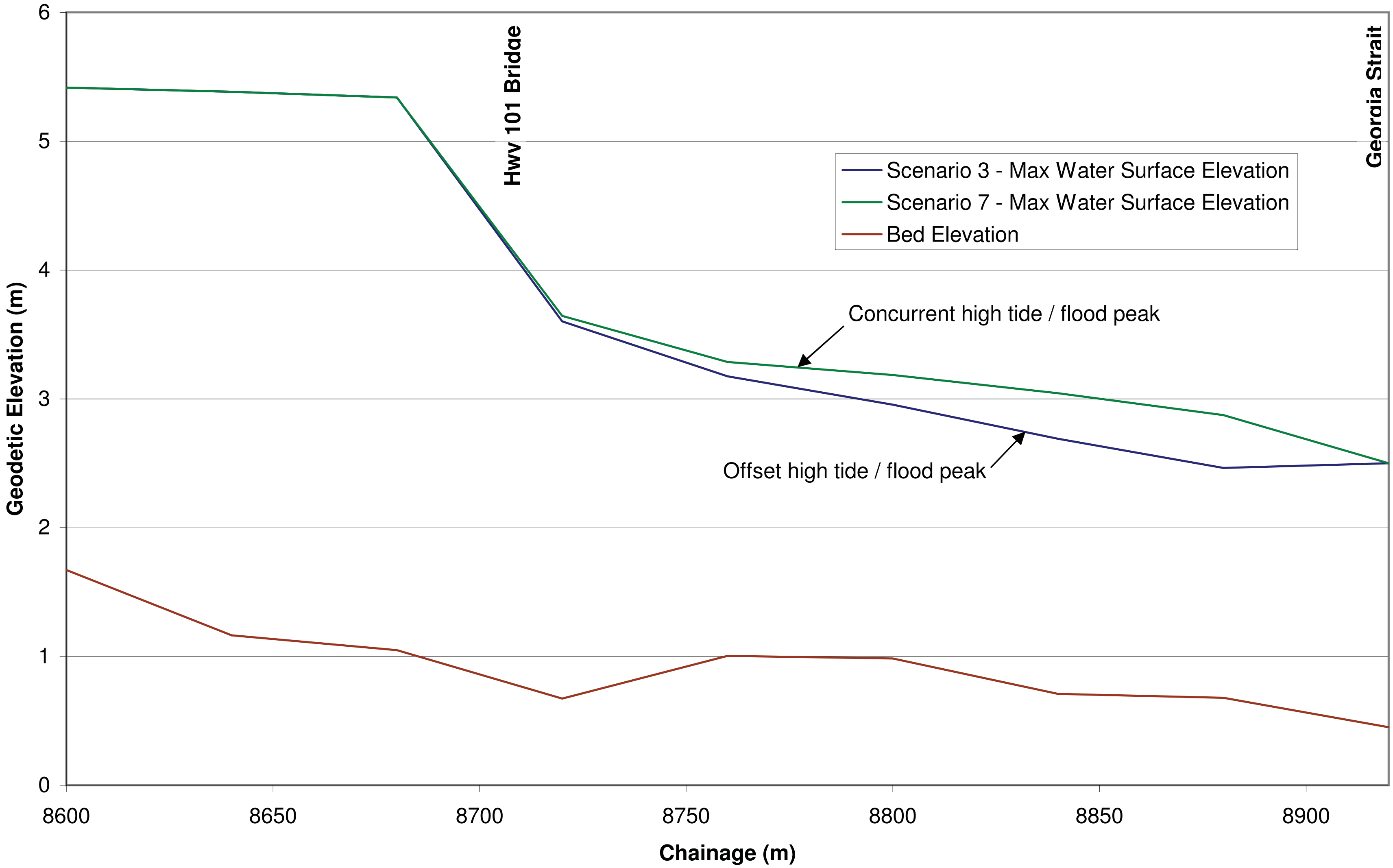

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Figure 5-14

Section 6

Land Use and Planning

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6. LAND-USE AND PLANNING

This section provides an interpretation of the field observations and hydraulic modelling results in the context of providing additional information to the 1993 development permit area mapping. The development permit areas were developed to identify potentially hazardous or environmentally sensitive areas and direct development away from these areas. A total of nine characteristic development permit areas were designated that include the following:

1. Coniferous Forest Areas;
2. Gravel Pit Areas;
3. **Watercourse Habitat Areas;**
4. All Shoreline and Foreshore Areas;
5. Rocky Beach Front and Upland Slopes;
6. Beach Front Escarpments;
7. Rockfall Hazards;
8. Watercourse Hazards; and
9. **Watercourse Hazards along Gray and Chapman Creeks.**

For Chapman Creek, DPA 3 and 9 are identified as applicable; however only DPA 9 pertains to flood hazards. A discussion of the requirements for DPA 9 follow.

6.1 DEVELOPMENT PERMIT AREA 9 – CHAPMAN CREEK FAN

As reviewed in Section 2, the 1993 reconnaissance study classified the Chapman Creek Fan as part of Development Permit Area 9: Watercourse Hazards along Chapman and Gray Creeks. DPA 9 is intended to regulate development in areas potentially subject to natural hazards including inundation, deposition, and/or bank erosion and undercutting. Evidence of specific hazards on the Chapman Creek fan noted in the report include 30 m high erosion scars in the steep ravine slopes and active undercutting of the bank about 200 m upstream from the Highway 101 bridge.

In response to these hazards, the 1993 reconnaissance study recommends that DPA 9 include all areas within the following limits, where the most restrictive criteria applies:

- Minimum 30 m horizontal setback from each side of the natural boundary of the creek high water;

- 15 m horizontal setback from the crest of the ravine or eroded slopes of the creeks and their tributaries; or

- Any areas less than 3.0 m above the creek high water.

The DPA also requires site specific investigation reports that would address:

- a complete hydrological study;
- the consideration of tides on floods;
- potential for creek erosion, deposition and channel avulsion;
- requirements for flood and bank protection;
- requirements for management and maintenance along creeks;
- vegetation protection;
- effects of septic and drainage systems on slope stability and water quality; and
- effects of forest harvesting.

The following Figure 6-1 is a portion of the DPA mapping from the 1993 Golder report for reference.

Figure 6-1: Development Permit Area 9 – Chapman Creek Fan

The above figure indicates a broad development permit area for Chapman Creek that includes the entire historic fan surface, creek corridor, tributary creeks, foreshore and is contiguous with the Wilson Creek fan.

6.2 FRAMEWORK FOR WATERCOURSE HAZARDS MANAGEMENT

To move forward with land-use change (or re-development) of the Chapman Creek fan with respect to watercourses and hazard mitigation, there is a framework of regulations, guidelines and management strategies that restrict and shape development. The following sections summarize these issues:

REGULATORY REQUIREMENTS

There are a number of regulatory instruments that control development from a variety of perspectives. The Local Government Act is empowers the local government as the approval agency for subdivision, and therefore provides the link between local planning and land-use decisions.

From an environmental perspective, the federal *Fisheries Act* includes key provisions for the protection of habitat, including aquatic and riparian habitats, and the protection of water and sediment quality which has a bearing on stormwater and local sanitary systems. From a provincial level, there are environmental regulations under the Water Act and Fish Protection Act, the latter which includes the Riparian Areas Regulation.

For creek areas like Chapman Creek, all land-use decisions, especially adjacent to the creek, will need to consider both the Federal and Provincial environmental regulations.

DEVELOPMENT PLANNING

Development planning at the municipal level determines the land use and through instruments such as the Development Permit Area mapping, provides tools to require specific engineering assessments and address hazard protection. A key approach to development planning includes delineation of the land and implementation of restrictive setbacks.

Flood management strategies are also often prepared in conjunction with development planning to provide a comprehensive protective approach under development plans for watercourse areas. A comprehensive approach is preferred to avoid potential transfers of risk whereby protection of a small area could worsen hazards in other areas.

FLOOD PROTECTION STRATEGY

A general approach to flood protection is the provision of sufficient area for natural processes (floods, creek channel avulsion, etc.) to occur, and to protect the developed areas to a standard level.

Primary Flood Protection

Primary flood protection is recommended for all proposed flood prone developments, and is generally considered a dyke or training berm system, but could include other components such as debris barriers. When considering any new or redevelopment, appropriate consideration should be made for both the current dyke structure and future dyke upgrading works.

In very sparsely developed areas, often dyke systems are too costly for the local area and other site specific measures or secondary flood protection works are favoured. In these circumstances, the dyke system should still be planned, and appropriate areas reserved for that purpose.

Secondary Flood Protection

Secondary flood protection works are utilized to minimize residual risks associated with floods (e.g. dense development, or possible debris flow/flood events), and are always required in the absence of primary flood protection works. Secondary flood protection works can include:

- Flood Construction Level (FCL) designating the minimum floor elevation for habitable space through either engineered land fill or structural means;
- Local erosion protection for engineered land fill or building foundations;
- Local training works (e.g. berms);
- Designation of floodways to convey floodwaters; and
- Structural flood-proofing.

Administrative Requirements

In addition to primary and secondary flood protection works, there are a number of administrative tools and requirements that enforce and provide for operation and maintenance of the flood protection works by the local authority. These include:

- Rights-of-Way: all primary flood protection works require legal rights-of-way in the name of the dyking authority (e.g. local government) to allow all operation and maintenance works.
- Restrictive Covenants: covenants should be used to enforce all secondary flood protection measures that are not covered by rights-of-way, and ensure that no changes are made following occupancy.

6.3 DEVELOPMENT PLANNING AND SECONDARY PROTECTION MEASURES

The 1993 implementation of development permit areas provides a good basis for screening development. Since 1993 there have been several changes to environmental regulations that have a bearing on the requirements and the current study has provided the required detail to address local flood conditions.

The following is proposed changes and updates for the Chapman Creek development permit area:

- All new development shall be set back a minimum of 30 m horizontal from each side of Chapman Creek and shall consider primary flood protection works.
- All new development shall be set back a minimum of 15 m from the crest of ravine and eroded slopes, subject to both the Riparian Areas Regulation and geotechnical assessment.
- The "design" flood area and flood construction levels (FCLs) shall be as designated **(Pending Approval)**.
- In the absence of primary flood protection works all developments in the design flood area should have local erosion protection.
- All developments shall provide a grading plan to delineate floodways.
- All floodways and community flood protection works shall be in rights-of-way in the name of the District of Sechelt.
- All units in the development shall be subject to restrictive covenants.

6.4 PRIMARY FLOOD PROTECTION MEASURES

A flood management strategy should be developed and formalized by the District to allow long-term implementation of a primary flood protection works over a cycle of redevelopment. A number of concepts have been developed and include:

SETBACK DYKE FROM HIGHWAY 101 TO FAN APEX

The most conventional approach would be to allow for the development of a setback dyke (the right-of-way) a minimum of 30 m from the edge of creek from Highway 101 to the fan apex. This would comprise about 500 m of dyke works that would be constructed to a grade higher than that of Highway 1.

ALTERNATE DYKE SECTIONS

An alternate dyke sections could include the following areas which are prone to specific flooding:

- the fish hatchery;
- upstream of Big Maple mobile home park at the secondary channel;
- along low-lying areas of the west bank near Brookman Park; and
- along the east creek bank downstream of Highway 101.

Inundation occurs on the west bank downstream of Highway 101, however GIS data supplied by the District shows that the flooding would essentially affect a single property. As such, the landowner could probably build a private works at their discretion.

BANK PROTECTION WORKS

This study did not include a specific assessment and inventorying of possible erosion sites. However, in a large flood it is expected that velocities will be low within backwater area due to the restriction of the Highway 101 bridge and highway embankment. There will be areas of high velocity in the channel and during initial flood surge.

The area of greatest concern for erosion from a flood perspective is the left bank north of trailer park. Bank erosion here could compromise local high ground and allow additional overland flow through trailer parks and across the fan. Other areas of concern include existing eroding banks on the right bank of Chapman Creek at Brookman Park, around the Highway 101 bridge, and near the fish hatchery where non-standard (boulder armouring) is susceptible to failure.

6.5 SITE SPECIFIC ISSUES

During the course of the project several proposed developments and areas of municipal infrastructure where identified. The following provides a brief description of these issues:

1. Lot 1 is located on the left bank of Chapman Creek upstream of Highway 101. The current owner is proposing a multi-family development for this site. Development of this site will remove active floodplain from Chapman Creek if a dyke system is constructed or if the site is filled. This would likely increase flood levels elsewhere and would require detailed investigation. If this is developed for any kind of residential land-use, we strongly recommend primary and secondary flood protection works, and provision of a minimum 30 m setback for creek processes. Provision of primary flood protection works could provide the level of protection necessary for residential land-use, but would require off-site continuation of the works. If Lot 1 were to be used a recreational site (e.g. camping, etc.), either protective works would be recommended, or a detailed risk study and operational plan may appropriate. A similar example is the Riverside Campground along Fitzsimmons Creek in Whistler.

2. The current Big Maples mobile home park is seeing periodic upgrading of mobile homes to higher elevation. Should this site redevelop to permanent structures, establishment of setbacks, and primary flood protection works are recommended.

3. Areas between the Big Maples park and Canadian Tire have been discussed for redevelopment for commercial use. This area is not shown to be flood prone under the present simulations; however, secondary measures that include FCL establishment, local grading / floodway establishment should be required.

4. Downstream of Highway 101, flooding is expected during a storm surge event coupled with a creek flood. Large portions of the area adjacent to Mission Road is

expected to flood. This area is not expected to redevelop soon; however, if redevelopment were proposed, a primary flood protection system is proposed.

5. Just north of the Wilson Creek marina, some low level flooding could occur due to storm surge. Installation of tide regulated gate may be favoured at this local if required to limit high tides, but still allow intertidal flushing. This may be also required if primary flood protection works re-route local drainage towards this area.

6.6 ADMINISTRATIVE ISSUES

The Highway 101 bridge has been identified as a restriction in the Chapman Creek system. Replacement of the bridge would reduce the flood levels upstream of the highway and a cost-benefit type analysis may be warranted to compare replacement of the bridge with flood protection works as the favoured solution.

Section 7

Summary

7. SUMMARY AND REPORT SUBMISSION

7.1 SUMMARY

1. Chapman Creek is a steep-sided watershed with strong hillslope to channel coupling, and a long contemporary history of landslides associated with logging.

2. Chapman Creek is capable of generating debris flood events likely initiated from landslide dam breaches, and two likely events occurred in 1962 and 1969.

3. The probability of "natural" landslides inducing "geomorphic" floods that affect Chapman Creek fan is estimated to be 0.006 per annum, or a 1/160 year return interval. The rate of geomorphic floods affecting the fan under poor landuse practices is estimated to be one order of magnitude more frequent, and these events should be considered in floodplain management for residential uses on Chapman Creek alluvial fan.

4. Debris flood event magnitudes were estimated both by numerical methods in estimating likely a dam breach in the upper watershed coupled with a large flood, and by statistical frequency analysis. The 200-year debris flood event developed from frequency analysis is the largest flood estimated for this study.

5. The Chapman Creek fan has had a complex evolution, such that Chapman Creek has degraded on the fan (since about 8,000 years ago), such that the western portion of the fan is no longer hydraulically active for the present condition and normal hydrological events (> 200-year flood).

6. Hydrualic modelling shows only areas up to and including the Big Maple mobile home park would be inundated during a 200-year return period flood upstream of the highway, and a similar extend for be inundated downstream of the highway.

7. Prior to this study guidelines for the Chapman Creek development permit area required setbacks, and the need for local engineering studies. This study addresses the general (existing condition) requirements for the engineering studies.

7.2 RECOMMENDATIONS

1. The District select a design debris flood event for planning purposes.

2. The District move forward with a flood protection strategy for the Chapman Creek fan.

3. Based on the findings of this report, the District should consider an update to the local area plan or OCP.

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Appendix A

Photo Appendix

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

Photo 1
Chapman Creek Watershed overlooking from the West

Photo 2
Chapman Creek Wateshed upstream of the District of Sechelt

Photo 3
Chapman Creek SCRD Water Intake

Photo 4
Eroding Bank on Bend Upstream of Chapman Creek Fan

Photo 5
Typical Confined higher energy channel section upstream of Chapman Creek fan

Photo 6
Typical channel section on Chapman Creek fan – note substrate size and rafted wood

Photo 7
Informal bank protection works and intake structure at DFO hatchery

Photo 8
Recent bank erosion upstream of Hwy 101

Photo 9
Looking downstream at Highway 101 bridge and riprap on left bank

Photo 10
Looking downstream of Highway 101

Photo 11
Typical drainage structure in Highway 101

Photo 12
Chapman Creek at the mouth