Final Report

Tahsis Flood Risk Assessment

Project No. 2221-49140-10
June 30, 2019

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June 30, 2019

Village of Tahsis
977 South Maquinna Drive
P.O. Box 219
Tahsis, BC, V0P 1X0

Attention: Mark Tatchell, CAO

TAHSIS FLOOD RISK ASSESSMENT – FINAL REPORT

We are pleased to submit three [3] hard copies of the attached Flood Risk Assessment report for the Village of Tahsis. The report is a comprehensive assessment for new floodplain mapping and guidance document for moving forward with planning for floods that may happen in the near future, as well as those events which may occur as we experience greater climate change.

Included in the report is full size mapping sheets. Please advise if you'd like us to produce more copies of the mapping product.

It has been our pleasure servicing the community on this project, and we look forward to assisting you in the future as you may see fit.

Yours truly,
McELHANNEY CONSULTING SERVICES LTD.

PROFESSIONAL PROVINCE OF BRITISH COLUMBIA M. P. J. DEGAGNE # 29825 ENGINEER

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Table of Contents

EXECUTIVE SUMMARY

The potential for flooding in Tahsis has not undergone a thorough review since the early 2000s, with the last major comprehensive flooding assessment completed in 1992. Historic flooding in the Village, especially in the northeast sector along the Tahsis River, has been somewhat mitigated through the construction of the North Maquinna Drive Floodwall and the Cook Street Dike and the subsequent construction of a large internal drainage system along Boston Road. Through funding provided by the Union of BC Municipalities under the Province of BC's Community Emergency Preparedness Fund, the Village has engaged in the process of updating its Floodplain Mapping from 1992. The scope of the assignment includes assessing the hazards and risks of flooding along the Tahsis and Leiner Rivers, updating floodplain maps and presenting mitigation options looking forward in a world with a changing climate that is subject to Sea Level Rise (SLR).

As the Village has grown, the Tahsis River (78 km^2 drainage area) and its tributary, McKelvie Creek (22 km^2 drainage area), have been "trained" and armoured throughout the Village reach, resulting in a primarily stable channel that is influenced by tide levels from Head Bay Road to just downstream of the Perry Brothers Bridge at the end of North Maquinna Drive. The Leiner River (108 km^2 drainage area) however, is a natural gravel bed stream that wanders throughout its otherwise confined valley between adjacent mountains. The Leiner is bordered to the North by the Head Bay Forest Service Road (FSR), which is the only land link from Tahsis to the rest of Vancouver Island.

The assessment follows legislated guidelines for the Flood Risk Assessment and floodplain mapping, and the latest computer modelling technology was employed for determining both the hydrologic response (the amount of flow in the rivers) of each basin and the dynamics (levels and velocities) to which it flows through the study reach of each channel. In terms of peak river discharges, the following table lists the estimated peak instantaneous discharges for the streams in the study area.

Summary of Estimated Peak Instantaneous Discharges

River	Catchment Area (km^2)	Peak Instantaneous Discharge (m^3/s)	
		20-Year Return Period	200-Year Return Period
McKelvie Creek	22	162	183
Tahsis River Upstream of McKelvie Creek	54	327	428
Tahsis River at the Mouth	78	436	607
Leiner River	108	562	826

These peak discharges are about 24-31% less than previously estimated, but they are based on current practice for regional hydrologic assessments and use longer periods of records from more than one stream (the Zeballos River).

The above design discharges were then simulated in the two-dimensional hydrodynamic computer model (*HEC-RAS*) with updated topography based on LiDAR imaging collected specifically for this study. The LiDAR digital elevation model was supplemented with survey data, collected to ensure accuracy of such things as river cross-sections at the bridges and the top elevation of the floodwall. Boundary conditions were based on 2011 work by other coastal engineers, resulting in an estimated 3.95m geodetic elevation for the 2019 conditions at the Tahsis Inlet. The model was verified in comparison to the past model to ensure consistency between studies and to test the accuracy of the current model in relation to past predicted levels. Compared to 1992 results, there was generally good agreement when using the same flow and boundary conditions with the new topographic information.

Simulations were conducted for the 1:20 year and 1:200 year current predicted flows and Tahsis Inlet levels, as well as future 2100 scenarios which included a net Sea Level Rise amount of 0.73m and an additional 12% runoff added to the peak instantaneous flows to account for probable climate change conditions, which predict 12% wetter winter months of November, December and January. The resulting floodplain maps include an allowance of 0.3m of freeboard and show extensive flooding throughout the northeast sector, requiring a strategy to address the potential flooding in the Village even with the existing flood mitigation works in place.

The "Protect/Accommodate/Retreat/Avoid" ("PARA") framework is widely used to categorize and examine flood disaster risk reduction approaches for building climate change resilience in communities across Canada. The PARA framework, first developed for climate change adaptation planning in communities facing Sea Level Rise, is also a useful framework for flood risk reduction

and flood resilience. In the case of Tahsis, both Sea Level Rise and flood risk reduction apply, and therefore this framework forms the basis of establishing recommendations for a comprehensive flood risk / flood mitigation strategy.

In terms of flood risk, the Risk Assessment and Information Template (RAIT) used for the National Disaster Mitigation Plan (NDMP) was used to identify areas of risk within the flood hazard zone, as provided on the attached Flood Hazard / Flood Risk Map. As suspected, there are several key municipal assets within the flood hazard area including the school, fire hall, recreation centre, water supply well, sewage treatment plant and public works yard. In addition, Head Bay Road and the bridge connecting north and south Tahsis are also at risk and form the only overland route connecting Tahsis to other major centres on Vancouver Island. Head Bay Road is also jeopardized by flooding on the Leiner River and was closed during previous flood events when cross culverts were washed out during extreme storm events. The RAIT table also scores other socio-economic and environmental risks associated with flooding with most scores in the 3-5 range, with 5 being the highest severity or consequence from flood impacts.

Building on previous projects to protect the Village assets, which are estimated at over $41 million within the flooded areas, three protection options are presented to accommodate immediate and future flood issues.

1. The North Maquinna Drive floodwall needs to be upgraded and extended to protect against an imminent 1:20 year magnitude flood, with minor improvements required for the Head Bay Road. *$6.1 M*
2. If the Village is going to protect its assets from a 1:200-year flood, all existing dikes need to be raised, in addition to raising Head Bay Road and the Head Bay Road Bridge. The raising of Head Bay Road extends to sections up to the Leiner River Bridge and should consider improvements in capacity to all cross culverts within the section. *$15.1 M*
3. To continue to protect against rising sea levels and climate change, further raising of flood protection infrastructure will be necessary. *$20.1 M*

All of the above estimates are considered Class 'D' and carry a 40% contingency, as they require further refinement through the detailed design process if they are to be implemented.

The Village of Tahsis may decide to pursue the other three avenues of PARA framework, and must do so by implementing policy that will:

- Accommodate flooding for redeveloped structures that could possibly limit habitable floor areas above the predicted flood levels, leaving streets and lower levels to be flood resistant construction, and subject to periodic flooding
- Retreat from flood hazard areas by implementing policy that limits development in the flood zone to more compatible uses, such as parks, trails and/or agricultural uses
- Avoid the flood hazard areas by limiting any further development in these areas

Regardless, the Village should address flooding and flood mitigation within its OCP and Zoning Bylaws and should adopt a Floodplain Bylaw specific to the requirements for Flood Construction Levels along the inlet and within the natural environment as determined through this study.

As the science of climate change progresses, the Village is encouraged to review the results of this study routinely and adapt policy and regulation to suit the changing environmental factors that may limit the habitable use of the floodplain on the north east portion of the Village.

1 INTRODUCTION

1.1 FLOODPLAIN MANAGEMENT VISION FOR TAHSIS

The Village of Tahsis (the Village) lies within the floodplain of the Tahsis and Leiner Rivers. Through funding provided by the Union of BC Municipalities under the Province of BC's Community Emergency Preparedness Fund, the Village has engaged in the process of updating its current flood risk mapping with the goal to inform the long-term planning for the community.

The study is intended to provide two main deliverables: new Floodplain and Risk Maps, and a Flood Risk Assessment (FRA) Brief. The FRA Brief and mapping were developed to reassess potential flood levels and extents and to identify flood mitigation strategies to reduce current risks. The FRA was completed in accordance with Legislated Flood Assessments in a Changing Climate in BC[1], commissioned by the British Columbia (BC) Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (MFLNRORD), and the Professional Practice Guidelines – Flood Mapping in BC[2]. These two documents dictate the requirements for good practice when assessing flood risks, and they include guidelines for anticipating climate change and future landform changes. On this basis, the agreed upon scope for climate change is to consider gradual Sea Level Rise and review conceptual adaptations to potential sea levels at Year 2100. Given the slow pace of Sea Level Rise, these longer-term adaptations should be considered as future targets for planning purposes and should be revisited formally on an ongoing basis.

The guidelines include considerations for structural mitigation works and provide an assessment that arrives at a comprehensive mitigation strategy: a strategy that includes other "softer" approaches like alternate land use policies and restrictions to further or renewed development. Protection of property is an important, but it is not a paramount goal. Protection of the environment (the community's property in-common) is considered of equal importance with protection of private property.

This Flood Risk Assessment is focused solely on the riverine environment and its interactions with the receiving marine environment, meaning flooding caused by a tsunami is not considered as part of this scope of work. The occurrence of a major flood and a tsunami event are considered independent, and it is highly improbable that the events would coincide. Historical experience shows that flooding damage in Tahsis has always been caused by overland flooding from the rivers and creeks in the Village. To this end, previous reports[3] have indicated that a tsunami event in March 1964 reached a maximum elevation of *2.0m,* which is not a governing flood event.

In addition, the report focuses on the two major rivers with respect to the Village, though previous reports indicate the two major creeks within the southern townsite – Ubedam Creek and Extravagant Creek – have previously caused flooding issues. The assessment of internal drainage creeks, ditches, culverts and underground systems is considered outside the scope of this assignment but is nonetheless important when considering mitigation or adapting factors. When assessing the impacts of high river levels, commentary on internal drainage systems is provided with recommendations for further study or consideration when the planning recommendations move forward to design and implementation. Where necessary, allowances for internal system costs associated with upgraded flood infrastructure work have been included at a high level. Further refinement will be necessary as projects get selected for possible implementation.

[1] Engineers and Geoscientists BC, Legislated Flood Assessments in a Changing Climate in BC, Version 2.1, August 2018
[2] Engineers and Geoscientists BC, Flood Mapping in BC APEGBC Professional Practice Guidelines V1.0, January 2017
[3] Klohn Leonoff Ltd., Floodplain Mapping Tahsis, Leiner and Zeballos Rivers, February 1992

1.2 GOALS AND OBJECTIVES FOR THE FLOOD RISK ASSESSMENT

The goal of the FRA is to increase awareness and preparation for the Village of Tahsis and its citizens inhabiting the Tahsis River and Leiner River Floodplains, with the goal of adopting responses to future flooding risks.

Specific objectives and deliverables of the study included:

1. Integration of detailed topographic survey (river bathymetry and LiDAR imaging).
2. Regional hydrologic analysis based on historic recorded data collected in comparable watersheds in the region.
3. Technical modeling of rivers and sea interactions with various storm events (current conditions, Year 2100 projections).
4. Flood hazard map showing the inundated areas, the estimated water depth and velocity and the resultant combined hazard rating.
5. Flood risk map showing the potential risk to life, property and/or infrastructure due to the identified flood hazard.
6. Results of the hydraulic model will be exported into the appropriate GIS formats and provided to the Village of Tahsis.
7. Identification of existing land use in the floodplain.
8. Review of existing land uses and proposed land use designations that might be affected by these new flood levels.
9. Develop options, at the conceptual level, to adapt to the flood risks.
10. Development of a long-term strategy to reduce impacts of flooding on the community while protecting the ecological, economic and cultural values of the river and floodplain.

1.3 COMMUNITY ENGAGEMENT

Three public information meetings were held to provide a forum to share information as the project progressed from start to finish, with an intermediate session in between. The meetings, located in the Council Chambers at the Municipal Hall, were open to the public and encouraged public comments or questions.

Kick-off Meeting (March 12, 2019)

On March 12, 2019 from 1:30 to 3:00 p.m., the Village hosted an introductory public event. All interested parties were welcome to attend a presentation of the need to develop updated floodplain and risk maps, and the study scope. Content of the presentation is attached in Appendix A, and the intent of the meeting was to inform the public of the scope of the project and review past flooding in the Village to garner historical information from citizens that were in Tahsis during past floods. The meeting was held in two sessions (afternoon and evening), both of which werewell attended.

Meeting (May 7, 2019)

A second meeting was held on May 7, 2019 to present preliminary results of the hydrologic assessment and present simulations of preliminary flood model animations. The presentation showed approximate flood extents and general options for flood mitigation to the community. This meeting focused on providing information about current flood risks, as well as the trends towards increased risks stemming from climate change and Sea Level Rise. Early ideas on how to adapt to these evolving risks were presented, including examples of what other communities have considered in similar circumstances. Respondents were asked to provide input on options that warrant further study, and to express “values” that would be relevant to selection of preferred options.

A final meeting and presentation to council and the community is to be held after the receipt of the final report.

2 THE STUDY AREA

The last comprehensive floodplain study covering the Tahsis and Leiner Floodplains was completed in 1992[4]. That study defined 200-year flood extents and elevations for the two rivers and included floodplain maps and elevation profiles. The previous study area, see Figure 1, covered the floodplain of the Tahsis River up to 3.1km from its mouth, McKelvie Creek 0.4km from its confluence of the Tahsis River and the Leiner River up to 1.9km from its mouth.

The current FRA focuses on those same sections and extents of the Tahsis River, McKelvie Creek and Leiner River that impact the Village of Tahsis.

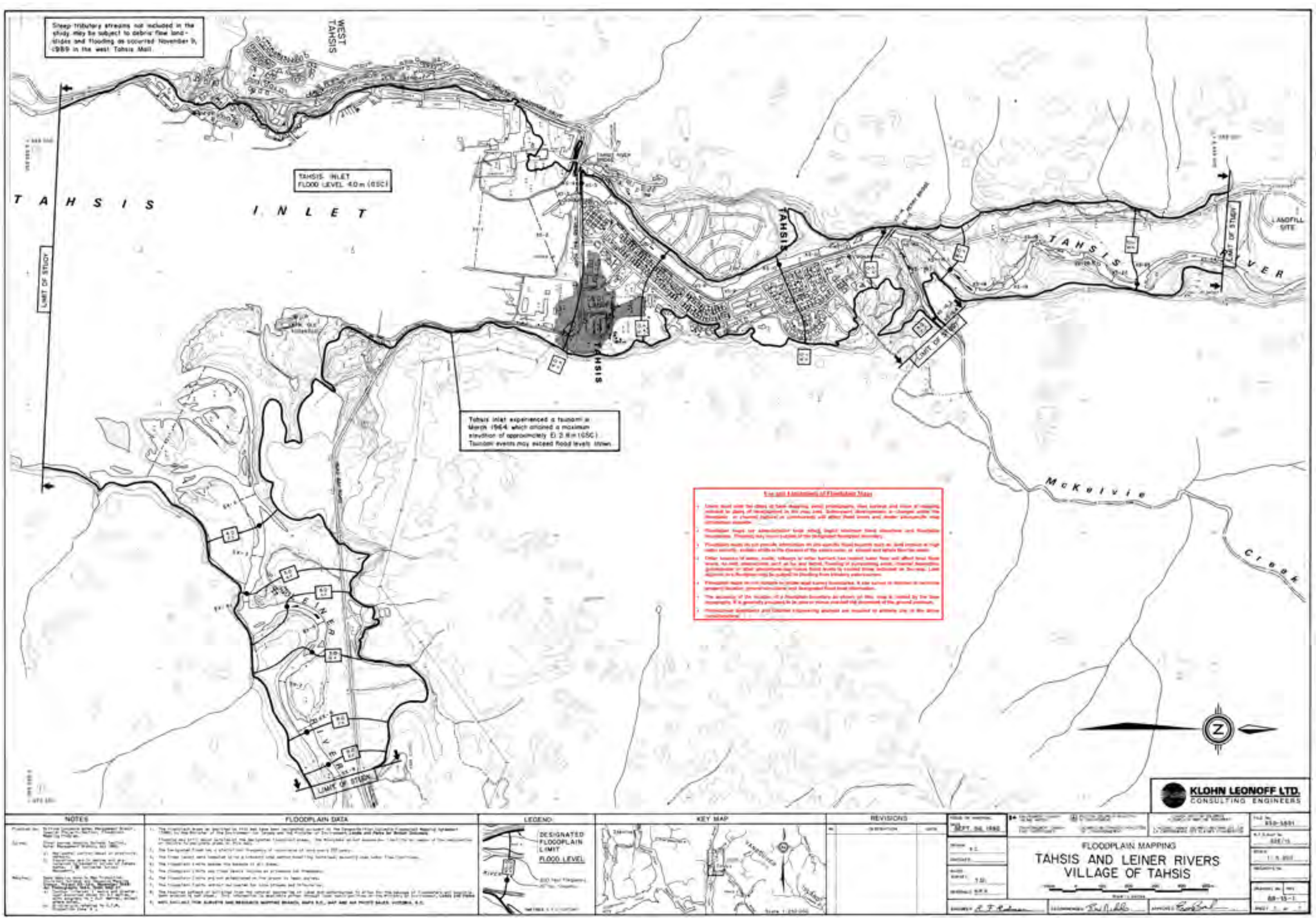

Figure 1: Tahsis Flood Risk Assessment Study Area

[4] Klohn Leonoff Ltd., Floodplain Mapping Tahsis, Leiner and Zeballos Rivers, February 1992

2.1 MAPPING

New analytical tools used in this study demand, and benefit from, greater precision in representation of the surface topography. As a result, the study area was newly mapped with digital aerial photography and topographic mapping using Light (or Laser Imaging) Detection and Ranging (LiDAR). The LiDAR scanner is housed in an aircraft along with the aerial photography equipment and scans the land over the flight path. Thousands of data points are collected to produce a digital elevation model (DEM) of the valley. LiDAR does not work under water, so the LiDAR data was collected during a low tide event, maximizing the resulting coverage.

To supplement the LiDAR data, limited conventional surveys of the rivers and floodplains were completed. This included the confirmation of a number of channel cross-sections and the top elevations of the Cook Street Dike (Dike #298) and the North Maquinna Flood Wall.

3 HISTORY OF FLOODING IN TAHSIS

3.1 THE WATERSHED

The Tahsis River extends about 8.4 km from its headwaters, through the Village of Tahsis and to its mouth at the Tahsis Inlet. The total drainage area of the Tahsis River is 78 km^2, including the 22 km^2 McKelvie Creek catchment area, which has its confluence with the Tahsis River just upstream of the Perry Brothers Bridge. The Tahsis River watershed ranges from sea level up to 1,669m at the peak of Minke Mountain which is also holds the Minke Glacier.

The Leiner River flows for 10.7 km from its headwaters to its mouth at the Tahsis Inlet. The Leiner River watershed topography ranges from sea level up to 1,688m at the peak of Mount Bate. An overview of all the watersheds are shown on Figure 2, and the Study Area for each watershed is shown previously on Figure 1, an excerpt from the 1992 Study.

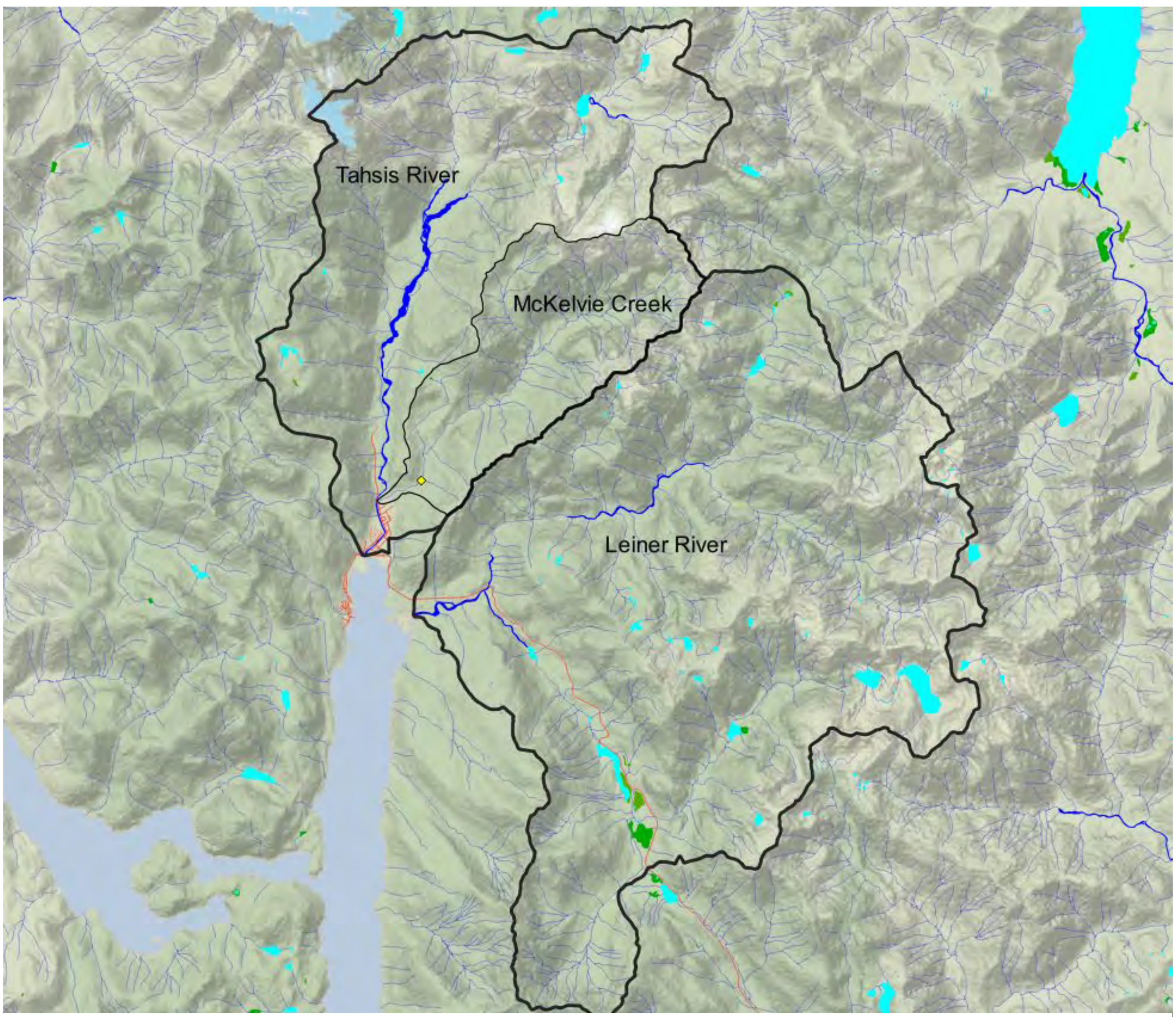

Figure 2: Tahsis and Leiner Rivers Catchment Areas

Significant snowpack can accumulate in both the Tahsis and Leiner River watersheds at higher elevations during the winter months. However, peak discharges resulting from spring snowmelt are generally smaller than those peak flows associated with heavy rainfall events, especially during large frontal storms from the Pacific Ocean. Often these frontal storms result in low pressure systems and high winds which can cause storm surge and wave set-up in the Tahsis Inlet. As a result, flooding in the Tahsis River and surrounding river systems occurs most frequently between October and February, when higher tides and higher precipitation are prevalent.

3.2 Past Flooding and Flood Mitigation in Tahsis

The Tahsis and Leiner River floodplains have flooded many times since 1900. The dates of more significant floods and a brief commentary are listed in Table 1.

Table 1: Historical Flood Events

Date	Comments
November 13, 1975	As documented in the "Tahsis Inlet Outlet", Tahsis, BC
November 9, 1989	As documented in the "Tahsis Inlet Outlet", Tahsis, BC. Flood waters rose rapidly on November 9th after two days of rain totaling 400mm. A rock and mudslide rolled through the west townsite depositing silt and mud in area businesses. Newspapers reported that this flood was comparable to the 1975 flood.
November 11, 1990	Considered by locals as worse than the previous 1989 flood.
September 25, 2010	At least 6" deep flooding video recorded along North Maquinna Drive (see Figure 3).

As reported in the "Tahsis Inlet Outlet" newspaper on November 15, 1989 (see Appendix A), the 1989 flood was a result of runoff from an extreme rainfall event that saw about 16" (450mm) of rain fall on the Tahsis and Leiner River watersheds the previous day. The two rivers and many local creeks burst their banks and flooding occurred all over the Village, including the south end at what was then the Tahsis Plaza and the now closed Maquinna Resort.

After the 1989 and 1990 floods, the Province initiated a study[5], which resulted in the first floodplain maps for the Village (see Appendix A). The study resulted in recommendations for flood protection levels along the ocean front (4.0m GSC, Geodetic Survey of Canada) and flood levels from the Tahsis and Leiner Rivers for the 1:20 year and 1:200 year predicted flood returns. In both cases, it was determined that the instantaneous peak discharges were the most conservative estimates when including a 0.3m freeboard allowance according to the floodplain mapping guidelines of the day. These maps have been used as reference by the Village but are not currently enacted in bylaws for floodplain management and development.

Subsequent flooding after the above-mentioned storms occurred with some regularity, spurring the need for the Village to act. In 2001, the Cook Street earth dike and concrete lock-block floodwall (Along North Maquinna) were constructed to mitigate flooding from the Tahsis River onto the east portion of north Tahsis. The dike was built to an elevation of 6.3m GSC, which appears to be about a 1:20 year return period flood based on the 1992 mapping. The floodwall was built to an elevation of

[5] Klohn Leonoff Ltd., Floodplain Mapping Tahsis, Leiner and Zeballos Rivers, February 1992

6.3m at the north end sloping with the water surface profile to end up at a finished height of 4.26m on the south end near the Quadra Street intersection. Record drawings for the project are appended with the above-mentioned flood study brief.

The dike and floodwall were effective in preventing flood waters from over spilling the east bank of the Tahsis river, but further problems existed with internal flooding until a new drainage facility along Boston Road was constructed in 2006 (record drawings are attached in Appendix A).

More recent highwater events have occurred with little to know flood damage reported. The link below is to a highwater event recorded and available on "YouTube" (https://www.youtube.com/watch?v=zYC1c5GIEv0&feature=share). The video shows high water on the Tahsis River in September of 2010. Environment Canada records show that a total of 115.2mm of rain were recorded at the Tahsis Village North weather station (Climate ID: 1037899). There is some minor flooding of North Maquinna Road, but the floodwall and dike are holding flood waters back as designed. Still, Internal drainage systems may need to be looked at for improvement in preventing internal flooding. This may include the requirement for a stormwater pumping station.

Figure 3: High Water Event "September 2010" – Minor Flooding on North Maquinna Road

3.3 THE EFFECT OF CLIMATE CHANGE, SEA LEVEL RISE AND LAND USE ON FLOODING

Current practice for establishing Flood Risk Hazards in BC require consideration for climate change. Though the science is still evolving, global climate change models used in the prediction of potential Sea Level Rise and changes in long-term weather patterns have been refined and are a requirement of planning for Developers, Municipalities and Provincial and Federal Agencies. In BC, the Pacific Climate Impacts Consortium (PCIC) is a regional climate service centre at the University of Victoria that provides practical information on the physical impacts of climate variability and change in the Pacific and Yukon Region of Canada. The tools provided by PCIC and the two reference guidelines published by the Engineers and

Geoscientists BC (EGBC) and the Ministry of Forests, Lands, Natural Resource Operations and Rural Development (MFLNRORD)[6] form the basis for year 2100 estimates for changings in precipitation and Sea Level Rise.

In 2011, the then BC Ministry of Environment (MoE) published a "Draft Policy Discussion Paper" based on assessments produced by Ausenco Sandwell. The *"Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use, Draft Policy Discussion Paper"*[7] was the leading report to address Sea Level Rise, and the recommended planning levels from that paper, as shown on Figure 4, has become the standard to which planning studies in BC need to adhere to. While research has advanced somewhat, the Policy remains in place, and the recommended 1m Sea Level Rise estimate has been incorporated into the assessment of the Tahsis and Leiner Rivers

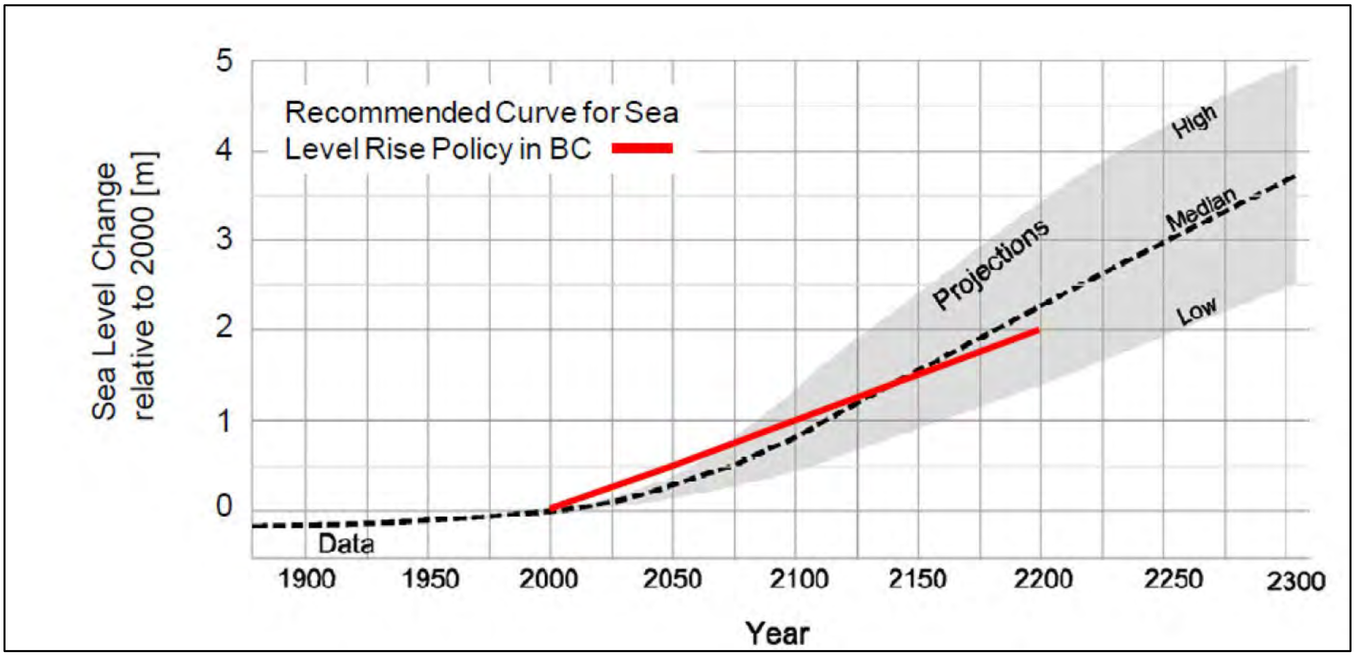

Figure 4: Provincial SLR Policy in BC

The following excerpt from the BC MoE's 2013 report titled *"Sea Level Rise Adaptation Primer, A Tool Kit to Build Adaptive Capacity on Canada's South Coasts"*[8] provides the most succinct rationale for the state of Sea Level Rise and why it is important to consider it now within the context of floodplain management:

> *"How much sea level rise will occur is subject to uncertainty – and the longer the time frame, the greater the degree of uncertainty.*

[6] Legislated Flood Assessments in a Changing Climate in BC, BC Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (MFLNRORD), and Professional Practice Guidelines – Flood Mapping in BC (Engineers and Geoscientists BC 2017a)
[7] Ausenco Sandwell, Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use Guidelines for Management of Coastal Flood Hazard Land Use, January 2011
[8] British Columbia Ministry of Environment, Sea Level Rise Adaptation Primer, A Tool Kit to Build Adaptive Capacity on Canada's South Coasts, Fall 2013

In its Fourth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) projected global sea level rise using six different scenarios of future greenhouse gas (GHG) emissions. Variables used to determine GHG emissions included population projections, economic growth and the use of technology.

Depending on the IPCC scenario used, the estimated rise in global sea level to the end of this century (i.e. 2100) varies from 18 to 59 cm. Based on the large body of research which has taken place since the IPCC scenarios were prepared in 2007, these projections may be quite conservative. Recent scientific research based on empirical relationships between atmospheric carbon concentrations and sea levels in the paleoclimatological record suggests that the upper bounds of physically plausible sea level rise is larger than once thought, owing to thermal expansion and glacial and ice sheet melt. These "semi-empirical" studies generally project a sea level rise of between 0.47 m and 1.9 m by the year 2100.

Both B.C. and Atlantic Canada recommend planning for sea level rise of approximately 1.0 m by the year 2100. A 2011 study for the Government of B.C. recommended sea level rise planning levels of 0.5 metres (50 cm) to the year 2050, 1.0 metre to the year 2100 and 2.0 metres to the year 2200. This is higher than the 2007 IPCC scenarios but is consistent with sea level rise projections used for planning purposes in Europe and the U.S.A.

Even if drastic measures are undertaken to slow down or even stop carbon emissions, sea levels will continue to rise for many centuries after global temperatures stabilize: a reality which has significant implications for local government planning. Planning for sea level rise presents a challenge for local governments; especially as many communities in Canada are relatively young and growing rapidly. For example, the first local government to be incorporated in B.C. was New Westminster in 1859 and the oldest continuously occupied building in the province is less than 170 years old.

Most buildings and infrastructure have a lifespan much longer than the 20-30 year future time period often used when designing infrastructure and planning communities. Planning for a century of change is a challenge, but is a realistic goal given the implications of projected sea level rise. Figure 2 (below) shows the effect of incremental increases in minimum building elevation planning over time, based on a 100-year lifespan for a structure.

Regardless of the time frame used, observations and predictions of sea level rise will need to be periodically re-evaluated. Predictions of sea level rise will continue to evolve and be refined as the science progresses and more data becomes available."

For the purposes of this study, Sea Level Rise needs to be considered in relation to isostatic rebound (lifting of the earth's crust after the last glacial age). Isostatic rebound will be counter to Sea Level Rise, reducing its net effect on the rising ocean levels. In the process of determining appropriate ocean levels, Sea Level Rise and isostatic rebound need to be considered with appropriate allowances for other ocean level dynamics such as storm surges and the effects of tides and wave environments. Since most flooding in Tahsis is a result of significant storm activity generating significant rainfall accumulations, it makes sense to consider the effect of all probable phenomena at the receiving ocean inlet coincident with the peak flood waters discharging from the two rivers. The work to estimate the conditions at the inlet for present day mean sea levels, as well as future Sea Level Rise, has been completed by others and is generally accepted for use in this study. Details of the levels at the sea both present and future are provided in Section 5.3 below.

As the climate warms, weather patterns are expected to change, which will affect natural systems to varying degrees. The PCIC has developed several local models for predicted climate change and its effect on weather. The local estimates for Tahsis are provided on Table 2 below and show increases of rainfall in the fall and winter with drier summers.

Table 2: Predicted Climate Change Normals for the Tahsis Area, Summary of Climate Change for Strathcona in the 2080s[9]

Climate Variable	Season	Projected Change from 1961-1990 Baseline	
		Ensemble Median	Range (10th to 90th percentile)
Mean Temperature (°C)	Annual	+2.5 °C	+1.3 °C to +3.7 °C
Precipitation (%)	Annual	+8%	+1% to +16%
	Summer	-12%	-32% to -0%
	Winter	+12%	+1% to +22%
Snowfall* (%)	Winter	-33%	-59% to -13%
	Spring	-72%	-86% to -14%
Growing Degree Days* (degree days)	Annual	+521 degree days	+270 to +832 degree days
Heating Degree Days* (degree days)	Annual	-877 degree days	-1328 to -467 degree days
Frost-Free Days* (days)	Annual	+35 days	+19 to +52 days

The table above shows projected changes in average (mean) temperature, precipitation and several derived climate variables from the baseline historical period (1961-1990) to the **2080s** for the **Strathcona** region. The ensemble median is a mid-point value, chosen from a PCIC standard set of Global Climate Model (GCM) projections (see the 'Notes' tab for more information). The range values represent the lowest and highest results within the set. Please note that this summary table does not reflect the 'Season' choice made under the 'Region & Time' tab. However, this setting does affect results obtained under each variable tab.

* These values are derived from temperature and precipitation. Please select the appropriate variable tab for more information.

The additional 12% rainfall in the winter is considered to be in exchange for a 33% decrease in snowfall for the most part. The chosen scenario is the Mean predictions from the various models, which represents a reasonable forecast at this time. Like any predictions about climate and weather, these are continuously being researched and updated. Moving forward, the Village of Tahsis should re-visit the science and predictions to update the floodplain model on a more routine basis. Coupled with the need to monitor Tahsis river discharges, the model can then be better calibrated and used for the intended purpose of planning for development policy in the floodplain.

For this study, the modelling of the year 2100 scenario assumes that 12% increase in precipitation will result in 12% higher predicted river discharges. This estimation is conservatively high but deemed reasonable since it is likely that, during the most extreme events, the antecedent conditions in the watersheds will be at full saturation of soils, resulting in a direct increase in runoff.

[9] www.pacificclimate.org, Plan2Adapt Tool Kit, April 2019

3.4 THE RIVER CHANGES WITHIN THE FLOODPLAIN

The fluvial geomorphologic assessment in this report is a high-level analysis of the channel reaches within the boundaries of the study area and is by no means a detailed geomorphologic assessment of the entire river network. The analysis used an extensive collection of aerial photos taken from 1958 up to 2003 and available images from Google Earth up to 2013. Figure 5 shows some of the images used in the analysis.

McKelvie Creek, the Tahsis River and the Leiner River are all relatively well confined river channels. This confinement is typical, given the steep and rocky mountain terrain within which these rivers flow.

Through the north townsite portion of the Tahsis River and McKelvie Creek, the historic air photos (Figure 6) show a continual training of the channels with re-alignment of McKelvie Creek and armouring of the two channels. Air photos from 1958 to 1966 show a definite straightening of McKelvie Creek at its confluence with the Tahsis River. This reach was then armoured, and the resulting channel has since been stable within that reach.

The riprap armoring of the Tahsis River and McKelvie Creek banks was intended to protect development areas of the northern townsite and has resulted in trained, stable channels which historically meandered across the deltaic mouth flowing into the Tahsis Inlet. The Leiner River, however, is untrained and comparatively less stable than the lower Tahsis River, but it is still confined to its natural floodplain with Head Bay Rd along its northern extents.

Figure 5: Chronologic Aerial Comparison of the Tahsis Floodplain

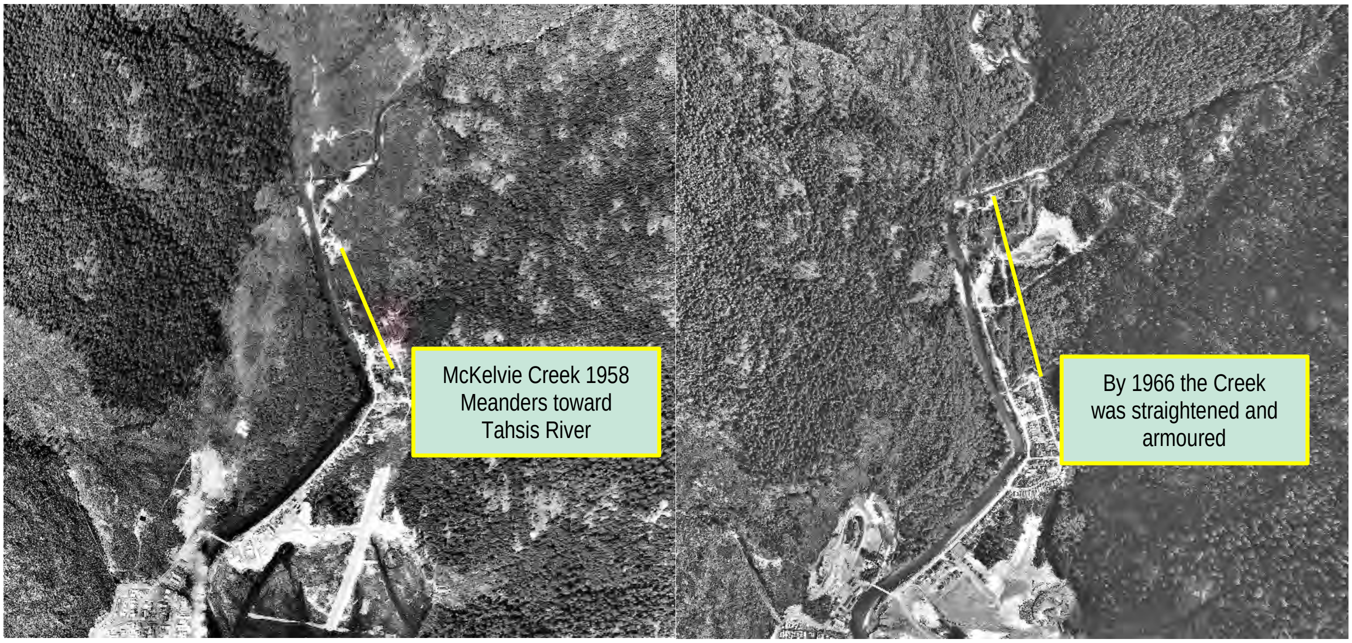

Figure 6: Apparent River Training of McKelvie Creek

The sediment transport and deposition within the Tahsis River and McKelvie Creek appears to be balanced, with no considerable signs of channel scour or aggradation. Gravel bars merely shift over the years, and, even at the mouth of the Tahsis River, sediment deposition does not appear to be significant. The Leiner River behaves similarly to the Tahsis River, in that sediment transport loads are balanced with deposition volumes except at its mouth, which deposits materials in a typical alluvial fan expected of rivers of this nature.

3.5 NORTH MAQUINNA DRIVE FLOODWALL

In response to flood events, the Village of Tahsis had a floodwall along the west bank of the Tahsis River designed and built, see Figure 7. The floodwall extends from the Perry Brothers Bridge along North Maquinna Drive to just south of Quadra Street. The wall was expected not only to protect the adjacent residential properties but also to protect the public works yard and access to it.

The floodwall is registered with the Diking Authority at the Ministry of Forest, Lands and Natural Resource Operations (MFLNRO), Water Management Branch: Dike #298

Figure 7: Flood Wall Construction Along North Maquinna Drive

3.6 COOK STREET DIKE

The Cook Steet dike was constructed in 2001 and was designed as a means of protecting the west side of the townsite from advancing water surging down McKelvie Creek. The dike was constucted to an elevation of 6.3m, see Figure 8. It is a registed dike and, as such, must be inpected on an annual basis by trained Village staff, whose findings are then audited by the Inspector of Dikes (IOD). The dike has proved effective in protecting from flooding since 2001.

Figure 9, below, shows the current extents of flood protection structures along the banks of the Tahsis River and McKelvie Creek.

Figure 8: Construction of the Cook Street Dike

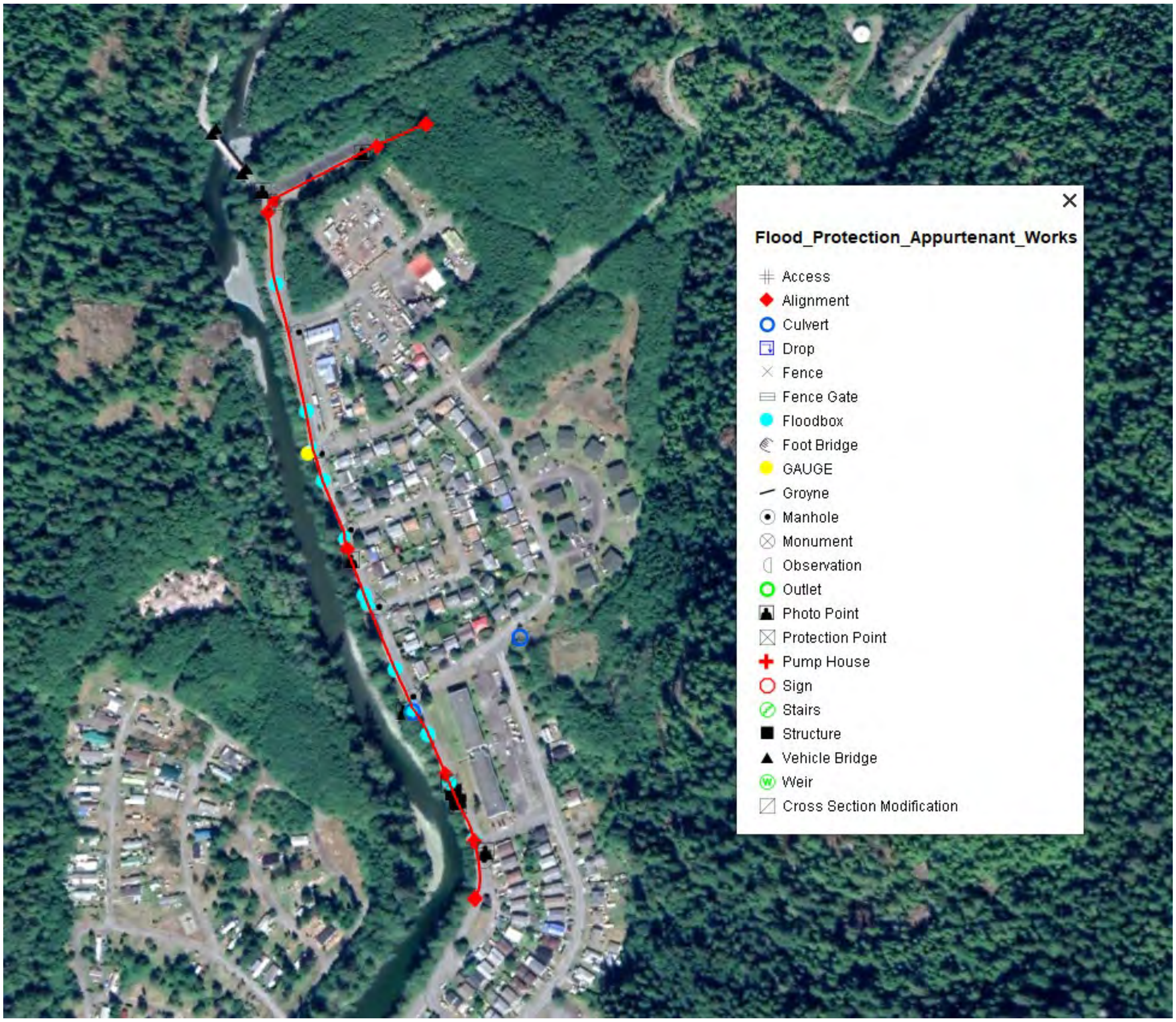

Figure 9: BC Water Resources Atlas showing the extents of Dike #298 and Appurtenances, maps.gov.bc.ca/ess/hm/wrbc

3.7 BOSTON STREET DRAINAGE CULVERT AND STORM POND

To mitigate flood waters, a drainage culvert and storm pond was constructed in 2006 on the corner of Boston Street and Jewitt Drive, see Figure 10. The updated internal drainage structure was required because the area would "back flood" from high river levels while preventing internal runoff from reaching the river, flooding area homes as shown on the photo. The culvert has a large flood gate at the river end, and modifications to internal drainage ditches have successfully alleviated the issue with no known flood events occurring since.

Figure 10: Historic Photo of the Flooded Boston Street Flood Pond

These internal drainage features need to be reviewed in the context of rising flood waters and internal storage capacities during high water events. Future work that may be required to improve the flood protection of the Village will have to consider improvements to the internal drainage system in conjunction with any improved diking strategies.

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4 FLOODPLAIN MANAGEMENT TOOLS

4.1 MUNICIPAL LEVEL

The study area includes lands within the Village of Tahsis, and floodplain management is generally provided by a combination of Zoning Bylaw Regulations and the Official Community Plan.

4.1.1 *Village of Tahsis Official Community Plan*

The Village of Tahsis Official Community Plan (Bylaw No. 547, 2010) provides a land use and infrastructure policy framework to guide development in the Village. Policies and content of significance in a Floodplain context include:

- Environmentally sensitive areas as they pertain to protecting the public, property and future long-term planning goals.
- Discouraging residential development within high risk areas, including the floodplain.
- Ensuring industrial development is outside floodplain areas.
- Development permit area for natural hazard conditions, which requires a development permit for any proposed development, except for three or less self-contained dwelling units, located within 30m of the highwater of any watercourse.

4.1.2 *Village of Tahsis Zoning Bylaw*

The Village of Tahsis Zoning Bylaw No. 176 addresses various new building location conditions and construction levels in terms of 200-year flood elevations. These are outlined in *Section 6.5 - Siting of Buildings Adjacent to Lakes and Watercourses.* The bylaw does not currently identify or designate areas of potential flood hazard.

4.2 PROVINCIAL LEVEL

The Environmental Management Act[10] provides the Ministry of Forest, Lands and Natural Resource Operations (FLRNO) with broad powers to establish guidelines, regulations and hazard management plans with respect to flood protection, dikes and the development of land subject to flooding.

Through the Act, FLNRO has established the Integrated Flood Hazard Management Program. The objective of the program is to reduce the impacts of flooding on people, communities and infrastructure through the development of policies, guidelines, and information to assist local governments. The program provides guidance in three primary areas:

1. Managing land use within the floodplain;
2. Managing flood protection systems; and
3. Preparing for and responding to emergencies.

[10] BC Environmental Management Act, SBC 2003, Chapter 53

Effective flood management practice integrates all three of these components. Although flood protection works, such as dikes, provide protection from flood damage, they require on-going maintenance and periodic upgrades to be effective over time. It is, typically, not cost effective to rely solely on constructed flood protection works to control the threat of flooding. It has been shown that appropriate land use management and flood mitigation are the most practical and cost-effective ways to reduce flood damage. Finally, in the event that flooding does occur, communities having an effective emergency planning and response program can reduce the risk of loss of life and trauma as well as improve recovery times.

4.2.1 *Floodplain Land Use Management*

The provincial Flood Hazard Area Land Use Management Guidelines[11] provide guidance for local government, land use managers and approving officers to develop and implement land use management plans and subdivision approvals for floodplain areas.

Land Use Management Policies

The guidelines suggest that general land use policy statements regarding flood hazard management and maps showing areas of flood hazard, should be included in Official Community Plans. The guide provides general examples of policy statements. Under sections of the Local Government Act[12], local governments may incorporate requirements for flood protection measures or restrictions on floodplain development through floodplain bylaws, land use bylaws and development permit areas. The guideline provides example bylaws that local governments can use.

During the subdivision approval process for lands that are deemed subject to flooding or erosion, the approving officer can require an engineering certification that the land may be used safely for its intended purpose. The provincial government has prepared a guide to selecting qualified professionals for preparation of flood hazard assessment reports. Engineers and Geoscientists of British Columbia have published Professional Practice Guidelines for Legislated Flood Assessments in a Changing Climate in BC[13], which provide qualified professionals with guidance on flood standards and methodologies to use when reviewing flood hazards for land development.

Where land may be subject to flood hazard beyond what is considered safe for the intended use, a restrictive covenant can be used to restrict development within all or part of the land parcel. The guidelines provide a summary of specific conditions that should be included in a restrictive covenant for flood hazard management as well as examples.

Floodplain Mapping

Local governments must consider relevant floodplain mapping in the development of flood hazard bylaws and other land use management policies. Floodplain maps show the route and limits of water courses, surrounding features, ground elevations, flood levels and floodplain limits. One of the primary purposes of the Tahsis Flood Risk Assessment has been to update the floodplain mapping for purposes of land management planning.

The impacts of Climate Change and Sea Level Rise must now be considered in the preparation of floodplain mapping. The Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use and Coastal Floodplain Mapping

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[11] BC Ministry of Water, Land and Air Protection, Flood Hazard Area Land Use Management Guidelines, May 2004
[12] BC Local Government Act, RSBC 2015, Chapter 1
[13] Engineers and Geoscientists BC, Legislated Flood Assessments in a Changing Climate in BC, Version 2.1, August 2018

Guidelines[14] recommend that a 1.0m increase in average sea level should be used for planning purposes for the Year 2100 timeline.

Recommended Minimum Flood Hazard Reduction Requirements

The Flood Hazard Area Land Use Management Guidelines[15] also provide a list of minimum requirements for higher flood risk areas, where detailed floodplain mapping has not yet been prepared. Some of these requirements include:

- Establishing floodplain setbacks, ensuring development is kept away from areas of potential erosion and avoiding restriction of flow capacity. The minimum recommended setback for rivers is 30m.
- Flood Construction Levels (FCL) are used to keep living spaces and areas used to store goods that could be damaged by flooding above the established flood levels. The minimum recommended Flood Construction Level is either 0.6 m above the designated flood water level or 3.0 m above the natural ground level adjacent to the water course if no flood levels have been established.
- Designated flood is the flood having an average recurrence interval of 200 years or that has an average 0.5% likelihood of occurring in any given year.

The guidelines also provide suggestions intended to reduce flood hazards by land use type and recommendations on access and egress requirements from the floodplain during flood events.

Legislated Flood Assessment Guidelines

The Engineers and Geoscientists BC, in conjunction with Provincial Ministry of Forest, Lands and Natural Resource Operations and Natural Resources Canada, have developed a professional practice guideline for "Legislated Flood Assessments in a Changing Climate in BC"[16]. The purpose of this guideline is to provide a framework for communities and professionals to define the roles and scope of flood assessments required for building permits, subdivision approvals and other land development activities that are reviewed by Approving Authorities. The scope of the guidelines provides recommendations on how to:

- Undertake flood assessments consistently and transparently;
- Provide for appropriate consultation with approving authorities;
- Use a level of effort and approach appropriate for the nature of the elements at risk;
- Standardize the flood assessments to make them directly comparable within BC;
- Consider existing regulations and the level of protection provided by structural mitigation works;
- Increasingly consider "risk management" and "adaptation" as opposed to solely "protection" and "defense";
- Consider a broader range of issues and analytical techniques to help achieve improved social and environmental outcomes as part of development;
- Include predicted changes in the hydroclimate as well as natural and anthropogenic changes to channel morphology and watersheds in the flood assessment; and
- Identify situations that require expert input.

[14] Ausenco Sandwell, Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use Guidelines for Management of Coastal Flood Hazard Land Use, January 2011
[15] BC Ministry of Water, Land and Air Protection, Flood Hazard Area Land Use Management Guidelines, May 2004
[16] Engineers and Geoscientists BC, Legislated Flood Assessments in a Changing Climate in BC, Version 2.1, August 2018

Although the guidelines have been primarily developed as a tool for qualified flood assessment professionals, the document also provides guidance on how local governments can better define flood assessment requirements as part of their land development approval processes.

4.2.2 *Dike Safety Management*

The responsibility for construction and maintenance of dikes lies with local government or other diking authorities such as regional districts, first nations or other public authority designated by the provincial minister. The provincial government has responsibility for general supervision relative to construction and maintenance of dikes, including administering the Dike Maintenance Act, setting dike design and maintenance standards and monitoring and auditing functions.

Under the Integrated Flood Hazard Management Program, the provincial government has prepared guidelines and policies for local government and other diking authorities to use to meet the requirements of the Dike Maintenance Act[17]. These include the following:

- Dike Design and Construction Guide Best Management Practices for British Columbia[18]
- Riprap Design and Construction Guide[19]
- Seismic Design Guidelines for Dikes[20]

The publications listed above provide recommendations on preferred design approaches and best management practices, as well as specific detailed design criteria that dikes must meet to be considered a "standard dike".

4.2.3 *Flood Emergency Management*

Emergency Management BC (EMBC) is the primary provincial government agency responsible for coordinating flood response. This said, emergency planning and response should be coordinated from within households, local governments and higher levels of government. Through the Integrated Flood Management Program, the provincial government has prepared several guidance documents to help local governments and households prepare for flood emergencies:

- British Columbia Flood Plan, 2012;
- Flood Planning and Response Guide for British Columbia;
- Flood Precautions;
- Local Authority Planning Guide;
- BC Tsunami Warning Plan; and
- Other Hazard Specific Plans.

The BC Flood Plan provides specific recommendations and guidelines to assist in preparing for flood emergencies, both at local and provincial level. It identifies some of the specific issues associated with flood events, including:

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[17] BC Dike Maintenance Act, RSBC 1996, Chapter 95
[18] BC Ministry of Water, Land and Air Protection, Dike Design and Construction Guide Best Management Practices for British Columbia, July 2003
[19] Riprap Design and Construction Guide, BC Ministry of Environment, Lands and Park, March 2000
[20] BC Ministry of Forests, Lands and Natural Resource Operations, Seismic Design Guidelines for Dikes, June 2014

- Flash flooding without warning, which can be extremely hazardous and pose significant risk to infrastructure and loss of life;
- Flooding which can occur across a wide geographic area or at several locations across the province at the same time, which can overwhelm provincial and local resources;
- Health risks associated with flooded sewage systems or other hazardous waste and contaminated drinking water supplies;
- River forecasting, which can allow for advanced planning in locations where snowmelt dominates the flood process and issues advisories and warnings;
- Dike authorities (such as those of a local government), who actively monitor flood protection works;
- Waterways which should be monitored for hazardous materials and debris; and
- Potential need to implement site-specific flood protection measures, such as sandbags or other temporary structures.

4.3 FEDERAL LEVEL

4.3.1 *Flood Damage Reduction Program*

Under the Canadian Constitution, floodplain management falls under the jurisdiction of the provinces. However, the federal government's role is to reduce major disruptions to regional economies and to reduce disaster assistance payments through the Flood Damage Reduction Program. Generally, this program has provided funding of flood protection works, such as the recent partial funding of the provincial Flood Protection Program, which has provided funding to upgrade and construct new flood protection works across BC. In addition, specific programs are supported federally such as the Provincial-Federal Floodplain Mapping Program carried out from 1987 to 1998.

4.3.2 *Public Safety*

Under the Emergency Management Act[21] (EMA), the Federal Government provides overarching Emergency Management Planning and Disaster Mitigation support in the event of disasters of national importance to protect critical infrastructure. As emergencies most often have the greatest impact at the local level, the Act provides clear guidance on working collaboratively and sharing information with provincial and local emergency management agencies. Public Safety Canada, which administers the EMA, has developed high level emergency planning and recovery policies and guidance for provincial and local governments.

4.3.3 *Other Relevant Federal Legislation*

Often flood protection works require alterations of stream channels or construction near watercourses that could have impacts to fish habitat. Under the Federal Fisheries Act[22], administered by the Department of Fisheries and Oceans (DFO), any potential Harmful Alteration Disruption or Destruction (HADD) of fish habitat requires prior approval from DFO. Should DFO determine that proposed flood protection works result in HADD, compensation is typically required in the form of construction of habitat enhancement works. During design and planning of flood protection works, opportunities for potential habitat enhancement should be identified to compensate for HADD.

[21] Canada Emergency Management Act, S.C. 2007, Chapter 15
[22] Canada Fisheries Act, R.S.C. 1985

In addition to the Fisheries Act, the approvals under the following legislation may also be required for flood protection works:

- Navigation Protection Act[23], should works impact navigability of waterways
- Environmental Assessment Act[24], if works are partially funded through Federal Grants
- Species at Risk Act[25], if works could impact species identified on the list of wildlife species at risk

It should be noted that the Federal Government enacted legislation (Bill C-38 and C-45), which have imposed changes to the Environmental Assessment Act, the Fisheries Act and the Navigation Protection Act which will impact the way that works carried near waterways are approved in the future.

4.4 FLOOD MANAGEMENT PRACTICES AND STRATEGIES

Figure 11: Flood Management Solution Space

The "solution space" for flood management (see Figure 11) moves from "resistance strategy" to one of "avoidance" depending on the risk and the values assigned to the cost and benefit of the resistance method[26]. As shown to the left, the paradigm moves from the "protect" to the "avoid" space with the added intermediate solutions of "accommodate" and "retreat". Thus, local governments can choose depending on resources and local values how they want to deal with predicted floods and flood damages and, to some extent, determine the survival of their communities. Is it better to resist, or get out of harm's way? The following sections provide brief summaries for both conventional ("protect") and more recently adopted practices ("accommodate", "retreat" and "avoid") in flood mitigation, as they pertain to the Village of Tahsis Floodplain situation.

4.4.1 *Dikes, Levees, and Flood Walls ("Protect")*

The conventional method of protecting private and public assets is to provide an engineered solution such as dikes, levees and flood walls. As described above, there are regulations for the development of these structures and typically other constraints, such as costs and environmental impacts, which need to be considered. Structures like these will continue to require maintenance if the near bank land use and managing risks to property are of consequence to the Village.

4.4.2 *Flood Proofing of Buildings ("Accommodate")*

The Village of Tahsis should consider revising bylaws such that existing structures and new buildings need to be built to a set Flood Construction Level. Such a bylaw would allow for filling of land to achieve this elevation. As sea levels rise, it may be

23 Canada Navigation Protection Act, R.C.S 1985
24 BC Environmental Assessment Act, SBC 2002, Chapter 43
25 Canada Species at Risk Act, S.C. 2002
26 British Columbia Ministry of Environment, Sea Level Rise Adaptation Primer, A Tool Kit to Build Adaptive Capacity on Canada's South Coasts, Fall 2013

necessary to raise the living areas of buildings further as depicted in Figure 12 below, which shows some buildings on raised "pads" of earth, and some with raised habitable areas above flood levels. These techniques are considered as methods for "flood proofing" buildings within floodplain areas. More novel techniques like floating houses have been implemented in other jurisdictions successfully and could be considered as an option in Tahsis for future re-development within the floodplain area.

The Village could create restrictive covenants for lots within the floodplain and Section 219 covenants for developments wanting to vary from required flood construction levels, which would indemnify the Village or Province of any responsibility for flood damage to properties developed below recommended floodplain levels.

Figure 12: Examples of Raised Building Pads for Foundations[27]

4.4.3 *Managed Retreat ("Retreat" and "Avoid")*

From a longer-term perspective, adaptation to increased flood risks is a preferred approach, and the solutions for flood mitigation tend to move away from the engineered flood protection structures such as dikes and levees. A balance needs to be achieved between the uses of the land today and future uses, which include assessment of environmental and socio-economic values, potentially returning the land to a more natural state. Termed "managed retreat", the mitigation strategy involves zoning and land use designations to be "downgraded" as properties are brought forward for re-development, preventing re-development of the land. The land is effectively returned to the Village and managed as a natural floodplain area, or for more flood tolerant uses such as agriculture, as illustrated in Figure 13.

In the case of Tahsis, many of the residential properties in the northeast quadrant of the Village are nearing the end of their useful life, and it may be prudent to consider restrictions on redevelopment in this area to mitigate damages from future flood events, especially as predicted sea levels begin to rise and cause more flooding on a more frequent basis. There are strategic areas which can be re-developed to higher Flood Construction Levels within the northeast quadrant, but there are better long-term residential opportunities on the West side of the river.

The community must also decide how to protect its assets like the school, the community centre, the water well pumping station and the north end treatment plant, which could all be considered individually for protection from future flooding. The Village is considering moving the fire station and may want to find a more suitable location for both it and the Public Works yard for the long-term and outside of the floodplain.

[27] UBC Faculty of Forestry, Collaborative for Advanced Landscape Planning, http://calp.forestry.ubc.ca/, Accessed April 2019

Figure 13: Illustration of Managed Retreat Strategy[27]

5 HYDROLOGIC AND HYDRAULIC MODELING

5.1 HYDROLOGIC ASSESSMENT

The provincial Floodplain Mapping Guidelines are based on an estimated 200-year return period peak water levels to determine floodplain mapping levels (or flood construction levels). The 200-year return period event is also used in developing flood protection options and assessing upstream and downstream impacts.

Flood hydrology of the Tahsis and Leiner River basins is dependent on a complex number of variables. These combine to influence the magnitude of river flow experienced during a flood event. Development of design floods for the mandated 200-year return period requires an assessment of flows within the tributary streams, an assessment of the timing of tributary peak flows relative to each other and the magnitude and timing of tide levels in the Tahsis Inlet.

The detailed hydrologic assessment related available hydrometric data to the timing of peak flows and tide levels, arriving at predicted design discharges and hydrographs. This information was then used as input to the development of flood profiles in the river and floodplain.

5.1.1 *Available Hydrologic Data*

There are eight Water Survey of Canada (WSC) hydrometric stations that are located adjacent to or within the same hydrologic region as the Tahsis and Leiner River basins. These stations provided the flow data that is required to complete the complex statistical analysis, which utilized to estimate peak flow rates. These stations are listed below, and their locations are shown on Figure 14:

- Zeballos River near Zeballos (08HE006)
- Zeballos River near Moot Peak (08HE008)
- Ucona River at the Mouth (08HC002)
- McKelvie Creek above intake (08HE010)
- Klaskish River at Klastino Inlet (08HE009)
- Tofino Creek near the Mouth (08HB086)
- Sarita River near Bamfield (08HB014)
- Carnation Creek at the mouth (08HB048)

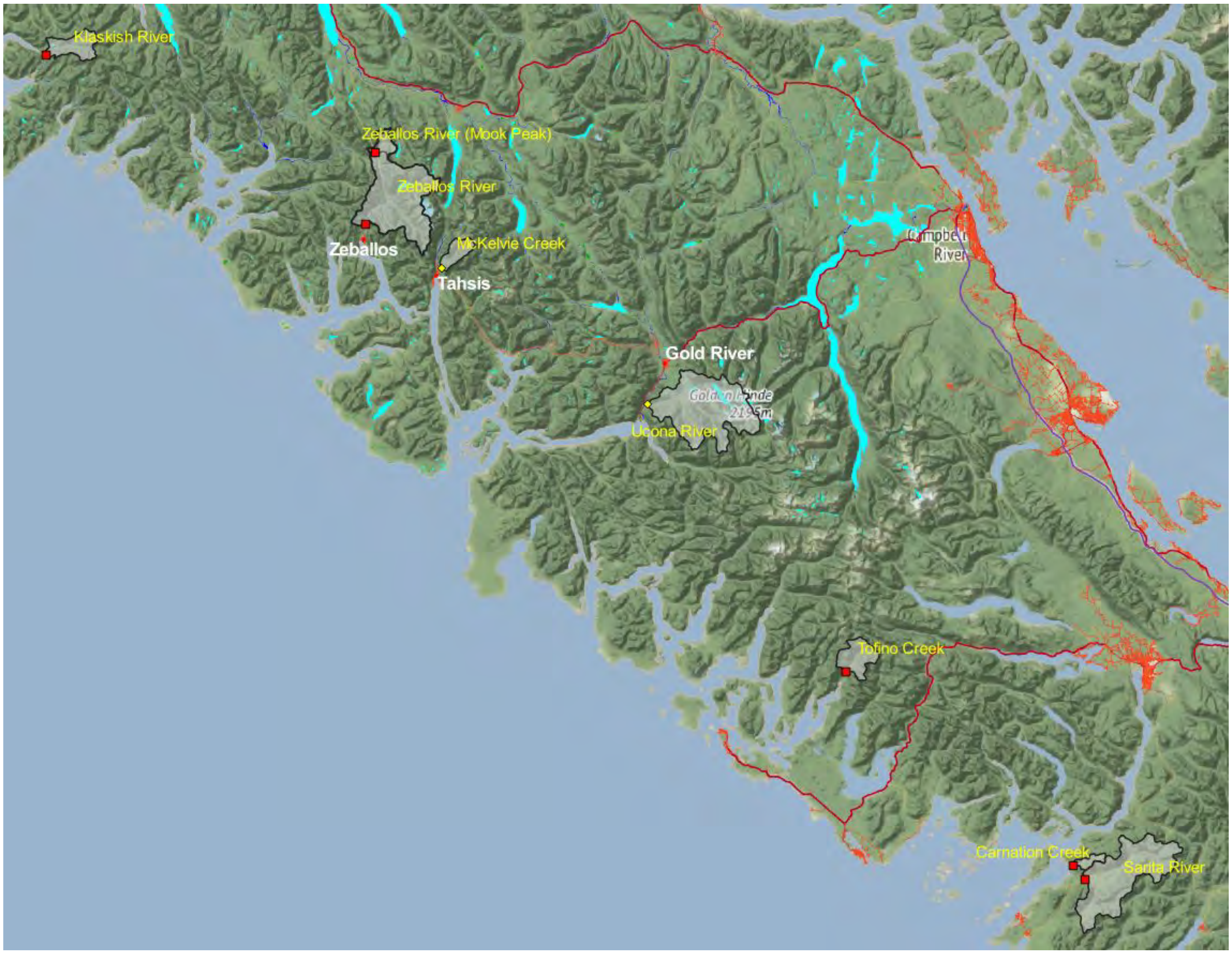


Figure 14: Water Survey of Canada Hydrometric Station Locations Considered in the Study

5.1.2 *Previous Hydraulic Analysis Results*

A previous study from February 1992 titled "Floodplain Mapping Tahsis, Leiner and Zeballos Rivers" presented a regional hydrologic assessment for the 20-year and 200-year peak daily and instantaneous flow rates. The study's estimated peak daily flow rates were developed using the slope of a unit discharge envelope, which was provided in a Ministry of Environment report from 1985[28]. The following relationship was then derived based on the Zeballos River catchment:

$$Q = Q_z \left(\frac{A}{A_z}\right)^{0.75}$$

[28] Ministry of Environment, Magnitude of Floods – British Columbia and Yukon Territory, 1985

Where: Q = Estimated daily discharge, in m^3/s.

Q_z = Zeballos River discharge, in m^3/s.

A = Catchment area, in km^2.

A_z = Zeballos River catchment area, in km^2.

The report then established peak instantaneous values by deriving ratios of maximum instantaneous to daily discharges (I/D) and multiplying them to the recorded peak daily flow rates This approach tended to produce conservatively high results given as it was developed with less recorded hydrometric data and fewer established WSC stations. The peak instantaneous results from the 1992 study are presented in Table 3 below.

Table 3: Summary of Estimated Instantaneous Discharge from 1992 Report

River	Catchment Area (km^2)	Peak Instantaneous Discharge (m^3/s)	
		20-Year Return Period	200-Year Return Period
McKelvie Creek	22	274	344
Tahsis Upstream of McKelvie Creek	54	501	664
Tahsis River at the Mouth	78	639	846
Leiner River	108	792	1094

5.1.3 *Hydrologic Analysis Results*

For the purposes of this study, the magnitude of the peak instantaneous design flows for the Tahsis and Leiner Rivers have been estimated through a regional flood frequency analysis. This analysis utilizes peak flood records from hydrometric stations across multiple watersheds, which have similar physical characteristics, geological conditions and statistical peak flood characteristics as the Tahsis and Leiner River's watersheds.

Regional flood frequency analysis involves calculating the 20-year and 200-year return period peak instantaneous discharges for each of the selected regional stations. These peak flood estimates are then plotted against watershed area to develop a regional flood frequency curve for each of the return periods.

When the 20-year and 200-year peak instantaneous discharges were plotted, the resulting regional curves were inconsistent with the results as presented in the 1992 study. The inconsistency can be explained in the differences in physical and statistical peak flood characteristics of Carnation Creek, McKelvie Creek, and Zeballos River near Moot Peak compared to the other station watersheds. These are explained in the following factors:

- The watershed areas are comparatively small and do not react to storms in the same manner as the other catchments analyzed.
- The physiography of the catchments with regards to shape are elongated compared to the pear shape of the other stations.
- The date range of available data for McKelvie and Zeballos near Moot Peak is substantially shorter than that of the other stations, which makes predictions from a frequency analysis less reliable.
- McKelvie Creek was missing data for years in which significant storms were experienced in the region, which will likely decrease the magnitude of any predicted return period flowrates.

For these reasons, the frequency analyses from Carnation Creek, McKelvie Creek, and Zeballos River near Moot Peak were not used to develop the regional flood frequency curves.

To confirm that the remaining hydrometric stations are regionally experiencing the same storm systems, the dates of peak annual flows ranging from 1999 to 2013 were compared to corresponding rankings of highest magnitude flowrates. The results, shown in Table 4 below, demonstrate that all the watersheds had similar high-ranking flow rates and confirmed that each experienced the same regional peak rainfall events.

Table 4: Comparison of Peak Flow Dates and Ranking of WSC Watersheds 1999-2013

Zeballos River		Ucona River		Klaskish River		Tofino Creek		Sarita River	
Date	Rank	Date	Rank	Date	Rank	Date	Rank	Date	Rank
May. 12 2013	15	Sep. 30 2013	15	2013	15	Mar. 01 2013	15	Mar. 01 2013	12
2012	5	Jan. 04 2012	9	2012	11	2012	1	Jan. 04 2012	11
Nov. 26 2011	2	Nov. 27 2011	2	2011	2	2011	9	Nov. 27 2011	7
Sep. 25 2010	1	Dec. 31 2010	4	2010	1	Jan. 11 2010	5	2010	4
Oct. 30 2009	4	Nov. 16 2009	3	Sep. 18 2009	6	Oct. 30 2009	7	Nov. 16 2009	3
Nov. 21 2008	14	Dec. 31 2008	14	2008	9	Oct. 17 2008	14	Nov. 08 2008	10
Nov. 12 2007	8	Nov. 12 2007	5	Nov. 12 2007	4	Oct. 07 2007	2	Nov. 12 2007	5
Nov. 15 2006	6	Nov. 15 2006	1	Nov. 15 2006	12	Nov. 15 2006	3	Nov. 15 2006	1
Dec. 24 2005	7	Dec. 24 2005	8	Oct. 10 2005	4	Dec. 24 2005	10	Jan. 19 2005	6
Nov. 14 2004	3	Nov. 15 2004	7	Nov. 14 2004	3	Nov. 15 2004	4	Dec. 10 2004	13
Jan. 26 2003	11	Oct. 18 2003	6	Oct. 08 2003	7	Oct. 18 2003	6	Oct. 18 2003	2
Nov. 18 2002	9	Nov. 18 2002	10	Dec. 12 2002	10	Nov. 18 2002	8	Nov. 18 2002	9
2001	10	Nov. 15 2001	11	Dec. 15 2001	13	Dec. 15 2001	13	Dec. 16 2001	14
Nov. 25 2000	12	Oct. 20 2000	12	Nov. 25 2000	8	Oct. 17 2000	11	Oct. 17 2000	15
Aug. 24 1999	13	Nov. 09 1999	13	Nov. 09 1999	14	Aug. 24 1999	12	Jan. 29 1999	8

The resulting regional flood frequency curves for the 20-year and 200-year return period peak instantaneous discharges are included in Figure 15 and Figure 16, respectively. These figures show the calculated discharges and basin areas for the hydrometric stations, the best fit line for the data points, and the predicted discharges for the study areas.

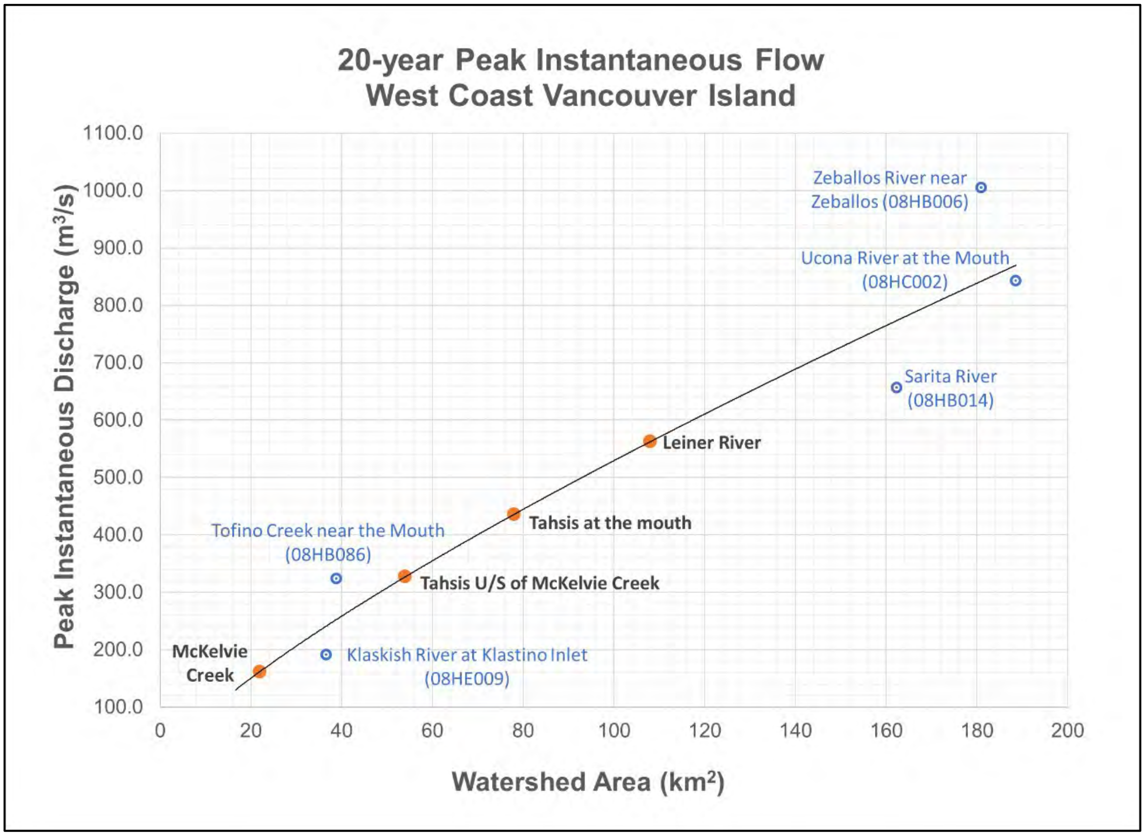


Figure 15:Regional Flood Frequency Curve for 20 Year Return Period

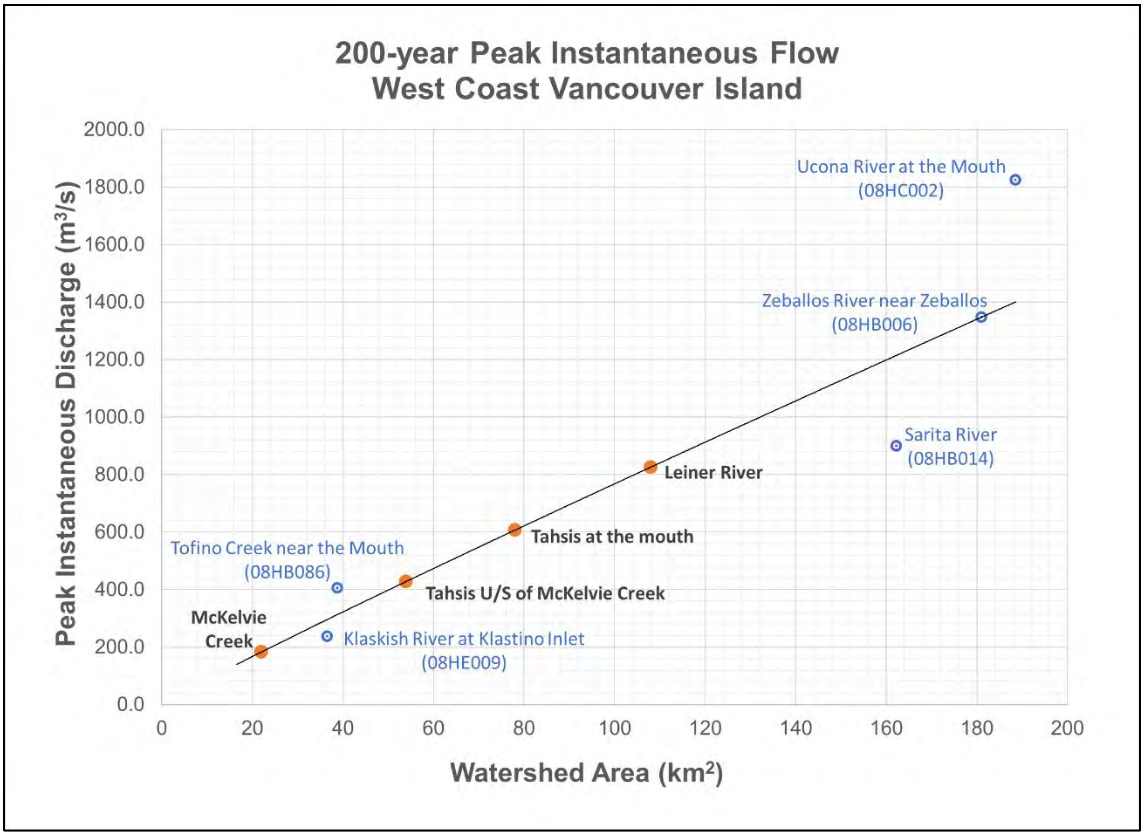


Figure 16: Regional Flood Frequency Curve for 200 Year Return Period

Instantaneous peak flow estimates for each of the rivers in the study have been estimated using the results of the regional flood frequency curve's line of best fit equations. The equations are power functions as shown below:

20-Year Return Period $Q_{20} = 14.419A^{0.7825}$

200-Year Return Period $Q_{200} = 9.785A^{0.9474}$

Where: A = Catchment area, in km^2.

The resulting estimated peak instantaneous flowrates are less than those presented in the 1992 study and are summarized in Table 5 below:

Table 5: Summary of Estimated Peak Instantaneous Discharges

River	Catchment Area (km^2)	Peak Instantaneous Discharge (m^3/s)	
		20-Year Return Period	200-Year Return Period
McKelvie Creek	22	162	183
Tahsis River Upstream of McKelvie Creek	54	327	428
Tahsis River at the Mouth	78	436	607
Leiner River	108	562	826

Once the magnitude of peak flows for each of the Tahsis and Leiner River catchments was estimated, the distribution of flow over time (hydrograph shape) and relative timing of flows had to be established for the design event. This was done by reviewing the historical data for the Zeballos River and McKelvie Creek, finding a characteristic shape for a significant flood event and then scaling it to the required peaks provided above.

Relative timing of the peak floods was based on the requirement to have a certain additive value of the Tahsis River and McKelvie Creek above the confluences, such that the peak at the mouth equated to 607 m^3/s for a 1:200-year design flood. The flood duration as derived from rainfall events lasts no more than 3-4 days, with the entire high-water period no more than a week in duration

5.1.4 *Comparison of 1992 to Present Analysis Results*

The 20-year and 200-year return period predicted flowrates from 1992 are 24-31% higher than those predicted in the current study. This reduction in currently predicted values does not imply that the 1992 results are incorrect. It is merely that, as addressed earlier in the brief, the previous study based its predictions on now outdated statistics and numerical approaches, which were acceptable at the time. However, the range of discrepancy between results is reduced when factors for the increase of precipitation are added for expected climate change.

5.2 HYDRAULIC MODEL DEVELOPMENT

HEC-RAS is hydrodynamic computer modeling software developed by the US Army Corps of Engineers for flood modeling. It is an integrated tool for river channel, floodplain, and coastal flood studies, and it is widely regarded as the industry standard in river flood modeling software. The HEC-RAS model for the Tahsis and Leiner Rivers watersheds is a two-dimensional model in the floodplain and coastal areas. The model covers the following extents:

- Tahsis River from tide water at the Tahsis Inlet to 2.4 km upstream of its confluence with McKelvie Creek.
- McKelvie Creek 0.4 km upstream from its confluence with the Tahsis River.
- Leiner River from tide water at the Tahsis Inlet to 1.6km downstream of the bridge crossing on Head bay Road.

The limits of the model are shown on Figure 1 and are consistent with the limits of the study area.
The physical geometry of the modeled area was represented by detailed dike and floodwall elevations, based on topographic surveys completed in April 2019, combined with floodplain topography based in LiDAR data collected December 2018.

The river cross-sections below the available LiDAR data (as the LiDAR technology used does not penetrate water) were corrected using the previous study data in relation to survey data at the bridge sites. Since the LiDAR data collected occurred at low tide during a low discharge period, the cross-sectional area below the water line is not of significance when considering large in frequent events such as a 1:20 and 1:200-year flood.

5.3 COASTAL CONDITIONS

The HEC-RAS river model of Tahsis Inlet was established roughly between the eastern shore at the mouth of the Tahsis River and the southern shoreline at the mouth of the Leiner River and is based on the LiDAR data collected. The river model considers the impacts of the geometry of the Tahsis Inlet, storm surge and wind set up.

According to a 2011 BC ministry of Environment study[29] (see Table 6), the High High-Water Level Tide (HHWLT) for West Vancouver Island is approximately 2.0m, geodetic. The storm surge allowance is 1.3m and includes allowances for local wind set up, and the wave effect is 0.65 m. Therefore, the estimated combined sea level elevation used in the model is 3.95m, geodetic. This will produce conservatively high flood levels, but the likelihood of coincident peaks on rainfall events during high tide and storm surge events is considered reasonable given that the storms tend to occur during the higher tide months of November, December and January.

[29] Ausenco Sandwell, Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use Guidelines for Management of Coastal Flood Hazard Land Use, January 2011

Table 6: Preliminary 2100 Flood Construction Levels Estimated for Various Locations[8]

FCL Component	Fraser River Delta	Vancouver Harbour	Squamish River Delta	East Vancouver Island	West Vancouver Island	Central and North Coast
Global SLR (2100)				1 m		
Regional Adjustment	+0.21 m	0 m	0 m	-0.17 m	-0.27 m	-0.22 m
HHWLT	2.0 m	1.9 m	2.05 m	1.6 m	2.0 m	3.8 m
Storm Surge	1.7 m	1.4 m	1.3 m	1.3 m	1.3 m	1.7 m
Wave Effect	0.65 m	0.65 m	0.65 m	0.65 m	0.65 m	0.65 m
Freeboard	0.6 m	0.6 m	0.6 m	0.6 m	0.6 m	0.6 m
FCL	**6.2 m**	**5.6 m**	**5.6 m**	**5.0 m**	**5.3 m**	**7.5 m**

Notes:
1. Reproduced from Ausenco Sandwell (2011b), Table 3-2.
2. Regional adjustment based on current values. Vancouver and Squamish assumed to be neutral.
3. HHWLT = Higher High Water Large Tide. Varies by site and location in BC.
4. Storm surge allowance includes allowances for local wind setup.
5. Wave effect allowance assumes runup on natural gravel-pebble shoreline.
6. FCLs are elevations relative to Canadian Vertical Geodetic Datum.

5.4 MODEL CALIBRATION AND VERIFICATION

A comparison to previous floodplain assessment results was deemed a suitable methodology to verify results of new modelling for the valley. The verification is not straight forward because, though there have been few changes to the land use or riverine environment, the newer modelling techniques provide a means for modeling two-dimensional unsteady flow (discharge varies over time) where previously only one-dimensional steady state (one single discharge over time) was possible. The other more significant change in the valley is the construction of diking systems, which change the physical characteristics of the flow path and would readily breach full bank stage.

On this basis, the previous calibrated water levels were compared to current values to ensure a reasonable "fit" or comparison is being made to previous work completed. Similar channel and overbank roughness factors were used, and the results were compared at several locations to ensure that the model predictions at the peak are similar. The table below lists several stations on the Tahsis and Leiner Rivers from the 1992 study in comparison to the new results for the 1:200 year flood, given the same previously estimated discharge and inlet conditions.

Table 7: Tahsis River Model Validation (Level in meters)

Tahsis River at the Mouth Discharge (Tide Level = 2.7m)				
Cross Section	1992 Report	1992 Report with Datum Shifted	2D HEC RAS Model	Difference
1	2.7	2.9		
2	2.8	3.0	2.8	-0.2
3	2.7	2.9	3.0	0.1
4	3.3	3.5	3.5	0.0
5	3.7	3.9	3.6	-0.3
6	3.9	4.1	3.9	-0.2
7	4.5	4.7	4.6	-0.1
8	5.0	5.2	5.3	0.1
9	5.1	5.3	5.6	0.3
10	5.7	5.9	6.1	0.2
11	5.8	6.0	6.4	0.4
12	5.7	5.9	6.7	0.8
14	6.8	7.0	7.1	0.1
15	6.8	7.0	7.2	0.2
16.1	7.5	7.7	7.3	-0.4
Tahsis U/S of McKelvie Creek Discharge				
16.1	7.5	7.7	7.5	-0.2
18	8	8.2	7.8	-0.4
19	8.2	8.4	8.0	-0.4
20	8.2	8.4	8.1	-0.3
21	8.4	8.6	8.6	0.0
22	8.5	8.7	8.9	0.2
34	8.8	9.0	9.2	0.2
24	9.3	9.5	10.1	0.6
McKelvie Creek				
16.1	7.5	7.7	7.4	-0.3
16.3	7.7	7.9	7.8	-0.1
16.4	7.3	7.5	7.8	0.3

*Water levels include no contingency allowances

Table 8: Leiner River Model Validation (Level in meters)

Leiner River at the Mouth (Tide Level = 2.7m)				
Cross Section	1992 Report	1992 Report with Datum Shifted	2D HEC RAS Model	Difference
1	2.7	2.9	3.0	0.1
2	2.8	3.0	3.7	0.7
3	4.4	4.6	4.6	0.0
4	4.8	5.0	5.7	0.7
6	6.3	6.5	6.3	-0.2
7	7.2	7.4	7	-0.4
8	7.6	7.8	7.8	0.0
9	9.1	9.3	9	-0.3

*Water levels include no contingency allowances

As can be seen in Table 7 and Table 8, there is variation in water levels from one model to the next, but again these are explained by the difference and accuracy of the two-dimensional model over the one-dimensional calculations based on the following points:

- The 1992 one-dimensional model tended to simplify the river geometry between cross-sections, spaced 100 plus metres apart, where the 2D 2019 model uses the entire topographical surface at 5m to 10m grids
- One-dimensional flows average flow velocities over the entire cross-section in one direction, while two-dimensional models assess velocities in any direction through space and time.
- Though the flood protection structures breach during the 200-year event, they do have an effect on the flow dynamics through the reach causing variations in water levels.
- The previous model had a water level decrease between cross-section X and Y in the upstream direction, which is not likely to occur as no hydraulic jump has been observed there, nor do hydraulic conditions present themselves to cause such a phenomenon. This is considered an oversight error in the previous model.

Though the two models differ in results for the same flow and inlet conditions, the results of the new model are considered reasonable and accurate for the basis of future flood predictions in Tahsis.

5.5 200-YEAR RETURN PERIOD DESIGN FLOOD ANALYSIS

Flooding in the Village of Tahsis has two primary contributing factors: high river flows and high tides. Not surprisingly, flooding in the upper part of the study area is mainly controlled by peak flows. Flooding in the lower section of the study area is due to high tide levels. Flooding in the middle sections of the study area are a result of the combined effects of high flows and high tides. To develop a design flood event model with the expected return 200-year period for the entire study area, both the design river flows and tide data were used.

The peak downstream water level at Tahsis Inlet for the 200-year river flood events was assumed to be the combination of the return period storm surge and wind set up occurring on top of the high tide level, which occurs two or three times a year on average. The 200-year return period tide and river flows, under current climate and sea level conditions, were modeled to determine the floodplain mapping levels of the Tahsis and Leiner River.

Flooding at both rivers is comparable to the previous results in comparison to both extent and depth. Areas that were previously at risk of flooding, primarily east of the river within the north townsite, are still vulnerable to flooding and over-topping of currently constructed flood works. The sections below provide more detail of the results in terms of flood extents, depths and velocities that lead to an assessment of flood risks and hazards in the Village of Tahsis.

5.6 FLOODPLAIN MAPPING

Table 9 provides a summary of peak 20 & 200-year return period flood levels compared to those of the 1992 study levels[30] at key locations along the rivers. These are based on existing conditions in the floodplain and do <u>not</u> include potential impacts of future flood protection works or future development in the floodplain.

30 1992 Levels are based on different (higher) flows and different inlet starting conditions (lower inlet levels) and are provided for comparison only

The Flood Inundation Map, found in the Maps Section at the end of this report, illustrates the difference in in flood profile elevations with similar isolines to that of the flood map produced for the 1992 flood study. It also identifies the 1992, current, and 2100 200-year flood extents within the study area.

The area of potential flooding is extensive, as evident on the Flood Map. The existing flood mitigation measures (i.e. Cook Street Dike and Maquinna Floodwall) are inadequately sized to control the rising flood waters for not only the 200-year flows, but even the predicted 20-year flows. This spotlights the need and importance for the Village to consider improving and adding new mitigation measures. Suggested flood mitigation options are outlined later in Section 7 of this report.

Table 9: Estimated Peak Design Water Levels

Location	20-Year Return Period Flood Level (m-GSC) *	200-Year Return Period Flood Level (m-GSC) *	1992 200-Year Floodplain Level (m-GSC) *
Tahsis River			
At Perry Brothers Bridge	5.9	6.6	6.8
At North Maquinna Drive and McKelvie Road	5.3	5.8	5.8
At North Maquinna Drive and Boston Street	5.0	5.4	5.4
At North Maquinna Drive and Rogers Street	4.5	4.9	5.0
At North Maquinna Drive and Harbour View Road	4.3	4.6	4.5
At Tahsis River Bridge on Head Bay Road	4.0	4.1	3.8
Leiner River			
at Leiner River Campground Entrance	8.0	8.5	9.1

*m-GSC equals metres above geodetic datum
Note: The downstream boundary condition or Peak high tide level (3.95m) is set to match the peak runoff rate in the river

5.7 SENSITIVITY OF FLOODING TO CONDITIONS AT THE TAHSIS INLET

The boundary condition requirement under current guidelines is to use the Higher High Water Large Tide (HHWLT), which is The average of the highest high waters, one from each of 19 years of predictions. These levels are published by the Canadian Hydrographic Service for a number of reference stations, the closest to Tahsis being Zeballos. This condition when simulated with coincident peak river discharges produces a conservatively high estimate for flood levels, and to test the sensitivity of the floodplain to varying inlet levels, a lower tide level was used. In this case, the mean HWLT was used and simulations were completed by reducing the HHWLT by 0.8m to see what effect they had on flooding on the Tahsis River.

Table 10 and Figure 17, below, compare the flood levels for the Inlet boundary condition for the HHWLT to the normal HWLT at a number of locations in Tahsis.

Table 10: Comparison of Water Levels for Varying Tahsis Inlet Tide Levels

Location	200-Year Return Period Flood Level (m-GSC) * HHWLT	200-Year Return Period Flood Level (m-GSC) * HWLT
Perry Brothers Bridge	6.6	6.6
North Maquinna Drive and McKelvie Road	5.8	5.7
North Maquinna Drive and Boston Street	5.4	5.3
North Maquinna Drive and Rogers Street	4.9	4.7
North Maquinna Drive and Harbour View Road	4.6	4.2
Tahsis River Bridge on Head Bay Road	4.1	3.5
Leiner River Campground Entrance	8.5	8.5

*m-GSC equals metres above geodetic datum

Note: The downstream boundary condition or peak high tide level (3.95m HHWLT, and 3.15m HWLT) is set to match the peak runoff rate in the river

Table 10 and Figure 17 show that tide levels have little to no impact on flood levels at the Perry Brothers Bridge and show only minor variation in overall flood extents, with the most significant change located along the foreshore of the Inlet. The most noticeable change is that the Head Bay Road and Head Bay Road Bridge under smaller high water tides is not submerged, and further review of the timing of floods and inlet conditions should be completed prior to make a commitment to replacing the Head Bay Road Bridge. It may be more opportunistic to determine a proper height of the bridge when it ultimately needs to be replaced, and, at this time, the HHWLT should be used as the boundary condition.

Figure 17 shows that all locations above Rogers Street flood to the same extent and roughly the same levels even with lower inlet conditions, as these areas are subject to flooding from riverbank breach rather than ocean water over topping the Head Bay Road due to storm surge conditions.

The above sensitivity shows that the assumption of using the HHWLT is the correct one to use for planning purposes as either extreme marine conditions or riverine conditions can cause extensive flooding in northeast Tahsis.

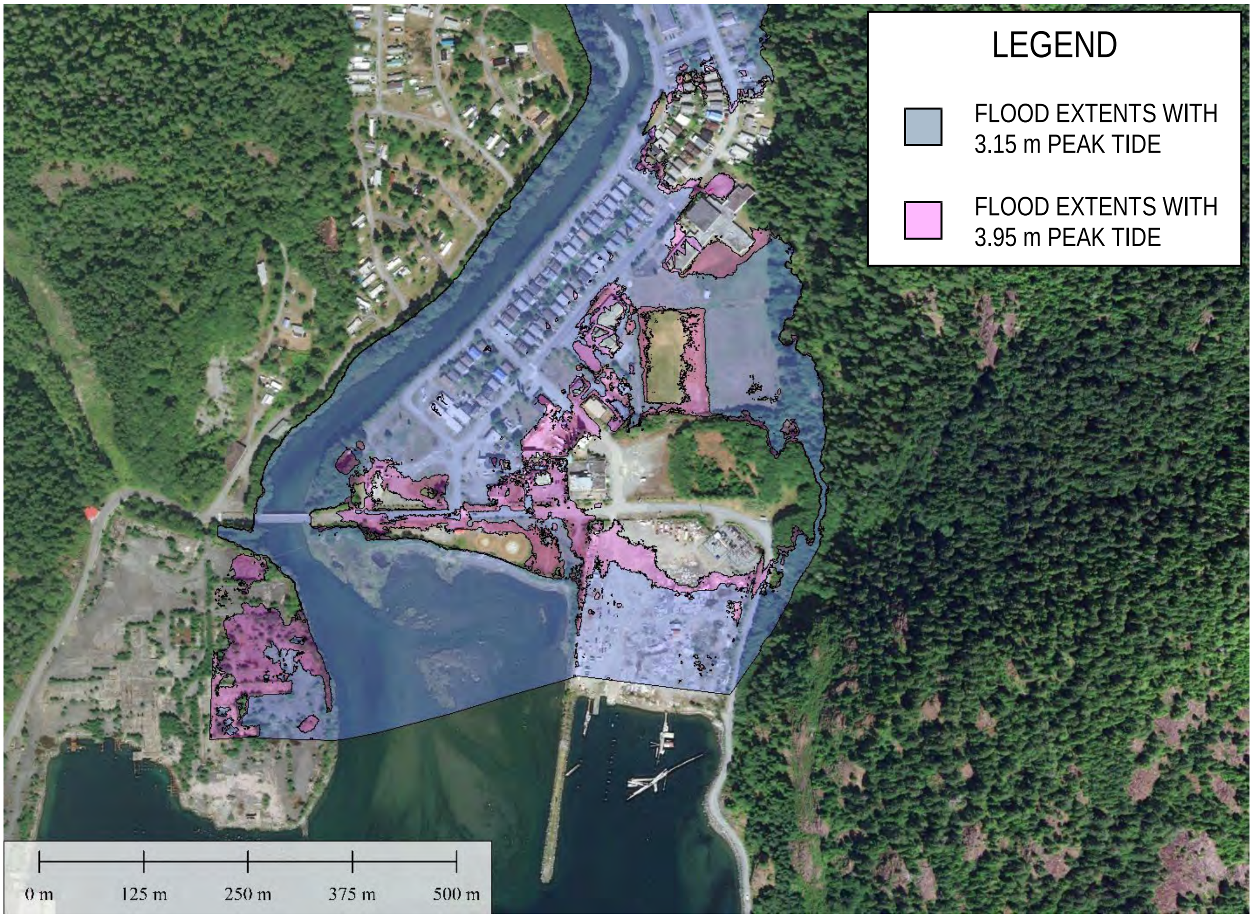


Figure 17: Comparison of HHWLT vs HWLT 200-Year Flood Levels for

5.8 CLIMATE CHANGE IMPACT ANALYSIS

Global temperature records indicate a warming trend over the Earth's surface since the beginning of the 20th century, with more rapid acceleration of warming in recent decades. Over the past century, global average surface temperature increased by approximately 0.6°C. Coincident with the temperature increase, climate change impacts related to sea levels and precipitation are generally accepted to be occurring.

As outlined in Section 3.3, predicted Sea Level Rise will be about 1.0m, with a net gain of 0.73m of Tahsis inlet water levels due to the regional uplift adjust of 0.27m (see Table 6). Coupling Sea Level Rise with estimated increases in precipitation, and in turn runoff, of 12%, the HEC-RAS model was rerun to simulate future climate change scenarios for the 1:20 and 1:200-year floods for the year 2100. Table 11, below, shows predicted flood levels at various locations along the rivers in comparison to today's estimates.

Table 11: Future Planning Flood Levels Due to SLR and Climate Change

Location	1992 200-Year Floodplain Level (m-GSC)*	200-Year Return Period Flood Level (m-GSC)*	2100 Climate Planning Flood Level (m-GSC)*
Tahsis River			
Perry Brothers Bridge	6.8	6.6	6.9
North Maquinna Drive and McKelvie Road	5.8	5.8	6.2
North Maquinna Drive and Boston Street	5.4	5.4	5.8
North Maquinna Drive and Rogers Street	5.0	4.9	5.5
North Maquinna Drive and Harbour View Road	4.5	4.6	5.3
Tahsis River Bridge on Head Bay Road	3.8	4.1	5.0
Leiner River			
Leiner River Campground Entrance		8.5	8.8

*m-GSC equals metres above geodetic datum

As previously mentioned, the current Tahsis Zoning Bylaw (No. 176, 1981) has relatively general construction level regulations as the flowing excerpt from Section 6.5.1.C2 states that buildings be constructed:

> "…not lower than zero point six (0.6) metres above the two-hundred-year flood level where it has been determined to the satisfaction of the Ministry of Environment and Climate Change Strategy, or if not, not lower than three (3) metres above the natural boundary of the Tahsis River or Leiner River."

Model results show significant flood levels in the lower reaches of the Tahsis and Leiner Rivers, reducing upstream as the influence of tide levels on peak river levels decreases. A listing of the peak flood levels estimated under future climate conditions is shown in Table 11. The water levels are based on existing conditions in the floodplain and do not include potential impacts of flood protection works or other development in the floodplain.

5.9 BRIDGE CLEARANCES

Typical standards require 1.5 m of clearance between the water surface elevation of a 200-year return period flood and the bottom of bridge girders[31], to allow for passage of debris and for uncertainty in modeling. A summary of the clearance for current climate and sea level conditions as well as forecast conditions for year 2100 are shown in Table 12, below.

Table 12: Estimated Bridge Clearances

Bridge	Bottom Girder Elev. (m)	200- Year		200-Year, at 2100	
		Peak WL Elev. (m)	Clearance (m)	Peak WL Elev. (m)	Clearance (m)
Perry Brothers Bridge on N. Maquinna Drive	6.9	6.6	0.3	6.9	0.0
Tahsis River Bridge on Head Bay Road	4.1	4.1	0.0	5.0	-0.9

Note: Cells highlighted in Yellow indicate bridges with clearance less than 1.5 m under 200-year return period conditions and cells highlighted in Red indicate bridges with no clearance under 200-year return period flood conditions.

Based on the above information, the two bridges in Tahsis are at risk of being damaged during flood events. Previous work to protect the Head Bay Road bridge from debris impacts proves that floating debris and log jams are possible at these bridges and maintaining clearances is imperative to long-term performance of the structures. The Head Bay Road bridge is especially at risk for future predicted floods and should be under consideration for replacement to proper flood protection levels, as it is the only connection between the north and south townsites.

[31] BC Ministry od Transportation and Infrastructure, Bridge Standards & Procedures Manual Volume 1 - Supplement to CHBDC S6-14 Section 1.9.7.1, October 2016

6 FLOOD HAZARD MAPPING, RISK MAPPING, & RISK ASSESSMENT

The EGBC Guidelines on Flood Mapping in BC define Flood Hazard Maps as "Maps that go beyond inundation maps by providing information on the hazards associated with defined flood events, such as water depth, velocity and duration of flooding and Flood Risk Maps as "Maps that reflect the potential damages that could occur as a result of a range of flood probabilities, by identifying populations, buildings, infrastructure, residences and the environment, cultural and other assets that could be damaged or destroyed.".

The mapping produced as part of this report used the Village of Tahsis' base GIS data, flood modeling data for the 200-year flood event and information obtained from public consultation and news reports.

6.1 HAZARD & RISK MAPPING

The EGBC Guidelines on Flood Mapping in BC outlines a formulaic method of hazard rating developed by the UK Department of Environment[32]. The hazard ratings are a function of the flood depth and flood velocity applied in the following formula:

$$HR = d \times (v + 0.5) + DF$$

Where: HR = Flood hazard rating, see Table 13 below.

d = depth of flooding, in m

v = Velocity of floodwaters, in m/s

DF = Debris Factor, either 0, 0.5, or 1 depending the probability that debris will lead to a significantly greater hazard.

Table 13: Hazard to People Classification

Hazard Rating	Hazard to People Explanation
< 0.75	Low - Very Low Hazard (caution)
0.75 – 1.25	Moderate - Danger for Some (includes children, the elderly, and the infirm)
1.25 – 2.00	Significant - Danger for Most (includes the general public)
> 2.00	Danger for All (includes emergency services)

Once determined, hazard ratings are illustrated as a color gradient within flood inundation extents. These hazard rating gradients, coupled with the plan locations of assets and infrastructure (schools, hospitals, wastewater plants, etc.), make it

[32] HR Wallingford, Flood Risks to People – Phase 2 FD2321/TR2 – Guidance Document, UK Department of the Environment, 2006

easier to visually identifying and quantify risks to the community at large. The complete Hazard & Risk Map for the study are attached herewith in the full-scale Map section at the end of this report.

6.2 SEVERITY OF THE RISK EVENT

The risk event is based on a combination of anecdotal information, photos and news reports of past flooding events. Flooding includes events in 1975, 1989, 1990 and 2010, as well as high water events that are experienced annually. The risk event tends to be due to heavy local rainfall that results in local transportation and access disruptions, as well as flooding of homes, businesses and properties.

The previous flooding that has been experienced has also resulted in mobilization of contaminants, with residents reporting that they witnessed oil and sewage in flood waters.

6.3 IMPACTS AND CONSEQUENCES ASSESSMENT

The area of inundation includes many residential, commercial and institutional areas, including associated infrastructure such as the water supply well pumping station at the corner of Jewett Drive and McKelvie Road and the North Sewage Treatment Plant near the bridge on Head Bay Road. There is also a school, recreation centre, RCMP station, firehall, municipal public works yard, museum/info centre, playground, community garden, salmon hatchery and gas station within the study area, many of which have been affected by previous flooding.

The attached maps show the areas that could be at risk during the 200-year event based on current modelling and identify key infrastructure within the Village that has been included in the Flood Risk Assessment.

BC has not adopted formal Flood Risk tolerance criteria. However, the Government of Canada's National Disaster Mitigation Program (NDMP) has developed a Risk Assessment Information Template (RAIT) which is used by the NDMP as a risk assessment tool for determining eligibility of funding to communities for assessments, mapping, planning and mitigation projects. The Tahsis Flood Risk Assessment project was not intended as an application for funding from the NDMP, but the RAIT was utilized as an effective means of risk assessment and rating the impacts of flood hazards. The risk assessment included a review of impact categories within impact classes rated on a scale of 1 to 5 from least to greatest impact relatively. The impact categories are as follows:

- People and Societal Impacts
    - Fatalities
    - Injuries
    - Displacement
- Environmental Impacts
- Local Economic Impacts
- Local Infrastructure Impacts
    - Transportation
    - Energy and Utilities
    - Information and Communications Technology
    - Health, Food, and Water
    - Safety and Security
- Public Sensitivity Impacts

Each of these impacts has been assessed in the sections below, along with an explanation of the risk rating is assigned in the RAIT.

6.3.1 *People and Societal Impacts*

Protecting the health and safety of Canadians is of the utmost importance to all levels of government. The impact of flooding on people is considered most significant in the assessment process given that hazards could result in societal disruptions, including evacuations and injuries.

Fatalities

Head Bay Road is the only road into the Village of Tahsis. When flooded, not only is access to and from Tahsis disrupted, but movement within the Village is also restricted. The potential for road flooding presents a large concern for emergency access during times of flooding. If evacuation routes are cut off, the chances of death and serious injury occurs. Lack of evacuation routes also poses a risk of fatalities from non-flooding related medical emergencies due to emergency responders unable to access patients, etc. The risk rating for fatalities has therefore been set as 2 (could result in 1-4 fatalities).

Injuries

Injuries could occur before, during and after the flood and may be a direct result of flood waters, such as hypothermia, or otherwise induced by the event, such as an accident during cleanup activities, post-flood depression and sleep disorders. The difficulties faced due to flooded access routes and the potential fast flowing water means that there is a risk of injuries that could not be addressed by local or regional healthcare resources and additional support or intervention may be required from other regions and supplementary support may be required from the province. The risk rating has therefore been assigned as 3.

Displacement

The Federal Emergency Management Agency (FEMA) estimates a recovery time equating to 45 days per 30cm of flood water. Based on flood depths modelled, it is likely that flood recovery time could extend to several months in some localized areas. And given the risk of inaccessibility of the single route into the Village of Tahsis, it is likely that more than 15% of the total local population could be affected. The risk rating has therefore been set at 5 for the percentage of displaced individuals and for the duration of displacement.

6.3.2 *Environmental Impacts*

Another priority for municipal, provincial and federal governments is to protect Canada's natural environment for current and future generations. Therefore, environmental impacts are included in the assessment to measure the risk event in relation to the degree of damage and predicted scope of clean up and restoration needed following a flood event.

Several potential environmental hazards were identified within the Village floodplain and include the gas station on Alpine View Road, which houses above ground fuel storage tanks and related dispensing facilities. The public works yard contains industrial chemicals, fertilizers, lubricants and above-ground fuel storage. There is also a likelihood of some residential home heating oil tanks within the flood area. Among all three hazards, there is the potential to mobilize chemical and fuel contamination in the water. This will lower the water quality and have adverse impacts on marine ecosystems. This contaminated water may also reduce the soil quality within the floodplain after the waters recede.

Similarly, the Village's sewage system and treatment pant near the mouth of the Tahsis River may release untreated effluent, which can increase the risk to human health and may leave properties contaminated once the flood waters subside.

The well water pumping station at McKelvie Road and Jewitt Drive will likely have wellhead protection, but over time, the well may be susceptible to contamination as the installed protection deteriorates. Contamination of the water supply will affect all areas of the Village, not just those within the flood extents.

Though the risks are real, the volumes of expected pollutants are relatively small in comparison to the volumes of expected discharges in the river and the receiving environment, which degrades the overall risk assessment for this category. Based on these factors, the risk ranking for Environmental Impacts has been set as 3.

6.3.3 *Local Economic Impacts*

The impact to commercial properties extends beyond the impact of floodwater within the properties. The potential impact of inaccessible roads has the potential to cause widescale economic disruption to local businesses as well as cost implications for recovery.

In addition to the time and costs related to building restoration and repairs, there are likely to be local economic impacts relating to responding to the flood during the flood event. This would include requirements for RCMP to provide security if buildings are evacuated and support for evacuees and government response, all of which could have impacts on local taxation.

Although the Village of Tahsis has a local population of less than 350 full-time residents, the area does see a population increase to about 1500 in the summer months. The Village benefits from day tourism, with some overnight and multiple day visitors attracted by the abundance of natural recreational opportunities in the area. Tahsis identifies over 130 small to medium-sized businesses, and, despite the decline in forestry as the primary economic input, the Village remains strategically located for multiple sectors from aquaculture to tourism.

Given the far-reaching impacts of road disruption on the entire community, the risk rating has been assigned as 5, more than 15% of the local economy impacted.

6.3.4 *Local Infrastructure Impacts*

The impact of flooding on local infrastructure will have an impact on the residents of the Village of Tahsis who depend upon it, both during the event and over the ensuing hours, days, weeks and months. For the purposes of this report, local infrastructure has been classified as Transportation; Energy and Utilities; Information and Communications Technology; Health, Food and Water and Safety and Security.

Transportation

As mentioned throughout the Risk Assessment, Head Bay Road is the main access into the Village of Tahsis, and flooding can result in the Village being completely cut off from road access due to high waters for numerous days. If bridges are damaged or washed-out, this could extend to weeks. Alternative access/evacuation possibilities are water access or helicopter access. Given the far reaching and wide-scale disruption caused to the local infrastructure, the risk rating for transportation has been assigned as 5, the highest level as it is felt that this is the greatest risk to the local community.

Energy and Utilities

During flood events there may be energy and utility disruption at individual property service connections and at the BC Hydro substation on Head Bay Road, although these impacts are likely to be restricted to the properties directly affected by the flooding. As there is likely to be energy and utility infrastructure within the affected area, we would estimate that, although local activity may be disrupted for a short time, there is a potential that roads would also be flooded and hence access may be difficult for energy and utility providers to access properties to undertake repairs. The risk rating for energy and utility disruption has therefore been set as 2, duration of impact 13-24 hours.

Information and Communications Technology
Any disruption to Information and Communications Technology (ICT) is likely to be at the property level, as individual property services become flooded. Wider impacts are not anticipated, therefore the risk assessment for impacts to ICT has been set as 1.

Health, Food, and Water
The potential health impacts of contamination of floodwaters was previously discussed. In past events, people have been unable to evacuate due to inaccessible roads, which poses a great risk to the health of the local community. Lack of safe emergency access and egress, as well as access to food and clean drinking water is of greatest concern. Therefore, the risk rating for health, food and water has been set as 5, the highest rating, with greater than 20% of the local population impacted.

Safety and Security
No intelligence or defense assets are identified within the study area, so it is considered that no risk to safety and security on a regional level exists during flooding, although there is a direct risk to the properties that are affected as houses are left unoccupied during times of evacuation. The safety and security risk have therefore been assigned a risk rating of 2.

6.3.5 *Public Sensitivity Impacts*

The potential disruption to the roads and the lack of safe emergency access and egress poses a large risk to the community. Given the wide-scale disruption that this would cause (and has caused in the past) at a local level, this could negatively impact the reputation of the Village.

It is evident from the level of input that was provided by some of the residents at the public consultation meetings that flooding is a very emotional subject for the community, with some people having experienced flooding on numerous occasions. The long-term mental health impacts of flooding cannot be calculated but it is evident that members of the community are suffering from the fear of flooding with each extreme weather event. There is an expectation from the community that the Regional District act to mitigate against the risk of flooding to the community. The risk rating has therefore been assigned a value of 4.

7 FLOOD MITIGATION ALTERNATIVES

The various options for flood mitigation were developed after thorough analysis of the flood, risk and hazard maps. It needs to be emphasized that the options do not each afford the same level of flood protection or area of protection. Ultimately, a combination of the outline options may be considered and implemented based on the overall priorities of the Village and the feasibility of such options with regard to budgeting.

7.1 PREPARE FOR 20-YEAR FLOODING – OPTION 1

The following mitigation measures are intended to protect the Northern Townsite from predicted 20-year flood levels (see Figure 18):

- Extend the flood wall on North Maquinna Drive for an additional ±660m to the Head Bay Rd Bridge and be constructed ±2.0 above the existing grade.
- Raise ±570m of the existing flood wall by ±1.5m.
- Elevate ±290m of Head Bay Road between the bridge and Harbour View Rd by 0.3m.
- Raise sections of Head Bay Road, ±650m along the east side of the inlet and ±450m along the Leiner River (see Figure 19) by ±1.6m and ±0.6m respectively.
- Erect 1-2m high flood walls around high value properties and build up entry driveways to protect from rising waters.
- Install standby pumps at the Boston Street Pond.

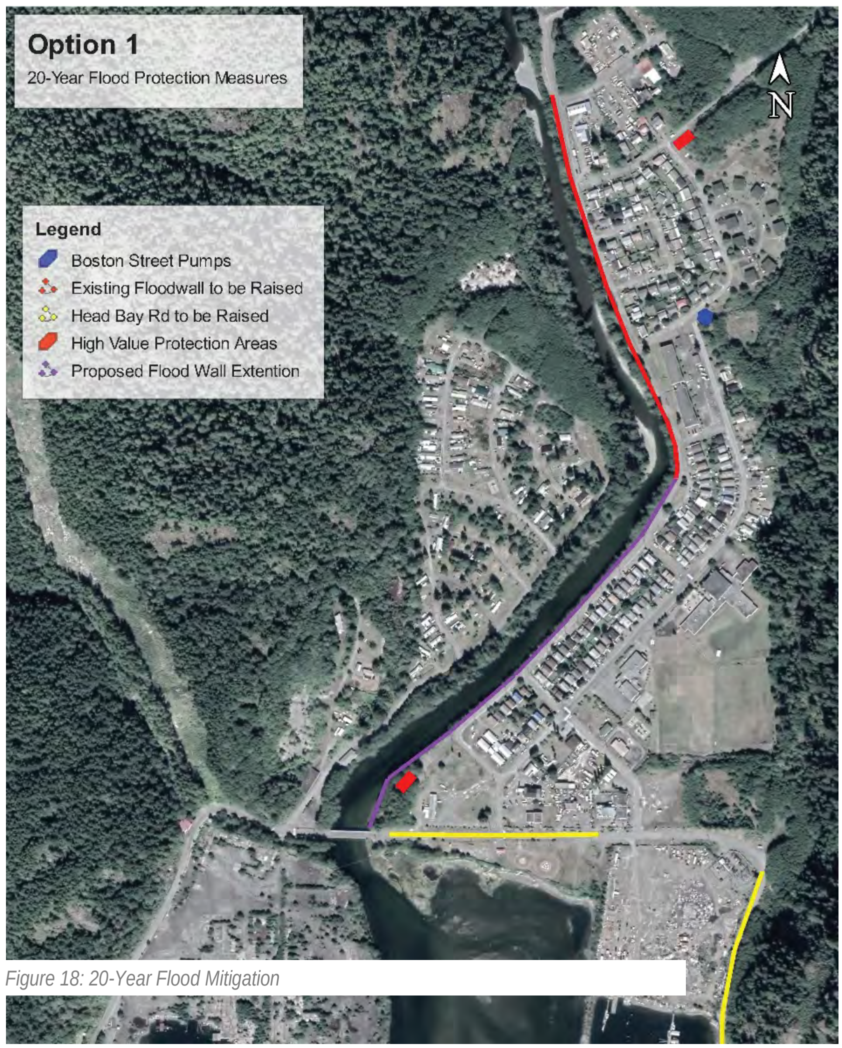


Figure 18: 20-Year Flood Mitigation

Figure 19: Head Bay Rd Flood Mitigation Along Leiner River

7.2 PREPARE FOR 200-YEAR FLOODING – OPTION 2

To adequately protect the Northern Townsite from 200-year flooding, the same mitigation efforts as outlined in Option 1 will need to be enhanced, and the existing Cook Street Dike will need to be raised by ±0.4m and extended upstream for ±140m (see Figure 20).

Figure 20: 200-Year Flood Mitigation

As shown in Table 11 of Section 5.8, estimates show no clearance for debris flows under the Head Bay Rd Bridge crossing the Tahsis River during 200-year floodwaters. As such, floating debris has the potential to damage or overtop the bridge. To maintain access and egress for the Southern Townsite, the existing bridge would need to be elevated and/or ultimately replaced with a longer structure.

The predicted floodwaters would not overtop the Perry Brothers Bridge deck in a 200-year flood, but there would likely be no clearance below the girders. Despite not having the MOTI required 1.5m high water clearance, this structure could be risk managed as the bridge primarily provides access to the Village's landfill, and it is unlikely that bridge access would be required during a 200-year flood event. Should damage or a washout occur, then the structure could be considered for repairs or replacement with the required highwater clearance. While this is true for today's situation in Tahsis, future links north of Tahsis to Woss or Zeballos are entirely feasible providing a secondary access to Tahsis or an emergency route out of Tahsis. If this were the case, Tahsis should consider the importance of the Perry Brothers Bridge and the need for possible raising of the bridge to ensure alternate routes can be accessed in and out of Tahsis in the future.

7.3 PREPARE FOR 200-YEAR FLOODING IN 2100 – OPTION 3

To entirely hold back the 2100 200-year flood waters, the proposed measures in Options 1 & 2 and shown in Figure 18 & Figure 19 would have to be enhanced further as listed below:

- Cook Street Dike would need to be extended by ±140m and raised by 0.9m with a flood box installed at the upstream lateral drainage course.
- The existing floodwall would need to be elevated by 1.9m from current elevations and an extension constructed 2.7m high.
- Head Bay Road along the entire waterfront would need to be raised by 1.3m from current elevations.
- Head Bay Road Bridge over the Tahsis River and the Perry Brothers Bridge would need to be replaced with longer structures at higher elevations.
- Higher flood walls would need to be erected around high value properties and entry driveways would need to be built up to protect from rising waters.

7.4 MANAGED RETREAT THROUGH ZONING AND OCP UPDATES – OPTION 4

As discussed in Section 4.4.3, managed retreat may be an effective means of floodplain risk mitigation. Despite the value of land and assets, political sensitivities and social costs, financial limitations may make managed retreat a feasible option when other mitigation measures, such as dike and flood walls, are not economically sustainable. The Village's official community plan (OCP) can adopt a managed retreat strategy to guide land use and policy decisions within the floodplain. Hazardous areas identified on the flood and hazard maps can be outlined in the OCP as areas with restricted uses. This may result in parcels of land, both undeveloped and developed, being ineligible for new or reconstructed buildings. As such, the lands could be rezoned for lower risk use, like agriculture. Land may also be purchased by the Village and repurposed into park or nature lands. The implementation of managed retreat ultimately requires transparency by the Village through community engagement.

In conjunction with an updated OCP, the introduction of a floodplain bylaw or amending the current zoning bylaw should reflect and be consistent with the managed retreat strategy. This can be done by better defining construction elevations and building setbacks in floodplain hazard areas. However, setting minimum foundation levels may not go far enough in reducing the risks in certain flood areas.

Managed retreat can be offset by finding alternate settlement areas like the west side of the Tahsis River or further south of town as an extension to South Maquinna Drive. The cost of restricting re-development and moving villagers to new properties will certainly be more expensive than current assessed values. Though the current assessed values of the structures in the floodplain area is about $41 million dollars, the cost for relocation would likely be substantially higher, as developments elsewhere in the Village need to be serviced and prepared for new structures; additionally, new builds will certainly be more expensive than the current assessed values, given the remoteness of Tahsis and escalating costs for construction. All of this excludes land costs for current NE homeowners to purchase another property in a different location in Tahsis.

Financial incentives can be explored through innovative taxation policy or grants from other levels of government, which may come forward as climate change progresses or as the need to make coastal villages like Tahsis viable into the future moves to the forefront.

The Village should not be intimidated by the prospect of implementing a managed retreat policy, as there is time due to the slow increase of expected Sea Level Rise. It is recommended for the Village to pursue additional funding for further study and assessment of the planning and policy definition for initiatives like managed retreat. The study should as a minimum investigate:

- Current infrastructure condition and timing for redevelopment or needed property improvement in the floodplain area.
- Areas for relocation or development that can support the required relocation.
- Costs for development or improvement of lands to support relocation and potential sources for government assistance, such as local tax incentives or other mechanisms to support a policy for Managed Retreat.
- Re-zoning requirements.
- The mechanism for property transfer of floodplain properties to the Village, as may be required or desired.
- Timing and policy development to support Managed Retreat and its implementation.

The idea of Managed Retreat can be complicated, and further assessment requires that a more detailed planning study be completed to see if the transfer of the land from residential use to other uses makes sense and is achievable.

8 COSTS AND BENEFITS

8.1 ESTIMATED COSTS FOR CONSTRUCTION

Cost estimates for the suggested options have been prepared at a conceptual level for this study without the benefit of detailed engineering. They include a 40% contingency for uncertainty of both scope and price. A breakdown of estimates for the three options is provided in Appendix C, summarized below in Table 14.

Table 14: Summary of Estimate Construction Costs

Mitigation Option	Construction*	Soft Costs**	Total
Option 1 – Prepare for 20-Year Flooding	$5,300,000	$800,000	$6,100,000
Option 2 – Prepare for 200-Year Flooding	$13,200,000	$1,900,000	$15,100,000
Option 3 – Prepare for 200-Year Flooding in 2100	$17,600,000	$2,500,000	$20,100,000
Option 4 - Managed Retreat	/	/	$41,200,000

* Construction includes a 40% Contingency
** Costs include engineering, environmental approvals, administration and financing
Note: Estimate does not include additional capital or other costs related to mitigation of upstream/downstream impacts.

8.2 ESTIMATED NORTHERN TOWNSITE ASSETS VALUES

The estimated aggregate asset value for the northern townsite on the east and west side of the Tahsis River is approximately $41.2 million and $1 million respectively. These figures are based on the BC Assessment "land improvements" values only and do not account for the assessed land values. It should be recognized that the market value for properties is typically higher than the assessed values and varies regionally. These figures do not include the values for the South Treatment Plant or the water well pumping station. When looking at the value of protected assets, there are significant public and private assets worth protecting.

8.3 OTHER MITIGATION/COMPENSATION COSTS

Another alternative is to purchase the affected properties. This can occur over time, either as they are marketed for sale or through negotiated agreements for assumed ownership over time. This type of agreement can perhaps be formulated on the basis of reduced / no property taxes or reduced claims for incremental flood damage as payment for eventual ownership.

There are several mechanisms to transfer the ownership of the land to the public domain, but a detailed assessment of such is beyond the scope of this assignment.

There are opportunities for additional development on the west side of the River, which has been shown to be elevated beyond imminent flood hazards to the year 2100. A program for relocation could be provided through tax incentives or other government sponsored programs from Provincial or Federal resources.

8.4 BENEFITS

The benefit to improving existing flood protection infrastructure is in the protection and mitigation of flood damage to public and private property, some of which is essential to life in Tahsis. These include:

- Numerous residential and commercial properties assessed at $41.2M of structural improvements.
- Retailers and businesses, such as the Tahsis Supermarket & Gas Station and Tahsis Building Supply.
- In home-based businesses, such as vacation rental properties and bed & breakfasts.
- Emergency first response stations for fire, ambulance and police.
- Public Works Yard ($2.5M).
- Salmon Hatchery ($1M) and water well.
- Tahsis Recreation Centre ($8M).
- Captain Meares Elementary Secondary School ($10M).
- Wastewater Treatment Pant ($3M).
- Water Pump Station ($0.75M)

Considering the lengthy list of assets to the Village as a whole, a 200-year magnitude flood event would be expected to cause considerable building, property and inventory damage, not to mention a loss of revenue. A detailed cost-benefit analysis is not necessary to see that the importance of flood mitigation in the area is clearly emphasized by the base cost of the assets to be protected.

8.5 REVIEW OF OPTIONS

Table 15 is intended to summarize the spectrum of criteria used when deciding which of the options may be best to be pursued further, as a flood mitigation strategy.

Table 15: Summary Review of Mitigation Options

Review Criteria	Option 1 20-Year Protection	Option 2 200-Year Protection	Option 3 200-Year Protection for 2100	Option 4 Managed Retreat
Other Mitigation / Compensation Costs	Low	Low	Low	Moderate-High

Level of Flood Protection for North Townsite	20-year Return Period	200-year Return Period	200-year Return Period for 2100	200-year Return Period for 2100
Relative Capital Cost	High	High	High	Highest
Land Use Benefits	Moderate-High	Moderate-High	High	Low
Habitat Impacts	Low	Low	Low	Low
Emergency Response Benefits	High	High	Highest	Low
Adaptability to Climate Change	Moderate	Moderate	Moderate	High
Cost Sharing Potential	To be determined	To be determined	To be determined	To be determined

In regard to cost sharing potential, funding agencies would need to be petitioned through either Provincial or Federal Flood Damage Reduction Programs. There will be a Provincial funding grant intake for flood mitigation projects in the fall of 2019. The Village of Tahsis should position itself to prepare a funding application in order to move forward with additional flood mitigation work if it feels compelled to continue to protect those assets that make up the north townsite

9 RECOMMENDATIONS

9.1 GUIDING PRINCIPLES

Based on the combination of technical analysis and community engagement, the following broad recommendations to Council are provided.

1) Continue to protect the majority of the floodplain, imposing compatible land uses that will accommodate floods over the long-term (Managed Retreat 2100 and beyond):

    - The majority of area in north townsite is residential and contains critical municipal infrastructure, including the water pump station and sewage treatment plant.
    - Plan for adaptation through intermediate raising of dikes and flood protection structures.
    - Managed retreat from high hazard areas to more suitable development sites on the surrounding hillside or in the southern townsite

2) Consider the North Maquinna Floodwall Upgrades (Option 1) as an interim solution to an overall flood mitigation strategy;

    - Determine a suitable cost-sharing arrangement with benefitting landowners.
    - Option 1 is subject to satisfactory environmental review and permitting.
    - Option 1 is subject to legal review pertaining to flood protection to levels less than the 200-year return period standard.
    - Anticipate future integration of larger flood protection dikes with the floodwall.

3) Review Emergency Plans for Today and Year 2100:

- Review key emergency routes to analyze how these routes might need to be raised to accommodate today's climate and flood levels and Year 2100's potential climate and flood levels and to identify potential land requirements and cost.
    - o Investigate potential connection of logging road from Nomash ML (Zeballos) to Tahsis as an alternative route out of the Village.
- Make recommendations to Council to refine emergency routes and related adaptation / evacuation strategies.
    - o Raise Head Bay FSR in areas required to resist flooding and washout.
    - o Complete crossroad drainage assessment and improve culverts / bridges accordingly.

4) Identify where and when additional diking might be warranted for consideration, subject to the general direction in item 1 above, such that diking along the watercourses will be very limited in area and scope:

    - Compare plans and compile a final set of options for diking and the anticipated year such diking might be required.

5) Evaluate diking options, including financial / cost sharing analysis:

- Investigate scale, land requirements, habitat compensation, capital cost and other mitigation/compensation costs required for diking (beyond the notion of emergency transportation routes) – consider climate change implications on future investment required.
- Summarize joint funding opportunities, including a mix of other levels of government, property owners (development cost charge or special levy) and local government finance.
- Review the public cost-benefit of each option considering all the above, as well as the relative current and build-out assessed value of the area to be protected for each option.
- Undergo public review and Village Council deliberations, which might include a mix of limited dike areas, combined with more broad and general strategies of flood proofing and managed retreat.

9.2 FLOOD MITIGATION

In the short-term, the Village should pursue the construction of flood protection infrastructure along the Tahsis River and further assess Head Bay Road for required improvements to resist flooding and washout.

North Maquinna Road is the first area of breach for more frequent flooding, and adequate flood protection upgrades are warranted, presuming the infrastructure built can be integrated in a broader medium-term flood mitigation strategy, consistent with the guiding principles listed above.

In looking at the medium term (prior to the next turn of Century), the existing infrastructure, institutional properties, residential properties and commercial enterprises in the northern townsite are of relatively high value. Taking into account that some of these properties will have useful serviceable lives of perhaps another 30-40 years and the fact that this area includes the key transportation link out of the Village, it is recommended that the Village pursue a flood mitigation strategy to protect these assets. Based on the assessment of the hydraulic modelling, cost–benefit and environmental impacts, it appears that either Options 1 or 2 could be considered for protecting this area over the short to medium term. Each option has different costs, benefits and impacts as outlined, which need to be evaluated by the Village from the perspective of overall community needs and impacts.

The Village should begin to incorporate Sea Level Rise and climate change into its long-range flood mitigation strategy. This long-term planning should focus on methods and strategies (including bylaw and OCP changes) to return the floodplain to a more natural state, employing land use policies that are more tolerant of infrequent flooding (parks, agriculture and/or environmental reserves). More study in this regard is required, looking at the planning horizon for needed re-development in the floodplain in conjunction with potential development areas outside of the floodplain and costs, policies and implementation strategies to achieve a balance of the socio-economic values and viability of the Village of Tahsis.

9.3 PUBLIC OUTREACH AND EDUCATION

Ongoing public outreach is advised to help landowners and the community understand the evolving flood risk, related to Sea Level Rise and to increases in river flow due to heavier rainfall, both of which result from climate change. This knowledge will allow the public and landowners to be prepared for emergency evacuation if necessary, given the sudden onset of floodwaters predicted. This emergency preparedness education should include:

- Accessing flood and storm forecasting from reputable sources, such as the BC River Forecast Centre's Flood Warning and Advisories web page (http://bcrfc.env.gov.bc.ca/warnings).
- Developing household plans for emergency evacuation, including options for dwellings given the potential of long-term flood impacts to housing.

- Having emergency bags ready in case short notice evacuation and being stocked with supplies including shelf stable food, water, medication, first aid kits, pet supplies, extra batteries and charging devices for phones and other critical equipment.
- Keeping important documents in waterproof containers.
- Obtaining satellite emergency communication devices such as satellite phones or handheld GPS devices available from manufacturers such as Garmin and SPOT.
- Keeping an emergency checklist that is easily accessible and includes last minute reminders for turning of building utilities.

To help landowners and community members better plan land use and development with knowledge of the risk and how to mitigate the impacts, key themes of public education should include:

- *Tahsis' need for an improved floodplain development policy/bylaw*
- Major areas of the floodplain should continue to flood in large events (>20 – 200 year) – these areas could transition to agriculture, recreation and environmental uses.
- New structures would need to be designed to suit gradually rising flood levels (rising by Year 2100) or be built in areas not at risk of flooding.
- Current BC policy is that new or replaced buildings would need to meet Flood Construction Levels for habitable floors.
- Non-habitable areas, if not raised to flood proof levels, buildings could be constructed of flood resistant materials. Anecdotal evidence has stated that this was the policy in Tahsis, but over the years, many landowners have made flood zone areas habitable, and these are now subject to flood damage. The policy needs to be rigorous enough to prevent future modifications within the flood zone.
- Where not raised, local roads and parking would be flooded during design storm events as an accepted risk.

9.4 VILLAGE BYLAW AND POLICY REVISIONS

Section 4.1of this report introduces existing municipal tools to manage flood risk and related land use regulations/guidelines. Section 9.4 describes how the new floodplain level information contained herein, including climate change risks, could lead to refinements to those municipal tools.

9.4.1 *Official Community Plan and Zoning Bylaw*

The Village is currently updating the OCP, which is to consider the recommendations herein, and the Village should extend those OCP recommendations to the current Zoning Bylaw in developing a long-term land use strategy for the vulnerable areas of the floodplain.

More fundamental decisions will need to be made in the current review of the Official Community Plan, specific to localized areas along the Tahsis River, where flooding and Sea Level Rise are a risk. It is within these areas where new consideration of flood mitigation strategies will be warranted as OCP and Zoning Bylaws are updated. Options to be considered include:

- Accepting flood risk and focusing on evacuation plans for rare events.
- Reviewing land use types to allow commercial (low risk to life) rather than residential uses (higher risk to life) on properties with higher flooding risk.
- Localized filling and diking to protect flood risk sites.
- Flood proofing of proposed buildings only, with parking/driveways allowed to flood occasionally

- Flood proofing by raising key roads, bridges, and emergency routes (e.g. Head Bay Rd) in the local areas where it is at risk.
- Public sector or Non-government organization purchase of lands at risk for public use (parks, recreation, agriculture or environment).

The above options are best discussed in the context of broader land use, emergency preparedness and policy plans, where the multi-variant aspects of these decisions can be weighed in a thorough public process.

Three points are very important in addressing these climate change concerns:

1. Sea Level Rise will be very slow (averaging 1 cm per year), and therefore it is not urgent to move higher – there is time to adapt, to the extent that in most cases adaptation could be allowed to occur at the end of life of a building (at the time of redevelopment).
2. However, it is important to recognize the need to establish Sea Level Rise Planning Areas that include the areas potentially at flood risk both in the present day and in the Year 2100. Within these Sea Level Rise Planning Areas, land use decisions should include an acceptable strategy to either avoid flood risk impacts or adapt proposed land uses to the evolving risk at reasonable benefit to cost ratios.
3. It is very important that land use decisions be made with a full awareness of the evolving flood risk, so that there are adequate mechanisms in place to balance life and safety, environmental, economic and public/private investment responsibility. Applications for land use change in the floodplain should provide a clear flood mitigation strategy prior to being formally considered by Council. Any additional Flood Risk Assessment carried out as part of land development applications should follow the EGBC Legislated Flood Assessment Guidelines where appropriate.

The flood risk information in this report provides scientific and societal values information to allow land use decisions to be made without passing large flood mitigation costs onto future generations in the Village.

9.4.2 *Floodplain Bylaw*

The existing Tahsis Zoning Bylaw No 176 Section 6.5 addresses the risk of flooding from existing climate conditions and is based on previous flood mapping extents estimates from 1992. These requirements include:

- Existing Bylaw Buildings Setback: min 30m from the Tahsis River and Leiner River.
- Existing Bylaw Building Elevations underside of the floor system not lower than:
    - 0.6m above the 200-year flood level
    - 3.0m above the natural boundary of the Tahsis River or Leiner River.

It is recommended that a Floodplain Management Bylaw based on the 2100, 200-year results of this study be introduced to amend Section 6.5 and consist of the following:

- Floodplain designation of the 200-year flood extents.
- Updated and specific flood construction levels at locations throughout the floodplain.
- Well defined floodplain setbacks based areas of varying risk.
- Siting and flood construction setback requirements.
- Elevation and flood construction level requirements.
- Any and all exemptions to the bylaw.

Also, any new proposed construction within the floodplain should be assessed using the hydraulic model, prepared as part of this study, to ensure that the proposed development does not have any significant effects on neighbouring properties. Impacts due to the magnitude of the 1:200 year return period flood are likely to occur on neighboring properties, especially if the proposed development is of substantial size. Should this approach be taken, the Zoning Bylaw should also be amended to reference the Floodplain Management Bylaw, where appropriate, to ensure that the regulations and requirements of the two bylaws are coordinated.

10 IMPLEMENTATION

Public entity adaptation to climate change in British Columbia is still developing as society grasps Climate Change and its effect on our lives. However, it is time to become aware and to prepare. It is especially important that the Village not make uninformed land use decisions that would result in flood risks and consequences worse than existing conditions, given the growing knowledge of Sea Level Rise. Four general actions are recommended below.

10.1 UPDATED OFFICIAL COMMUNITY PLAN TO REFLECT AREAS OF HIGH RISK

The Village is currently updating its Official Community Plan, which will provide opportunity to include the Flood Risk Assessment recommendations into revised Official Community Plan policies and development permit guidelines for natural hazard areas.

10.2 FLOODPLAIN BYLAW AMMENDMENT TO CURRENT ZONING BYLAW

A new Floodplain Bylaw that accounts for Sea Level Rise and climate change impacts should be introduced to amend Zoning Bylaw 176, with new minimum Flood Construction Levels and Setbacks along with the other recommendations outlined in Section 9.4.2 of this report.

10.3 INTEGRATION OF LAND USE CLIMATE ADAPTATION INTO ON-GOING PLANNING REVIEWS

When the Village reviews the Official Community Plan and Zoning Bylaws, it is recommended that evolving flood risks be carefully considered in any revisions. It is recognized that many objectives are balanced in these planning initiatives, but it is strongly encouraged that a clear strategy for adapting to the evolving flood risk is incorporated into policy and financial planning programs over time.

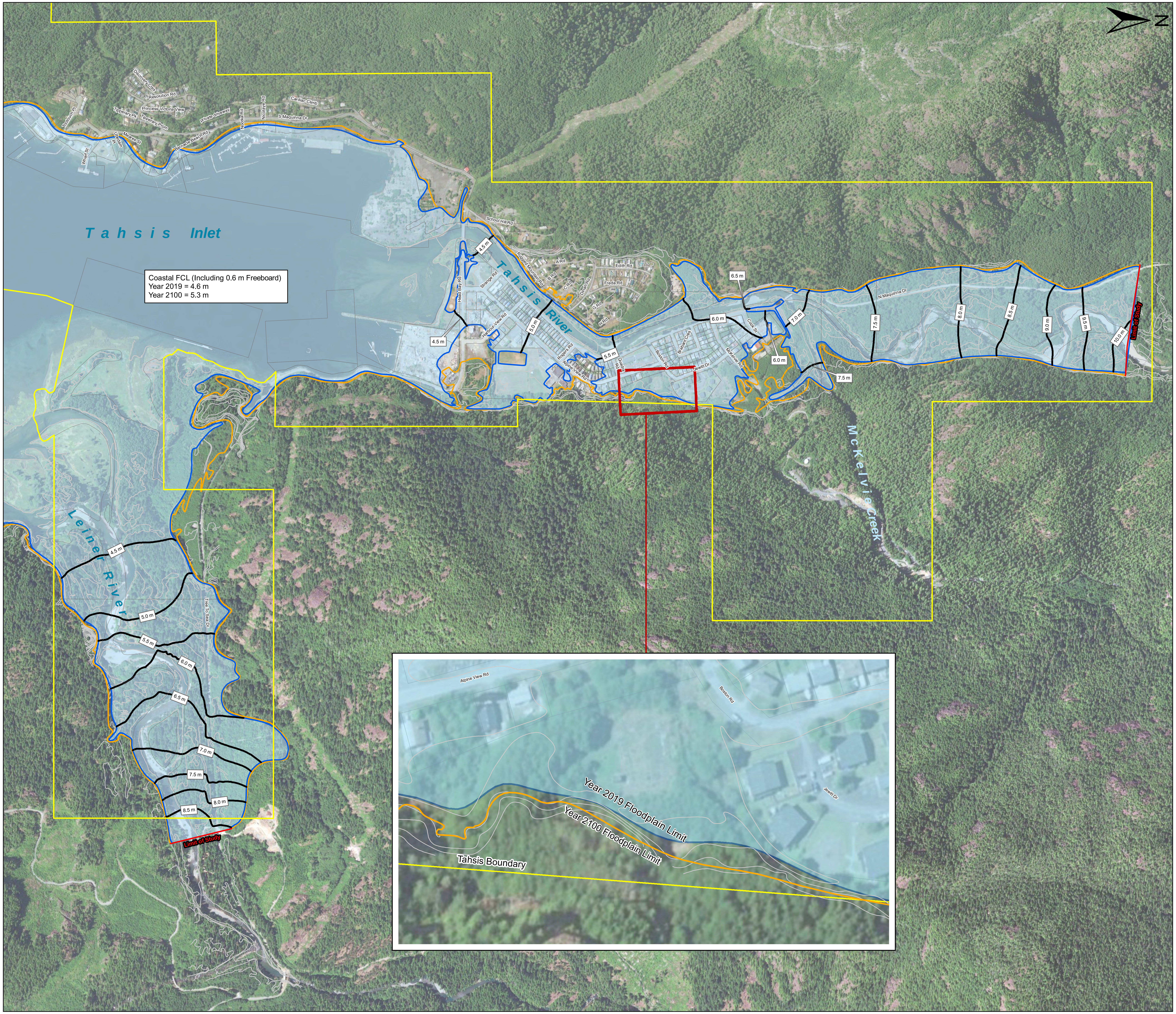
10.4 MONITORING AND ADAPTIVE MANAGEMENT

This Tahsis and Leiner River Flood Risk Assessment is a first step toward local government adaptation to Sea Level Rise and climate-change flood risk analysis and planning. We expect much greater certainty and understanding of risks and, perhaps, adaptation strategies will become evident as our society undertakes further research.

The scale of the Sea Level Rise and climate change impacts around the world will mean that society in general, all levels of government and the private sector will need to refine programs and undertake adaptive strategies. Given this gradually evolving challenge, it is appropriate to begin planning now to minimize local consequences, risks and costs.

At the same time, it would be prudent <u>not</u> to react too quickly to issues of Sea Level Rise, but rather to monitor the evolving government programs and overall body of scientific understanding on the issue, setting the stage for focused adaptations. There remains time to discuss and refine a long-term strategy prior to major investments being made by the Village of Tahsis. In the meantime, immediate attention should focus on beginning local flood protection works (such as raising the North Maquinna Dr Floodwall) to mitigate the flood impacts on existing development.

MAPS



Legend

- River Flood Isolines and FCL (0.3m Freeboard)
- Contours
- Year 2100 Floodplain Limit
- Year 2019 Floodplain Limit
- Municipal Boundary
- Parcels

Use and Limitations of Floodplain Map:

1 – Under the provisions of the Flood Hazard Statutes Amendment Act, 2003 (Bill 56), local governments have the role and responsibility for making decisions about local floodplain development practices, including decisions about floodplain bylaws within their communities. Information on floodplain management guidelines can be found in the BC Flood Hazard Area Land Use Management Guidelines.

2- Users must note the dates of base mapping, aerial photography, ground or bathymetric surveys and issue of mapping relevant to dates of development in the map area. Subsequent developments or changes within the floodplain or channel will affect flood levels and render site-specific map information obsolete.

3 – The accuracy of the location of a floodplain boundary as shown on this map is limited by the base topography.

4 – The floodplain limits are not established on the ground by legal survey. A site survey is required to reconcile property location, ground elevations and designated flood level information. Building and floodproofing elevations should be based on field survey and established benchmarks.

5 – Flooding may still occur outside the defined floodplain boundary and the local government does not assume any liability by reason of the failure to delineate flood areas on this map.

6 – The required or recommended setback of buildings from the natural boundaries of watercourses to allow for the passage of floodwaters and possible bank erosion is not shown. This information is available from the local government. In addition, site-specific setbacks from the floodplain limit must be considered.

7 – Flood construction level is based on a global sea level rise of 1 m by the year 2100. May need to be revised in the future – see accompanying report dated June 30, 2019.

Notes on Map Data:

A – ESRI Imagery Basemap, July 2013

B – 1 m contours derived from LiDAR collected by McElhanney (December 2018)

Key Map

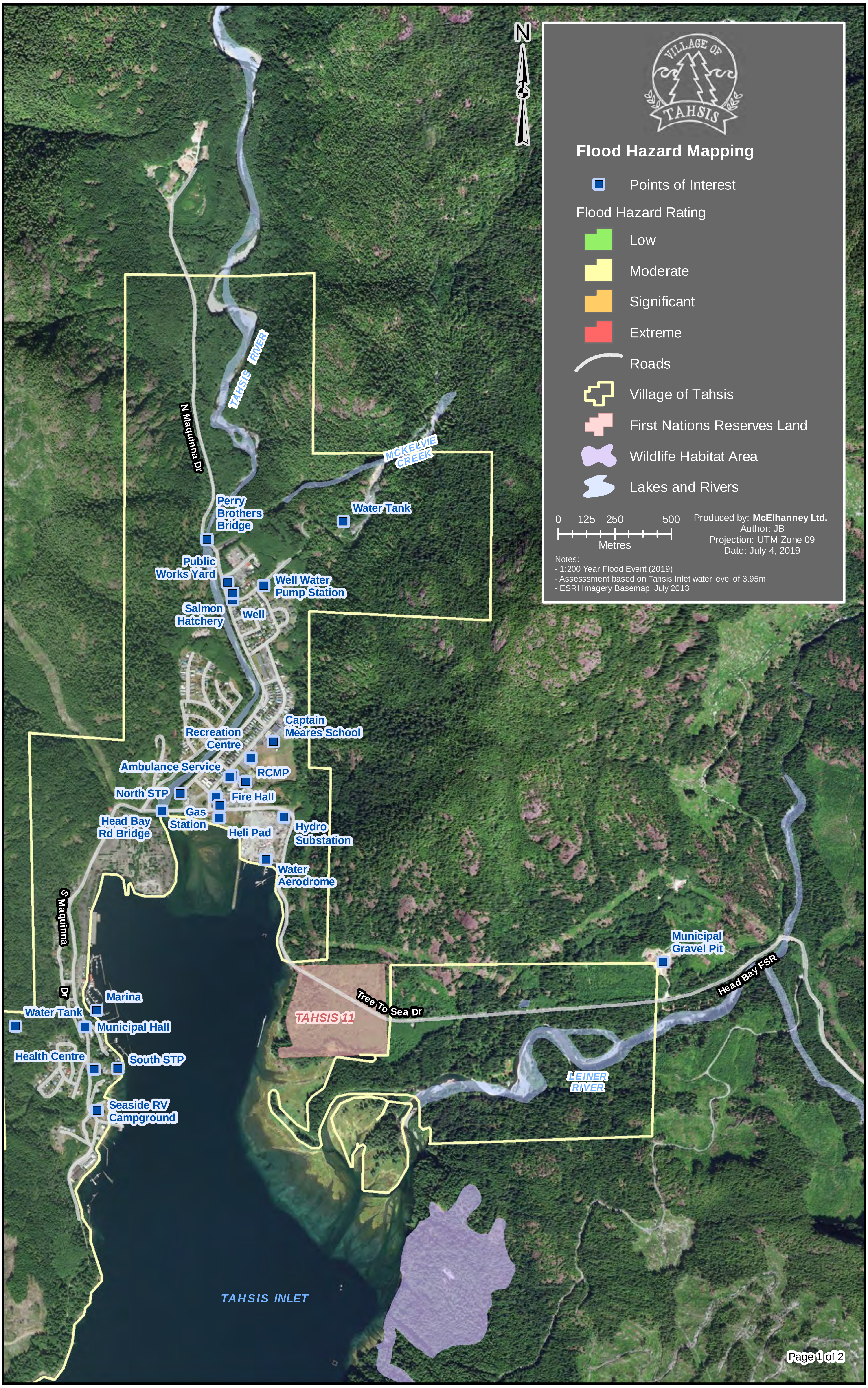
McElhanney

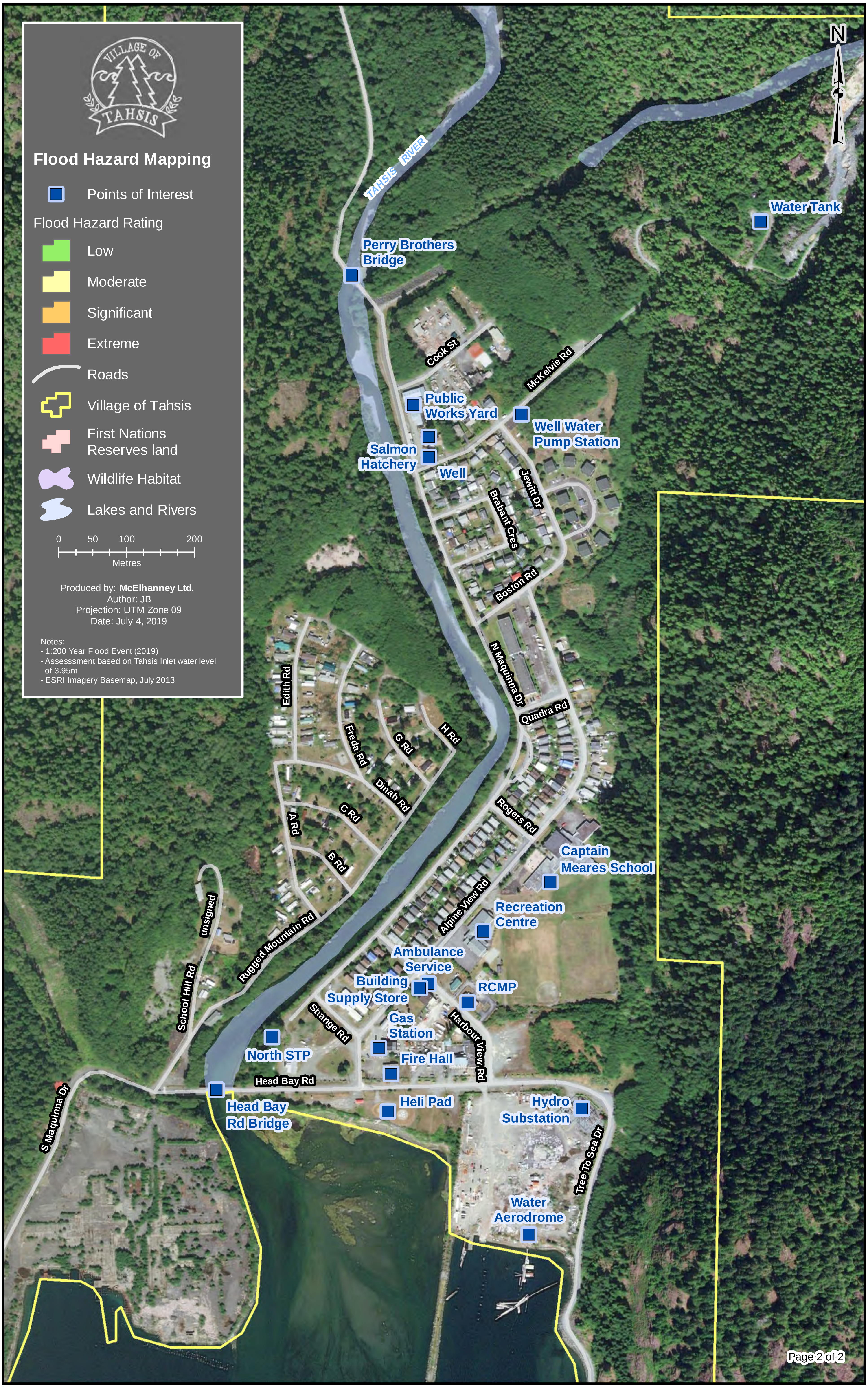
1:10000

0 250 500 750 1,000 (m)

Project No.	Date	Drawn By
2221-49140-2010	July 4, 2019	CF

Village of Tahsis
Tahsis and Leiner River
2019 Floodplain Map


VILLAGE OF TAHSIS
Flood Hazard Mapping
Points of Interest
Flood Hazard Rating
Low
Moderate
Significant
Extreme
Roads
Village of Tahsis
First Nations Reserves Land
Wildlife Habitat Area
Lakes and Rivers
0 125 250 500
Metres
Produced by: McElhanney Ltd.
Author: JB
Projection: UTM Zone 09
Date: July 4, 2019
Notes:
- 1:200 Year Flood Event (2019)
- Assesssment based on Tahsis Inlet water level of 3.95m
- ESRI Imagery Basemap, July 2013
N
TAHSIS RIVER
N Maquinna Dr
MCKELVIE CREEK
Perry Brothers Bridge
Water Tank
Public Works Yard
Well Water Pump Station
Salmon Hatchery
Well
Captain Meares School
Recreation Centre
Ambulance Service
RCMP
North STP
Fire Hall
Gas Station
Head Bay Rd Bridge
Heli Pad
Hydro Substation
Water Aerodrome
S Maquinna Dr
Municipal Gravel Pit
Head Bay FSR
Tree To Sea Dr
TAHSIS 11
Marina
Water Tank
Municipal Hall
Health Centre
South STP
Seaside RV Campground
LEINER RIVER
TAHSIS INLET



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Well
Jewitt Dr
Brabant Cres
Boston Rd
N Maquinna Dr
Quadra Rd
Edith Rd
Freda Rd
G Rd
H Rd
Dinah Rd
C Rd
A Rd
B Rd
Rogers Rd
Captain Meares School
Alpine View Rd
Recreation Centre
unsigned
Rugged Mountain Rd
School Hill Rd
Ambulance Service
Building Supply Store
RCMP
Strange Rd
Gas Station
Harbour View Rd
North STP
Fire Hall
Head Bay Rd
S Maquinna Dr
Head Bay Rd Bridge
Heli Pad
Hydro Substation
Tree To Sea Dr
Water Aerodrome
Page 2 of 2

APPENDIX A: RECORD INFORMATION

Prepared for:
ENVIRONMENT CANADA
Inland Waters Directorate
and
B.C. ENVIRONMENT, LANDS and PARKS
Water Management Division

FLOODPLAIN MAPPING
TAHSIS, LEINER AND ZEBALLOS RIVERS

Design Brief

Cover Photo: High tide flooding on Maquinna Avenue, Zeballos, 1938. (Zeballos Heritage Board and Museum).

PB 5749 0101

FEBRUARY 1992

THE TAHSIS INLET OUTLET

NOVEMBER 15, 1989 VOL. 1 NO. 7

Flood Waters Threaten Residents

By Danielle Cosens and
Staff Writers

Tahsis residents rolled up their pant legs last week as British Columbia experienced record rainfalls across the province. According to weather reports, Tahsis flooding was some of the worst in B.C. and the heaviest in this area since 1975.

The flooding began Thursday morning, November 9th, after a two day rainfall of over 400mm. or 16 inches occured. The Tahsis River escaped the confinement of its banks, roseup over the road and threatened the door-steps of several residents living in the river valley. As the river gathered volume and momentum it swept up, and carried off picnic tables, lumber and anything else in its path as it rushed to the Inlet.

Water intake lines were washed out at the dam causing an interruption in water service to the village. Logs and debris carried by the force of the river punctured a hole in the grate of the intake, washing out the system.

A rock and mud slide, brought on by the heavy rains flushed through the west townsite including the Tahsis Plaza. Shopkeepers from the Plaza spent their business day mopping and vacuuming water, silt and mud deposited in their stores. The Plaza parking lot sat submerged in approximately eight inches of water and mud as village workers laboured to clear drains and gutters in an attempt to divert the flow of water. Village workers became concerned over the state of the slide area as the rain continued. A helicopter was brought in from Gold River to monitor the slide area after Village crew member, Les Dowding, had surveyed the sight and realized its potential danger.

Tahsis volunteer firemen patrolling streets during flooding

Photo by Kathleen Meikle

Five Public Works employees worked around the clock Thursday and Friday to repair water lines and monitor slide areas. Said Public Works employee John Zurch, "It's a big concern in something like this, there's only so many of us."

The village crew received help Thursday as the Tahsis Volunteer Fire Department waded through the streets as residents prepared for possible flooding to occur during the 10 AM high tide.

C.P.F.P. fire chief, Colin McPhail, noted that twelve of the T.V.F.D. volunteers that were not on shift at the mill were aiding residents until the high tide had subsided on Thursday. The firemen helped to move furniture and belongings to the upstairs portion of two residences. According to Deputy Fire Chief, Tim Schmitz, other riverside homes in the valley of the community "had some water and moisture in the basements." Several homeowners will be mopping water from their basements this weekend, but John Zurch says that that is the extent of the residential damage.

While C.M.E.S.S. was not forced to house any evacuees, school was cancelled for two days while flooding subsided and water pressure was restored. According to Mr. McPhail, Tahsis was without running water, of the household variety, from 10:15pm Thursday until after 9:00 Friday morning, with sporadic interruptions early Thursday.

The several hours of flooding in the region drew media attention as "the only road to Tahsis" was described by B.C.T.V. as one of the hardest hit areas. The Tahsis/Gold River road was closed to traffic on Thursday morning after flooding in the areas near Pete's Farm and Perry Falls left vehicles stranded, and in some cases completely submerged in flood waters.

Gurney Contracting has been working on the road repairs. Mike Mountain, an equipment operator for the company, stated that the road was washed out in three areas, causing some damage to the roadway. According to the Forestry service, eight spots along the road were covered with water during Thursday's flooding. The road re-opened Friday after work began on the repairs.

According to Tahsis R.C.M.P. Constable Kevin Kimbler, Tahsis fared better than other areas. "We were pretty lucky in Tahsis," he said. "The reserve at Rivers Inlet was evacuated."

The flood markers along the Tahsis River measured 5 1/2 meters on Friday. Public Works employee, Les Dowding seemed to agree with Constable Kimbler, he said,

(see Flood, page 3)

KLOHN LEONOFF

Our File: PB 5749 0101
WP 596

February 28, 1992

Ministry of Environment, Lands and Parks
Water Management Division
Engineering Branch
5th Floor, 765 Broughton Street
Victoria, British Columbia
V8V 1X5

Mr. P.J. Woods, P.Eng.

Floodplain Mapping Project
Tahsis, Leiner and Zeballos Rivers

Dear Sir:

We are pleased to enclose one original unbound volume and twelve bound copies of the Design Brief for the Floodplain Mapping Program: Tahsis, Leiner and Zeballos Rivers. A copy of the study file, one copy of the floodplain maps and reproducible copies of the floodplain maps are also enclosed.

Thank you for this opportunity to provide consulting services to the Floodplain Mapping Program.

Yours very truly,

KLOHN LEONOFF LTD.

C. David Sellars, P.Eng.
Project Manager

CDS:fjo

Klohn Leonoff Ltd., 10200 Shellbridge Way, Richmond, B.C., Canada V6X 2W7 • Telephone: (604) 273-0311 • Telex: 04-355520 • Fax: (604) 279-4300
Member, Consulting Engineers of British Columbia Member, Association of Consulting Engineers of Canada

TABLE OF CONTENTS

PAGE

TABLE OF CONTENTS
(continued)

FIGURES

TABLES

TABLE OF CONTENTS
(continued)

TABLES
(continued)

TABLE OF CONTENTS
(continued)

APPENDICES

DRAWINGS

1. INTRODUCTION

1.1 Purpose and Scope of Study

Klohn Leonoff Ltd. has completed a study for the Tahsis, Leiner and Zeballos Rivers under the joint Federal/Provincial Floodplain Mapping Agreement. This study was carried out in accordance with specifications outlined in the Ministry of Environment, Invitation for Proposal for Engineering Services, dated June 25, 1991, and our Proposal for Engineering Services dated July 12, 1991. Drawing B-1001 shows the study area location. The purpose of this study is to delineate the limits of the 200-year floodplain and to display flood elevations on a topographic base map.

The scope of this study includes:

- review of available river survey data to confirm that it meets with the Ministry's requirements for floodplain mapping;
- determination of the 20-year and 200-year return period daily and instantaneous discharges for Tahsis, Leiner, Zeballos Rivers and McKelvie Creek;
- determination of the ocean flood levels to be used for backwater modelling and for floodplain delineation for Tahsis and Zeballos Inlets;
- setup and calibration of an HEC-2 backwater model for Tahsis, Leiner, and Zeballos Rivers and McKelvie Creek; and
- delineation of the 200-year floodplain on topographic maps supplied by the British Columbia Ministry of Environment.

The floodplain maps are included in Appendix III of this report. A study file, which contains the HEC-2 output for all runs, is bound separately. To ensure compliance with Ministry of Environment standards and procedures, discussions were held throughout the study with Water Management Division staff, Mr. Peter J. Woods, P.Eng., and Mr. Richard W. Nichols, P.Eng. Contact was also made with Mr. Jim Card, P.Eng., of the Nanaimo office of the Ministry of Environment. Discussions regarding tidal levels and storm surge were held with Mr. Fred Stevenson and Mr. David English of the Institute of Ocean Sciences, Tides and Currents Section. Meetings were held with the Village of Tahsis and Village of Zeballos personnel and local residents to discuss historical flooding.

2. SITE DESCRIPTION

The study area is located on the west side of Vancouver Island approximately 100 km northwest of Tofino, see Drawing B-1001. As shown on this drawing the study area has been divided into two areas: Drawing 89-15-1, Tahsis and Leiner Rivers, Village of Tahsis, which also includes McKelvie Creek; and Drawing 89-45-1, Zeballos River. The Village of Tahsis and the Village of Zeballos, shown on their respective Drawings, are both located in the Comox Strathcona Regional District.

These rivers have steep gradients with rapids and cascades. The river valleys are narrow with steep sides. The tributaries feeding the main rivers are very steep with waterfalls and occasional debris torrents. Some of the valley slopes have been logged.

The Village of Tahsis has carried out bank protection work on both banks of the Tahsis River. The protection reduces scour and bank erosion but does not prevent flooding.

The Village of Zeballos has constructed left bank protection from the Zeballos River Bridge downstream. This included a dyke in 1940/41 which redirected the river near its mouth out of its left channel and around an island away from the Village. On the right bank the Keno Crescent "Dyke", properly referred to as a "Training Berm", was constructed to deflect flood flows away from a new subdivision.

These rivers are subject to storms coming off the Pacific Ocean between the months of October and April. Due to the storm intensities and the steep terrain these rivers are very flashy and can rise and fall within a couple of days. Since the rivers discharge into tidal waters, tidal, storm surge and wave runup levels were accounted for in the floodplain mapping analyses.

3. DATA USED FOR STUDY

3.1 Data Sources

Data sources are referenced below with brief explanations of their applicability.

- **Floodplain Mapping Design File**, British Columbia Ministry of Environment, Lands, and Parks, Water Management Division, Special Projects Section.

  The following data was provided:

  - river survey, carried out in July 1990, described under River Surveys below;
  - two base floodplain maps, produced in January 1989 with air photos from 1984 and 1986: Drawing 89-15-1, Tahsis and Leiner Rivers, Village of Tahsis, at 1:5000 scale with 1-m contour interval; and Drawing 89-45-1, Zeballos River, at 1:5,000 scale with 2-m contour interval;
  - reports on Tahsis River floods of November 1989 and November 1990;
  - "Preliminary Report on Tahsis River Flooding", by A. Brown, P.Eng., Rivers Section, Water Management Branch, dated February 1985;
  - Department of Mines and Technical Surveys, "Tsunami of March 27-29, 1964, West Coast of Canada", unpublished report by Wigen, S.O. and W.R.H. White, 1964, Table 2, page 5;
  - Office of the Provincial Civil Defense Co-ordinator, "Report on the Alberni Tidal Wave Disaster", May 20, 1964, Part II;
  - "Evaluation of Tsunami Levels Along the British Columbia Coast", by Seaconsult Marine Research Ltd., dated March 1988; and
  - "Coastal Environment and Coastal Construction - A Discussion Paper", by B. Holden, P.Eng., Special Projects Section, Water Management Branch, 1987.

  This data was used to setup and calibrate the HEC-2 backwater models. The base maps were used to delineate the 200-year return period floodplain.

- **River Surveys**, British Columbia Ministry of Environment, Lands and Parks, Surveys Section.

  The following data was provided:

  - surveyed cross sections in digital and plotted format for Tahsis, Leiner and Zeballos Rivers and McKelvie Creek including photos of all cross sections (carried out in July 1990); and

  - profile of the Keno Crescent and left bank dykes on the Zeballos River.

  Survey data was used to prepare and calibrate the HEC-2 backwater model.

- **Tahsis hydrometric data**, British Columbia Ministry of Environment, Technical Support Section.

  Data for the Tahsis River collected during 1988 and 1989 including stream flow measurements and recorder charts.

  This data was used to confirm the relationship between the Zeballos River response and the Tahsis River response and also to check on the ratio of instantaneous to daily discharge.

- **Stream flow data**, Water Survey of Canada (WSC).

  Data for the following stations were obtained from WSC:

  Station 08HB048 - Carnation Creek at the Mouth;
  Station 08HB014 - Sarita River near Bamfield;
  Station 08HE006 - Zeballos River near Zeballos; and
  Station 08HC002 - Uncona River at the Mouth.

  After review of the data it was decided to exclude stations 08HB014 and 08HC002. The remaining two stations were used to estimate the 20-year and 200-year return period daily and instantaneous discharges for Tahsis, Leiner and Zeballos Rivers and McKelvie Creek. Details of the hydrologic data analyses are presented in Appendix I.

- **Tidal information**, Government of Canada, Fisheries and Oceans, Tides and Currents Section.

Various recorded and predicted tidal levels and the mean water levels and Highest High Water Large Tide levels were provided for the following stations:

Station 8615 - Tofino;
Station 8650 - Gold River;
Station 8658 - Tahsis;
Station 8664 - Ceepeecee; and
Station 8670 - Zeballos.

Review of this data assisted in determining the recommended ocean flood levels. Details of this analysis are presented in Appendix I.

- **Wind data**, Atmospheric Environment Service of Environment Canada.

  Maximum recorded winds for Spring Island, Estevan Point and Tofino were provided. These data were used to estimate wave generation, runup and setup in Tahsis and Zeballos Inlets. Details of these analyses are contained in Appendix I.

- **Village of Tahsis Archives.**

  Data collected from the archives included photos and interviews with long term residents. The archives had been compiled by Laurie Jones as a joint project funded by the B.C. Heritage Trust and the Village of Tahsis in 1985.

- **Village of Zeballos Archives.**

  The archives, kept by the Zeballos Heritage Board and Museum, were organized by a volunteer, Freda Rodgers. They included photos and copies of the Zeballos Miner, a local paper, dating from 1938 to 1946.

- **Local resident interviews**, including:

  For Tahsis:

  - Gary Ross, Village of Tahsis Public Works Superintendent;
  - Les Dowding, Village of Tahsis Public Works Foreman;
  - Tom Gurney, a local Tahsis contractor;
  - Pete Choats, a long term resident on the right bank of the Leiner River;
  - Ron Todd, an employee of Canadian Pacific Forest Products and former resident of Tahsis;

For Zeballos:

- Joanne Johnson, Village of Zeballos Clerk;
- Bruce and Margaret Davies, long term residents;
- Sue Vessey and Reid Robinson;
- Rodger Stewart (Alderman); and
- Cliff Pederson (Mayor of Zeballos).

• **Gower, Yeung and Associates Ltd.**

  - Proposed Zeballos River Bridge (Project 833) design drawings and correspondence.

4. HISTORICAL FLOODING

4.1 Tahsis Area

4.1.1 River Flooding

The area was first visited by British and Spanish explorers in the 1770s and 1780s. Friendly Cove, in Nootka Sound, became the site for refitting sailing vessels. Homesteaders and hand loggers settled on Tahsis Inlet as early as 1882. A floatcamp logging operation started in the late 1930s. The first mill was built in 1945.

The map of Tahsis, Drawing B-1002, dated 1951, and the air photo, Photo 1, dated 1953, show the extent of low lying mud flats between the east side of the river (left bank) and the valley wall. At one time an air strip was built on these flats. The floodplain map, Drawing 89-15-1, Appendix III, shows that the bridge near the mouth of the river has been replaced with a bridge further downstream, the Tahsis River Bridge. Much of the mud flats has been filled in to create a storage area, transformer station, baseball diamond and sports fields. The village itself now stretches from McKelvie Creek down to the mouth of the Tahsis River.

Flooding has always been a problem in Tahsis. North Maquinna Drive, which runs along the east bank of the river, used to be flooded regularly to at least 0.6 m in depth. Flooding would occur where the apartment building is now located, immediately upstream of cross section 9. The 1951 map shows this area as a pond. Flooding on the Tahsis River destroyed the original bridge near McKelvie Creek three times.

The present village experienced significant flooding in November 1989 and 1990. Appendix II contains a newspaper article about the 1989 flood. The 1990 flooding was the worst in recent memory. Photos 2 to 4, supplied by the Village of Tahsis, show the extent of flooding. Section 6.2.1 contains a detailed analysis of these floods. High river levels create internal drainage problems which add to the flooding in the village (see Photo 5). In the 1970s and 1980s the Tahsis River flooded the road to the land-fill site, upstream of the Perry Bridge, almost every year.

Head Bay Road, along the north bank of the Leiner River, has been reported to flood several times a year. Significant bank erosion, totalling 20 m to 30 m at one bend has occurred on the Leiner River since the 1960s. Photo 6 shows the mouth of the Leiner River.

4.1.2 Tidal/Tsunami Flooding

June high tides used to flood up to the area where the sports fields and school are now located. Head Bay Road, which crosses the Tahsis River and becomes South Maquinna Drive, and the sports fields have been built up, thus preventing high tides from flooding the village.

As remembered by Neil MacLeod (a long term resident interviewed by Laurie Jones in 1985):

> "The tsunami of 1964 caused water levels to rise approximately 2 m. Residents evacuated to the Fire Hall and the Legion Hall. No damage was reported in the village."

An unpublished Department of Mines report, by Wigen and White, estimated that the March 28, 1964 tsunami attained a maximum elevation of approximately El. 2.8 m (GSC) at Tahsis. A tidal gauge was not available at that time and so the levels must have been based on observed high water marks. The 1964 tsunami was simulated mathematically (Seaconsult Marine Research) and resulted in a wave height of 2.0 m above mean sea level.

John Zurch, the Provincial Emergency Program Area Coordinator, stated that contingency emergency evacuation plans have been drafted and are in the process of being reviewed and finalized. Barb Newton, the Emergency Social Services Director has developed a plan for food and clothing supplies.

4.1.3 Debris Flow

During the November 9, 1989 Tahsis River flood, a debris flow event occurred in West Tahsis on the creek adjacent to the Tahsis Village Mall. Photos 5.1 to 5.2 show the creek with debris and the resulting damage at the Tahsis Village Mall. The mall and creek are identified on Drawing 89-15-1.

4.2 Zeballos

4.2.1 River Flooding

In the mid to late 1930s a significant gold rush took place in Zeballos. By 1938 a village, complete with a planked road, was in existence. Along with several gold mining operations, the Tahsis Logging Company established itself in Zeballos. The Tahsis Logging Company was purchased by Canadian Pacific Forest Products Limited (CPFP) in the mid 1980s. In the late 1950s, early 1960s, the Zeballos Iron Mines began shipping iron ore out of Zeballos.

Flooding was a problem then, as shown by the 1938 high tide photos, Photos 7 to 9. The original housing was all on stilts. In that year the first wharf was constructed.

The local paper the "Zeballos Miner", reported in October 19, 1940, "the river rose 9 ft in a few hours and flowed down Main Street". The winter of 1940/1941 a dyke was built of river gravels to direct the river to the west, away from village limits, and out of one of the original river channels (see Drawing 89-45-1, Appendix III). Dyke refurbishing was done in 1946. This dyke washed out in the early 1960s and was replaced by the Zeballos Iron Mines which was now shipping iron ore out of Zeballos. The company also built an access road in the old river channel (see Photo 10), which led to a new wharf for ocean going ore ships. The wharf is now gone and the road, Pandora Crescent, has CPFP housing on it (see Drawing 89-45-1, Appendix III).

In the early 1970s the Zeballos Iron Mines riprapped the left bank during a large flood to prevent the river from flowing down Main Street, now called Maquinna Avenue. Photos 11 to 13 show various stages of bank erosion protection in the early 1970s. In

1974 the Ministry of Highways placed riprap on the left bank and replaced a culvert in the overflow channel with a clear span log bridge (see Photo 17). Approximately 70% of the riprap was washed out in the November 1975 flood. This protection was replaced and extended further upstream in 1976 by a joint venture between Tahsis Logging Company, the Village of Zeballos and the B.C. Ministry of Lands, Forests and Water Resources. Further upstream, extension of the bank protection was carried out by the Village of Zeballos and the Ministry of Environment, Water Management Branch, in 1990 (see Photo 14).

During river flood events water has been seen to seep through the left bank dyke in several locations between sections 3 and 4. This is probably due to the use of river gravels and rock material to construct the left bank protection and dyke over the years. Photos 19 and 20 show the Zeballos River in flood on November 11, 1990.

An overflow channel is located on the west side of the river (see Drawing 89-45-1, Appendix III). It used to be possible to boat up the overflow channel on a high tide. Now, possibly due to aggradation in the overflow channel, flowing water is present in the overflow channel only when the Zeballos River is in flood. Keno Crescent Training Berm, located on the right bank, was built in the mid 1970s to prevent the river from shifting its course into the new Keno Crescent subdivision.

4.2.2 Tidal/Tsunami Flooding

Some of the houses and Maquinna Avenue itself have been raised so that flooding due to high tides now occurs infrequently. High tides often lap at the back door of houses along the east side of the village. The tide waters rise up the slough located between the village and the east valley wall (see Photo 15 and Drawing 89-45-1, Appendix III).

According to local residents there was no warning of the 1964 tsunami in Zeballos. The "Report on the Alberni Tidal Wave Disaster", May 20, 1964, Office of the Provincial Civil Defence Coordinator, stated that "30 homes were knocked off their foundations and considerable damage was done to personal property, such as furniture and appliances from silt and salt water". Local residents stated that they only recalled one house and the Zeballos Community Centre (see Photo 16) being shifted by the tsunami. The Community Centre was lifted and rotated clockwise moving its front door approximately 5 m from the original location.

An unpublished Department of Mines report, by Wigen and White, estimated that the March 28, 1964 tsunami attained a maximum elevation of approximately El. 2.6 m (GSC) at Zeballos. A tidal gauge was not available at that time and so the levels must have been based on observed high water marks. The 1964 tsunami was simulated mathematically (Seaconsult Marine Research) and resulted in a wave height of 3.9 m.

Discussions were held with Don Parker, the Provincial Emergency Program Area Coordinator. Contingency emergency evacuation and sheltering plans are in the draft stage at this time. These plans are to be finalized in the next six months. The Emergency Social Services Director, Judy Dunn, has organized food supplies and clothing should an emergency occur.

Evacuation of the Village was successfully carried out in approximately 20 minutes 2 to 3 years ago. This was in response to a tsunami watch. No ocean flood wave occurred at that time. Communications during an emergency would be carried out by a local ham radio operator. Several village residents have cellular telephones and the ambulance also has a radio hook-up with B.C. Tel.

5. FLOOD FREQUENCY ANALYSES

5.1 General

The flood frequency analyses involved derivation of the instantaneous and mean daily discharges for Tahsis, Leiner and Zeballos Rivers for 20-year and 200-year return period events. The catchment areas of these rivers are 78 km^2, 108 km^2 and 193 km^2 respectively. The upper reach of Tahsis River was subdivided into two catchments: Tahsis upstream of McKelvie Creek, 54 km^2; and McKelvie Creek, 22 km^2. Sections 5.2 and 5.3 describe data processing and analyses. Section 5.4 describes application of these analyses to Zeballos River while Section 5.5 describes application to Tahsis and Leiner Rivers and McKelvie Creek.

For comparison purposes the "Guide to Peak Flow Estimation for Ungauged Watersheds in the Vancouver Island Region (Nanaimo)", Ministry of Environment 1987a, was also used to estimate the 20-year and 200-year return period discharges. This methodology resulted in discharge estimates ranging from 12% higher to 30% lower than those presented in Sections 5.4 and 5.5. This methodology relies on data along the entire west coast of Vancouver Island and therefore is not site specific. The daily discharge values presented in Tables 3 and 4 were used for the present floodplain mapping study.

The following flood frequency studies were based on recorded Water Survey of Canada (WSC) discharges. A review of available WSC data, on the west coast of Vancouver Island, identified the stations listed in Table 1 as possible sources of information.

Table 1 - Water Survey of Canada Gauging Stations

STATION NAME	STATION NUMBER	CATCHMENT AREA (km^2)	NUMBER OF YEARS OF RECORD
Carnation Ck at the Mouth	08HB048	10.1	18
Sarita River near Bamfield	08HB014	162	38
Zeballos River near Zeballos	08HE006	181	30
Uncona River at the Mouth	08HC002	185	29

5.2 Maximum Daily Discharge

Detailed review of the recorded data at the stations listed in Table 1 indicated that, although they are all located on the west coast of Vancouver Island, they have different runoff characteristics for annual maximum daily discharge. No apparent relationship between annual maximum daily discharge and catchment area could be derived from this data. Microclimatic differences in precipitation due to sheltering from the Olympic Peninsula to the south, distance from the coast, storm path, catchment orientation and catchment slopes are the major factors in producing the variable runoff response.

Daily discharge estimates are based on recorded data from the Zeballos River gauge. This gauge is located on the Zeballos River approximately 4 km upstream of the Zeballos River mouth. Its catchment is adjacent to the Tahsis and Leiner River catchments. The main stem river gradients and the lateral feeder gradients are similar for these three rivers. Catchment orientation and maximum elevations are also similar.

The upper end of the WSC rating curve for Zeballos River is defined by a discharge measurement of 410 m^3/s on January 15, 1974, at a stage of 2.5 m. Based on field observations this measurement point should be representative of high discharge flow conditions. Until other high discharge measurements are made, the existing data must be relied upon.

The annual maximum 20-year and 200-year return period daily discharges for the Zeballos River gauge were estimated from the average of three frequency distributions: General Extreme Value; Three Parameter Log Normal; and Log Pearson Type III. Thirty years of data were available. A sample frequency plot, produced by the CFA88 flood frequency program, is included as Figure 1. The resulting daily discharge estimates for the 181 km^2 WSC Zeballos River gauge were 682 m^3/s for the 20-year return period flood and 1120 m^3/s for the 200-year return period flood.

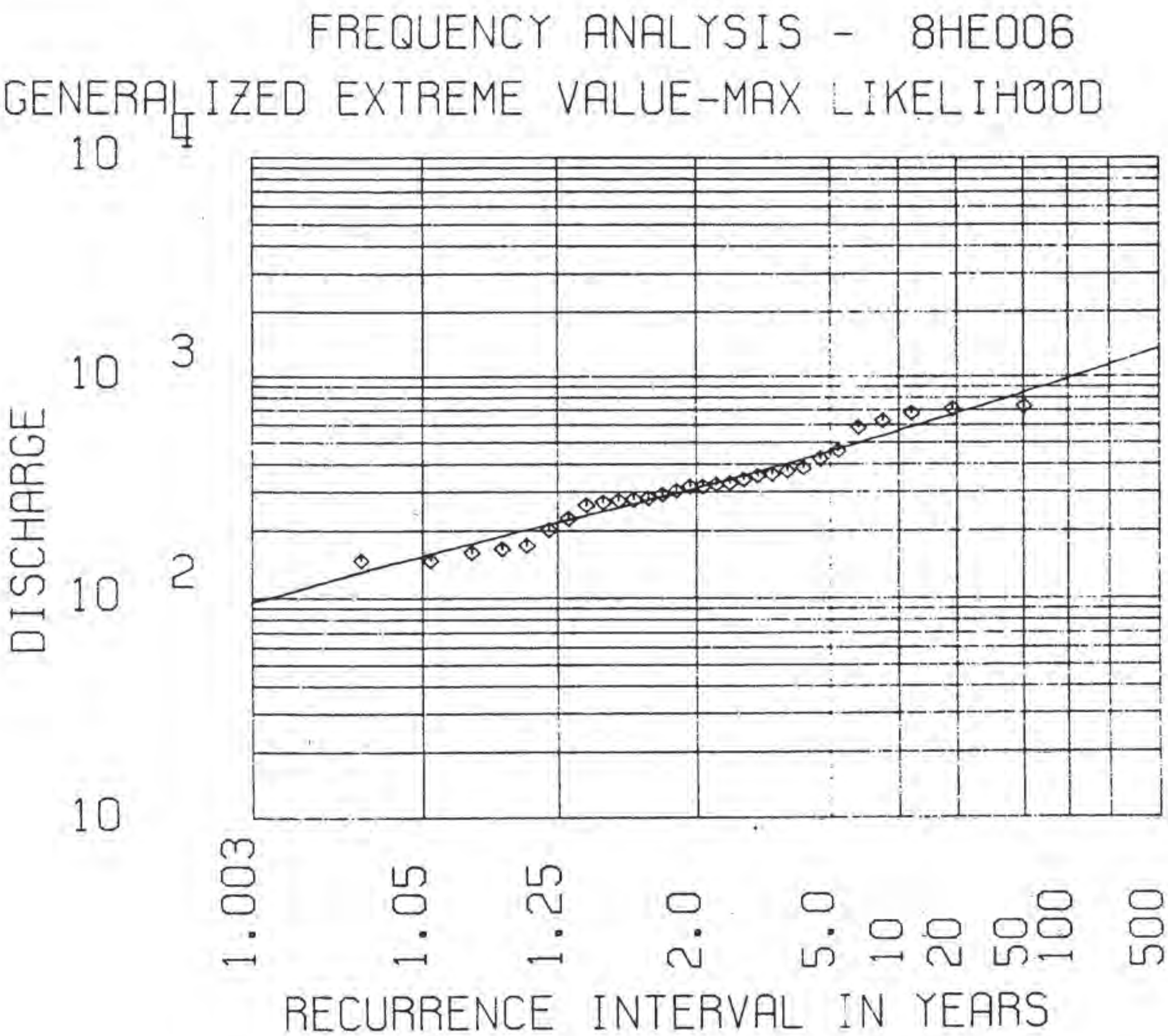


Figure 1 - Annual Maximum Daily Discharge (m^3/s) for Zeballos River Gauge

The report "Magnitude of Floods - British Columbia and Yukon Territory", Ministry of Environment 1985b, was used to estimate daily discharges for the required drainage areas. Based on the slope of the unit discharge envelope curve developed in the above report, which is shown in Figure 2, the following relationship was derived:

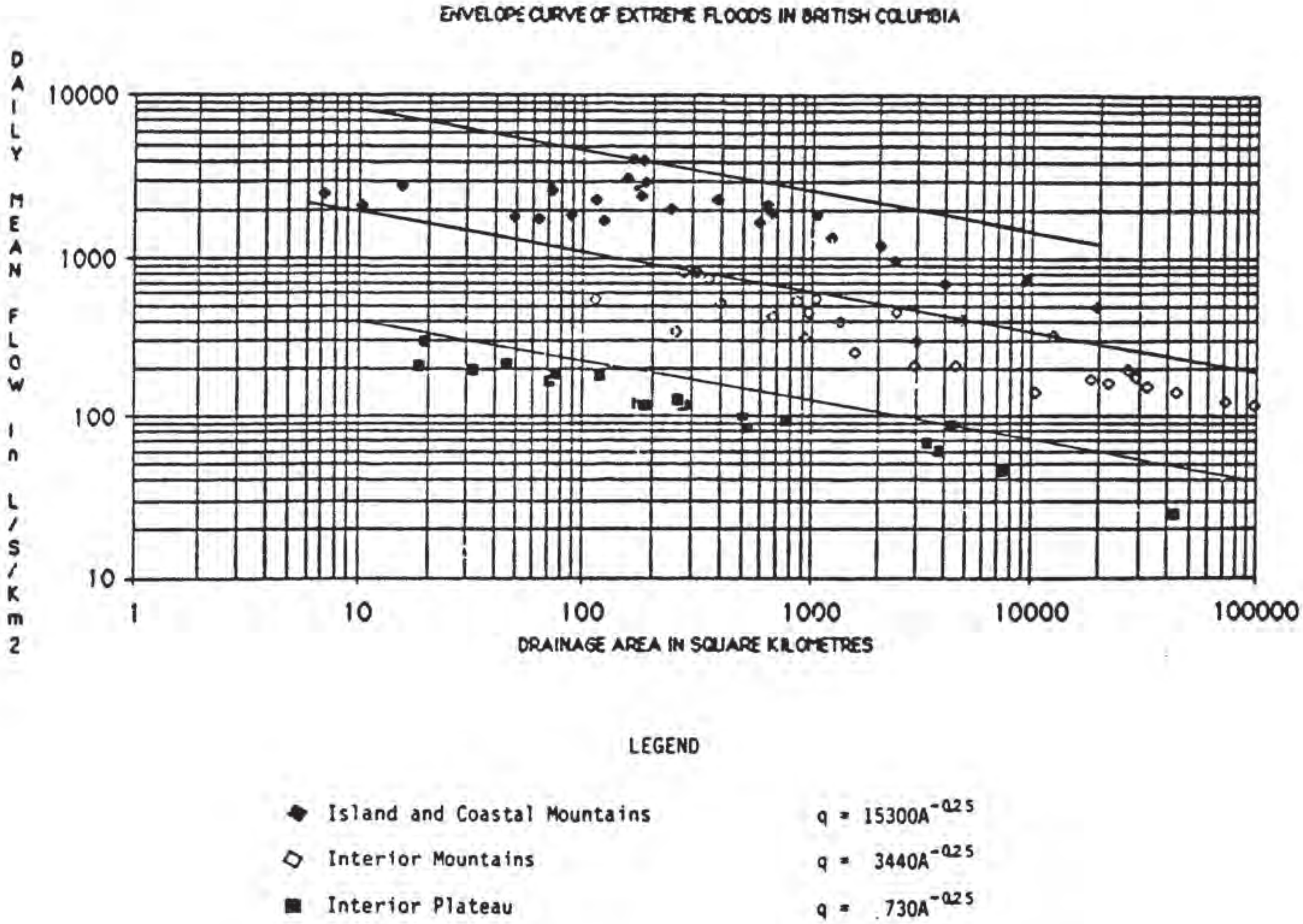
$$Q = Q_z \left(\frac{A}{A_z}\right)^{0.75}$$

Where: Q = Estimated daily discharge, in m^3/s for catchment with area A, in km^2.

Q_Z = Zeballos River daily discharge, in m^3/s.

A_Z = Zeballos River catchment area (181 km^2).

This relationship is applied to the catchments of interest in Sections 5.4 and 5.5.



(Reference: "Magnitude Floods - British Columbia and Yukon Territories", Ministry of Environment, 1985)

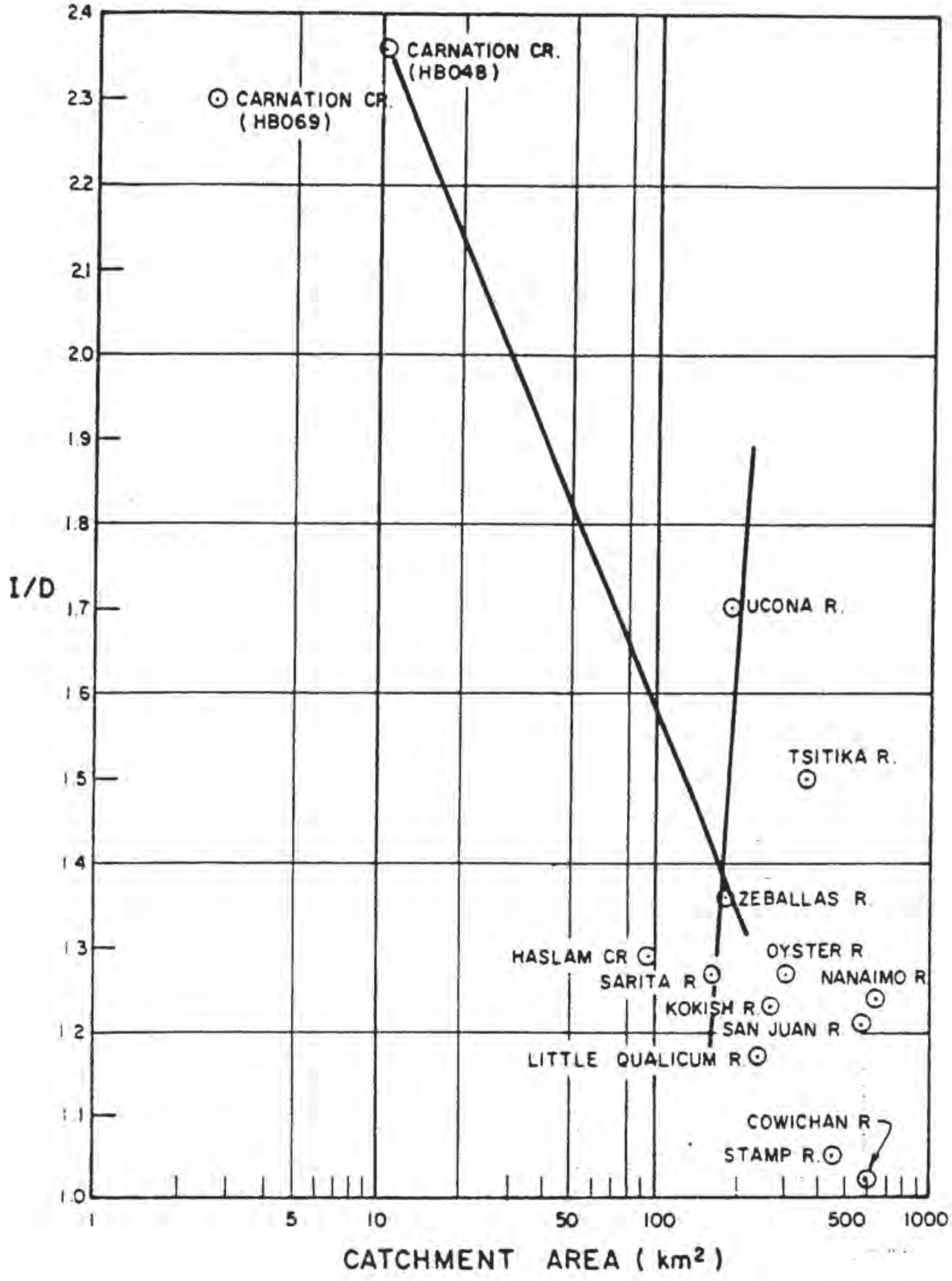
Figure 2 - Envelope Curve of Extreme Floods in British Columbia

5.3 Maximum Instantaneous Discharge

Estimation of maximum instantaneous discharge on Vancouver Island is hampered by the scarcity of water level recorders for a range of catchment areas and by the conflicting relationships derived from the data which is available. Both catchment area and flood magnitude appear to play a role in the determination of the ratio of maximum instantaneous to daily discharge (I/D).

If a relationship for I/D is based on the Sarita, Zeballos and Uncona data, a very steep curve is obtained with I/D increasing as catchment area increases. If Zeballos and Carnation data are used, the I/D ratio increases with decreasing catchment area. Figure 3 shows these relationships and the scatter in data for Vancouver Island.

> "Another problem in regionalizing I/D (Instantaneous Discharge/Daily Discharge) ratios is an apparent absence of trends in variation of I/D with respect to D. Some trends have been detected but are uncertain. On Vancouver Island some I/D ratios decrease with increasing D whereas in other regions some stations exhibit increasing I/D with increasing D." (Ministry of Environment, 1988)



(Reference: Data points from Ministry of Environment, 1987a)

Figure 3 I/D versus Catchment Area

Frequency analyses, as described for the annual maximum daily discharges for Zeballos River in Section 5.2, were carried out independently for the annual maximum instantaneous and daily discharges for both Zeballos River and Carnation Creek. Only years with both instantaneous and daily maximums were used for the analyses. Twenty five years of data were used for Zeballos River and 17 years of data for Carnation Creek. The results of these analyses are presented in Table 2 along with the resulting I/D ratios.

The relationship between I/D and return period for the Zeballos River and Carnation Creek WSC gauges is tenuous but at least consistent. The Sarita and Uncona data is not consistent with the Zeballos data and therefore has not been used.

Table 2 - Derived I/D Values for Zeballos River and Carnation Creek Gauges

RETURN PERIOD (YEARS)	ZEBALLOS RIVER GAUGE			CARNATION CREEK GAUGE		
	INSTANTANEOUS DISCHARGE (m^3/s)	DAILY DISCHARGE (m^3/s)	INSTANTANEOUS / DAILY	INSTANTANEOUS DISCHARGE (m^3/s)	DAILY DISCHARGE (m^3/s)	INSTANTANEOUS / DAILY
2	535	284	1.89	30	13	2.28
5	715	403	1.77	44	19	2.34
10	830	488	1.70	53	24	2.24
20	936	574	1.63	61	29	2.09
50	1070	693	1.54	72	38	1.87
100	1173	787	1.49	80	47	1.69
200	1267	887	1.43	87	57	1.52

The instantaneous discharge estimates presented in Sections 5.4 and 5.5 are based on data from both Zeballos River and Carnation Creek. Both flood magnitude and drainage area are accounted for when selecting an I/D ratio. This approach could err on the conservative side, i.e. an overestimation of instantaneous discharge, since use of this data will result in increasing I/D ratio with decreasing catchment area. The selected I/D versus catchment area relationships for 20-year return period and 200-year return period events are shown on Figure 4.

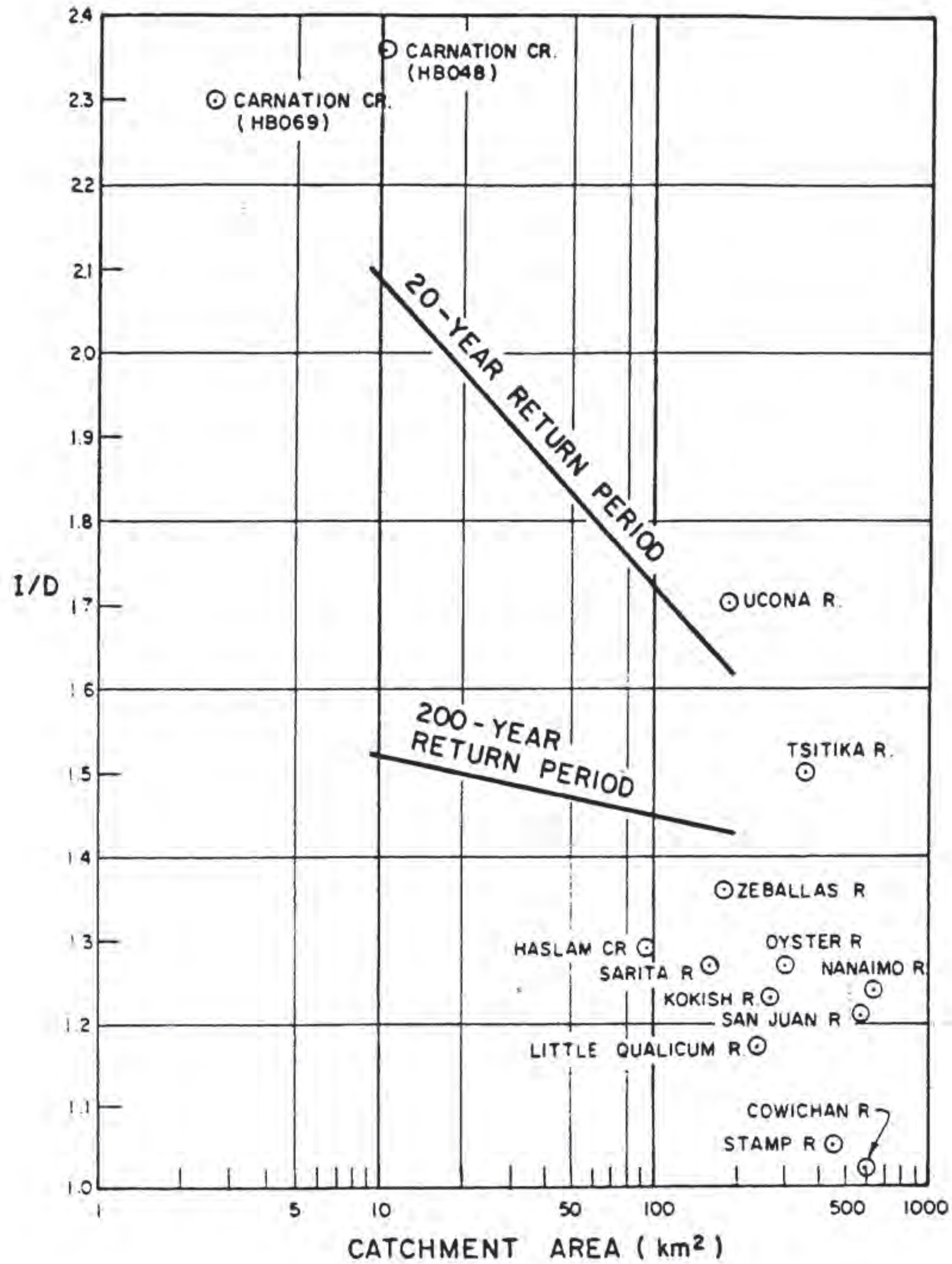


Figure 4 Selected I/D Relationships

5.4 Zeballos River Discharges

The analyses in Section 5.2 and 5.3 have been used to derive the 20-year and 200-year instantaneous and mean daily discharges. Using the WSC Zeballos River gauge data and the unit discharge equation resulted in the daily discharges presented in Table 3 below. The instantaneous discharges presented in Table 3 resulted from the I/D values selected from Figure 4 times the daily discharges.

Table 3 - Zeballos River Derived Discharges

RIVER	CATCHMENT AREA (km^2)	20-YEAR RETURN PERIOD			200-YEAR RETURN PERIOD		
		I/D	DAILY (m^3/s)	INSTANTANEOUS (m^3/s)	I/D	DAILY (m^3/s)	INSTANTANEOUS (m^3/s)
Zeballos	193	1.62	716	1160	1.43	1175	1680

5.5 Tahsis and Leiner Rivers and McKelvie Creek Discharges

The analyses in Sections 5.2 and 5.3 have been used to derive the 20-year and 200-year instantaneous and mean daily discharges. As described in Section 5.2 the rivers in this study have similar catchments and river gradients. Due to their location and small catchment sizes, floods on these rivers occur very quickly and once precipitation stops the flood waters recede quickly. The daily discharge values presented in Table 4 are based on the unit discharge equation from Section 5.2. The instantaneous discharges are derived from the I/D values from Figure 4 times the daily discharges.

Table 4 - Tahsis and Leiner River and McKelvie Creek Derived Discharges

RIVER	CATCHMENT AREA (km^2)	20-YEAR RETURN PERIOD			200-YEAR RETURN PERIOD		
		I/D	DAILY (m^3/s)	INSTANTANEOUS (m^3/s)	I/D	DAILY (m^3/s)	INSTANTANEOUS (m^3/s)
McKelvie Creek	22	1.96	140	274	1.49	231	344
Tahsis U/S of McKelvie Creek	54	1.82	275	501	1.47	452	664
Tahsis at the mouth	78	1.76	363	639	1.45	596	864
Leiner	108	1.71	463	792	1.44	760	1094

For comparison purposes the Tahsis River flood of November 9, 1989 (Ministry of Environment, 1990a) was analyzed. Ministry of Environment installed a water level recorder at the Perry Bridge for the period August 1988 to December 1989. Discharge measurements had been carried out for discharges ranging from 4 m^3/s to 64 m^3/s. The HEC-2 model was used to estimate the discharge using the November 9, 1989, recorded floodlevel hydrograph. Assumed "n" values and expansion/contraction loss coefficients were adjusted to conform to the profile of surveyed high water marks. During the flood the tide level varied from -1.0 m (GSC) to 1.3 m (GSC) to -1.1 m (GSC). This was accounted for in the five simulations which were run to estimate the mean daily discharge. These simulations resulted in a mean daily discharge of 242 m^3/s and a maximum instantaneous discharge of 400 m^3/s. The resulting I/D ratio was 1.65. Since this is a single event, and I/D ratios vary significantly for both the Zeballos and Carnation catchments, it is difficult to draw definite conclusions from this analysis. This flood had a return period of less than 20 years and the estimated I/D ratio is consistent with catchments on the west coast of Vancouver Island.

6. HYDRAULIC ANALYSES

6.1 General

All water surface profiles were estimated with the HEC-2 computer program. Input to this program includes cross section geometry, reach lengths, discharges, ineffective flow areas and estimates of energy loss coefficients. Calibration of the input data with known flows and corresponding river elevations is required to model river levels at other flows.

Cross section geometry and reach lengths were obtained from detailed surveys which were carried out by the Ministry of Environment in July 1990. Locations of all cross sections are shown on the two floodplain maps in Appendix III. The cross section data was provided to Klohn Leonoff along with a topographic map showing their locations and a set of photographs at each cross section showing the banks and views looking upstream and downstream. Extensions to the cross sections were made, where required, based on the topographic maps.

The following sections describe tidal levels, the river profile model developed for each river, calibration of the models and sensitivity analyses.

6.2 Tidal Levels

The Terms of Reference state that the Higher High Water Large Tide (HHWLT) should be used for the backwater studies. The Institute of Ocean Sciences (IOS) supplied tidal information for gauges installed at the villages of Tahsis and Zeballos. Only 6 months of data was available for Tahsis and therefore tidal levels from Tofino, with 86 years of data, were used. Eleven years of data, starting in 1980, were available for Zeballos. The HHWLT values estimated by IOS were 2.0 m (GSC) and 1.8 m (GSC) for Tahsis and Zeballos respectively. The Leiner River mouth is located adjacent to the Tahsis River mouth and therefore these two rivers will experience the same tidal level of 2.0 m.

Storm surge is caused by changes in atmospheric pressure. Storm surge can be estimated from the difference between recorded and predicted tide levels. According to the IOS a good estimate of the storm surge is the difference between the highest recorded tidal level and the HHWLT. For the recorded data at Tofino, Zeballos and Tahsis this would be 0.7 m, 0.6 m and 0.3 m respectively. The longer the record, the more likely a large storm surge has been recorded. Since Tofino has an extremely long record, 86 years, it is recommended that the ocean flood levels for both Tahsis and Zeballos Inlets include a storm surge allowance of 0.7 m.

Since the storm surge can be present for up to approximately 6 hours during a storm, the ocean water level used for the backwater analyses should include the storm surge allowance. We recommend that all backwater analyses use the HHWLT plus the storm surge allowance of 0.7 m as the ocean water level.

The tidal levels used for all backwater calculations are therefore 2.7 m and 2.5 m for Tahsis and Zeballos Inlets respectively. For comparison purposes, the maximum recorded high tide levels for Tofino, Zeballos and Tahsis are 2.7 m, 2.4 m and 2.2 m, respectively.

6.3 Tahsis River and McKelvie Creek

6.3.1 River Profile Model

The cross sections supplied by the Ministry of Environment were used to develop the river profile model. Photographs of the cross sections, supplied by the Ministry of Environment, and photographs of the November 1989 flood, supplied by the Village of Tahsis, were used to determine the preliminary loss coefficients and ineffective flow areas. A site visit was carried out on October 7 and 8, 1991 by Richard F. Rodman, P.Eng. The site visit assisted in evaluation of cross section data and coefficient selection. Information on historical floods was also obtained as described in Section 4.

Due to the abrupt expansion at the mouth of the Tahsis River some of the left bank area was considered ineffective flow area. Cross section 13, immediately downstream of the Perry Bridge, was not used in the model due to the significant amount of overland flow which occurs on the left bank at cross sections 14 and 15. This overland flow re-enters the river between cross sections 12 and 13. Cross section 16 and M1 (on McKelvie Creek) were consolidated into one, cross section 16.1, due to the significant submergence of the bar separating the two water courses at this location during flood flows. Cross sections 17 and M2 were renumbered -16.1 for computational purposes. Cross sections M3 and M4 were numbered 16.3 and 16.4 to identify them as McKelvie Creek cross sections.

Cross sections 1 to 16.1 carry the discharge of the Tahsis River at the Mouth, while cross sections -16.1 to 24 carry the discharge of the Tahsis River Upstream of McKelvie Creek and cross sections -16.1 to 16.4 carry the discharge of McKelvie Creek. For a particular return period event the two tributaries of the Tahsis River each have a starting elevation, upstream of the Perry Bridge, which is consistent with the same return period event on the Tahsis River downstream of the Perry Bridge.

Very good water level data were available for calibration of the Tahsis River model. The Ministry of the Environment surveyed the high water river profiles for the November 1989 and November 1990 floods which had been identified by Village of Tahsis personnel (see Drawings A-1003 and A-1004). A water level hydrograph was available from a Ministry of Environment water level recorder located immediately downstream of the Perry Bridge. Part of the rising and falling limbs of the flood hydrograph had to be estimated. The peak water levels at the Perry Bridge were 4.7 m(GSC) and 5.1 m(GSC), respectively for the 1989 and 1990 events.

Due to the tidal influences in the lower Tahsis River the appropriate tide levels were required for modelling. The tide levels at the time of the flood peaks were estimated as 1.3 m(GSC) and -0.3 m(GSC) respectively for the 1989 and 1990 events. Tide levels were also estimated for 5 points on the 1989 flood hydrograph. Recorded tide levels at Tofino and Zeballos were used to derive tide levels for Tahsis.

Measured discharges were not available for both of these events and therefore the discharges had to be estimated based on assumed "n" values and the water level profiles. This is similar to the methodology used by the Water Survey of Canada when estimating discharge from water surface profile information. The "n" values, contraction coefficients and expansion coefficients were modified to obtain the surveyed river profiles. Drawings A-1003 and A-1004 show the surveyed highwater marks and the calibrated water surface. The resulting peak discharges were 400 m^3/s and 480 m^3/s for the 1989 and 1990 flood events. The calculated mean daily discharge for the 1989 flood event was 242 m^3/s.

The "n" values selected for use in the backwater model for the river channel ranged from 0.030 to 0.042 while left and right overbank "n" values ranged from 0.150 to 0.170 and 0.070 to 0.200 respectively. The contraction and expansion coefficients used for the river were 0.1 and 0.3 respectively.

The special bridge routine in HEC-2 did not provide sufficient headlosses when compared to the surveyed water levels. Therefore, normal river routing was used for bridge sections with high "n" values and loss coefficients. For the highway bridge an "n" value of 0.043 was used with contraction and expansion coefficients of 0.6 and 0.8, while for the Perry bridge 0.043, 0.4 and 0.6 were used. These values produced the best match to both surveyed water level profiles.

The Ministry of Environment report, "Preliminary Report on Tahsis River Flooding" dated February 1985, presented a 200-year flood profile based on a mean daily discharge of 552 m^3/s. The starting tide level was 2.4 m(GSC). Using these values in the present model produced water levels from 0.1 to 0.4 m lower than those from the 1985 study. This indicates that the two river profile models are consistent within the contingency allowance. Some of the difference may be accounted for by the approximate conversion of the mill datum water levels in the 1985 report to GSC water levels.

6.3.2 Sensitivity Analyses

Sensitivity analyses were carried out for starting water level, discharge and Manning's "n". The resulting variation in water levels was compared to the contingency allowances of 0.3 m for instantaneous discharge and 0.6 m for mean daily discharge.

The starting tidal water level used for all the back water analyses on the Tahsis River was 2.7 m(GSC). This level was based on the Higher High Water Large Tide plus storm surge, as explained in Section 6.2. The 200-year return period instantaneous discharges, 864 m^3/s for Tahsis at the mouth, 664 m^3/s for Tahsis upstream of McKelvie Creek and 344 m^3/s for McKelvie Creek, were used as the base case. For the base case the tide level was varied ± 0.5 m. The resulting water levels were affected up to cross section 7. The 200-year floodplain delineation at the mouth of the Tahsis River is governed by the recommended ocean flood level up to cross section 5.

Sensitivity to discharge was investigated by varying the discharge $\pm 20\%$ of the 200-year instantaneous discharge for the three reaches of interest. The results are presented in Table 5 below. The maximum difference in water level for the 200-year instantaneous discharge +20% and -20% was 1.5 m.

Table 5 - Tahsis River and McKelvie Creek Water Level (m) Discharge Sensitivity

CROSS SECTION	DISCHARGE		
	200-YEAR INSTANTANEOUS MINUS 20%	200-YEAR INSTANTANEOUS	200-YEAR INSTANTANEOUS PLUS 20%
Tahsis River at the Mouth Discharge	691 m^3/s	864 m^3/s	1037 m^3/s
1	2.7	2.7	2.7
2	2.7	2.7	2.8
3	2.7	2.7	2.7
4	3.0	3.3	3.7
5	3.3	3.7	4.2
6	3.4	3.9	4.4
7	3.9	4.5	5.1
8	4.4	5.0	5.6
9	4.5	5.1	5.7
10	5.0	5.7	6.4
11	5.2	5.8	6.5
12	5.2	5.7	6.3
14	6.2	6.8	7.4
15	6.2	6.8	7.2
16.1	6.7	7.5	8.2
Tahsis River U/S of McKelvie Creek Discharge	531 m^3/s	664 m^3/s	797 m^3/s
-16.1	6.7	7.5	8.2
18	7.2	8.0	8.7
19	7.4	8.2	8.9
20	7.4	8.2	8.9
21	7.7	8.4	9.0
22	7.9	8.5	9.1
23	8.4	8.8	9.3
24	9.1	9.3	9.6
McKelvie Creek Discharge	275 m^3/s	344 m^3/s	413 m^3/s
-16.1	6.7	7.5	8.2
16.3	7.0	7.7	8.4
16.4	6.8	7.3	7.8

The model sensitivity to Manning's "n" value was tested by varying "n" by ±10%. The 200-year instantaneous discharge was used for this test. The results are presented in Table 6 below. The maximum difference in water level from +10% to -10% of "n" was 0.5 m

Table 6 - Tahsis River and McKelvie Creek Water Level(m) "n" Value Sensitivity (200-Year Instantaneous Discharge)

CROSS SECTION	"n" - 10%	BASE CASE	"n" + 10%
Tahsis River at the Mouth Discharge	864 m³/s		
1	2.7	2.7	2.7
2	2.7	2.8	2.8
3	2.7	2.7	2.7
4	3.1	3.3	3.4
5	3.6	3.7	3.8
6	3.7	3.9	4.0
7	4.2	4.5	4.7
8	4.8	5.0	5.2
9	4.9	5.1	5.4
10	5.5	5.7	6.0
11	5.6	5.8	6.1
12	5.4	5.7	6.0
14	6.8	6.8	7.0
15	6.8	6.8	6.9
16.1	7.4	7.5	7.6
Tahsis River U/S of McKelvie Creek Discharge	664 m³/s		
-16.1	7.4	7.5	7.6
18	7.9	8.0	8.1
19	8.1	8.2	8.3
20	8.1	8.2	8.3
21	8.2	8.4	8.5
22	8.4	8.5	8.6
23	8.7	8.8	8.9
24	9.1	9.3	9.5
McKelvie Creek Discharge	344 m³/s		
-16.1	7.4	7.5	7.6
16.3	7.6	7.7	7.9
16.4	7.0	7.3	7.5

The Ministry of Environment requested calculation of a flood profile assuming a left bank dyke to determine the effect on flood levels of possible future encroachments. These calculations are intended for information only and further study is required for dyke design. The assumed dyke stretches from the Tahsis River Bridge to cross section 12, just downstream of the Perry Bridge. The results for the 200-year mean daily and instantaneous discharge are presented in Table 7. The contingency allowances of 0.6 m and 0.3 m, for daily and instantaneous discharge, have been included. The resulting water levels in the dyked reach are up to 0.4 m higher with the dyke in place than the existing conditions (compare Table 7 with Table 14). The dyke causes the 200-year instantaneous discharge to significantly impinge on the lower chord of the Perry Bridge, located between cross sections 14 and 15, raising water levels at the bridge by approximately 0.8 m. The elevation of the lower chord is 6.6 m.

Table 7 - Tahsis River and McKelvie Creek Water Level (m) Raised Left Bank Dyke (including contingency allowance*)

CROSS SECTION	DISCHARGE	
	200-YEAR DAILY	200-YEAR INSTANTANEOUS
Tahsis River at the Mouth Discharge	596 m^3/s	864 m^3/s
1	3.3	3.0
2	3.3	3.1
3	3.3	3.0
4	3.5	3.6
5	3.7	4.0
6	3.9	4.2
7	4.4	4.9
8	4.9	5.6
9	5.0	5.8
10	5.4	6.1
11	5.6	6.3
12	5.8	6.4
14	6.7	7.9
15	6.7	7.8
16.1	7.1	8.4
Tahsis River U/S of McKelvie Creek Discharge	452 m^3/s	664 m^3/s
-16.1	7.1	8.4
18	7.6	8.8
19	7.7	8.9
20	7.8	8.9
21	8.0	9.0
22	8.3	9.1
23	8.9	9.3
24	9.6	9.6
McKelvie Creek Discharge	231 m^3/s	344 m^3/s
-16.1	7.1	8.4
16.3	7.4	8.6
16.4	7.2	8.2

* Contingency allowance is 0.6 m on daily water levels and 0.3 m on instantaneous water levels.

6.4 Leiner River

6.4.1 River Profile Model

The cross sections supplied by the Ministry of Environment were used to develop the river profile model. The model was set up based on the photographs of the cross sections, supplied by the Ministry of Environment, and the site visit made in October 1991. Cross section 5 was omitted from the model since, at high flows, a large portion of discharge, on the left and right banks, would flow parallel to this section. Cross sections 3, 4, 7, and 8 were extended to Head Bay Road on the right bank.

The Leiner River has gravel bars and meanders similar to the Tahsis River upstream of the Perry Bridge. The selected "n" values and loss coefficients were based on the calibrated values from the Tahsis River. The main channel and overbank "n" values were 0.035 and 0.170 respectively. At the mouth the contraction and expansion coefficients were 0.3 and 0.7 respectively while in the river upstream these coefficients were 0.1 and 0.3.

No surveyed calibration data were available, but it was determined from a road maintenance contractor and the Village of Tahsis personnel that Head Bay Road floods on a regular basis between cross sections 3 and 6. A 5-year return period instantaneous discharge of 460 m^3/s, approximately equal to the 20-year return period daily discharge, was estimated based on the flood frequency analyses presented in Section 5. Using this discharge and the coefficients described above resulted in water levels high enough to flood Head Bay Road (see Drawing A-1005). This was the only means of checking the calibration of the flood profile model.

6.4.2 Sensitivity Analyses

Sensitivity analyses were carried out for starting water level, discharge and Manning's "n". The resulting variation in water levels was compared to the contingency allowances of 0.3 m for instantaneous discharge, and 0.6 m for mean daily discharge.

The starting tidal water level used for all the back water analyses on the Tahsis River was 2.7 m(GSC). This level was based on the Higher High Water Large Tide plus storm surge, as explained in the Section 6.2. For the 200-year return period instantaneous discharge, 1094 m^3/s, the tide level was varied ± 0.5 m. The resulting water levels were affected up to cross section 4. The 200-year floodplain delineation at the mouth of the Leiner River is governed by the recommended ocean flood level up to cross section 2.

Sensitivity to discharge was investigated by varying the discharge ±20% of the 200-year instantaneous discharge. The results are presented in Table 8 below. The maximum difference in water level for the 200-year instantaneous discharge +20% and -20% was 1.0 m.

Table 8 - Leiner River Water Level (m) Discharge Sensitivity

CROSS SECTION	DISCHARGE		
	200-YEAR INSTANTANEOUS MINUS 20% 875 m^3/s	200-YEAR INSTANTANEOUS 1094 m^3/s	200-YEAR INSTANTANEOUS PLUS 20% 1313 m^3/s
1	2.7	2.7	2.7
2	2.7	2.8	3.1
3	3.8	4.4	4.7
4	4.4	4.8	5.1
6	5.9	6.3	6.7
7	6.7	7.2	7.7
8	7.2	7.6	7.9
9	8.6	9.1	9.5

The model sensitivity to Manning's "n" value was tested by varying "n" by ±10%. The 200-year instantaneous discharge was used for this test. The results are presented in Table 11 below. The maximum difference in water level from +10% to -10% of "n" was 0.4 m.

Table 9 - Leiner River Water Level (m)
"n" Value Sensitivity
(200-Year Instantaneous Discharge, 1094 m^3/s)

CROSS SECTION	"n" - 10%	BASE CASE	"n" + 10%
1	2.7	2.7	2.7
2	2.8	2.8	2.8
3	4.2	4.4	4.5
4	4.8	4.8	4.8
6	6.1	6.3	6.5
7	7.0	7.2	7.4
8	7.6	7.6	7.8
9	9.0	9.1	9.1

6.5 Zeballos River

6.5.1 River Profile Model

The cross sections supplied by the Ministry of Environment were used to develop the river profile model. The model was set up based on the photographs of the cross sections, supplied by the Ministry of Environment, and the site visit made in October 1991.

Due to the size of the right bank overflow channel it was modelled as a separate channel, starting at cross section 3 at the downstream end and terminating at cross section 8 at the upstream end. The cross sections in the overflow channel were numbered 3.1 through 8.1 corresponding to the main river cross sections 3 through 8. Based on subsequent modelling it was found that approximately 10% to 15% of the total river flow passed through the overflow channel. The main river and the overflow channel discharges were adjusted until the calculated water levels at cross section 8 and 8.1 matched.

Although water levels were obtained during the July 1990 survey of cross sections, these could not be used for calibration purposes. The tidal influence, during low flow conditions affects water levels up to approximately cross section 9. The average discharge during the survey, July 5 through 7, 1990 was approximately 12.5 m^3/s, less than half of the mean annual discharge. Because of this the "n" values were selected based on the similarity between the Zeballos River and the Tahsis River.

The "n" values selected were based on the Tahsis River calibrated "n" values. The main river channel value was 0.035 while the overbank "n" values were 0.170. At the mouth the contraction and expansion coefficients were 0.3 and 0.6 respectively while upstream of the mouth they were 0.1 and 0.3. At the Zeballos River Bridge an "n" value of 0.040 was used, based on the calibration of the Tahsis River. Due to several log jams and debris in the overflow channel the selected "n" values were 0.100 for the channel and 0.200 for the overbanks (see Photo 18). An "n" value of 0.045 was used for the small bridge over the overflow channel (see Photo 17).

The Zeballos River Bridge was designed and built in 1977. Studies carried out for the design of the bridge, by Gower, Yeung and Associates Ltd., indicated that the November 13, 1975 flood level at the future location of the bridge was approximately 5.0 m(GSC). The recorded maximum instantaneous discharge for November 13, 1975, when prorated to the mouth of the Zeballos River, resulted in a discharge of 1240 m^3/s, approximately a 20-year return period event. The maximum tide level of 1.4 m(GSC) occurred at approximately 8:50 AM, while the peak instantaneous discharge occurred at 9:30 AM. Using this tide level and peak instantaneous discharge a water level of 5.3 m(GSC) was calculated at the bridge (see Drawing A-1006). According to local residents, the flow in the overflow channel has reduced significantly from what it used to be. If a higher flow capacity were attributed to the overflow channel the water level at the bridge would be reduced closer to the 5.0 m(GSC) elevation.

The calculated flood profile for the 1975 flood indicates that the existing left bank protection was not overtopped (see Drawing A-1006). There was no reported overtopping of the left bank during the 1975 flood. Photos 19 and 20 show the Zeballos River during the November 11, 1990 flood. Residents observed that approximately 0.5 m of freeboard was available on the left bank dyke during the flood. The recorded maximum instantaneous discharge, when prorated to the mouth of the Zeballos River, resulted in a discharge of 910 m^3/s, less than the 1975 flood. This means that marginal freeboard is available along portions of this dyke.

6.5.2 Sensitivity Analyses

Sensitivity analyses were carried out for starting water level, discharge and Manning's "n". The resulting variation in water levels was compared to the contingency allowances of 0.3 m for instantaneous discharge and 0.6 m for mean daily discharge.

The starting tidal water level used for all the back water analyses on the Zeballos River was 2.5 m(GSC). This level was based on the Higher High Water Large Tide plus storm surge, as explained in Section 6.2. For the 200-year return period instantaneous discharge, 1680 m^3/s, the tide level was varied ± 0.5 m. The resulting water levels were affected up to cross section 5. The 200-year floodplain delineation at the mouth of the Zeballos River is governed by the recommended ocean flood level up to cross section 2.

Sensitivity to discharge was investigated by varying the discharge ±20% of the 200-year instantaneous discharge. The results are presented in Table 10 below. The maximum difference in water level for the 200-year instantaneous discharge +20% and -20% was 1.6 m.

Table 10 - Zeballos River Water Level (m) Discharge Sensitivity

CROSS SECTION	DISCHARGE		
	200-YEAR INSTANTANEOUS MINUS 20%	200-YEAR INSTANTANEOUS	200-YEAR INSTANTANEOUS PLUS 20%
Discharged the Mouth	1344 m^3/s	1680 m^3/s	2016 m^3/s
1	2.5	2.5	2.5
2	2.5	2.4	2.4
3	3.0	3.3	3.7
Main Channel Discharge	1152 m^3/s	1420 m^3/s	1684 m^3/s
4	4.4	4.8	5.0
5	5.5	6.1	6.7
6	5.5	6.1	6.7
7	6.1	6.7	7.3
8	7.1	7.9	8.6
9	7.4	8.1	8.8
10	7.6	8.2	8.8
11	7.7	8.2	8.7
Overflow Channel Discharge	192 m^3/s	260 m^3/s	332 m^3/s
-3	3.0	3.3	3.7
4.1	4.9	5.2	5.6
5.1	5.1	5.5	5.9
6.1	5.2	5.6	6.0
7.1	6.5	7.3	8.1
8.1	7.1	7.9	8.6

The model sensitivity to Manning's "n" value was tested by varying "n" by ± 10%. The 200-year instantaneous discharge was used for this test. The results are presented in Table 11 below. The maximum difference in water level from +10% to -10% of "n" was 0.5 m.

Table 11 - Zeballos River Water Level (m) "n" Value Sensitivity (200-Year Instantaneous Discharge)

CROSS SECTION	"n" - 10%	BASE CASE	"n" + 10%
Discharge at the Mouth		1680 m^3/s	
1	2.5	2.5	2.5
2	2.4	2.4	2.4
3	3.3	3.3	3.5
Main Channel Discharge		1420 m^3/s	
4	4.5	4.8	4.9
5	6.1	6.1	6.2
6	6.1	6.1	6.2
7	6.6	6.7	6.8
8	7.8	7.9	8.0
9	8.0	8.1	8.3
10	8.0	8.2	8.4
11	8.0	8.2	8.5
Overflow Channel Discharge		260 m^3/s	
-3	3.3	3.3	3.5
4.1	5.1	5.2	5.4
5.1	5.3	5.5	5.7
6.1	5.5	5.6	5.8
7.1	7.2	7.3	7.4
8.1	7.7	7.9	8.1

For comparison purposes a flood profile was calculated for the 200-year instantaneous discharge assuming that the overflow channel was ineffective. All flow was assumed to be in the main river channel and the overbanks. The resulting water levels were 0.3 m to 0.5 m higher downstream of the Zeballos River Bridge and 0.7 m higher upstream of the bridge.

7. FLOOD HAZARDS

7.1 Ocean Flood Levels

7.1.1 General

As defined in the Terms of Reference flood levels for the ocean shall generally be based upon higher High Water Large Tide (HHWLT) plus an allowance for storm surge and wave runup from coincident winds. In the case of Tahsis and Zeballos long ocean inlets will also allow wind setup to occur. HHWLT and storm surge have been discussed in Section 6.2. The following sections describe the wind setup and wave runup components of the ocean flood levels and ocean flood levels are derived for Tahsis and Zeballos Inlets.

7.1.2 Wind Setup

Wind setup is caused by the wind pushing water to one end of a basin and raising the water level. The rise in water level is dependant on the wind velocity and the length and depth of the basin. Wind data from three Atmospheric Environment Stations, Spring Island (30 km NW), Estevan Point (50 km SE) and Tofino (120 km SE), were reviewed. These stations are located on the west coast of Vancouver Island both north and south of the study area. The maximum hourly recorded winds are from the south and occur in the winter. These winds range from 90 km/h to 130 km/h. Due to the partial sheltering of the Tahsis and Zeballos Inlets, a wind speed of 100 km/h is recommended for setup and wind wave calculations. This wind speed is consistent with wind speeds used by B.C. Hydro (1985a and b) for Probable Maximum Precipitation studies on Vancouver Island.

Based on calculation methods originally developed in the Netherlands and described by Saville (1962), the estimated setup for Tahsis and Zeballos Inlets is 0.04 m and 0.02 m respectively. The assumptions and results of the setup calculations are presented in Table 12.

**Table 12 - Wind Setup
Assumptions and Results**

	WIND SPEED (km/hr)	FETCH (km)	DEPTH (m)	SETUP (m)
Tahsis Inlet	100	32	128	0.04
Zeballos Inlet	100	19	183	0.02

7.1.3 Wave Runup

Estimation of wind wave heights depends on the effective fetch (the total fetch reduced by a factor which accounts for the width of the body of water) and the wind speed. The U.S. Army Corps of Engineers (1984) describe a methodology to calculate the significant wave height, the average height of the upper third of the waves. Using the 100 km/h wind speed and an effective fetch of 3.2 km for Tahsis and 1.2 km for Zeballos resulted in significant wave heights of 1.16 m and 0.70 m for Tahsis and Zeballos respectively.

These wave heights must then be adjusted for runup on the shore. Wave runup is variable depending on the geometry of the shore line, foreshore slope and type of slope protection. Developed areas of the shoreline have riprap protection. Undeveloped areas have long tidal flats where waves would be expected to dissipate. Assuming a riprap bank slope of 2H:1V results in a runup of 1.28 m for Tahsis and 0.77 m for Zeballos. The runup calculation procedures are described by Saville (1962).

7.1.4 Recommended Ocean Flood Levels

As described in the Terms of Reference the ocean flood levels should be based on the HHWLT plus an allowance for storm surge and wave runup from coincident winds. Table 13 demonstrates these calculations, including an allowance for wind setup. The recommended ocean flood levels are 4.0 m for Tahsis Inlet and 3.3 , for Zeballos Inlet.

Table 13 - Ocean Flood Levels

	TAHSIS INLET (m)	ZEBALLOS INLET (m)
HHWLT	2.00 (GSC)	1.80 (GSC)
Storm Surge	0.70	0.70
Setup	0.04	0.02
Wave Runup	1.28	0.77
Ocean Flood Level	4.02 (GSC)	3.29 (GSC)
Recommended Ocean Flood Level	4.0 (GSC)	3.3 (GSC)

The ocean flood levels indicated on the floodplain maps govern the designated flood level up to cross section 5 on the Tahsis River, cross section 2 on the Leiner River and cross section 2 on the Zeballos River. The location of the transition from ocean flood level to riverine flood level is indicated on Drawings 89-15-1 and 89-45-1 by an isogram for the ocean flood level.

7.2 River Flood Levels

As stated in the Terms of Reference, the designated flood level generally consists of the 200-year daily peak profile plus 0.6 m contingency allowance or the 200-year instantaneous peak profile plus 0.3 m contingency allowance, which ever is higher. Tables 14 through 16 present the flood profiles, including contingency allowance, for Tahsis, Leiner, and Zeballos Rivers. From these tables it is evident that due to the magnitude of the floods the 200-year instantaneous peak profile, including contingency allowance, results in the highest levels for all the rivers. These values, therefore, have been used to plot the flood lines on the floodplain maps contained in Appendix III. Drawings A-1003 to A-1006 show the selected 200-year flood profile without contingency allowance.

The floodplain maps were checked by Richard F. Rodman, P.Eng. during a site visit on December 9 to 11, 1991.

Table 14 - Tahsis River and McKelvie Creek Water Level[1] (m) (including contingency allowance)[2]

CROSS SECTION	RETURN PERIOD OF DISCHARGE			
	20-YEAR DAILY	20-YEAR INSTANTANEOUS	200-YEAR DAILY	200-YEAR INSTANTANEOUS
Tahsis River at the Mouth Discharge	363 m^3/s	639 m^3/s	596 m^3/s	864 m^3/s
1	3.3	3.0	3.3	3.0
2	3.3	3.0	3.3	3.1
3	3.3	3.0	3.3	3.0
4	3.4	3.2	3.5	3.6
5	3.4	3.5	3.7	4.0
6	3.5	3.6	3.8	4.2
7	3.7	4.1	4.3	4.8
8	4.0	4.6	4.7	5.3
9	4.0	4.7	4.8	5.4
10	4.3	5.1	5.2	6.0
11	4.5	5.3	5.4	6.1
12	4.7	5.3	5.5	6.0
14	5.3	6.3	6.4	7.1
15	5.3	6.3	6.4	7.1
16.1	5.7	6.8	6.9	7.8
Tahsis River U/S of McKelvie Creek Discharge	275 m^3/s	501 m^3/s	452 m^3/s	664 m^3/s
-16.1	5.7	6.8	6.9	7.8
18	6.3	7.3	7.4	8.3
19	6.6	7.5	7.6	8.5
20	6.7	7.6	7.6	8.5
21	7.2	7.8	8.0	8.7
22	7.8	8.1	8.3	8.8
23	8.5	8.7	8.9	9.1
24	9.2	9.4	9.6	9.6
McKelvie Creek Discharge	140 m^3/s	274 m^3/s	231 m^3/s	344 m^3/s
-16.1	5.7	6.8	6.9	7.8
16.3	6.2	7.2	7.2	8.0
16.4	6.4	6.9	7.1	7.6

1 Tidal level of 2.7 m was used for all profiles.
2 Contingency allowance is 0.6 m on daily water levels and 0.3 m on instantaneous water levels.

Table 15 - Leiner River Water Level[1] (m) (including contingency allowance[2])

CROSS SECTION	RETURN PERIOD OF DISCHARGE			
	20-YEAR DAILY 463 m^3/s	20-YEAR INSTANTANEOUS 792 m^3/s	200-YEAR DAILY 760 m^3/s	200-YEAR INSTANTANEOUS 1094 m^3/s
1	3.3	3.0	3.3	3.0
2	3.3	3.0	3.3	3.1
3	3.6	3.9	4.1	4.7
4	4.1	4.5	4.7	5.1
6	5.3	6.1	6.3	6.6
7	6.1	6.8	7.0	7.5
8	6.9	7.3	7.6	7.9
9	8.0	8.7	8.9	9.4

1 Tidal level of 2.7 m was used for all profiles.
2 Contingency allowance is 0.6 m on daily water levels and 0.3 m on instantaneous water levels.

Table 16 - Zeballos River Water Level[1] (m) (including contingency allowance[2])

CROSS SECTION	RETURN PERIOD OF DISCHARGE			
	20-YEAR DAILY	20-YEAR INSTANTANEOUS	200-YEAR DAILY	200-YEAR INSTANTANEOUS
Discharge at the Mouth	716 m^3/s	1160 m^3/s	1175 m^3/s	1680 m^3/s
1	3.1	2.8	3.1	2.8
2	3.1	2.8	3.1	2.7
3	3.1	3.1	3.4	3.6
Main Channel Discharge	646 m^3/s	1000 m^3/s	1013 m^3/s	1420 m^3/s
4	4.0	4.5	4.8	5.1
5	4.8	5.4	5.8	6.4
6	4.8	5.5	5.8	6.4
7	5.3	6.0	6.3	7.0
8	6.1	7.0	7.4	8.2
9	6.5	7.3	7.6	8.4
10	6.8	7.5	7.8	8.5
11	7.1	7.7	8.0	8.5
Overflow Channel Discharge	70 m^3/s	160 m^3/s	162 m^3/s	260 m^3/s
-3	3.1	3.1	3.4	3.6
4.1	4.4	4.9	5.3	5.5
5.1	4.6	5.2	5.5	5.8
6.1	4.6	5.2	5.6	5.9
7.1	5.2	6.4	6.7	7.6
8.1	6.1	7.0	7.4	8.2

1 Tidal level of 2.5 m was used for all profiles.
2 Contingency allowance is 0.6 m on daily water levels and 0.3 m on instantaneous water levels.

7.3 Tsunami Hazard

A tsunami is a long-period wave caused by an underwater disturbance such as a volcanic eruption or earthquake. Sometimes, it is incorrectly called a "tidal wave". Due to the location of the Tahsis and Zeballos Inlets, the threat of tsunami flooding is present. The present study does not include tsunami estimation, although an information note is included on the floodplain maps. The following data is presented for information purposes only. Possible future tsunami occurrences might result in water levels higher than the Designated flood levels depending upon the size of event, local amplification effects, and coincident tide level.

As noted in sections 4.1.2 and 4.2.2, the 1964 tsunami attained maximum elevations of approximately El. 2.8 m and El. 2.6 m (GSC) at Tahsis and Zeballos Inlets, respectively. Probable maximum wave heights, as determined by the Seaconsult Marine Research, are be 3.1 m and 6.1 m above mean sea level for Tahsis and Zeballos Inlets, respectively. Runup is not included in these probable maximum wave heights and they are based on simulation of tsunamis generated at remote offshore locations and not tsunamis resulting from local subduction zone earthquakes.

7.4 Debris Flow Hazard

Debris flows occur on steep mountainous gullies, creeks and streams. They consist of a rapidly moving mixture of organics, inorganics and water. Generally they are triggered by periods of intense precipitation. These hazards are not part of the present study, although an information note has been placed on the floodplain maps. As stated in section 4.1.3, a debris flow did occur in the west Tahsis townsite during the November 9, 1989 Tahsis River flood.

8. RECOMMENDATIONS

1. The floodplain areas outlined on Map 89-15-1 for Tahsis and Leiner Rivers and McKelvie Creek are recommended for designation pursuant to the Canada-British Columbia Floodplain Mapping Agreement.

2. The floodplain areas outlined on Map 89-45-1 for Zeballos River are recommended for interim designation (due to the 2-m contour intervals) pursuant to the Canada-British Columbia Floodplain Mapping Agreement.

3. Dyking and bank protection should be considered for the Village of Tahsis to reduce potential flood damage to existing development.

4. Raising the left bank dyke on the Zeballos River should be considered to increase freeboard.

5. Monitoring of future floods on all water courses addressed in this study should be carried out to verify the calculated flood profiles.

KLOHN LEONOFF LTD.

PROFESSIONAL PROVINCE OF Richard F. Rodman BRITISH COLUMBIA ENGINEER

Richard F. Rodman, P.Eng.
Project Engineer

PROFESSIONAL PROVINCE OF C. D. SELLARS BRITISH COLUMBIA ENGINEER

C. David Sellars, P.Eng.
Project Manager

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Village of Tahsis Archives.

Village of Zeballos Archives.

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APPENDIX I

PHOTOGRAPHS

PROJECT NO: PB 5749 0101

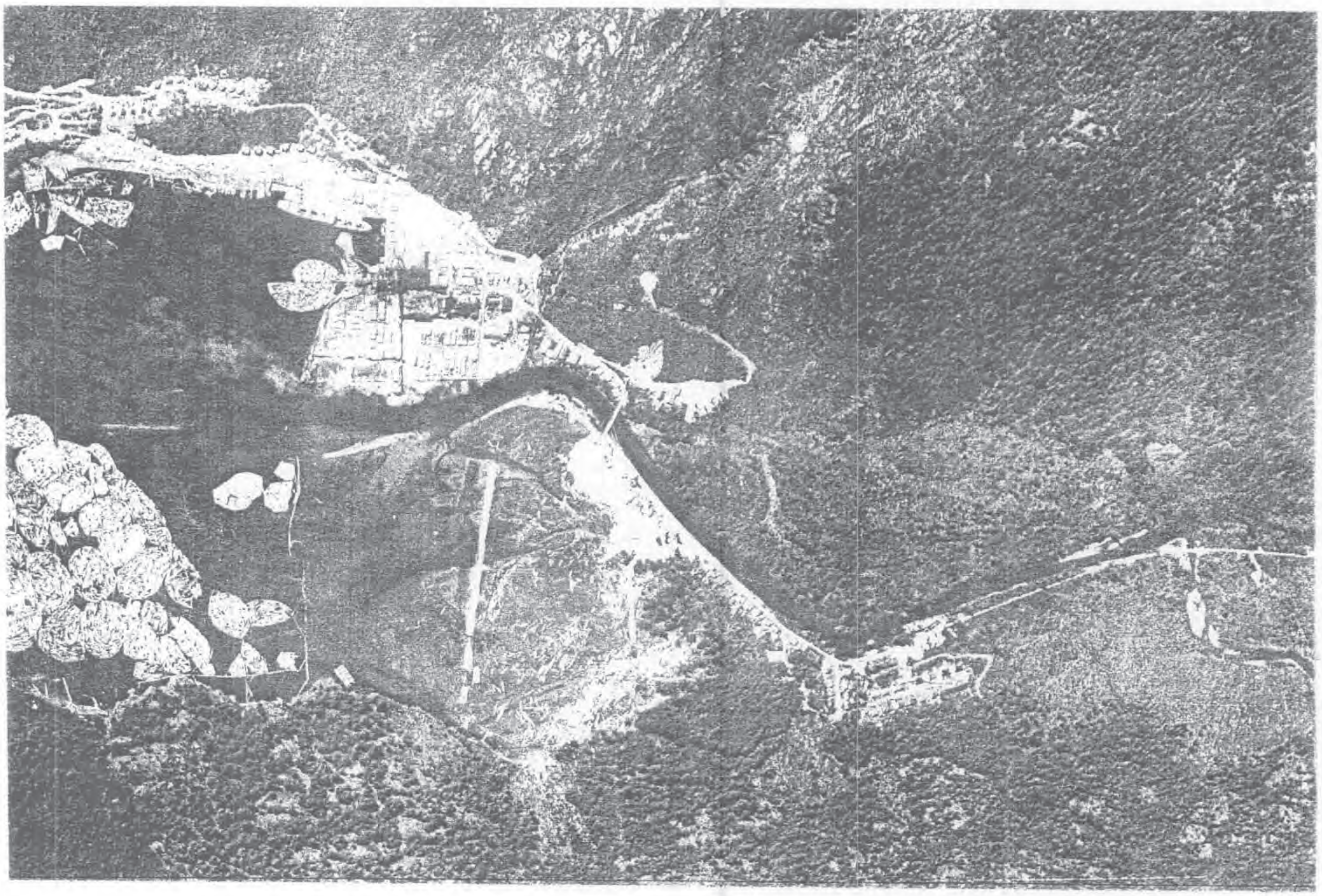
DATE: FEBRUARY 1992

TITLE: Tahsis, Leiner, and Zeballos Rivers Floodplain Mapping

ROLL NO:

TAHSIS (Photo 1)

1953 Airphoto showing mudflats which are now filled in.
(Village of Tahsis Archives)



PROJECT NO: PB 5749 0101

DATE: FEBRUARY 1992

TITLE: Tahsis, Leiner, and Zeballos Rivers Floodplain Mapping

ROLL NO:

TAHSIS (Photo 2)

Looking upstream on McKelvie Creek at cross section 16.3 during November 9, 1989 flood. (Photo by Village of Tahsis)

TAHSIS (Photo 3)

Looking downstream at approximately cross sections 19 to 21 during the November 9, 1989 flood. (Photo by Village of Tahsis)

PROJECT NO: PB 5749 0101

DATE: FEBRUARY 1992

TITLE: Tahsis, Leiner, and Zeballos Rivers Floodplain Mapping

ROLL NO:

TAHSIS (Photo 4)

Looking downstream at cross section 11 and flooded Maquinna Drive during November 9, 1989 flood.
(Photo by Village of Tahsis)

TAHSIS (Photo 5)

Internal flooding on left bank in Pit between cross sections 9 and 10.
November 9, 1989 flood.
(Photo by Village of Tahsis)

PROJECT NO: PB 5749 0101

TITLE: TAHSIS, LEIMER AND ZEBALLOS RIVERS FLOODPLAIN MAPPING

DATE: FEBRUARY 1992

ROLL NO: ....

TAHSIS (Photo 5.1)

Debris flow above Tahsis Village Mall in West Tahsis on November 9, 1989. (Photo by Village of Tahsis)

TAHSIS (Photo 5.2)

Tahsis Village Mall in West Tahsis on November 9, 1989. (Photo by Village of Tahsis)

PROJECT NO: PB 5749 0101

DATE: FEBRUARY 1992

TITLE: Tahsis, Leiner, and Zeballos Rivers Floodplain Mapping

ROLL NO:

LEINER (Photo 6)

Leiner River at the mouth.

PROJECT NO: PB 5749 0101

DATE: FEBRUARY 1992

TITLE: TAHSIS, LEINER AND ZEBALLOS RIVERS FLOODPLAIN MAPPING

ROLL NO:

ZEBALLOS (Photos 7 and 8)

High Tide Flooding on Maquinna Avenue, 1938. (Zeballos Heritage Board & Museum)

PROJECT NO: PB 5749 0101

DATE: FEBRUARY 1992

TITLE: TAHSIS, LEINER AND ZEBALLOS RIVERS FLOODPLAIN MAPPING

ROLL NO:

ZEBALLOS (Photo 9)

High Tide Flooding on Maquinna Avenue, 1938. (Zeballos Heritage Board & Museum)

PROJECT NO: PB 5749 0101

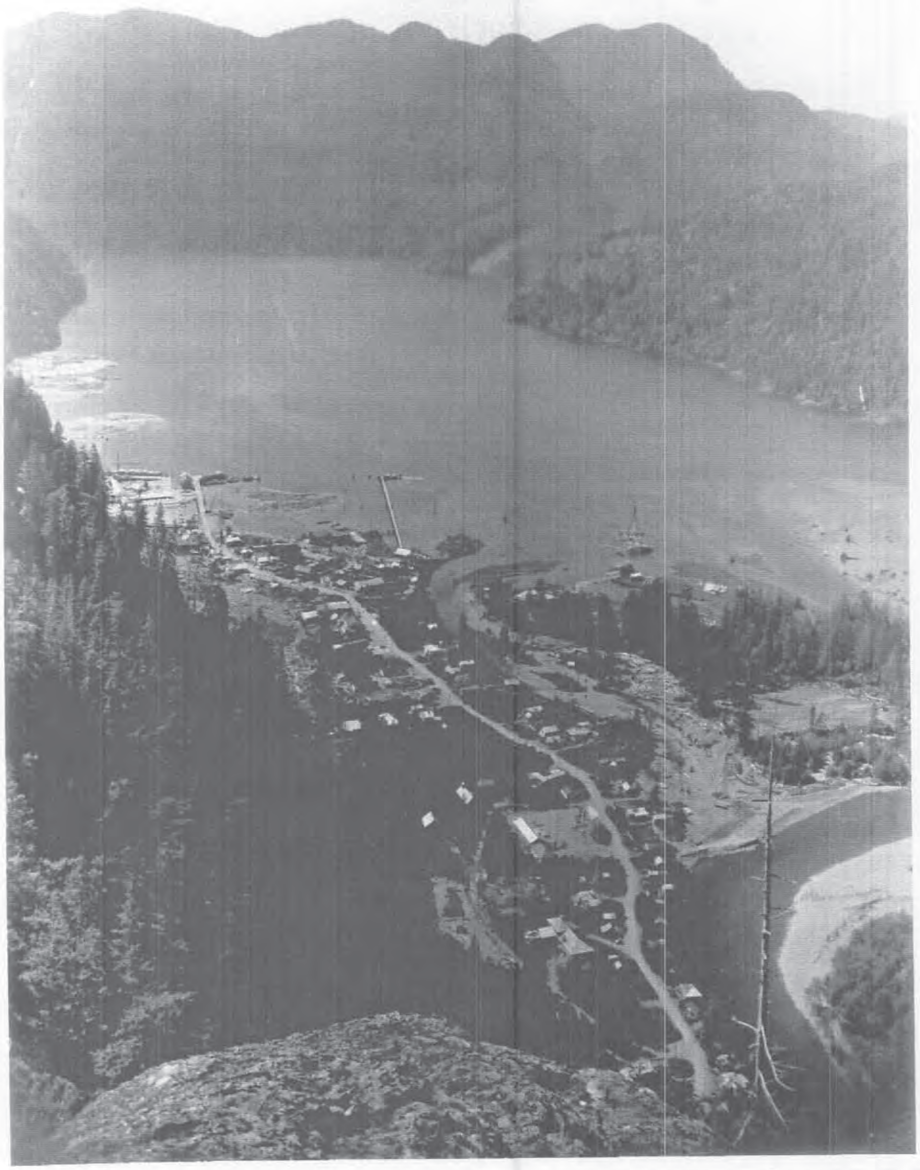
DATE: FEBRUARY 1992

TITLE: ~~TAHSIS, LEINER AND ZEBALLOS~~ RIVERS FLOODPLAIN MAPPING

ROLL NO:

ZEBALLOS (Photo 9.1)

Photo showing completed deflection dyke and former river bed dry. Pandora Crescent has not yet been built down centre of dry river channel (1940/41).



PROJECT NO: PB 5749 0101

DATE: FEBRUARY 1992

TITLE: Tahsis, Leiner, and Zeballos Rivers Floodplain Mapping

ROLL NO:

ZEBALLOS (Photo 10) Former Zeballos river channel blocked off with dyke in 1940/41. Channel partially infilled by Zeballos Iron Mines for access road to wharf (now called Pandora Crescent).

ZEBALLOS (Photo 11)

Left bank erosion in the early 1970's. Looking upstream at cross section 4 prior to Zeballos River Bridge. (Photo by Mr. & Mrs. B. Davies)

PROJECT NO: PB 5749 0101

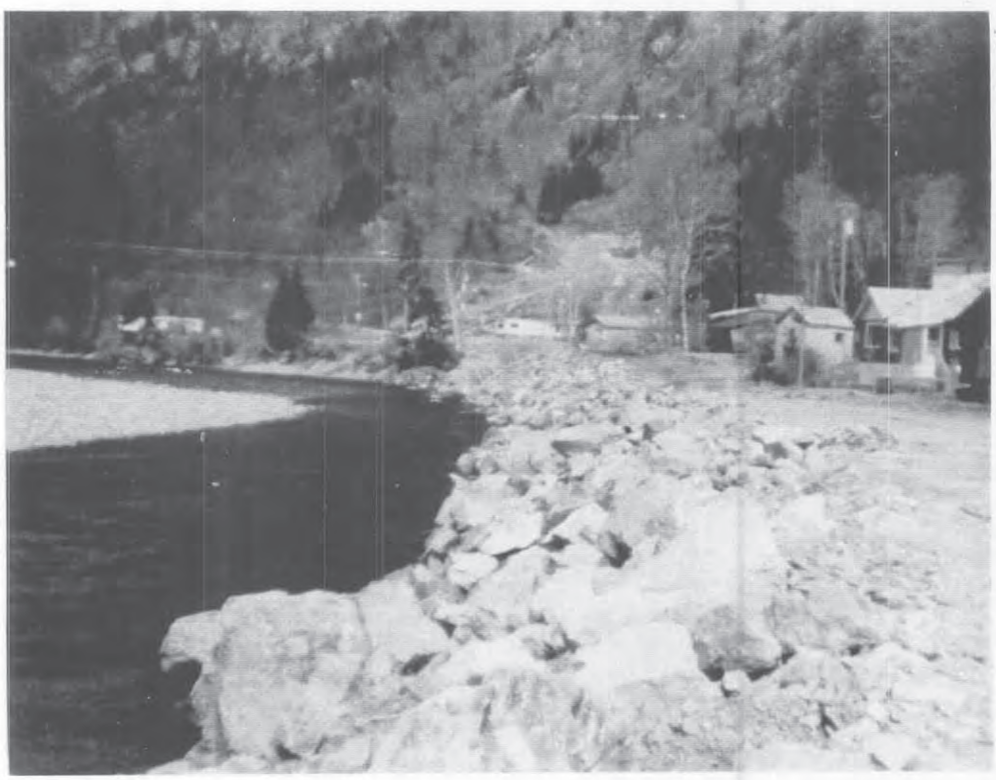
DATE: FEBRUARY 1992

TITLE: Tahsis, Leiner, and Zeballos Rivers Floodplain Mapping

ROLL NO:

ZEBALLOS (Photo 12)

Left bank erosion protection construction in the early 1970's. Looking downstream at cross section 4.
(Photo by Mr. & Mrs. B. Davies)



ZEBALLOS (Photo 13)

Completed left bank erosion protection in the early 1970's.
(Photo by Mr. & Mrs. B. Davies)

PROJECT NO: PB 5749 0101

DATE: FEBRUARY 1992

TITLE: Tahsis, Leiner, and Zeballos Rivers Floodplain Mapping

ROLL NO:

ZEBALLOS (Photo 14)

Left bank erosion protection installed in 1990 between cross sections 6 and 7.

PROJECT NO: PB 5749 0101

DATE: FEBRUARY 1992

TITLE: Tahsis, Leiner, and Zeballos Rivers Floodplain Mapping

ROLL NO:

ZEBALLOS (Photo 15) Looking upstream along slough against the east valley wall.

ZEBALLOS (Photo 16) Community center which was floated and rotated clockwise in the 1964 Tsunami.

PROJECT NO: PB 5749 0101

DATE: FEBRUARY 1992

TITLE: Tahsis, Leiner, and Zeballos Rivers Floodplain Mapping

ROLL NO:

ZEBALLOS (Photo 17) Looking downstream in overflow channel at cross section 5.1 and 6.1

ZEBALLOS (Photo 18) Log jam partly blocking overflow channel between cross sections 7.1 and 8.1

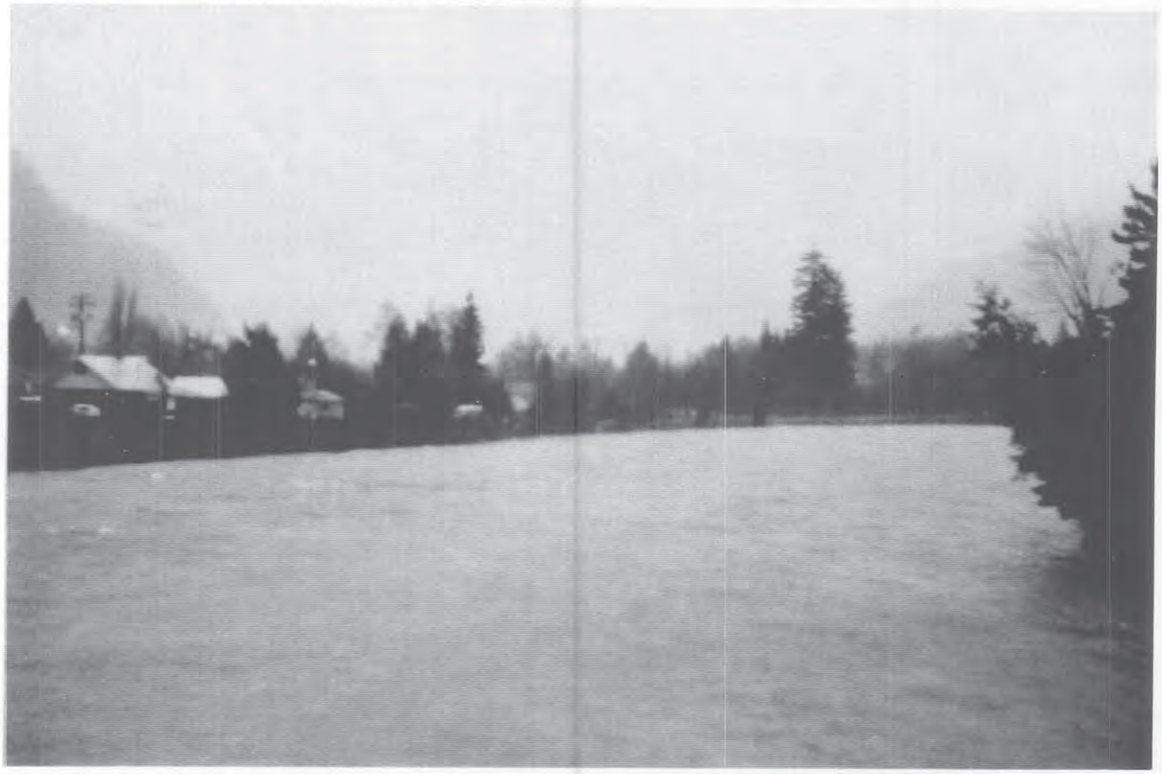
PROJECT NO: PB 5749 0101

DATE: FEBRUARY 1992

TITLE: Tahsis, Leiner, and Zeballos Rivers Floodplain Mapping

ROLL NO:

ZEBALLOS (Photo 19) Looking downstream from Zeballos River Bridge during November 11, 1990 flood. Low point in background is where Photo 20 was taken. (Photo by Bill Heidrick)



ZEBALLOS (Photo 20) Looking downstream on left bank dyke between cross sections 3 and 4 during November 11, 1990 flood. Approximately 0.5 m of freeboard on dyke. (Photo by Bill Heidrick)

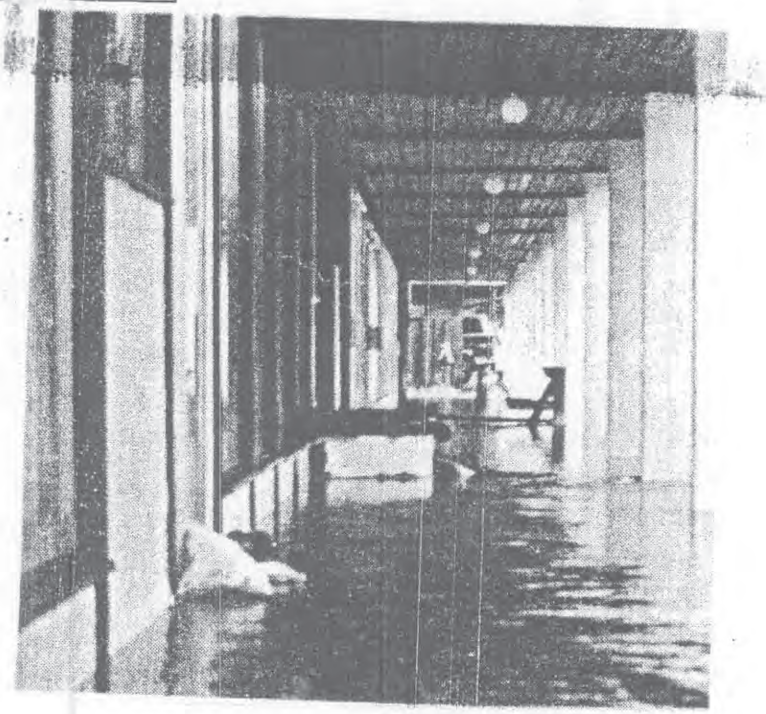
APPENDIX II

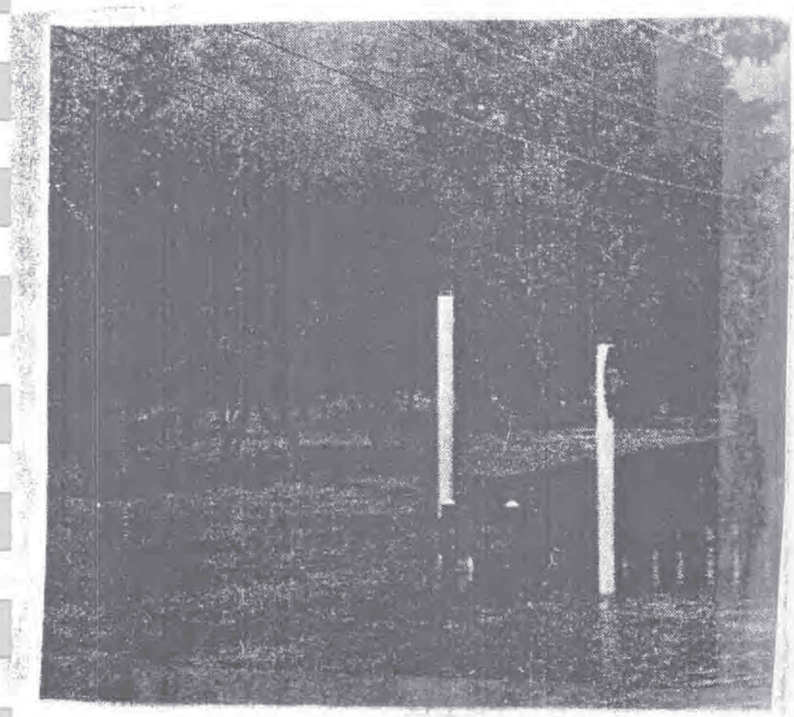
TAHSIS NEWSPAPER ARTICLE, November 15, 1989

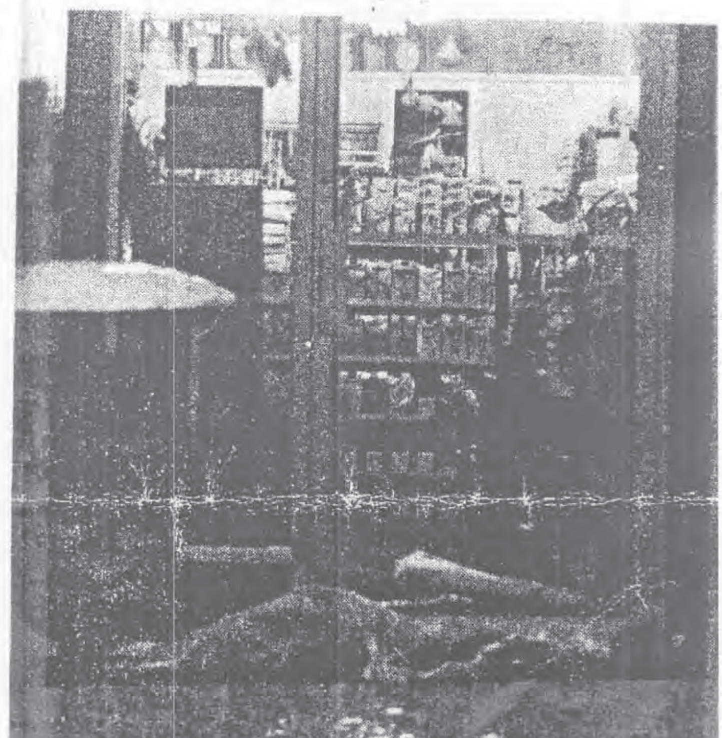
Flood Pictures:

Counter clock-wise from top left:

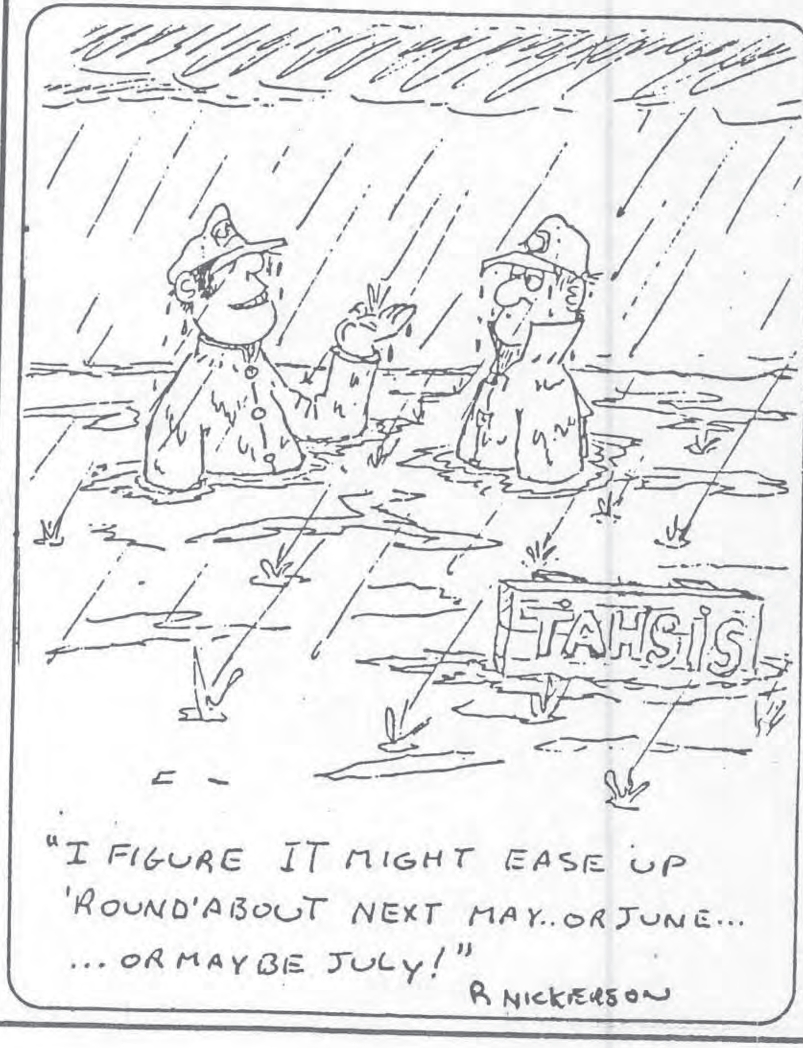
A flooded valley street, Larry Stevens uses an alternate form of transportation during the flood, sandbags used by shopkeepers in vain, and Tahsis Plaza flooding.







Tahsis Weather Report



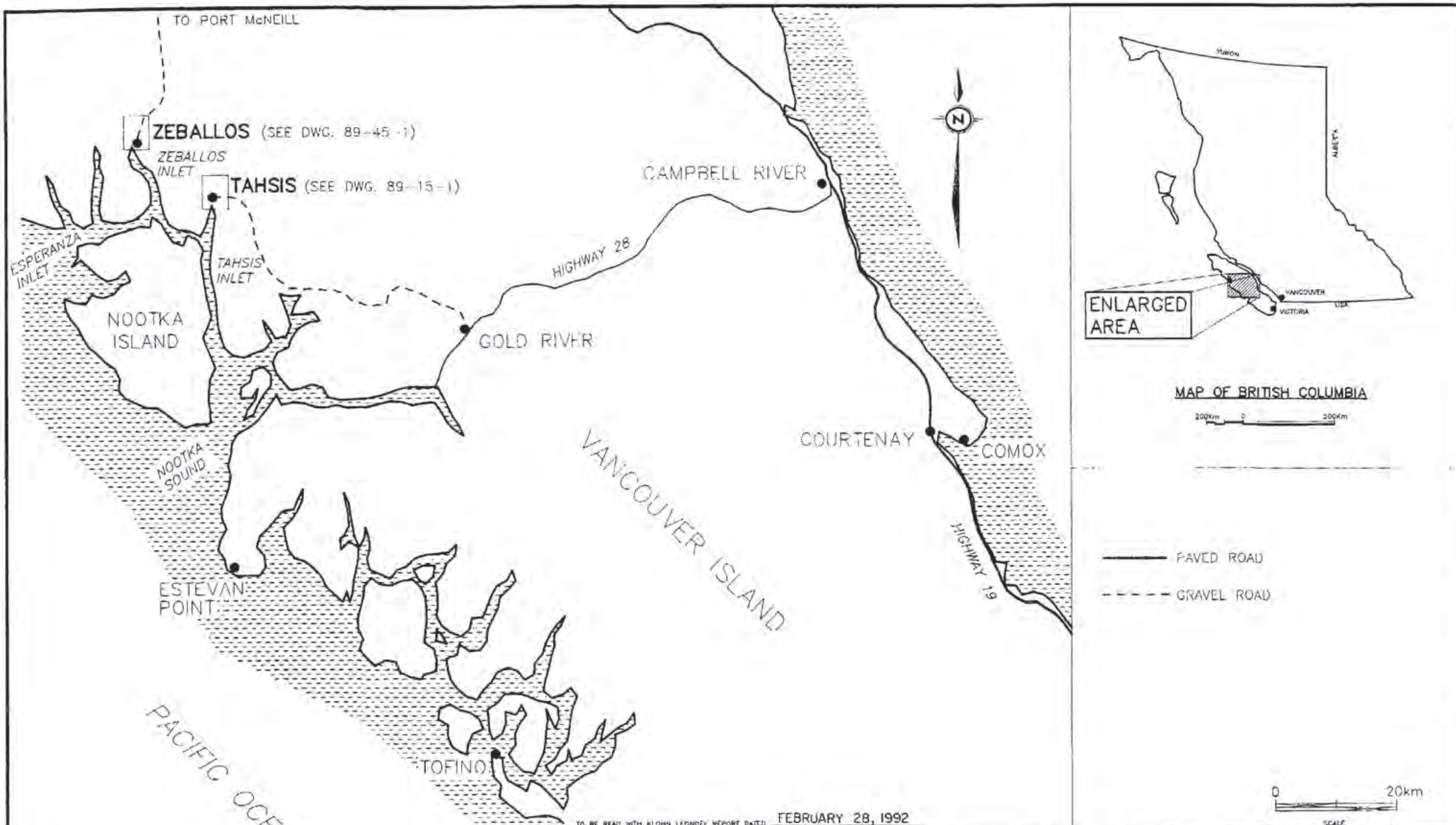
The climatological station report providedby the Village's Public Works employees on November 10 recorded 560.9mm of rain already this month, with 312mm of rain causing lasts weeks flooding.

The Inlet-Outlet will keep you up to date on weather information in future issues, for those of you who like the details. For those of you who don't, it will suffice to say, "It's monsoon season again."

APPENDIX III

FLOODPLAIN MAPS

DRAWINGS



TO BE READ WITH KLOHN LEONOFF REPORT DATED FEBRUARY 28, 1992

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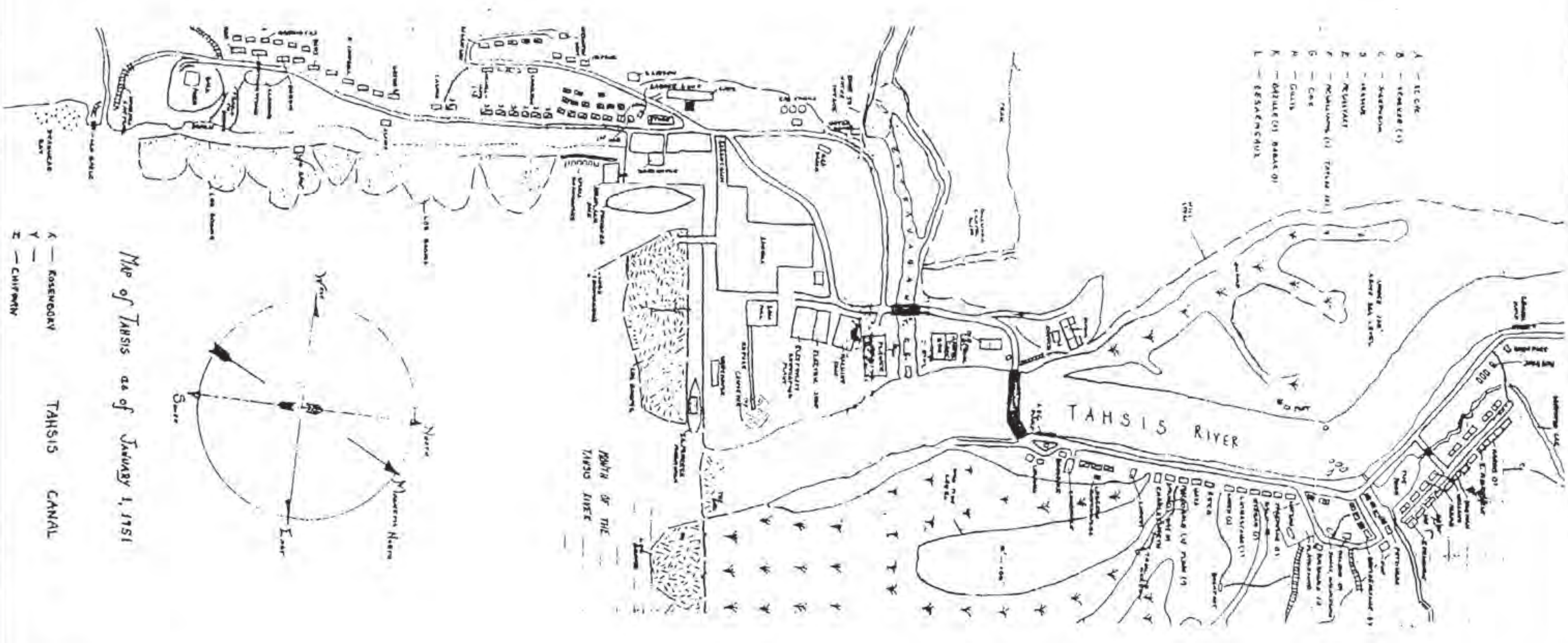
CLIENT: B.C. ENVIRONMENT, LANDS AND PARKS
ENVIRONMENT CANADA

PROJECT: FLOODPLAIN MAPPING PROGRAM
TAHSIS, LEINER AND ZEBALLOS RIVERS

TITLE: LOCATION PLAN

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
FEB. 28, 1992	PB5749 01	B-1001	



SOURCE

TAHSIS VILLAGE ARCHIVES

TO BE READ WITH KLOHN LEONOFF REPORT DATED FEBRUARY 28, 1992

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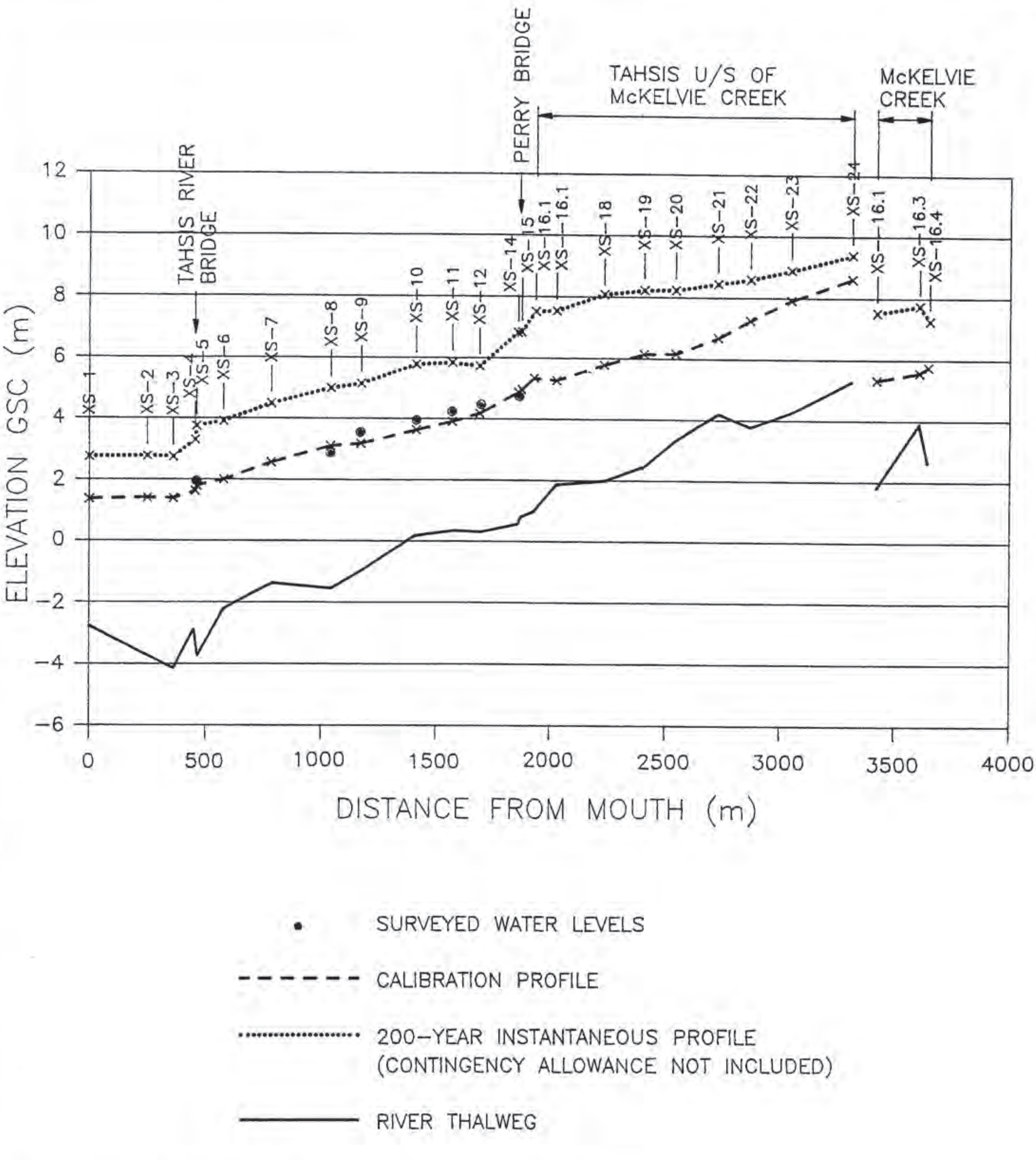
B.C. ENVIRONMENT, LANDS AND PARKS
ENVIRONMENT CANADA

PROJECT
FLOODPLAIN MAPPING PROGRAM
TAHSIS, LEINER AND ZEBALLOS RIVERS

TITLE
VILLAGE OF TAHSIS, 1951

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
FEB 28, 1992	PB5749 01	B-1002	



SCALE

PROJECT: FLOODPLAIN MAPPING PROGRAM TAHSIS, LEINER AND ZEBALLOS RIVERS

KLOHN LEONOFF LTD.

TITLE: TAHSIS RIVER CALIBRATION NOVEMBER 9, 1989

CLIENT: B.C. ENVIRONMENT, LANDS AND PARKS ENVIRONMENT CANADA

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
FEB. 28, 1992	PB5749 01	A-1003	

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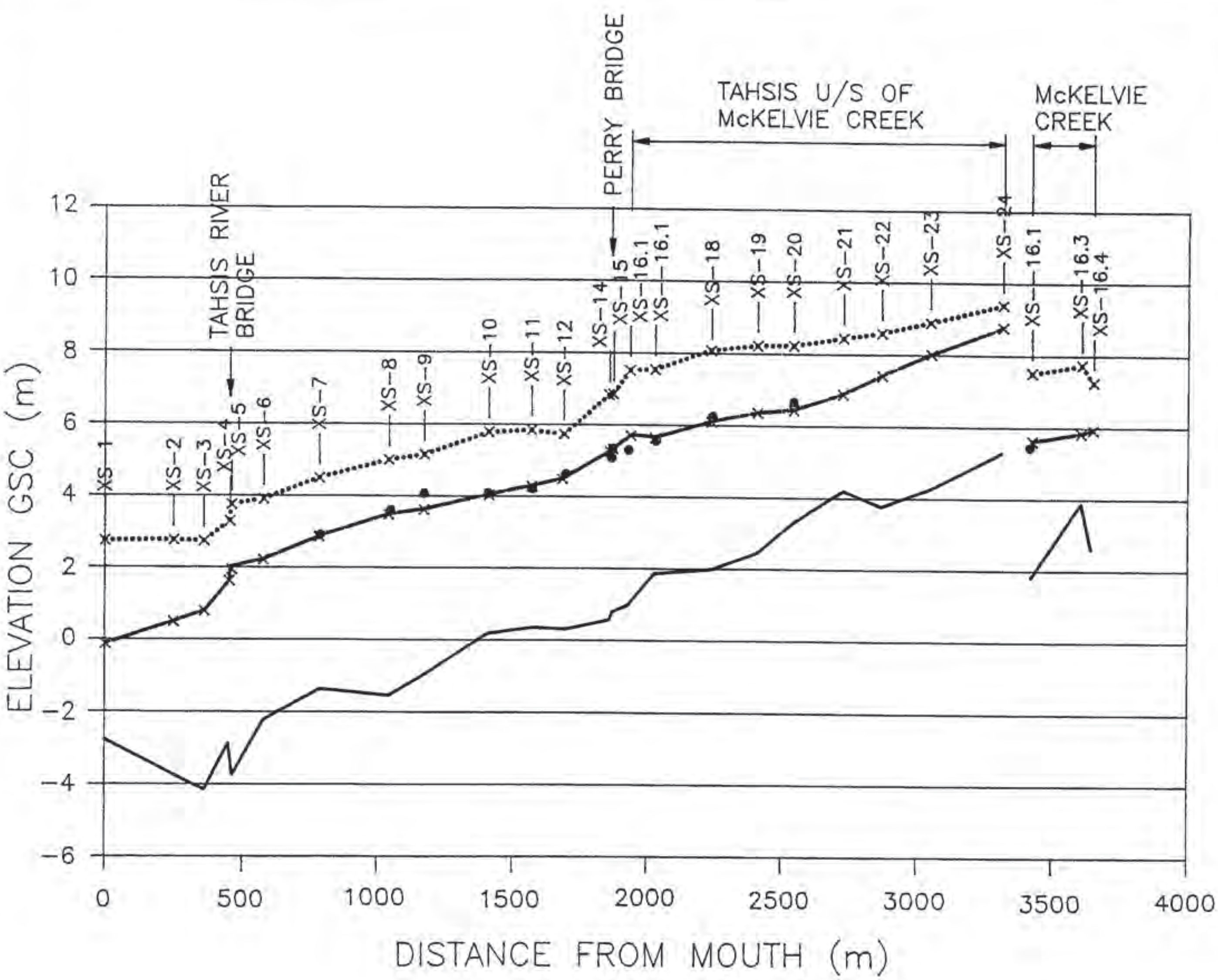


• SURVEYED WATER LEVELS

------ CALIBRATION PROFILE

·········· 200-YEAR INSTANTANEOUS PROFILE (CONTINGENCY ALLOWANCE NOT INCLUDED)

—— RIVER THALWEG

SCALE

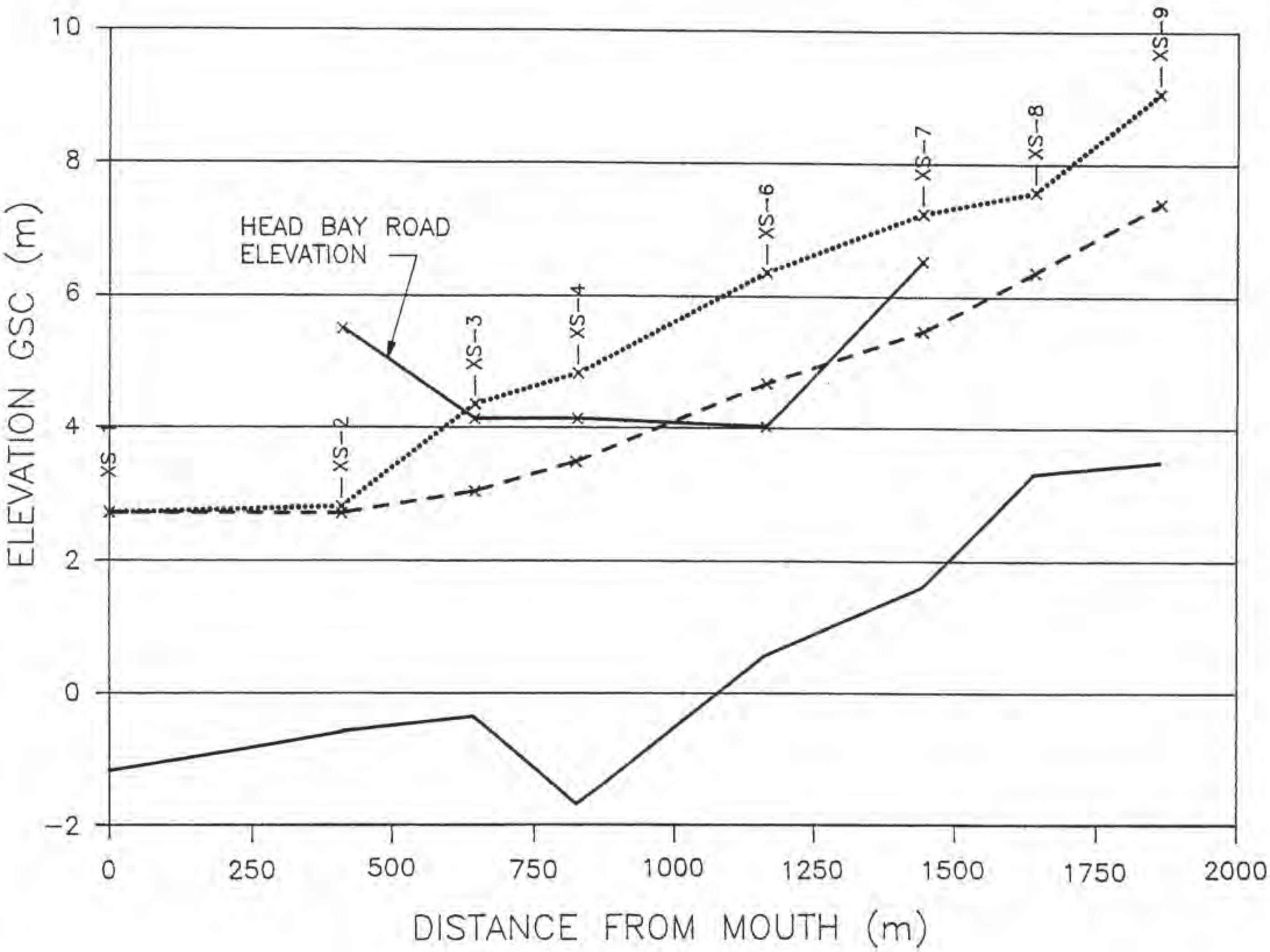
KLOHN LEONOFF LTD.

PROJECT: FLOODPLAIN MAPPING PROGRAM TAHSIS, LEINER AND ZEBALLOS RIVERS

TITLE: TAHSIS RIVER CALIBRATION NOVEMBER 11, 1990

CLIENT: B.C. ENVIRONMENT, LANDS AND PARKS ENVIRONMENT CANADA

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
FEB. 28, 1992	PB5749 01	A-1004	
APPROVED			



5-YEAR INSTANTANEOUS PROFILE

200-YEAR INSTANTANEOUS PROFILE
(CONTINGENCY ALLOWANCE NOT INCLUDED)

RIVER THALWEG

SCALE

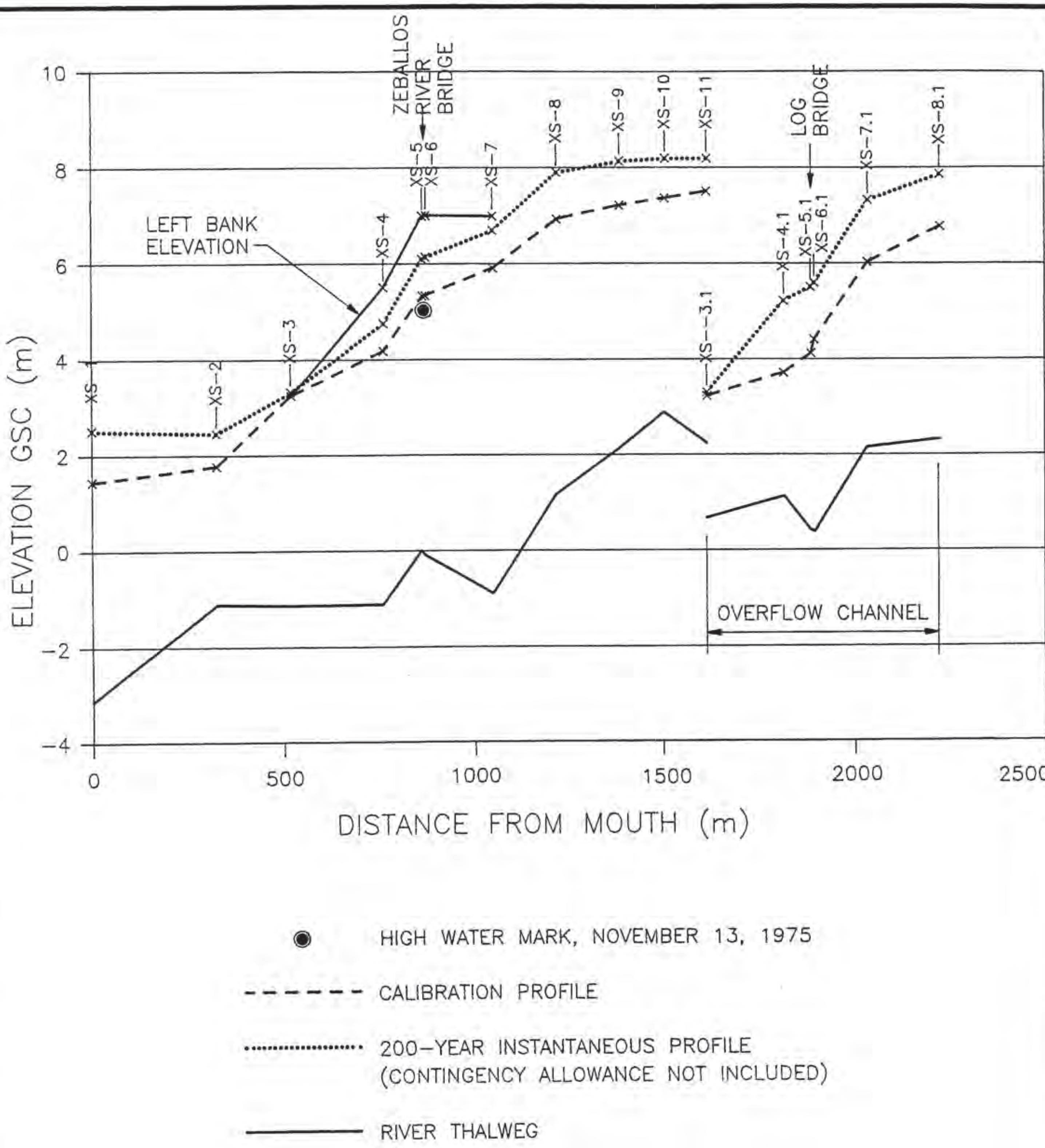
KLOHN LEONOFF LTD.

PROJECT: FLOODPLAIN MAPPING PROGRAM
TAHSIS, LEINER AND ZEBALLOS RIVERS

TITLE: LEINER RIVER FLOOD PROFILES

CLIENT: B.C. ENVIRONMENT, LANDS AND PARKS
ENVIRONMENT CANADA

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
FEB. 28, 1992	PB5749 01	A-1005	
APPROVED			



SCALE

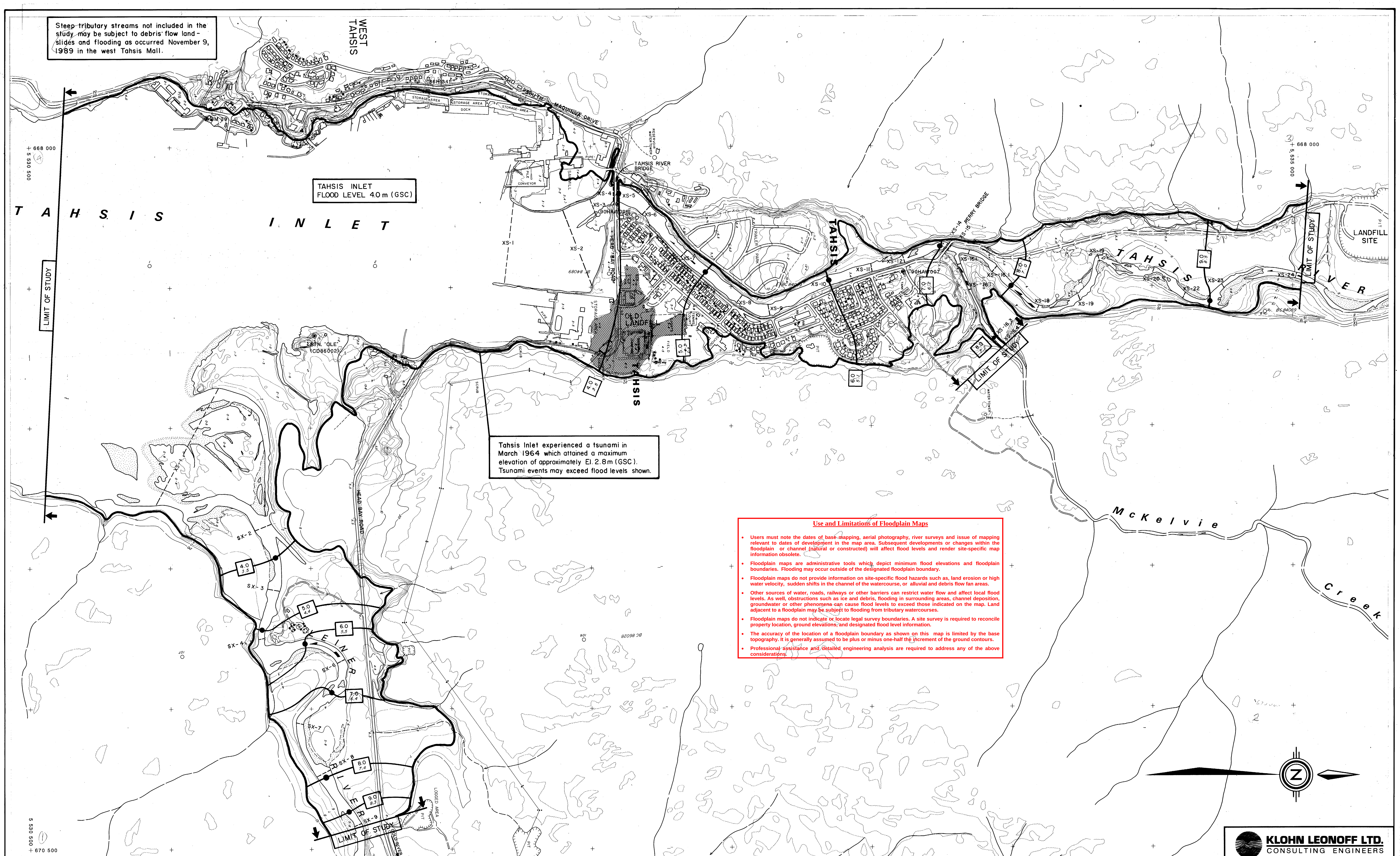
KLOHN LEONOFF LTD.

PROJECT: FLOODPLAIN MAPPING PROGRAM TAHSIS, LEINER AND ZEBALLOS RIVERS

TITLE: ZEBALLOS RIVER FLOOD PROFILE NOVEMBER 13, 1975

CLIENT: B.C. ENVIRONMENT, LANDS AND PARKS ENVIRONMENT CANADA

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
FEB. 28, 1992	PB5749 01	A–1006	
APPROVED			



Use and Limitations of Floodplain Maps

- Users must note the dates of base mapping, aerial photography, river surveys and issue of mapping relevant to dates of development in the map area. Subsequent developments or changes within the floodplain or channel (natural or constructed) will affect flood levels and render site-specific map information obsolete.
- Floodplain maps are administrative tools which depict minimum flood elevations and floodplain boundaries. Flooding may occur outside of the designated floodplain boundary.
- Floodplain maps do not provide information on site-specific flood hazards such as, land erosion or high water velocity, sudden shifts in the channel of the watercourse, or alluvial and debris flow fan areas.
- Other sources of water, roads, railways or other barriers can restrict water flow and affect local flood levels. As well, obstructions such as ice and debris, flooding in surrounding areas, channel deposition, groundwater or other phenomena can cause flood levels to exceed those indicated on the map. Land adjacent to a floodplain may be subject to flooding from tributary watercourses.
- Floodplain maps do not indicate or locate legal survey boundaries. A site survey is required to reconcile property location, ground elevations, and designated flood level information.
- The accuracy of the location of a floodplain boundary as shown on this map is limited by the base topography. It is generally assumed to be plus or minus one-half the increment of the ground contours.
- Professional assistance and detailed engineering analysis are required to address any of the above considerations.

NOTES

Produced by: British Columbia Water Management Branch, Special Projects Section, Floodplain Mapping Program.

Survey: River survey done by Surveys Section, Water Management Branch, July 1990.

a) Horizontal control based on provincial network.
b) Elevations are in metres and are referred to Geodetic Survey of Canada datum. (◉ indicates Survey Monument).

Mapping: Base mapping done by Map Production Division, Surveys and Resource Mapping Branch, Project 88-024, November 1988; Air Photography 1984, 1986; NAD 27.

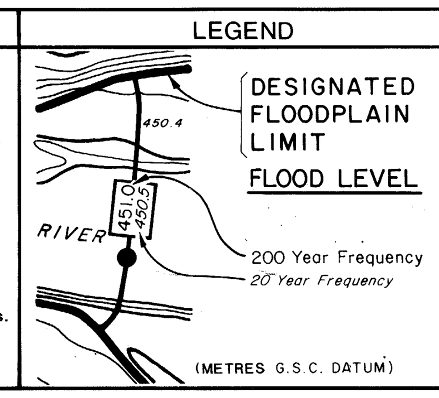
a) Contour interval 1 metre and greater; spot elevatons shown to 0.1 metres, with accuracy to ± 0.3 metres, except where noted.
b) Grid origin referred to U.T.M. Projection Zone 9 .

FLOODPLAIN DATA

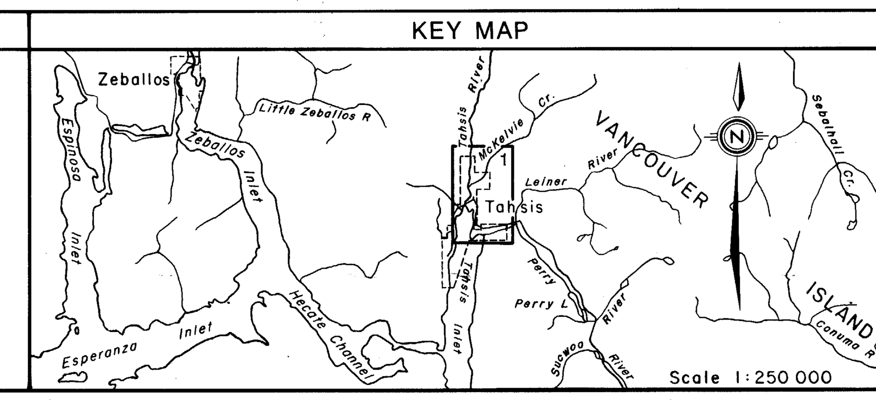
1. The floodplain areas as depicted on this map have been designated pursuant to the Canada/British Columbia Floodplain Mapping Agreement (1988) by the Minister of the Environment for Canada and the Minister of Environment, Lands and Parks for British Columbia.

   Flooding may still occur outside of the designated floodplain areas. The Ministers do not assume any liability by reason of the designation or failure to designate areas on this map.
2. The Designated Flood has a statistical frequency of occurrence of once every 200 years.
3. The flood levels were computed using a standard step method modelling technique, assuming open water flow conditions.
4. The floodplain limits assume the absence of all dykes.
5. The floodplain limits and flood levels include an allowance for freeboard.
6. The floodplain limits are not established on the ground by legal survey.
7. The floodplain limits are not delineated for side streams and tributaries.
8. The required setback of buildings from the natural boundaries of lakes and watercourses to allow for the passage of floodwaters and possible bank erosion is not shown. This information is available either through local municipalities or the Ministry of Environment, Lands and Parks.
9. MAPS AVAILABLE FROM SURVEYS AND RESOURCE MAPPING BRANCH, MAPS B.C., MAP AND AIR PHOTO SALES, VICTORIA, B.C.

LEGEND



KEY MAP



REVISIONS

No.	DESCRIPTION	DATE

ISSUE OF MAPPING
DATE SEPT. 30, 1992

ENVIRONMENT CANADA INLAND WATERS / ENVIRONNEMENT CANADA EAUX INTÉRIEURES
BRITISH COLUMBIA MINISTRY OF ENVIRONMENT / COLOMBIE-BRITANNIQUE MINISTÈRE DE L'ENVIRONNEMENT
CANADA BRITISH COLUMBIA FLOODPLAIN MAPPING AGREEMENT / L'ACCORD CANADA COLOMBIE-BRITANNIQUE SUR LA CARTOGRAPHIE DES PLAINES D'INONDATION

KLOHN LEONOFF LTD.
CONSULTING ENGINEERS

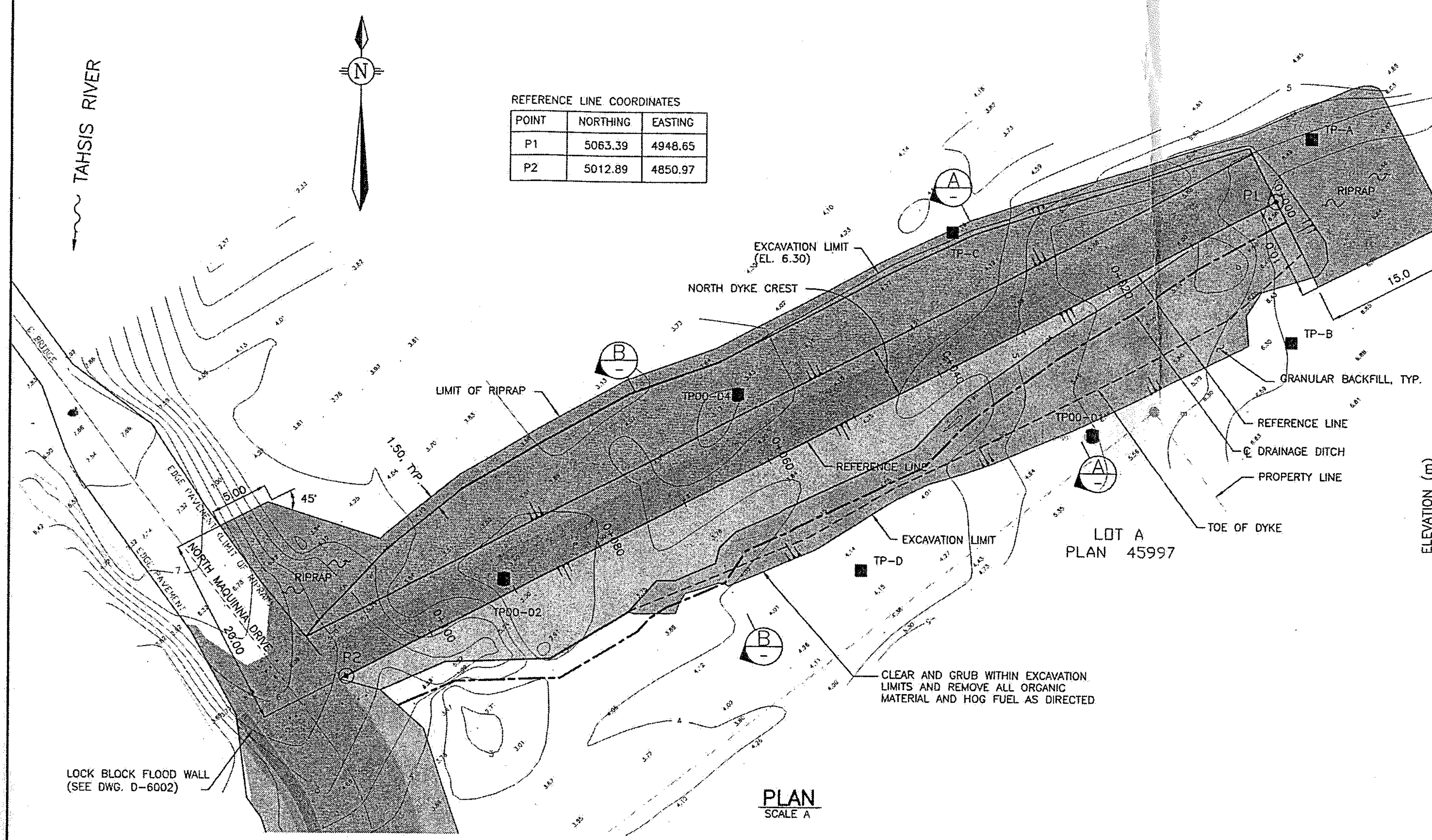
FLOODPLAIN MAPPING
TAHSIS AND LEINER RIVERS
VILLAGE OF TAHSIS

100m 0 100 200 300 400 500m
Scale in metres

DRAWN F.C.
CHECKED
RIVER SURVEY T.D.
DESIGNED R.F.R.
ENGINEER R. F. Rodman
RECOMMENDED R W Nichols
APPROVED [signature]

FILE No. 930-5691
N.T.S. MAP No. 92E/15
SCALE 1 : 5 000
NEGATIVE No.
DRAWING No. 89-15-1 REV.
SHEET 1 of 1

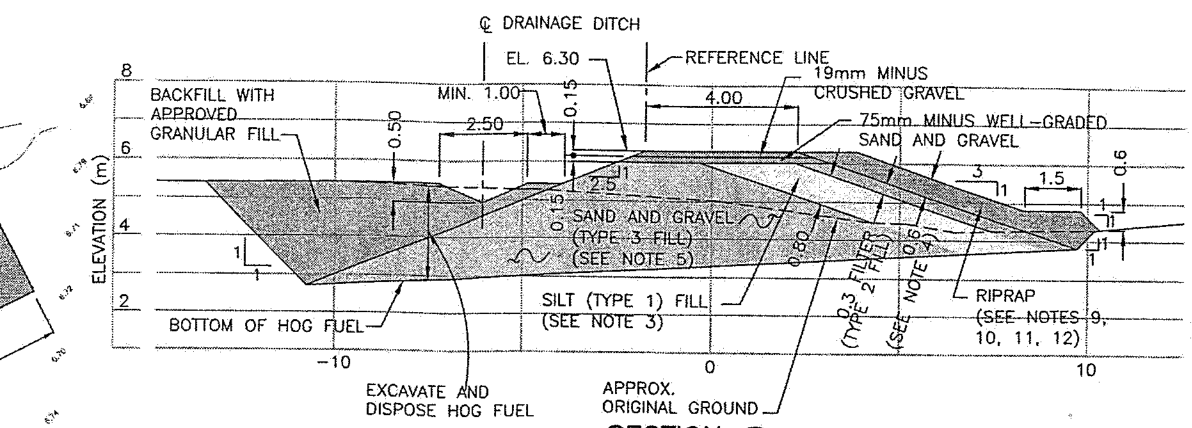
DDflmg



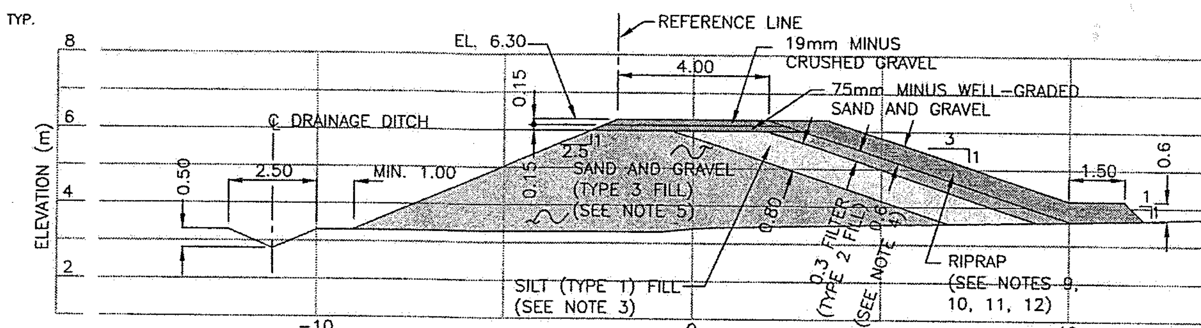
REFERENCE LINE COORDINATES

POINT	NORTHING	EASTING
P1	5063.39	4948.65
P2	5012.89	4850.97

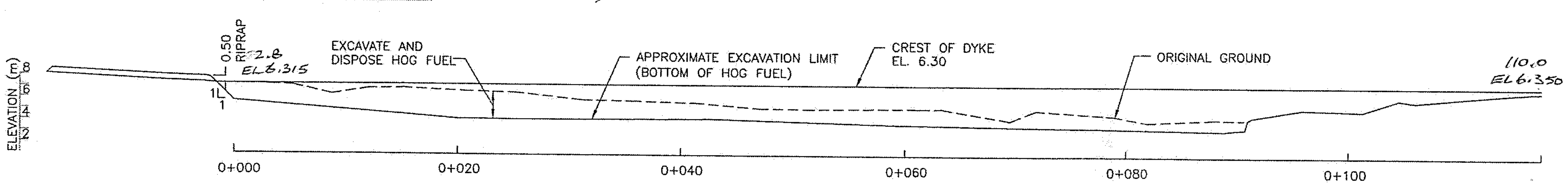
PLAN
SCALE A



SECTION A
SCALE C



SECTION B
SCALE C



PROFILE
SCALE B

LEGEND

TP-D TEST PIT No. D

NOTES:

1. PROOF ROLL STRIPPED SUBGRADE BEFORE PLACING COMPACTED FILL.
2. FOR SAND SUBGRADES, SATURATE THE SUBGRADE AND COMPACT BEFORE PLACING DYKE FILL.
3. TYPE 1 FILL MATERIAL SHALL BE NON-ORGANIC SILT OR SILTY SAND HAVING NOT LESS THAN 25% BY WEIGHT PASSING A 0.075 mm (NO. 200 MESH) SIEVE, MEETING THE GRADATION SHOWN IN FIGURE 1.
4. FILTER MATERIAL (TYPE 2 FILL) SHALL BE MADE BY PROCESSING MATERIAL FROM THE FORESTRY PIT (TYPE A AS SHOWN IN FIGURE 1) TO REMOVE THE MINUS 10mm (3/8 INCH) FRACTION SUCH THAT IT MEETS THE GRADATION FOR TYPE 2 FILL SHOWN IN FIGURE 1.
5. THE MINUS 10mm (3/8 INCH) FRACTION GENERATED FROM PROCESSING FOR TYPE 2 FILL SHALL CONSTITUTE THE DYKE BODY SAND AND GRAVEL (TYPE 3) FILL AND SHALL MEET THE GRADATION SHOWN IN FIGURE 1.
6. ALL FILL MATERIALS SHALL BE PLACED IN LAYERS NOT EXCEEDING 300 mm IN THICKNESS, AND EACH LAYER SHALL BE MACHINE-COMPACTED AT OR NEAR OPTIMUM MOISTURE CONTENT TO A DENSITY OF NOT LESS THAN 95% OF THE MAXIMUM DRY DENSITY, DETERMINED BY THE MODIFIED PROCTOR TEST, ASTM D1517. AT OPTIMUM WATER CONTENT, THIS DENSITY USUALLY CAN BE ACHIEVED BY 6 UNIFORM PASSES OF A MINIMUM 10 TONNE VIBRATORY DRUM ROLLER.
7. PLACEMENT AND COMPACTION OF MATERIALS IN HORIZONTAL LAYERS IS PREFERABLE.
8. USE OF FROZEN OR OVERLY WET MATERIALS IS NOT PERMITTED. PROTECT TYPE 1 FILL FROM EXCESSIVE WETTING.
9. RIPRAP SHALL BE HARD, DENSE, ROUGHLY EQUIDIMENSIONAL, WITH ANGULAR FACES AND WITH RELATIVE DENSITY NOT LESS THAN 2.65, DURABLE QUARRY STONE, FREE FROM SEAMS, CRACKS OR OTHER STRUCTURAL DEFECT. TO MEET THE SIZE DISTRIBUTION SHOWN IN FIGURE 1. RIPRAP SHALL BE SHAPED SUCH THAT NEITHER THE BREADTH NOR THICKNESS OF ANY INDIVIDUAL PIECE IS LESS THAN ONE-THIRD OF ITS LENGTH.
10. RIPRAP SHALL BE PLACED ON CLEAN, SMOOTH, UNFROZEN SURFACE, FREE FROM SNOW AND ICE, USING METHODS WHICH DO NOT LEAD TO SEGREGATION OR DEGRADATION. RIPRAP STONES SHALL BE PLACED IN A MANNER TO SECURE SURFACE AND CREATE A STABLE MASS. LARGER STONES SHALL BE PLACED AT BOTTOM OF SLOPES. THE FINISHED SURFACES SHALL BE FREE FROM OBJECTIONABLE POCKETS OF SMALL STONES AND/OR CLUSTERS OF LARGER STONES.
11. COMMENCE PLACING RIPRAP AND FILTER AT TOE OF SLOPE AND CONTINUE PLACEMENT WORKING UP SLOPE. DRESS RIPRAP BY REWORKING SURFACE AT LEAST ONCE SO THAT VOIDS ARE FILLED AND SURFACES ARE WELL-KEYED, DENSE AND UNIFORM. DO NOT RUN EQUIPMENT ON FINISHED SURFACES.
12. ROUNDED RIPRAP IS ACCEPTABLE FOR USE. HOWEVER IT SHALL FORM NOT MORE THAN 20 PERCENT OF THE RIPRAP MASS BY WEIGHT, AND IT SHALL BE EVENLY DISTRIBUTED THROUGHOUT THE RIPRAP MASS.
13. PROVIDE ENVIRONMENTAL PROTECTION IN ACCORDANCE WITH SECTION 01561 – ENVIRONMENTAL PROTECTION, VOLUME II OF THE MASTER MUNICIPAL CONSTRUCTION DOCUMENTS, PRINTED 2000.

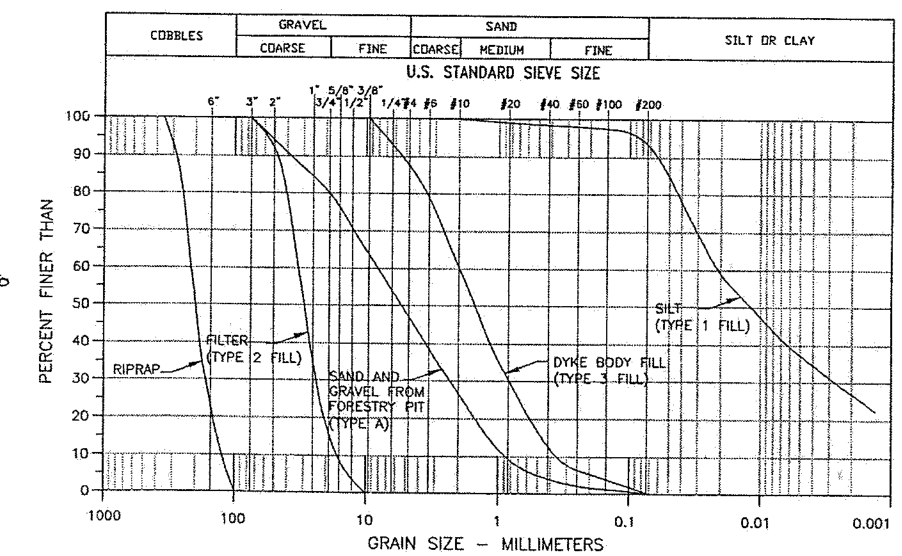


FIG. 1 FILL MATERIAL GRADATION

SCALE C 0 5m
SCALE B 0 10m
SCALE A 0 20m
SCALE AS SHOWN

NO.	DATE	ISSUE / REVISION	DRAWN	CHK'D	DESIGN	APP'D
0	FEB. 06/01	ISSUED FOR CONSTRUCTION	CYW	DP	RAV	AD

PROFESSIONAL ENGINEER, PROVINCE OF BRITISH COLUMBIA, R. A. VIDONI, 6-2-2001

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

CLIENT: VILLAGE OF TAHSIS

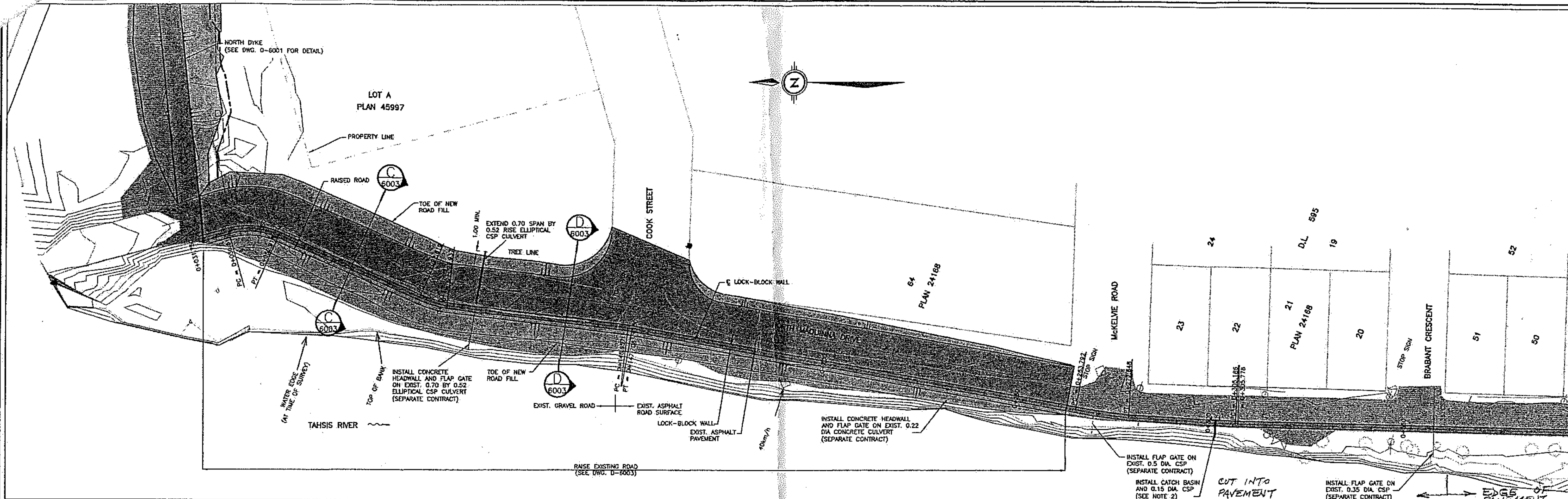
KLOHN CRIPPEN

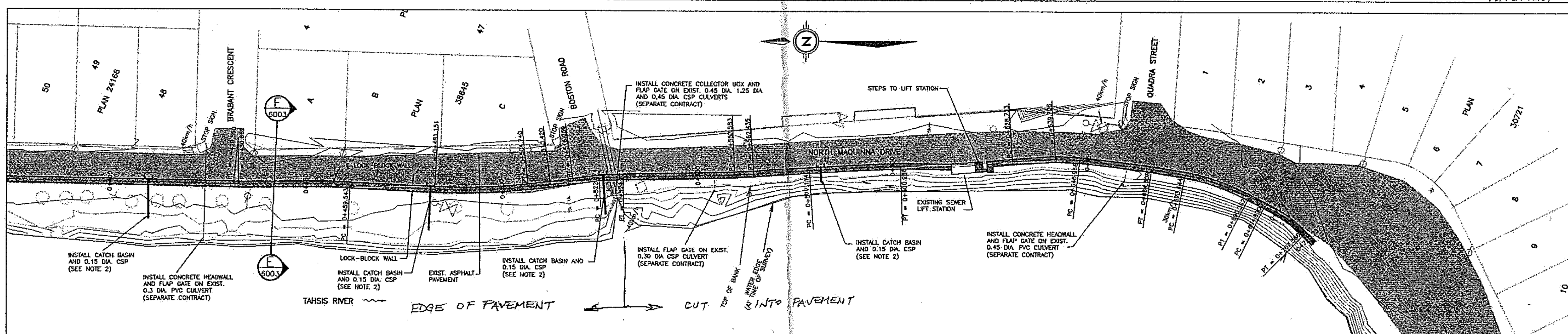
PROJECT: TAHSIS FLOOD PROTECTION

TITLE: NORTH DYKE PLAN AND SECTIONS

PROJECT No. PG7442 06 | DWG. No. D-6001 | REV 0

CANCEL PRINTS BEARING PREVIOUS





SCALE 0 25m

LEGEND

- DENOTES STREET SIGN
- DENOTES UTILITY POLE
- DENOTES WATER VALVE
- DENOTES FIRE HYDRANT
- DENOTES CATCH BASIN
- DENOTES NEW CATCH BASIN
- DENOTES SANITARY MANHOLE
- DENOTES TREE
- DENOTES TEST PIT

NOTES

1. FOR PROFILE AND CROSS SECTIONS SEE DWG. D-6003.
2. CATCH BASIN SHALL CONFORM TO TOP INLET CATCH BASIN AS SHOWN IN STANDARD DETAIL DWG. NO. S11 IN VOLUME II OF THE MASTER MUNICIPAL CONSTRUCTION DOCUMENT. LEAD PIPE SHALL BE 0.15 DIA. CSP. FINAL LOCATION OF CATCH BASINS TO BE DETERMINED IN THE FIELD BY THE CONTRACT ADMINISTRATOR.

NO.	DATE	ISSUE / REVISION	DRAWN	CHK'D	DESIGN	APP'D
0	FEB. 06/01	ISSUED FOR CONSTRUCTION	CYW	DP	RAV	AO

PROFESSIONAL ENGINEER — PROVINCE OF BRITISH COLUMBIA — R. A. VIDONI — 2-2-2001

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CLIENT: VILLAGE OF TAHSIS

KLOHN CRIPPEN

PROJECT: TAHSIS FLOOD PROTECTION

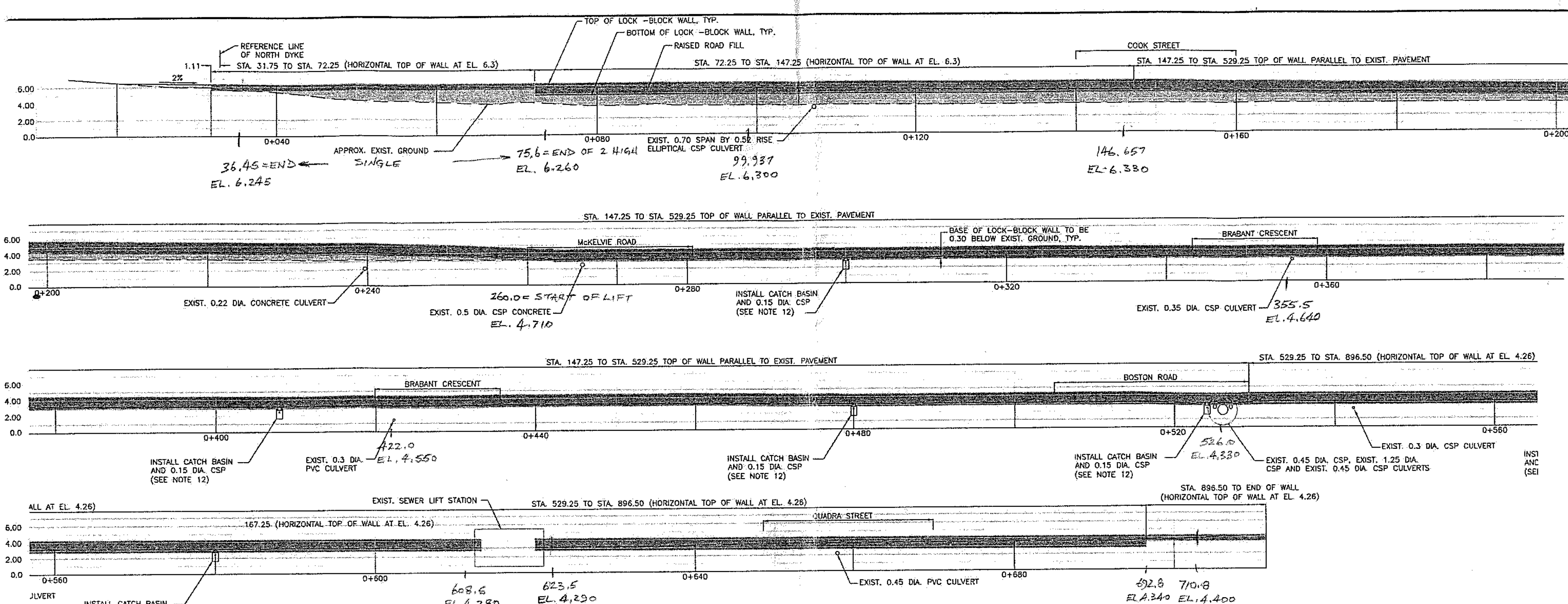
TITLE: CONCRETE LOCK BLOCK FLOOD WALL PLAN

PROJECT No: PG7442 06

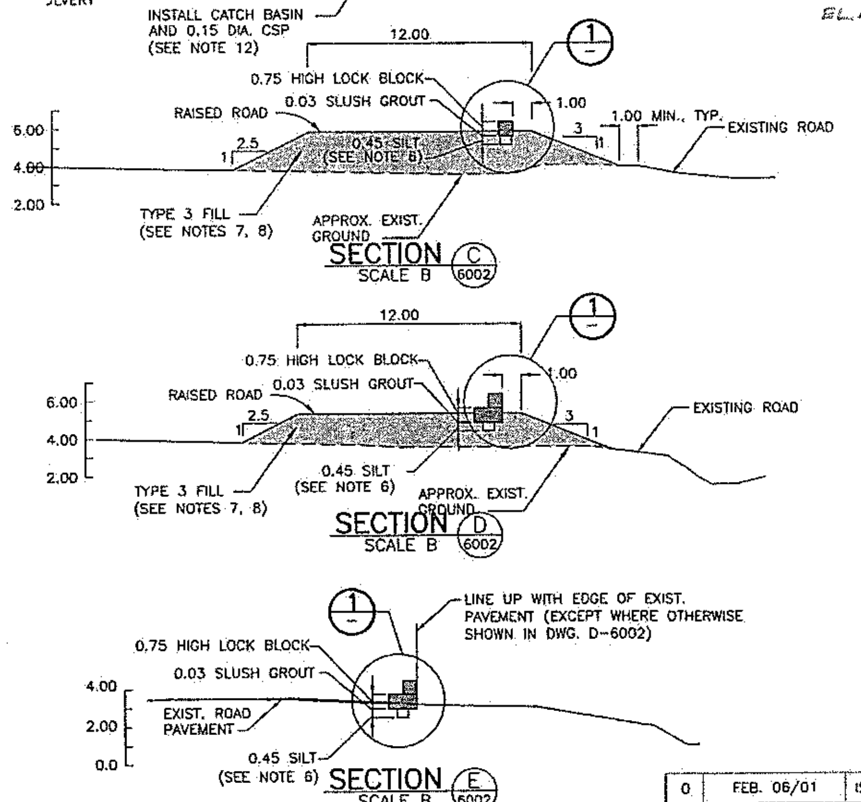
FIG. No.: D-6002

REV.: 0

CANCEL PRINTS BEARING PREVIOUS



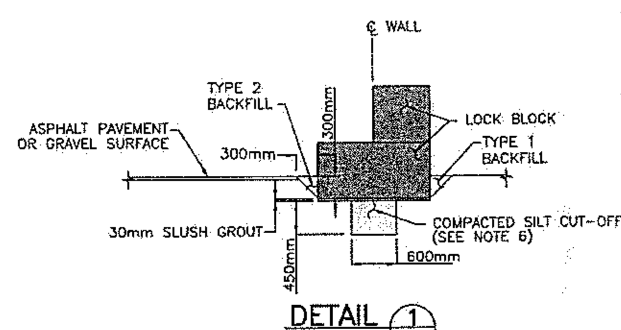
PROFILE
SCALE A



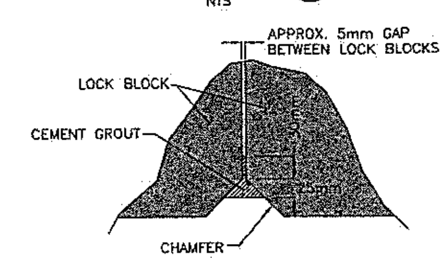
SECTION C — SCALE B (6002)

SECTION D — SCALE B (6002)

SECTION E — SCALE B (6002)



DETAIL 1 — NTS



DETAIL 2 — NTS

NOTES:

1. THE CONTRACTOR SHALL CONFIRM THE ACTUAL SIZES, DIMENSIONS AND LOCATIONS OF ALL EXISTING SERVICES AND STRUCTURES WITHIN THE AREA OF OPERATIONS, AND SHOULD NOT ASSUME THAT SIZES, DIMENSIONS AND LOCATIONS SHOWN ON THE DRAWINGS ARE EITHER ACCURATE OR COMPLETE.
2. LOCK-BLOCK WALL TO BE SET MIN. 0.3m BELOW SURFACE OF GROUND OR ROAD ON A BED OF 0.03m THICK SLUSH GROUT.
3. PRIOR TO PLACING SLUSH GROUT, SUBGRADE UNDER FLOOD WALL SHALL BE PROOF ROLLED.
4. SLUSH GROUT SHALL BE MIXED HAVING A SAND/CEMENT RATIO OF 5:1 WITH JUST ENOUGH WATER ADDED TO RENDER IT TO A PUTTY-LIKE CONSISTENCY. LOCK BLOCKS SHALL BE SEATED ON THE SLUSH GROUT BED IMMEDIATELY AFTER IT IS LAID.
5. THE VERTICAL AND HORIZONTAL GAPS AND JOINTS BETWEEN LOCK BLOCKS SHALL BE FILLED WITH CEMENT MORTAR AS SHOWN IN DETAIL 2. CEMENT MORTAR SHALL BE SAKRETE OR APPROVED EQUAL, MIXED IN ACCORDANCE TO MANUFACTURER'S SPECIFICATIONS TO FORM A STIFF PUTTY AND TROWLED INTO THE GAPS AND JOINTS. DO NOT OVERWORK. DO NOT ADD WATER OR "WET-UP" MATERIAL THAT HAS STARTED TO SET. PROTECT FROM FREEZING OR RAPID DRYING FOR AT LEAST 24 HOURS.
6. A SILT CUT-OFF IS TO BE CONSTRUCTED UNDER THE SLUSH GROUT. THE FILL FOR THE CUT-OFF SHALL MEET THE GRADATION FOR TYPE 1 FILL AS SHOWN IN FIGURE 1, DWG. D-6001. THE CUT-OFF FILL SHALL BE PLACED IN LAYERS NOT EXCEEDING 150mm IN THICKNESS, WITH EACH LAYER COMPACTED TO 95 PERCENT OF THE MAXIMUM DRY DENSITY, AS DETERMINED BY THE MODIFIED PROCTOR TEST, ASTM D1517, AT OPTIMUM WATER CONTENT.
7. RAISED ROAD FILL SHALL MEET THE GRADATION FOR TYPE 3 FILL AS SHOWN IN FIGURE 1, DWG. D-6001.
8. RAISED ROAD FILL SHALL BE PLACED IN LAYERS NOT EXCEEDING 300mm IN THICKNESS, WITH EACH LAYER MACHINE-COMPACTED AT OR NEAR OPTIMUM MOISTURE CONTENT TO A DENSITY OF NOT LESS THAN 95% OF THE MAXIMUM DRY DENSITY, DETERMINED BY MODIFIED PROCTOR TEST ASTM D1517, AT OPTIMUM WATER CONTENT. THIS DENSITY USUALLY CAN BE ACHIEVED BY 6 UNIFORM PASSES OF A MINIMUM 10 TONNE VIBRATORY DRUM ROLLER.
9. MINIMUM SOIL COVER BETWEEN TOP OF CULVERTS, SEWER AND WATER PIPES AND BOTTOM OF LOCK-BLOCKS SHALL BE 300mm. WHERE COVER IS LESS THAN 300mm, THE LOCK-BLOCK UNITS IN THE VICINITY OF THE PIPE SHALL BE PLACED AT A HIGHER ELEVATION AS DIRECTED TO PROVIDE THE MINIMUM COVER. IN AREAS WHERE COVER BETWEEN TOP OF PIPE AND EXISTING GROUND SURFACE IS LESS THAN 200mm, THE LOCK-BLOCKS SHALL BE PLACED AT EXISTING GROUND LEVEL.
10. ANY DAMAGED OR OVER-EXCAVATED PAVEMENT TO BE REPLACED TO CONTRACT ADMINISTRATOR'S SATISFACTION.
11. PROVIDE ENVIRONMENTAL PROTECTION IN ACCORDANCE WITH SECTION 01561 – ENVIRONMENTAL PROTECTION, VOLUME II OF THE MASTER MUNICIPAL CONSTRUCTION DOCUMENTS, PRINTED 2000.
12. CATCH BASIN SHALL CONFORM TO TOP INLET CATCH BASIN AS SHOWN IN STANDARD DETAIL DWG. NO. S11 IN VOLUME II OF THE MASTER MUNICIPAL CONSTRUCTION DOCUMENT. LEAD PIPE SHALL BE 0.15 DIA. CSP. FINAL LOCATION OF CATCH BASINS TO BE DETERMINED IN THE FIELD BY THE CONTRACT ADMINISTRATOR.

SCALE B 0 — 10m

SCALE A 0 — 10m

SCALE AS SHOWN

NO	DATE	ISSUE / REVISION	DRAWN	CHK'D	DESIGN	APP'D
0	FEB. 06/01	ISSUED FOR CONSTRUCTION	CYW	DP	RAV	AD

PROFESSIONAL ENGINEER — PROVINCE OF BRITISH COLUMBIA — R. A. VIDONI — 6-2-2001

CLIENT: VILLAGE OF TAHSIS

KLOHN CRIPPEN

PROJECT: TAHSIS FLOOD PROTECTION

TITLE: CONCRETE LOCK BLOCK FLOOD WALL PROFILE AND SECTIONS

PROJECT No: PG7442 06 — FIG. No: D-6003 — REV: 0

CANCEL PRINTS BEARING PREVIOUS

Time: 12:49:28 Date: 1/16/2001 Scale: 1=1(PS) Drawing File: G:\7442\CADD\06\B-6002.DWG (WONGC)

RECORD DRAWINGS

VILLAGE OF TAHSIS

BOSTON ROAD CULVERT IMPROVEMENT PROJECT

INTERNAL STORM DETENTION AND DRAINAGE
BOSTON ROAD, VILLAGE OF TAHSIS, B.C.

DRAWING INDEX

NO.	DATE	ISSUE / REVISION	DRAWN	CHK'D	DESIGN	APP'D
1	MAR 10/06	CHANGES RECORDED – RECORD ISSUE	DX	AD	AG	AD
0	AUG 12/05	DWG 1&2 DELETED. ISSUED FOR CONSTRUCTION	DX	AD	RAV	AD

DRAWING NO.	REFERENCE DRAWING

PROFESSIONAL ENGINEER — A. DALPATRAM — BRITISH COLUMBIA — 10 Mar/06

CLIENT: VILLAGE OF TAHSIS

KLOHN CRIPPEN

PROJECT: BOSTON ROAD CULVERT IMPROVEMENT

TITLE: DRAWING INDEX

SCALE	PROJECT No.	DWG. No.	REV.
AS SHOWN	G 07442A09	D-9000	1

CANCEL PRINTS BEARING PREVIOUS REVISION

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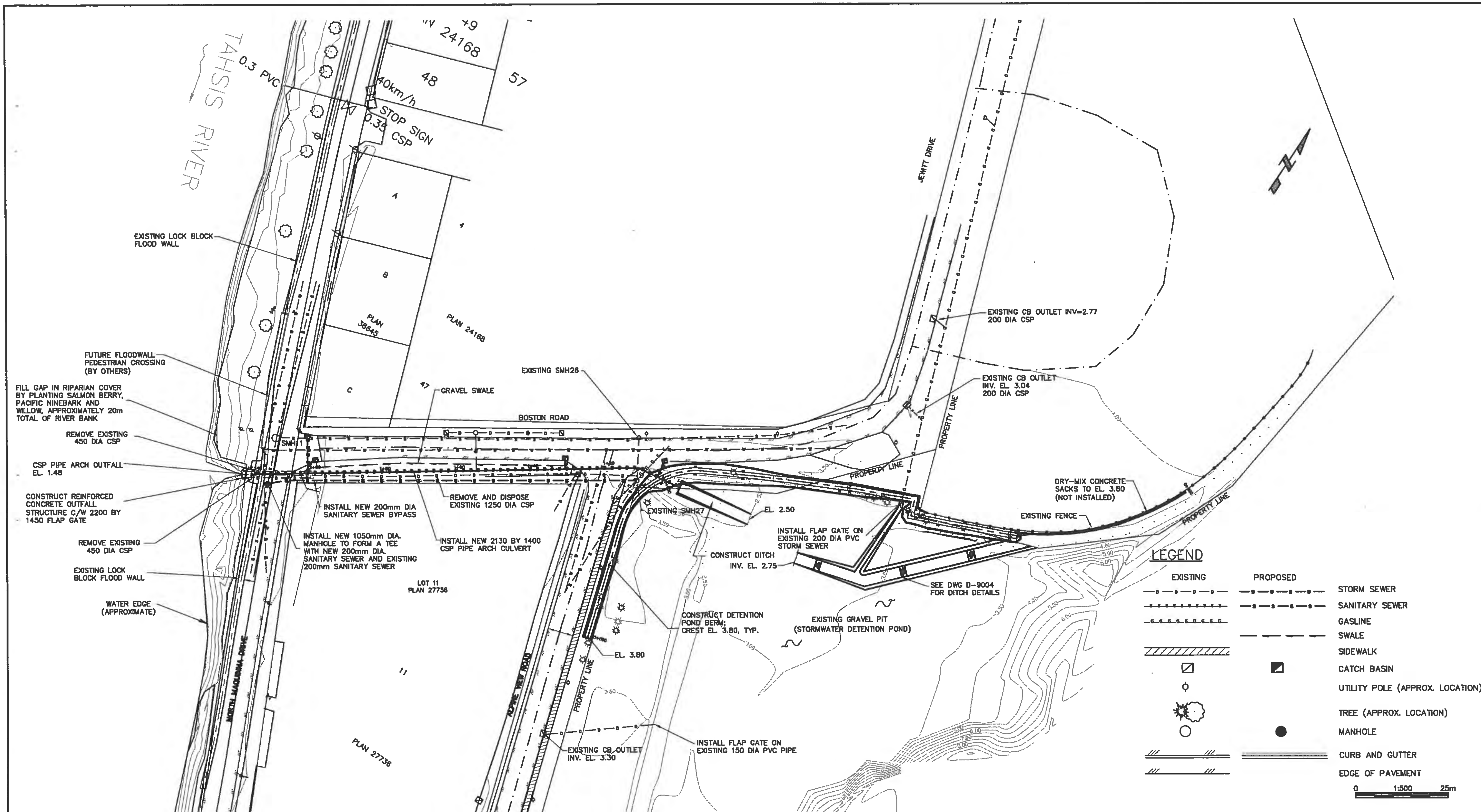
LAYOUT: Layout1



NO.	DATE	ISSUE / REVISION	DRAWN	CHK'D	DESIGN	APP'D
1	MAR 10/06	CHANGES RECORDED – RECORD ISSUE	DX	AD	AG	AD
0	AUG 12/05	ISSUED FOR CONSTRUCTION	DX	AD	RAV	AD

DRAWING NO. | REFERENCE DRAWING

PROFESSIONAL ENGINEER — DALPATRAM — 14 Mar 06

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CLIENT: VILLAGE OF TAHSIS

KLOHN CRIPPEN

PROJECT: BOSTON ROAD CULVERT IMPROVEMENT

TITLE: GENERAL ARRANGEMENT

SCALE	PROJECT No.	DWG. No.	REV.
AS SHOWN	G 07442A09	D–9001	1

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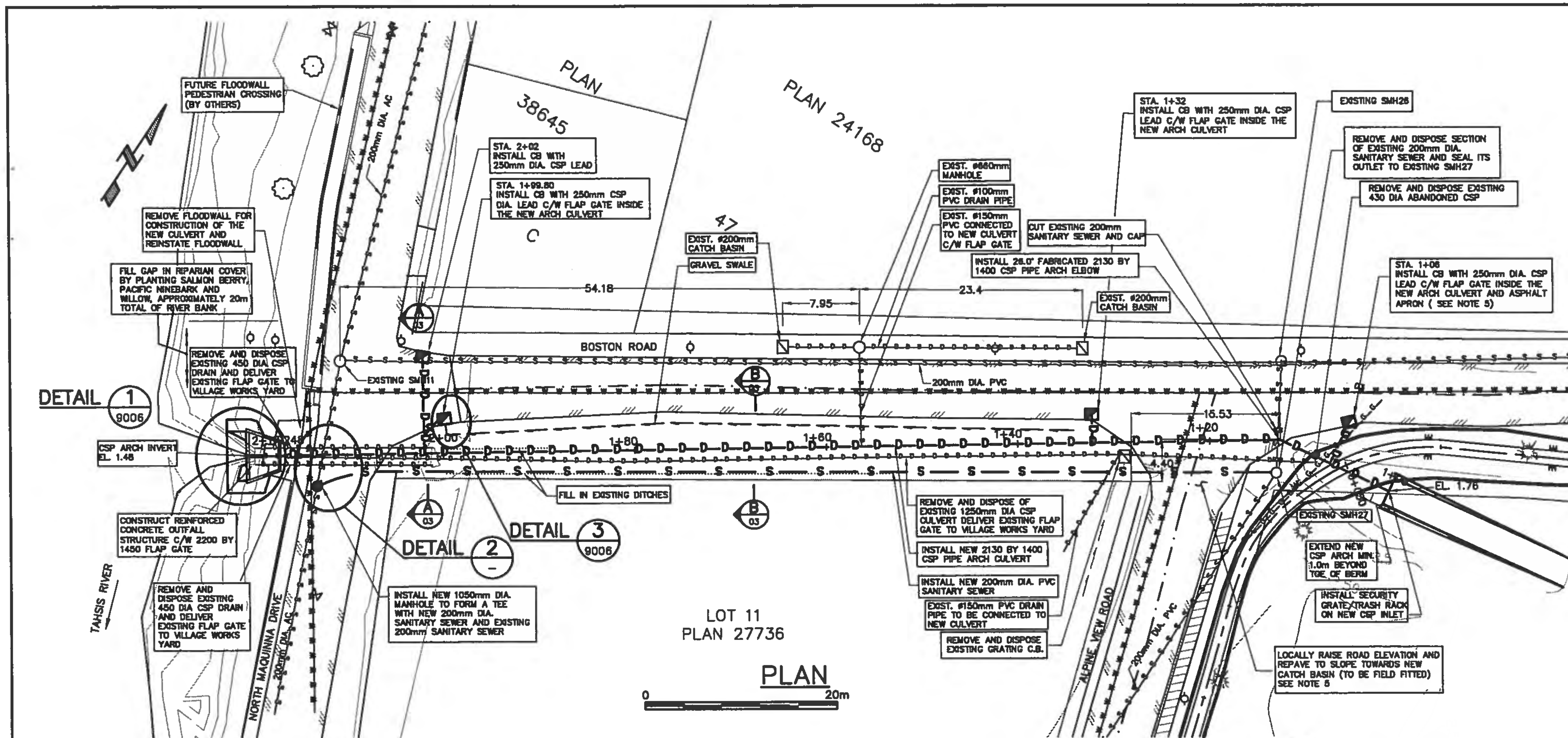

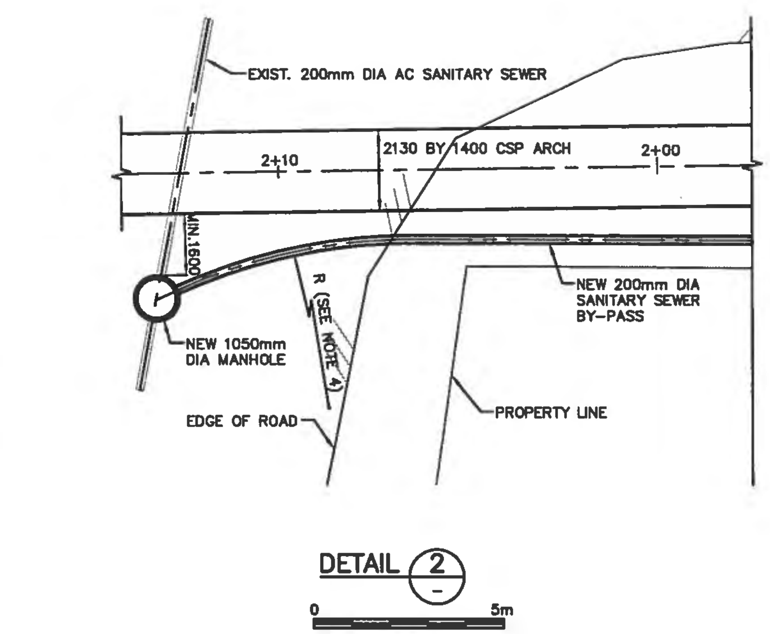

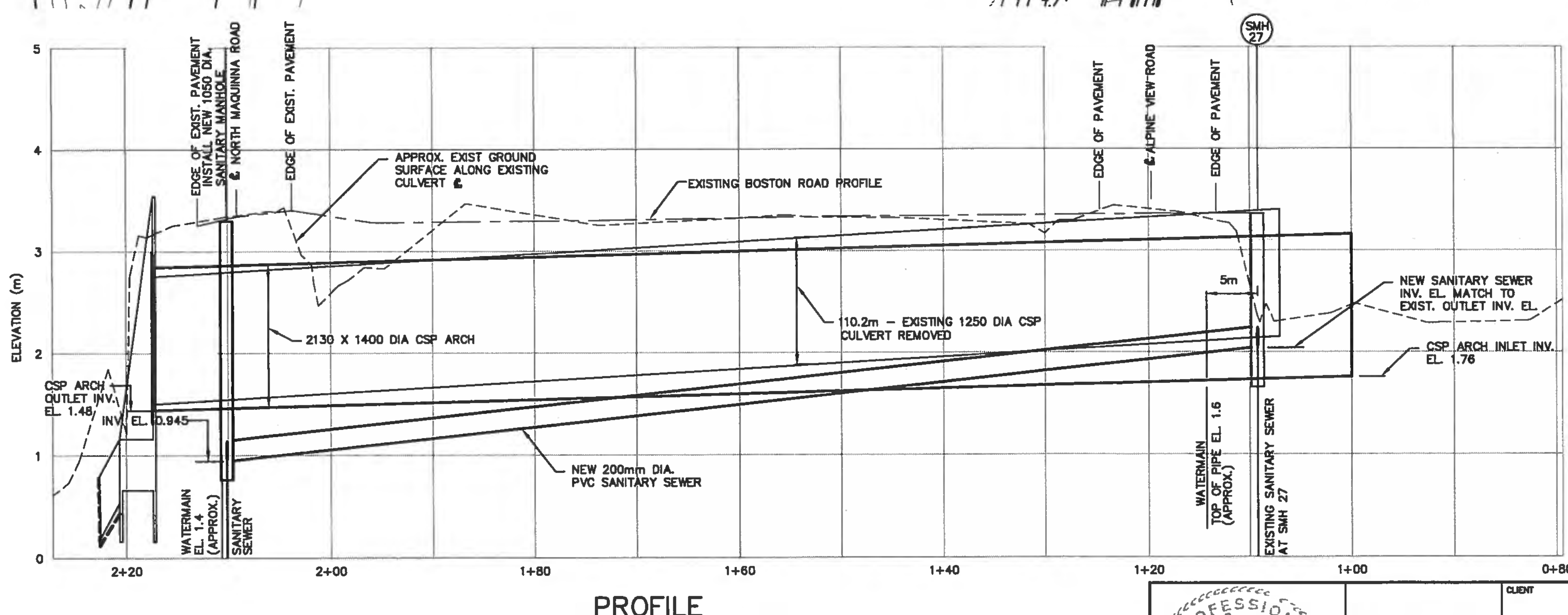

GENERAL NOTE:

INFORMATION ON EXISTING SERVICES MAY NOT BE COMPLETE OR ACCURATE. THE CONTRACTOR SHALL LOCATE ALL UNDERGROUND UTILITIES IN ACCORDANCE WITH GENERAL CONDITIONS, CLAUSE 4.3

NOTES:

1. FOR GENERAL ARRANGEMENT SEE DWG D-9001.
2. DRAWING SHALL BE READ IN CONJUNCTION WITH TECHNICAL SPECIFICATIONS.
3. AT OUTFALL THE CENTRELINE OF NEW 2130mm BY 1400mm CSP ARCH CULVERT IN PLAN SHALL COINCIDE WITH THE CENTRELINE OF DISUSED 1250 CSP CULVERT.
4. MAXIMUM INSTALLED DEFLECTION OF SANITARY SEWER PIPE NOT TO EXCEED ONE-HALF MANUFACTURER'S RECOMMENDED DEFLECTION OR 7.5% OF BASE INSIDE DIAMETER, WHICHEVER IS LESS.
5. PAVING AND INSTALLATION OF ASPHALT APRON WAS REMOVED FROM THIS CONTRACT.

LEGEND

EXISTING | PROPOSED
- STORM SEWER
- SANITARY SEWER
- GAS LINE
- WATER MAIN
- WATER VALVE
- SWALE
- UTILITY POLE (APPROX. LOCATION)
- TREE (APPROX. LOCATION)

EXISTING | PROPOSED
- SIDEWALK
- MANHOLE
- CATCH BASIN
- CURB AND GUTTER
- EDGE OF PAVEMENT
- PROPERTY LINE

NO.	DATE	ISSUE / REVISION	DRAWN	CHK'D	DESIGN	APP'D
1	MAR 10/06	CHANGES RECORDED – RECORD ISSUE	DX	AD	AG	AD
0	AUG 12/05	ISSUED FOR CONSTRUCTION	DX	AD	RAV	AD

DRAWING NO.	REFERENCE DRAWING

PROFESSIONAL ENGINEER — A. DALPATRAM — BRITISH COLUMBIA

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CLIENT: VILLAGE OF TAHSIS

KLOHN CRIPPEN

PROJECT: BOSTON ROAD CULVERT IMPROVEMENT

TITLE: CSP ARCH CULVERT AND SANITARY SEWER BY-PASS PLAN AND PROFILE

SCALE	PROJECT No.	DWG. No.	REV.
AS SHOWN	G 07442A09	D-9002	1

CANCEL PRINTS BEARING PREVIOUS REVISION

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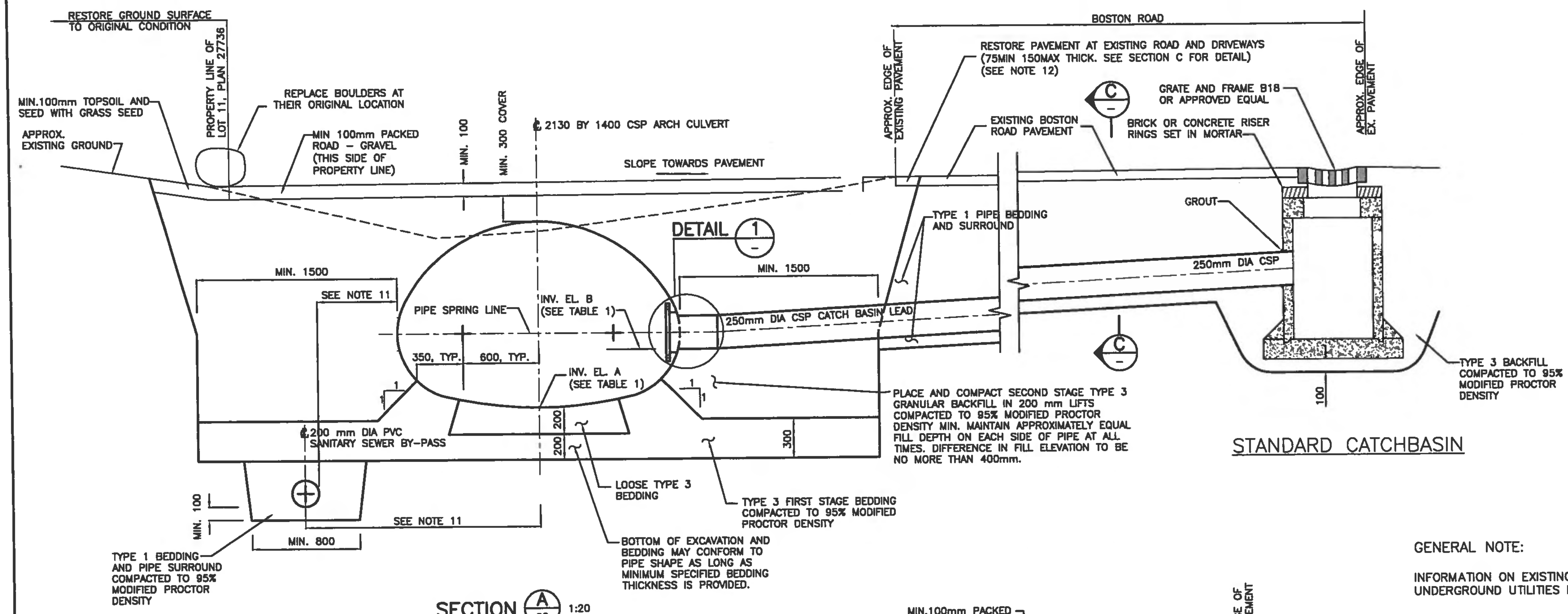


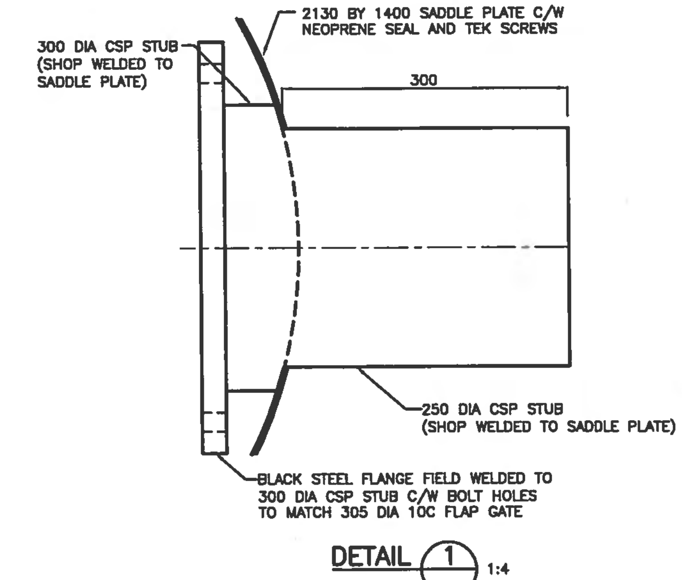
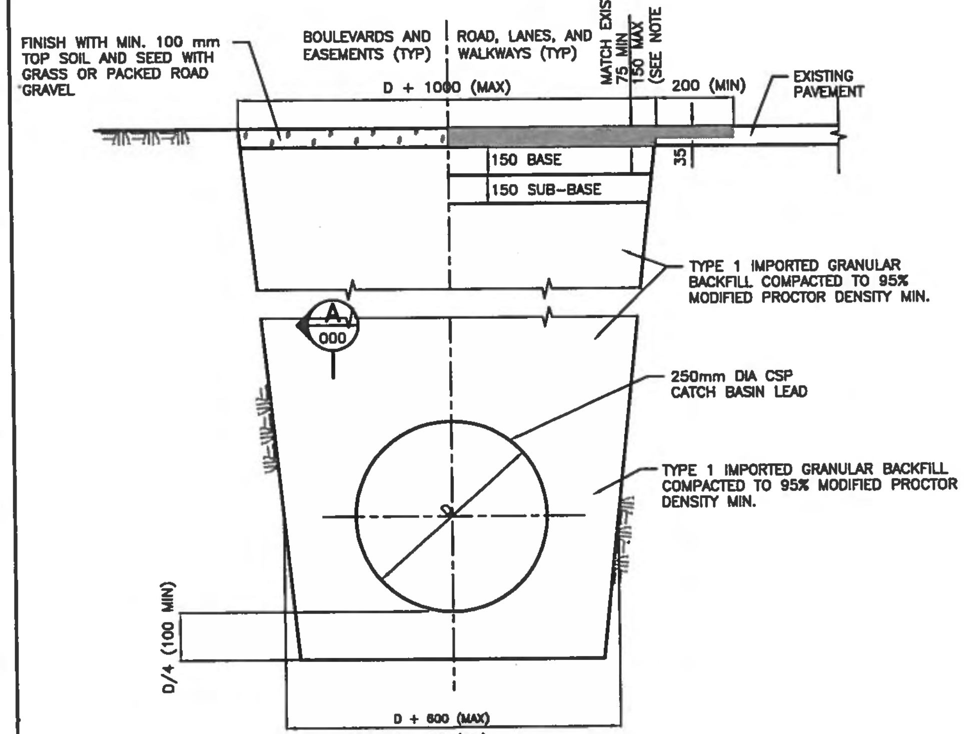


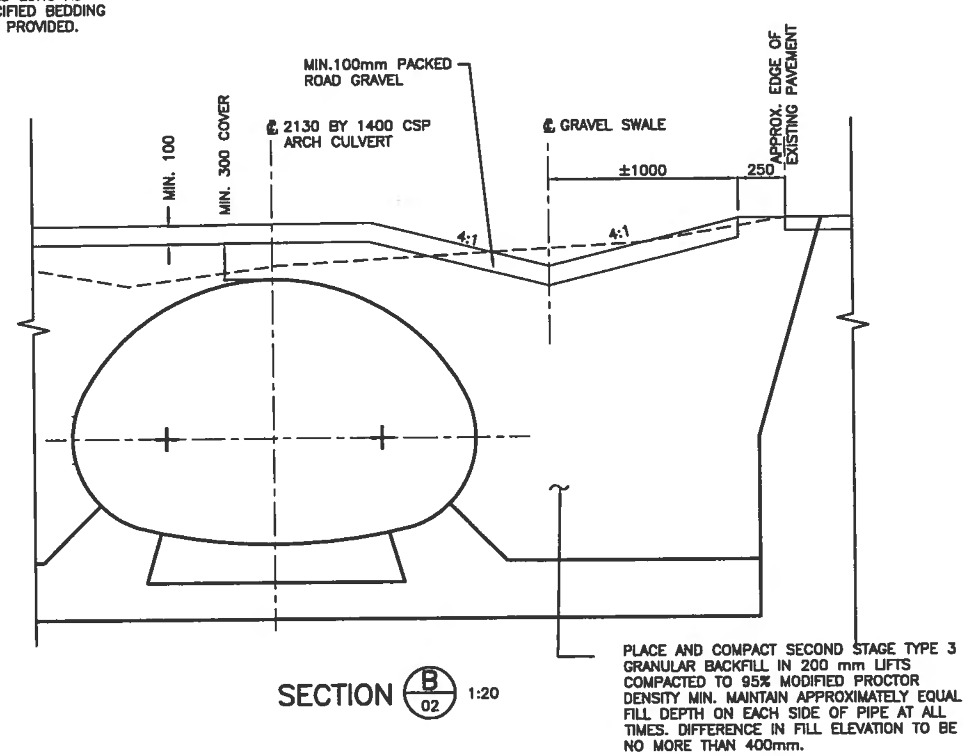
TABLE 1

CATCH BASIN LEAD AT STA.	2130 BY 1400 CSP INV EL. (INV EL A)	CATCH BASIN LEAD INV EL. (INV EL B)
1+08.00	1.554	1.989
2+02.00	1.456	1.891



TYPICAL CROSS–SECTION THROUGH CATCH BASIN LEAD TRENCH

SECTION C



GENERAL NOTE:

INFORMATION ON EXISTING SERVICES MAY NOT BE COMPLETE OR ACCURATE. THE CONTRACTOR SHALL LOCATE ALL UNDERGROUND UTILITIES IN ACCORDANCE WITH GENERAL CONDITIONS, CLAUSE 4.3

NOTES:

1. DRAWING SHALL BE READ IN CONJUNCTION WITH TECHNICAL SPECIFICATIONS.
2. TRENCHING TO COMPLY WITH ALL REQUIREMENTS OF THE WORKERS' COMPENSATION BOARD.
3. REFER TO SECTION 02223 FOR DETAILED SPECIFICATIONS.
4. PRECAST CATCH BASIN UNITS c/w BASE, APPROVED BY CONTRACT ADMINISTRATOR, ARE ACCEPTABLE. REFER TO DRAWINGS AND SECTION 02725 FOR DETAILED SPECIFICATIONS.
5. DURING WATER CONDITIONS IT IS IMPORTANT THAT THE FOUNDATION AND BEDDING BE FREE OF FROST, FROZEN LUMPS, ICE AND SNOW, FROZEN MATERIAL MUST BE REMOVED BEFORE COMPACTION COMMENCES.
6. USE HEAVY EQUIPMENT ONLY AS CLOSE TO THE CSP ARCH STRUCTURE AS IS ALLOWED BY THE CONTRACT ADMINISTRATOR.
7. FILL MATERIAL SHALL NOT BE DUMPED ON TOP OF THE CSP ARCH STRUCTURE, BUT SHALL BE PLACED IN LAYERS SUITABLE FOR THE TYPE OF COMPACTION EQUIPMENT BEING USED. TRUCK END-DUMPING OR DOZER PLACEMENT AGAINST THE SIDES OF THE STRUCTURE ARE ABSOLUTELY NOT PERMITTED.
8. HEAVY EQUIPMENT SHALL VEER AWAY FROM THE ENDS OF THE STRUCURE SO AS TO REDUCE HORIZONTAL PRESSURES AGAINST THE ENDS OF THE PIPE BARREL.
9. TRUCKS CAN UNLOAD IN ROUGH LAYERS STARTING NO CLOSER THAN 1500mm FROM THE PIPE SIDE WALLS WHILE MOVING OUT.
10. CATCH BASIN LEADS SHALL HAVE A MINIMUM LONGITUDINAL SLOPE OF 1%.
11. TO PROVIDE ROOM FOR PROPER COMPACTION, CLEAR DISTANCE BETWEEN NEW SANITARY SEWER AND CSP ARCH MUST BE AT LEAST 1.6m ANYWHERE THAT CROWN ELEVATION OF SANITARY SEWER IS EQUAL TO OR HIGHER THAN CSP ARCH INVERT ELEVATION. BELOW CSP ARCH INVERT MINIMUM PIPE CENTRELINE TO CENTRELINE DISTANCE SHALL BE 1760mm.
12. PAVEMENT WORK WAS REMOVED FROM THIS CONTRACT.

NO.	DATE	ISSUE / REVISION	DRAWN	CHK'D	DESIGN	APP'D
1	MAR 10/06	CHANGES RECORDED – RECORD ISSUE	DX	AD	AG	AD
0	AUG 12/05	ISSUED FOR CONSTRUCTION	DX	AD	RAV	AD

DRAWING NO.	REFERENCE DRAWING

PROFESSIONAL ENGINEER – A. DALPATRAM – BRITISH COLUMBIA – 14 Mar/06

CLIENT: VILLAGE OF TAHSIS

KLOHN CRIPPEN

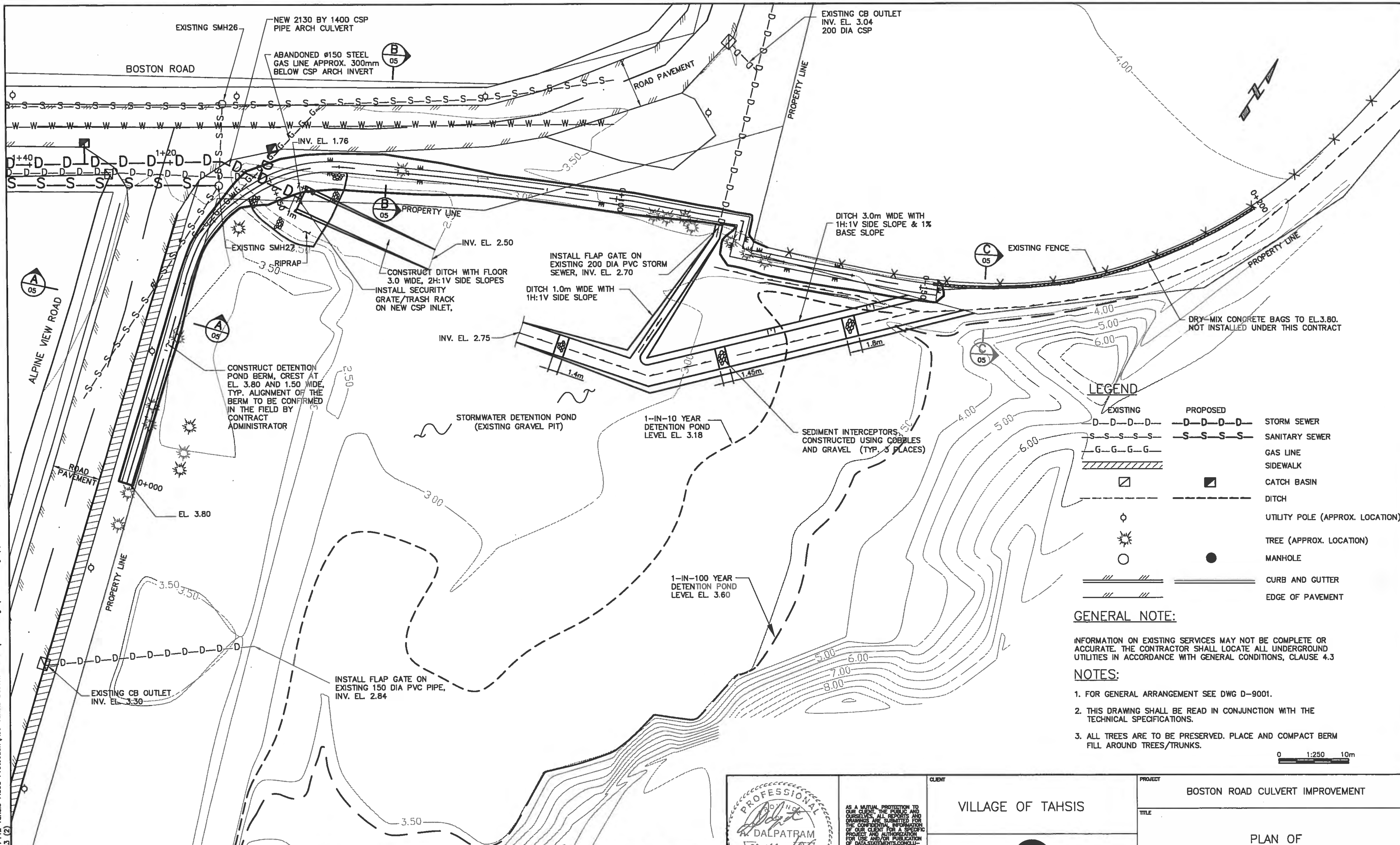
PROJECT: BOSTON ROAD CULVERT IMPROVEMENT

TITLE: DETAIL AND TYPICAL SECTION OF CATCH BASIN, LEADS, CSP ARCH AND SANITARY SEWER

SCALE	PROJECT No.	DWG. No.	REV.
AS SHOWN	G 07442A09	D–9003	1

CANCEL PRINTS BEARING PREVIOUS REVISION

DATE: 2006/03/13 – 5:01pm
PATH: P:\G\G07442 Tahsis Flood Protection\A09 Tahsis Boston Culvert\400 Design\410 Drawings\\D-9003-MAY05.dwg
LAYOUT: Layout1



GENERAL NOTE:

INFORMATION ON EXISTING SERVICES MAY NOT BE COMPLETE OR ACCURATE. THE CONTRACTOR SHALL LOCATE ALL UNDERGROUND UTILITIES IN ACCORDANCE WITH GENERAL CONDITIONS, CLAUSE 4.3

NOTES:

1. FOR GENERAL ARRANGEMENT SEE DWG D-9001.
2. THIS DRAWING SHALL BE READ IN CONJUNCTION WITH THE TECHNICAL SPECIFICATIONS.
3. ALL TREES ARE TO BE PRESERVED. PLACE AND COMPACT BERM FILL AROUND TREES/TRUNKS.

0 1:250 10m

PROFESSIONAL ENGINEER — DALPATRAM

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CLIENT: VILLAGE OF TAHSIS

KLOHN CRIPPEN

PROJECT: BOSTON ROAD CULVERT IMPROVEMENT

TITLE: PLAN OF STORMWATER DETENTION POND

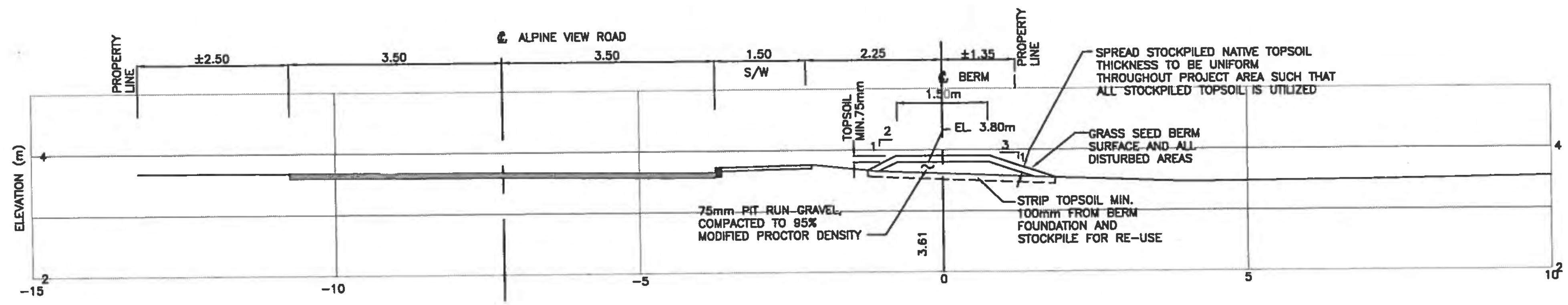
SCALE	PROJECT No.	DWG. No.	REV.
AS SHOWN	G 07442A09	D-9004	1

CANCEL PRINTS BEARING PREVIOUS REVISION

NO.	DATE	ISSUE / REVISION	DRAWN	CHK'D	DESIGN	APP'D
1	MAR 10/06	CHANGES RECORDED - RECORD ISSUE	DX	AD	AG	AD
0	AUG 12/05	HOLD ADDED. ISSUED FOR CONSTRUCTION	DX	AD	RAV	AD

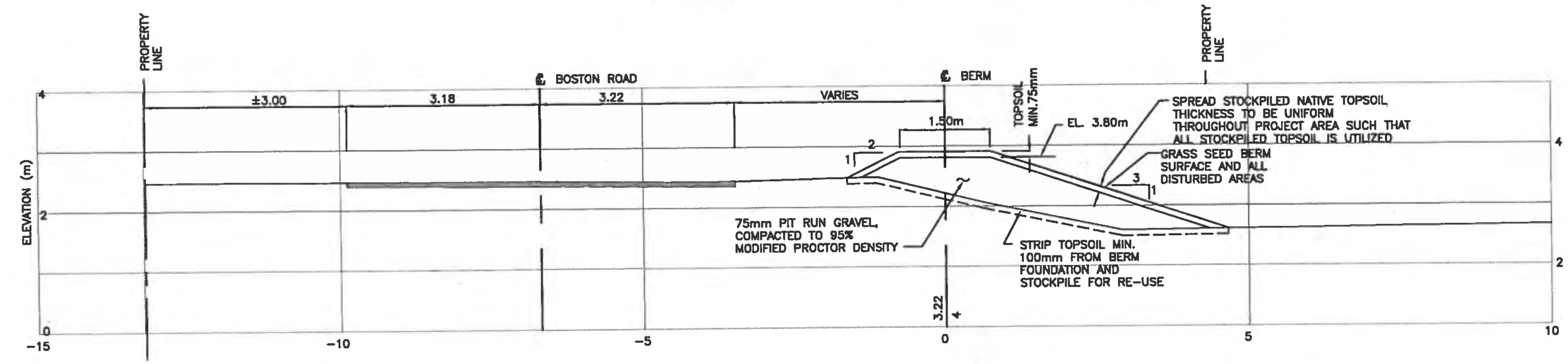
DRAWING NO.	REFERENCE DRAWING

DATE: 2006/03/13 - 1:48pm
PATH: P:\G\G07442 Tahsis Flood Protection\A09 Tahsis Boston Culvert\400 Design\410 Drawings\\D-9004-OCT5.dwg
LAYOUT: Layout3 (2)



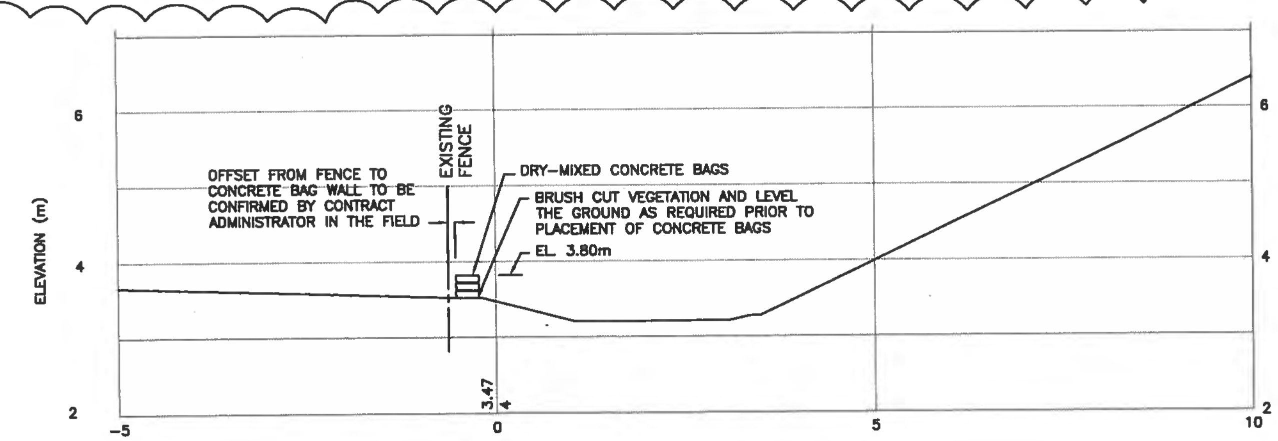
SECTION A/04

TYPICAL DETENTION POND BERM SECTION–ALPINE VIEW ROAD



SECTION B/04

TYPICAL DETENTION POND BERM SECTION–BOSTON ROAD



SECTION C/04

TYPICAL DETENTION POND CONCRETE BAG WALL SECTION

CONCRETE BAG WALL WAS NOT CONSTRUCTED UNDER THIS CONTRACT

NOTE:
1. DRAWING SHALL BE READ IN CONJUNCTION WITH TECHNICAL SPECIFICATIONS.

NO.	DATE	ISSUE / REVISION	DRAWN	CHK'D	DESIGN	APP'D
1	MAR 10/06	CHANGES RECORDED – RECORD ISSUE	DX	AD	AG	AD
0	AUG 12/05	HOLD ADDED. ISSUED FOR CONSTRUCTION	DX	AD	RAV	AD

DRAWING NO. | REFERENCE DRAWING

PROFESSIONAL ENGINEER – PROVINCE OF BRITISH COLUMBIA – A. DALPATRAM – 14 Mar 06

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CLIENT: VILLAGE OF TAHSIS

KLOHN CRIPPEN

PROJECT: BOSTON ROAD CULVERT IMPROVEMENT

TITLE: DETAILS AND TYPICAL SECTIONS OF DETENTION POND BERM AND CONCRETE BAG WALL

SCALE	PROJECT No.	DWG. No.	REV.
AS SHOWN	G 07442A09	D-9005	1

CANCEL PRINTS BEARING PREVIOUS REVISION

DATE: 2006/03/13 - 5:03pm
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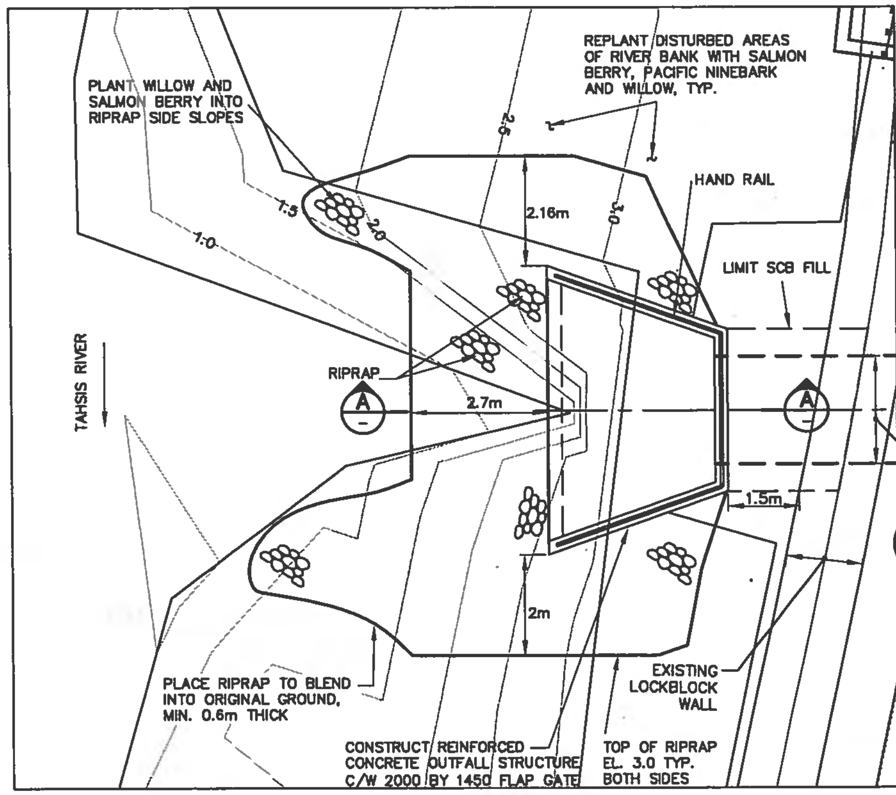
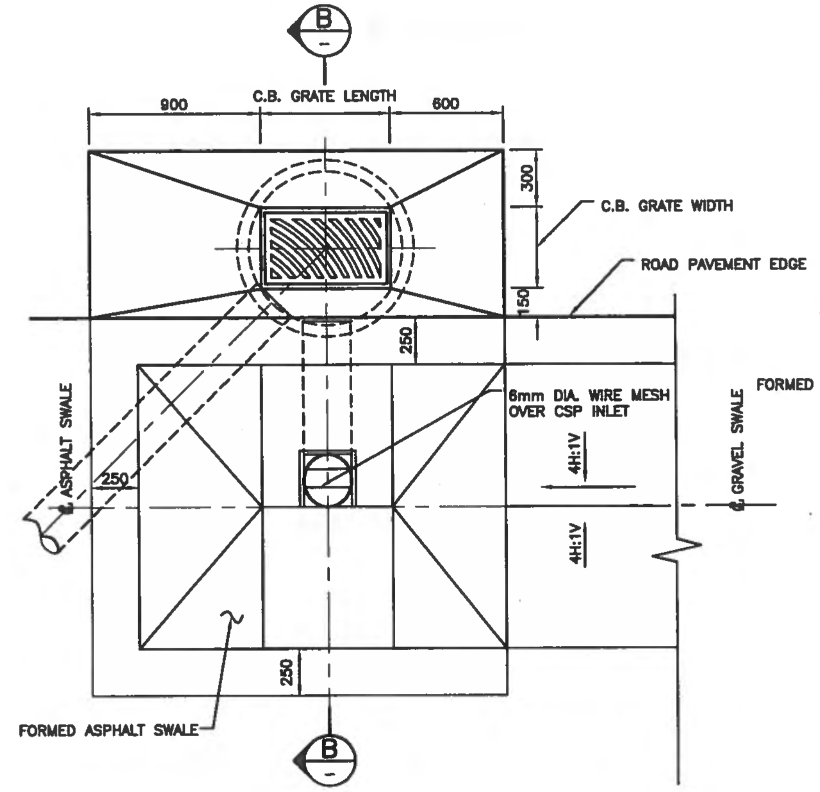
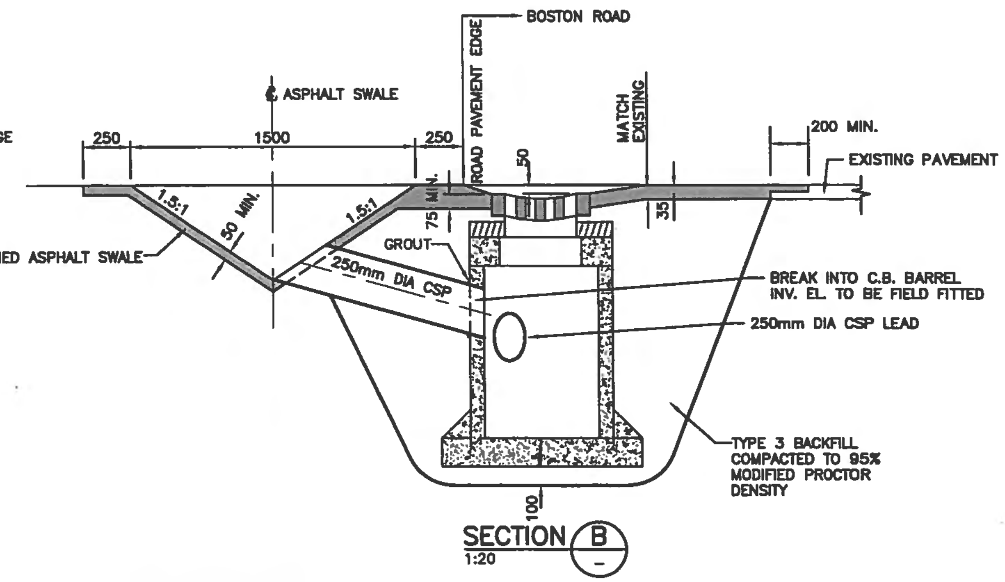
LAYOUT: Layout1



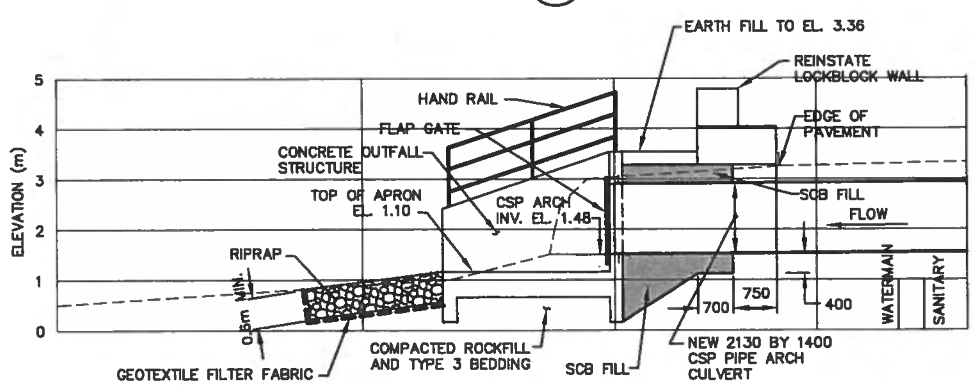
DETAIL 1
1:75



DETAIL 3
1:50 9002



SECTION B
1:20



SECTION A
1:75

RIPRAP GRADATION		
PERCENT LIGHTER THAN	MASS (kg)	EQUIVALENT SPHERICAL DIAMETER (mm)
85	30	300
50	10	200
15	1	100

GENERAL NOTE:

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NOTES:

1. SOIL-CEMENT BENTONITE (SCB) IMPERMEABLE FILL TO BE MIXED IN THE FOLLOWING PROPORTIONS BY WEIGHT:
   SOIL (S): 50% SILTY CLAY AND 50% FINE SAND
   PC/S = 8% (PC = PORTLAND CEMENT)
   B/S <1% (B = BENTONITE CLAY)
   SLUMP = 100 TO 200 mm (4 TO 8 INCHES)

SILTY CLAY AND SAND SHALL BE PRE-MIXED IN A 1:1 RATIO AT A SEPARATE LOCATION. SCB BATCH PROPORTIONS MAY BE ADJUSTED FOR WORKABILITY BY VARYING THE PROPORTION OF BENTONITE AS REQUIRED TO ACHIEVE A WORKABLE SLUMP. IN GENERAL, 4 TO 6 BATCHES (30 TO 35 GALLONS PER BATCH) OF BENTONITE SLURRY ARE MIXED WITH 8 BAGS (88.2 POUNDS/BAG) OF PORTLAND CEMENT TO MAKE A CEMENT-BENTONITE GROUT THAT IS MIXED WITH 4 CU. YDS OF MIXED SOIL TO MAKE THE SCB. ADDITIONAL BENTONITE SLURRY MAY BE ADDED TO PRODUCE A MORE FLUID MATERIAL. THE SCB SHOULD SET OVERNIGHT AND BE ABLE TO SUPPORT FOOT TRAFFIC THE NEXT DAY. PENETRATION TESTS ON THE SURFACE OF THE HARDENED SCB SHALL BE MADE TO VERIFY TESTS USING A POCKET PENETROMETER.

THE SCB MIX SHALL BE PREPARED IN THREE-STEP BATCHES.

STEP 1: SOIL SHALL BE PLACED IN A BEDDING BOX TO SERVE AS A MIXING CONTAINER. THE QUANTITY OF SOIL SHALL BE MEASURED BY BUCKET COUNT AND BY MEASURING THE VOLUME PLACED INTO THE BEDDING BOX.
STEP 2: THE GROUT SHALL BE PREPARED WITH PORTLAND CEMENT AND BENTONITE SLURRY TO PRODUCE A GROUT WITH THE REQUIRED PROPORTIONS. THE GROUT IS MADE BY PLACING A KNOWN VOLUME OF BENTONITE SLURRY INTO A GROUT MIXER AND ADDING THE APPROPRIATE NUMBER OF BAGS OF PORTLAND CEMENT.
STEP 3: AFTER MIXING THE PORTLAND CEMENT THE GROUT IS TO BE PLACED INTO THE MIXING BOX. THE INGREDIENTS SHALL BE BLENDED TOGETHER IN THE BOX BY CONTINUALLY TURNING AND KNEADING THE MIXTURE UNTIL IT BECOMES HOMOGENOUS. THE SCB SHALL BE PLACED AS SHOWN ON THE DRAWING.

2. A SLUSH GROUT OF CEMENT, BENTONITE AND WATER SHALL BE USED TO BOND THE LOCK-BLOCKS TO THE SCB CUT-OFF. THE SLUSH GROUT SHALL CONSIST OF THE FOLLOWING MATERIAL PROPORTIONS:
   PC/W = 1.2 TO 2 (W = WATER)
   B/W = 0.03

NO.	DATE	ISSUE / REVISION	DRAWN	CHK'D	DESIGN	APP'D
1	MAR 10/06	CHANGES RECORDED - RECORD ISSUE	DX	AD	AG	AD
0	AUG 12/05	ISSUED FOR CONSTRUCTION	DX	AD	RAV	AD

DRAWING NO.	REFERENCE DRAWING

PROFESSIONAL ENGINEER — A. DALPATRAM — PROVINCE OF BRITISH COLUMBIA — 16 Mar 06

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CLIENT: VILLAGE OF TAHSIS

KLOHN CRIPPEN

PROJECT: BOSTON ROAD CULVERT IMPROVEMENT

TITLE: CSP ARCH OUTFALL STRUCTURE PLAN AND SECTIONS

SCALE	PROJECT No.	DWG. No.	REV.
AS SHOWN	G 07442A09	D-9006	1

CANCEL PRINTS BEARING PREVIOUS REVISION

KCC-BM

DATE: 2006/03/13 - 1:56pm
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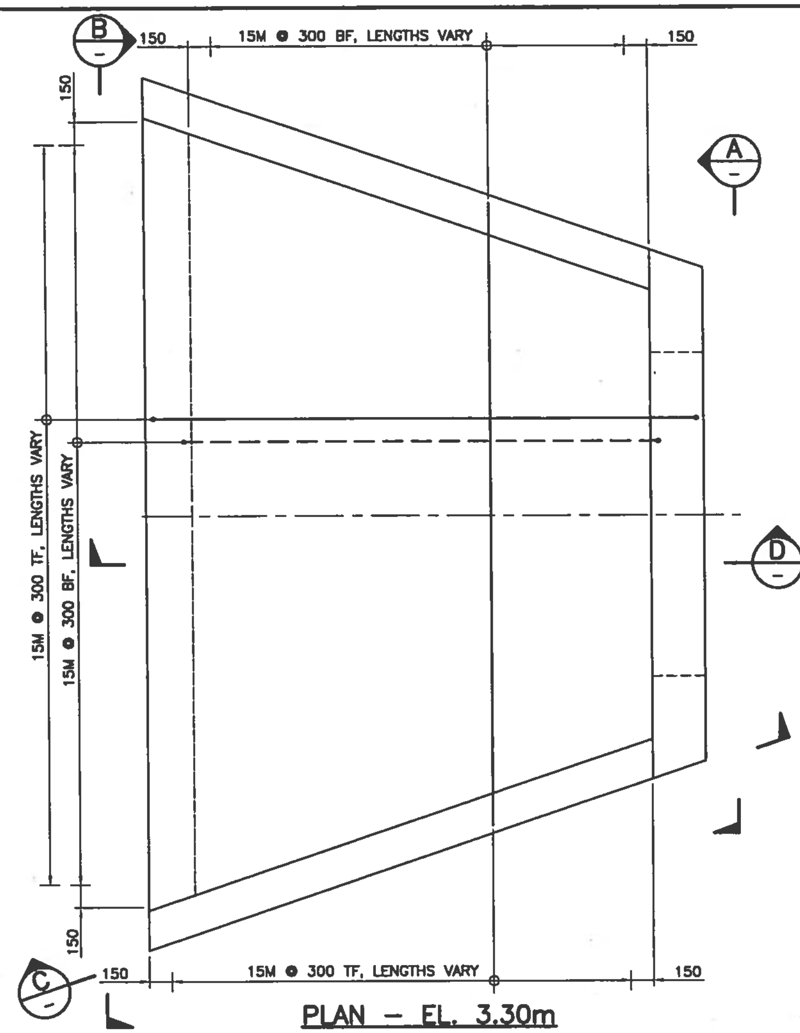
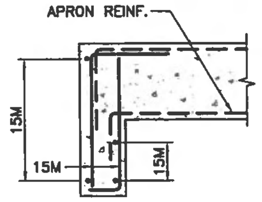
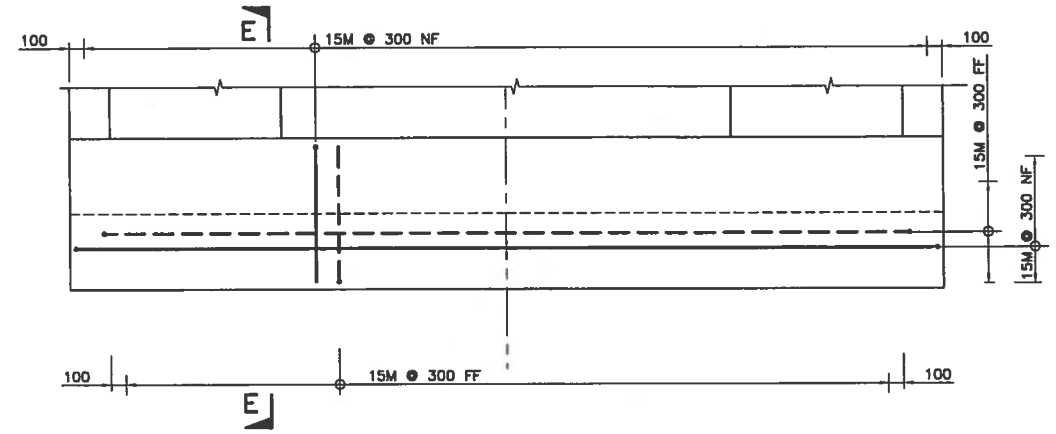
LAYOUT: Layout1



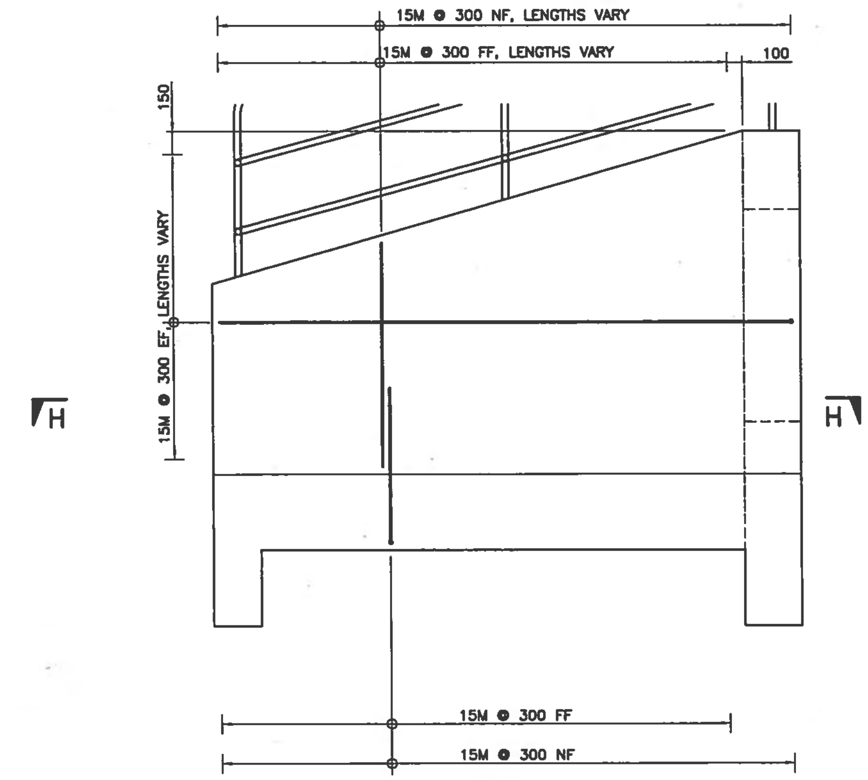
PLAN – EL. 3.30m



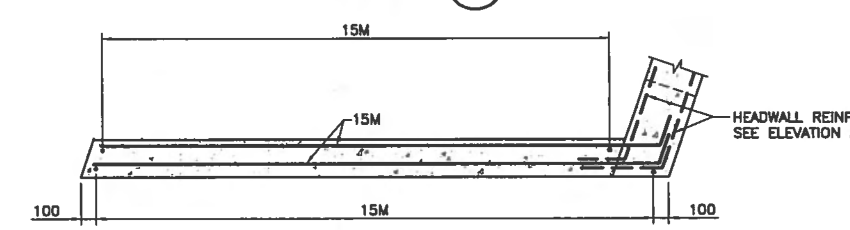
SECTION E–E



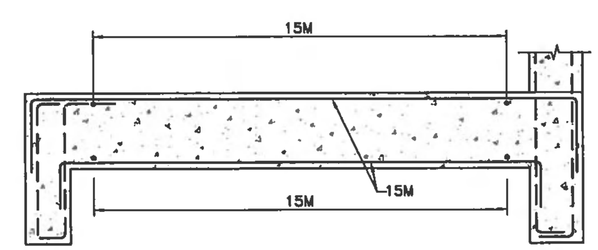
ELEVATION B
1:25



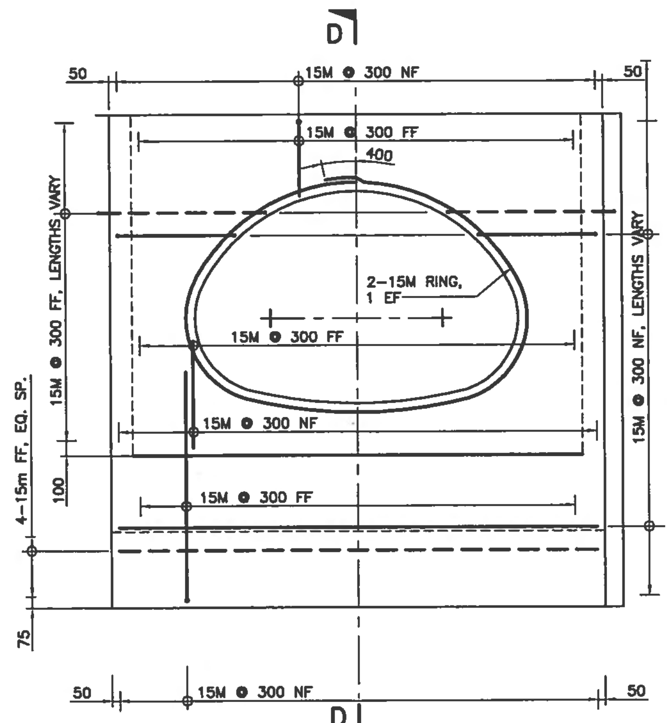
ELEVATION C
1:25



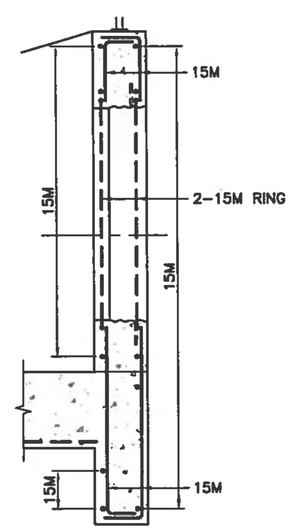
SECTION H–H



SECTION D
1:25



ELEVATION A
1:25



SECTION D–D

NOTES:

1. REINFORCEMENT FOR CONCRETE AND METHODS OF TEST FOR REINFORCEMENT SHALL CONFORM TO THE REQUIREMENTS OF ONE OR MORE OF THE FOLLOWING STANDARDS: CSA STANDARDS G30.3, G30.5, G30.15, G30.18

2. ALL REINFORCEMENT SHALL BE OF GRADE 400 WITH A YIELD STRENGTH, f_y = 400 MPa. REINFORCEMENT WITHOUT ROLLED–IN GRADE IDENTIFICATION MARKS SHALL BE OTHERWISE IDENTIFIED TO THE SATISFACTION OF THE CONTRACT ADMINISTRATOR.

3. ALL BARS FOR CONCRETE REINFORCEMENT SHALL BE DEFORMED BARS.

4. REINFORCEMENT, AT THE TIME CONCRETE IS PLACED, SHALL BE FREE FROM MUD, OIL, OR OTHER CONTAMINANTS THAT MAY ADVERSELY AFFECT BOND.

5. MINIMUM BEND INSIDE DIAMETERS SHALL BE 100mm.

6. ALL BARS SHALL BE BENT AT TEMPERATURES BETWEEN 10° AND 100° C.

7. NO BARS PARTIALLY EMBEDDED IN CONCRETE SHALL BE FIELD BENT.

8. THE SPACING OF BARS SHALL BE AS SHOWN.

9. CONCRETE CLEAR COVER SHALL BE 75mm, FOR SURFACES IN CONTACT WITH GROUND; 50mm FOR OTHER SURFACES.

10. REINFORCEMENT SHALL BE ACCURATELY PLACED AND SUPPORTED BY BAR SUPPORTS AND SIDE FORM SPACERS TO ENSURE PROPER CONCRETE COVER AND SPACING WITHIN A TOLERANCE OF +/– 8mm BEFORE AND DURING PLACING OF CONCRETE. BAR SUPPORTS SHALL BE MADE OF PRECAST CONCRETE BLOCKS, PLASTIC OR WIRE. SIDE FORM SPACERS SHALL BE USED FOR ALL WALL CONSTRUCTION TO SECURE THE REINFORCEMENT AGAINST DISPLACEMENT AND MAINTAIN THE REQUIRED COVER DISTANCE BETWEEN THE REINFORCEMENT AND VERTICAL FORMWORK. SIDE FORM SPACERS SHALL BE OF A TYPE AND MATERIAL THAT WILL NOT CAUSE BLEMISHES, RUST SPOTS, OR SPALLING OF EXPOSED CONCRETE SURFACE.

11. PRECAST BLOCKS WITH EMBEDDED PLASTIC–COATED WEIRS SHALL BE USED FOR SUPPORTS IN CONTACT WITH THE SOIL.

12. SPLICING OF REINFORCEMENT SHALL BE MADE ONLY AS SHOWN. SPLICE LENGTH SHALL BE NO LESS THAN 520mm.

13. WELDING OF REINFORCEMENT SHALL NOT BE PERMITTED.

0 1:25 1m

NO.	DATE	ISSUE / REVISION	DRAWN	CHK'D	DESIGN	APP'D
1	MAR 10/06	CHANGES RECORDED – RECORD ISSUE	DX	AD	SD	AD
0	AUG 12/05	ISSUED FOR CONSTRUCTION	DX	YD	RAV	AD

DRAWING NO.	REFERENCE DRAWING

PROFESSIONAL ENGINEER – DALPATRAM – 14 Mar/06

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CLIENT: VILLAGE OF TAHSIS

KLOHN CRIPPEN

PROJECT: BOSTON ROAD CULVERT IMPROVEMENT

TITLE: CSP ARCH OUTFALL STRUCTURE REINFORCEMENT

SCALE	PROJECT No.	DWG. No.	REV.
AS SHOWN	GO 7442A09	D-9008	1

CANCEL PRINTS BEARING PREVIOUS REVISION

DATE: 2006/03/13 – 2:11pm
PATH: P:\G\G07442 Tahsis Flood Protection\A09 Tahsis Boston Culvert\400 Design\410 Drawings\\D-9008-MAY05.dwg
LAYOUT: Layout1

KCC-DM

THE TAHSIS INLET OUTLET

NOVEMBER 15, 1989 VOL 1 NO. 7

Flood Waters Threaten Residents

By Danielle Cosens and Staff Writers

Tahsis residents rolled up their pant legs last week as British Columbia experienced record rainfalls across the province. According to weather reports, Tahsis flooding was some of the worst in B.C. and the heaviest in this area since 1975.

The flooding began Thursday morning, November 9th, after a two day rainfall of over 400mm, or 16 inches occured. The Tahsis River escaped the confinement of its banks, roseup over the road and threatened the door-steps of several residents living in the river valley. As the river gathered volume and momentum it swept up, and carried off picnic tables, lumber and anything else in its path as it rushed to the Inlet.

Water intake lines were washed out at the dam causing an interruption in water service to the village. Logs and debris carried by the force of the river punctured a hole in the grate of the intake, washing out the system.

A rock and mud slide, brought on by the heavy rains, flushed through the west townsite including the Tahsis Plaza. Shopkeepers from the Plaza spent their business day mopping and vacuuming water, silt and mud deposited in their stores. The Plaza parking lot sat submerged in approximately eight inches of water and mud as village workers laboured to clear drains and gutters in an attempt to divert the flow of water. Village workers became concerned over the state of the slide area as the rain continued. A helicopter was brought in from Gold River to monitor the slide area after Village crew member, Les Dowding, had surveyed the sight and realized its potential danger.

Five Public Works employees worked around the clock Thursday and Friday to repair water lines and monitor slide areas. Said Public Works employee John Zurch, "It's a big concern in something like this, there's only so many of us."

The village crew received help Thursday as the Tahsis Volunteer Fire Department waded through the streets as residents prepared for possible flooding to occur during the 10 AM high tide.

C.P.F.P. fire chief, Colin McPhail, noted that twelve of the T.V.F.D. volunteers that were not on shift at the mill, were aiding residents until the high tide had subsided on Thursday. The firemen helped to move furniture and belongings to the upstairs portion of two residences. According to Deputy Fire Chief, Tim Schmitz, other riverside homes in the valley of the community "had some water and moisture in the basements." Several homeowners will be mopping water from their basements this weekend, but John Zurch says that that is the extent of the residential damage.

While C.M.E.S.S. was not forced to house any evacuees, school was cancelled for two days while flooding subsided and water pressure was restored. According to Mr. McPhail, Tahsis was without running water, of the household variety, from 10:15pm Thursday until after 9:00 Friday morning, with sporadic interruptions early Thursday.

The several hours of flooding in the region drew media attention as "the only road to Tahsis" was described by B.C.T.V. as one of the hardest hit areas. The Tahsis/Gold River road was closed to traffic on Thursday morning after flooding in the areas near Pete's Farm and Perry Falls left vehicles stranded, and in some cases completely submerged in flood waters.

Gurney Contracting has been working on the road repairs. Mike Mountain, an equipment operator for the company, stated that the road was washed out in three areas, causing some damage to the roadway. According to the Forestry service, eight spots along the road were covered with water during Thursday's flooding. The road re-opened Friday after work began on the repairs.

According to Tahsis R.C.M.P. Constable Kevin Kimbler, Tahsis fared better than other areas. "We were pretty lucky in Tahsis," he said. "The reserve at Rivers Inlet was evacuated."

The flood markers along the Tahsis River measured 51/2 meters on Friday. Public Works employee, Les Dowding seemed to agree with Constable Kimbler, he said,

(see **Flood**, page 3)

Tahsis volunteer firemen patrolling streets during flooding

Photo by Kathleen Meikle

Tahsis Weather Report

The climatological station report providedby the Village's Public Works employees on November 10 recorded 560.9mm of rain already this month, with 312mm of rain causing lasts weeks flooding.

The Inlet-Outlet will keep you up to date on weather information in future issues, for those of you who like the details. For those of you who don't, it will suffice to say, "It's monsoon season again."

Puddle Duck Play Centre Under Government Scrutiny

By Debbie Vandenberg

The only play centre for preschool children to attend in Tahsis is near closure for failing to meet government requirements.

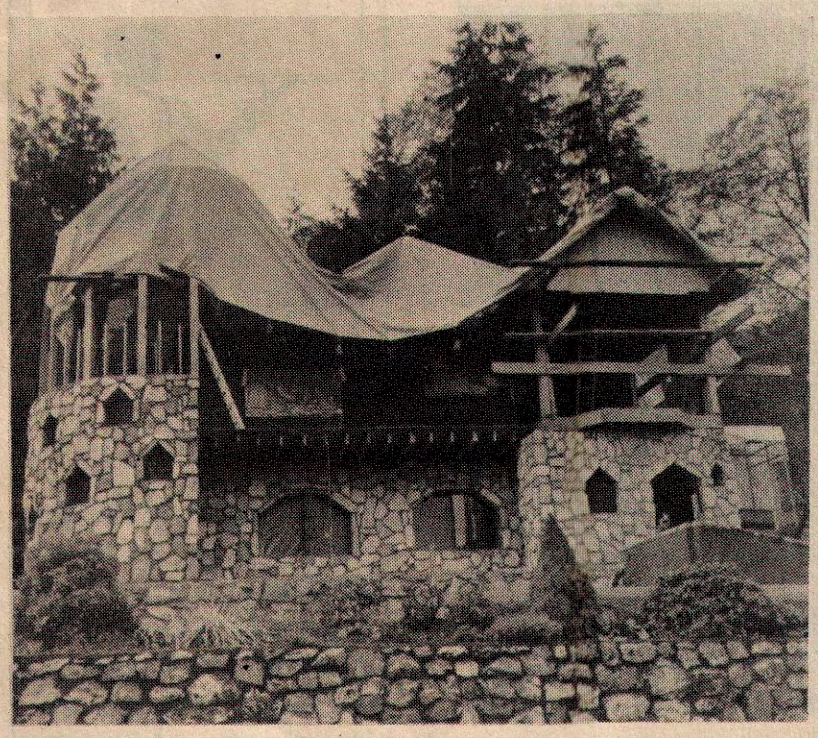
At present, a government regulation is being broken by the centre. Section 15 of the Child Care Facility Act states that to operate such a child care facility government certification is required. Proper certification includes a first aid certificate as well as medical and psychological testing to ensure the person is mentally and physically healthy for working closely with children. Mrs. Pieters, presently the only person working at the school, says that she is "not willing to get certified." She feels that it will cost more money to become certified than she earns. Instead every day that the school is in operation Mrs. Pieters could receive a fifty

(see **Puddle Duck**, page 3)

Tahsis children attending Puddle Duck play centre.

News & Views News & Views News & Views

A Man's Home is His Castle



Rudy Shedler's new home

By Greg Lien

There is a new building being constructed in Tahsis that is drawing many stares from the local townspeople. It has the look of a castle, with a rock face and German design. The owner and builder of the house, Rudy Shedler, had his previous home destroyed by fire, and had intended to re-build the old home for the sake of preserving Tahsis history. Mr. Shedler decided that the costs and work involved was too much, and elected instead to build a more beautiful and well made home.

The house, while looking like a castle at present, will look more like a home after it is complete. Mr. Shedler feels that some people who think he is in fact building a castle, may be disappointed with the end result. While the face of the construction will resemble a medieval German castle, the remainder will be a modern North American style home.

Mr. Shedler chose the medieval look for two reasons. Firstly, he says, he was inspired by the architecture of castles built in the medieval age. Secondly the materials are easily accessible which lowered the cost of construction. In a continued effort to reduce the costs of the building, the gates of the home were salvaged from the old RCMP station. Says Mr. Shelder, "they make a better gate than jail bars." Although the materials may be easily acquired, they must be carried by hand to the location of the work sight, due to its position on the town site hill. Mr. Shedler has received both volunteer and paid help from many members of the community.

The construction has been slowed by rain, but Mr. Shedler hopes to have the house completed by Christmas. Mr. Shedler has no intention of selling the home, but instead, intends to pass it on to his children and hopefully keep it in the family for many generations to come.

The management and staff of theOutlet would like to welcome our first and newest volunteer staff member, Greg Lien. Greg, a long-time resident of Tahsis will continue to contribute in future issues.

Puddle Duck

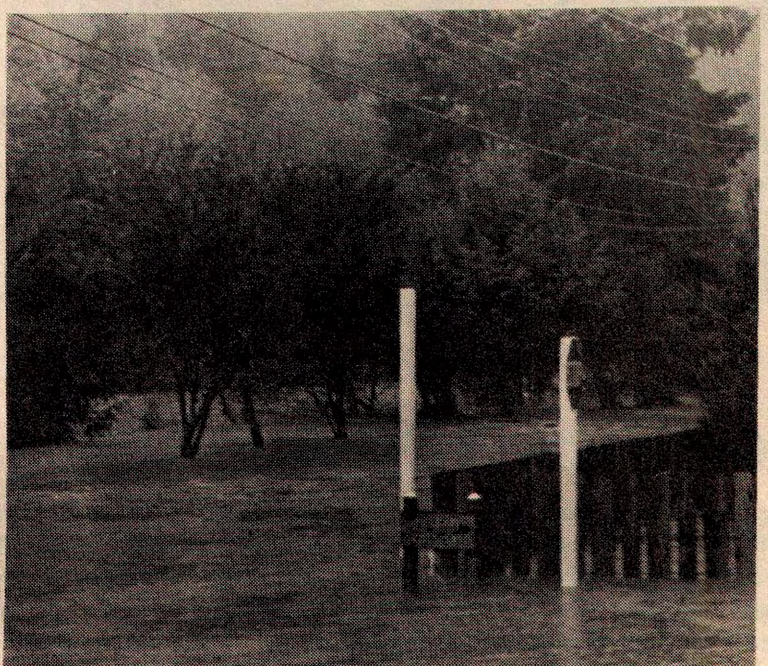
dollar fine. In addition to operator's certification, regulations also apply to the building. A building inspection, fire inspection, as well as a health inspection must be passed.

Mrs. Pieters says, "They (the parents) really appreciate that the United Church is available for this purpose." At the moment there is no one in the community with the qualifications to operate the centre. If there were, it is doubtful that they would be willing to work for the $150 per month that Mrs. Pieters makes. The centre is now in operation Tuesdays and Thursdays from 9:30-11:30am. At present ten children are regular participants at the school at a cost to the parents of $40 per month. This cost covers all the expenses incurred by the centre, including, rent, arts and crafts supplies, snacks, a yearly business licence and Mrs. Pieters salary.

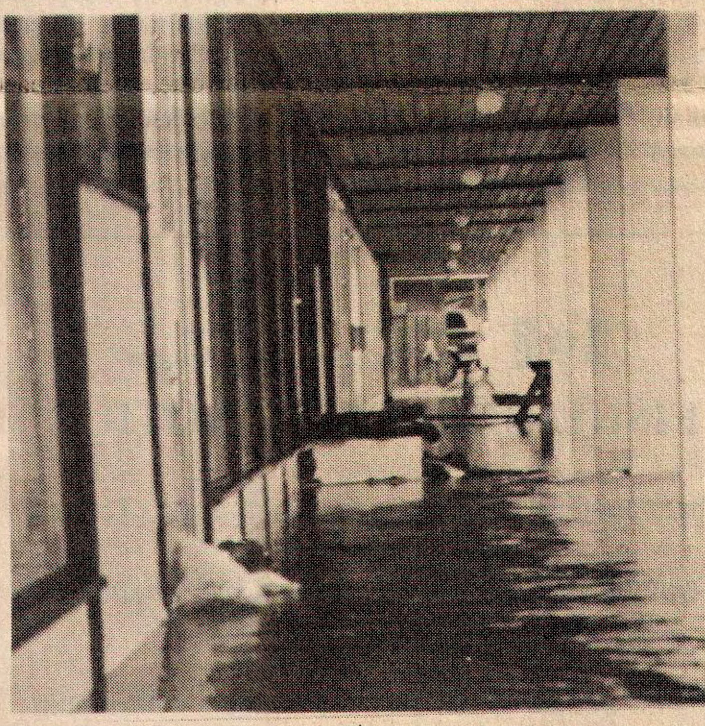
The parents of the children attending Puddleduck feel that it is a shame for such a service to be stopped in a community like Tahsis, where there is no other place for children between the ages of three and five get together. Mrs. Daynes, a parent with a child attending the centre, says "It is not a daycare centre," but "an opportunity for kids to socialize before entering kindergarten." The parents have launched a letter writing campaign to Council and the licensing office in Campbell River to stop the closure of the centre. In a letter to the Upper Island Health Unit the parents expressed their concern for possible closure of the centre. It stated that the parents do not consider Puddleduck to be "a playschool or a place of learning," and do not expect the centre "to raise them for us or prepare them for school."

The letter continues by stating that, "The situation at Puddleduck Play Centre is satisfactory to all involved," in addition, "regulations must be flexible enough to fit into all levels of society." Ms. Tymchuck, licensing officer for the upper Island area, was unavailable to comment on the situation at the Tahsis centre. Next week the parents will bring their concerns to council in hope of rallying some support for their cause.

TAHSIS BOYS CLUB
CHRISTMAS DRAW
COMING SOON

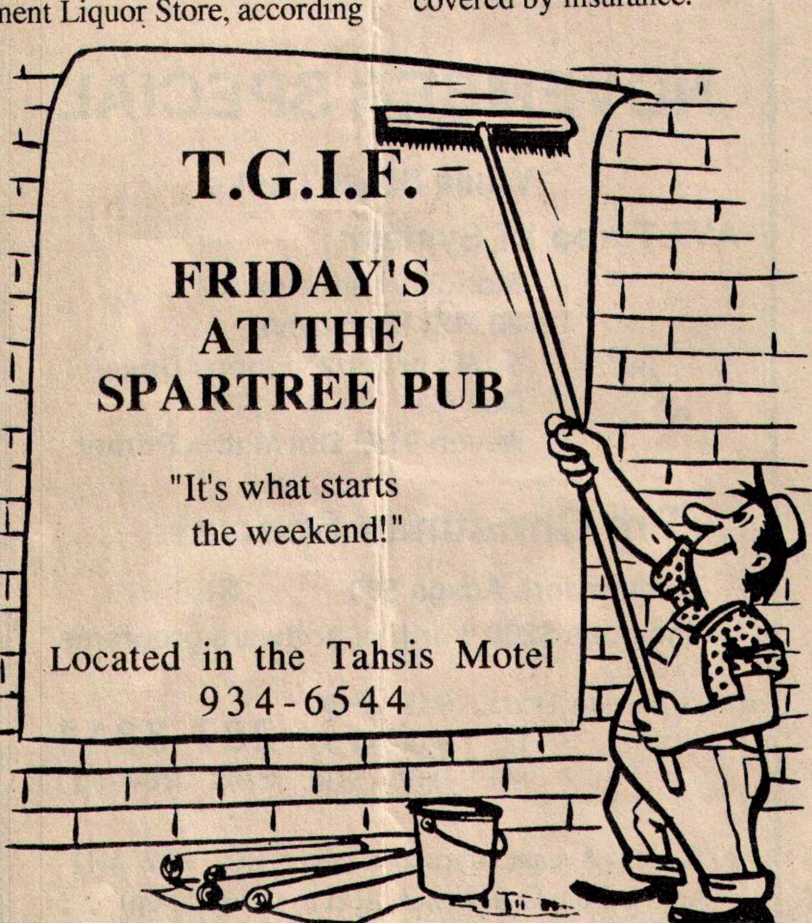


Flood Pictures:
Counter clock-wise from top left:
A flooded valley street, Larry Stevens uses an alternate form of transportation during the flood, sandbags used by shopkeepers in vain, and Tahsis Plaza flooding.



"We should be thankful that it stopped when it did."

Merchants who were interviewed Friday don't feel quite so thankful. Sharon Taparowski, owner of Pandora's Gift Shop, spent ten hours vacuuming two hundred gallons of water and fifty gallons of mud from her store. The Government Liquor Store, according to employee Susan Thomson, had a liquor display collapse and several cartons split causing damage to some merchandise. Ms. Thomson said, "We haven't had time to ascertain the value of the damage." Other merchants suffered minor loses and according to Dan Hindle, Coast Tahsis Chalet manager, most will be covered by insurance.



Flood Photos November 9, 1989


89 11 9

Flood Photos November 23, 1990


90 11 23


90 11 23

Flood Photos December 3, 1990

APPENDIX B: PUBLIC ENGAGEMENT REPORTS

McElhanney

Tahsis and Leiner River

Floodplain Mapping and Risk Assessment

March 12, 2019

1

What are we talking about today?

- **Why re-study the floodplain issues now?**
  - **Things have changed since 1992. We need to get up-to-date!**
  - **Things will continue to change from 2020 to 2100. We need to plan for the future!**
  - **We need to look at the risks and plan to mitigate them**

- **Bring the past to the present and look to the future:**
  - **Updates to the Hydrology in the region are required. There is a lot more data and new data to consider.**
  - **New modelling to determine more accurate flood predictions**
  - **Look to the future by considering Changes to Climate and Sea Level Rise (SLR)**
  - **Evaluate the risks and make a plan to protect the community**

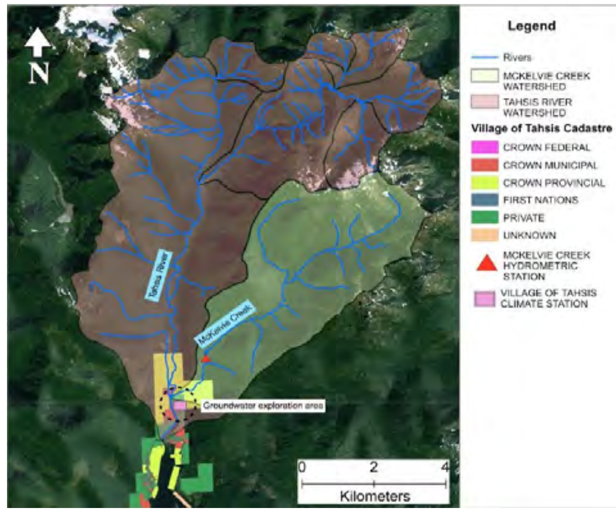
- **Review how you can help and participate**

2

The Watersheds

Tahsis River & McElvie Creek

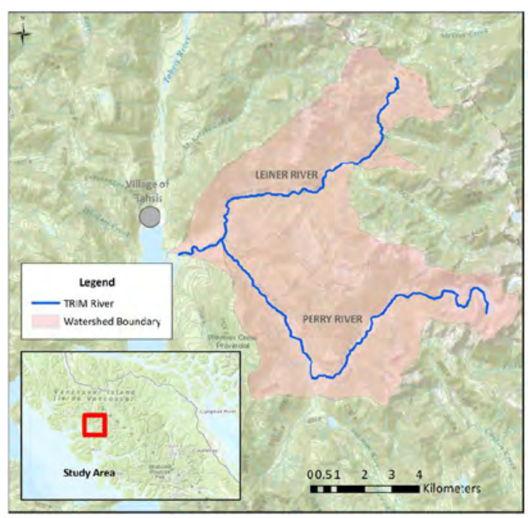
- Tahsis River Drainage Area is 78 km^2 with McElvie Creek about 22.2 km^2
- In 1992 engineer's estimated the Peak Daily Flood Discharges for 1:200 Year Flood at:
  - Tahsis River = 452 m^3/s
  - McElvie Creek = 231 m^3/s
  - Combined Peak = 596 m^3/s
- Discharges were based on records from Zeballos River (30 years of data) and Carnation Creek (18 years of data)



The Watersheds

Leiner River

- Leiner River Drainage Area is 108 km^2 and includes the Perry River
- In 1992 engineer's estimated the Peak Daily Flood Discharges for 1:200 Year Flood at:
  - Leiner River = 760 m^3/s
- Discharges were based on records from Zeballos River (30 years of data) and Carnation Creek (18 years of data)



Historical Flooding

Nov 1989

- Worst Flooding Since 1975
  - 400mm of rain (That's 16"!!)
  - North townsite Flooded
  - Roads Washed Out
  - No Drinking Water
  - Mud slides
- North Townsite was built-up from the floodplain, which flooded routinely
- Tsunami event of March 1964
  - Maximum Elevation of 2.8m
  - Not part of this study but should be reviewed with Emergency Preparedness Planning

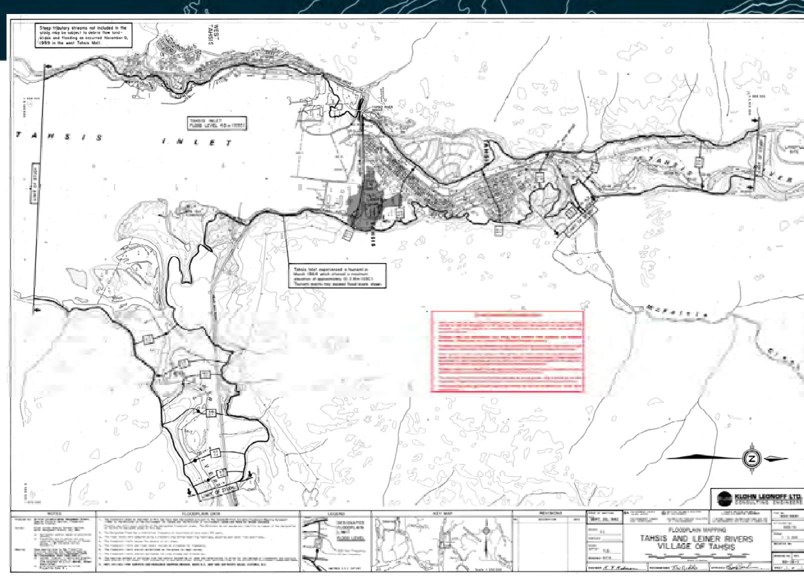

THE TAHSIS INLET OUTLET

Flood Waters Threaten Residents

Floodplain Mapping

1992

- Showed the need to protect the Village



Flood Protection Projects

Cook Street Dike - Registered as a dike with the province, continually maintained

North Maquinna Drive Flood Wall

Boston Street Drainage Culvert and Storm Pond

What does the Future Hold?

Sea Level Rise (SLR)

- **1m rise as a guide for the year 2100**

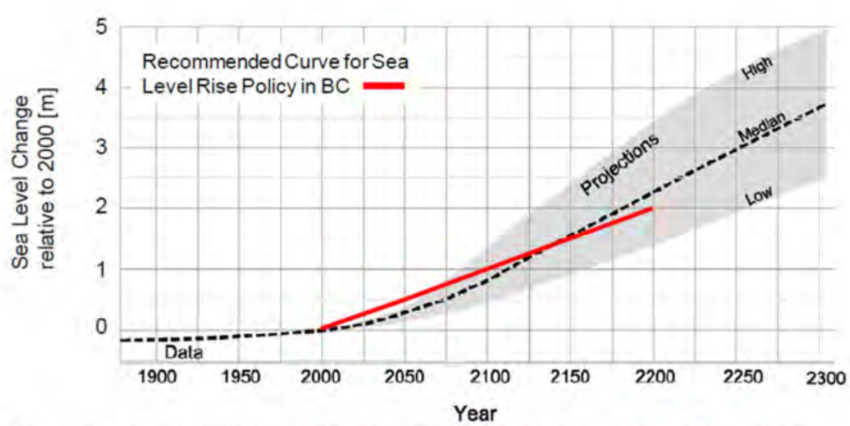


Figure 2-2: Recommended Global Sea Level Rise Curve for Planning and Design in BC (Ausenco Sandwell, 2011a)

What does the Future Hold?

Sea Level Rise (SLR)

- 1m rise as a guide for the year 2100
- Flood Construction Level for Tahsis is 5.3m, includes, tidal effects, storm surge, wave effects and freeboard (Safety Factor)

Table 2-4: Preliminary 2100 FCL Estimates for Various Locations (Ausenco Sandwell, 2011b)

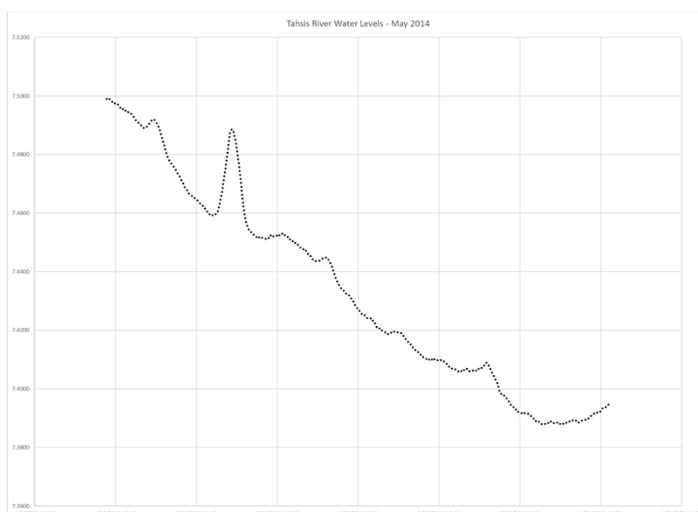
FCL Component	Fraser River Delta	Vancouver Harbour	Squamish River Delta	East Vancouver Island	West Vancouver Island	Central and North Coast
Global SLR (2100)	1 m					
Regional Adjustment	+0.21 m	0 m	0 m	-0.17 m	-0.27 m	-0.22 m
HHWLT	2.0 m	1.9 m	2.05 m	1.6 m	2.0 m	3.8 m
Storm Surge	1.7 m	1.4 m	1.3 m	1.3 m	1.3 m	1.7 m
Wave Effect	0.65 m	0.65 m	0.65 m	0.65 m	0.65 m	0.65 m
Freeboard	0.6 m	0.6 m	0.6 m	0.6 m	0.6 m	0.6 m
FCL	**6.2 m**	**5.6 m**	**5.6 m**	**5.0 m**	**5.3 m**	**7.5 m**

Notes:
1. Reproduced from Ausenco Sandwell (2011b), Table 3-2.
2. Regional adjustment based on current values. Vancouver and Squamish assumed to be neutral.
3. HHWLT = Higher High Water Large Tide. Varies by site and location in BC.
4. Storm surge allowance includes allowances for local wind setup.
5. Wave effect allowance assumes runup on natural gravel-pebble shoreline.
6. FCLs are elevations relative to Canadian Vertical Geodetic Datum.

Next Steps

Climate Change & Hydrologic Updates

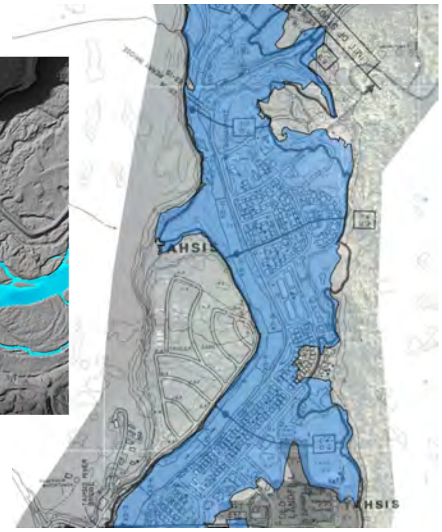
- More Data on Zeballos River
- Available Data on McElvie Creek
- Better models for regional effects
- Climate change according to PCIC – The Pacific Climate Impacts Consortium
- Dryer summers, wetter winters
- 12-15% more rain in November and December



Next Steps

Update Flood Model

- Use latest elevation data. LiDAR data collected in 2018
- New 2D computer models



Next Steps

Identify the Risks

- Land Use and property values
- Hazardous Sites
- Critical Infrastructure
  - Roads & Bridges
  - Drinking Water Supply
  - Sewage Treatment Plants

Mitigation Strategy

- PROTECT
- ACCOMMODATE
- RETREAT
- AVOID

Planning and Bylaws
Capital Works – Upgrade dikes

Next Steps

Emergency Planning

- Preparation
- Emergency Response
- Recovery

13

Your Role

Public Participation:

- Anecdotal Evidence of Historic Flooding is important
  - Photos
  - Reports on property flooding
    - Duration
    - Depth

- Get involved and provide feedback for potential bylaw creation-update
- Feedback on potential long-term planning impacts

14

THANK YOU

Contact:
Name: Mark DeGagné
Location: McElhanney, Campbell River Office
Phone: 250-287-7799
Email: mdegagne@mcelhanney.com

McElhanney

Tahsis and Leiner River

Floodplain Mapping and Risk Assessment

May 7, 2019

VILLAGE OF TAHSIS

1

What are we talking about today?

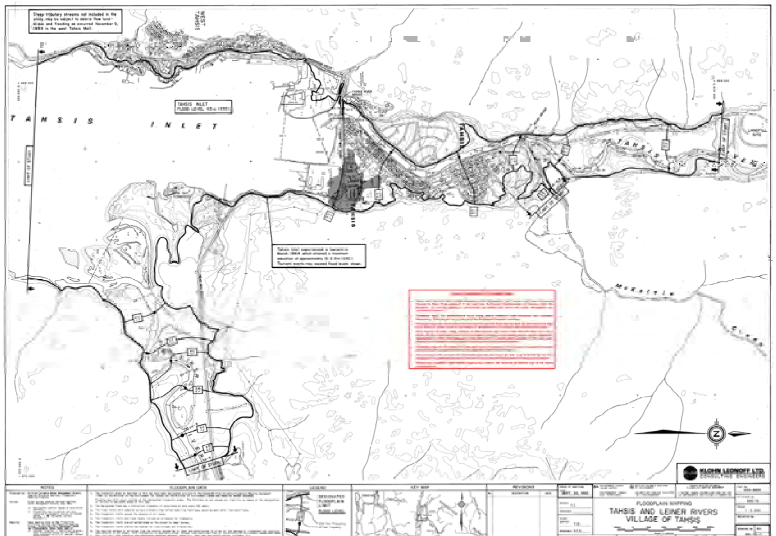
- **Quick review of the March 12, 2019 presentation**
- **Presentation of Hydrologic Analysis**
  - **What are the new estimated Flood Flows, and how do they compare to 1992**
- **Initial Flood Simulation Results**
  - **What are floods of the future going to look like**
- **Next Steps - Finalising the Report**

2

Floodplain Mapping

1992

- **Showed the need to protect the Village**
- **Based on ocean levels of 4.0m, which is high high tide, plus ocean set-up and waves heights during a storm**

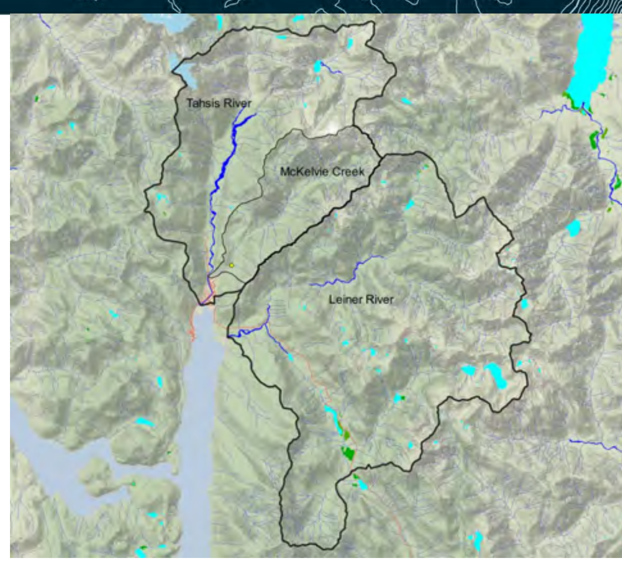


3

The Watersheds

Tahsis River, McKelvie Creek & Leiner River

- **Tahsis River Drainage (above McKelvie Creek) = 54 km^2**
- **McKelvie Creek = 22 km2**
- **Tahsis River at the mouth = 78 km2**
- **Leiner River Drainage (includes the Perry River) =108 km^2**



4

New Peak Flood Estimates

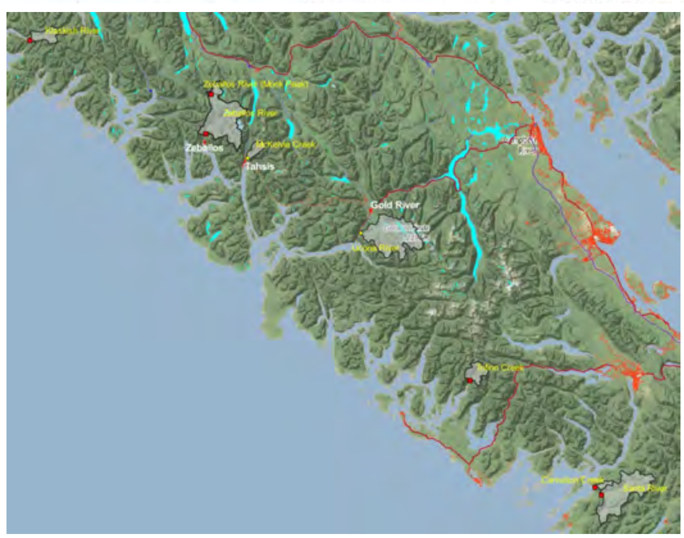
Preliminary estimates based on new 30 more years of data

		Predicted Instantaneous Peak Flood Discharge (m^3/s)			
		20-Year Flood		200-Year Flood	
	Area (km^2)	1992 Study	Current Estimate	1992 Study	Current Estimate
Tahsis River	78	639	359	864	545
Leiner River	108	792	518	1094	830

Why are the new estimates so different?

- There's more data:
  - Zeballos River had 30 years of data available in 1992 compared to 57 years currently.
- Newer statistical methods were used.
- Previous study relied heavily ONLY on the Zeballos River
- New study compared 5 rivers in the region.
  - Zeballos (recorded data from1960)
  - Ucona (recorded data from1957)
  - Zeballos near Moot Peak
  - McKelvie
  - Klaskish

  (Zeballos near Moot Peak, McKelvie, Klaskish: Recorded data from1999)
- The 1992 estimates are considered conservative.

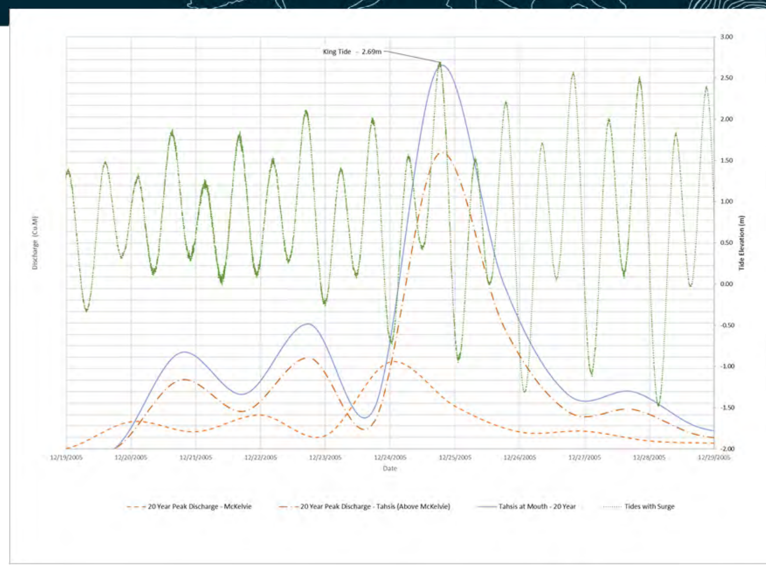


Modelling the Design Floods

Assume Peak Tides (conservative)

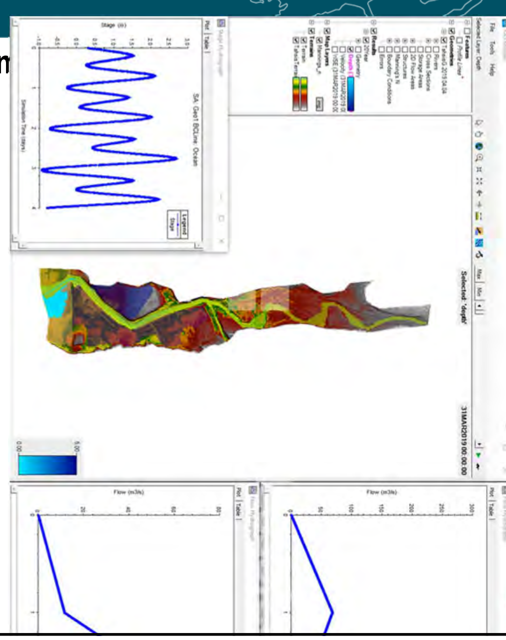
McKelvie Creek peaks before the Tahsis River

Perry and Leiner Rivers peak at about the same time



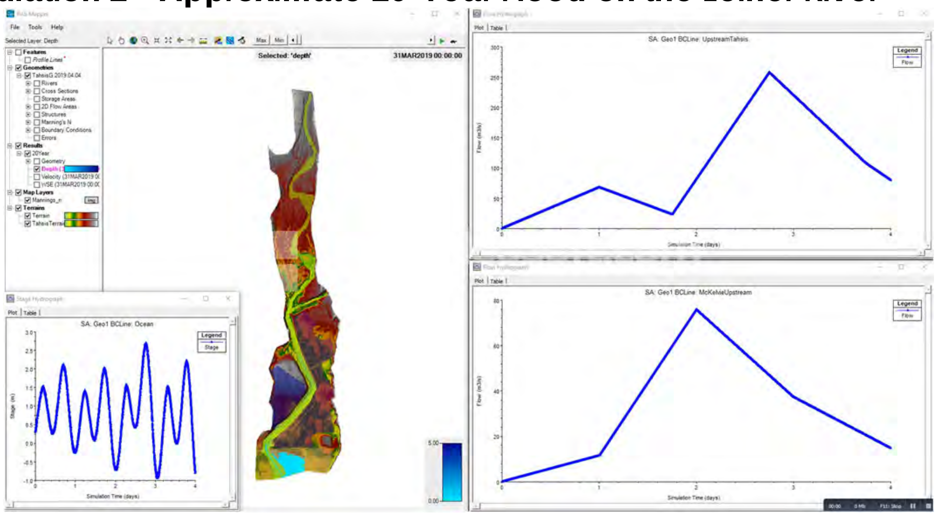
Model Simulations

Simulation 1 - Approxin **River**



Model Simulations

Simulation 2 - Approximate 20-Year Flood on the Leiner River

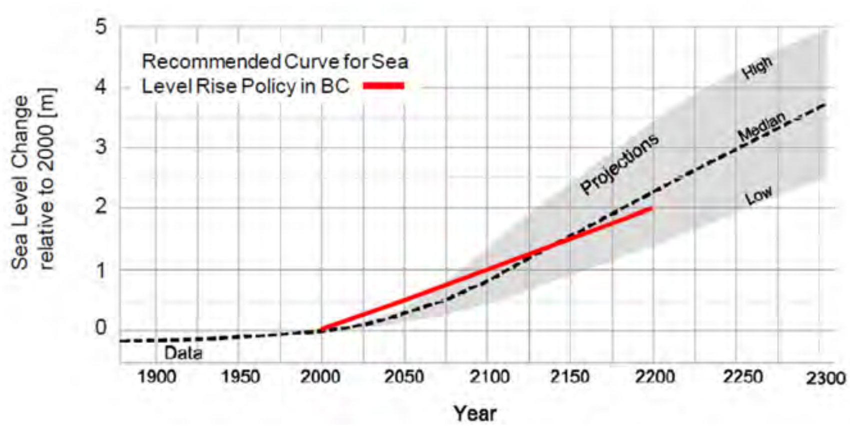


McElhanney Consulting Services Ltd. Floodplain Study 9

Next Steps – Modelling Sea Level Rise and storm surge

Sea Level Rise (SLR)

- **1m rise as a guide for the year 2100**



Recommended Global Sea Level Rise Curve for Planning and Design in BC (Ausenco Sandwell, 2011a

McElhanney Consulting Services Ltd. Floodplain Study 10

Establish Flood Construction Levels

Sea Level Rise (SLR)

- **1m rise as a guide for the year 2100**
- **Flood Construction Level for Tahsis recommended to be 5.3m, includes, tidal effects, storm surge, wave effects and freeboard (Safety Factor)**
- **Modelling to confirm this recommendation**

Table 2-4: Preliminary 2100 FCL Estimates for Various Locations (Ausenco Sandwell, 2011b)

FCL Component	Fraser River Delta	Vancouver Harbour	Squamish River Delta	East Vancouver Island	West Vancouver Island	Central and North Coast
Global SLR (2100)	1 m					
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HHWLT	2.0 m	1.9 m	2.05 m	1.6 m	2.0 m	3.8 m
Storm Surge	1.7 m	1.4 m	1.3 m	1.3 m	1.3 m	1.7 m
Wave Effect	0.65 m	0.65 m	0.65 m	0.65 m	0.65 m	0.65 m
Freeboard	0.6 m	0.6 m	0.6 m	0.6 m	0.6 m	0.6 m
FCL	**6.2 m**	**5.6 m**	**5.6 m**	**5.0 m**	5.3 m	**7.5 m**

Notes:
1. Reproduced from Ausenco Sandwell (2011b), Table 3-2.
2. Regional adjustment based on current values. Vancouver and Squamish assumed to be neutral.
3. HHWLT = Higher High Water Large Tide. Varies by site and location in BC.
4. Storm surge allowance includes allowances for local wind setup.
5. Wave effect allowance assumes runup on natural gravel-pebble shoreline.
6. FCLs are elevations relative to Canadian Vertical Geodetic Datum.

Adjust Floods for Climate Change

Model Climate Change

- **Climate change according to the Pacific Climate Impacts Consortium**
- **Dryer summers, wetter winters**
- **12% more rain in November, December and/or January**

PACIFIC CLIMATE IMPACTS CONSORTIUM

PLAN2ADAPT

PCIC Home | Contact Us

Summary
Region & Time
Temperature
Precipitation
Snowfall
Growing DD
Heating DD
Frost-Free Days
Impacts
Notes
References

Summary of Climate Change for Strathcona in the 2080s

Climate Variable	Season	Projected Change from 1961-1990 Baseline	
		Ensemble Median	Range (10th to 90th percentile)
Mean Temperature (°C)	Annual	+2.5 °C	+1.3 °C to +3.7 °C
Precipitation (%)	Annual	+8%	+1% to +16%
	Summer	-12%	-32% to -0%
	Winter	+12%	+1% to +22%
Snowfall* (%)	Winter	-33%	-59% to -13%
	Spring	-72%	-86% to -14%
Growing Degree Days* (degree days)	Annual	+521 degree days	+270 to +832 degree days
Heating Degree Days* (degree days)	Annual	-877 degree days	-1328 to -467 degree days
Frost-Free Days* (days)	Annual	+35 days	+19 to +52 days

The table above shows projected changes in average (mean) temperature, precipitation and several derived climate variables from the baseline historical period (1961-1990) to the **2080s** for the **Strathcona** region. The ensemble median is a mid-point value, chosen from a PCIC standard set of Global Climate Model (GCM) projections (see the 'Notes' tab for more information). The range values represent the lowest and highest results within the set. Please note that this summary table does not reflect the 'Season' choice made under the 'Region & Time' tab. However, this setting does affect results obtained under each variable tab.

* These values are derived from temperature and precipitation. Please select the appropriate variable tab for more information.

Next Steps – Planning and Mitigation

Identify the Risks

- Land Use and property values
- Hazardous Sites
- Critical Infrastructure
  - Roads & Bridges
  - Drinking Water Supply
  - Sewage Treatment Plants

Mitigation Strategy

- PROTECT
- ACCOMMODATE
- RETREAT
- AVOID

Next Steps – Planning and Mitigation

Protect

Planning and Bylaws
Capital Works – Upgrade dikes

Emergency Planning

- Preparation
- Emergency Response
- Recovery

Reporting

Draft Report:

- **Summarize all the findings and recommendations – DRAFT for early June**
- **Presentation to Council**
- **FINAL report by end of June**

THANK YOU

Contact:
Name: Mark DeGagné
Location: McElhanney, Campbell River Office
Phone: 250-287-7799
Email: mdegagne@mcelhanney.com

PUBLIC INFORMATION MEETING
2019 FLOOD RISK ASSESSMENT PROJECT

Tuesday, May 7, 2019
Tahsis Municipal Hall

1:30 pm to 3:30 pm

Name	Address	Comments
Barbara Hylton	651 N. Maquinna	
Gabe Gagnier	"	
Pat Gray	80 McKelvie	
RUTH RUSSELL	86 McKelvie	
Sue MacDonald - SIMCOY	1152 DISCOVERY Cr.	
BRAD McRAE	497 Muchalat, Gold River.	
June Taylor	390 South Mcquinna Dr.	
Graham Bosecker EPC/TVFD D.C.	1162 Discovery Tahsis.	
Judy Burgess	751. N. Maquinna Dr.	
John Manson.	staff.	
Catherine Gordon	150 McKelvie Rd.	
RAY MACKENZIE	860 JEWITT DR.	
LAURA MACKENZIE	860 JEWITT DR.	

PUBLIC INFORMATION MEETING
WELL HED PROTECTION PLAN

Monday, February 25, 2019
Tahsis Municipal Hall

7:30 pm to 8:30 pm

Name	Address	Comments
Sally Atkinson	1164 Discovery Cres.	
Patricia Rice	Late	
G. Fraser	Tahsis	Good Job!

APPENDIX C: COST ESTIMATES

LEVEL D COST ESTIMATES FOR TAHSIS FLOOD RISK ASSESSMENT OPTIONS 1, 2, & 3

Mitigation Measures for Option 1	Construction*	Soft Costs**	Total
Raising and Extending N. Maquinna Drive Flood Wall	$2,122,400.00	$303,200.00	$2,425,600
Raising Head Bay Road	$2,069,505.20	$295,643.60	$2,365,149
Perimeter Protection of Critical Infrastructure	$435,120.00	$62,160.00	$497,280
Boston Street Flood Pond Pump	$700,000.00	$100,000.00	$800,000
Grand Total	$5,327,025	$761,004	$6,088,029

Mitigation Measures for Option 2	Construction*	Soft Costs**	Total
Raising and Extending Cook Street Dike	$1,113,840.00	$159,120.00	$1,272,960
Raising and Extending N. Maquinna Drive Flood Wall	$2,122,400.00	$303,200.00	$2,425,600
Raising Head Bay Road	$2,959,314.40	$422,759.20	$3,382,074
Raise/ Replace Bridge (Head Bay Road)	$3,850,000.00	$550,000.00	$4,400,000
Raise Replace Bridge (Perry Brothers)	$2,030,000.00	$290,000.00	$2,320,000
Perimeter Protection of Critical Infrastructure	$435,120.00	$62,160.00	$497,280
Boston Street Flood Pond Pump	$700,000.00	$100,000.00	$800,000
Grand Total	$13,210,674	$1,887,239	$15,097,914

Mitigation Measures for Option 3	Construction*	Soft Costs**	Total
Raising and Extending Cook Street Dike	$1,243,670.40	$177,667.20	$2,309,674
Raising and Extending N. Maquinna Drive Flood Wall	$3,752,000.00	$536,000.00	$4,288,000
Raising Head Bay Road	$4,472,067.60	$638,866.80	$5,110,934
Raise/ Replace Bridge (Head Bay Road)	$4,550,000.00	$650,000.00	$5,200,000
Raise Replace Bridge (Perry Brothers)	$2,450,000.00	$350,000.00	$2,800,000
Perimeter Protection of Critical Infrastructure	$435,120.00	$62,160.00	$497,280
Boston Street Flood Pond Pump	$700,000.00	$100,000.00	$800,000
Grand Total	$17,602,858	$2,514,694	$21,005,888

* Construction includes a 40% Contingency

** Costs include engineering, environmental approvals, administration and financing

Note: Estimate does not include additional capital or other costs related to mitigation of upstream/downstream impacts.

NORTHERN TOWNSITE EAST SIDE OF TAHSIS RIVER - ASSET VALUES

Based on BC Assessment Land Improvements Values and McEhanney Estimates.

Street Name	Description	Property #	PID #	Value
Head Bay Rd		210	009-802-975	$780,000.00
Head Bay Rd		230	009-802-967	$812,100.00
Head Bay Rd		125	003-150-755	$0.00
Head Bay Rd		154	009-803-173	$0.00
Head Bay Rd		125	003-150-755	$0.00
N of Head Bay Rd E of Harbour View			009-803-017	$0.00
N of Head Bay Rd E of Harbour View			009-803-238	$0.00
N of Head Bay Rd E of Harbour View			017-376-297	$0.00
Head Bay Rd		187	000-256-439	$95,500.00
Head Bay Rd		177	001-024-591	$24,300.00
Harbour View Rd		144	000-256-447	$45,900.00
Head Bay Rd		167	000-228-460	$22,600.00
Alpine View Rd		115	000-228-478	$36,800.00
Alpine View Rd		127	000-228-486	$75,800.00
N of Head Bay Rd W of Alpine View			009-802-916	$68,100.00
N of Head Bay			009-803-149	$0.00
N of Head Bay			009-803-114	$0.00
Maquinna Dr	Wastewater Treatment Plant	15	002-966-921	$3,000,000.00
Alpine View Rd		120	000-328-189	$73,200.00
Alpine View Rd		129	002-915-677	$88,000.00

Street Name	Description	Property #	PID #	Value
Alpine View Rd		141	000-256-447	$45,900.00
Harbour View Rd		166	001-015-923	$205,800.00
Harbour View Rd		156	001-015-842	$113,000.00
Harbour View Rd		146	001-015-893	$0.00
Alpine View Rd		134	000-328-171	$77,900.00
Alpine View Rd		146	000-328-162	$0.00
Alpine View Rd		150	000-328-154	$125,000.00
Alpine View Rd		164	001-229-265	$66,900.00
Alpine View Rd		170	001-229-257	$96,900.00
Alpine View Rd		182	001-229-249	$83,800.00
Alpine View Rd		200	001-229-010	$71,700.00
Alpine View Rd		214	001-229-028	$83,600.00
Alpine View Rd		230	001-229-036	$90,500.00
Alpine View Rd		242	001-229-044	$109,000.00
Alpine View Rd		248	001-229-052	$76,400.00
Alpine View Rd		254	001-229-061	$81,000.00
Alpine View Rd		260	001-229-079	$81,300.00
Alpine View Rd		251	001-115-154	$0.00
Alpine View Rd	Rec Centre	285	002-785-986	$8,000,000.00
Alpine View Rd	High School	391	003-030-580	$10,000,000.00
Alpine View Rd		268	000-020-311	$74,900.00
Alpine View Rd		276	001-229-087	$102,000.00
Alpine View Rd		288	001-229-095	$90,400.00
Alpine View Rd		302	001-229-109	$78,500.00
Alpine View Rd		316	001-229-117	$72,400.00
Alpine View Rd		324	001-229-125	$79,100.00

Street Name	Description	Property #	PID #	Value
Alpine View Rd		332	001-229-133	$79,900.00
Alpine View Rd		344	001-229-141	$81,000.00
Alpine View Rd		352	001-229-150	$77,900.00
Alpine View Rd		366	001-229-168	$78,400.00
Alpine View Rd		374	001-229-176	$77,600.00
Alpine View Rd		386	001-229-184	$76,300.00
Maquinna Dr		215	001-229-001	$77,800.00
Maquinna Dr		223	001-228-994	$62,500.00
Maquinna Dr		229	001-228-986	$84,000.00
Maquinna Dr		235	001-228-978	$88,500.00
Maquinna Dr		241	001-228-960	$100,000.00
Maquinna Dr		253	001-228-951	$86,700.00
Maquinna Dr		265	001-228-943	$77,300.00
Maquinna Dr		277	001-228-935	$74,500.00
Maquinna Dr		281	001-228-927	$74,700.00
Maquinna Dr		293	000-211-770	$78,100.00
Maquinna Dr		301	000-549-380	$98,800.00
Maquinna Dr		315	001-228-919	$85,700.00
Maquinna Dr		323	001-228-901	$73,100.00
Maquinna Dr		339	001-228-897	$59,000.00
Maquinna Dr		347	001-228-889	$85,600.00
Maquinna Dr		359	001-228-871	$94,300.00
Maquinna Dr		363	001-228-862	$104,000.00
Maquinna Dr		379	001-228-854	$94,300.00
Maquinna Dr		385	001-228-846	$74,700.00
Maquinna Dr		407	001-228-706	$105,000.00

Street Name	Description	Property #	PID #	Value
Maquinna Dr		415	001-228-692	$68,500.00
Maquinna Dr		423	001-228-684	$74,600.00
Maquinna Dr		431	001-228-676	$92,300.00
Maquinna Dr		445	001-228-668	$91,100.00
Maquinna Dr		457	001-228-650	$81,200.00
Maquinna Dr		463	001-228-641	$85,500.00
Maquinna Dr		501	001-228-633	$77,800.00
Maquinna Dr		525	001-228-625	$77,200.00
Maquinna Dr		537	000-088-111	$82,600.00
Maquinna Dr		543	000-075-043	$77,400.00
Maquinna Dr		555	001-228-617	$73,100.00
Maquinna Dr		567	000-372-391	$91,400.00
Alpine View Rd		404	001-228-714	$89,700.00
Alpine View Rd		412	001-228-722	$69,100.00
Alpine View Rd		420	001-228-731	$113,000.00
Alpine View Rd		428	001-228-749	$88,000.00
Alpine View Rd		436	001-228-757	$82,700.00
Alpine View Rd		444	001-228-765	$134,000.00
Alpine View Rd		452	001-228-773	$50,400.00
Alpine View Rd		460	000-607-606	$47,200.00
Alpine View Rd		468	000-321-524	$72,000.00
Alpine View Rd		522	000-032-166	$93,500.00
Alpine View Rd		534	001-228-781	$76,700.00
Alpine View Rd		542	001-228-790	$76,600.00
Alpine View Rd		556	001-228-803	$77,200.00
Alpine View Rd		564	001-228-811	$94,800.00

Street Name	Description	Property #	PID #	Value
Alpine View Rd		570	001-228-820	$78,100.00
Alpine View Rd		582	000-546-127	$80,600.00
Alpine View Rd		596	001-228-838	$78,700.00
Alpine View Rd		461	000-326-224	$141,000.00
Alpine View Rd		469	000-326-216	$100,000.00
Alpine View Rd		473	000-326-208	$136,000.00
Alpine View Rd		477	000-326-194	$118,000.00
Alpine View Rd		481	000-326-186	$123,000.00
Alpine View Rd		523	000-326-160	$167,000.00
Alpine View Rd		537	001-229-273	$80,500.00
Alpine View Rd		565	002-181-398	$0.00
Alpine View Rd		587	001-145-088	$95,400.00
Alpine View Rd		601	002-181-291	$0.00
Alpine View Rd		623	002-182-548	$51,000.00
Alpine View Rd		635	002-182-432	$46,700.00
Alpine View Rd		663	002-182-386	$0.00
Alpine View Rd	Tahsis Springs x 61	651	018-985-823	$756,400.00
Maquinna Dr		721	000-982-105	$113,000.00
Maquinna Dr		751	000-982-091	$77,800.00
Maquinna Dr		781	000-982-083	$36,200.00
Maquinna Dr		841	001-782-282	$71,400.00
Maquinna Dr		861	002-980-860	$78,100.00
Maquinna Dr		941	002-980-681	$92,600.00
Maquinna Dr		961	001-523-686	$68,400.00
Maquinna Dr		1015	002-981-068	$92,600.00
Boston Rd		21	001-624-075	$74,000.00

Street Name	Description	Property #	PID #	Value
Boston Rd		41	002-980-851	$75,900.00
Boston Rd		61	001-624-148	$71,800.00
Boston Rd		81	001-624-121	$74,000.00
Boston Rd		121	001-930-648	$77,200.00
Boston Rd		141	002-980-835	$79,200.00
Boston Rd		181	001-930-613	$70,700.00
Jewitt Dr		760	001-930-605	$67,700.00
Jewitt Dr		780	001-930-621	$85,700.00
Jewitt Dr		820	001-785-770	$80,700.00
Jewitt Dr		840	001-785-761	$70,600.00
Jewitt Dr		860	001-785-737	$91,900.00
Jewitt Dr		880	001-785-729	$120,000.00
Jewitt Dr		890	001-785-711	$58,000.00
Jewitt Dr		902	002-980-797	$88,600.00
Jewitt Dr		920	001-789-775	$80,500.00
Jewitt Dr		940	001-789-686	$118,000.00
Jewitt Dr		960	001-789-660	$65,400.00
Brabant Cr		7	001-782-321	$40,900.00
Brabant Cr		10	001-524-119	$72,700.00
Brabant Cr		11	001-487-086	$98,600.00
Brabant Cr		14	002-980-029	$100,000.00
Brabant Cr		15	002-980-941	$72,700.00
Brabant Cr		18	001-524-127	$66,300.00
Brabant Cr		20	001-524-097	$115,000.00
Brabant Cr		21	001-487-094	$94,800.00
Brabant Cr		24	001-524-101	$74,200.00

Street Name	Description	Property #	PID #	Value
Brabant Cr		28	000-082-589	$70,700.00
Brabant Cr		32	000-082-597	$67,000.00
Brabant Cr		36	000-082-619	$69,200.00
Brabant Cr		40	000-082-601	$76,100.00
Brabant Cr		44	000-715-948	$76,600.00
Brabant Cr		48	002-980-045	$99,700.00
Brabant Cr		52	002-980-070	$77,300.00
Brabant Cr		56	000-133-124	$64,900.00
Brabant Cr		57	002-980-908	$102,000.00
Brabant Cr		58	001-963-601	$84,600.00
Brabant Cr		62	002-980-657	$75,400.00
Brabant Cr		63	001-487-108	$82,800.00
Brabant Cr		66	002-980-673	$71,800.00
Brabant Cr		67	002-980-886	$73,900.00
Brabant Cr		79	000-040-479	$66,400.00
Brabant Cr		82	001-523-660	$89,600.00
McKelvie Rd		10	001-523-716	$79,000.00
McKelvie Rd		20	002-083-647	$109,000.00
McKelvie Rd		41	000-122-823	$125,000.00
McKelvie Rd		50	002-980-738	$76,000.00
McKelvie Rd		71	001-888-226	$0.00
McKelvie Rd		80	002-081-059	$65,300.00
McKelvie Rd		110	002-083-710	$86,900.00
McKelvie Rd		121	002-980-967	$141,000.00
McKelvie Rd		130	002-980-762	$102,000.00
McKelvie Rd		141	002-980-975	$140,000.00

Street Name	Description	Property #	PID #	Value
McKelvie Rd		150	001-789-643	$106,000.00
McKelvie Rd		161	002-980-991	$91,500.00
McKelvie Rd		181	002-981-025	$105,000.00
McKelvie Rd	Pump Station			$750,000.00
Cook St	Public Works Yard and Salmon Hatchery	1015	002-981-068	$3,500,000.00
Cook St		1017	002-093-766	$25,200.00
Cook St		1019	027-730-581	$19,400.00
Cook St		1020	009-242-759	$27,400.00
Cook St		1021	000-050-873	$46,700.00
Cook St		1023	002-116-685	$184,000.00
			Total =	$41,210,600.00

NORTHERN TOWNSITE WEST SIDE OF TAHSIS RIVER - ASSET VALUES

Based on BC Assessment Land Improvements Values and McEhanney Estimates.

Street Name	Description	Property #	PID #	Value
Maquinna Dr		112	018-470-696	$36,600
School Hill Rd		114	009-809-481	$47,300
	Radio Site adjacent to school		009-809-562	$2,700
Rugged Mtn Rd		120	006-894-607	$79,900
Rugged Mtn Rd		36	017-152-585	$11,000
Rugged Mtn Rd		80	009-809-627	$0
S of Dinah Rd	Mobile Home Park		017-516-170	$31,000
N of Dinah Rd	Mobile Home Park		017-516-170	$31,000
Edith Rd		1	000-246-620	$0
Edith Rd		2	000-174-726	$0
Edith Rd		3	000-246-638	$30,800
Edith Rd		4	000-174-742	$20,700
Edith Rd		5	000-246-646	$20,500
Edith Rd		6	000-369-055	$12,000
Edith Rd		7	000-368-954	$14,700
Edith Rd		8	000-369-063	$8,500
Edith Rd		9	000-246-654	$4,900
Edith Rd		10	000-369-071	$0
Edith Rd		11	000-368-962	$0
Edith Rd		12	000-369-080	$26,000
Edith Rd		13	000-368-971	$16,300
Edith Rd		14	000-369-098	$10,100

Street Name	Description	Property #	PID #	Value
Edith Rd		15	000-368-989	$29,500
Edith Rd		16	000-369-101	$19,900
Edith Rd		17	000-369-004	$13,400
Edith Rd		18	000-369-110	$25,300
Edith Rd		19	000-369-012	$26,800
Edith Rd		20	000-369-128	$0
Edith Rd		21	000-369-039	$47,100
Edith Rd		22	000-369-136	$41,700
Edith Rd		23	000-174-688	$42,700
Edith Rd		25	000-174-696	$34,800
Freda Rd		1	023-373-148	$55,100
Freda Rd		3	023-373-148	$55,100
Freda Rd		5	000-369-284	$0
Freda Rd		7	000-369-292	$0
Freda Rd		8	000-369-373	$0
Freda Rd		10	000-369-381	$0
Freda Rd		11	000-369-314	$0
Freda Rd		12	000-369-390	$10,800
Freda Rd		13	000-369-331	$71,100
Freda Rd		14	000-369-403	$9,300
Freda Rd		15	000-369-349	$65,900
Freda Rd		16	000-369-411	$11,100
Freda Rd		17	000-369-357	$0
Freda Rd		18	000-369-420	$0
Freda Rd		19	000-369-365	$0
Freda Rd		20	000-369-438	$2,300

Street Name	Description	Property #	PID #	Value
Freda Rd		22	000-369-446	$18,900
			Total=	$984,800