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).

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FEBRUARY 1992

THE TAHSIS INLET OUTLET

NOVEMBER 15, 1989 VOL. 1 NO. 7

Flood Waters Threaten Residents

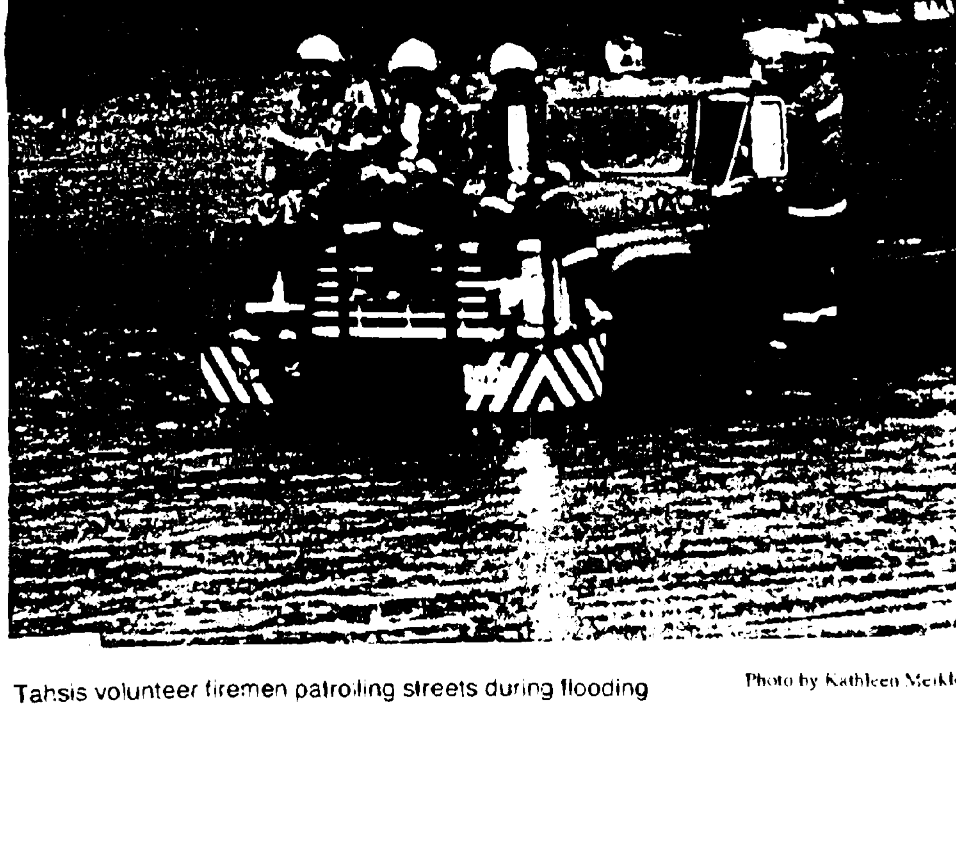
By Danielle Cowens and Staff Writers

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

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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.

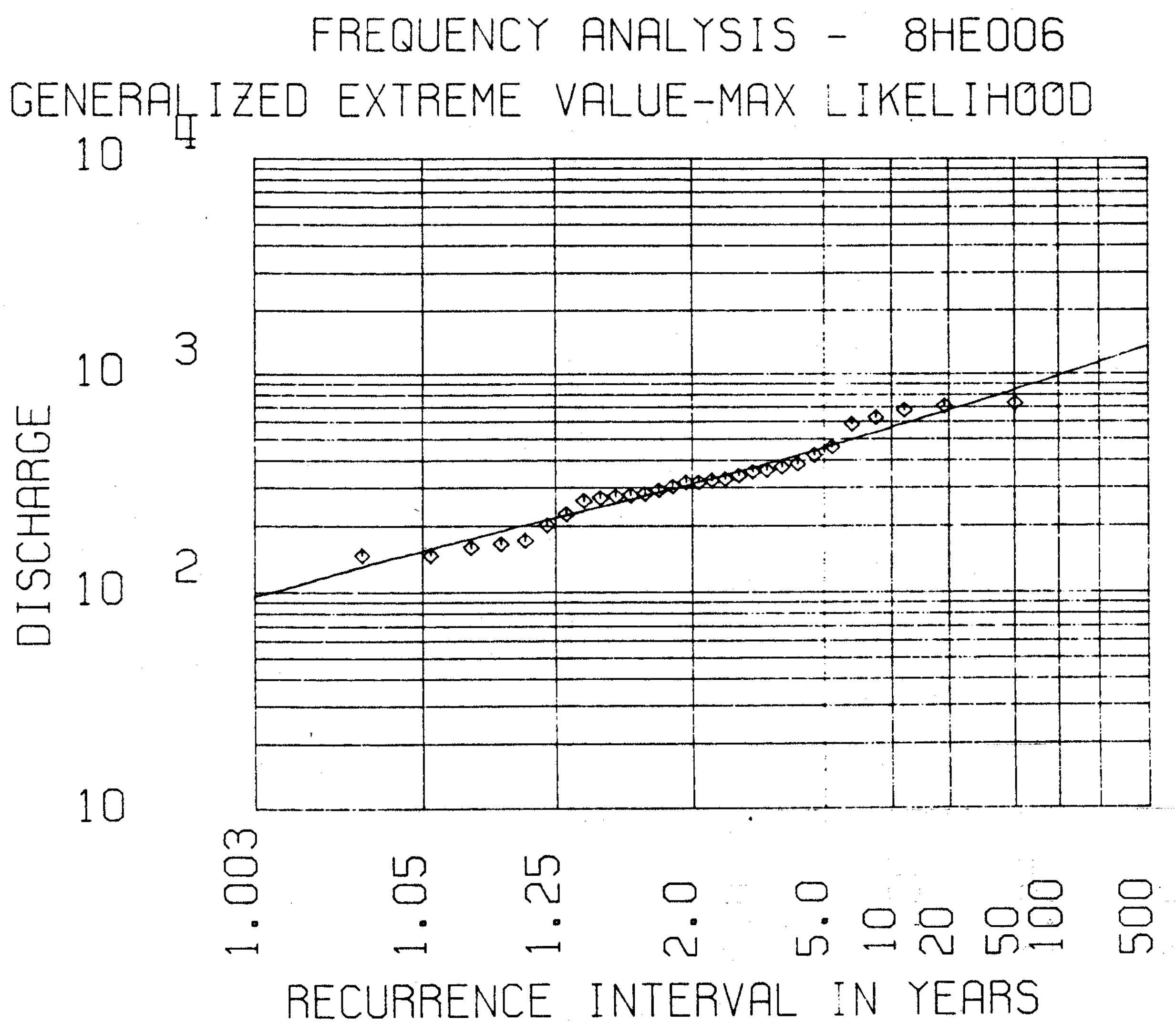


Figure 1 - Annual Maximum Daily Discharge (m^3/s) for Zeballos River Gauge

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:

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

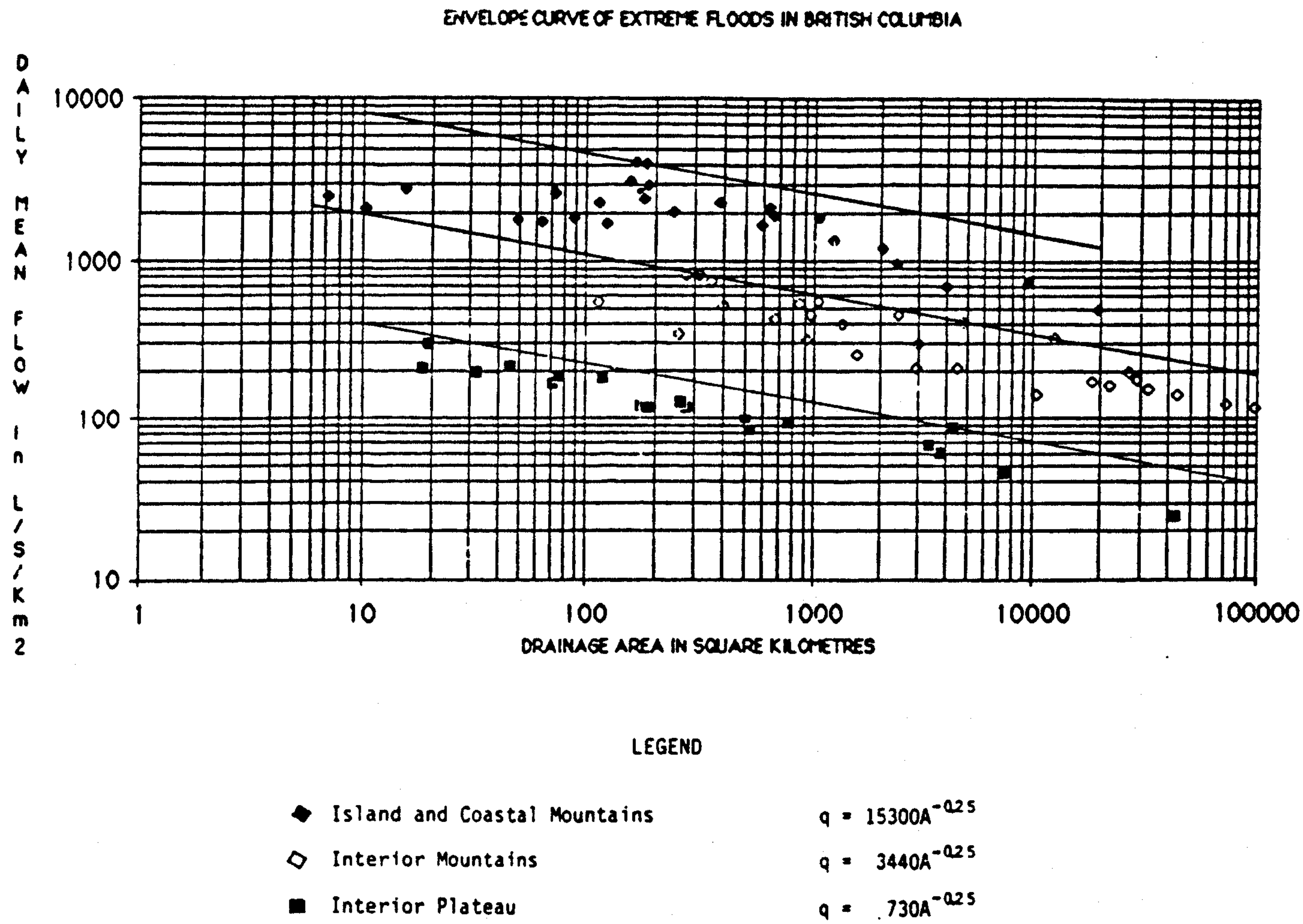
Where:

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)

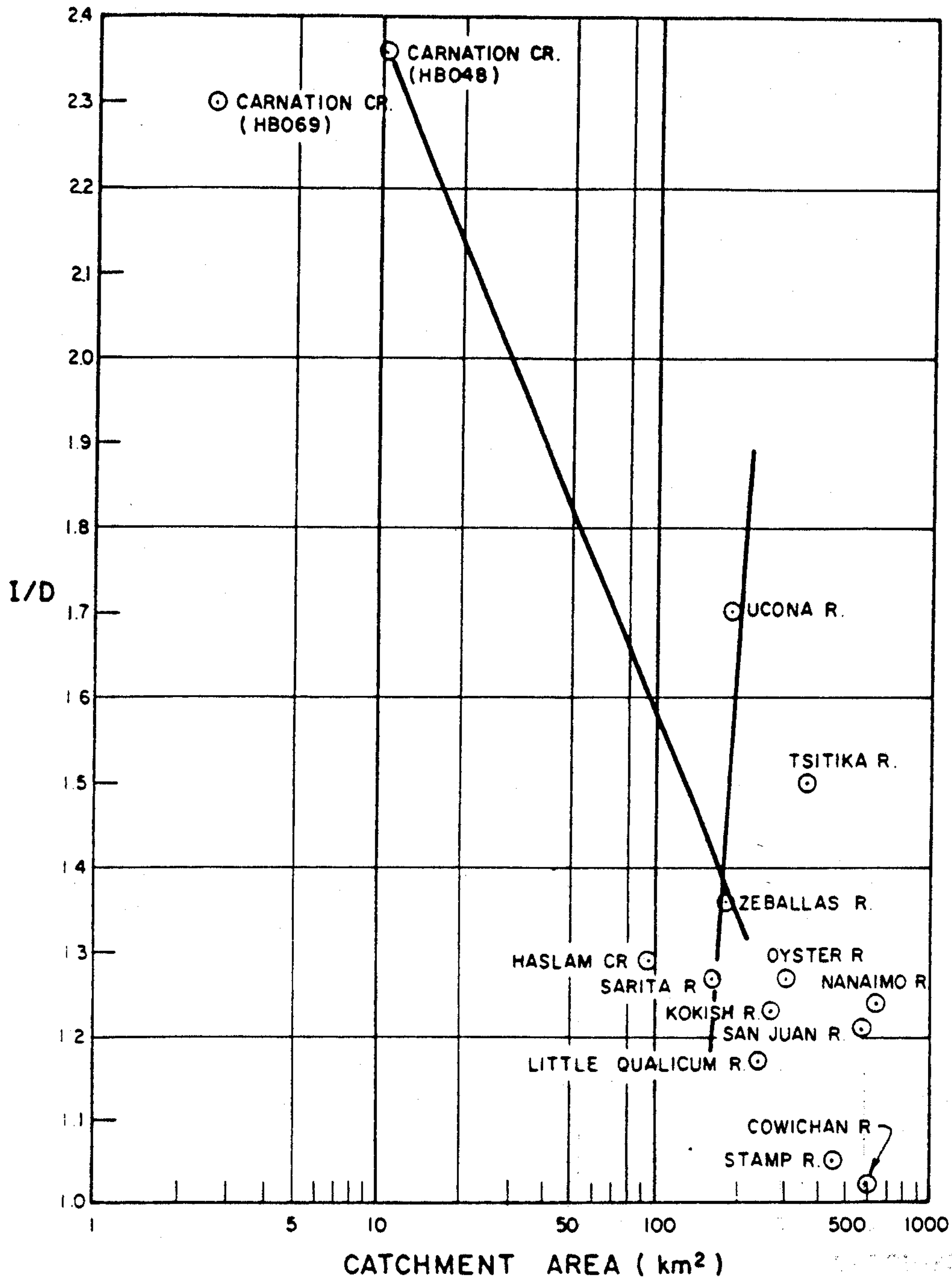
Figure 2 - Envelope Curve of Extreme Floods in British Columbia

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.

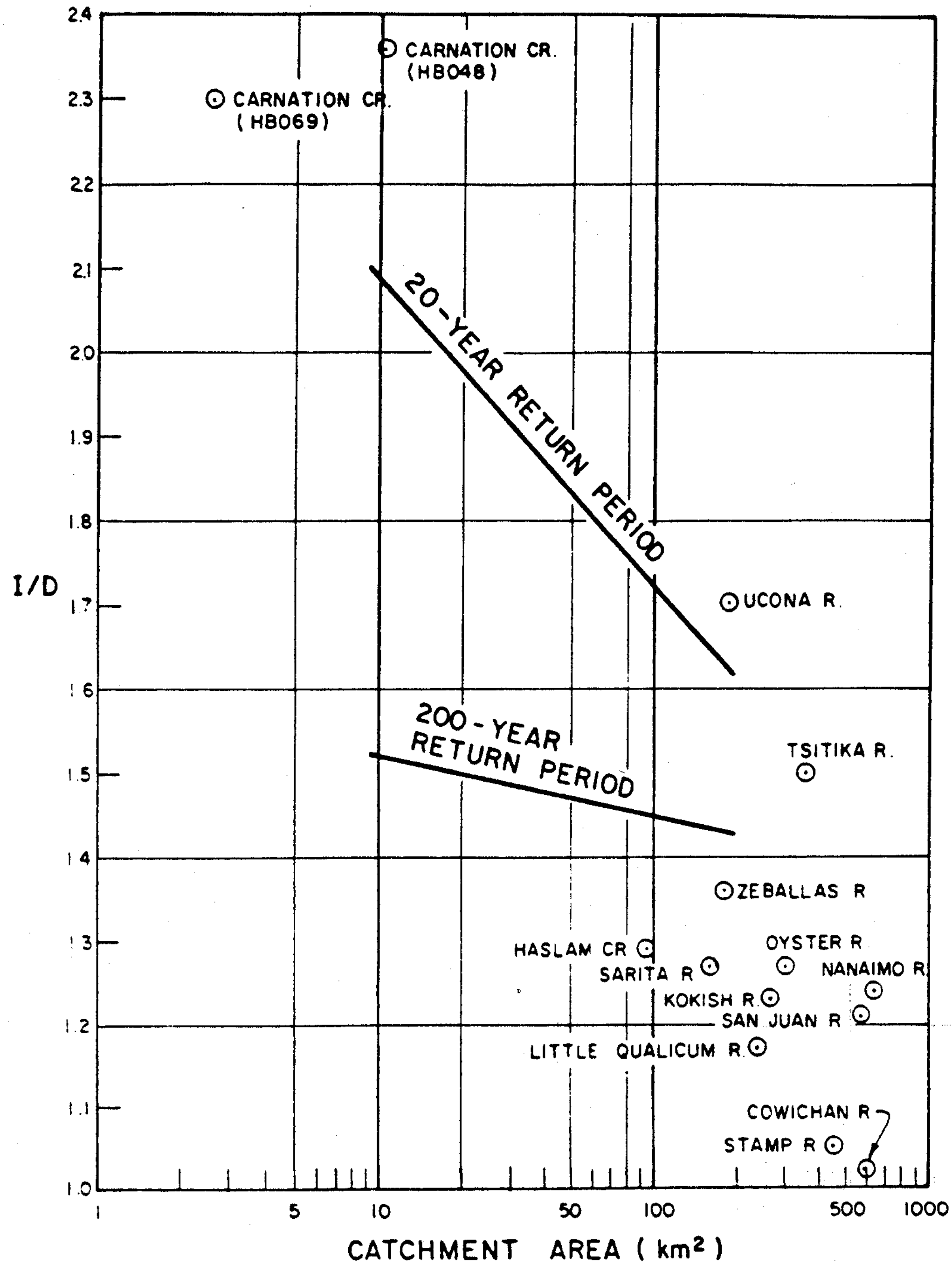


Figure 4 Selected I/D Relationships

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 (km²)	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 $\pm$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 m³/s	864 m³/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 m³/s	664 m³/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 m³/s	344 m³/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 m³/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 Engineer — Province of British Columbia — Richard F. Rodman

Richard F. Rodman, P.Eng.
Project Engineer

Professional Engineer — Province of British Columbia — C. D. Sellars

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

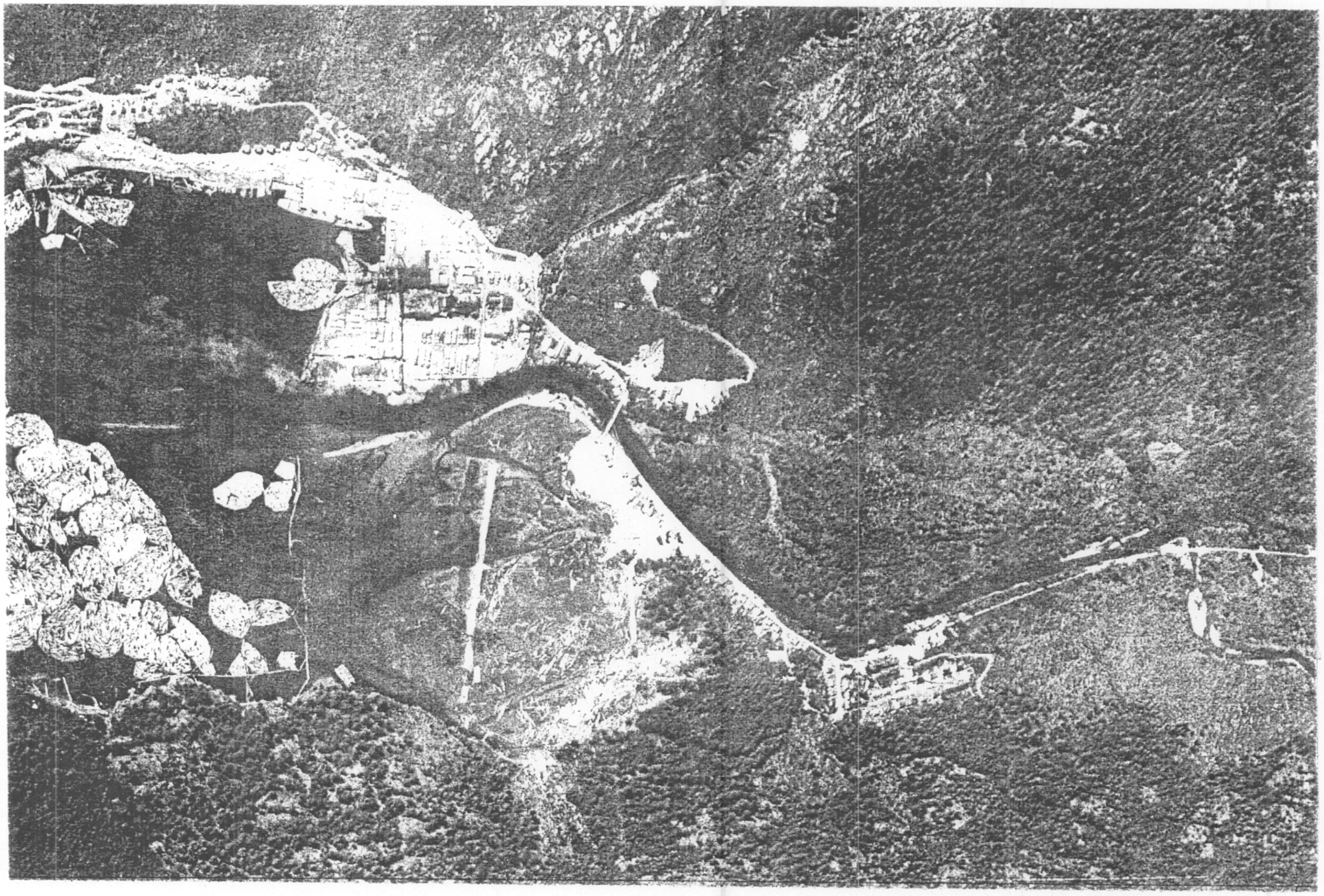
DATE: FEBRUARY 1992

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

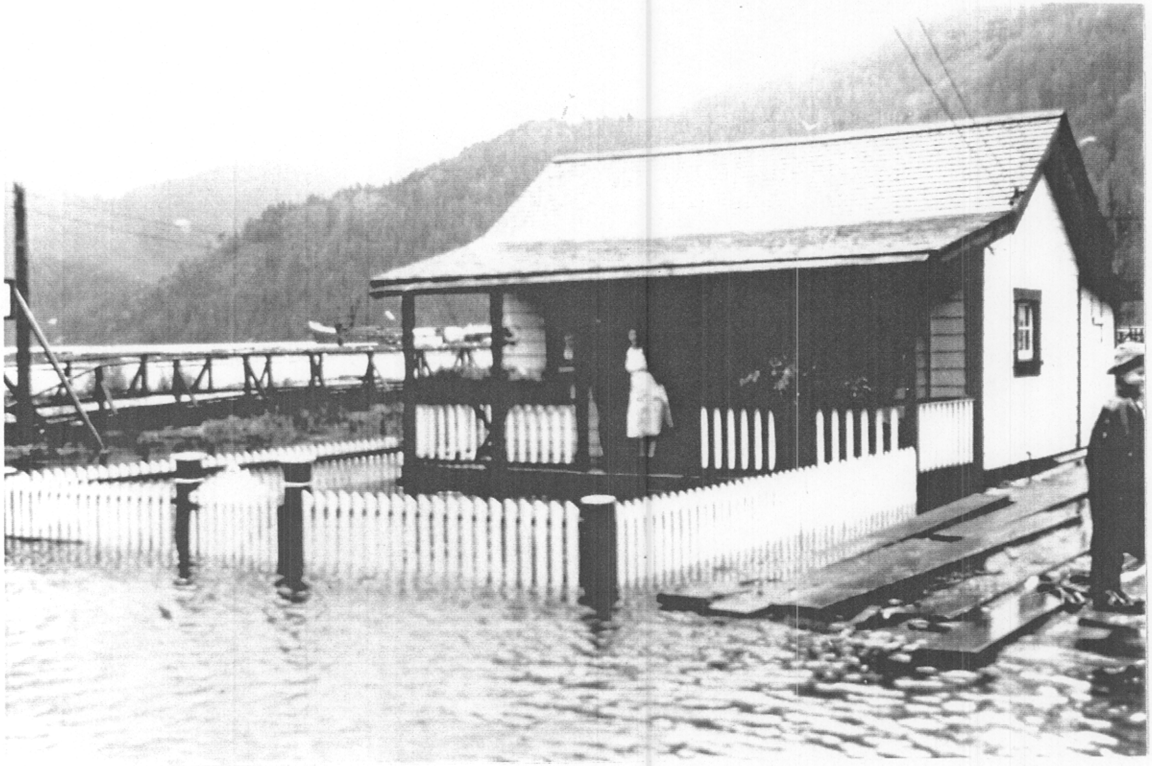
DATE: FEBRUARY 1992

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

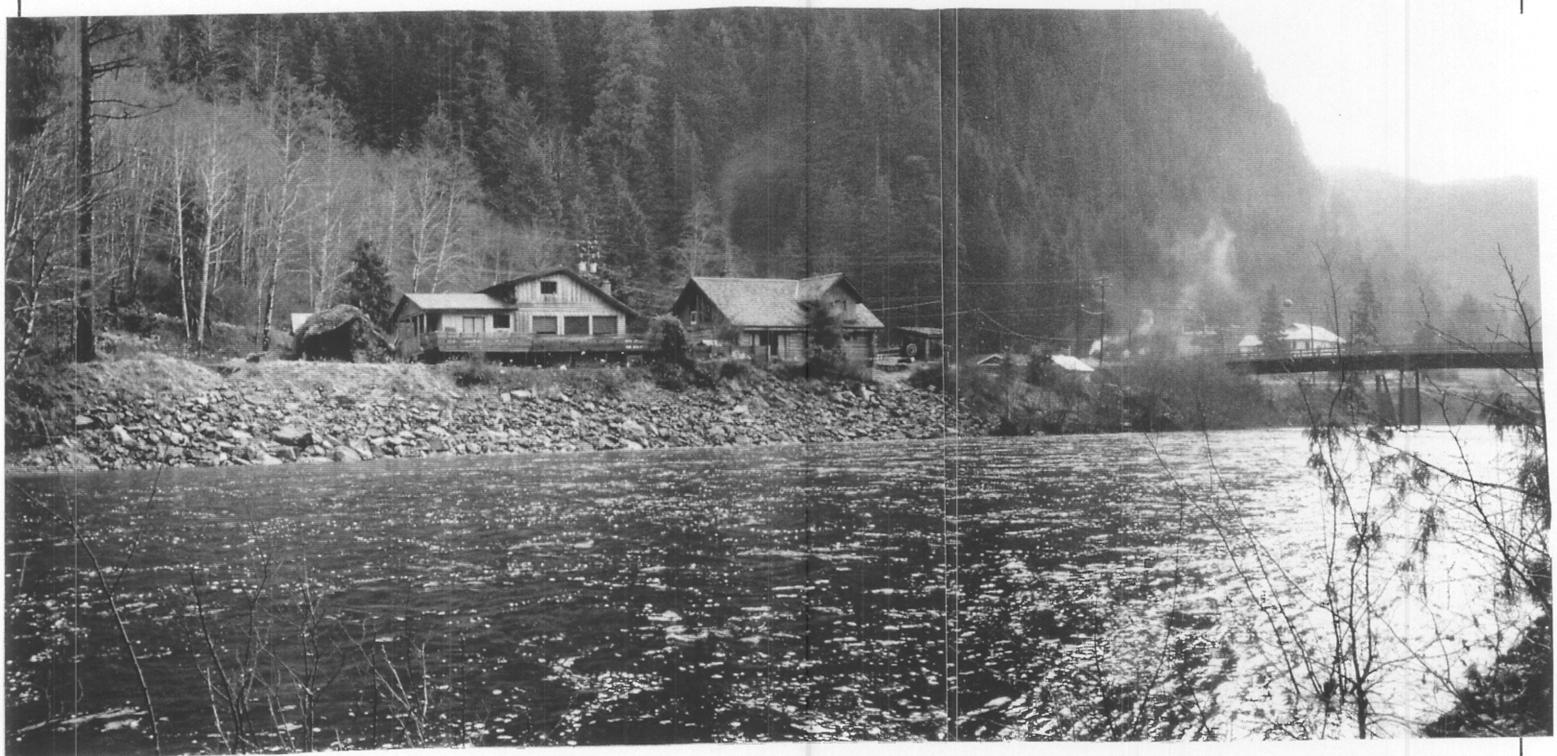
DATE: FEBRUARY 1992

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.

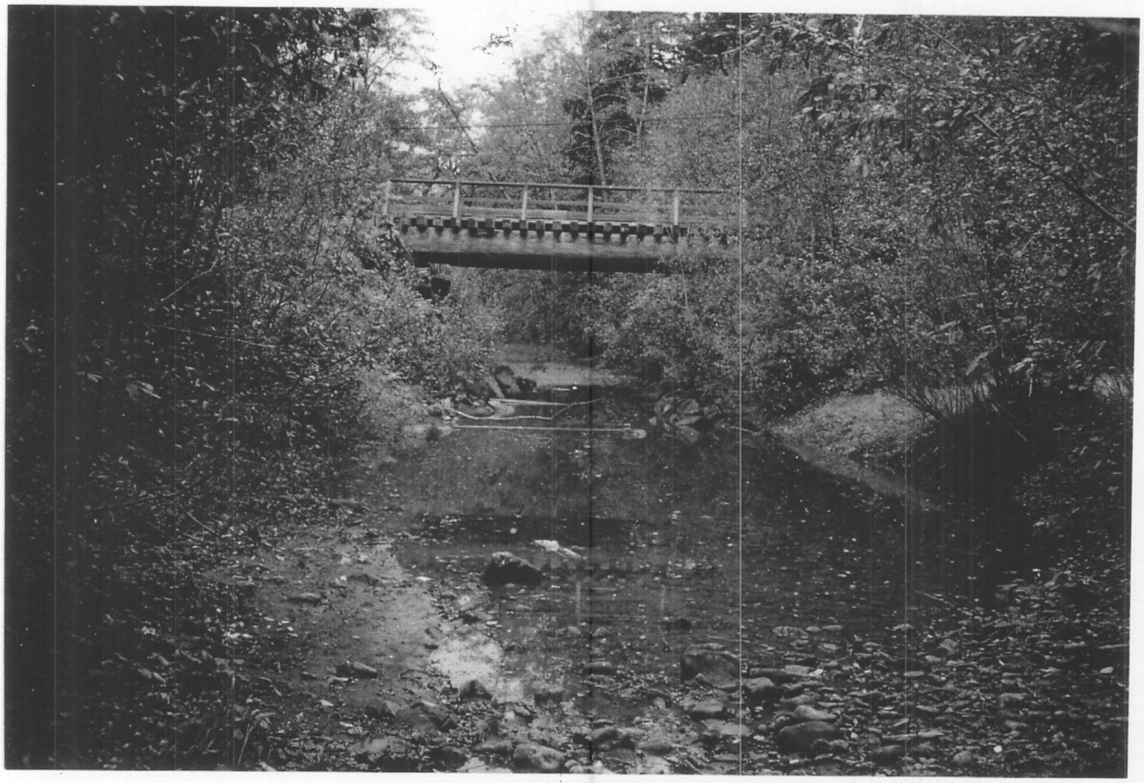
PROJECT NO: PB 5749 0101

DATE: FEBRUARY 1992

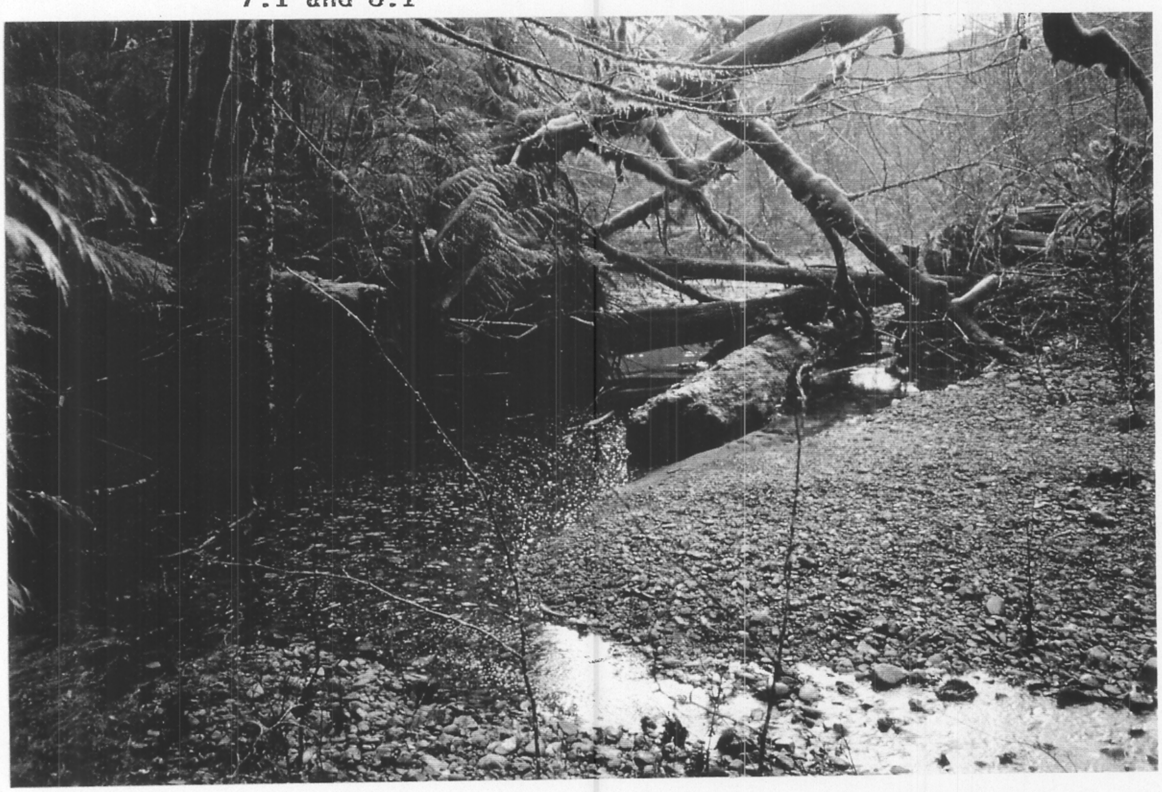
TITLE: Tahsis, Leiner, and Zeballos Rivers
Floodplain Mapping

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



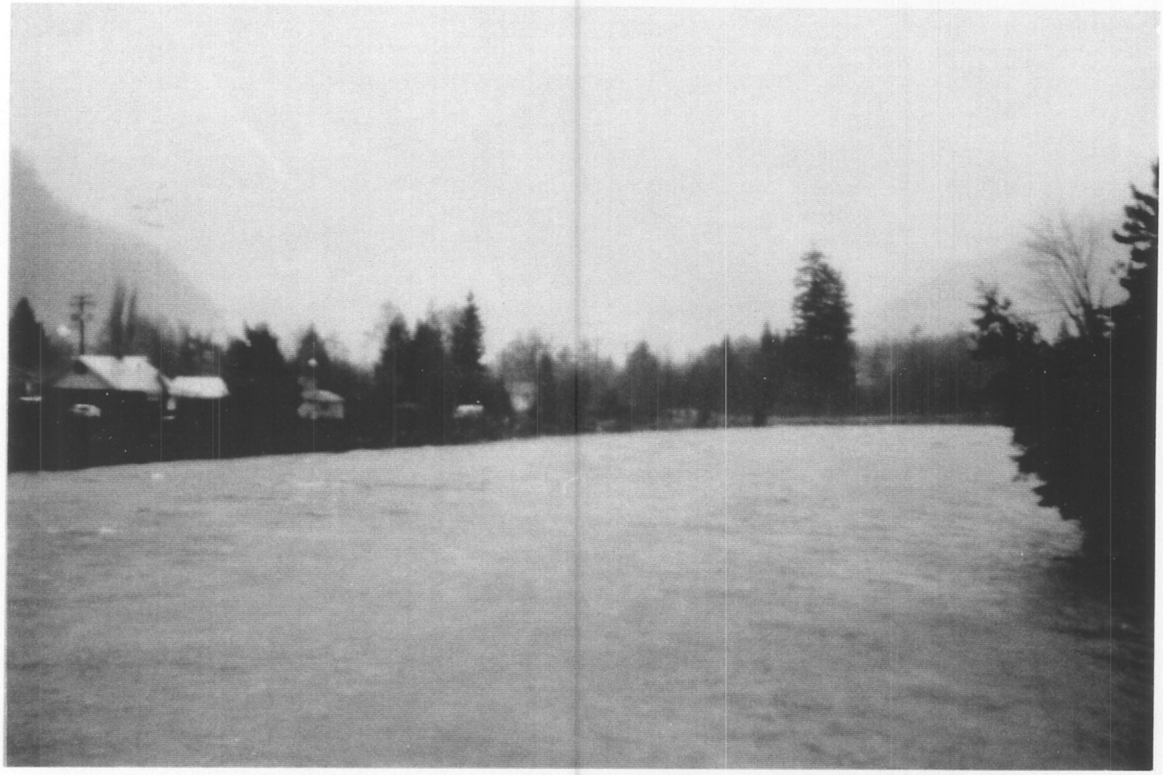
PROJECT NO: PB 5749 0101

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)



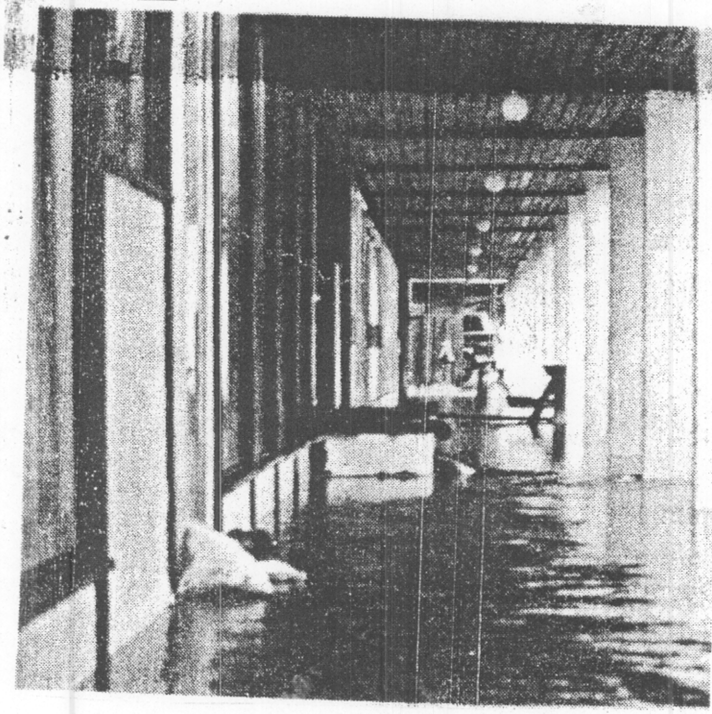
ZEBALLOS (Photo 20) Looking downstream on left bank dyke between cross sections 3 and 4 during November 11, 1990 flood. Approximately 0.5 m of freeboard on dyke. (Photo by Bill Heidrick)

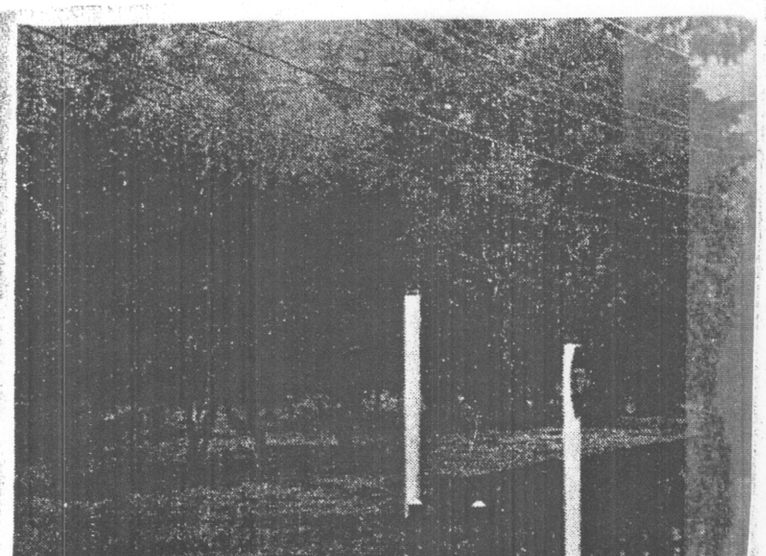
APPENDIX II

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

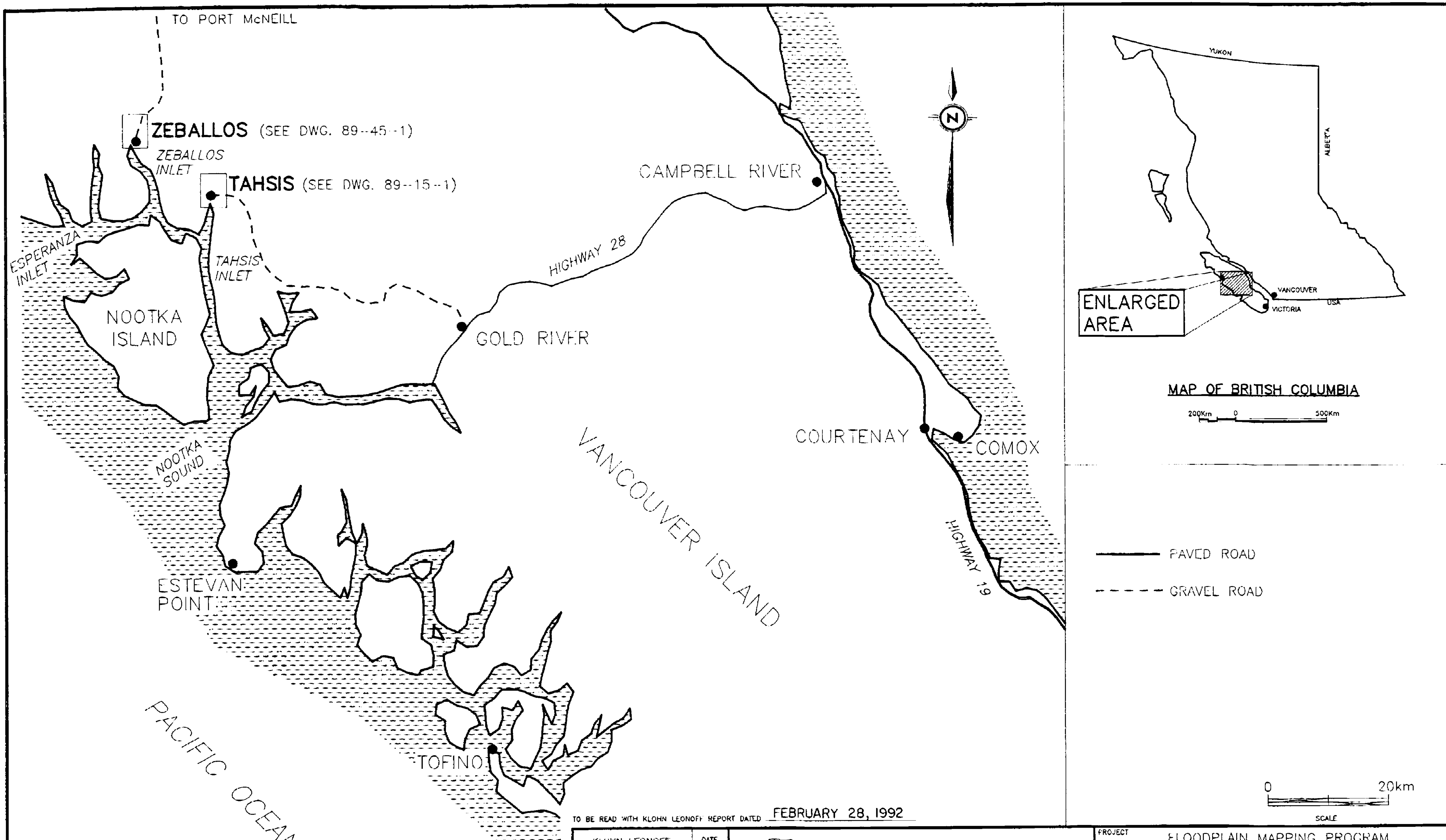
The climatological station report providedby the Village's Public Works employees on November 10 recorded 560.9mm of rain already this month, with 312mm of rain causing lasts weeks flooding.

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



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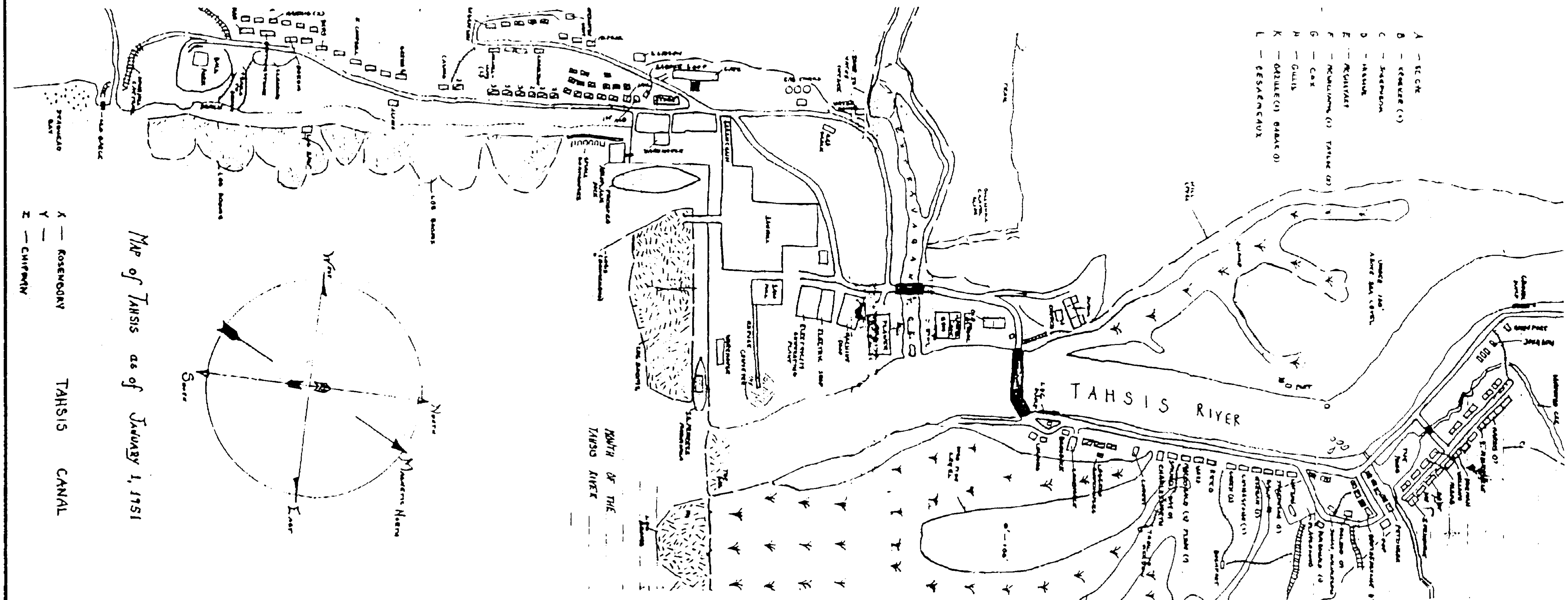
PROJECT
FLOODPLAIN MAPPING PROGRAM
TAHSIS, LEINER AND ZEBALLOS RIVERS

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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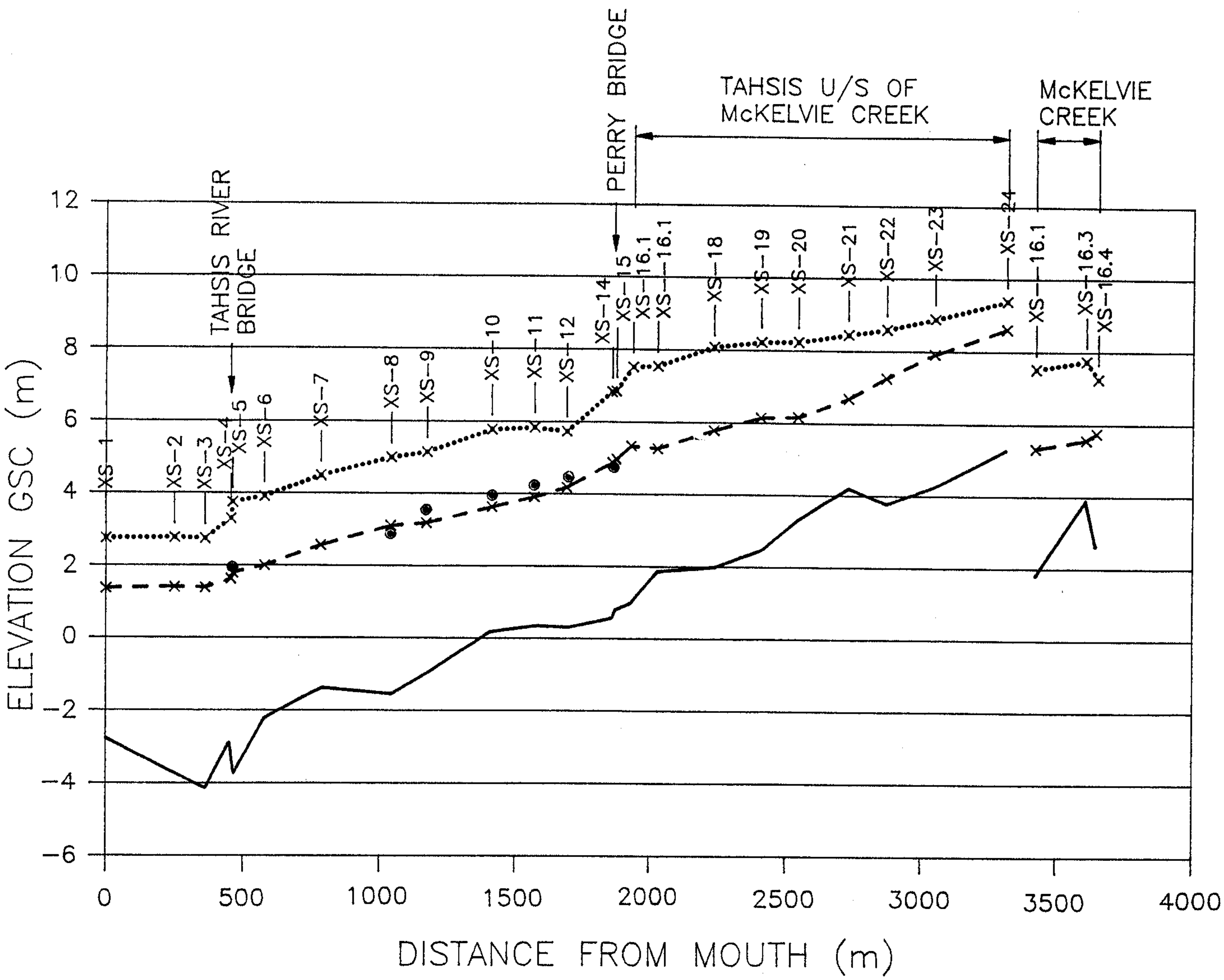
TAHSIS, LEINER AND ZEBALLOS RIVERS

TITLE
VILLAGE OF TAHSIS, 1951

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



• SURVEYED WATER LEVELS

- - - - - - CALIBRATION PROFILE

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

———— RIVER THALWEG

SCALE

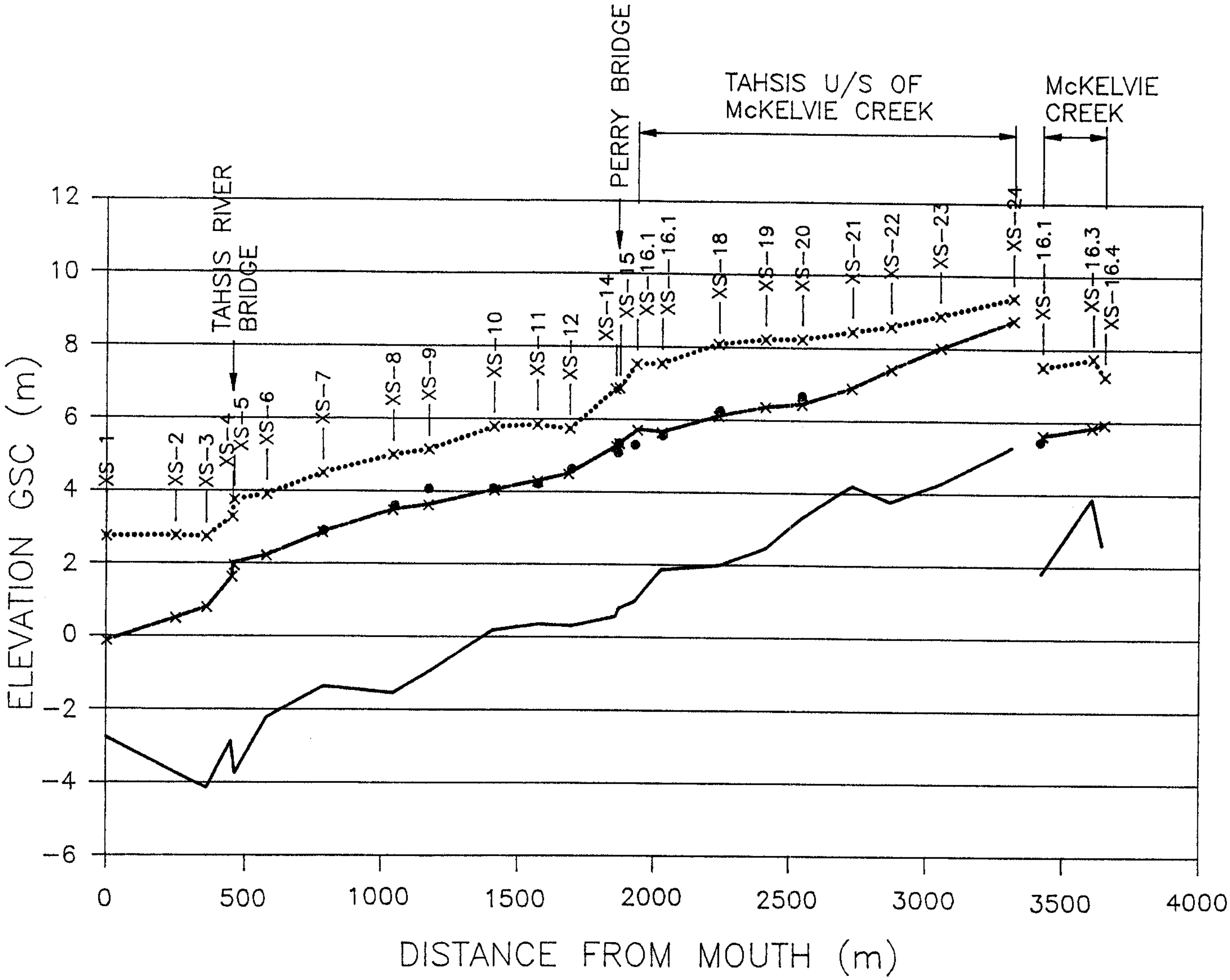
KLOHN LEONOFF LTD.

PROJECT: FLOODPLAIN MAPPING PROGRAM
TAHSIS, LEINER AND ZEBALLOS RIVERS

TITLE: TAHSIS RIVER CALIBRATION
NOVEMBER 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	
APPROVED			



• 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

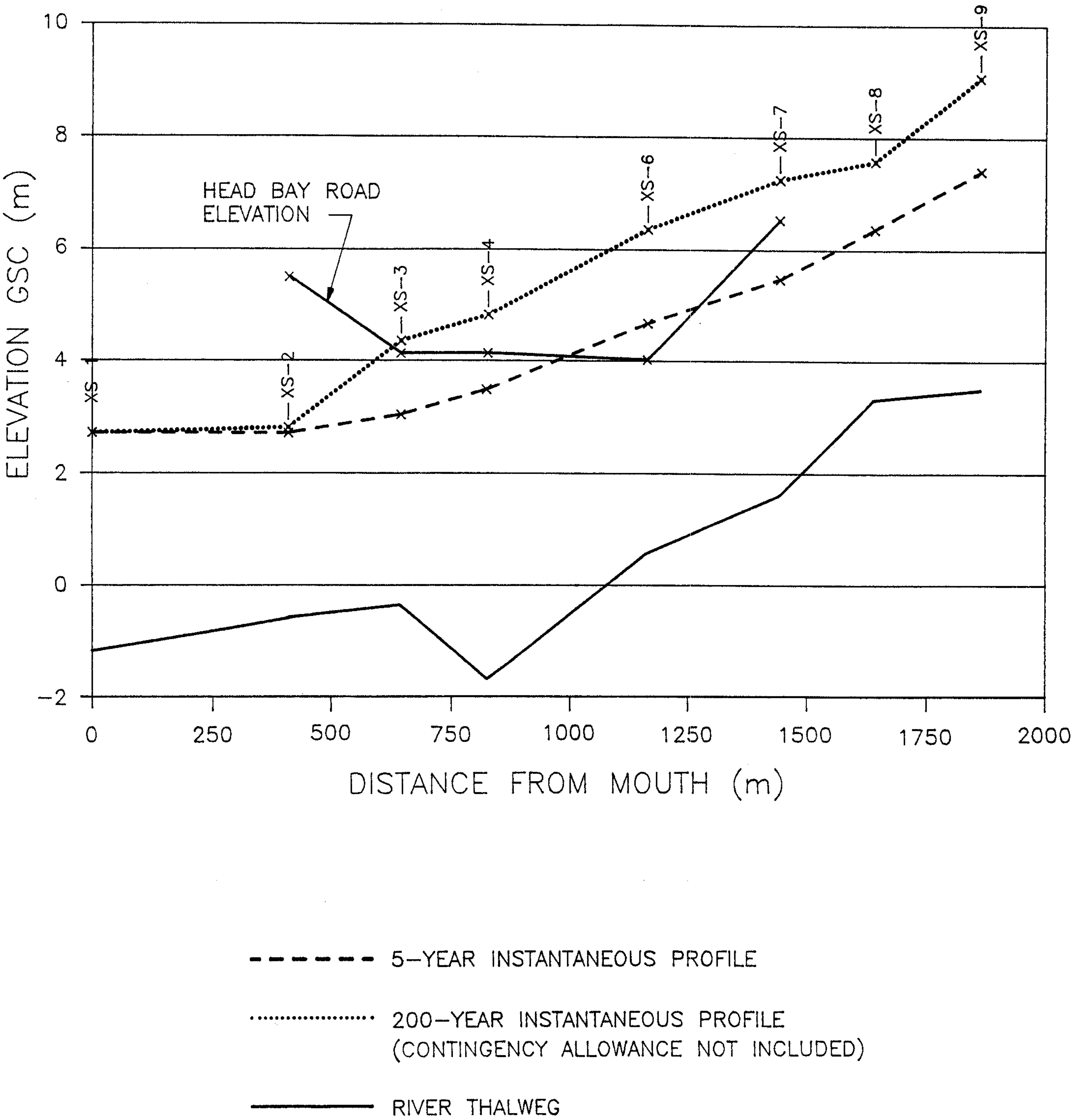
DATE OF ISSUE: FEB. 28, 1992

APPROVED

PROJECT No.: PB5749 01

DWG. No.: A-1004

REV.



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

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FEB. 28, 1992	PB5749 01	A−1005	

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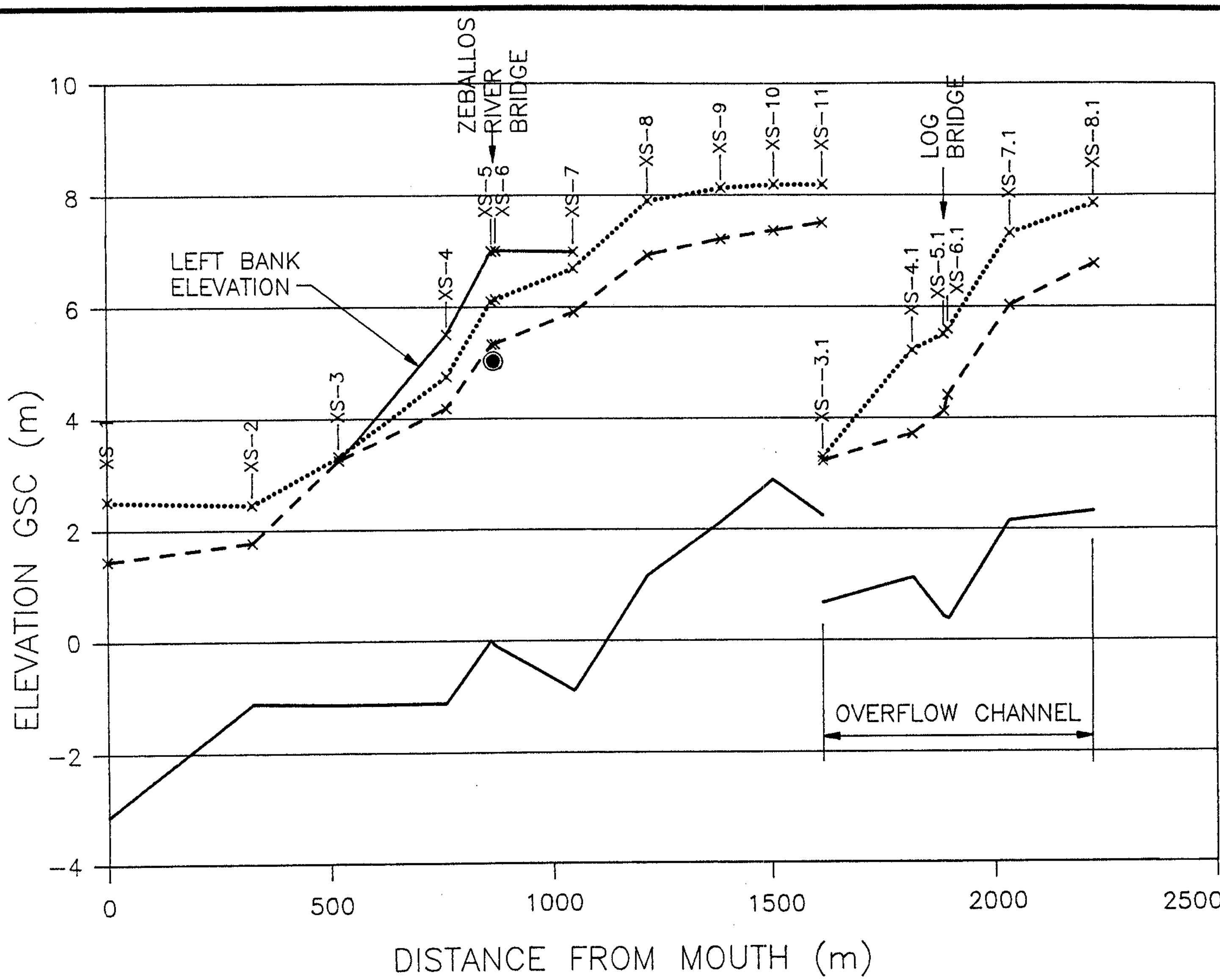

● HIGH WATER MARK, NOVEMBER 13, 1975

- - - - - - CALIBRATION PROFILE

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

———— RIVER THALWEG

KLOHN LEONOFF LTD.	PROJECT: FLOODPLAIN MAPPING PROGRAM TAHSIS, LEINER AND ZEBALLOS RIVERS	SCALE	
	TITLE: ZEBALLOS RIVER FLOOD PROFILE NOVEMBER 13, 1975		
CLIENT: B.C. ENVIRONMENT, LANDS AND PARKS ENVIRONMENT CANADA	DATE OF ISSUE: FEB. 28, 1992 APPROVED	PROJECT No.: PB5749 01	DWG. No.: A–1006 · REV.