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Environment Canada
Inland Waters Directorate

Province of British Columbia
Ministry of Environment
Water Management Branch

FLOODPLAIN MAPPING PROGRAM

COURTENAY, PUNTLEDGE AND TSOLUM RIVERS

DESIGN BRIEF

File: 2638

January, 1990

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DESIGN BRIEF

1.0 INTRODUCTION

This Design Brief and affiliated Floodplain Maps for the Courtenay, Puntledge and Tsolum Rivers were prepared under the Canada - British Columbia Floodplain Mapping Agreement by the engineering firm, Ker, Priestman & Associates Ltd. (KPA). The floodplain delineation study, which was conducted from August to December 1989, encompassed a total channel length of 27.4 km in the Courtenay River Basin on East Central Vancouver Island. This Brief presents a summary of the data and methodologies used in the study and the subsequent findings.

The Ministry of Environment, Water Management Branch contact persons in Victoria for this study were P. J. Woods, P. Eng., Head, Special Projects Section and R. W. Nichols, P. Eng., Senior Hydraulic Engineer. B. Holden, P. Eng., Coastal Engineer with the Special Projects Section, provided advice regarding determination of the Comox Harbour Flood Level. The Ministry of Environment contact person in the Regional Office in Nanaimo was J. R. Card, P. Eng.

The floodplain delineation study completed by KPA contained the following components:

- a hydrology study to determine flood frequency characteristics of the Courtenay, Puntledge and Tsolum Rivers
- development and calibration of a computer model to estimate flood profiles
- determination of 200-Year Flood Levels along the rivers and adjacent to Comox Harbour
- delineation of the land occurring below the 200-Year Flood Levels plus freeboard as the 200-Year Floodplain.

River surveys were conducted by the Ministry of Environment, and the resulting survey data was provided to KPA. The Ministry also provided topographic mapping for use as a base for the Floodplain Maps.

The Floodplain Maps produced by this study at a scale of 1:5000, appear on seven sheets entitled "Floodplain Mapping, Courtenay, Puntledge and Tsolum Rivers" (Drawing Numbers 89-13-1 to 89-13-7). These maps are not bound to this Design Brief.

Printed output from the computer runs, a profile drawing (No. 2638-1) and two cross section drawings (Nos. 2638-2 and 2638-3) and other supporting documentation have been submitted to the Ministry of Environment under separate cover.

The methods and procedures used for the flood estimates, hydraulic analyses and preparation of the Floodplain Maps conformed to the standards and specifications set forth by the B. C. Ministry of Environment (1) and by Environment Canada (2).

2.0 THE COURTENAY RIVER DRAINAGE BASIN

2.1 Geography

The Courtenay River basin is located in the East Central portion of Vancouver Island, lying mainly to the west of the City of Courtenay (Figure 1). It covers 875 km^2 of terrain which varies from the mountainous Forbidden Plateau on the west side to the flat Nanaimo Lowland on the east. Elevations in the catchment range from sea level at the mouth of the Courtenay River to approximately 2100 m at the highest mountain peak.

The Courtenay River is formed by two tributaries, the Tsolum and Puntledge Rivers. The name Courtenay River refers only to the 3.1 km long stream channel between the confluence of these two tributaries and the mouth at Comox Harbour. The influence of tides on river water levels extends up the entire length of the Courtenay River, and a short distance up the Tsolum and Puntledge Rivers. A broad lowland area, known as the Courtenay Flats, lies to the east of the Courtenay River and measures 2.7 km^2 in area.

The Tsolum and Puntledge River channels actually join in two separate locations. An old confluence of the two rivers exists just upstream of cross section XSC-15. At some time between 1976 and 1987, a meander bend of the Tsolum River broke through to the Puntledge, forming a new confluence 500 m upstream of the old one. The new confluence has become hydraulically dominant and sedimentation is transforming the former Tsolum River channel below the upper confluence into a slough.

The Puntledge River has a total drainage area of 605 km^2, while the Tsolum drains 255 km^2. The types of terrain drained by these two rivers are very different from one another. Most of the Puntledge River runoff originates in the mountainous portion of the basin. The

Cruickshank River and the upper Puntledge River feed Comox Lake, a 15 km long body of water with a drainage area of 464 km^2 situated just inside the mountainous part of the basin.

Comox Lake significantly reduces the magnitudes of its inflow flood peaks because some of the inflow is required to raise the lake level before the outflow peak is reached. Regulation of Comox Lake outflows by B. C. Hydro for power generation purposes at the Puntledge Generating Station also has a major impact on downstream discharges. The unregulated Browns River, which also drains mountain slopes, enters the Puntledge River between Comox Lake and the upstream limit of the floodplain mapping associated with this study.

In contrast, most of the Tsolum River drainage area is located on the lowlands. One exception is the area in its headwaters draining the east slopes of Mount Washington, which reaches a peak elevation of 1590 m. There is one large lake in the Tsolum drainage basin, named Wolf Lake, which modifies the peak flows on Headquarters Creek, but has a minor impact on the Tsolum River flood peaks. Despite the notation in Water Survey of Canada (WSC) publications that the Tsolum River is regulated, there are no large impoundments in the Tsolum basin which could affect flood discharges to any significant degree.

2.2 Hydrologic Characteristics

The rainy season on Vancouver Island occurs in late fall and winter. During this period, frontal systems travel onshore from the Pacific Ocean, often bringing heavy precipitation, strong winds and mild temperatures. Single storm durations vary from several hours to several days. It is common for several storms to cross the region in succession, with intervals between storms typically ranging from 12 hours to a few days.

Peak flows on both the Puntledge and Tsolum Rivers typically occur from October to March. Despite the substantial snowpacks which accumulate at the high elevation areas, all of the larger recorded floods on the Puntledge and Tsolum Rivers have occurred during this period. This indicates that virtually all major floods are caused by heavy rain or rain-on-snow events, rather than snowmelt alone.

In addition to flow regulation and geographic reasons for dissimilar hydrologic responses to rain events in the Tsolum and Puntledge River basins, there appear to be frequent differences in the precipitation patterns also. For example, the 1975 and 1983 floods along the Courtenay River indicated heavier precipitation in the Tsolum basin, while the 1980 and 1982 floods resulted from higher runoff to Comox Lake and subsequent discharges to the Puntledge River. It is conceivable that a storm could produce high runoff in both basins simultaneously, resulting in a greater flood on the Courtenay River than these past events.

Because of the differences between the hydrologic responses of the Puntledge and Tsolum Rivers, flood frequency estimates were determined separately for each river.

2.3 Historic Floods

Several damaging flood events have occurred along the Courtenay, Puntledge and Tsolum Rivers since 1900. The dates of these floods and, where records exist, their peak discharges are listed in Table 1. The 200-year floods estimated by this study for nearby locations are also presented in Table 1 for comparison purposes.

Table 1
Peak Discharges for Major Historic Floods

Gauge Site: / Flood Date	Recorded Peak Discharge - m^3/s					
	Comox Lake Inflow (B.C.Hydro)	Puntledge/ Cumberland 08HB007	Puntledge/ Courtenay 08HB006		Tsolum/ Courtenay 08HB011	
	daily	daily	daily	inst.	daily	inst.
13 October, 1905	--	--	--	--	--	--
1 February, 1935	388	222	--	--	--	--
15 November, 1939	425	217	--	--	--	--
8 December, 1939	--	224	--	--	--	--
13 November, 1953	--	--	--	--	--	--
13 November, 1975	402	--	263	313	170 (est.)	223
26 December, 1980	483	--	281	467	136	215
25 October, 1982	447	--	319	344	105 (est.)	--
11 February, 1983	325	--	246	364	180	235

Estimated 200-Year Peak Flow - m^3/s
(for comparison)

Location	Comox Lake Inflow	Puntledge at the Mouth		Tsolum at the Mouth	
	daily	daily	inst.	daily	inst.
	710	540	748	358	495

Brief commentaries appear below about the floods listed in Table 1, and photographs appear in Appendix 1. Information about earlier floods was generally more scarce than for later events.

October 1905

Although no records of discharge were found for this event, an article in the Colonist newspaper from Victoria dated October 13, 1905 stated that:

"Advices from Comox are to the effect that the heaviest rain and wind storms experienced in years raged last week. Besides minor damage done to farms, thirty feet of the government dyke where it crosses the big slough between Courtenay and Comox ... gave way under the enormous body of water accumulated by the heavy downpour.

1 February, 1935

Flow records indicate that a moderate flood occurred on the Puntledge River, however newspaper accounts stated that this was the largest flood in the preceding 40 to 60 years. The flood was associated with a period of mild weather and steady rain which melted a heavy accumulation of snow. The tides were relatively low during the flood, therefore were not a major contributing factor. The flooding lasted for more than 24 hours in Courtenay.

In addition to inundated roads and buildings, major damages included the partial collapse of the Condensory Road Bridge over the Puntledge River (Photo 1). The Comox Argus reported that a "battery of huge logs at a speed of seven to eight knots ... knocked out the centre pier of the road bridge and weakened another". A water main was also severed by a washout along Comox Road. Structures in Lewis Park were damaged by water and logs (Photo 2).

A long stretch of the Island Highway near the Courtenay Hotel was under water (Photos 3 and 4), as were portions of Comox Road (Photo 5) and Condensory Road. The Courtenay Flats were completely inundated with floodwaters and were described as "one vast lake" from the River to the far side of the Flats.

15 November, 1939

Flood waters rose rapidly during the night of the 14th, and peaked on the 15th just before a high tide of 1.32 m geodetic, which crested at 11:00 a.m. Southeast gale-force winds accompanied the heavy rain, which set a precipitation record of 83 mm in 24 hours on the 15th. Newspapers reported that residents found this flood to be more severe than the 1935 flood.

The Courtenay Flats were again transformed into a lake and water inundated the Island Highway and Comox Road from Dyke Mill to Sandwick corner (Photos 7 and 8). The lower floors of many buildings were flooded, Lewis Park was inundated, and several vehicles were stranded. The Condensory Road Bridge was threatened when logs accumulated against the piers and caused the bridge to shake.

8 December, 1939

A second flood in 3 weeks occurred along the Courtenay River, however the maximum stage did not reach the levels attained in the November flood, although the Puntledge River gauge recorded a higher daily peak for the December event. The Island Highway was overtopped again, but the Flats were not completely filled with water as they were 3 weeks earlier.

13 November, 1953

There were no WSC gauges in operation on either the Puntledge or Tsolum Rivers during the latter part of 1953. Also, no records of

Comox Lake inflows could be found for this period, which immediately followed the date of purchase of the facilities by the B. C. Power Commission. It was impossible, therefore, to compare the 1953 peak discharges to other floods.

A very high tide of 2.24 m geodetic occurred at noon on November 13, although flooding had already commenced early the same morning. A total of 229 mm of rain in 5 days was measured at Courtenay, with 57 mm falling on the 13th. The storm was accompanied by a 50 kmh southeast wind. From the newspaper accounts, it appears that the 1953 flood was not as high as the 1939 flood.

Damage from this flood was mainly limited to inundated ground floors and basements of homes and floors of barns. A new dyke around Lewis Park was credited for reducing the extent of damage to the Park in comparison to effects of the 1935 and 1939 floods. Newspaper reports indicate that the Island Highway, Comox Road and the Courtenay Flats were also flooded by this event.

13 November, 1975

Snowmelt and widespread heavy rains caused flooding in many locations on northeastern Vancouver Island. The recorded peak flows for the Puntledge River (Table 1) were not the highest for the year. They were exceeded only eight days earlier, however, the Tsolum River discharges were much lower during the earlier event, so that the net effect on the Courtenay River was a lower discharge and little flooding.

A hydrograph for the flood on the Puntledge River, and reconstructed hydrographs using WSC estimates and earlier work by Nielsen (3) for the Tsolum and Courtenay Rivers are presented in Figure 2. In the calibration of the backwater model for this study, there were indications that the estimated Tsolum River discharges listed in Table 1 for the 13 November flood are lower than the flows which actually occurred. The tide variations throughout the peak flow period are also shown in Figure 2. A high tide of 1.73 m geodetic occurred about 2 hours before the peak discharge was recorded on the Puntledge River.

Flood waters caused considerable damage in the Rye Road area, entering homes and businesses in the lowlands north of Ryan Road (Drawing No. 89-13-2). Some residents expressed the opinion that the construction of Ryan Road caused higher flood levels in this area. Flooding also occurred along the approaches to the Condensory Road Bridge. Puntledge Park and Lewis Park were heavily inundated (Photos 10 and 11). The Courtenay Flats received some flood waters from the rivers, but were not filled as they had been in earlier floods.

At its highest, the water level of Comox Lake was reported to be 1.2 m below the crest of the dam. However, in anticipation of a flood, the lake had been lowered by 1.5 m before the storm began by B. C. Hydro dam operators.

26 December, 1980

Several days of record warm temperatures and heavy rain resulted in very high discharges, especially in the Puntledge basin. The highest recorded peak inflow to Comox Lake occurred with this event, however the high flows were not sustained over a long period of time. The peak instantaneous flow for the Puntledge River also set a record. The Tsolum River flows, however, were not as extreme.

The flood hydrographs for the Tsolum and Puntledge Rivers and the tidal variations at Little River are presented in Figure 2. Fortunately, the peak of the flood coincided with the lower high tide for the 26th, which reached a height of 1.11 m geodetic. Maximum flood levels would have been much higher if the discharge peak had coincided with the 2.38 m higher high tide which crested about 10 hrs. earlier.

An additional factor in the flood was the accumulation of debris at a temporary work bridge in the river at the construction site for the 17th Street Bridge. Estimates by observers of the maximum head drop at the log jam varied from 0.9 to 1.2 m.

Much of the damage was confined to buildings in the Rye Road area. The Old Island Highway near the Courtenay Hotel and sections of Anderton Avenue, Condensory Road and Comox (Dyke) Road were reported to have been underwater. The Courtenay Flats were inundated to a greater depth than in the 1975 event.

25 October, 1982

In Courtenay, this was not a large flood, but it was associated with a high inflow to Comox Lake. Although Puntledge Park was under water, the regulated Puntledge River discharges resulted in very little reported flood damage in the Courtenay area, when combined with the minor flood flows in the Tsolum River. The high tide of 1.72 m geodetic occurred 6 hrs. before the peak Puntledge flow was recorded.

11 February, 1983

Warm temperatures, high winds and heavy rains, including 80.2 mm on the 11th, caused flooding along the Tsolum and Courtenay Rivers. In contrast to the 1980 and 1982 flood events, this flood was more extreme in the Tsolum River than in the Puntledge, and was similar in some respects to the 1975 event.

The flood was directly responsible for the death of a 37-year old man who lived on the left bank of the Tsolum River near XST-73. The man was being rescued from his flooded home when the canoe carrying him and two other people capsized. The man spent about 2 hrs. in the water before he was brought to shore alive, but died en route to the hospital from the effects of shock and hypothermia.

Dove Creek Road near its crossing of the Tsolum River was overtopped by flood waters (Photo 14). The Old Island Highway near Ryan Road and the Rye Road area were flooded once again (Photo 15). Water did not, however, inundate the Courtenay Flats on this occasion. The tide was very low at the time when the Tsolum and Puntledge Rivers peaked.

3.0 DATA USED FOR STUDY

3.1 Data Sources

Many different types of information were acquired for this study from a variety of sources. The main sources of data are listed below, and reports from which information was obtained are listed in the References section:

Mapping

Maps used for this study are listed below:

- NTS 1:250,000 scale map sheet 92F
- NTS 1:50,000 scale map sheets 92 F/6, F/10, F/11, F/14 and F/15
- B. C. Ministry of Environment, Surveys and Resource Mapping Branch 1:5000 scale topographic base maps (seven sheets) 89-13-1 to 89-13-7, and the nine 1:5000 scale Work Sheets which were spliced and trimmed to form the base maps.
- B. C. Ministry of Environment, Surveys and Resource Mapping Branch uncontrolled mosaics numbered 89-20-1, 20-2, 20-3 and 21-1.

Floodplain limits were delineated on the 1:5000 scale base maps. This mapping was found to agree closely with most of the cross section and road profile survey data. In a few heavily forested areas, however, significant discrepancies were discovered. In these areas, which are identified on the Floodplain Maps, the floodplain limits were located on the basis of the cross section survey data, field inspection and additional air photo interpretation.

Air Photos

Selected stereo pairs from the 1987 B. C. Government aerial photography, Roll No. BC 87025, Photo Numbers 004 to 200, were used in the study. These photos provided stereo coverage of the full extent of the rivers and floodplains within the study limits.

Surveys

Survey data for a total of 121 cross sections, measurements for the 6 bridges in the study reaches, bridge photographs and channel photographs were provided by the B. C. Ministry of Environment (Project 88-FDC-5). The survey data was found to be up-to-date, reliable and accurate for the purposes of this study.

Road profile survey data for Highway 19, Comox Road and the Old Island Highway in the vicinity of Lewis Park and the Courtenay Flats, was also provided by the B. C. Ministry of Environment (Project 8934F036). The survey was conducted when it became apparent that flood levels would be sensitive to road elevations in this area.

High Water Marks

A substantial number of high water mark measurements were obtained for this study. However, the data varied in reliability and applicability for study purposes. The most useful high water marks were those read from gauges or related accurately to distinct physical features at recorded times and dates. A listing of the source of each set of high water mark data appears in Table 2 below:

Table 2

Summary of High Water Mark Data

Flood Event	No. of HWMs	Source of Data	Comments
1975	16	R. A. Waugh, Sup't. of Public Works, Courtenay	dates, but no times; marks fixed during or right after flood
1975	10	MoE Surveys Section (18 Nov. 1975)	dates, but no times
1975, 1983	8	MoE Surveys Section (Aug. 1988)	marks measured years after flood; some dates but no times
Unspecified	113	MoE Surveys Section (Aug. - Sept. 1988)	no dates, no times; measured with cross sections
1975, 1980, 1983	9	B. C. Hydro	manual staff gauges readings with dates and times
1980, 1983	2	WSC	recorder gauge readings at only one location with dates and times

Hydrologic Data

The types and sources of hydrologic data used in this study are listed below:

Type of Data	Source
peak daily and instantaneous discharges for regional streams	Water Survey of Canada (4, 5, 6)
15-minute discharges for selected flood events at key gauges	Water Survey of Canada (7)
hourly tide heights and maxima at Comox and Little River during selected flood events	Institute of Ocean Sciences, Department of Fisheries and Oceans
peak daily inflows at Comox Lake, Elsie Lake and Upper Campbell Lake	B. C. Hydro
records of annual maximum inflows for Comox Lake, 1913 - 1988	B. C. Hydro
computed hourly inflows for selected storm events	B. C. Hydro

In addition to the data listed above, a wealth of valuable information was obtained from reports by the B. C. Ministry of Environment (8, 9, 10), B. C. Hydro (11, 12, 13, 14), Nielsen (3) and Hardy BBT (15). Historical flood information was obtained from newspapers filed with the Provincial Archives, the Greater Victoria Public Library, the Comox District Free Press and the Courtenay and District Museum.

3.2 Field Investigations

Two site investigations were conducted during the course of this study. The first field visit commenced on 29 August, 1989 and spanned four days. It included a thorough site reconnaissance, meetings with local government and B. C. Hydro representatives, and interviews with local residents. During the second visit, on 23 - 24 November, 1989, a detailed field check was conducted in specific locations to resolve uncertainties identified on the preliminary floodplain mapping, including those areas where the contours and survey data did not concur.

A number of interviews were conducted by the Project Engineer during the field visit to collect information on high water marks, recent changes along the rivers, and other information related to past flooding. The persons interviewed and the dates of the interviews are listed below:

1. J. R. Card, P. Eng., Water Management Branch, Nanaimo (29 August, 1989)
2. Mr. Peter Crawford, Regional District of Comox-Strathcona (30 August, 1989).
3. Mr. Tom Bingham, City of Courtenay (30 August 1989).
4. Mr. John Farquharson, long-term resident and farmer on the Courtenay Flats (31 August, 1989).
5. Norm Smith, P. Eng., B. C. Hydro - John Hart Generating Station (31 August, 1989).
6. Mr. Hal Harrison, B. C. Hydro - Puntledge Generating Station (31 August, 1989).
7. Mr. & Mrs. Backlund, Maplepool Campsite, 4701 Headquarters Road (31 August, 1989).
8. Mrs. R. A. Davidson, resident at 4673 Headquarters Road (31 August, 1989)
9. Mr. Ray Furse, resident on Headquarters Road near XST-12 (1 September, 1989)
10. Mr. R. S. Cropper, 3441 Dove Creek Road (1 September, 1989)
11. Mr. Harold Cresswell, 3499 Dove Creek Road (1 September, 1989)
12. Mr. John DeWitt, resident near south end of the Condensory Road Bridge (1 September, 1989)
13. Mr. Hans Jorgensen, resident at the end of Todd Road near XST-50 (1 September, 1989)
14. Mr. Bill Walton, Waltav Industries, Courtenay Airstrip (23 November, 1989)
15. Woman resident on Winn Road near XST-65 (24 November, 1989)
16. Woman resident off Dove Creek Road near XST-38 (24 November, 1989)

4.0 FLOOD FREQUENCY STUDIES

This section of the Design Brief describes the estimation of flood discharges which were used to determine floodplain limits. The return period of primary concern in this study is 200 years. Estimates of both mean daily and peak instantaneous floods were determined in order to map the floodplains in accordance with standards set by the British Columbia Ministry of Environment.

The flow of the Puntledge River is regulated by B. C. Hydro at the Comox Lake Dam. Because the effect of the regulation is great enough to modify the peak flows significantly, the flood frequency characteristics of the Puntledge River could be very different from those in natural rivers. Therefore, the Comox Lake outflow flood estimates were derived by a different method than the unregulated flood frequencies were.

4.1 Unregulated Flows

4.1.1 Selection of Method

A regional approach was used to estimate flood frequencies for the Tsolum River and for the Comox Lake inflows. The regional method involves the estimation of flood frequencies for all gauged streams in a region which are hydrologically similar to the stream under study, then plotting all the computed unit runoff values onto a single plot against drainage area. A "design curve" is then fit to those points which best represent the conditions in the drainage basin in question.

There are six WSC streamflow gauges in the Courtenay River basin, however three are on tributaries which measure flows in smaller parts of the total catchment area and have short periods of record. The two gauges on the Puntledge River are of limited use because they measure regulated flows from Comox Lake.

Comox Lake inflow data has been calculated by Canadian Collieries and by B. C. Hydro, using lake levels to monitor changes in storage and outflows, for a combined total of 69 years. This is a less direct method of measuring discharge than the conventional streamflow gauge method, and may be subject to errors induced by wind setup on Comox Lake. A regional analysis provides an approximate check on the results of a single station analysis using computed inflows.

Single station analysis using Tsolum River gauge data could be used to provide 200-year flood estimates at the gauge site. A regional analysis provides a more valid way of estimating floods for upstream locations than simply prorating on a drainage area basis.

Finally, a regional flood frequency analysis provides insight into the runoff patterns across the region. Therefore, the regional method was selected for this study, rather than relying entirely on single station analyses for the 200-year flood estimates.

4.1.2 Flood Frequency Analysis

Single station flood frequencies were analyzed with the aid of a computer program known as the Consolidated Frequency Analysis Package (CFA), prepared by Environment Canada (16) as a supplement to their Guide for procedures for floodplain delineation. Four probability distributions are provided in CFA, and these are:

- Generalized Extreme Value
- Three Parameter Log Normal
- Log Pearson Type III
- Wakeby.

The CFA program was used to analyze peak daily flow data for each of the regional gauging stations. Instantaneous peak flow data was not used in this part of the analysis because there was much less of it available. All four probability distributions were applied to each set of flood peak data. A plot of each flood frequency curve showing the individual data points was reviewed before a "best fit" probability distribution was selected.

In general, each of the four probability distributions exhibited good fit and the frequency estimates were similar. In most cases the Three Parameter Log Normal distribution provided the second highest estimate and a good fit. The range from the high to low estimate for the four distributions was small compared to the range in unit peak flows over the region.

4.1.3 Regional Streamflow Gauges

The streamflow gauging stations selected for analysis extend from Englishman River on the south side to the Salmon River on the north. Several gauges for streams on the Port Alberni side of the Beaufort Range were included because of their proximity to the Comox Lake drainage area. The stations were classified into three groups on the basis of their catchment types as follows:

- streams draining mostly mountainous terrain, similar to the Comox Lake catchment
- streams draining mostly east coast lowland terrain, with a minor proportion of mountainous area, similar to the Tsolum River catchment
- streams containing a large lake in their system which would modify peak flows significantly by storage routing.

The selected gauging stations, their drainage areas, catchment types, flood flows and unit runoff values are listed in Table 3.

TABLE 3
REGIONAL STREAMFLOW STATIONS

	Station Number	Station Name	Catch-ment Type	Drainage Area (km2)	Period of Record	Mean Annual Flood m3/s	M.A.F. Unit Runoff m3/s/km2	20 Yr Flood m3/s	20 Y.F. Unit Runoff m3/s/km2	200 Yr Flood m3/s	200 Y.F. Unit Runoff m3/s/km2
*1	08HB023	Ash R. below Moran Cr.	Lk	378	1956-88	224.9	0.59	540	1.43	1000	2.65
	08HB025	Browns R. near Courtenay	LM	86	1960-88	77.2	0.90	185	2.15	388	4.51
	08HD001	Campbell R. at outlet of Campbell Lake	Lk	1400	1910-49	421.5	0.30	756	0.54	1240	0.89
	08HB074	Cruickshank R. near the Mouth	Mt	214	1982-88	201.6	0.94	NA	NA	NA	NA
	08HB002	Englishman R. near Parksville	LM	324	1913-17, 1970-88	228.8	0.71	502	1.55	757	2.34
	08HB004	Little Qualicum R. at outlet of Cameron Lake	Lk	135	1913-22, 1960-88	70.2	0.52	162	1.20	303	2.24
	08HB029	Little Qualicum R. near Qualicum Beach	Lk	237	1960-86	94.2	0.40	170	0.72	224	0.95
	08HB022	Nile Creek near Bowser	LM	15	1959-88	17.4	1.16	38	2.55	80	5.30
	08HD011	Oyster R. below Woodhus Cr.	LM	298	1974-88	145.1	0.49	281	0.94	389	1.31
	08HB006	Puntledge R. at Courtenay	Lk	583	1914-20, 1955-57 1964-88	204.1	0.35	335	0.57	408	0.70
	08HB007	Puntledge R. near Cumberland	Lk	453	1914-53	125.3	0.28	211	0.47	299	0.66
*2	08HB001	Qualicum R. near Bowser	Lk	148	1913-17, 1919-22 1956-74	36.7	0.25	75	0.50	140	0.95
	08HD005	Quinsam R. near Campbell River	Lk	280	1956-88	65.8	0.24	135	0.48	234	0.84
	08HB037	Rosewall Creek at the Mouth	LM	43.3	1968-72, 1974-78	52.4	1.21	NA	NA	NA	NA
	08HD007	Salmon R. above Memekay R.	Mt	448	1960-88	210.7	0.47	366	0.82	482	1.08
	08HD006	Salmon R. near Sayward	Mt	1200	1956-88	721.2	0.60	1340	1.12	2080	1.73
	08HB010	Stamp R. near Alberni	Lk	899	1914-31, 1941-78	416	0.46	737	0.82	1090	1.21
	08HB009	Stamp R. near Great Central	Lk	456	1913-22, 1958-88	237	0.52	353	0.77	425	0.93
	08HB024	Tsable R. near Fanny Bay	Mt/LM	113	1960-88	143.2	1.27	252	2.23	330	2.92
	08HB011	Tsolum R. near Courtenay	LM	258	1914-17, 1955-57 1964-88	121.2	0.47	194	0.75	242	0.94
*3		Comox Lake Inflows	Mt	464	1914-50, 1958-88	268.9	0.58	450	0.97	583	1.25
*3		Elsie Lake Inflows	Mt	223	1960-87	198.4	0.89	365	1.64	552	2.48
*3		Upper Campbell Lake Inflows	Mt	1194	1959-87	704.6	0.59	1170	0.98	1600	1.34

*1 Combined with prorated Ash R. nr Gr. Central data
*2 One outlier (1918 flood) excluded
*3 Data provided by B. C. Hydro

Catchment Types:
Lk - contains large lake in basin
Mt - primarily mountainous terrain in basin
LM - lowland with minor proportion of mountains

4.1.4 Ratios of Instantaneous to Daily Peaks

Although there are several streamflow gauges in the east central Vancouver Island area, there are few recording gauges with long periods of record. The recording gauges allow the instantaneous peak flow to be determined for each flood event. It was necessary to develop a relationship between the instantaneous to daily peak ratio, or peaking factor, and drainage area.

The peaking factors for all regional gauging stations without large lakes in their catchments were investigated. It was found that the peaking factors corresponding to high floods were often lower than the mean peaking factor for the entire period of record. Mean peaking factors were selected for analysis, as this would lead to slightly more conservative flood estimates.

Because there were so few gauges in the region for which peaking factors could be calculated, records from several gauges outside the region were also used. The peaking factors were plotted against drainage area, and the plot showed that the mountainous catchments were associated with higher peaking factors than the lowland catchments were. Three curves were drawn, as shown in Figure 3, one for each of the following types of drainage basin:

- mountainous, applicable to Comox Lake basin
- lowland with some mountain area, applicable to Tsolum River basin
- a combination of the above two, applicable to the lower Puntledge catchment and Courtenay River total drainage area.

These curves were used to estimate the 200-year instantaneous peak flows for the Tsolum, Puntledge and Courtenay River floods.

4.1.5 Derivation of Design Curves

The unit runoff values corresponding to mean annual daily floods and 200-year floods return periods were plotted against drainage area for all the regional streams. The points corresponding to mountainous catchments typically had a greater unit runoff than those for catchments with a substantial proportion of lowland. The rivers draining large lakes generally plotted lowest of all, reflecting the major impact that large lakes have on flood peaks.

Using the points as guides, curves were drawn for the purpose of estimating floods for Comox Lake inflows and for the Tsolum River. These "design curves" for the 200-year daily floods are presented in Figure 4.

The point for Comox Lake inflows plotted below the general trend for nearby mountainous catchments, such as Cruickshank River, Elsie Lake inflows and Upper Campbell Lake inflows, and below the trend for the Tsable River, which has some lowland area in it. The reason for this difference was not evident. The design curve was drawn between the Comox Lake point and the trend for the other mountainous catchments.

Similarly, the Tsolum River point fell below those for other nearby streams, such as the Tsable, Oyster, Browns and Englishman Rivers. However, the accuracy of some of the Tsolum River peak flows published by WSC was questioned for the following reasons:

- Mr. W. Edwards, the WSC Technician (17) who has serviced the Tsolum gauge for many years stated that the extrapolation of the stage-discharge rating curve may not have included the effect of flow over the left bank in a high flood, yet flow over the left bank was observed in 1983 (Photo 14).

- It was noted that the highest instantaneous flood peak published by WSC for the Tsolum River was 250 m^3/s on 28 November, 1966. Yet there were no accounts of flooding reported in the local newspapers on or around this date. However, the 1975 and 1983 floods on the Tsolum, listed by WSC as 223 and 235 m^3/s respectively, were widely reported flood events.

- During the calibration of the backwater model in a later part of this study, profiles for 1975 and 1983 flood discharges based on WSC flows could not be made to match recorded gauge heights or high water marks.

These factors pointed to the possibility that some of the highest Tsolum River discharges might be underestimated. Therefore, despite the 30 year period of record, the design curve for the Tsolum River was drawn above the point for the Tsolum single station frequency analysis, and the points for neighbouring catchments were used as a guide to position the curve.

The ultimate effects of placing the design curve higher are modest increases to the 200-year flood estimates. In view of the purpose of the floodplain mapping, this mild degree of conservatism in response to uncertainty in the data is prudent.

4.1.6 Tsolum River and Comox Lake Inflow Flood Estimates

The drainage area for the Tsolum River within the limits of the floodplain mapping study ranges from 106 km^2 to 255 km^2. Cumulative catchment areas along the study reach were measured at locations immediately upstream of all major tributaries. Using the curves in Figures 3 and 4, estimates of mean daily and instantaneous peak flows were calculated, and appear in Table 4 below. The flood frequency estimates for Comox Lake inflows are also listed in Table 4.

Table 4

Isolum River Design Flows

Location	Cumulative Drainage Area-km²	Estimated Peak Flows - m³/s Daily 20-Yr.	200-Yr.	Instantaneous 20-Yr.	200-Yr.
Tsolum River above:					
U/S limit (XST-82)	106	147	209	224	317
Headquarters Creek	142	180	259	267	384
Dove Creek	197	215	311	307	445
Portuguese Creek	244	249	349	348	489
Mouth (XST-5)	255	255	358	353	495
Comox Lake Inflows	464	545	710	851	1107

4.2 Regulated Flows

4.2.1 Methodology

The regulated outflow from Comox Lake for the 200-year flood was determined as follows:

- the 200-year peak inflows were taken from the regional flood study,
- a hydrograph shape was selected,
- an initial reservoir water level was selected,
- the hydrograph was routed through the reservoir,
- the resulting outflow hydrograph provided the 200-year peak instantaneous and daily discharges from the reservoir.

Storage routing was computed on the basis of the modified Puls method. This method is based on the principal that change in storage is equal to the difference between inflow and outflow multiplied by the time interval involved.

The constraints on flow regulation to limit downstream damage during floods and high tides, as summarized in B. C. Hydro's Operating Order No. 432 (14), were simulated in the analysis.

4.2.2 Regulation of Comox Lake Outflows

A concrete buttress dam was originally built at the outlet of Comox Lake in 1913, and operated by Canadian Collieries (Dunsmuir) Ltd. to supply electricity to the many coal mines in the area. The system was purchased by the B. C. Power Commission in 1953, and major reconstruction to the dam was completed in early 1958. Dam safety studies in 1980 showed the need for increased spillway capacity, and major modifications were completed in 1982 to permit the concrete gravity section of the dam to withstand overtopping during the passage of the Probable Maximum Flood.

With the current configuration, flood water can be discharged at the dam in the following ways:

- through the two vertical lift sluice gates (4.27 m wide by 7.32 m high) with an invert elevation of 128.93 m
- over the 4-bay uncontrolled overflow spillway with an invert elevation of 135.33 m
- over the crest of the dam at elevation 136.86 m

There is no generating facility linked directly to the Comox Lake Storage Dam. A low diversion dam and intake located 2.5 km downstream feed power flows through a pipeline and penstock to the Puntledge Generating Station which is located 450 m upstream of the uppermost cross section on the Puntledge River (XSP-24).

4.2.3 Inflow Hydrograph Shape

A 200-year flood hydrograph for the Comox Lake inflows was required to simulate the effects of storage routing by Comox Lake and operation by B. C. Hydro. In order to ensure a realistic integration of the effects of both flood peak and volume, a review of past hydrograph shapes for Comox Lake inflows (1962-88) and Cruickshank Creek (1982-88) was conducted.

The daily peak discharges and the 1 to 5-day volumes for the Comox Lake inflows were ranked. Hydrographs of the largest flood events for which data was available were normalized by dividing the discharges by the mean annual flood. The hydrographs, consisting of 6-hr. average flows extracted from B. C. Hydro's design files for the Comox Lake Probable Maximum Flood Study (11), were plotted and compared.

The December 1980 and October 1982 events were the two largest with respect to both peak and volume. However, when the hydrographs were raised to the level of the 200-year flood, the hydrograph derived from the 1982 event showed a significantly greater volume. The normalized Cruickshank River and Comox Lake inflow hydrographs for the 1982 event were compared. The Cruickshank normalized hydrograph had a higher peak and larger volume than the Comox Lake inflow hydrograph did. As the Cruickshank hydrograph was based on recorded data rather than calculated inflows, its shape was adopted for the 200-year design hydrograph.

The 200-year design hydrograph shown in Figure 5 was based on hourly flows from the 23 - 27 October, 1982 flood on the Cruickshank River increased by the ratio of the Cruickshank 1982 daily peak to the 200-year daily peak. The 200-year hydrograph shape for the peak day was modified to match the peak instantaneous discharge of 1107 m^3/s while maintaining a maximum daily discharge of 710 m^3/s.

4.2.4 Initial Reservoir Level

The selection of which Comox Lake water level to use in the simulation at the beginning of the 200-year flood event was made after a review of the regulatory requirements, historical levels and sensitivity test results.

The regulatory requirements of the Water Licence are specified in B. C. Hydro's Operating Order No. 432 (14), and require the following Normal Maximum Operating Elevations:

15 October to 15 February	134.42 m
15 March to 15 September	135.33 m (spillway crest elevation)

A historical review of the initial water level at the beginning of the largest storms each year was conducted for the period 1962-88. In most years the lake level was below the winter operating level of 134.42 m. In 15 of the 26 years of available data, the lake level was within 1.0 m of the winter operating level.

It was also noted that in a number of years the annual maximum inflow had been preceded a few days earlier by an inflow peak that in several cases was as large as the average annual flood. It is significant that the second, third, fourth and seventh highest floods during the 26-year period had been preceded by another major flood only 2 - 10 days previously.

During these paired events, the lake level has always dropped back to near the winter operating level before the second storm began. With such short intervals between major recorded events historically, a scenario for a 200-year flood could be two storms in rapid succession, with a lake level near the spillway crest elevation of 135.33 m at the beginning of the second event.

The sensitivity of the routed peak outflow to the initial lake level was tested for a range of lake levels. The peak outflow resulting from a simulation using an initial level at the spillway crest was 9.4% higher than if the normal winter operating level was used for the initial lake level.

On the basis of the foregoing, the spillway crest elevation (135.33 m) was adopted as the initial reservoir water level for routing the 200-year inflow flood hydrograph.

4.2.5 Operation of Comox Dam Sluice Gates

The operation of the sluice gates at Comox Dam during the passage of floods must take into consideration several factors related to the reduction of flood damage downstream. There are also concerns regarding flood damage from high lake levels, but due to the population density downstream, the downstream concerns predominate. These considerations are reflected by restrictions on discharge when the downstream tributaries are in flood and when tides are high. The restrictions are detailed in B. C. Hydro's Operating Order No. 432 (14) and summarized as follows:

1. With normal high tides and normal flows in the Browns and Tsolum Rivers, releases of less than 280 m^3/s will generally not cause flooding downstream.
2. If the Browns River and the Tsolum River are high, releases should not exceed 170 m^3/s.
3. For reservoir levels between 134.42 and 135.33 m releases should not exceed 221 m^3/s. Regulate to avoid serious flooding as affected by high tides and tributaries.
4. For reservoir levels between 135.33 and 137.46 m releases should not exceed 280 m^3/s. Regulate to avoid serious flooding as affected by high tides and tributaries.
5. For reservoir levels at or above 137.46 m continue to open gates incrementally and do not close them until the reservoir level ceases to rise.

These restrictions were intended to ensure that dam operators would use storage in Comox Lake to improve rather than worsen downstream flooding conditions during small and medium floods. During major events such as the 200-year flood these operating restrictions may not have their intended effect of reducing the peak discharges. While the flood flows are rising, it is very difficult for the operator to determine whether or not the event is another moderate flood or the beginning of a much larger event for which some of the rules should be changed. In this study it was assumed that the operators would generally adhere to the written rules.

The Operating Order lists a variable travel time of 3 to 5 hrs. from the Dam to the City of Courtenay. For this study, a constant 4-hr. travel time was assumed. In conjunction with the use of the 1982 storm inflow hydrograph, the timing of the recorded tides of October 1982 were used to determine the timing of discharge restrictions. The Operating Order specifies that with high tributary flows and, by implication, high tide levels, the dam discharges should be restricted to less than 170 m^3/s. In this simulation the releases were restricted to 135 m^3/s at the higher high tide and to 155 m^3/s at the lower high tide.

However, the Comox Lake outflows were not reduced to accommodate the high flows in the downstream tributaries, the Browns and Tsolum Rivers. This was one concession to the likelihood that the 200-year flood might be recognized in advance as a major event, therefore this operating rule should not dominate, in order to make more storage available in advance of the peak inflow. This appears to be consistent with what actually happened at Comox Lake in 1975, 1980 and 1982.

4.2.6 Comox Lake Outflow Flood Estimates

The results of the 200-year flood routing are shown graphically in Figure 5. The instantaneous routed outflow peak was 584 m^3/s, and the maximum daily peak outflow was 562 m^3/s. These represent reductions of 21% and 47% from the daily and instantaneous inflow peaks, respectively. The maximum lake level attained was 137.96 m. There was a delay of 18 hours between the inflow and outflow peaks.

As shown in Figure 5, the inflow hydrograph has both a broad base with inflows of the order of 400 m^3/s for more than 75 hrs. and a high peak. As a result of this broad base there is a significant volume of inflow before the peak, causing the reservoir to be nearly full to the crest at the time the peak occurs. This is partly the result of the discharge restrictions but primarily the size of the inflow flood.

As the dam crest is designed to be overtopped, the whole width of the dam would act as a broad crested weir in extreme floods and would limit the depth of overtopping to a small range. Because this small range represents a relatively small volume of lake storage, there is little likelihood that modifications to the hydrograph shape will produce significant changes to the peak water levels and outflows. As the present inflow hydrograph is a modification of an actual event with the timing of the main and minor peaks preserved, the results obtained should be realistic.

The effect of operating restrictions to accommodate the timing of high tides was found from sensitivity tests to increase the peak outflow from 519 m^3/s to 584 m^3/s, an increase of 12.5%. It can be concluded that, although the operating restrictions would reduce downstream flooding during small and medium events, they could result in an increased outflow during major events. This increase would be small at the dam site, and would be even smaller as a percentage downstream in the populated areas.

4.3 Combined Regulated and Unregulated Flows

Results from the regional analysis were combined with the estimated regulated floods from Comox Lake to produce estimates for the lower Puntledge River and the Courtenay River. The 200-year peak discharges for these two rivers were estimated as follows:

A. The reduction in daily flood peak caused by storage routing and regulation at Comox Lake was computed to be 148 m^3/s.

B. A 200-year daily flood peak was computed using the regional curves for a hypothetical Puntledge (or Courtenay) River basin without a Comox Lake in it.

C. The reduction caused by Comox Lake, calculated in Step A, was subtracted from the regional estimates obtained in Step B, above.

D. A weighted peaking factor was calculated on the basis of drainage area, combining the peaking factor in the Comox Lake outflow component with the peaking factor from Figure 3 for the local inflow basins downstream from Comox Lake.

The final flood estimates for the lower Puntledge and Courtenay Rivers are presented in Table 5 below:

Table 5

Courtenay and Puntledge River Design Flows

Location	Drainage Area - km^2	Estimated 200-Year Peak Flows - m^3/s Daily	Instantaneous
Puntledge River at the Mouth	605	540	748
Courtenay River at the Mouth	875	694	926

5.0 HYDRAULIC ANALYSES

5.1 River Backwater Modelling

5.1.1 Model Development

The computer program known as HEC-2 was used to simulate 200-year flood profiles for the study reach. This program, written by the U. S. Army Corps of Engineers and widely used throughout North America for floodplain delineation studies, computes backwater profiles for steady state flow conditions using the Standard Step Method (18, 19).

The HEC-2 model was prepared for the study reaches of the Courtenay, Puntledge and Tsolum Rivers in the following manner:

1. The cross section data from the river survey was provided in HEC-2 input format (GR data) by the B. C. Ministry of Environment.

2. Cross sections which appeared to have insufficient height to contain a large flood flow were extended using the contours on the 1:5000 scale topographic mapping.

3. The six bridges were coded for the HEC-2 program.

   The old bridge piers which stand in the Puntledge River upstream of the Condensory Road Bridge were coded as a seventh bridge with no effective deck in order to model the head losses at the piers using momentum equations. Additional cross sections were inserted at two bridge locations to achieve the recommended cross section spacing upstream and downstream from the bridges.

4. Thalweg and overbank distances were measured from the 1:5000 scale mapping, and entered in the model.

5. Manning's "n" values for the river channels were estimated using photographic and tabular guides by Chow (20), taking into consideration roughness height (approximated from bed material sizes), river slope, vegetation, debris, sinuosity and cross section uniformity.

   Channel roughness coefficients used for the simulation ranged from .035 to .058. Generally, the steeper reaches contained larger bed material and were assigned higher roughness coefficient values. Along much of the upper part of the Tsolum River study reach, the bed was paved with very large boulders, and the highest coefficients were applied to these channel segments.

   Manning's "n" values for the overbank areas were estimated primarily on the basis of vegetation type. The values used ranged from .050 to .150.

   Overhanging branches, which were common along the banks of the Tsolum River, were accounted for in the model by setting the channel limits on the cross sections such that the vegetated zones would be excluded from the channel and included in the overbanks, which had higher roughness coefficient values.

6. Hydraulic loss coefficients for expansion, contraction, pier shape, orifice flow and weir flow at bridges were selected in accordance with the recommendations outlined in the HEC-2 User's Manual (18).

   The Dove Creek Road Bridge over the Tsolum River (XST-16) had river piers which were highly skewed to the direction of flow. The apparent width of the piers, rather than the true width, was used in the model.

The Farnham Road Bridge over the Tsolum River (XST-67) is a Bailey-type structure built over an old bridge with trestle approaches and log stringers. The old bridge was not removed, despite a note on the survey drawing stating that bridge removal was intended in the summer of 1989. The model was developed to reflect the existence of the old bridge, because its date of removal is unknown, and because it would offer significant resistance to flow, especially with debris accumulation.

7. The input data was completed by the addition of peak discharge data and necessary job control parameters. The higher high water large tide for Comox Harbour of 2.15 m geodetic was used for the starting water level.

5.1.2 Split Flow to Courtenay Flats

The complex hydraulics of the Courtenay River floodplain, which includes the Courtenay Flats, is essentially a two-dimensional flow problem. It was simulated with HEC-2, a one-dimensional model, by using the split flow option of HEC-2, and running two separate profile simulations iteratively. One profile was for the Courtenay River, and the other was for that portion of flood flows which is diverted through the Courtenay Flats.

The step-by-step procedure used in the analysis is outlined below:

A. For a given total flow in the Courtenay River system, the Courtenay River profile was simulated, using the split flow option to divide the flow between the River and the Flats. The top of road survey data provided by the Ministry of Environment was used to define the geometry of the split flow sections. The split flow boundary was taken to be the Old Island Highway from Headquarters Road to Comox Road, then along Comox Road to Highway 19. Assumptions were made for the water surface slopes along flow paths between the Old Island Highway and Highway 19. The normal depth solution was used for the split flow reach upstream of the Comox Road and Old Island Highway intersection. Weir coefficients for an unsubmerged weir were applied for the split flow reach downstream from this point.

B. Using the portion of flow diverted to the Flats by the model in Step A, the profile through the Flats was simulated. The split flow option was used in this model to return water as weir flow over the Comox Road to the Courtenay River at cross sections XSC-2, 3 and 4.

Iterative runs were made with this model to establish the starting water level which would just allow all the flow to return to the River. Test runs proved that this weir does not become hydraulically submerged in a 200-year event, even with Comox Harbour levels 1.0 m above the higher high water large tide.

C. Using the profiles calculated in Steps A and B, the modelled water surface slopes between the Old Island Highway and Highway 19 were computed, then compared with the values assumed in Step A. Also, the weir modelled in Step A was checked for its degree of submergence.

D. The slopes used in the Courtenay River model were adjusted to match the values calculated in Step C. Also, adjustments to the weir coefficients were made if the degree of submergence was significant.

E. Steps A through D were repeated, until the calculated and assumed slopes agreed and the degrees of submergence matched the coefficients used.

It was found that only two or three iterations were required for the above procedure to converge to a solution.

5.1.3 Model Calibration

After the initial HEC-2 model of the Courtenay, Puntledge and Tsolum River was developed, it was calibrated using observed flow, tide, and high water mark data from the following three historic flood events:

13 November, 1975
26 December, 1980
11 February, 1983

Of these events, the 1975 flood had the greatest number of observed high water marks which were related to a specific event. Therefore, it was used for the first calibration.

The peak flows estimated by WSC for each flood were prorated by drainage area and entered into the model. The high tide measured in Comox Harbour near the time of the peak Courtenay River flow was used as the starting water level in each case.

The HEC-2 program was executed, then the resulting profiles were plotted with the observed high water marks and a comparison was made. Channel roughnesses and coefficients were adjusted, the bridge coding was altered and the model was run again. This was repeated until a reasonable fit was achieved for the 1975 flood along the Courtenay River where most high water marks were taken.

Most of the 1983 high water marks were measured in the upper reaches of the Tsolum River. In this area, both the 1975 and 1983 profiles fell below the high water marks, and it required unreasonably high roughness coefficients to achieve a good fit. The profile also fell below the observed water levels at the WSC gauge on the Tsolum River. This, and other observations (see Section 4.1.5), indicated that some peak discharges reported by WSC may be low. It was found that by increasing the Tsolum discharges by 25%, a better fit was obtained at the upstream locations, and resulted in a very small increase to the Courtenay River water levels. It was apparent that a similar increase to the 1983 flows would improve the calibration for that flood also.

The 1980 high water mark data, consisting of three points on the Courtenay River, and one at the Tsolum gauge, was tested using the calibration developed for the 1975 and 1983 floods. An allowance was made for the head loss caused by the debris jam at the 17th Street Bridge site. The result was a poor fit for the three Courtenay River points, but a good fit at the Tsolum gauge. No additional adjustments were made and the final calibrated model was based on the fit obtained by the 1975 and 1983 floods.

Figure 6 shows the final calibrated profile and the high water marks for the 13 November, 1975 peak flow along the Courtenay and lower Puntledge Rivers.

5.1.4 Sensitivity Analyses

Sensitivity tests were conducted to estimate the impact of incorrect data or modelling inaccuracies on the final results. The tests were used to check whether the standard freeboard quantities generally used by the B. C. Ministry of Environment were in a reasonable proportion to the effects of uncertainties in this study.

The sensitivity analyses concentrated on three major parameters, flow, channel roughness and starting water level. An additional run tested the effect of blocking all flood flow from entering the Courtenay Flats.

The calibrated model using the 200-year peak instantaneous flow was established as the base simulation. The discharges in the model were all decreased by 10%, and the program was executed. The discharges were then increased by 10% and 25% above the base simulation for two subsequent runs.

Similarly, three more simulations were made with Manning's "n" factored by -10%, +10% and +25%. The results of these six runs are summarized in Table 6 in terms of mean and maximum water level differences at cross sections between each test run and the base simulation.

Table 6

Summary of Sensitivity Test Results

Test	Water Level Differences from Base Simulation - m Courtenay and Puntledge Rivers Mean	 Max.	 Courtenay Flats Mean	 Max.	 Tsolum River Mean	 Max.
Q-10%	-.131	-.25	-.066	-.08	-.160	-.45
Q+10%	.128	.24	.060	.07	.154	.48
Q+25%	.315	.79	.154	.19	.368	.82
n-10%	-.111	-.24	-.046	-.06	-.136	-.26
n+10%	.106	.21	.038	.04	.135	.41
n+25%	.252	.50	.096	.11	.326	.68

The results show that the Courtenay Flats are least sensitive to changes in flow (Q) or roughness (n), and that the Tsolum River is most sensitive. Not shown in the above table, but evident in the detailed output, is the fact that the Courtenay River is less sensitive than the Puntledge to these changes.

The freeboard used for instantaneous peak flood levels is 0.30 m. The percentage increase to flow or roughness necessary to match this freeboard can be estimated for each river by using the data in Table 6.

The sensitivity of the profile to a change in the Comox Harbour water level was tested by running the model for a high tide plus storm surge condition (see Section 5.2). The starting water level was increased from 2.15 m to 3.37 m, which would simulate the very unlikely event of a 1.22 m surge on the higher high water large tide coinciding exactly with the 200-year instantaneous peak flow.

The water level differences between this run and the base simulation decrease rapidly in an upstream direction from Comox Harbour. At the 17th Street Bridge, the model shows a difference of 0.68 m, and at the 5th Street Bridge, only 0.15 m. The water level in the Flats would be increased by only 0.15 m, and the levels at the mouths of the Puntledge and Tsolum Rivers would hardly be affected.

In order to estimate an approximate upper limit to the water level change that could be caused by elevating roadways in the floodplain area near Lewis Park, the split flow component was removed, the simulation was executed and the results compared to the output from the base simulation. Blocking all flow from entering the Flats would raise the water level of the 200-year flood in the Courtenay River by about 0.71 m near Lewis Park. From here, the differences decrease in both upstream and downstream directions. The water level increase at the 17th Street Bridge would be approximately 0.27 m. At the upper confluence of the Tsolum and Puntledge Rivers it would be about 0.49 m.

In summary, the freeboard value of 0.3 m on the instantaneous peak flood level appears to provide a reasonable margin of safety to account for uncertainties in the data and the computer model.

5.1.5 River Flood Levels

Using the HEC-2 program, flood profiles were generated for the 200-year peak instantaneous and mean daily peak flows. A freeboard of 0.3 m was added to the peak instantaneous flood profiles, and a freeboard of 0.6 m was added to the daily flood profiles. At each cross section, the higher combination of 200-year flood level plus freeboard was selected. This combination became the Flood Level (including freeboard) for that cross section, and a listing of these levels for all cross sections used in the modelling appears in Appendix 2. In general, the combination of peak instantaneous water level plus 0.3 m was higher at almost all cross sections upstream of the 5th Street Bridge.

The Flood Levels (including freeboard) were used to delineate the floodplain by plotting them on the 1:5000 scale topographic mapping at each cross section. The contours were used to identify the floodplain limits between cross sections. Isograms for the 200-year flood levels were located on the mapping by interpolating between cross sections.

In the event of a discrepancy between the surveyed cross section and the contours, the survey information was taken to be more accurate. In most areas where survey information did not extend to the area in question, field inspections were conducted to determine the approximate location of the floodplain limit under the tree canopy.

5.2 Comox Harbour Flood Level

Estimation of a Comox Harbour Flood Level must include components for astronomical tides and meteorological influences. The astronomical tidal fluctuations are well-known and predictable. The higher high water large tide for Comox Harbour was obtained from tide tables published by the Canadian Hydrographic Service (21) and converted to a geodetic elevation of 2.15 m.

Meteorological influences on ocean water levels, which include storm surge, wave setup, wind setup, and wave runup, are not as predictable as the tides. The maximum observed Strait of Georgia storm surge was measured on three occasions during high tide to be 0.9 m. For ocean flood level calculations, B. J. Holden, Coastal Engineer with the Ministry of Environment (10), recommended a height of 1.2 m be adopted as the maximum Strait of Georgia storm surge.

At the mouth of the Courtenay River, Comox Harbour is open to the southeast, which is the direction of the prevailing winds in the area. The shallow, 3-km long mud flats in Comox Harbour provide ideal conditions for wind and wave setup to occur during strong southeast winds. Holden estimated that the local wind and wave setup over the mud flats in Comox Harbour could reach a maximum height of 0.3 m.

Holden also recommended an additional allowance of 0.3 m be considered to cover number conversions and truncations in the tide data, wind chop, and possible El Nino effects.

Although possible, it would appear to be exceedingly unlikely that all of the maximum conditions outlined above would occur simultaneously. Therefore it would not be appropriate to simply add them all unless a probable maximum value was being estimated. However, there is insufficient data to mathematically estimate a 200-year return period flood level.

Local residents have reported that in the past 40 years, water has not risen above the elevation of the airstrip at the mouth of the Courtenay River and the head of Comox Harbour. Much of the ground at the airstrip lies at an elevation of 3.1 m.

In order to maintain an approximately consistent risk factor between the flood levels for the ocean and the river, the Comox Harbour Flood Level was calculated as follows:

Higher high water large tide elevation:	2.15 m
Strait of Georgia maximum storm surge:	1.2 m
Additional allowance for concurrent local wind setup, numerical errors in data, wind chop and El Nino effects:	0.35 m
Comox Harbour Flood Elevation (freeboard included):	3.7 m

The value of 3.7 m geodetic was adopted as the Comox Harbour Flood Level for the Courtenay River Floodplain Maps. When compared with the river Flood Levels (with freeboard), it was found that the Harbour Level dominated the downstream end of the Courtenay River to a point 260 m upstream of the 17th Street Bridge, near cross section XSC-9.

6.0 RECOMMENDATIONS

On the basis of the findings of this study, we recommend the following:

1. That the Floodplain Maps prepared for the Courtenay, Puntledge and Tsolum Rivers by this study be designated under the terms of the joint Federal/Provincial Floodplain Mapping Agreement.

2. That the Courtenay River Floodplain Maps produced in 1979 by the B. C. Ministry of Environment (Drawing Numbers A5240-1 to A5240-3) be superceded by the Floodplain Maps numbered 89-13-1 and 89-13-2, which were produced by this study.

3. That the Floodplain Maps be reviewed and updated as required on the basis of future flood data or information relating to major physical changes in the floodplain.

4. That Water Survey of Canada review the accuracy of flood peak data published for the Tsolum River in general, and for the years 1966, 1975 and 1983 specifically.

5. That the City of Courtenay and the Regional District of Comox-Strathcona be advised that flood levels shown on Map Numbers 89-13-1 and 89-13-2 may be sensitive to future flow obstructions such as buildings, walls or fill deposits in the floodplain between the Courtenay River and the Courtenay Flats north of the intersection of Comox Road and Highway 19.

6. That the City of Courtenay and the B. C. Ministry of Transportation and Highways be advised that elevation changes to those portions of the Old Island Highway, Comox Road, 5th Street and Highway 19 located within the floodplain limits may have significant impacts to flood levels shown on Map Numbers 89-13-1 and 89-13-2.

This Design Brief for the Floodplain Mapping Program for the Courtenay, Puntledge and Tsolum Rivers is respectfully submitted by:

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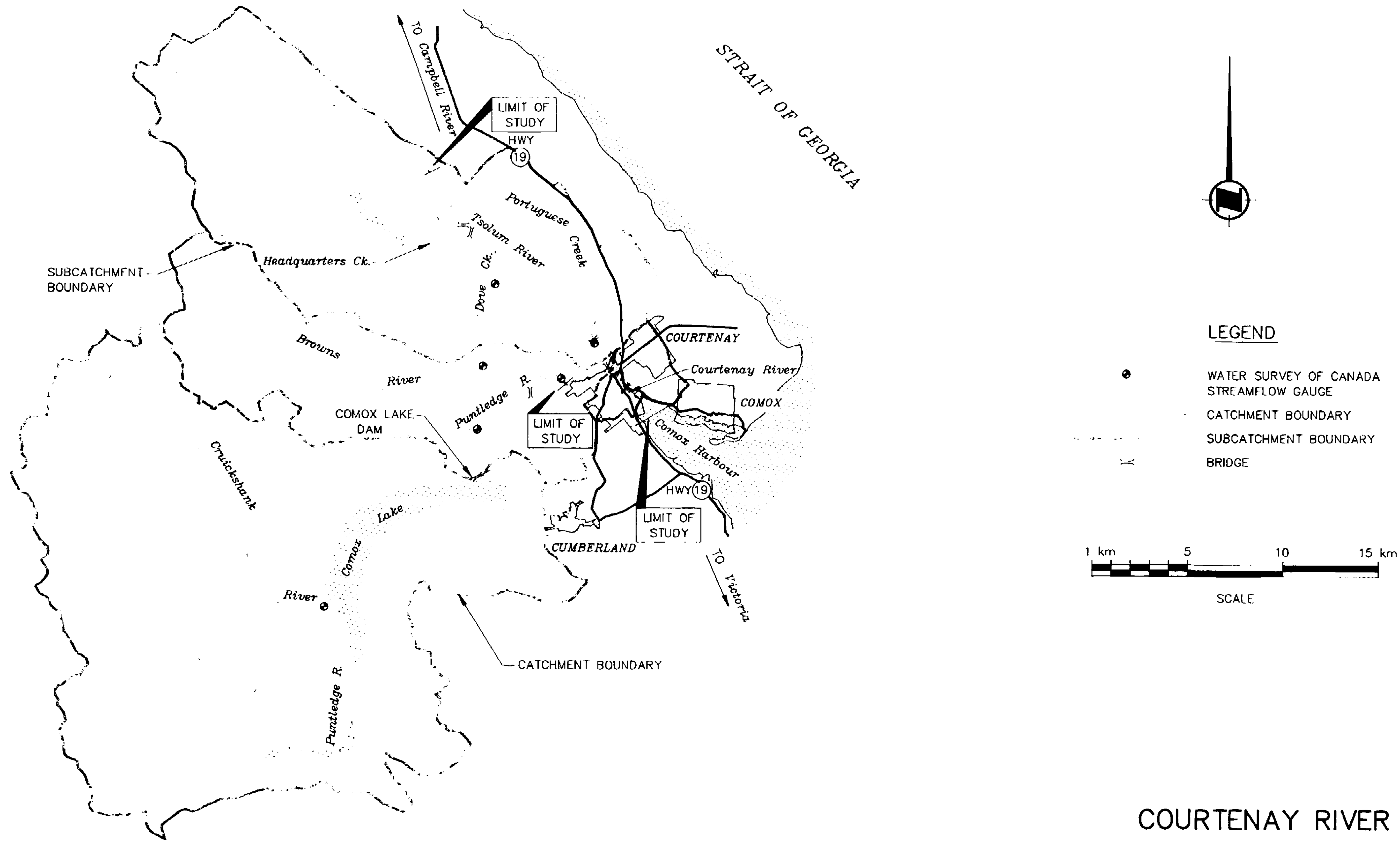
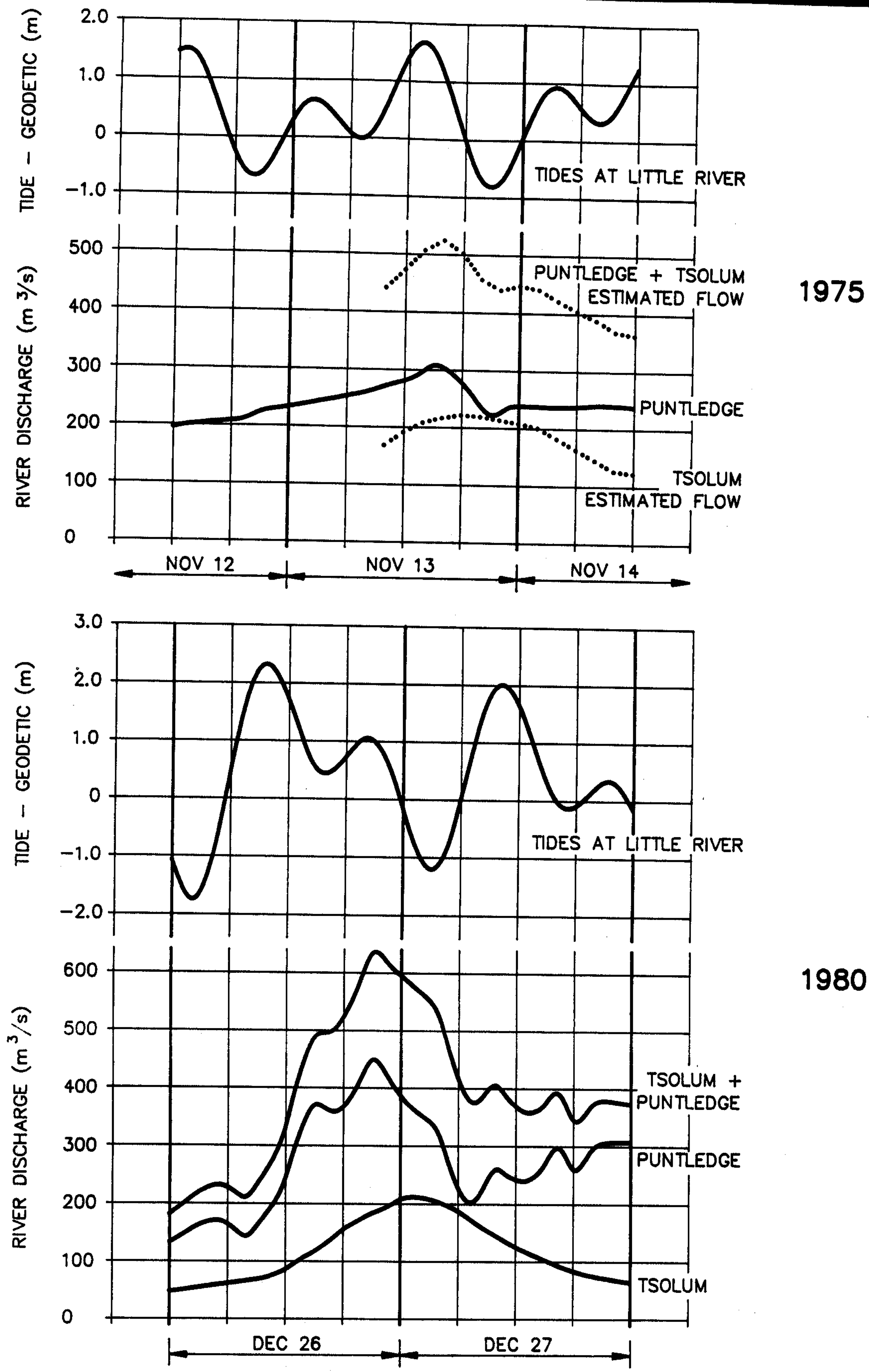
DATE : DECEMBER 1989



COURTENAY RIVER
DRAINAGE AREA

FIGURE 1

KER, PRIESTMAN & ASSOCIATES LTD



TIDES AND DISCHARGES FOR TWO FLOODS

FIGURE 2

KER, PRIESTMAN & ASSOCIATES LTD.

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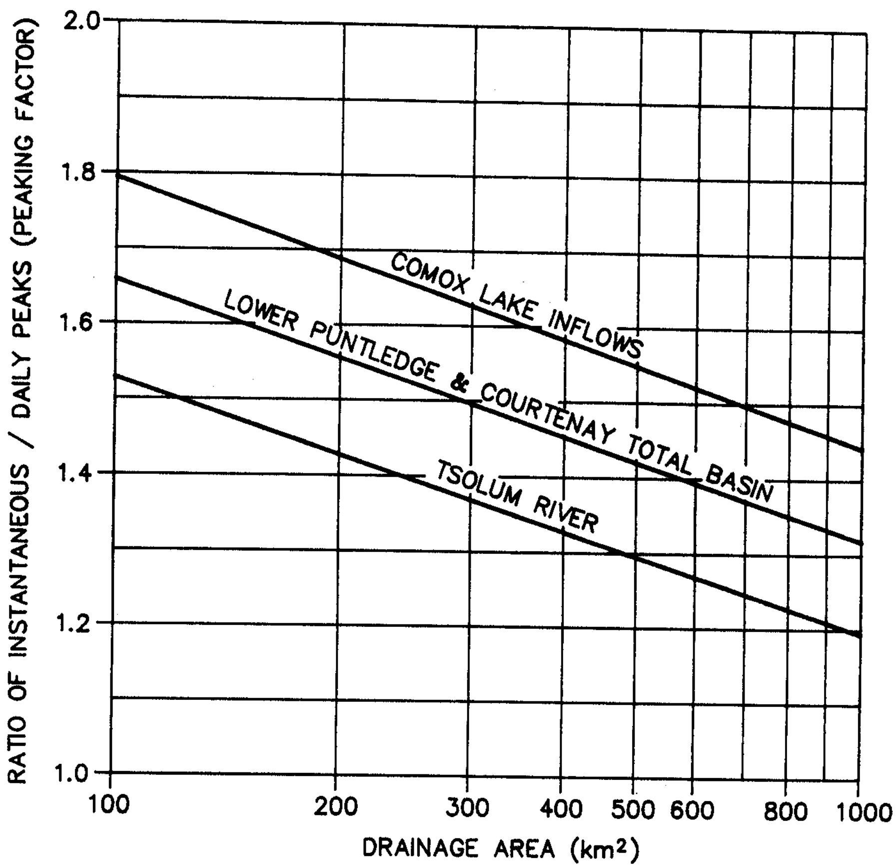

RELATION OF PEAKING FACTOR TO DRAINAGE AREA

FIGURE 3

DATE : DECEMBER 1989

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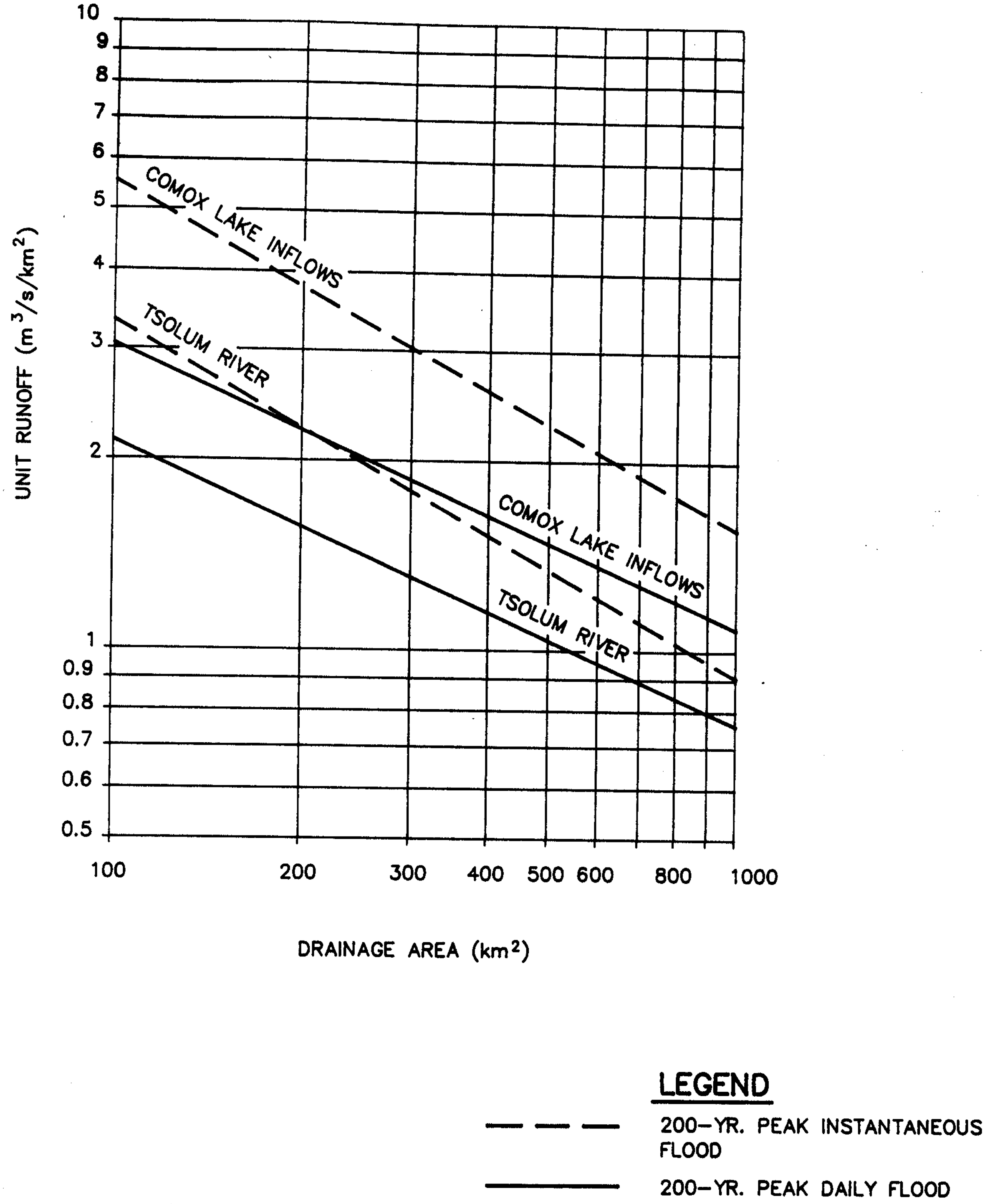

RELATION OF PEAK UNIT RUNOFF TO DRAINAGE AREA

FIGURE 4

KER, PRIESTMAN & ASSOCIATES LTD.

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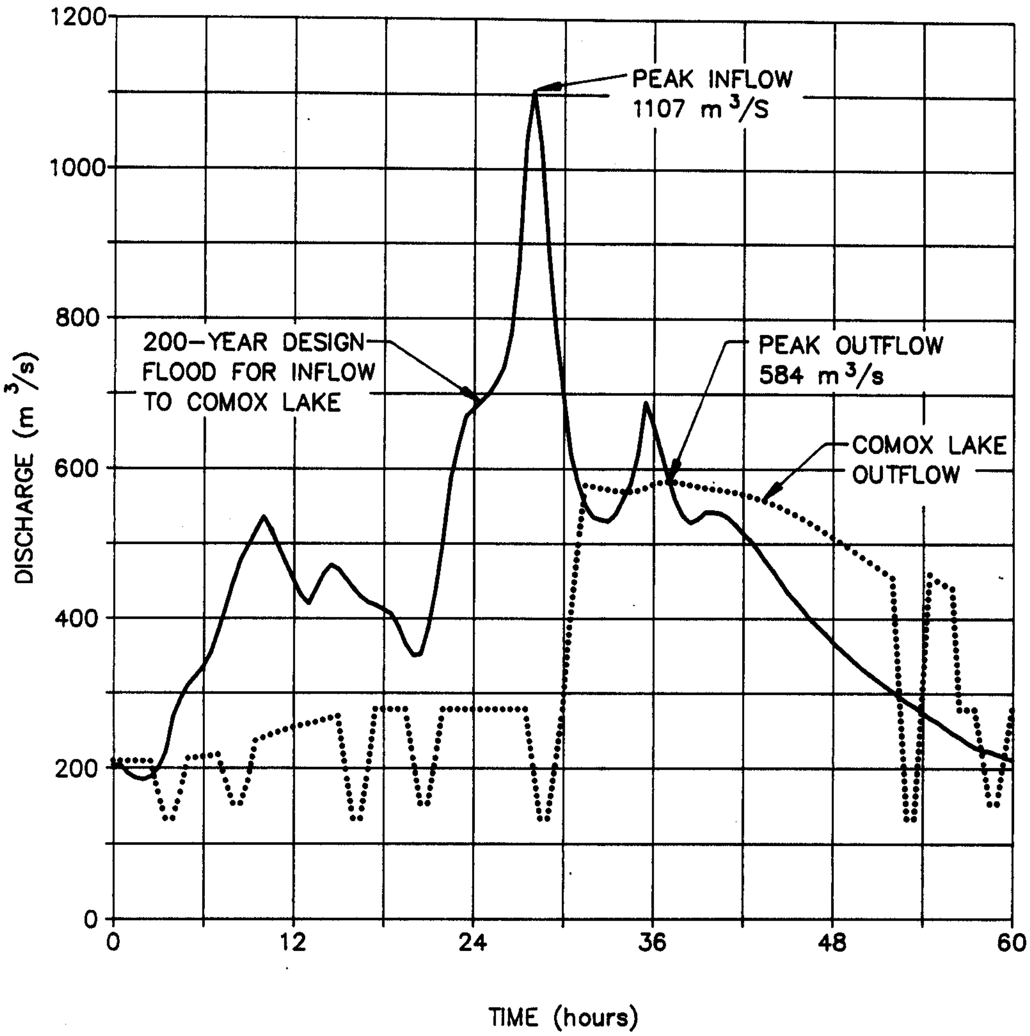

COMOX LAKE 200–YEAR FLOOD INFLOW AND OUTFLOW HYDROGRAPHS

FIGURE 5

KER, PRIESTMAN & ASSOCIATES LTD.

DATE : DECEMBER 1989

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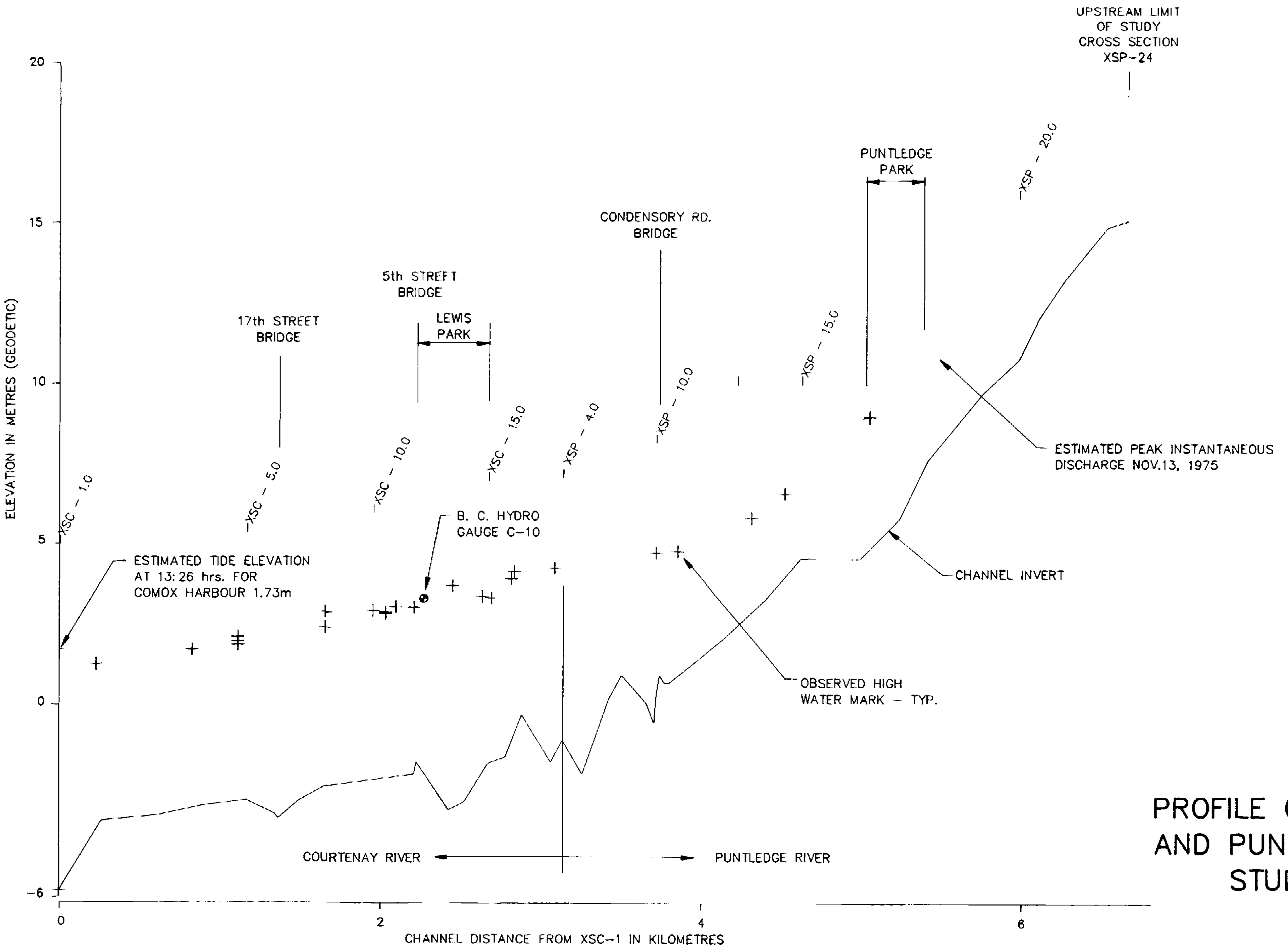


SCALE
HOR. 1:25 000
VERT. 1:125

PROFILE OF COURTENAY AND PUNTLEDGE RIVERS STUDY REACH

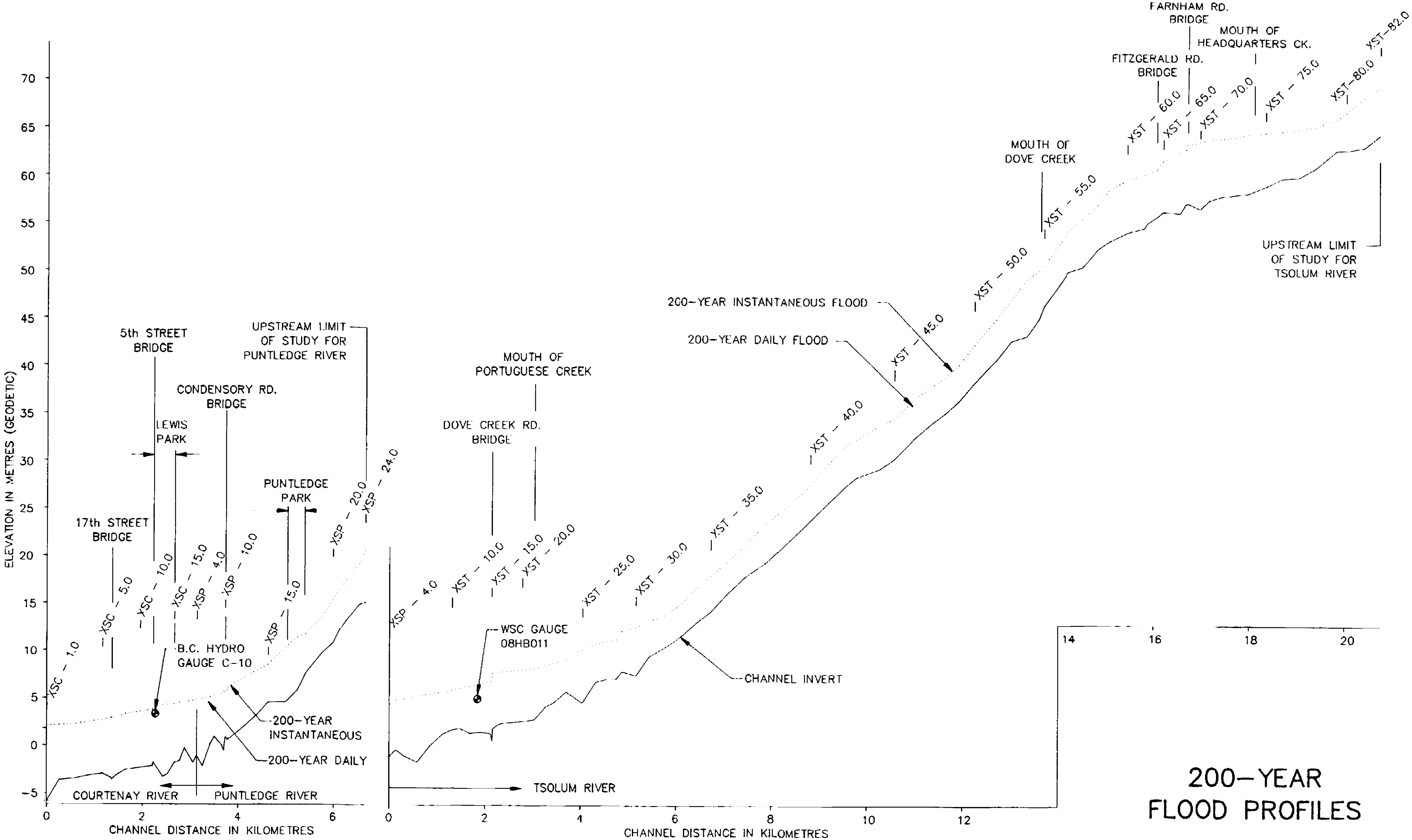
FIGURE 6

KER, PRIESTMAN & ASSOCIATES LTD

DATE : DECEMBER 1989

FILE NO. 2638

FILE NO. 2638
DATE : DECEMBER 1989



200-YEAR FLOOD PROFILES

FIGURE 7

KER, PRIESTMAN & ASSOCIATES LTD

APPENDIX 1

HISTORICAL FLOOD PHOTOGRAPHS

Photo 1 Looking downstream toward the Condensory Road Bridge over the Puntledge River. The centre pier was damaged by this flood and the bridge deck sagged deeply - 1 February 1935.

Photo 2 Looking northerly to Lewis Park - 1 February 1935.

Photo 3 Looking east across Anderton Avenue, the Courtenay River and Lewis Park toward the Courtenay Hotel - 1 February, 1935.

Photo 4 Looking northerly down the Old Island Highway from a point near the Courtenay Hotel. Lewis Park is on the left. 1 February, 1935.

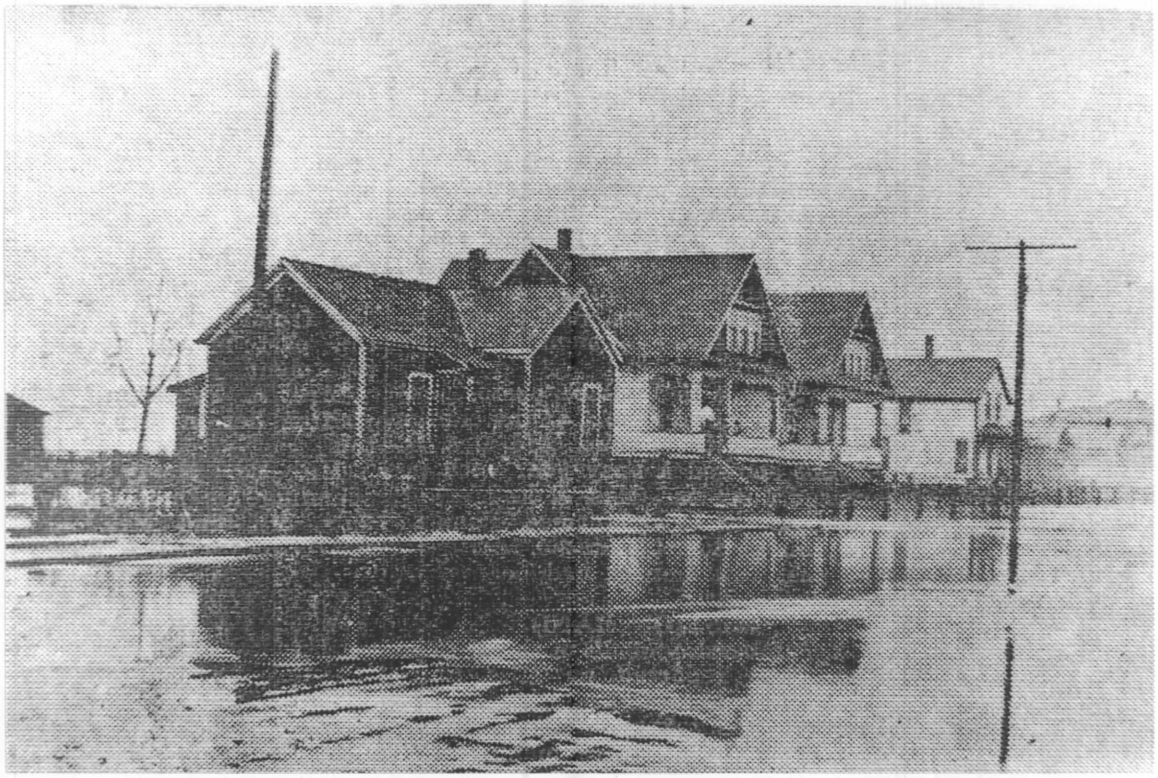


Photo 5 Residences on Comox Road near the Slough - 1 February, 1935.

Photo 6 A similar view in August 1989. The white house is common to both photographs.

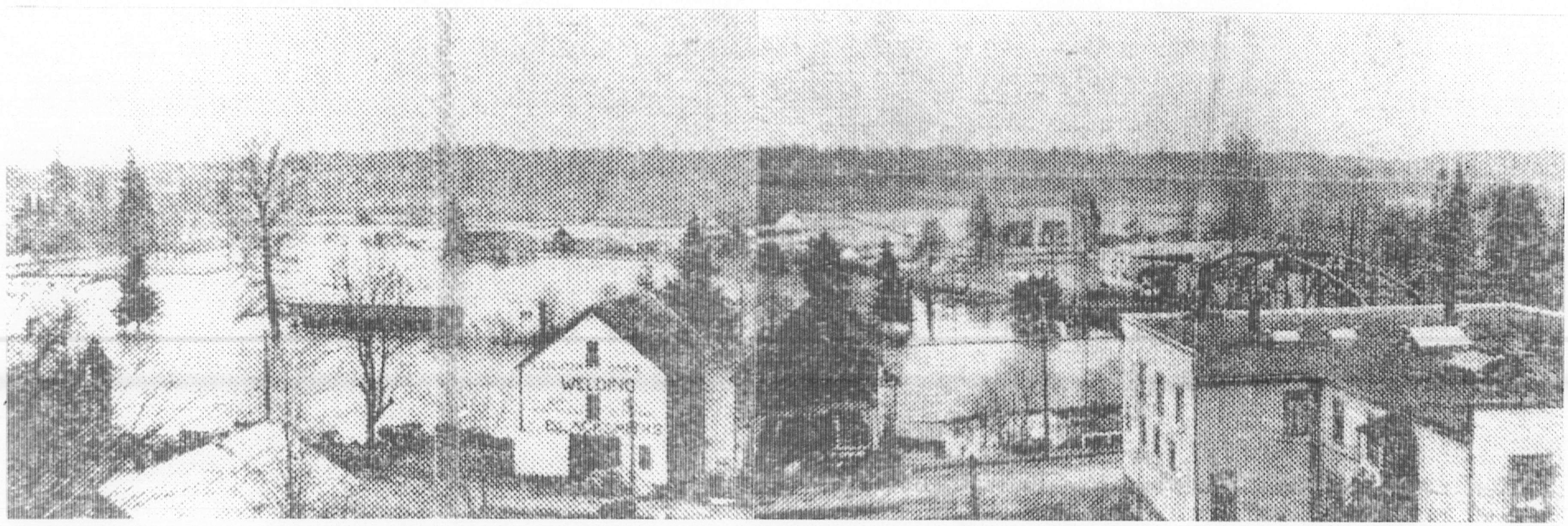


Photo 7 Looking east over Anderton Avenue, the Courtenay River and Lewis Park. The Courtenay Hotel is in the very centre and the flooded Courtenay Flats are partly visible in the background on the right. 15 November, 1939.

Photo 8 Looking south from the Courtenay Hotel down Comox Road 15 November, 1939.

Photo 9 A similar view in August 1989.

Photo 10 (left) and Photo 11 (above)

New forms of recreation for Lewis Park. Photo 10 shows the Old Island Highway under water. 13 November, 1975.

Photo 12   Puntledge Park - 26 December, 1980.

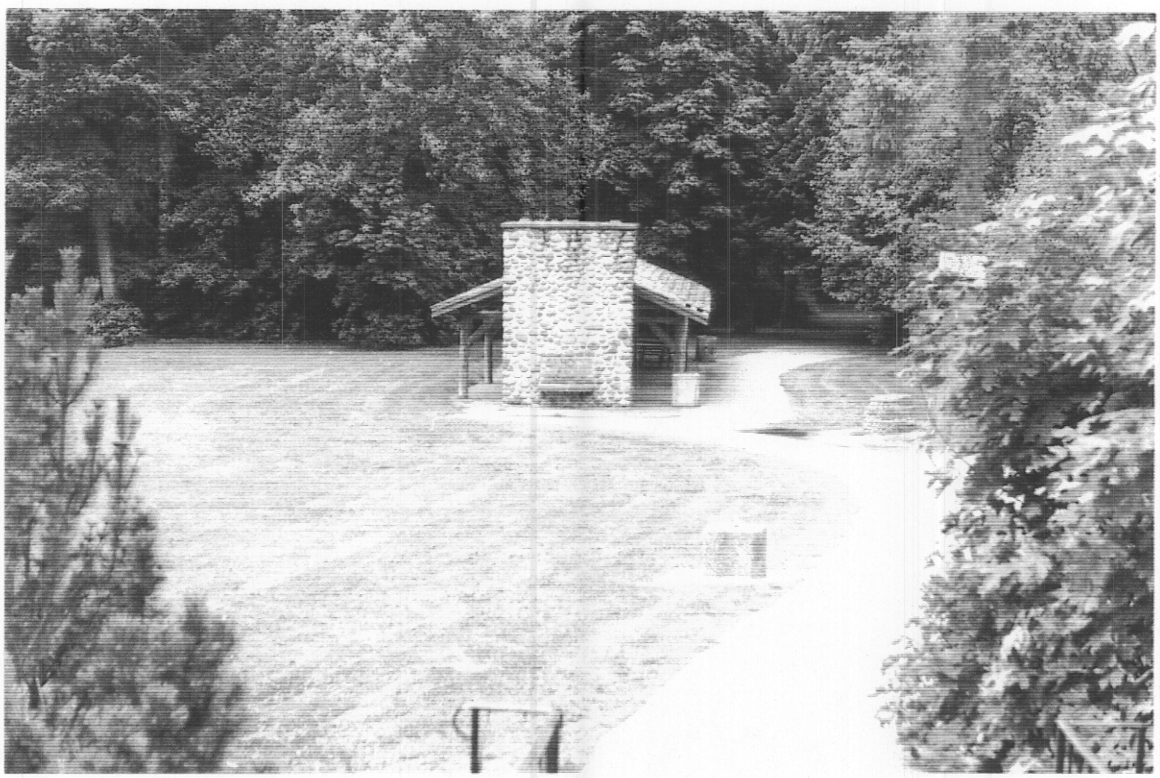


Photo 13   A similar view in August 1989.

Photo 14 Looking west along Dove Creek Road near the bridge over the Tsolum River - 11 February, 1983.

Photo 15 Residence at 621 Rye Road - 11 February, 1983.

APPENDIX 2

FLOOD LEVELS INCLUDING FREEBOARD

Appendix 2

Flood Levels Including Freeboard

Cross Section Number	Flood Level (m)	Cross Section Number	Flood Level (m)
Courtenay River		Puntledge River	
XSC - 1.0	2.75	XSP - 5.0	5.26
XSC - 2.0	2.78	XSP - 6.0	5.46
XSC - 3.0	2.86	XSP - 7.0	5.63
XSC - 4.0	2.98	XSP - 8.0	5.83
XSC - 5.0	3.11	XSP - 9.0	5.90
XSC - 6.0	3.32	XSP - 10.0	6.00
XSC - 7.0	3.35	XSP - 11.0	6.03
XSC - 8.0	3.47	XSP - 12.0	6.11
XSC - 9.0	3.75	XSP - 12.1	6.22
XSC - 10.0	4.00	XSP - 12.2	6.43
XSC - 11.0	4.20	XSP - 12.3	6.46
XSC - 12.0	4.21	XSP - 13.0	7.53
XSC - 12.1	4.56	XSP - 14.0	8.28
XSC - 13.0	4.62	XSP - 15.0	8.85
XSC - 14.0	4.67	XSP - 16.0	10.66
XSC - 15.0	4.71	XSP - 17.0	11.73
XSP - 1.0	4.87	XSP - 18.0	12.11
XSP - 2.0	4.96	XSP - 19.0	13.81
XSP - 3.0	5.08	XSP - 20.0	15.72
XSP - 4.0	5.20	XSP - 21.0	16.68
		XSP - 22.0	17.81
		XSP - 23.0	19.49
		XSP - 24.0	20.86

Cross Section Number	Flood Level (m)	Cross Section Number	Flood Level (m)
Tsolum River		Tsolum River, Cont.	
XST - 5.0	5.23	XST - 44.0	34.11
XST - 6.0	5.33	XST - 45.0	34.82
XST - 7.0	5.65	XST - 46.0	36.99
XST - 8.0	5.84	XST - 47.0	38.42
XST - 9.0	6.04	XST - 48.0	39.14
XST - 10.0	6.28	XST - 49.0	40.49
XST - 11.0	6.47	XST - 50.0	42.60
XST - 12.0	6.67	XST - 51.0	45.24
XST - 13.0	6.89	XST - 52.0	47.28
XST - 14.0	7.22	XST - 53.0	49.39
XST - 15.0	7.21	XST - 54.0	50.34
XST - 16.0	7.78	XST - 55.0	50.86
XST - 17.0	8.06	XST - 56.0	54.46
XST - 18.0	8.16	XST - 57.0	55.73
XST - 19.0	8.28	XST - 58.0	57.26
XST - 20.0	8.39	XST - 59.0	58.76
XST - 21.0	8.55	XST - 60.0	59.89
XST - 22.0	8.88	XST - 61.0	60.43
XST - 23.0	9.08	XST - 62.0	60.59
XST - 24.0	9.49	XST - 63.0	60.97
XST - 25.0	10.53	XST - 64.0	61.17
XST - 26.0	11.12	XST - 65.0	61.87
XST - 27.0	11.43	XST - 66.0	62.72
XST - 28.0	11.60	XST - 67.0	63.04
XST - 29.0	12.48	XST - 68.0	63.10
XST - 30.0	12.86	XST - 69.0	63.60
XST - 31.0	13.63	XST - 70.0	63.88
XST - 32.0	14.17	XST - 71.0	64.12
XST - 33.0	15.53	XST - 72.0	64.27
XST - 34.0	17.12	XST - 73.0	64.44
XST - 35.0	18.30	XST - 74.0	64.72
XST - 36.0	19.70	XST - 75.0	64.91
XST - 37.0	21.53	XST - 76.0	65.09
XST - 38.0	23.80	XST - 77.0	65.32
XST - 39.0	25.44	XST - 78.0	65.59
XST - 40.0	27.88	XST - 79.0	66.47
XST - 41.0	30.15	XST - 80.0	67.11
XST - 42.0	32.06	XST - 81.0	68.66
XST - 43.0	32.65	XST - 82.0	69.76