Canada - British Columbia
Floodplain Mapping Agreement

Floodplain Mapping Study
Chemainus River
Design Brief

Prepared For:

B. C. Ministry of Environment
Water Management Branch

Environment Canada
Inland Waters Directorate

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SUMMARY

The Chemainus River is situated on south eastern Vancouver Island in the Cowichan Valley Regional District. Floodplain mapping studies were carried out along 5 km of the lower Chemainus River and its tributary Bonsall Creek, from tide water up past the Island Highway. Flood profiles for the 200 year and 20 year instantaneous and daily floods were computed using the HEC-2 backwater program. Model calibration was performed using high water marks from a flood in January, 1986. Sensitivity analyses were carried out to verify the reliability of the computed flood levels. The extent of inundation and flood elevations have been presented on three 1:2,500 scale, 1 m contour map sheets.

TABLE OF CONTENTS

TABLES

FIGURES

1.0 INTRODUCTION

1.1 Scope of Study

This Design Brief and associated Floodplain Inundation Mapping were prepared under the Canada - British Columbia Floodplain Mapping Agreement. The floodplain mapping study delineates the 200 year flood boundaries and the flood elevations (freeboard included). The maps are then utilized in administration of local by-laws, official community plans, administration of the Land Title Act and in other water management functions (Reference 1).

This particular study encompassed 5 km of the lower Chemainus River, 2 km along Chemainus Slough and 3 km on Bonsall Creek on South East Vancouver Island (Figure 1). The investigation included the following components:

- a initial site visit and final field inspection of the floodplain
- a review of the basin's flood hydrology and determination of 20 year and 200 year instantaneous and daily flood discharges
- development and calibration of a standard step backwater model for estimating flood levels along the channels
- determination of the 200 and 20 year instantaneous and daily flood elevations along the streams and in the bay adjacent to Stuart Channel
- delineation of the 200 year flood boundaries on 1:2,500 scale, 1 m contour orthophoto maps

1.2 Authority and Acknowledgements

The investigation was carried out by Northwest Hydraulic Consultants Ltd (NHC) under an agreement with the B. C. Ministry of Environment dated September 5th, 1989. The contract manager was P. J. Woods P. Eng., Head, Special Projects Section, Water Management Branch, B. C. Ministry of Environment. Technical review and assistance was provided by R. W. Nichols P. Eng., Water Management Branch and J. R. Card P. Eng. of

the Nanaimo Regional Office. Mr. O. Nagy, Water Survey of Canada, Environment Canada provided historical data on flood levels that have been recorded at the hydrometric stations on the river.

2.0 STUDY REGION

2.1 Setting

The Chemainus River is located on south eastern Vancouver Island in the Cowichan Valley Regional District. The Chemainus River drains 355 km^2 of mainly forested uplands and mountains. The watershed has an overall length of 45 km and is typically 5 km to 10 km in width. The highest point in the basin is on the peak of Mount Whymper at an elevation of 1,540 m. Over most of its length, the Chemainus River flows in a south easterly direction in a structurally controlled valley. Near Mount Sicker, the valley turns northwards and the stream flows over the Nanaimo Lowlands. Throughout most of this region the channel is incised and frequently confined. Near Westholme the river flows over a broad alluvial plain. In this lower 5 km, (which encompasses the floodplain mapping reach) the stream has an irregularly meandering channel pattern with a broad valley flat. The alluvial plain has a number of recent channel scars or sloughs that indicate former positions of the river channel.

Typical channel characteristics of the Chemainus River in this reach are as follows:

- top width: 50 m - 60 m
- mean depth: 2 m - 3 m
- average slope: 0.0026 (2.6 m/km)
- bed material: gravel and cobble D_{50} = 50 mm (approx)

Bonsall Creek drains the southern and eastern slopes of Sicker Mountain, and the Somenos Lake Lowlands and a small upland north of Crofton. The maximum elevation in the basin is 700 m, however most of the watershed lies below El. 100 m.

Bonsall Creek watershed can be divided into three sub-basins. "Upper Bonsall Creek" consists of the portion upstream of Highway 1. This is the steepest part of Bonsall Creek, with an elevation range of 660 m in a 5.8 km^2 basin. "Whitehouse Creek" sub-basin drains a portion of the Chemainus valley and the eastern slopes of Big Sicker Mountain. The total contributing area is 9.3 km^2. "Lower Bonsall Creek" drains 13 km^2 of swampy lowland, that is characterized by very flat gradients, large flood storage retention capacity and a poorly defined drainage network. The total effective drainage area of the basin is 28.1 km^2.

Within the limits of the floodplain mapping, Bonsall Creek flows across the alluvial plain in an incised, irregularly meandering channel. The bed and banks of the creek are frequently composed of cohesive sediments and the channel is often clogged with debris or vegetation (cf. Photo 4 & 5). At its distal end, the creek splits into a series of distributary channels and flows over tidal flats into Stuart Channel.

2.2 Available Data

2.2.1 Hydrometric Data

Water Survey of Canada has operated a hydrometric station on the Chemainus River near Westholme (gauge 08HA001) between 1915 and 1917 and between 1953 to the present. Once daily stage measurements were made with a wire weight gauge located on the railway bridge, approximately in the centre of the study reach. On May 31, 1984 the gauge was re-located 1 km upstream to the Highway #1 bridge. In 1988 a Stevens Type "A" recorder was installed at this location. A summary of the station operations is provided in Table 1.

No hydrometric data is available for Bonsall Creek.

2.2.2 Cross Section Survey Data

Table 2 summarizes the cross section surveys and topographic mapping available in the study area. The key information includes 29 cross sections on the Chemainus River, 23 sections on Bonsall Creek and 17 sections on the slough situated between Bonsall Creek and the river. All of these cross sections were surveyed by the Ministry of Environment in 1986. The data were provided in digital form on diskette. In addition, a catalogue of photos was provided along with a hard copy listing of survey co-ordinates and a computer generated plot. Profiles of Crofton Road and Chemainus Road were also provided to assist in defining the floodplain topography.

2.2.3 Floodplain Mapping

Base mapping of the study area was obtained from the Map Production Division, Surveys and Resource Mapping Branch. The site topography was compiled on 1:2,500 scale, 1 m contour orthophotos that were produced from air photos flown in March, 1978. In most cases, the floodplain topography agreed closely to the overlapping ground survey information. However, in some locations along th Chemainus River, discrepancies were noted at the edge of the banks. Further review and site inspections showed that these differences were due to ongoing bank erosion and channel shifting. Therefore, the channel survey data were given preference to the floodplain mapping.

2.2.4 High Water Marks

Water Management Branch surveyed in 4 high water marks in February, 1986 and 24 high water marks in September, 1986 along the Chemainus River. These data were associated with a flood on January 18, 1986. Unfortunately, the data are only of limited usefulness in terms of calibrating a backwater model. There are two main reasons for this:

- only a single manual gauge reading was obtained by Water Survey of Canada during the flood. Therefore, it is not possible to determine the actual maximum instantaneous discharge associated with the high water marks;
- most of the high water marks were identified six months after the flood had occurred. This reduces the reliability of the measurements, since the some of the apparent high water marks could have been associated with more recently occurring smaller floods, or could be affected by human interference.

2.2.5 Site Inspections

Two site inspections were carried out during the course of the study. The first visit was made on November 29, 1989. During this visit, preliminary estimates were made of the channel and overbank roughness values. In addition, assessments were made of the hydraulic characteristics of the bridges and roads over the floodplain. A second visit was made on January 15, 1990. At this time field checks were made at sites where discrepancies were observed on the mapping. In addition, certain assumptions that had been made in the modelling were checked.

A number of informal interviews were held either during the field inspections or by telephone to obtain background information on the flood history of the area. The persons who provided useful information included:

- Mr. Jim Card, P. Eng., Water Management Branch, Nanaimo
- Mr. A. Brown, P. Eng., Water Management Branch, Victoria
- Mr. O. Nagy, P. Eng. Water Survey of Canada, Vancouver
- Mr. B. Walker, hydrometric technician, Water Survey of Canada, Nanaimo
- Mr. F. Stephenson, Institute of Ocean Sciences, Pat Bay
- Mr. A. Holman, 2747 Mount Sicker Road (resident for 65 years)
- Mr. D. Fitch, Chemainus resident for 30 years

3.0 METHODOLOGY

3.1 Approach

3.1.1 Design Floods

Water Management Branch estimated the daily and instantaneous 20 year and 200 year recurrence interval floods on the Chemainus River and Bonsall Creek (Ref. 3). NHC provided an independent review of the methods that were used to estimate these values. Since 36 years of annual maximum daily discharge data are available on the Chemainus River, a flood frequency analysis was carried out on these records. With no data on Bonsall Creek, a regional analysis had to be used. The list of available Water Survey of Canada stations that were used in the review are summarized in Table 3.

3.1.2 Hydraulic Analysis

The 1987 micro computer version of the HEC-2 standard step backwater program was used for the flood level computations. The data required for these computations incude:

- river channel and floodplain geometry
- downstream starting water level
- roughness coefficients for the channel and floodplain
- dimensions of all hydraulic structures such as bridges and dykes

The river channel and floodplain geometry was described by cross sections taken normal to the flow path and by reach lengths measured between sections. MOE provided cross sections of the stream channels. These surveys encompassed the underwater portions of the channels, exposed bars or islands and the channel banks. NHC extended these sections across and beyond the floodplain using the 1:2,500 scale, 1 m contour orthophotos furnished by MOE. Initial large scale plots of each extended channel/floodplain cross section were prepared and checked for errors and for reasonableness. Final summary cross sections were then prepared.

The starting water surface elevation for Chemainus River and Bonsall Creek is determined by the tide level. The study's Terms of Reference instruct that the starting tide level should be set to the Higher High Water, Large Tide. This value represents the average of the highest water levels recorded in each year since observations began.

Initial values of the channel and floodplain roughness were selected by engineering judgement, based upon the field inspections and photographs, and by reference to recognized publications (References 4, 5, 6 and 7). Following this initial formulation, the backwater model was calibrated by comparing predicted water levels with observed levels. The roughness values and loss coefficients were then adjusted until the predicted water surface profile was judged to properly represent the measured flood profile and high water mark data. Finally, independent verification runs were made to assess the reliability and stability of the calibration. This involved comparing the stage - discharge relations that have been established at WSC's two gauge sites with predictions from the model.

After the calibration and verification phase, 20 year and 200 year flood profiles were computed for Chemainus River, Chemainus Slough and Bonsall Creek.

The designated 200 year flood levels were determined for each cross section. These water levels include an allowance for freeboard to provide a factor of safety against modelling imprecision, effects of debris or channel infilling from sedimentation as well as factors such as surging or wave action.

The Terms of Reference for the study indicate that the designated 200 year water levels should be computed for each cross section as the higher of:

- the 200 year instantaneous water level plus 0.3 m
- the 200 year mean daily discharge plus 0.6 m
- or as deemed advisable if special conditions are apparent

3.2 Assumptions

3.2.1 Flood Hydrology

All of the frequency analysis that has been used to analyze flood discharges (and tide levels) has been based on historical measurements that span a period of about 40 years. It is assumed that the future hydrological characteristics of the basins will remain similar to conditions that have existed in the recent past. In effect, this implies that the annual flood time series will remain stationary. Some factors which could induce non-stationarity include long term climatic trends, short term (years to decades) persistence in climatic patterns, or changes in basin runoff generating characteristics caused by land use changes or natural changes. It is beyond the terms of reference of this study to explicitly consider any of these effects.

3.2.2 Hydraulic Analysis

All of the backwater computations were based on the assumptions of one dimensional steady, gradually varied flow. Furthermore, the computations have assumed unobstructed flow at all cross sections and bridge crossings. Thus, the designated flood levels remain valid only if the channel and bridges remain unobstructed by debris or sediment. Effects of debris may be partially accounted for by the freeboard (0.3 m - 0.6 m) that has been added to the computed flood levels.

4.0 HYDROLOGY

4.1 Historic Flooding

Peak flows on eastern Vancouver Island are generally caused by late fall and winter westerly frontal rain storms. These storms are often of relatively low intensity but may have a prolonged duration. Occasionally, frontal storms become unstable and remain stationary over a watershed for several days, producing thunderstorms and heavy precipitation which could cause severe flooding (Ref. 3).

The highest discharge measured on the Chemainus River was estimated to reach 537 m^3/s on February 11, 1983. The long term mean annual flood (based on 36 years of data) is 243 m^3/s. However, the discharge record on the Chemainus River shows that of the five highest measured flows, four have occurred in the last 10 years. Furthermore, the mean annual flood in the last 10 years is 40 % higher than the long term mean annual flood. The unusual flood activity in recent years may simply reflect short term fluctuations in rainstorm activity.

The river exceeded bankfull stage upstream of the Highway 1 bridge in November 1989 and January 1990 (cf. Photo 1). Mr. A. Holman of 2747 Mount Sicker Road reported that the overbank flows were concentrated in the minor overflow channel on the right bank (near Cross Section 25) and was directed into Whitehouse Creek. It was also mentioned that this overbank flooding had occurred several times in the last few years.

Past incidents of flooding between the Chemainus Road bridge and the E & N Railway bridge are summarized in Ref. 10. In September, 1984 a petition was signed by 24 residents and land owners to express concern over frequent flood damage and disruption of road access along the lower Chemainus River. The flooding has occurred along the east side of the channel in the vicinity of several prominent distributary channels that lead from the main river across the floodplain into a large slough. These flood channels suggest the Chemainus River has experienced considerable channel shifting and lateral instability in the past.

Another area of past flooding has occurred in the lower 2 km of the Chemainus River where it approaches its estuary. Figure 2 is an oblique air photo taken on December 17, 1973 (provided by the Ministry of Environment). The photo illustrates that overbank flows from the lower Chemainus River run in an easterly direction towards the slough. Unfortunately, the discharge was not measured during this event so that the recurrence interval of the flood can not be estimated.

4.2 Designated Floods - Chemainus River

Frequency curves of mean daily flood discharge were derived by MOE for the Chemainus River using 33 years of records from gauge 08HA001. Values of the 20 year and 200 year flood discharge from this analysis are summarized in Table 4. It was concluded by MOE that the estimates were reliable and the values were recommended for this site. The instantaneous discharges were estimated from a regional analysis which compared the ratio of instantaneous and daily discharges at four stations on Vancouver Island.

NHC reviewed three aspects of the flood hydrology on the Chemainus River:

- the influence of the method of discharge measurement on the flood frequency analysis
- the statistical basis of the frequency analyses
- the methods used to estimate instantaneous peak discharges from the daily discharge estimates

Prior to 1988 all of the stage measurements on the Chemainus River were collected manually once each day using a wire weight gauge. As a result, the published annual maximum daily discharges are not strictly daily averages or instantaneous peaks. The readings are simply instantaneous observations at a fixed time. In some years, the true daily discharge would be overestimated, in other years the true daily discharges will have been underestimated. If these errors are random, the mean annual flood will be accurately estimated by the manual gauge readings. However, the variance of the flood record will be over-estimated, since additional apparent flow variability will be introduced by the method of measurement. It is expected that this bias would cause the 20 year and 200 year flows to also be over-estimated by standard frequency programs.

Figure 3 shows a log - Normal flood frequency plot that was derived from 36 years of data from the Chemainus River. Frequency curves were also produced using the Gumbel, 3 Parameter log Normal, and log Pearson III distributions using the computer program "FLOWFREQ" for comparison. Using these various distributions, the 20 year daily discharges ranged from 460 m^3/s to 500 m^3/s and the 200 year daily discharges ranged between 670 m^3/s and 790 m^3/s.

Recommended methods for choosing the most appropriate frequency distribution include reviewing the goodness of fit statistics and visual examination of the flood frequency plots (Ref. 11). Based on this review, it was concluded that the estimates provided by MOE were reasonable. Therefore, values of 465 m^3/s and 706 m^3/s were adopted as the daily 20 year and 200 year flood values for the subsequent HEC-2 runs.

It should be recognized that the actual confidence limits that can be placed on the expected values from any particular distribution are relatively wide. For example, using the log Normal distribution, the 90% confidence interval for the 20 and 200 year floods were as follows:

- 20 year flood — 400 m^3/s - 600 m^3/s
- 200 year flood — 560 m^3/s - 1020 m^3/s

MOE adjusted the daily discharges (D) to instantaneous flows (I) using a relationship between maximum I/D ratios and drainage area. The curve was drawn to pass through an observation at Jump Creek (gauge 08HB048) with an I/D ratio of 2.35. A review of published data in WSC's Historical Streamflow Summary indicated the largest I/D ratio is only 1.79. Adjusting the curve to more closely envelope the corrected observations could substantially reduce the I/D ratio for the Chemainus River. Based on this adjusted curve the corresponding instantaneous 20 year and 200 year discharges were estimated to be 790 m^3/s and 1200 m^3/s, respectively. These values were subsequently adopted for use in the floodplain mapping study.

4.3 Designated Floods - Bonsall Creek

MOE estimated flood discharges on Bonsall Creek from a regional analysis of nearby stations. Frequency analyses were conducted on selected records of annual maximum daily discharge. The results were plotted as unit peak flows ($l/s/km^2$) against drainage area (km^2) on log - log graph paper. Envelope curves were defined for the middle eastern portion of Vancouver Island. Additional estimates were made using the rational formula from a regional analysis of rainfall data. The flows estimated using this approach were in the order of 40 % lower than the values from the regional analysis. The flows at Upper Bonsall Creek above Westholme Road were reduced by one third to account for ponding and storage in the valley bottom. Details of the procedures that were used are summarized in Ref 3.

NHC's review focused on trying to resolve the differences between the flood estimates from the regional analysis and the results from the rational formula. This involved comparing the climatic and topographic characteristics of the Bonsall Creek basin with the other basins used in MOE's regional analysis.

Virtually all of the streams that were included in MOE's regional analysis drain mountains or upland areas. Therefore, it was felt that some of the discrepancies could reflect differences in precipitation and runoff generation in the basins. The rainfall records show there is a steep increase of precipitation with elevation inland from the coast. A large portion of the storm runoff in moderately sized and larger basins may be generated from a relatively small area in the Insular Mountains. Basins in the Lowlands such as Bonsall Creek, can have lower unit floods due to lower rainfall intensities, flatter slopes and channels, overbank storage and poorly integrated drainage networks.

The two adjoining Lowland basins next to Bonsall Creek are Bings Creek and Averill Creek. Hydrometric stations have been maintained on both of these creeks:

- Bings Creek at the mouth (gauge 08HA016) between 1962 to 1988
- Averill Creek near Duncan (gauge 08HA015) between 1962 to 1963

Neither station was used in MOE's regional analysis. Both show substantially lower peak runoff values than the more mountainous streams on Vancouver Island. The 20 year and 200 year flood magnitudes on Bonsall Creek were estimated from the runoff values measured on Bings Creek. The runoff was estimated for the three main sub-basins in Bonsall Creek and then combined to determine the total peak discharges. The results of this analysis are summarized in Table 4. The daily discharge values fall close to MOE's estimates that were based on the rational method.

It was concluded that the runoff estimates derived from including Bings Creek data will provide the most realistic estimates of flood discharges on lower Bonsall Creek. Therefore, these values were input in the HEC-2 analysis. However, subsequent review of the backwater computations showed that during extreme flood conditions the overbank flows spilling from the Chemainus River into Bonsall Creek are much greater than the inflows to the creek itself. It will be shown that the flood levels along the creek are determined mainly by levels in the Chemainus River and are very insensitive to the actual inflows that are specified.

5.0 HYDRAULIC ANALYSIS

5.1 Flood Characteristics

The hydraulics of the Chemainus floodplain are complicated by several factors:

- the alluvial plain contains large areas that are unconfined so that floodwaters could spread out and possibly even be diverted into other adjacent basins;
- there are a number of former channels, sloughs and flood channels that may concentrate the overbank flows and convey the water away from the main channel;
- bridges and roads will provide local flow control and will have a major effect on directing overbank flows across the floodplain.

The following scenarios describe some of the potential flooding situations that were represented in the backwater models. Road names and cross sections that are referenced in these descriptions are shown on the accompanying floodplain maps. Actual cross section plots are summarized in Figures 4 and 5.

At the upstream end of the study, the Chemainus River is confined on its left bank by high bluffs. Between Cross Section 27 and 28, the right bank floodplain is relatively low and is subject to overtopping. Overbank flows would run along roads and grass lined flood channels, eventually concentrating in the small channel south of Mount Sicker Road. Once out of the Chemainus River channel these flows will head towards Whitehouse Creek. Highway 1 will act as a dyke, with an outlet at Whitehouse Creek and a 0.6 m culvert at the southernmost end of the floodplain. This water will pond in the large storage area between Highway 1 and Chemainus Road. Addition inflows to this area will be derived from flows from Bonsall Creek, coming under the Highway beside the railway overpass.

Right bank overflows from the Chemainus River at Cross Sections 19 and 20 will be separated from the storage area by the connector road and will head towards Bonsall Creek through old channels. Further downstream between Cross Sections 18 to 15, the overbank flows will mostly be contained in old side channels. However, some overbank flow may cross Chemainus Road and head towards Bonsall Creek.

Near the railway bridge, the rail line will re-direct overbank flows back towards the Chemainus River channel. Downstream of the bridge, the sharp bend and a bedrock spur will tend to cause the right overbank flows between Cross Section 12 and 11 to head towards Chemainus Road and into the major slough between the river and Bonsall Creek. Between Cross Sections 5 and 1 the right bank overflows will continue to be directed away from the Chemainus River towards the slough. However, at the downstream end of the study area the slough and the main channel will re-combine and flow over the tidal flats into Stuart Channel.

5.2 Approach for Modelling

5.2.1 General

A preliminary review of the high water mark data illustrated that the designated flood levels were much higher than bankfull stage, and a substantial portion of the flows were carried on the floodplain. Under these conditions it was believed that there would be diversion of water from the Chemainus River into Bonsall Creek. As a result, the actual flow over the flood plain will be very two dimensional in nature. Such conditions can only be represented approximately in a one dimensional model like HEC-2. In order to properly represent these flow exchanges, a series of iterative runs were performed. This involved running the three HEC-2 models (Chemainus River, Slough and Bonsall Creek) sequentially, estimating the overbank flow splits and diversions out of channels and "tuning" the backwater models until the results were considered satisfactory. Two criteria were used to judge the reasonableness of the results:

- the degree of agreement between water levels near the overlap of the model boundaries (water levels at model boundaries should agree);
- the overall discharge balance between the Chemainus River, Slough and Bonsall Creek (flow continuity had to be preserved).

5.2.2 Chemainus River

The "split flow" option was used extensively in this model to represent the losses out of the channel to Bonsall Creek and the slough. This option allowed the automatic determination of channel discharges and profiles in situations where flow is lost from the main channel. This approach was used in an attempt to represent the complicated, two dimensional flow characteristics of the floodplain. The approach was also necessary in order to account for the diversions of flow out of the Chemainus River system. Three different situations were modeled:

- in cases where the banks or low lying roads were overtopped and the overflows were diverted out of the channel, the splits were estimated using the normal depth option. This was the most common situation that was encountered during the model development;
- in cases where a dyke or elevated road was overtopped, a weir flow option was used;
- Upstream of the Highway 1 bridge a rating curve approach was used to estimate the split. This required a series of iterative computations to establish the right bank overflows for different inflow conditions.

Two interpolated cross sections were added to the model to improve its representation of the channel topography. These sections ("0" and "0.5") were placed downstream of the first surveyed cross section near the junction of the slough and the main channel. This also allowed the Split Flow option to return the overbank flows through the slough and back into the Chemainus Channel at its downstream end.

The three bridges on the Chemainus River were all represented initially using the Normal Bridge routine. This was considered reasonable since the bridges are all clear span structures and the low chords were thought to be above the expected flood levels. The bridge geometry was coded using the survey data provided by MOE. Expansion and contraction losses at the bridges were set to the values recommended by HEC (Ref. 4).

Initial estimates of channel and floodplain roughness were based on recommendations from available literature and from experience. The floodplain values generally varied from 0.12

to 0.05. Channel roughness values were estimated using Bray's method (Ref. 4) to range between 0.036 and 0.04.

5.2.3 Chemainus Slough

The Chemainus Slough was sub-divided into two reaches:

- a lower reach (Cross Sections 0 to 14) which was analyzed as a separate model;
- an upper reach (Cross Sections 1 to 10) which was incorporated into the model of Bonsall Creek.

The lower reach of the slough conveys water from Bonsall Creek back into the Chemainus River at the mouth. This part of the slough also carries overflows from portions of the Chemainus River (between Cross Sections 11 and the mouth).

The inflows to the slough were derived from the output of the Chemainus River model. This output consisted of calculated Split Flows from the Chemainus River channel. This allowed an overall water balance to be achieved between the slough and the river.

Two 0.9 m diameter culverts were included in the analysis. However, it was found that these structures had only a very minor influence on the computed flood levels. This was because the culverts were deeply submerged at all of the flood conditions.

5.2.4 Bonsall Creek

Bonsall Creek has a tortuously meandering channel pattern and is crossed in three locations by an abandoned rail line. This rail line acts like a dyke in some areas and partially isolates the overbank flows from the channel flows. A secondary factor in modelling Bonsall Creek is that in many locations, the creek and Slough are very close together and the overbank flows can not be easily distinguished.

In order to simplify these conditions the cross sections from the upper Slough were combined with the Bonsall Creek sections. Furthermore, some Bonsall Creek sections were eliminated to represent the situation when the floodplain will be deeply inundated.

The overbank and channel roughness values for Bonsall Creek and the slough were estimated from available guides and reference books (Ref. 5 and 6). The roughness values for the overbank areas were frequently assigned lower values than the creek's channel. This was because the channel was often choked with debris (logs and brush), while the fields were generally cultivated or grassed. As a result, typical roughness values in the channel were 0.035 to 0.07 while overbank values ranged between 0.035 and 0.05.

5.3 Model Calibration and Verification

Measured high water marks are available only on the Chemainus River from the flood of January,1986. The "daily" discharge for this event was reported by Water Survey of Canada to be 445 m^3/s, which corresponds to an annual recurrence interval of about 15 years (Figure 3). In the 5 km reach between tide water and Highway 1, 24 high water marks were measured. However, most of this data was collected several months after the flood event. This reduces the reliability of the data somewhat, since other intervening smaller floods could also leave apparent high water marks. Also, it is not possible to estimate the actual discharge that produced the high water marks.

Table 5 summarizes the measured and computed water levels along the river. In most cases the absolute difference ranged between 0.1 m and 0.3 m. The final adopted channel roughness values were most frequently set to 0.038 but were allowed to vary between 0.03 and 0.045. An independent check on the reliability of the calibration was provided by the stage - discharge relations that have been established by Water Survey of Canada at their two gauge sites. A comparison of the measured and predicted relations are shown on Figure 6. It can be seen that the HEC-2 model predictions agreed very closely to the measured water levels, particularly at the higher flows. Based on these comparisons it was considered that the model was adequate for producing estimates of flood levels.

Unfortunately, no high water mark data was available for calibrating the model of Bonsall Creek. Therefore, the adopted roughness values were based on engineering judgement and on experience from other similar streams.

5.4 Flood Profiles

Flood profiles were run for the 20 year and 200 year daily and instantaneous discharges. Figures 7, 8 and 9 summarize the computed water levels (without freeboard) along with the river thalweg and bridge deck elevations.

Tables 6 through 9 illustrate the magnitude of the overbank flows and water transfers across the floodplain for each flow condition. Table 9 shows that under a 20 year daily flood condition only a small per centage (10 %) of Chemainus River inflows will be diverted into Bonsall Creek. During a 200 year daily flood the per centage increases to 30 % and at the 200 year instantaneous discharge the per centage of flow diverted into Bonsall Creek will reach 50 %.

5.5 Sensitivity Studies

The sensitivity of the computed water levels to variations in downstream starting water level, discharge and roughness was evaluated. The 200 year instantaneous discharge was assumed to provide the base condition for comparison. The discharge, starting water level and "n" values were then adjusted in subsequent runs. Each resulting profile was compared to the base condition, and the mean absolute profile error was computed. These computations provide a means for judging the precision of the computed flood levels.

Table 10 provides a summary of the computations. It can be seen that the flood levels on Chemainus River, the slough and Bonsall Creek are not particularly sensitive to variations in roughness values or discharge. For example, a 20 % increase in discharge on the Chemainus River increased the flood levels by 0.16 m on average (range 0.07 m to 0.25 m). A 20 % increase in channel roughness raised the water levels by 0.1 m on average (range

0.03 m to 0.23 m). Comparable results were found on Bonsall Creek.

The influence of the starting water level at Cross Section 0 was assessed by varying the tide elevation between 1.8 m and 3.0 m during a 200 year instantaneous flood condition. By Cross Section 1, at the start of the study reach, the water level variations were less than 0.1 m. This shows that the starting tide level has virtually no effect on the computed flood levels in the river.

5.6 Designated Flood Levels

Table 11 summarizes the recommended designated flood levels at each cross section. In most cases the designated flood level corresponded to the 200 year instantaneous level plus 0.3 m of freeboard. These levels were typically 0.1 m to 0.2 m higher than the 200 year daily water levels with 0.6 m of freeboard.

5.7 Special Flood Conditions

The designated flood levels may be affected by special conditions such as debris jamming, bank erosion or channel avulsion. Some of the known special flood hazards that have been identified during the course of this investigation are summarized below.

One of the most critical potential flood hazard areas is situated upstream of the Highway #1 bridge on the right bank floodplain. In this vicinity a prominent overflow channel leads from the Chemainus River towards the culvert crossing of Whitehouse Creek. This overflow channel will be subject to flow concentration and high velocities (possibly in excess of 3 m/s) during flood conditions. The backwater calculations indicate that during an extreme flood over 25% of the total flow from the Chemainus River could spill out of bank and be diverted into Bonsall Creek.

A second potentially critical flood area on the Chemainus River is located along the right bank between the Railway bridge and the Chemainus Road bridge. In this reach the flow is deflected by a major sandstone outcrop and the channel is forced into a very sharp bend. Immediately upstream of this bend there is a relatively low bank which leads to a well defined actively flowing side channel (see Photo 6). This overflow channel could become a natural avulsion route during a major flood. This would divert the Chemainus River eastwards into the slough which parallels the present channel.

5.8 Flood Protection and Remedial Works

Past investigations of flood protection have considered dyking and bank protection requirements to limit overbank flooding along the east bank between the railway bridge and Chemainus Road bridge (Ref. 10). However, the results of this study indicate that during a major flood, consideration would also have to be given to controlling the upstream flow diversion between Chemainus River and Bonsall Creek near Highway 1. This is because areas between the railway bridge and Chemainus Road bridge could be subject to inundation from the overbank flooding that occurred further upstream.

Although remedial measures could be carried out near Highway 1 to contain overbank flows in Chemainus River, this would increase velocities in the main channel and could increase future channel instability and bank erosion in between the Highway 1 bridge and the railway bridge. Future flood protection designs on the Chemainus River will have to consider the impacts of river training and dyking on the overall stability of the channel.

6.0 COASTAL FLOOD LEVEL

Selection of the Coastal Flood Level at the mouth of the Chemainus River include three components:

- astronomical tides
- effects of storm surges
- possible additional effects of wave runup

The Higher High Water, Large Tide was estimated by the Institute of Ocean Sciences from tide levels recorded at Fulford Harbour on Saltspring Island. The value that was provided to NHC was 1.76 m (geodetic datum). This value represents the average of the highest water levels recorded in each year since observations began. The highest recorded tide level is 0.64 m higher or 2.4 m. The maximum observed storm surge in the Strait of Georgia has been measured at approximately 0.9 m. MOE currently recommends adopting a maximum storm surge of 1.2 m for assessing the Coastal Flood Level (Ref. 9).

The mouth of the Chemainus River is sheltered from wave action by the Shoal Islands. Furthermore, the available fetch in Stuart Channel is very narrow and restricted due to the presence of Saltspring Island, Kuiper Island and Thetis Island. Therefore, wave action in the lee of the Shoal Islands would be very minor. MOE recommends an additional allowance of 0.3 m be added to account for datum and unit conversions, wind chop and other local effects. Using this allowance the Coastal Flood Level at the mouth of the Chemainus River would be 3.3 m.

7.0 FLOODPLAIN BOUNDARIES

Map sheets 89-10-1 through 89-10-3 (at a scale of 1:2,500 and with 1 m contour intervals) were prepared to delineate the outline of the floodplain. This floodplain corresponds to the area inundated by the 200 year flood, including freeboard. The floodplain limits assume the absence of all dykes or structures which could act like dykes such as railroad embankments and road fills. In addition to the floodplain boundaries, the maps depict the following:

- river cross sections and monuments;
- interpolated flood levels for the 200 year designated flood and the 20 year flood (freeboard included);
- flood level isograms showing approximate lines of equal 200 year water levels to the edge of the floodplain.
- the designated Coastal Flood Level

8.0 CONCLUSIONS & RECOMMENDATIONS

The following conclusions and recommendations have been provided from this investigation:

1. The floodplain limits indicated on Map Sheets 89-10-1 through 89-10-3 can be designated under the joint Federal/Provincial Floodplain Mapping Agreement;

2. There are at least two sites where a major channel shift or avulsion could be initiated on the Chemainus River. These locations have been identified on the accompanying map sheets. The sites represent areas that could be subject to special hazards in (including high velocities, scour and erosion or impacts from debris) in addition to the normal flood hazards associated with inundation.

3. The floodplain maps should be reviewed at relatively frequent intervals to assess the impacts of any new developments on the floodplain, and the effects of channel changes on flood levels.

4. Future flood protection schemes on Chemainus River will have to consider flooding from water spilling out of Chemainus River across its floodplain into Whitehouse Creek, as well as overbank flooding between the two road bridges. Any measures that contain more flow in the main channel of the Chemainus River would result in higher channel velocities and produce increased potential for channel shifting and erosion, particularly in the reach near the E & N Railway.

Respectfully Submitted
Northwest Hydraulic Consultants Ltd.

David G. McLean, P. Eng.

9.0 REFERENCES

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4. U. S. Army Corps of Engineers, Hydrologic Engineering Center, "HEC-2 Water Surface Profiles, Generalized Computer Program, Users Manual", Davis, CA, 1982.

5. Chow, Ven Te, "Open Channel Hydraulics", McGraw Hill, New York, 1959.

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8. Fisheries and Oceans Canada, Canadian Hydrographic Service, "Canadian Tide and Current Tables, 1989, volume 5, Juan de Fuca Strait and Strait of Georgia, Ottawa.

9. B. C. Ministry of Environment, Water Management Branch, "Coastal Environment and Coastal Construction - A Discussion Paper" by B. Holden, P. Eng., Victoria.

10. Brown, A. A. "Preliminary Report on Lower Chemainus River Flooding", Ministry of Environment, Planning and Resource Management Division, Victoria, B. C., August 20, 1985, File: P74-6, 11 pp.

11. National Research Council, "Hydrology of Floods in Canada: A Guide to Planning and Design", Associate Committee on Hydrology, Ottawa, Ontario, 246pp., 1989.

TABLES

TABLE 1

HYDROLOGIC DATA USED FOR FREQUENCY ANALYSIS

Gauge Number:	08HA001
Gauge Name:	Chemainus River near Westholme
Drainage Area:	355 km^2
Period of Record:	1914-17, 1952-87 (annual maximum mean daily) 1988 (annual maximum instantaneous)
Gauge Location:	1914-1984 About 1.5 km from mouth, on E & N railway bridge (south abutment). 1984-1988 On Southbound span of twin bridge of the Island highway.
Additional Data:	WSC Rating Tables #23,24,28,29

TABLE 2

DATA USED FOR HYDRAULIC ANALYSES

Source	Comment
Ministry of Environment; Water Management Branch:	
Volume 1 Chemainus River Survey Project 86-FDC-3, August, 1986	cross sections 1-28 Chemainus 1-22 Bonsall Cr. 1-4 Slough incl. photographs Crofton Rd profile Crofton-Chemainus Road profile
Drawing No's. 87-18-1, 87-18-2, 87-18-3 Orthophoto showing location of cross sections 1986 high water works, water level and thalweg profiles.	photographs high water marks
Chemainus River Topographic Maps scale 1:5000, 1m contour internal sheets 89-10-1,2,3	

TABLE 3

HYDROMETIC STATIONS IN REGIONAL ANALYSIS

Stream Name	Gauge	Drainage Area km^2	Period of Record
Chemainus R. nr Westholme	08HA001	355	1915-17; 1953-89
Cowichan R. nr Duncan	02HA011	826	1960-1989
Cowichan R. at Lake Cowichan	08HA002	596	1913-19; 1940-89
Nanaimo R. nr Cassidy	08HB034	684	1965-88
Englishman R. nr Parksville	08HB002	324	1913-17; 1970-88
Koksilah R. at Cowichan	08HA003	209	1914-17; 1954-1989
Little Qualicum R.	08HB029	237	1960-86
Tsable R. nr Fanny Bay	08HB024	113	1960-88
Jump Cr. at mouth	08HB041	62.2	1970-1989
Nile Cr. nr Bowser	08HB022	15	1959-88
Bings Cr. nr mouth	08HA016	15.5	1961-1989

Table 4

Flood Frequency Estimates

RIVER	20 Year Flood DAILY	(m³/s) INST.	200 Year Flood DAILY	(m³/s) INST.
Ministry of the Environment Estimates:				
CHEMAINUS	465	860	706	1300
BONSALL CREEK	40	85	45	117
Adopted for HEC2 Runs:				
CHEMAINUS	465	790	706	1200
BONSALL CREEK (Inflows at upper boundaries only.)	15.4	26.2	22.1	37.6

NOTE: No allowances for storage effects in upper Bonsall included.

TABLE 5

RESULTS FROM MODEL CALIBRATION

SECTION NUMBER	1986 OBSERVED	WL,METERS COMPUTED	ABSOLUTE SITE ERROR
1	3.05	3.14	0.09
2	3.23	3.57	0.34
3	3.91	4.18	0.27
4	4.50	4.55	0.05
5	5.29	4.99	0.30
6	----	5.09	----
7	5.36	5.11	0.25
8	5.64	5.40	0.24
11	5.70	5.81	0.11
12	5.97	6.21	0.24
13	6.55	6.20	0.35
14	5.76	6.52	0.76
15	6.79	6.90	0.11
16	7.25	7.06	0.19
17	8.60	8.29	0.31
18	9.14	8.96	0.18
19	10.53	10.24	0.29
20	10.31	10.65	0.34
22	10.79	10.74	0.05
24	10.30	11.03	0.73
25	11.10	11.49	0.39
26	12.24	12.05	0.19
27	12.80	12.90	0.10
28	13.90	13.68	0.22

MEAN ABSOLUTE SITE ERROR: 0.27

TABLE 6

DISTRIBUTION OF FLOWS FOR 200-YEAR INSTANTANEOUS FLOOD

XS	BONSALL (m^3/s)	XS	SLOUGH (m^3/s)	OVER-FLOWS (m^3/s)	CHEMAINUS (m^3/s)	XS
	INFLOW 38				INFLOW 1200	
					1200	28
					1200	27
					1200	26
					1200	25
					1200	24
				394	806	22
					806	20
					806	19
				28	778	18
					778	17
					778	16
					778	15
					778	14
					778	13
22	459				778	12
21	459			184	594	11
20	459			19	575	8
19	459				575	7
18	459				575	6
8	643			10	564	5
7	643			76	489	4
6	643	14	175	70	419	3
5	643	13	175	31	388	2
4	643	11	259	53	335	1
3	643					
2	643				594	0.5
1	643				594	0

TOTAL DISCHARGE: 1238 m^3/s

TABLE 7

DISTRIBUTION OF FLOWS FOR 20-YEAR INSTANTANEOUS FLOOD

XS	BONSALL (m^3/s)	XS	SLOUGH (m^3/s)	OVER-FLOWS (m^3/s)	CHEMAINUS (m^3/s)	XS
	INFLOW 26				INFLOW 790	
					790	28
					790	27
					790	26
					790	25
					790	24
				187	603	22
					603	20
					603	19
				0	603	18
					603	17
					603	16
					603	15
					603	14
					603	13
22	213				603	12
21	213			100	504	11
20	213			3	501	8
19	213				501	7
18	213				501	6
8	313			8	493	5
7	313			58	435	4
6	313	14	119	51	384	3
5	313	13	119	20	364	2
4	313	11	173	34	330	1
3	313					
2	313				504	0.5
1	313				504	0

TOTAL DISCHARGE: 816 m^3/s

TABLE 8

DISTRIBUTION OF FLOWS FOR 200-YEAR DAILY FLOOD

XS	BONSALL (m^3/s)	XS	SLOUGH (m^3/s)	OVER-FLOWS (m^3/s)	CHEMAINUS (m^3/s)	XS
	INFLOW 22				INFLOW 706	
					706	28
					706	27
					706	26
					706	25
					706	24
				141	565	22
					565	20
					565	19
				0	565	18
					565	17
					565	16
					565	15
					565	14
					565	13
22	163				565	12
21	163			82	483	11
20	163			1	482	8
19	163				482	7
18	163				482	6
8	245			7	475	5
7	245			53	421	4
6	245	14	108	46	375	3
5	245	13	108	17	358	2
4	245	11	156	30	328	1
3	245				483	0.5
2	245				483	0
1	245					

TOTAL DISCHARGE: 728 m^3/s

TABLE 9

DISTRIBUTION OF FLOWS FOR 20-YEAR DAILY FLOOD

XS	BONSALL (m^3/s)	XS	SLOUGH (m^3/s)	OVER-FLOWS (m^3/s)	CHEMAINUS (m^3/s)	XS
	INFLOW 15				INFLOW 465	
					465	28
					465	27
					465	26
					465	25
					465	24
				18	447	22
					447	20
					447	19
				0	447	18
					447	17
					447	16
					447	15
					447	14
					447	13
22	33				447	12
21	33			32	416	11
20	33			0	416	8
19	33				416	7
18	33				416	6
8	65			5	410	5
7	65			39	371	4
6	65	14	76	31	340	3
5	65	13	76	9	331	2
4	65	11	102	17	314	1
3	65					
2	65				416	0.5
1	65				416	0

TOTAL DISCHARGE: 480 m^3/s

TABLE 10

RESULTS FROM SENSITIVITY ANALYSES

MEAN ABSOLUTE PROFILE DIFFERENCE (m)

REACH	ROUGHNESS COEFFICIENT			DISCHARGE		
	-10%	+10%	+20%	-10%	+10%	+20%
CHEMAINUS RIVER						
0-1	0.05	0.03	0.05	0.04	0.04	0.07
1-5	0.01	0.01	0.03	0.02	0.03	0.05
5-11	0.00	0.01	0.01	0.05	0.04	0.07
11-13	0.04	0.04	0.08	0.07	0.06	0.11
13-15	0.06	0.06	0.10	0.14	0.13	0.25
15-16	0.05	0.05	0.08	0.13	0.13	0.24
16-19	0.09	0.06	0.10	0.12	0.11	0.21
19-24	0.15	0.12	0.23	0.09	0.09	0.18
24-28	0.13	0.10	0.20	0.13	0.12	0.25
MEAN REACH DIFFERENCE	0.06	0.05	0.10	0.09	0.08	0.16
CHEMAINUS SLOUGH						
0-11	0.12	0.10	0.10	0.05	0.03	0.07
11-14	0.09	0.09	0.18	0.06	0.05	0.09
MEAN REACH DIFFERENCE	0.10	0.09	0.14	0.05	0.04	0.08
BONSALL CREEK						
1-3	0.09	0.09	0.19	0.06	0.06	0.10
3-6	0.06	0.06	0.12	0.12	0.11	0.22
6-8	0.05	0.03	0.07	0.11	0.09	0.17
8-20	0.04	0.05	0.10	0.10	0.10	0.19
20-22	0.08	0.08	0.14	0.13	0.13	0.25
MEAN REACH DIFFERENCE	0.06	0.06	0.12	0.10	0.10	0.19

NOTE: The 200-year instantaneous profile is assumed to be the base profile.

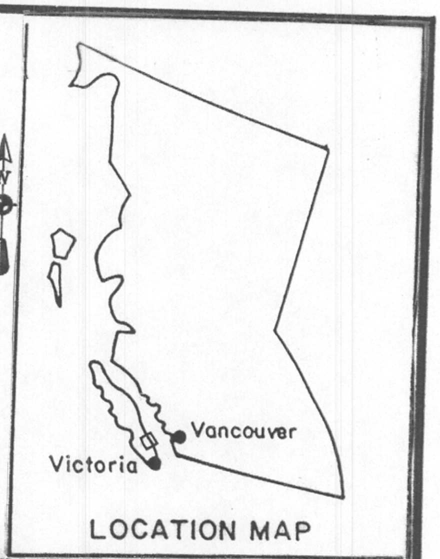
TABLE 11

FLOOD LEVELS INCLUDING FREEBOARD

SECTION NUMBER	FLOOD LEVEL (m)
CHEMAINUS RIVER	
1	3.9
2	4.3
3	4.9
4	5.3
5	5.7
6	5.8
7	5.9
8	6.2
11	6.8
12	7.1
13	7.0
14	7.9
15	8.4
16	8.3
17	9.6
18	10.2
19	11.2
20	11.6
22	11.7
24	12.6
25	12.8
26	13.4
27	14.1
28	15.5

SECTION NUMBER	FLOOD LEVEL (m)
CHEMAINUS SLOUGH	
11	3.8
12	3.8
12.1	3.8
12.2	3.8
12.3	3.8
12.4	3.8
13	3.8
14	3.9
BONSALL CREEK	
1	3.9
2	3.9
3	3.9
3.5	3.9
4	4.5
5	4.7
6	5.1
7	5.4
8	5.4
18	5.8
19	5.9
20	6.1
21	6.4
22	6.8

FIGURES



Chemainus River Floodplain Study

Vicinity

Map

northwest hydraulic consultants

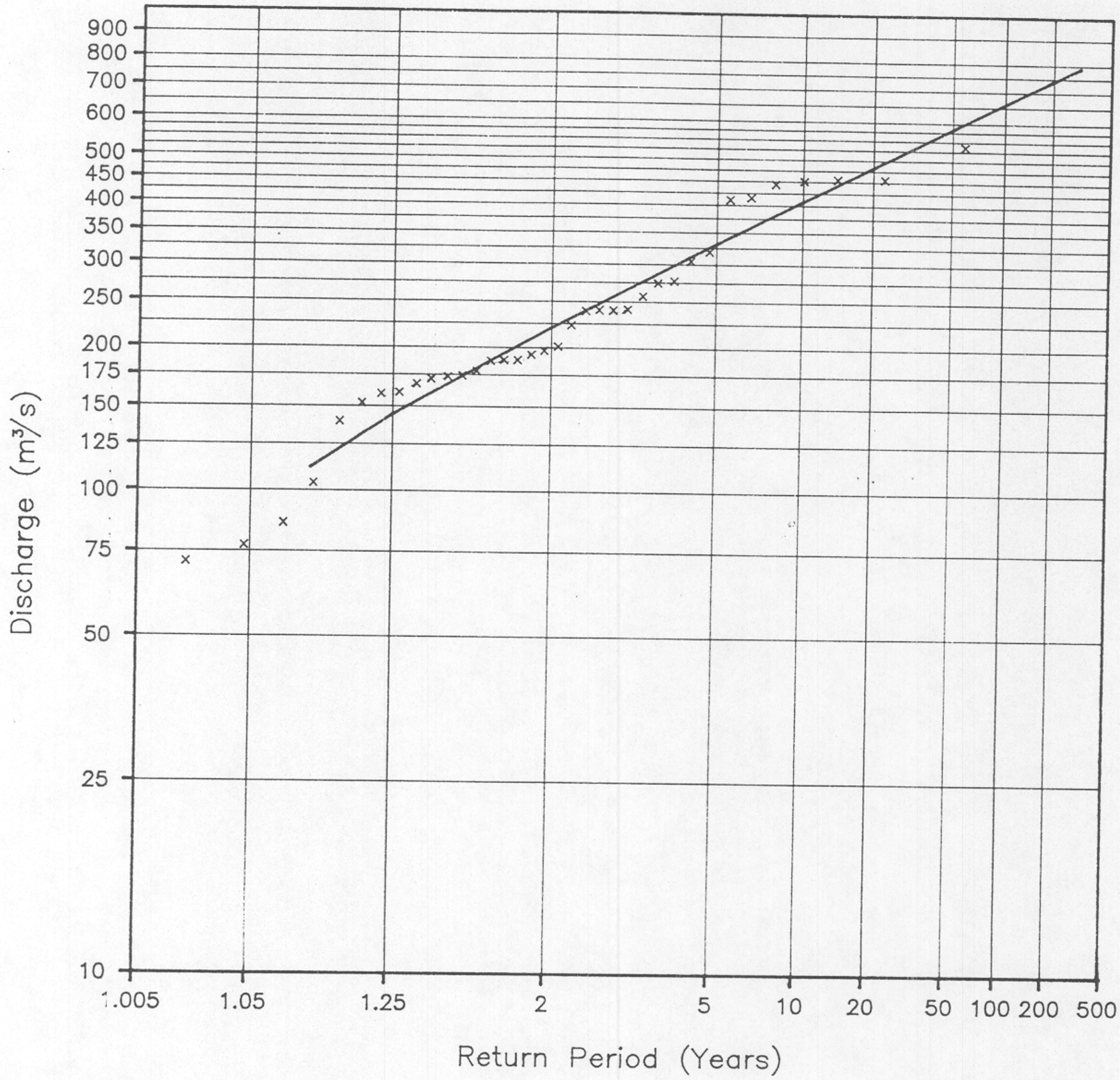
NHCV1615–007

Figure 1

Figure 2

Oblique Airphoto taken December 17th, 1973
showing overbank flooding at Chemainus mouth.

Figure 3



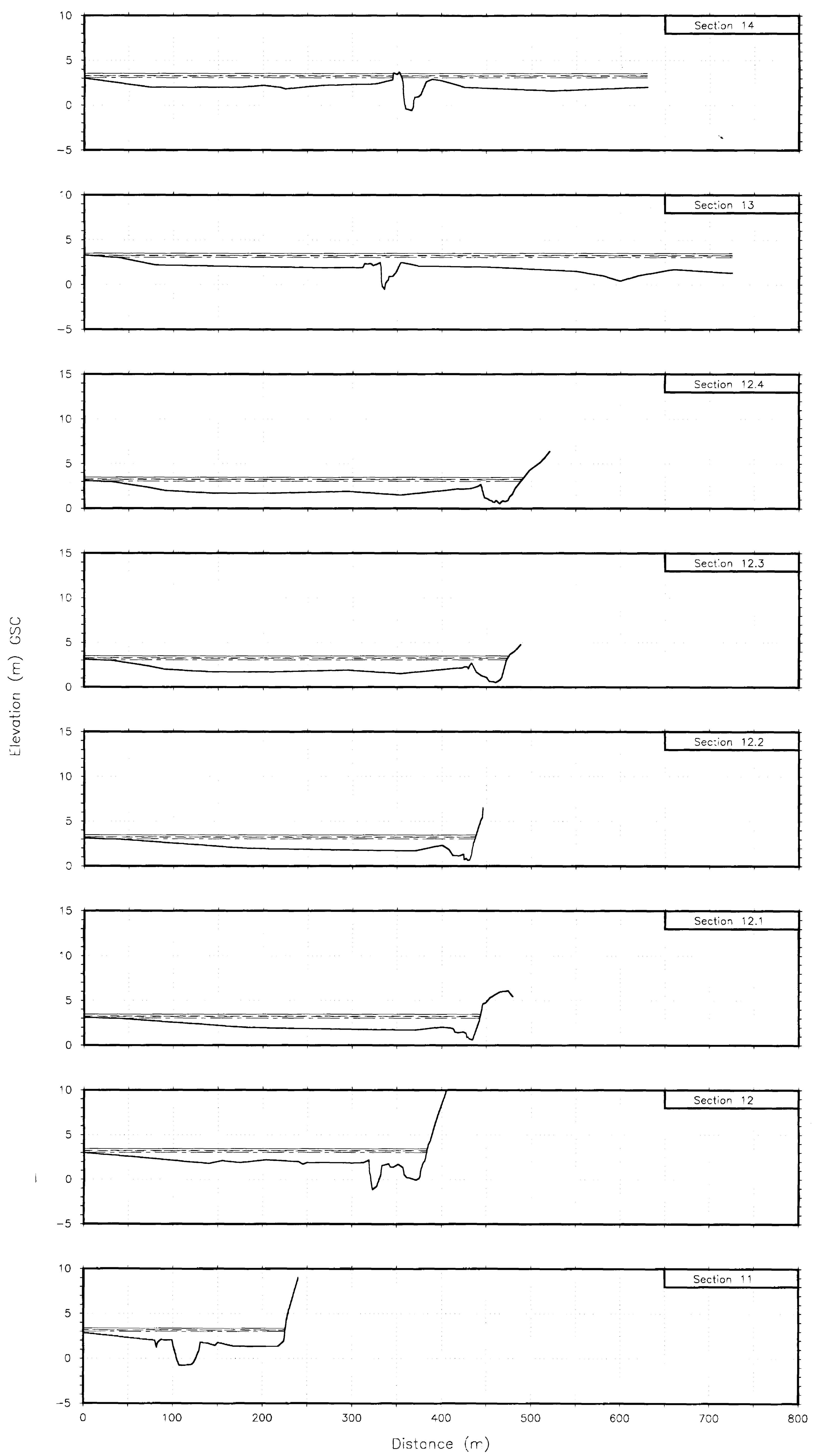
Note:
1. Chemainus River near Westholme 08HA001.
2. Period of Record 1915–17; 1953–88.
3. Flows are annual maximum daily discharges.

Chemainus River Floodplain Study

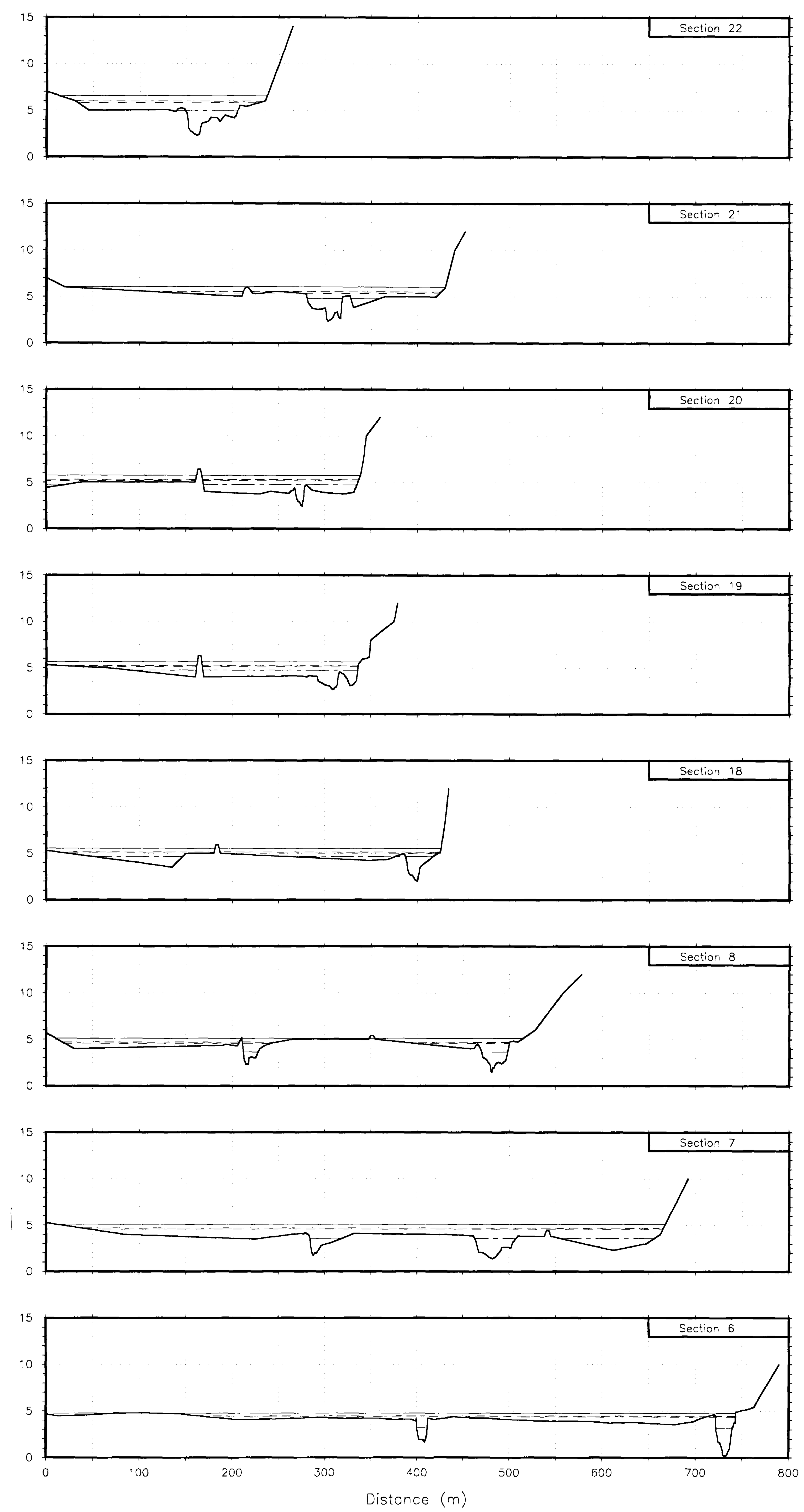
Chemainus River
Flood Frequency Analysis

northwest hydraulic consultants

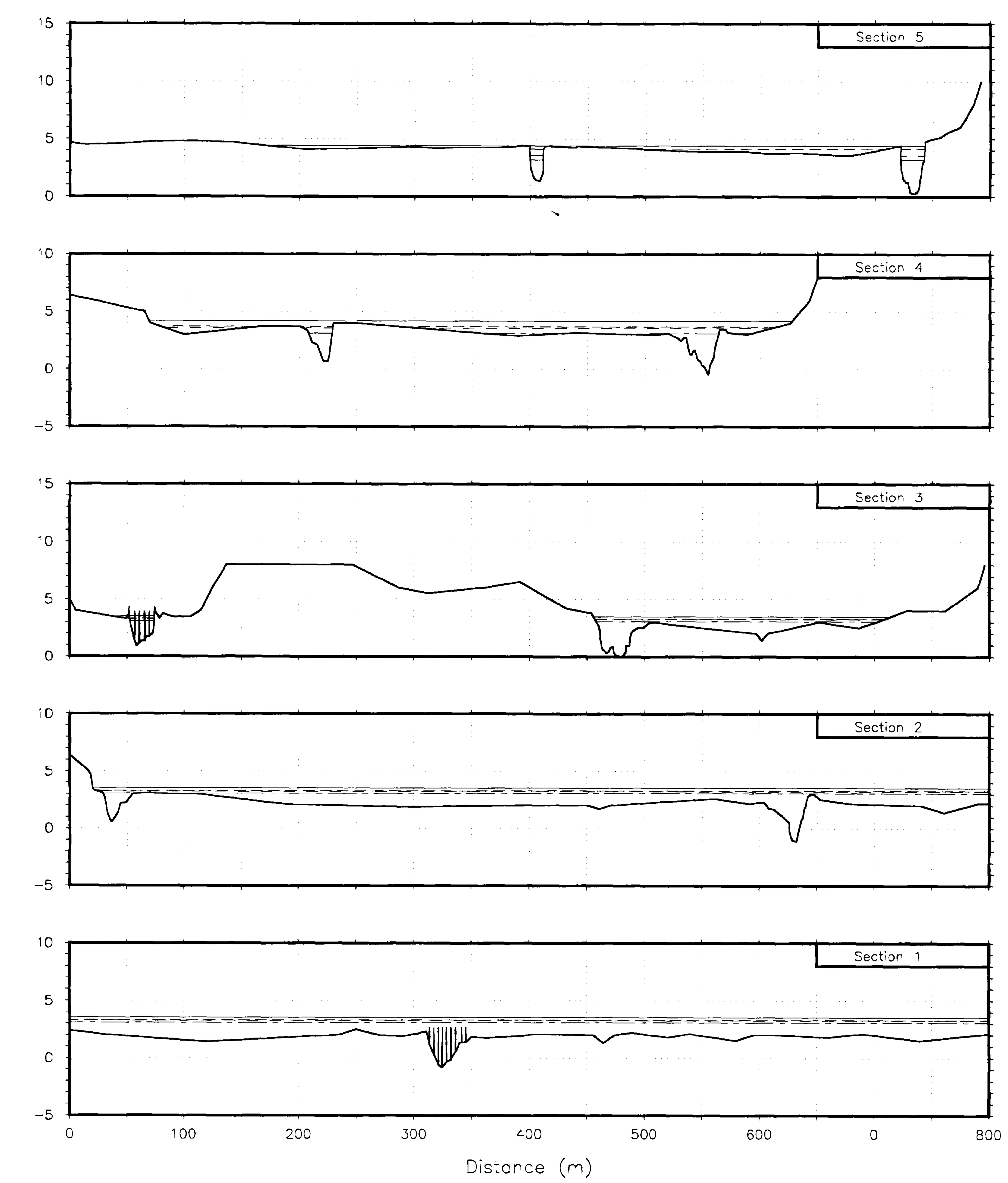
NHCV1615-008



Chemainus Slough



Bonsall Creek



Bonsall Creek

Notes:

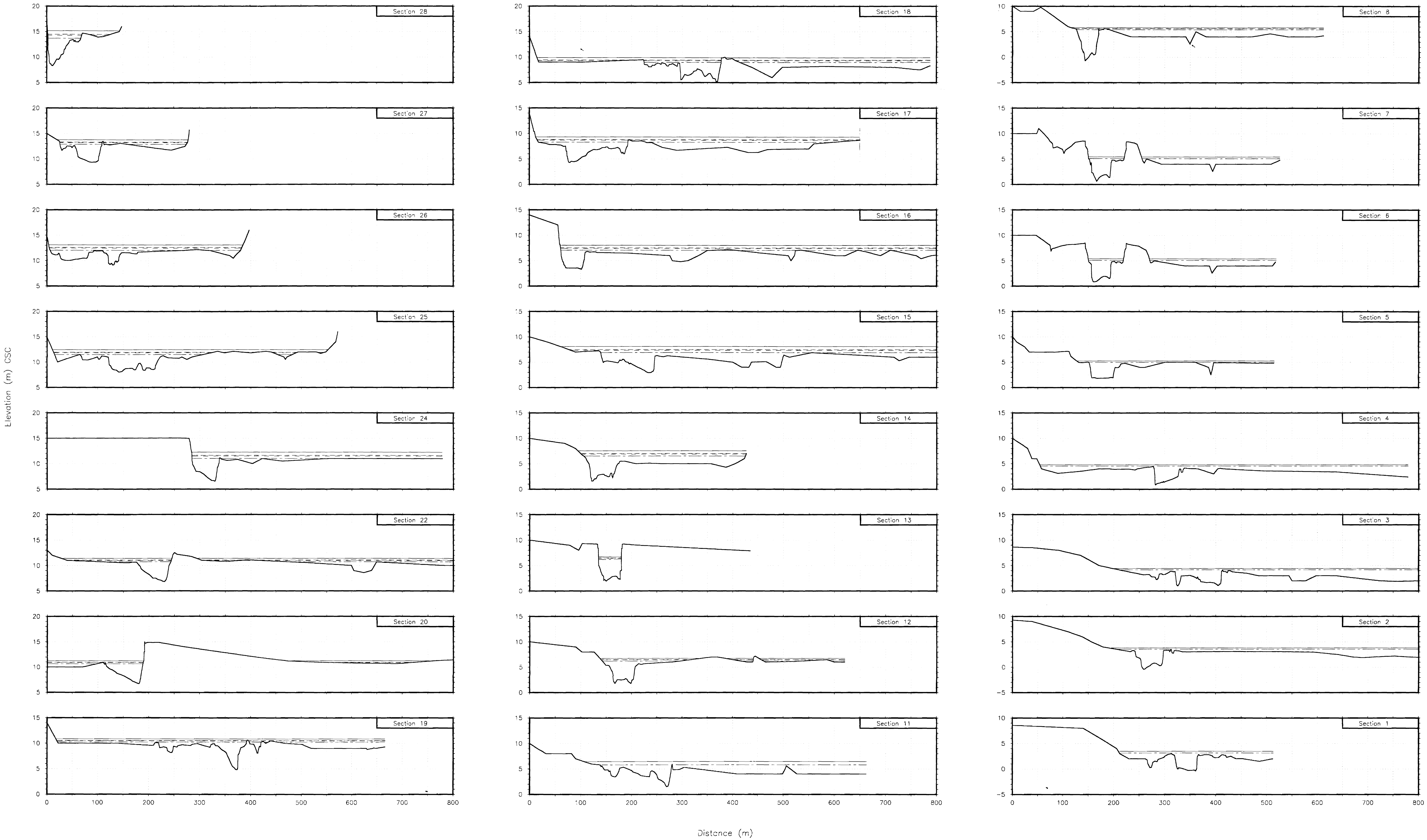
(1) All sections are viewed downstream.
(2) All flows include Chemainus River overflows, estimated by HEC2 numerical model.
(3) Water surface elevations are omitted for the two intermediate flows when the Q_{20D} and Q_{200I} elevations nearly coincide.

Legend:

———————— Q_{200I}
- - - - - - - - Q_{20I}
— — — — — Q_{200D}
——— - ——— Q_{20D}

For definition of discharges refer to Table 4.

Chemainus River Floodplain Study	
Chemainus Slough & Bonsall Cr. Sections 14–11 & Sections 22–1	
DATE	SHEET 2 OF 2
DWN	NHCV 1615-005
northwest hydraulic consultants ltd.	



Notes:

(1) All sections are viewed downstream.
(2) All flows refer to the Chemainus River above WSC gauge 08HA001.
(3) Water surface elevations are omitted for the two intermediate flows when the Q_{20D} and Q_{200I} elevations nearly coincide.

Legend:

———— Q_{200I}
– – – – – Q_{20I}
— — — — Q_{200D}
—·—·— Q_{20D}

For definition of discharges refer to Table 4.

Chemainus River Floodplain Study

Chemainus River
Cross-sections 28–1

DATE	SHEET 1 OF 2
DWN	NHCV 1615-001

northwest hydraulic consultants ltd.

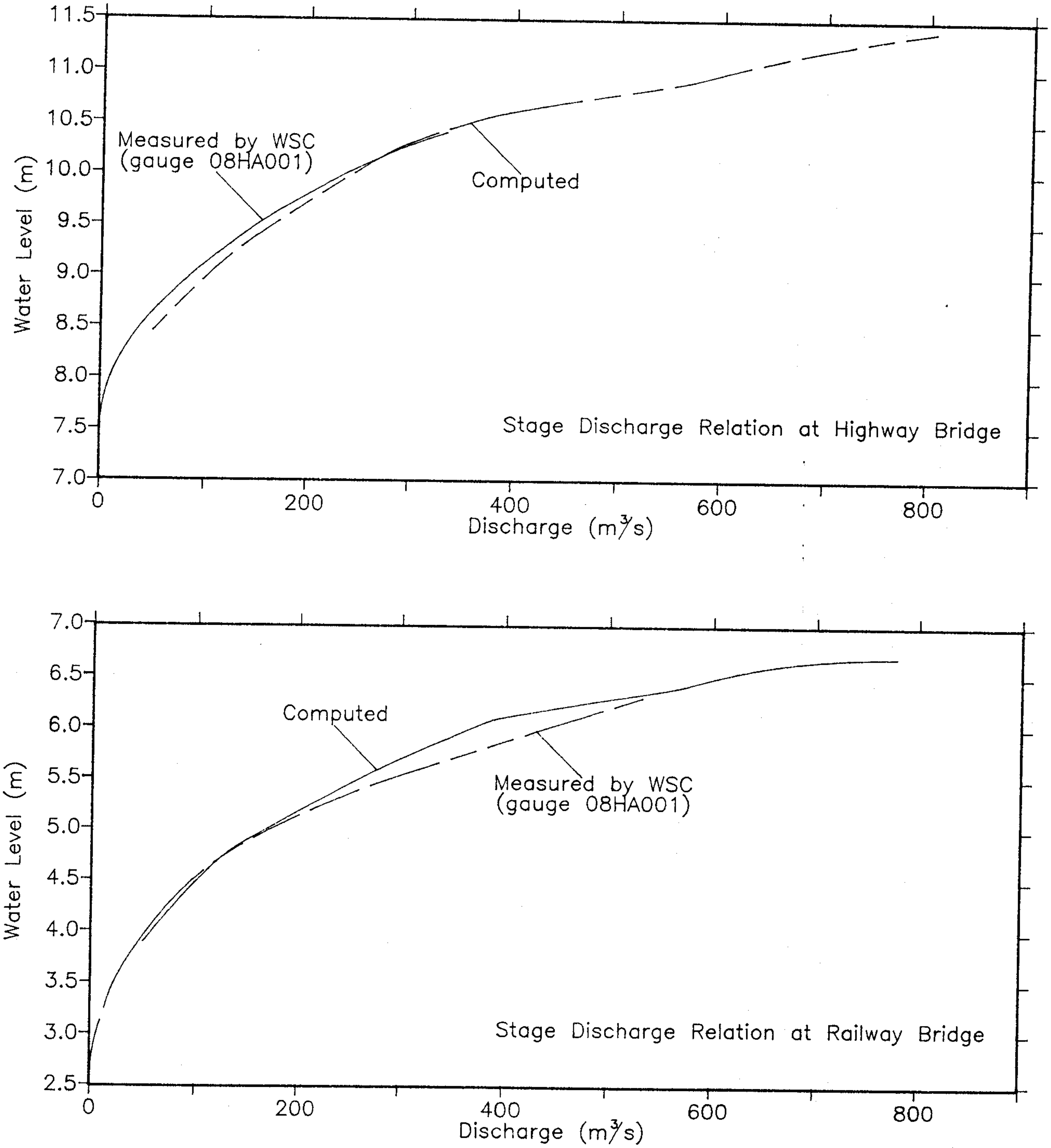


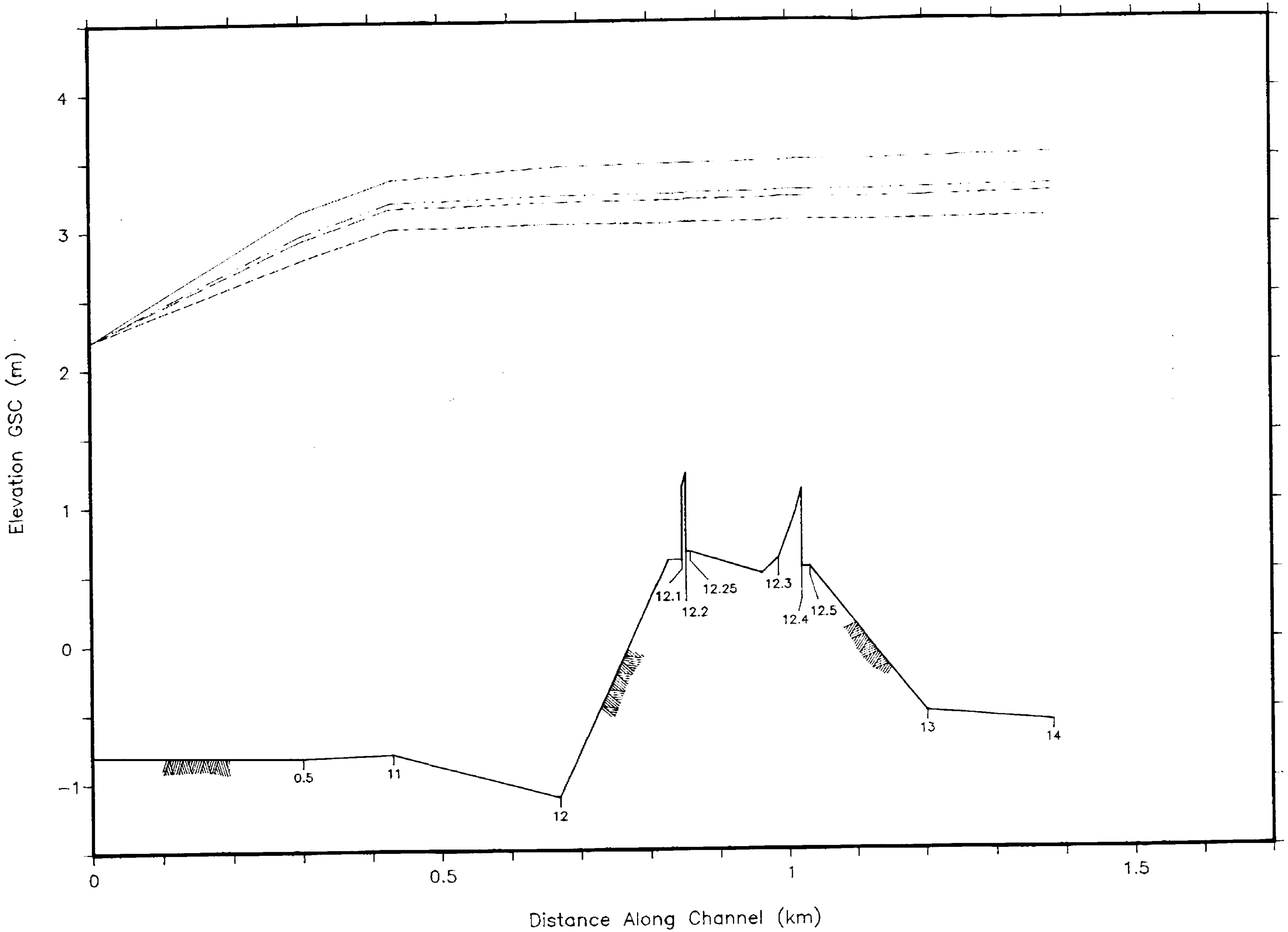
Figure 6

Chemainus River Floodplain Study

Verification of Computed Water Levels

northwest hydraulic consultants

NHCV1615-004



Notes

1. The water surface profiles were computed using a standard step backwater model assuming open flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross section locations are shown on Drawing 87−18−1,2

Notes

200-Year Instantaneous Flood.

200-Year Daily Flood.

20-year Instantaneous Flood.

20-Year Daily Flood.

Thalweg

Bridge

For discharge definitions, refer to Table 4.

Figure 8

Chemainus River Floodplain Study

Flood Profiles
Chemainus Slough

northwest hydraulic consultants

NHCV1615−012

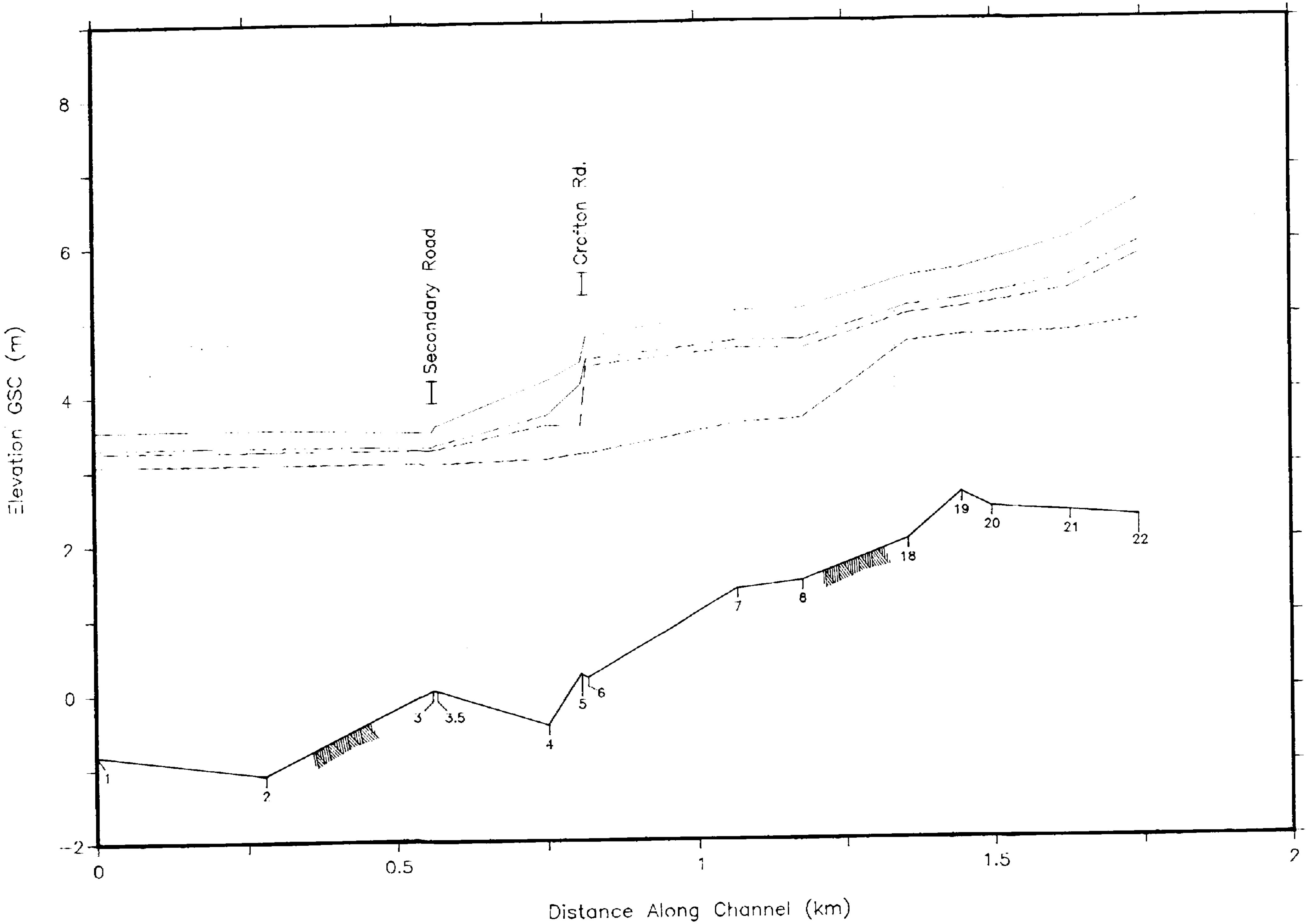


Figure 9

Notes

1. The water surface profiles were computed using a standard step backwater model assuming open flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross section locations are shown on Drawing 87-18-1,2

Notes

- 200-Year Instantaneous Flood.
- 200-Year Daily Flood.
- 20-year Instantaneous Flood.
- 20-Year Daily Flood.
- Thalweg
- Bridge

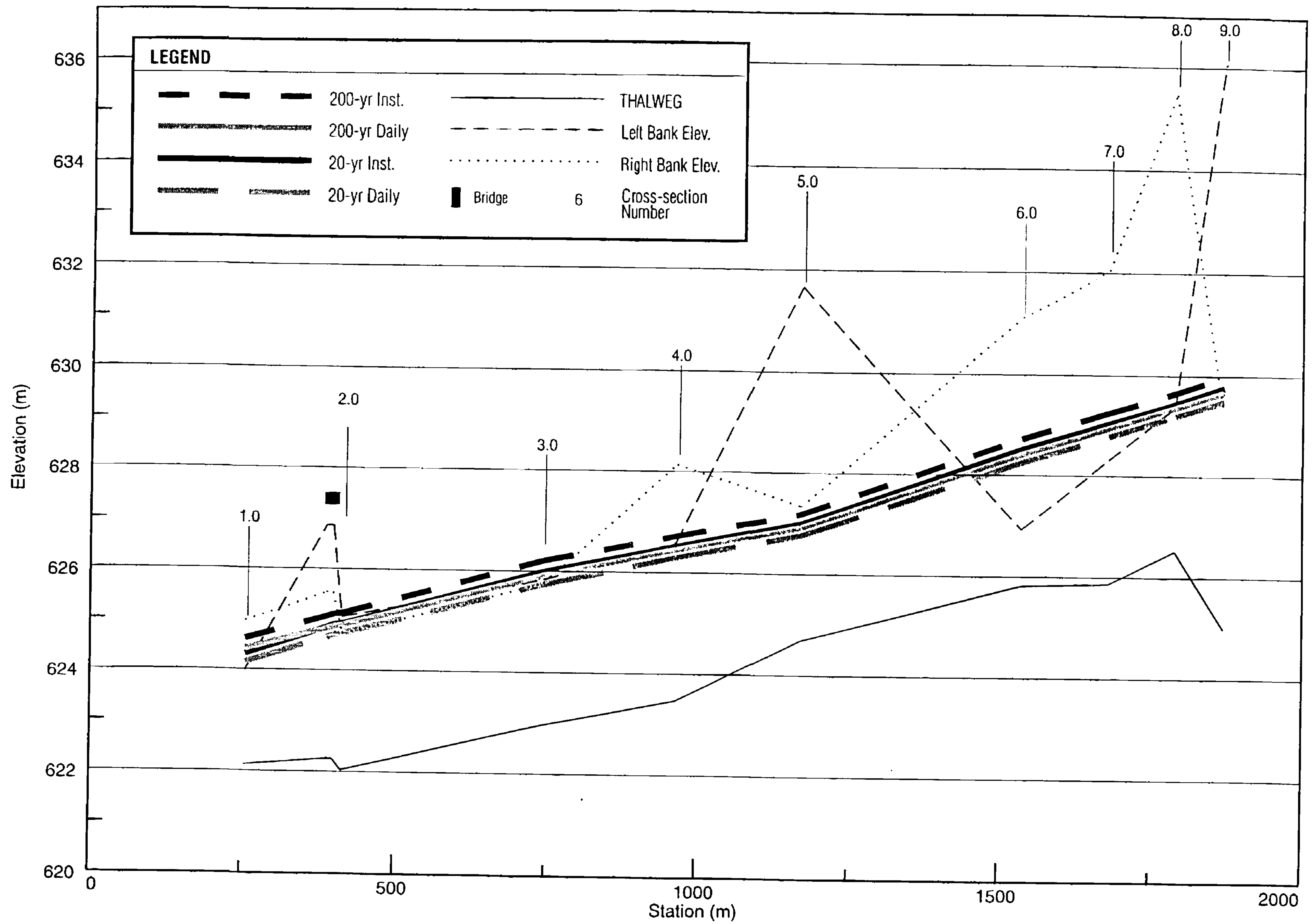
For discharge definitions, refer to Table 4.

Chemainus River Floodplain Study

Flood Profiles
Bonsall Creek

northwest hydraulic consultants

NHCV1615-011



NOTE:

1. The water surface profiles were computed assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross-section locations shown on drawing 93-13-7 and 93-13-8.

Fig. 4-9

BC Environment
Floodplain Mapping Program - Kettle River and Tributaries
West Kettle River - Computed Flood Profiles

ACRES

APPENDIX 'A'

Photo 1

HIGH WATER MARK FROM JANUARY, 1990
NEAR SECTION 27, RIGHT BANK
(JAN. 90)

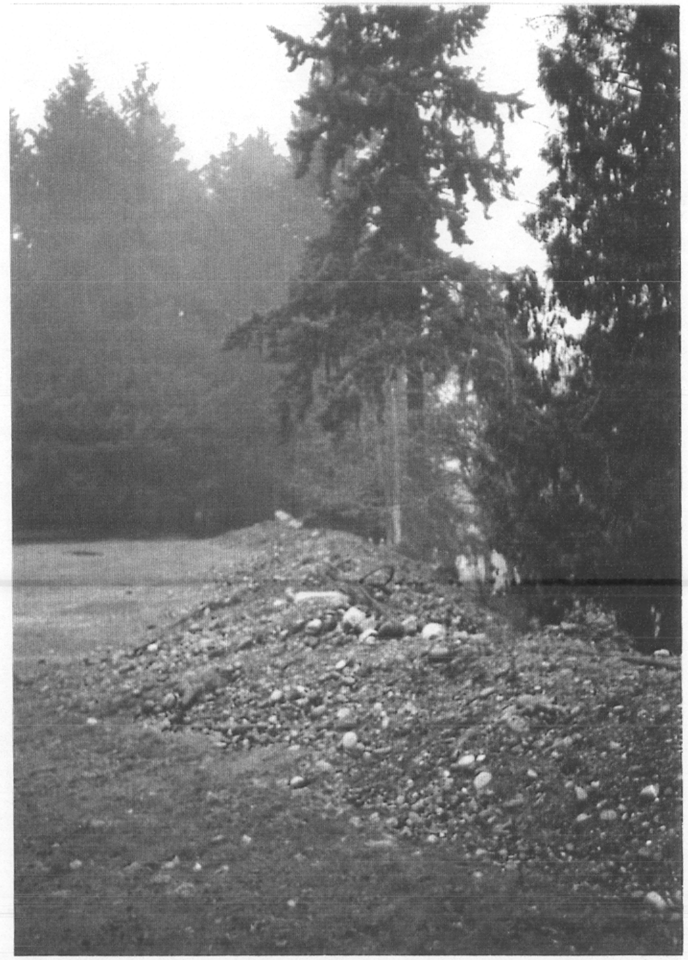


Photo 2

FARMER HOLMAN'S DYKE

NEAR SECTION 27, RIGHT BANK
(JAN. 90)

Photo 3

SIDE CHANNEL NEAR SECTION 26, RIGHT BANK
(JAN. 90)

Photo 4

GRASS CHANNEL LEADING FROM CHEMAINUS
TO WHITEHOUSE CREEK, NEAR HIGHWAY BRIDGE
(JAN. 90)

Photo 5

FIELD NEAR INTERSECTION OF
CHEMAINUS AND CROFTON ROADS SHOWING
SIGNS OF OVERFLOW (AUG. 86)

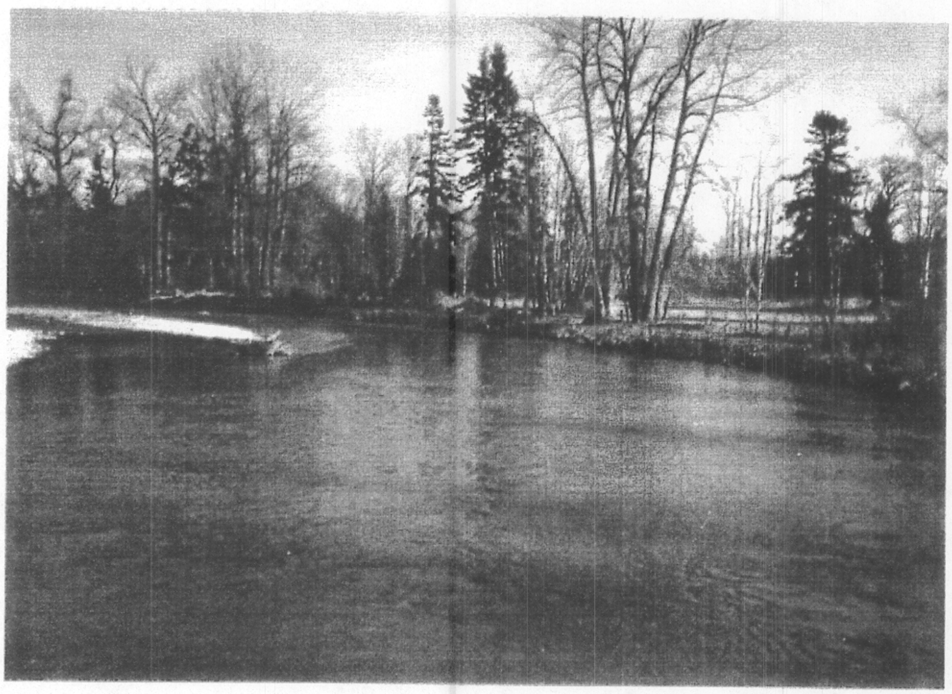


Photo 6

LOOKING DOWNSTREAM FROM RAILWAY BRIDGE
AT AREA OF RIGHT BANK OVERFLOW (AUG. 86)