Floodplain Mapping Study
Slocan River, British Columbia
Design Brief

Prepared for:

Water Management Branch
Ministry of Environment
Province of British Columbia

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1.0 INTRODUCTION

1.1 Purpose of Study

The British Columbia Ministry of Environment (MOE) is undertaking floodplain mapping under a joint federal/provincial agreement covering various watercourses in the province, including the Slocan River. The purpose of a floodplain mapping study as defined by the Ministry is to determine the 200-year floodplain. Floodplain maps will display the limits of the 200-year flood boundaries and the flood elevations (freeboard included). The maps are then utilized in development and administration of local bylaws, official community plans, administration of the Land Title Act and in other aspects of floodplain management to mitigate potential damage caused by flooding (Reference 1).

1.2 Authority and Acknowledgements

The hydraulic analyses for this study, including preparation of the 200 year floodplain maps, were prepared by Northwest Hydraulic Consultants Ltd (NHC) for the Ministry of Environment. The work was authorized by an agreement dated August 3, 1988. The study was completed on February 28th, 1989.

The floodplain mapping study was conducted by Doreen Gavin, project engineer under the direction of David McLean, project manager. Monica Mannerström assisted with the hydraulic analyses, and Dr. D.G. Mutter provided technical advice throughout the study.

The guidance and suggestions offered by the contract manager, P.J. Woods, Water Management Branch, Ministry of Environment and by R.W. Nichols, also of the Water Management Branch are greatly appreciated. Assistance in the field was provided by D. Boyer, regional MOE engineer in Nelson. The efforts and assistance of these gentlemen made the project a pleasurable undertaking.

2.0 GENERAL DESCRIPTION OF STUDY AREA

2.1 Scope of Study

This floodplain mapping study consisted of a detailed hydraulic and hydrologic analysis of 58 kilometres along the Slocan River and 4 kilometres along the Little Slocan River. The Slocan River drainage basin is located in the Selkirk Mountains and has an area of 3290 square kilometres. The river generally flows southward from Slocan Lake to its confluence with the Kootenay River near Shoreacres. Two primary tributaries are the Little Slocan River, which has a drainage area of 833 square kilometres and Lemon Creek, with a drainage area of 205 kilometres. The study area is shown on the Vicinity Map (Figure 1).

2.2 Principal Flood Problems

High flows on the Slocan River occur in late spring or early summer as a result of snowmelt. The maximum recorded flows have occurred between mid May and early July. The three highest flows recorded at the gauging station near Crescent Valley (Water Survey of Canada Station 08NJ013) since 1925 have been 708, 719, and 708 m^3/s. These floods occurred in 1948, 1961, and 1974, respectively. The 1974 flood was documented by aerial photography (Reference 2). Examination of the photographs showed the Slocan River level overtopped its natural river banks at several locations. A few of the sites are located approximately 11, 13 and 20 kilometres from the mouth of the Slocan River. Three major stretches along the river also experienced flooding in 1974 with flow across the floodplain: Vallican Bridge to Meadow Lark Dairy (25-32 km); Winlaw to Perrys (35-49 km); Lemon Creek to a logging bridge near Gwillim Creek (52-56 km).

Slocan River flood problems in the vicinity of Lemon Creek appear to be aggravated by sediment deposition from Lemon Creek. This deposition has caused Slocan River to develop a laterally unstable channel that is subject to channel shifting and bank erosion. The unique problems associated with the Lemon Creek alluvial fan have been well documented in studies performed by, or on behalf of the Ministry of Environment, Water

Management Branch (References 3 and 4).

2.3 Field Investigations

Project staff visited the project area. During the field investigation, river reach characteristics were evaluated and special areas of concern such as tributary alluvial fans, bank erosion and debris were noted. In addition, preliminary floodplain limits were appraised for their reasonableness. After completion of the floodplain mapping, project staff returned to the site to spot check specific locations and reaches.

3.0 DISCUSSION OF DATA SOURCES

3.1 Hydrologic Information

The hydrologic analyses for the Slocan River floodplain study was performed by the Ministry of Environment, Water Management Branch. Their work is summarized in a memorandum from R.Y. McNeil to R.W. Nichols, dated March 6, 1986 and reproduced in Appendix A. The hydrologic data supporting this memorandum are listed in Table 1.

3.2 Hydraulic Information

Table 2 lists the hydraulic data sources that were used in the floodplain mapping studies. Channel cross sections of the Slocan River and Little Slocan River were surveyed by the Ministry of Environment in 1980, 1981 and 1986. No additional surveys were necessary for this study because the existing coverage is generally excellent for a floodplain mapping study. Floodplain topography was obtained from 1:5000 scale, 1 m contour interval maps (Sheets 88-26-1 through 88-26-11) provided by MOE. Additional supplementary data including high water mark information and site photographs were also provided. Canadian Pacific Railway provided railroad profiles along the Slocan River. Information on Kootenay River water levels was furnished by BC Hydro and West Kootenay Power.

4.0 HYDROLOGIC ANALYSES

4.1 General

Hydrologic analyses were performed by B.C. Ministry of Environment (MOE) in 1986 to determine flood-frequency relationships for the Slocan River and the Little Slocan River. These are described in an internal report of March 1986 (See Appendix A). Specifically, daily and instantaneous flood discharges with return periods of 20 and 200 years were determined. As part of the present analysis, the 1986 MOE flood-frequency study was reviewed by Northwest Hydraulic Consultants (NHC), as summarized in 4.2 below. In addition, 20 year and 200 year flood discharges were estimated for the Little Slocan River, and "calibration" flood discharges corresponding to observed high water marks were estimated for several locations along the Slocan River. The methodology used by NHC in these additional studies is discussed in 4.3 and 4.4 below.

4.2 Slocan River Frequency Analysis

Flood frequencies on the Slocan River at Crescent Valley, near the mouth, were derived by MOE on the basis of a statistical analysis of data for WSC gauge 08NJ013 (Slocan River near Crescent Valley). A 62-year record of maximum daily discharges (1914, 1925-85) and a 51-year record of corresponding instantaneous maxima (1933, 1935-85) were analyzed by the frequency analysis program FREQAN. A similar analysis was conducted for the Slocan River at Slocan City (WSC gauge 08NJ014) using maximum daily discharges for the 31-year period of record (1916-22, 1945-68); instantaneous maxima are not available for this gauge. Frequency curves were derived for the Slocan River at Crescent Valley using three different probability distributions (log-normal, Gumbel and log-Pearson III), for both daily and instantaneous flows. The flows for selected return periods used in the present floodplain study represent the average of results obtained from the three distributions. Values for the Slocan River at Slocan City were derived similarly, in this case as the average of results from four distributions. Table 3 summarizes these computed results.

Flood frequency values were also derived for five locations along the main stem of the Slocan River: at the mouth, below Little Slocan River, above Little Slocan River, below Lemon Creek and above Lemon Creek. These locations are shown on Figure 1. A form of regional flood frequency analysis was used by MOE to estimate these values, as explained below.

A 1982 publication by Inland Waters Directorate of Environment Canada, "Magnitude of Floods in B.C. and the Yukon Territory" (Reference 5), proposed a relationship between unit runoff "q" and drainage area "A" for catchments in similar hydrologic regimes. The proposed relation was of the form $q = nA^{-0.24}$. This relationship was applied to gauge 08NJ013 at Crescent Valley and the corresponding values for n were calculated. The same equation with the calculated n values was then used to derive flows at the required return periods for the Slocan River at the mouth and below Little Slocan River.

It was considered by MOE that the above equation would overestimate flows on the Slocan River upstream of the Little Slocan River, because it did not account for the attenuating effect of Slocan Lake. To estimate the required flood values at the three upstream locations, certain adjustments were made on the basis of the computed flood-frequency curve at the lake outlet.

After reviewing the methods used and results obtained by MOE in the analyses summarized above, it is our opinion that although we might have conducted the analyses somewhat differently, the derived flood-frequency values are reasonable and appropriate for purposes of the present floodplain study. The derived MOE values are shown in Table 4, along with values for the Little Slocan River derived by NHC as described in 4.3 below.

4.3 Little Slocan River

No gauge data are available for the Little Slocan River. The required flood-frequency values were therefore derived from the regional relationship $q = nA^{-0.24}$. The equation was used in the same manner as described above for the lower two points on the Slocan River.

The resulting 20 and 200 year estimates are included in Table 4.

4.4 Calibration Flows

For purposes of calibrating a HEC-2 model of water surface profiles, discharge estimates were also required for specific flood events in June 1982 and June 1986, during which high water marks had been recorded along the Slocan River. Discharge estimates were derived for the Slocan River at all five locations described in Section 4.2 as well as at Winlaw, at Appledale, and at the logging bridge downstream of Slocan City (Figure 1). The procedure used is described below.

After reviewing the available hydrologic data it was concluded that the simple regional relation described in Sections 4.2 and 4.3 was not the most appropriate method for estimating the calibration flows along the river. Instead, a modified equation was used that applied the regional relationship to the drainage area below Slocan Lake and added a baseflow component to represent outflow from Slocan Lake during the downstream peak discharge. The modified equation has the form:

$$Q = n\,(A - A_{SL})^{0.76} + B$$

where;

- B represents the estimated lake outflow based on known lake levels,
- A is the drainage area on the mainstem Slocan River
- A_{SL} is the drainage area at the outlet of Slocan Lake (1660 km^2).

The lake outflow discharges were estimated by applying WSC's previously derived lake stage-outflow relation to the recorded lake levels during the floods.

The hydrometric records show that Slocan Lake has historically reached its peak elevation anywhere from 1 to 26 days after the discharge peak at Crescent Valley near the mouth of the Slocan River. For peak flows over 500 m^3/s, the average lag in lake level peak is 2.7 days. In order to calculate the base outflow (B) from Slocan Lake, it was assumed that at the time of the downstream peak in the Slocan River, the lake level was 0.1 m below its peak elevation. Table 5 shows the values for n and B used to derive the instantaneous peak discharges for the flow stage which crested at Crescent Valley on June 20, 1982 and June 1, 1986, and to derive the daily discharge on June 5, 1986. The computed calibration flows corresponding to the observed 1982 and 1986 water levels are given in Table 6.

5.0 HYDRAULIC ANALYSES

5.1 General

The hydraulic characteristics of the Slocan River and the Little Slocan River were analyzed in order to provide estimates of flood elevations for the 20 and 200 year daily and peak events. Water surface elevations were computed using a step backwater computer program and flood profiles were prepared. Standard hydraulic analyses were employed, including computer model development, model calibration to historical data, and studies to assess the model's sensitivity to variations in discharge and channel roughness.

5.2 Model Development

The 1985 microcomputer version of the HEC-2 computer program (Reference 6) was used to compute the water surface profiles. The data required for the computations include: river channel and floodplain geometry, downstream starting water elevations, roughness coefficients, and descriptions of hydraulic structures.

The river channel and floodplain geometry is described by cross-sections taken normal to the flow path and by reach lengths measured between sections. The Ministry of Environment, Water Management Branch surveyed 115 channel sections and 10 bridges on the Slocan River and 10 channel sections on the Little Slocan River. Northwest Hydraulic Consultants extended the channel sections across and beyond the floodplain using 1:5000 scale 1 m contour interval topographic mapping furnished by MOE. Pen plots of each extended channel/floodplain section were prepared, corrected as necessary, and furnished under separate cover. The reach lengths between sections were obtained from the topographic maps.

The starting water surface elevations for the Little Slocan River were assumed to be the elevations on the mainstem for the same return period floods. Similarly, the starting water surface elevation for the Slocan River backwater model should be the coincident elevation on the Kootenay River. The Kootenay River system is regulated by several dams. Brilliant Dam is located downstream of the Slocan/Kootenay confluence and upstream is situated South Slocan Dam. West Kootenay Power and BC Hydro operate generation facilities along the Kootenay River system. Both parties were contacted and information regarding the stage - frequency relationship for the Kootenay River was requested.

The 200 year flood elevation along the Kootenay River has been estimated approximately as part of earlier studies related to hydroelectric developments on the Kootenay and Columbia Rivers (References 7 and 8). A flood construction limit has also been specified by the Regional District of Central Kootenay for the Kootenay River upstream of Brilliant Dam. Based on these results, the 200 year flood stage on the Kootenay River at the Slocan River confluence was estimated to be approximately El. 452.6 m. However, this value was used solely as a starting condition for the Slocan River backwater calculations and was not used directly in any mapping of the floodplain limits.

A frequency analysis establishing the 20 year flood elevation for the Kootenay River was not available. Therefore, the water level for the Slocan River during a 20 year event was based upon normal depth computations. The sensitivity of computed water surface elevations to variations in downstream starting conditions was evaluated. This analysis confirmed that the influence of the assumed starting condition extends only a very short distance up the Slocan River.

Additional sensitivity analyses to assess effects of variations in roughness and flood discharge are discussed further in Section 5.4.

Channel and floodplain roughness values (as represented by Manning's "n") are used in the hydraulic computations. Initial values were selected by engineering judgment based upon field inspection and photo documentation, and by reference to recognized publications (References 9 and 10). The channel "n" values ranged from 0.032 to 0.045 and the overbank "n" values varied from 0.06 to 0.12.

5.3 Model Calibration

Calibration is an important phase of the initial model development. The loss coefficients are one of the most significant input items. The calibration process starts with the best estimate of the roughness coefficients and a reasonable range for their values. The profiles are then computed for historic floods and the computed results are compared with the observed values. The loss coefficients may be adjusted during the calibration process.

Historical data on Slocan River flood levels are available for the 1974, 1982 and the 1986 flood events. Figure 2 illustrates the range in flood levels and discharges that occurred during these events at the Crescent Valley hydrometric station (WSC gauge 08NJ013).

The 1974 flood was the second highest in the period of record at Crescent Valley, and had a return period of approximately 20 - 25 years. The return periods of the 1986 and 1982 flood were approximately 8 years and 4 years respectively. The 1974 flood was documented by aerial photography. Although high water marks were not obtained, the photographs are valuable because they show the extent of flooding on the floodplain. High water marks were obtained to represent the 1982 and the 1986 peak flood levels. Also, water levels were surveyed on June 5, 1986. A total of 32 water level measurements at 15 different locations were used during model calibration. The average density of high water data is one observation per 4 kilometres. The general location of the 1982 and 1986 flood data is shown in Table 7. No calibration data were available for the Little Slocan River.

Water surface profiles were computed for the peak 1982 and 1986 floods flows and for the June 5, 1986 flow. The downstream starting water surface elevation was assumed to be normal depth. The roughness coefficients were adjusted slightly on a general reach basis to better match the historic data. Table 8 shows the final "n" value range and an average water surface slope for eight reaches of the mainstem and for Little Slocan River. Within these reaches the river displays roughly similar hydraulic and morphologic characteristics.

The final computed water surface profiles agree favourably with the observed high water marks for the 1982 and 1986 events. The mean absolute reach errors (average error over the stream reach) were calculated for the 1982 and 1986 high water marks and the June 5, 1986 observed water level and were found to be 0.12, 0.25 and 0.20 m, respectively. For the majority of data sites, model calibration was excellent. The average absolute site error was less than 0.18 m at 10 locations covering about 46 kilometres of the Slocan River.

The remaining five sites from the suspension foot bridge near Slocan Park to Vallican have average absolute errors ranging from 0.27 m to 0.56 m. Model calibration was complicated for this 12 kilometre river reach because the 1982 high water marks were consistently higher than 1986 data even though the discharges in the two years were very similar. Therefore, engineering judgement was required in evaluating the fit between the observed and computed water levels. The final Manning's "n" values were selected so that the computed water levels were slightly higher than the average of the 1982 and 1986 high water data.

The observed and computed water elevations for the 32 observations are shown in Table 9. The absolute average error is also shown. Water surface profiles for the calibration flows were developed and furnished under separate cover and are on file at the Ministry of Environment, Water Management Branch.

5.4 Sensitivity Studies

The sensitivity of computed water surface profiles to variations in downstream starting conditions, estimates of discharge, and roughness coefficients was evaluated. The 200 year daily discharge was assumed to be the base flood profile. The discharge, starting elevation and "n" values were adjusted in subsequent computer model runs. Each resulting profile was compared to the base condition, and the mean absolute reach profile error was computed. These computations provide a means for assessing the precision of the estimated water levels.

The starting water surface elevation was adjusted to represent three conditions at the mouth of the Slocan River:

- critical depth;
- normal depth;
- El. 452.64 m, the approximate 200 year Kootenay River flood stage.

The resulting profiles are shown in Figure 3. The profiles converge within approximately 2 kilometres of the river's mouth. The computed water surface elevations upstream of this point are therefore not affected by assumed downstream starting conditions.

The accuracy of the computed flood profile could be affected by the reliability of the Manning's "n" values. In order to evaluate the backwater model's sensitivity to changes in roughness coefficients, the channel "n" value was adjusted by a factor of 1.1, 1.2 and 0.9. The corresponding profiles were compared with the base profile. The mean absolute errors for the Slocan River were found to be 0.15 m, 0.28 m, and 0.15 m for corresponding increases of 10 percent and 20 percent and a 10 percent decrease in channel "n" values. The mean absolute errors for the Little Slocan River reach with equivalent adjustments were 0.09m, 0.17m, and 0.09m. These results show the computed flood levels are not very sensitive to the estimated roughness values. Therefore, any uncertainties associated with the model calibration will not have a significant effect on the computed flood levels.

The discharge estimates are also a potential source of error. Although an adequate record of streamflow is available at the Crescent Valley gauge (WSC 08NJ013), limited data are available at other sites along the Slocan and Little Slocan Rivers. Therefore, non-rigorous methods were required to derive the flows at several locations. The sensitivity of the computed water surface profile to variations in discharge was evaluated. For the Slocan River the discharge was increased by 10 and 20 percent and decreased by 10 per cent. When compared to the 200 year base profile, the mean absolute errors ranged from 0.18 m to 0.34 m. The sensitivity of the Little Slocan River to adjustments in discharge was similarly analyzed. In addition to the flow variations tested on the Slocan River, a 25 percent decrease in discharge was also analyzed. This additional sensitivity test was considered appropriate because there are no direct hydrometric measurements available on the Little Slocan River so there is more uncertainty associated with these flood flow estimates. Table 10 summarizes the results of the sensitivity analysis. These results also confirm that the computed flood levels are not excessively sensitive to the estimated flood discharges.

5.5 Accuracy of Computed Profiles

The results of floodplain mapping studies are used in the development and administration of floodplain management policies. The absolute accuracy of the computed profiles is thus of major interest.

The calibration comparisons and sensitivity analyses described earlier provide one means for judging the reliability of the flood profiles. The following discussion outlines another approach that can be used to assess the accuracy of the computations. The U.S. Army Corps. of Engineers, Hydrologic Engineering Center (Reference 11) has carried out a comprehensive study to evaluate the expected accuracy of flood backwater computations. These studies involved comparing a large number of computed profiles with actual field measurements. A generalized relationship was then developed between the magnitude of the profile errors and the stream hydraulic properties, Manning's roughness coefficients and the survey methods that were used to collect the basic cross section data. The expected magnitude of the profile errors (E_{mean}) was described by the expression:

$$E_{mean} = .45 * HD^{.35} * S^{.13} * (Nr + Sn)$$

where;

HD = reach mean hydraulic depth in feet;

S = reach average channel slope in feet per mile;

Nr = reliability of estimation of Manning's coefficient on a scale of 0 to 1.0 with NR = 0 when the coefficient is precisely known;

Sn = the standard survey accuracy being analyzed - the contour interval in feet divided by 10.

For the special case when Manning's coefficient is precisely known through model calibration (Nr = 0), the profile error is better defined by;

$$E_{mean} = .632 * S^{.23} * Sn^{1.8}$$

The above equations were applied to eight distinct reaches of the Slocan River and the Little Slocan River. The values of Nr were judiciously selected considering the "n" value accuracy as represented by model calibration. Although the channel sections were field surveyed, the sections were extended from topographic maps with a contour interval of 1 metre; therefore, a value of Sn = 0.33 was used. The predicted errors calculated from the regression equations are shown in Table 11.

The three methods used in this study to evaluate the accuracy of the flood levels are compared in Table 12. It is interesting to note that the mean reach absolute error predicted by the regression equation is the same as the error determined by comparison of the June 5, 1986 high water data to the computed profile. The results of all of these analyses demonstrate that the uncertainties in the computed flood levels are apt to be small. Furthermore, a freeboard allowance of 0.6 m is adequate to account for any potential uncertainties in the calculations.

Of course, the model calibration, sensitivity studies and error analysis provide only a generalized indicator of the backwater model accuracy averaged over the entire water surface profile. Maximum errors at specific sites may be affected by local conditions not represented by the backwater model. For example, additional water level deviations might be expected to occur in some reaches as a result of hydraulic changes due to channel shifting, bank erosion, sedimentation or debris jamming.

5.6 Flood Profiles

Flood profiles were prepared to show the computed water surface profiles for the 20 and 200 year daily and instantaneous flood events. The river thalweg, highwater marks and bridges are also shown on the flood profiles. However, the water surface profiles do not include an allowance for freeboard.

The hydraulic analyses for this study are based upon unobstructed flow in the channel or at bridges. Thus, the computed flood elevations are valid if the channel remains unobstructed by debris and if the bridges also remain unobstructed, and do not fail.

The Slocan River flood profiles are represented on Figures 4-12, and the Little Slocan River profiles are shown on Figure 13.

5.7 Designated Flood Level

The recommended designated flood level is the water surface elevation computed for the 200 year mean daily flood plus 0.6 m of freeboard. This recommended level is higher than the 200 year instantaneous profile plus 0.3 m of freeboard, typically by 0.1 - 0.2 m . The recommended freeboard allowance of 0.6 m is considered an adequate factor of safety to allow for wave run up, surges, and other open water conditions, and to account for the accuracy of flood elevations computed by a standard step backwater model.

5.8 Special Flood Conditions

The designated flood level may be affected by special conditions such as debris jamming, bank erosion and other sediment processes. Analysis of these flood concerns is beyond the scope of this study. However, the known special flood hazards are discussed below.

Slocan River flood levels along the upstream 15 kilometres are influenced by Lemon Creek, and flood problems appear to be aggravated by sediment processes occurring because the creek's floodplain is an active alluvial fan. Sediment deposited at the confluence of the Slocan River and Lemon Creek is causing Slocan River levels to rise upstream and submerge previously farmed land. Downstream, the Slocan River flows at a very steep slope through coarse sediment associated with the Lemon Creek alluvial fan. The high velocity flow and erodible material lead to bank erosion, which also contributes to the loss of agricultural land.

These sediment processes are ongoing and can be expected to continue to influence Slocan River flood problems. The computed water surface profiles may not be representative of future flood conditions which are aggravated by the Lemon Creek alluvial fan. Furthermore, future projects undertaken to help alleviate this problem will result in flood levels which also may not be represented by the computed flood profiles.

6.0 SLOCAN LAKE FLOOD LEVEL ANALYSIS

6.1 Methods

Studies were undertaken to review the designated flood level for Slocan Lake. Two previous lake level frequency analyses that have been performed by the Ministry of Environment were reviewed. The lake levels computed from the HEC-2 backwater analysis in this study were compared with these statistically determined lake levels. Wave forecasting methods were used to calculate the height of wind-generated waves on Slocan Lake. The results of the wave height analysis were then used to assess the freeboard that should be applied to the estimated flood levels on the lake.

6.2 Lake Level Frequency Analyses

Hydrologic analyses were performed by B.C. Ministry of Environment in 1975 and 1986 in order to determine a flood level frequency relationship for Slocan Lake. These studies are documented in internal memorandums dated May 7, 1975 and March 6, 1986 (see Appendix A). The data used in these studies consists of a 31-year record of annual maximum discharges at WSC gauge 08NJ014 (Slocan River at Slocan City) and a coincident record of annual maximum daily lake levels at WSC gauge 08NJ137 (Slocan Lake at Slocan City). Figure 2 illustrates the stage-discharge rating curve that Water Survey of Canada has developed for the lake outflows. The rating curve defines the stage - discharge relationship quite well up to El. 537.81 m (gauge height of 3.4 m) and a flow of 350 m^3/s.

The 1975 study statistically analyzed the 31-year record of annual maximum daily lake levels by fitting a log normal probability distribution to the series. The maximum daily lake levels derived for 20 and 200 year return periods were 537.85 m and 538.5 m, respectively. An allowance of 0.70 m was added to establish the adopted 1:200 year lake level (including freeboard) of 539.2 m.

In the 1986 frequency analysis both the discharge and lake level records were statistically analyzed. Stage - frequency curves were developed for the 31-year record at WSC gauge 08NJ137, using four different probability distributions (log-normal, Gumbel, Pearson III, and log-Pearson III). The Pearson distributions were rejected and the two remaining distributions were averaged, obtaining a 20 year and 200 year lake level of 537.77 m and 538.31 m.

A flood frequency analysis was also performed by MOE on the lake outflows (Slocan River at Slocan City) using the same four distributions, and the results from the four distributions were averaged. The flows were converted to lake stage by means of the stage-discharge relationship constructed from the published record of Slocan Lake levels and Slocan River discharges. The estimates of the 20 year daily stage from the two methods agreed closely. However, for the 200 year daily lake level, the lake stage - frequency analysis provided higher estimates than the values computed from the frequency analysis of lake outflows. Accordingly, MOE decided to lower the 200 year lake level from 538.31 m to 538.11 m.

Instantaneous lake stage records are not available. Therefore, an adjustment was added to the daily recorded lake level. Specifically, the instantaneous lake levels were estimated by adding 0.2 m to the 20 year daily lake level and 0.1 m to the 200 year daily level. The Slocan Lake levels recommended by the 1975 and 1986 studies for selected return periods are shown in Table 13.

The water surface elevations at Slocan Lake that were computed from the HEC-2 backwater calculations also summarized in Table 13. It can be seen that the differences between the three methods of estimation are small. In general, the lake levels estimated from the backwater analysis are higher than those derived in 1986 for the same return period and lower than those derived in the 1975 frequency analysis.

6.3 Wave Height Prediction

The significant wave heights ($H_{1/3}$) were estimated for different storm conditions procedures outlined by the Corps of Engineers in Reference 12. The significant wave height is a statistical parameter and represents the average of the highest one third of the waves that occur in a wave field. The calculations require a knowledge of wind speed, direction, and duration and the fetch length. Information on wind speeds in the vicinity of Slocan Lake were obtained from Atmospheric Environment Service (AES). The nearest measurements of wind speed are located at Castlegar Airport and B.C. Hydro Damsite near Castlegar. These stations have provided hourly wind data for the periods 1954-1987 (airport) and 1970 - 1987 (dam site).

A review of the records at the two sites showed the wind speeds at the dam site were higher than at the airport. Based on discussions with AES it was decided that the dam site station would be more representative of conditions at Slocan Lake than the airport station. It was also recognized that the directions having the highest wind speeds at Slocan Lake could be quite different than at either station. This is because the winds will be affected by the local topography so that the highest winds will tend to be aligned along the axis of the lake.

The wave heights on Slocan Lake will be limited by the fetch, the distance the winds can blow over the water. The longest fetches on the lake reach 15 km from the NNW near Silverton and up to about 10 km from the NNE near Slocan City.

Table 14 summarizes results of the wave height calculations for Silverton, the site with the most severe wave climate on the lake.

The elevation reached by wave runup, not the deep water wave height, is the most important parameter for determining whether any structures will be inundated or overtopped by wave action. The height of wave runup will depend both on the deep water wave characteristics (wave height and wave length) as well as on several local factors that need to be evaluated on a site by site basis. These local factors include:

- the local depths and slopes in the vicinity of the breaking waves;
- the roughness and permeability of the surface where wave breaking occurs;
- the type of structures that are being subjected to wave breaking. (i.e. whether it is a natural beach, breakwater, or retaining wall).

Therefore, it is not possible to compute a single value of runup that will be representative of a particular storm condition on the lake. Instead, we have computed values for different conditions in order to illustrate the range in values that might occur. These calculations have been compared with the initial deep water wave heights (Table 14). The calculations assume the waves will be breaking on a smooth impermeable slope. The computations show that the height of the wave runup above the still water level will usually be less than the incident deep water height particularly when the waves break against relatively flat slopes.

Some additional superelevation may occur as a result of wind set up. This condition results in a tilting of the water surface with the water level rising on the down wind side of the lake. However, in relatively deep lakes wind set up affects should be substantially smaller than wave runup (Reference 12).

For the purposes of this study, we have used the incident deep water wave height for determining the maximum elevation that could be subject to wave action. As shown in Table 14, this approach should be conservative since under most conditions the wave runup will be substantially less than the incident wave.

6.4 Slocan Lake Designated Flood Level

The wave heights calculated for various extreme wind events were added to the lake levels computed by the earlier hydraulic analysis. The resulting elevation provides an indication of the maximum water levels that could occur in a flood that coincided with a storm event. The lake levels and wave height combinations were selected so that the combined joint frequency of occurrence had a 200 year return period. This analysis assumed that the storm conditions and lake levels could be treated as independent events. The resulting combinations are summarized below:

20 year lake level (537.84 m) + 10 year wave height (0.9 m) = 538.75 m
100-year lake level (538.16 m) + 2 year wave height (0.85 m) = 539.01 m
200 year lake level (538.36 m) + 1 year wave height (0.72 m) = 539.08 m

These results illustrate that the 200 year lake level with a 1 year storm produces the highest water surface elevations and governs flooding conditions on the lake. Furthermore, the results of the analysis agree very closely to the presently adopted 200 year lake level (including freeboard) of El. 539.2 m.

7.0 FLOODPLAIN BOUNDARIES

Floodplain maps (Map Sheets 88-26-1 through 88-26-11) at a scale of 1:5000 and contour intervals of 1 m were prepared to show the outline of the 200 year floodplain. This floodplain is the area inundated by the 200 year mean daily flood, plus freeboard. The floodplain limits assume the absence of all dykes such as railroad embankments and roadway fills. In addition to the floodplain boundary, the maps depict the following:

- location of river cross-sections, monuments and gauging stations;
- interpolated flood levels for the 200 year designated flood and the 20 year flood (freeboard included) are shown along the river thalweg;
- flood level isograms showing approximate lines of equal 200 year flood level to the edge of the floodplain;
- flood level for Slocan Lake (freeboard included)
- outline of the active Lemon Creek alluvial fan.

8.0 CONCLUSIONS AND RECOMMENDATIONS

1. The comparisons between measured highwater marks and computed water levels as well as the sensitivity analysis demonstrate that the HEC-2 backwater computations performed in this study are adequate for defining the 200 year flood levels and floodplain limits on the Slocan River and Little Slocan River.

2. It is recommended that the flood levels and floodplain limits shown on Map Sheets 88-26-1 through 88-26-11 be adopted for defining the 200 year floodplain on the Slocan and Little Slocan Rivers.

REFERENCES

1. British Columbia Ministry of Environment, Floodplain Mapping Program Specifications for Engineering Studies.

2. B.C. Department of Lands, Forests & Water Resources, "Slocan River Aerial Photographs", June 19, 1974.

3. B.C. Ministry of Environment, Water Management Branch, Slocan River - Lemon Creek Study, by B.R.W. McMullen, January 1984.

4. Northwest Hydraulic Consultants Ltd., Slocan River - Lemon Creek Investigation of Flood and Bank Erosion Problems, January, 1975.

5. Inland Waters Directorate, Magnitude of Floods in B.C. and the Yukon Territory, 1982.

6. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-2 Water Surface Profiles, Generalized Computer Program, Davis, California, 1982, Revised November 1976.

7. B.C. Hydro, Hydroelectric Engineering Division, Kootenay Canal Development, Dam Breach Inundation Study, Report No. H1876, June, 1986.

8. B.C. Hydro, Hydroelectric Generation Projects Diversion, Columbia River - Murphy Creek Project - Backwater Study, Report No. H1511, December 1984.

9. U.S. Department of the Interior, Geological Survey, Water Supply Paper 1849, Roughness Characteristics of Natural Channels, 1967.

10. Chow, Ven T., Hydraulics of Open Channels, 1959.

11. U.S. Army Corps of Engineers, Hydrologic Engineering Center, Accuracy of Computed Water Surface Profiles, December 1986.

12. U.S. Army Coastal Engineering Research Center, Shore Protection Manual Volume I, 1984.

TABLES

Table 1

Hydrologic Data Used for Frequency Analysis

Hydrometric Gauge Number	Name	Drainage Area (km^2)	Period of Record
08NJ013	Slocan R. nr. Crescent Valley	3290	1914, 1925-85 (1) 1933, 1935-85 (2) (except 1973)
08NJ014	Slocan R. at Slocan City	1660	1916-22 1945-68 (1)
08NJ137	Slocan Lake at Slocan City	-	1916-22, 1931 1945-1968 (3)
08NJ160	Lemon Ck. abv. South Lemon Ck.	178	1973-85 (1,2)

Additional Data:

Rating tables for WSC stations 08NJ013 & 08NJ014

Ministry of Environment memorandum dated March 6, 1986 from R.Y. McNeil to R.W. Nichols

Notes:

1. Annual maximum daily mean discharge
2. Annual maximum instantaneous discharge
3. Annual maximum peak level

Table 2

Data Used for Hydraulic Analyses

Source	Comment
Ministry of Environment; Water Management Branch:	
Volumes 1 and 2 - Slocan River, Surveys Section, Project 80-RPP-4, July 1980	cross sections 1-78 with photographs
Volume 1 - Slocan River, Project 80-RPP-4(81), October 1981	additional cross-sections nr. Lemon Ck.
Volume 1- Slocan River, Project 86-FDC-4, August 1986	55 cross-sections on Slocan R. & 10 on Little Slocan R.
Slocan River Design File June 11, 1986 notes to file, Slocan River Water Levels, June 1986	high water marks
Slocan River Design File - October 4, 1982, RE:high water marks June 5, 1986 high water mark photos	photographs, high water marks
Slocan River Topographic Maps scale 1:5000, 1 m contour interval Map Sheets 88-26 sheets 1 to 11	
Aerial Photographs, Slocan River Flooding, June 19, 1974. Flight Line BC 5599 photos 1-64	Scale 1:10,000 approx
Canadian Pacific Railway	
Track Profiles, Slocan Lake Branch, Mile 0 to 31-4, 1936	

Table 3

Computed Flood-Frequency Estimates by MOE (1986)

Location	Distribution	20-year maximum in cms		200-year maximum in cms	
		daily	instant.	daily	instant.
Crescent Valley 08NJ013	3-para. Lognormal	645	684	806	853
	Gumbel	673	712	898	945
	Pearson III	643	680	788	830
	Log-Pearson III	646	685	801	849
Slocan City	3-para. Lognormal	325	-	398	-
	Gumbel	340	-	446	-
	Pearson III	323	-	387	-
	Log-Pearson III	325	-	396	-

Note: Pearson III values for Crescent Valley were not used to derive average values.

Table 4

Flood Frequency Estimates Used in HEC-2 Runs

Location	Drainage Area km2	20-Year Max. Daily	20-Year Max. Inst.	200-Year Max. Daily	200-Year Max. Inst.
Slocan River:					
at mouth	3380	665	708	853	900
at WSC Sta. 08NJ013	3290	654	694	835	882
below Little Slocan R.	3196	637	679	817	863
above Little Slocan R.	2363	485	536	584	645
below Lemon Ck.	2137	425	471	534	592
above Lemon Ck.	1932	390	434	488	543
at WSC Sta. 08NJ014	1660	341	382	426	450
Little Slocan River:					
at mouth	833	230	244	294	310

Table 5

Coefficients used to derive calibration flows

Equation: $Q = n (A\text{-}1660)^{0.76} + B$

Flood Event	Above Lemon Creek n	B	Lemon Creek to Mouth n	B
1982, Peak	0.938	297	0.938	282
1986, Peak	1.06	324	1.06	308
June 5, 1986	0.437	308	1.06	308

Table 6

Estimated Calibration Flows

Location	Drainage Area (km^2)	Peak June 20, 1982	Peak June 1 1986	June 5 1986
Slocan River at mouth	3380	552	613	506
Gauging Sta. 08NJ013	3290	541	602	496
D/S Little Slocan River	3196	530	588	485
U/S Little Slocan River	2363	419	463	389
D/S Winlaw Bridge	2293	408	451	381
Appledale Bridge (removed)	2182	391	431	368
D/S Lemon Creek	2137	384	423	363
U/S Lemon Creek	1932	348	383	339
D/S XS 38-80 (1982 HWM)	1789	337	367	323
D/S Logging Bridge	1699	312	341	312
Slocan Lake	1660	297	324	308

Table 7

High Water Mark Data

Location	June 6, 1986	Peak 1982	Peak 1986
Crescent Valley bridge	X	X	X
WSC Gauge 08NJ013	X	X	X
Suspension bridge	X		
Farmhouse (XS 11-80)	X		X
Slocan Park bridge	X	X	X
Passmore bridge	X	X	X
Dairy (XS 38-86)	X (approx.)		X
Winlaw bridge	X	X	X
Appledale bridge	X	X	X
Perrys bridge	X	X	
XS 38-80		X	
Logging bridge	X	X	
Slocan bridge	X	X	
Slocan Lake	X		

Table 8

Summary of Channel "n" Values

River Reach km	Average Channel Slope	Channel "n" Value	Comment
SLOCAN RIVER:			
0 - 5	0.0035	.030 - .037	rapid flow, single channel
5 - 15	0.0013	.032 - .035	few islands
15 - 23.5	0.0020	.033 - .035	few islands
23.5 - 31.3	0.0010	.033 - .040	multiple channels
31.3 - 34.5	0.0041	.035 - .040	steep, single channel
34.5 - 46.5	0.0021	.033 - .037	single channel, wide floodplain
46.5 - 49.8	0.0042	.040 - .045	very steep, split braided channel
49.8 - 47.6	0.0004	.035 - .038	very wide flood-plain, tranquil
LITTLE SLOCAN RIVER:			
0 - 4	0.0062	.038 - .055	steep, braided channels

Table 9

Results From Model Calibration

Location	6-5-86 Observed	WL, metres Computed	1982 Observed	HWM, metres Computed	1986 Observed	HWM, metres Computed	Mean Absolute Site Error, m
Crescent Valley Bridge	468.3	468.22	468.31	468.37	468.7	468.56	.09
WSC Sta. 08NJ013	469.5	469.60	469.80	469.78	470.0	470.01	.04
Suspension Bridge	475.6	475.96					.36
XS-11 (86)	477.0	476.93			477.8	477.26	.31
Slocan Park Bridge	480.9	481.52	481.99	481.65	481.1	481.83	.56
Passmore Bridge	491.0	491.47	491.73	491.61	491.3	491.77	.35
Vallican Bridge	497.6	497.91	498.24	498.02			.27
XS-38 (86)	506.0	505.78			506.1	505.99	.12
Winlaw Bridge	518.8	518.65	518.93	518.77	519.1	518.96	.12
Appledale Bridge	520.0	520.07	520.00	520.22	520.4	520.42	.09
Perrys Bridge	520.7	520.70	520.76	520.83			.04
XS-38 (80)			536.58	536.67			.09
Logging Bridge	536.7	536.63	536.79	536.75			.06
Slocan Bridge	537.1	537.42	537.44	537.42			.17
Slocan Lake	537.6	537.62					.02
Mean Absolute Reach Error, m		0.20		0.12		0.25	

Note:

$$\text{Mean Reach Absolute Profile Error} = \frac{\sum_{i=1}^{n} |E_i|}{n}$$

Table 10

Results from Sensitivity Analyses

	Mean Absolute Profile Difference[1] (m)						
Reach, km	ROUGHNESS COEFFICIENT			DISCHARGE			
	+ 10%	+ 20%	- 10%	+ 10%	+ 20%	- 10%	- 25%
SLOCAN RIVER:							
0-5	0.16	0.32	0.17	0.16	0.33	0.16	
5-15	0.20	0.38	0.22	0.20	0.40	0.23	
15-23.5	0.17	0.32	0.18	0.19	0.37	0.20	
23.5-31.3	0.14	0.28	0.15	0.15	0.30	0.16	
31.3-34.5	0.13	0.25	0.12	0.16	0.31	0.16	
34.5-46.5	0.16	0.30	0.16	0.23	0.44	0.24	
46.5-49.8	0.15	0.22	0.08	0.13	0.21	0.14	
49.8-57.6	0.10	0.21	0.12	0.19	0.37	0.22	
Mean Reach Difference	0.15	0.28	0.15	0.18	0.34	0.19	
LITTLE SLOCAN RIVER:							
0-4	0.09	0.17	0.09	0.09	0.17	0.09	0.24

1 The 200-year daily profile is assumed to be the base profile.

Table 11

Predicted Mean Absolute Profile Error

Reach, km	Average Channel Slope, m/m (ft/mi)	Mean Hydraulic Depth, m (ft)	Nr	Mean, Absolute Error, m
SLOCAN RIVER:				
0-5	.0035 (18.5)	3.66 (12.01)	.5	.40
5-15	.0013 (6.86)	2.83 (9.28)	.3	.24
15-23.5	.0020 (10.56)	2.53 (8.30)	.4	.28
23.5-31.3	.0010 (5.28)	1.73 (5.67)	.2	.17
31.3-34.5	.0041 (21.64)	2.22 (7.29)	0	.10
34.5-46.5	.0021 (11.09)	2.59 (8.49)	0	.09
46.5-49.8	.0042 (22.18)	1.32 (4.33)	.5	.28
49.8-57.6	.0004 (2.11)	3.33 (10.91)	.2	.18
Mean Reach Error				.22
LITTLE SLOCAN RIVER:				
0-4	.0062 (32.74)	0.91 (2.99)	(0.8)	(0.36)

Table 12

Comparison of Flood Profile Accuracy

Reach, km	Mean Absolute Error, m: Predicted Error[1]	Calibration Error[2]	Discharge Error[3]
SLOCAN RIVER:			
0-5	.40	N.A.	.16
5-15	.24	.15	.20
15-23.5	.28	.55	.19
23.5-31.3	.17	.27	.15
31.3-34.5	.10	.15	.16
34.5-46.5	.09	.04	.23
46.5-49.8	.28	N.A.	.13
49.8-57.6	.18	.14	.19
Mean Reach Error	0.22	0.22	.18
LITTLE SLOCAN RIVER:			
0-4	0.36	N.A.	0.09

Table 13

Slocan Lake Return Period Levels

Return Period	Hydrologic Studies 1975	1986	Hec-2 Results
20-year daily	537.85	537.77	537.84
20-year instantaneous		537.97	538.09
200-year daily	538.50	538.11	538.36
200-year instantaneous		538.21	538.55

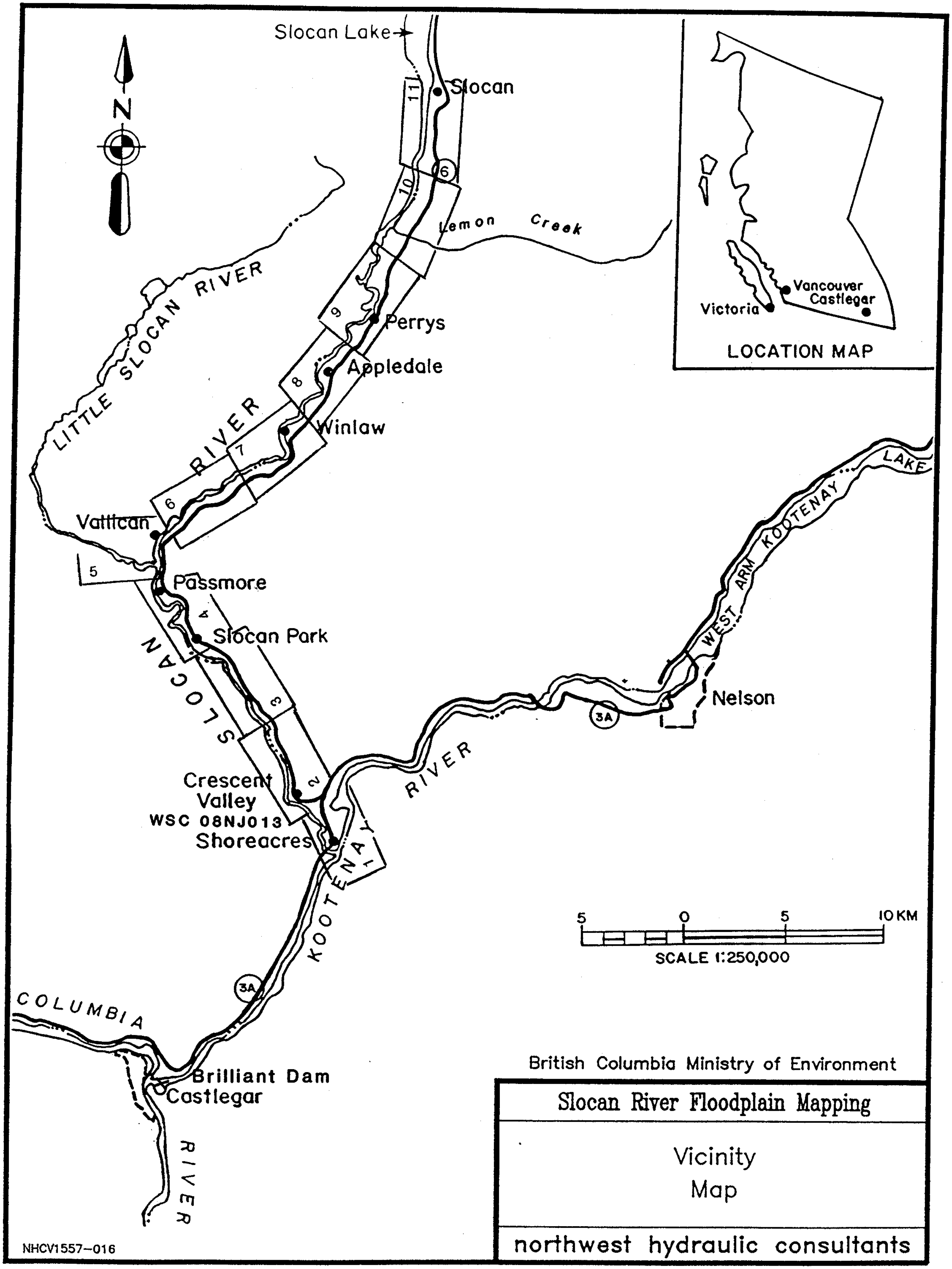
Table 14

Predicted Wave Heights on Slocan Lake

Return Period	Wind Speed km/hr	Significant Wave Height Metre	Wave Runup (m) Beach Slope 1:10	Beach Slope 1:2
1	50	0.72	.4	.6
2	59	0.85	.4	.7
10	67	.90	.4	.7
20	69	1.00	.4	.8

Note: The wave runup values were calculated for smooth impermeable slopes. These values are not representative of runup against vertical walls or riprap breakwaters.

FIGURES


Slocan Lake
Slocan
N
Lemon Creek
LITTLE SLOCAN RIVER
RIVER
Perrys
Appledale
Winlaw
Vallican
Passmore
Slocan Park
SLOCAN
Crescent Valley
WSC 08NJ013
Shoreacres
KOOTENAY
RIVER
WEST ARM KOOTENAY LAKE
Nelson
3A
6
1
2
3
4
5
6
7
8
9
10
11
COLUMBIA
RIVER
Brilliant Dam
Castlegar
Victoria
Vancouver
Castlegar
LOCATION MAP
5 0 5 10 KM
SCALE 1:250,000
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Vicinity Map
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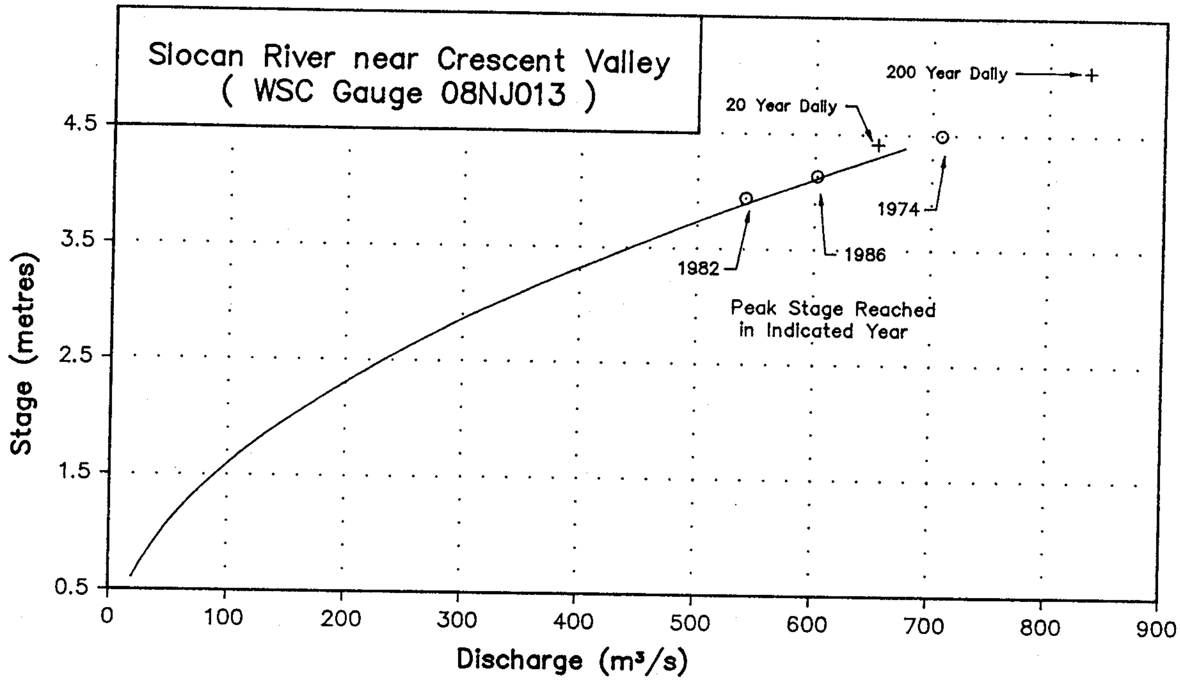
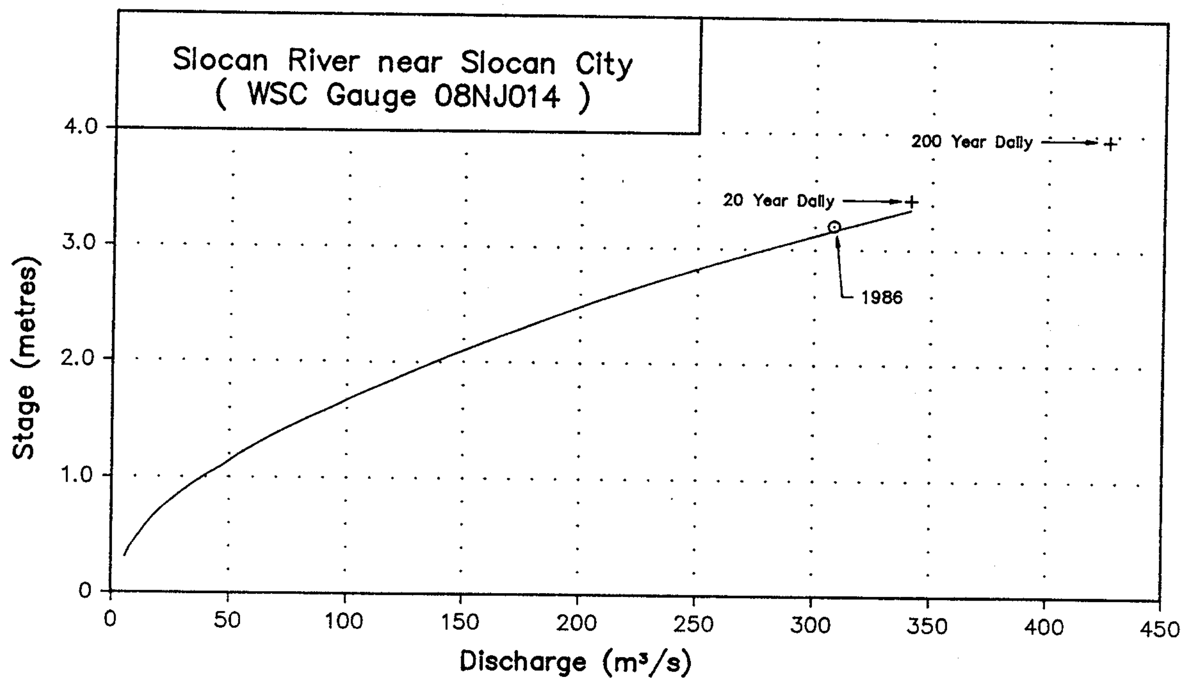
Figure 1





Note: 20 Year and 200 Year Daily Flood Stages are shown without 0.6 m freeboard allowance.

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Stage Discharge Relations At WSC Gauges

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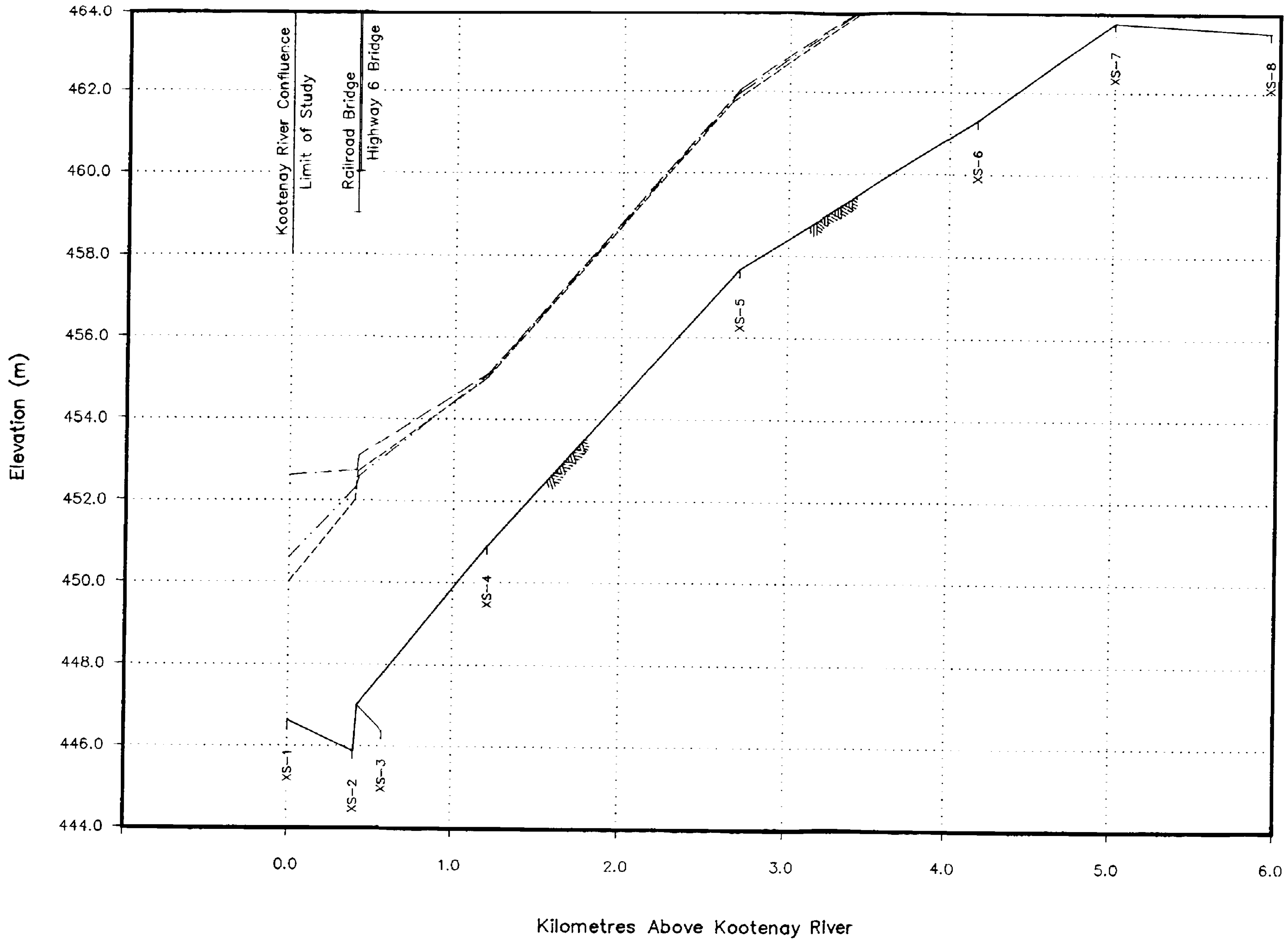
Figure 2



Notes

1. The water surface profiles were computed using a standard step backwater model assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross section locations shown on Drawing 88-26-1

Legend

- 200- Year Daily Flood. Elevation = 452.64 m
- Normal Depth
- Critical Depth
- Thalweg
- Bridge

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Slocan River Floodplain Mapping

Flood Profiles with Varying Starting Elevations

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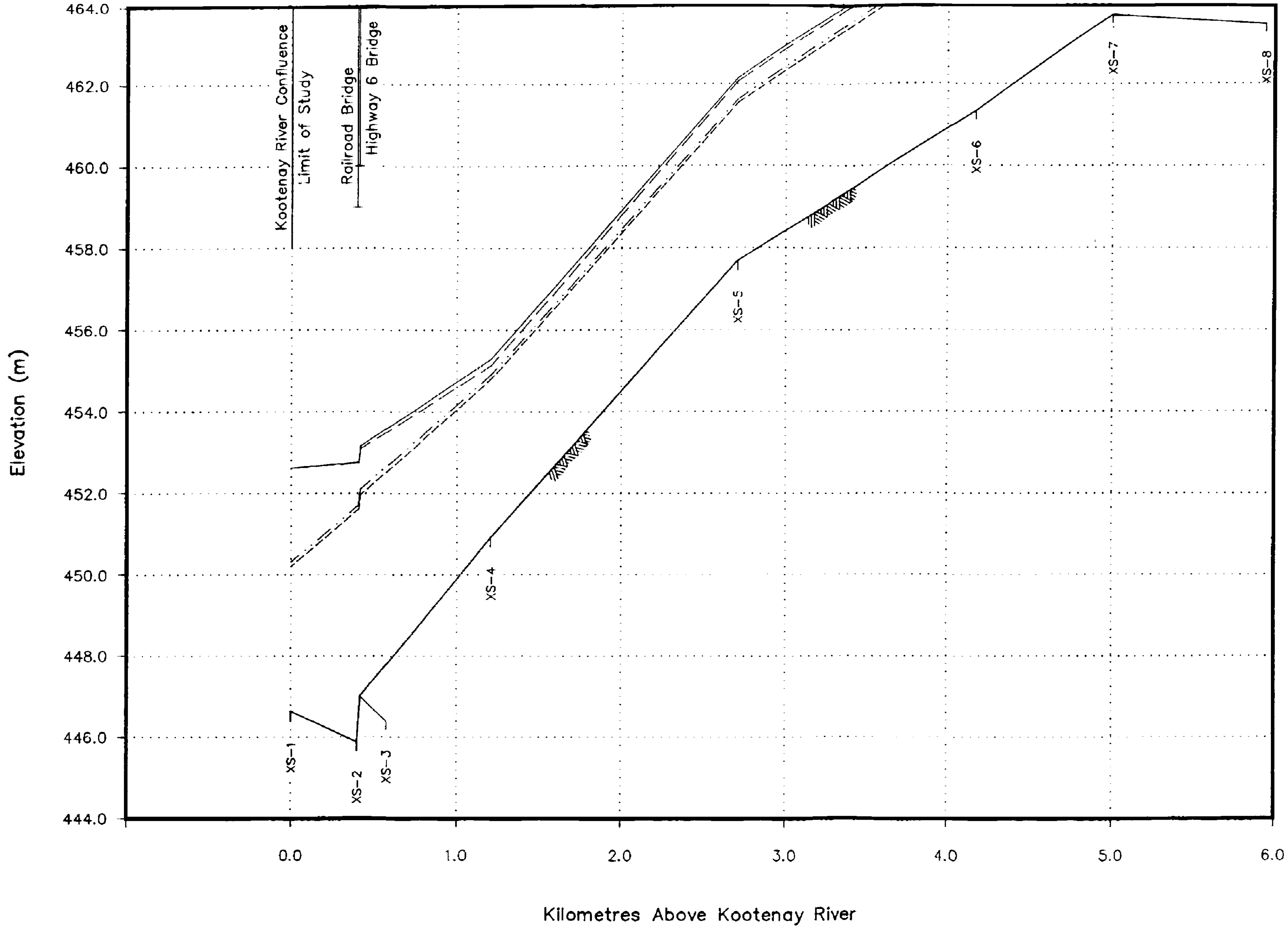
Figure 3



Notes

1. The water surface profiles were computed using a standard step backwater model assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross section locations shown on Drawing 88 26-1

Legend

- ——— 200-Year Instantaneous Flood.
- — — — 200-Year Daily Flood.
- —·· — 20-Year Instantancous Flood.
- ------ 20-Year Daily Flood.
- Thalweg
- I Bridge

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Slocan River Floodplain Mapping

Flood Profiles
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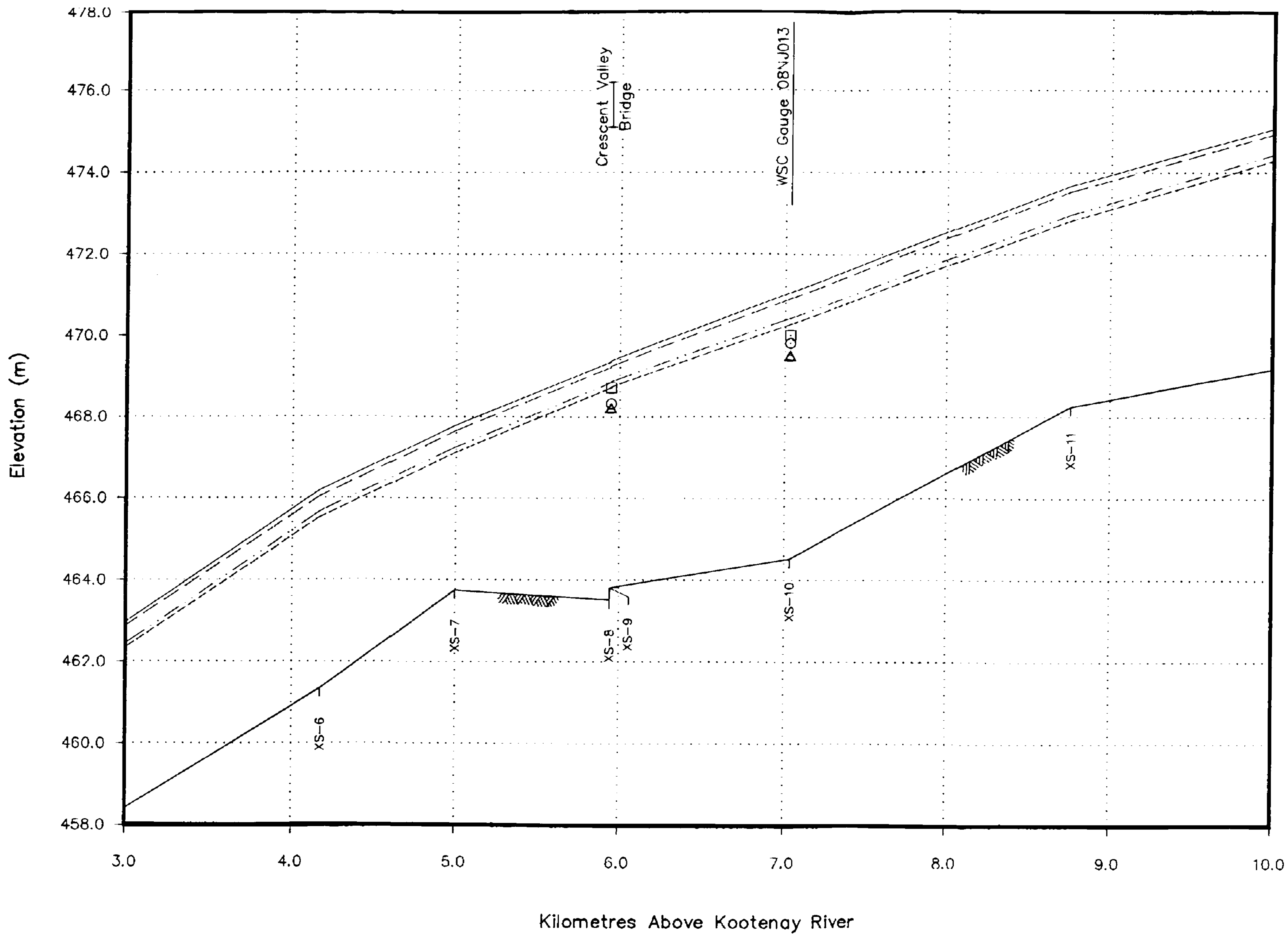
Figure 4



Notes

1. The water surface profiles were computed using a standard step backwater model assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross section locations shown on Drawing 88-26-2

Legend

- 200-Year Instantaneous Flood.
- 200-Year Daily Flood.
- 20-Year Instantaneous Flood.
- 20-Year Daily Flood.
- Thalweg
- I Bridge
- ○ 1982 Highwater Mark
- ⊡ 1986 Highwater Mark
- △ June 5, 1986 Water Level

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Slocan River Floodplain Mapping

Flood Profiles
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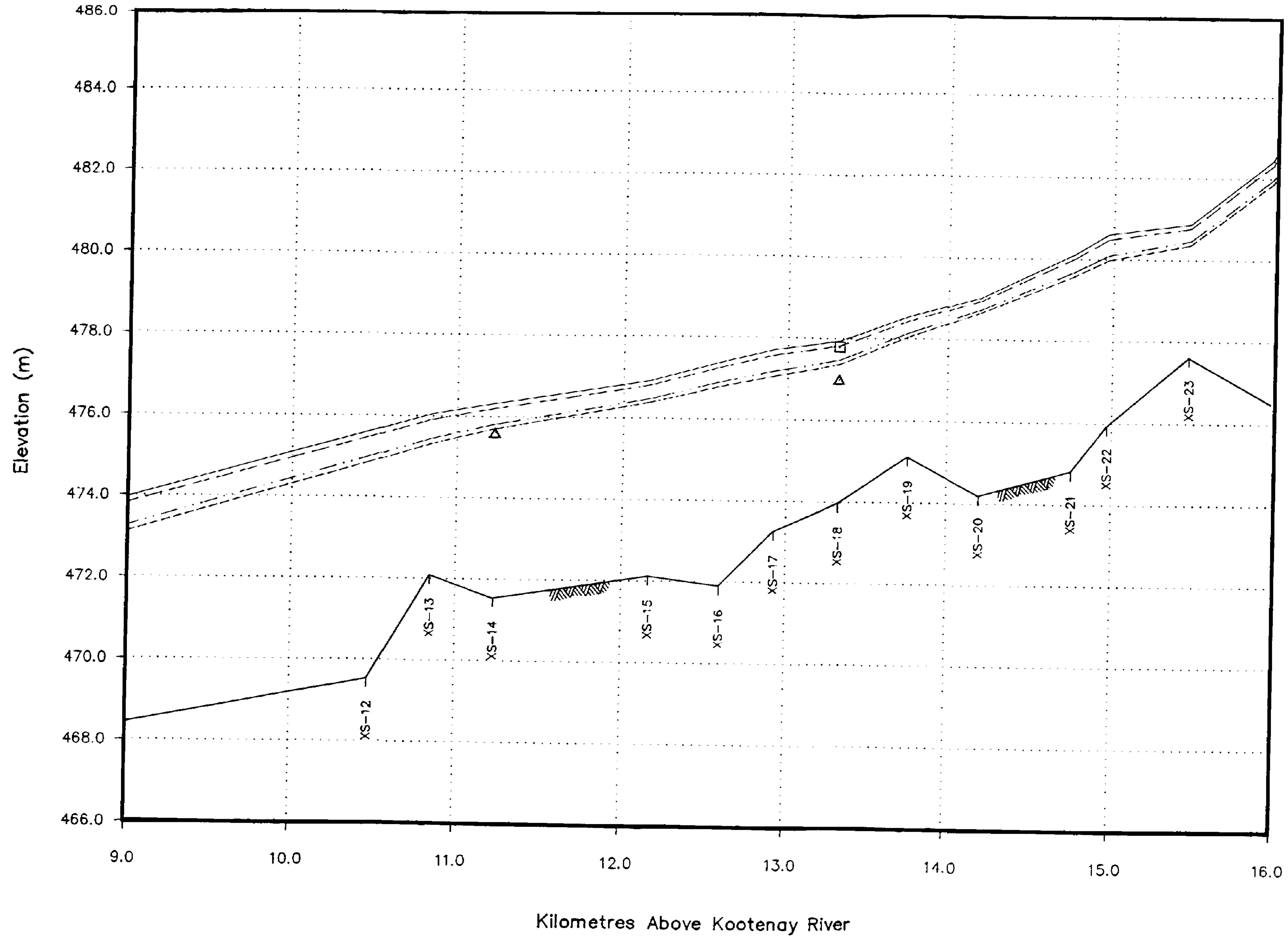
Figure 5



Notes

1. The water surface profiles were computed using a standard step backwater model assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross section locations shown on Drawing 88-26-3

Legend

- 200-Year Instantaneous Flood.
- 200-Year Daily Flood.
- 20-Year Instantaneous Flood.
- 20-Year Daily Flood.
- Thalweg
- Bridge
- 1986 Highwater Mark
- June 5, 1986 Water Level

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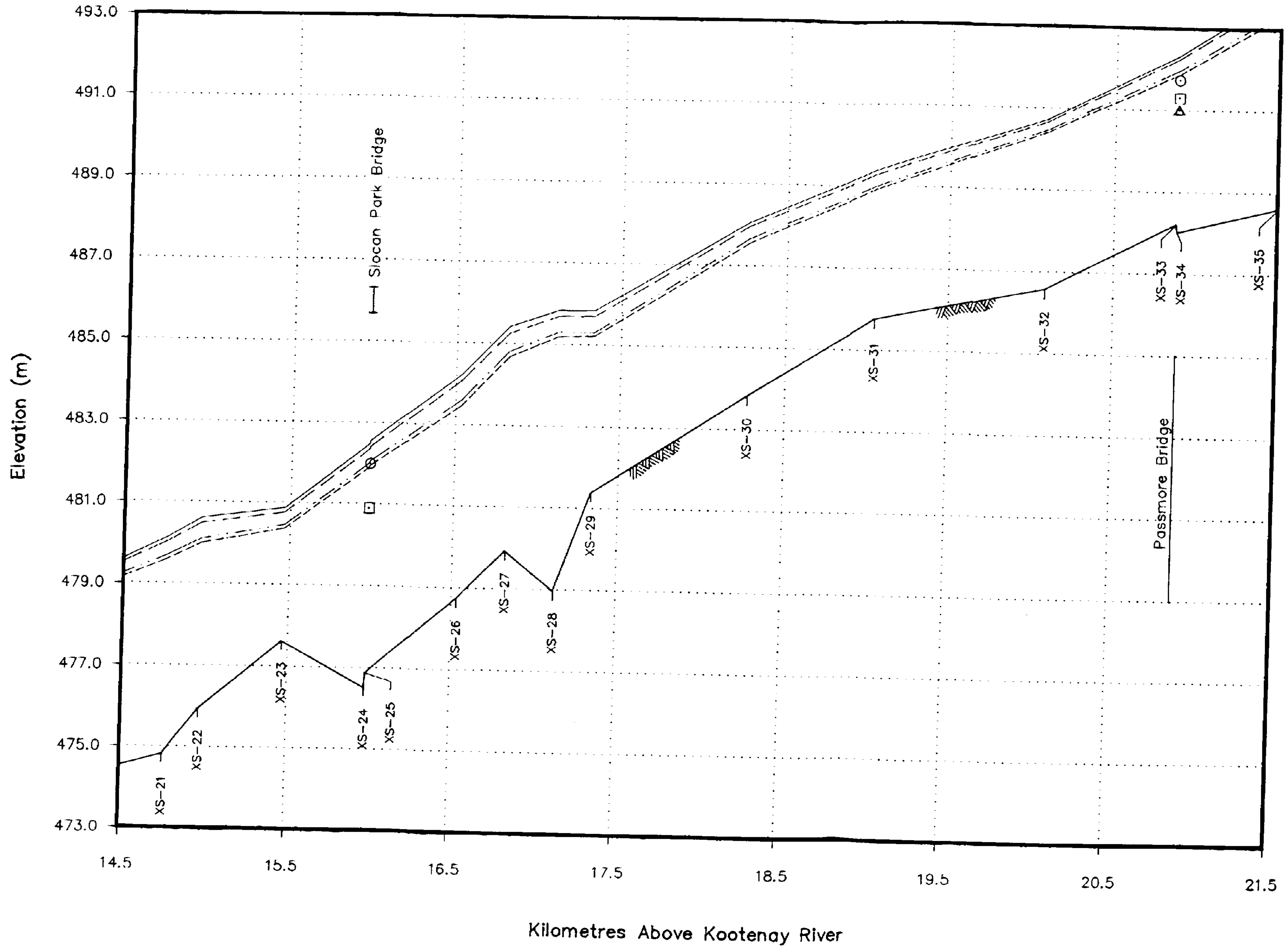
Figure 6



Notes

1. The water surface profiles were computed using a standard step backwater model assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross section locations shown on Drawing 88-26-4

Legend

- 200-Year Instantaneous Flood.
- 200-Year Daily Flood.
- 20-Year Instantaneous Flood.
- 20-Year Daily Flood.
- Thalweg
- Bridge
- 1982 Highwater Mark
- 1986 Highwater Mark
- June 5, 1986 Water Level

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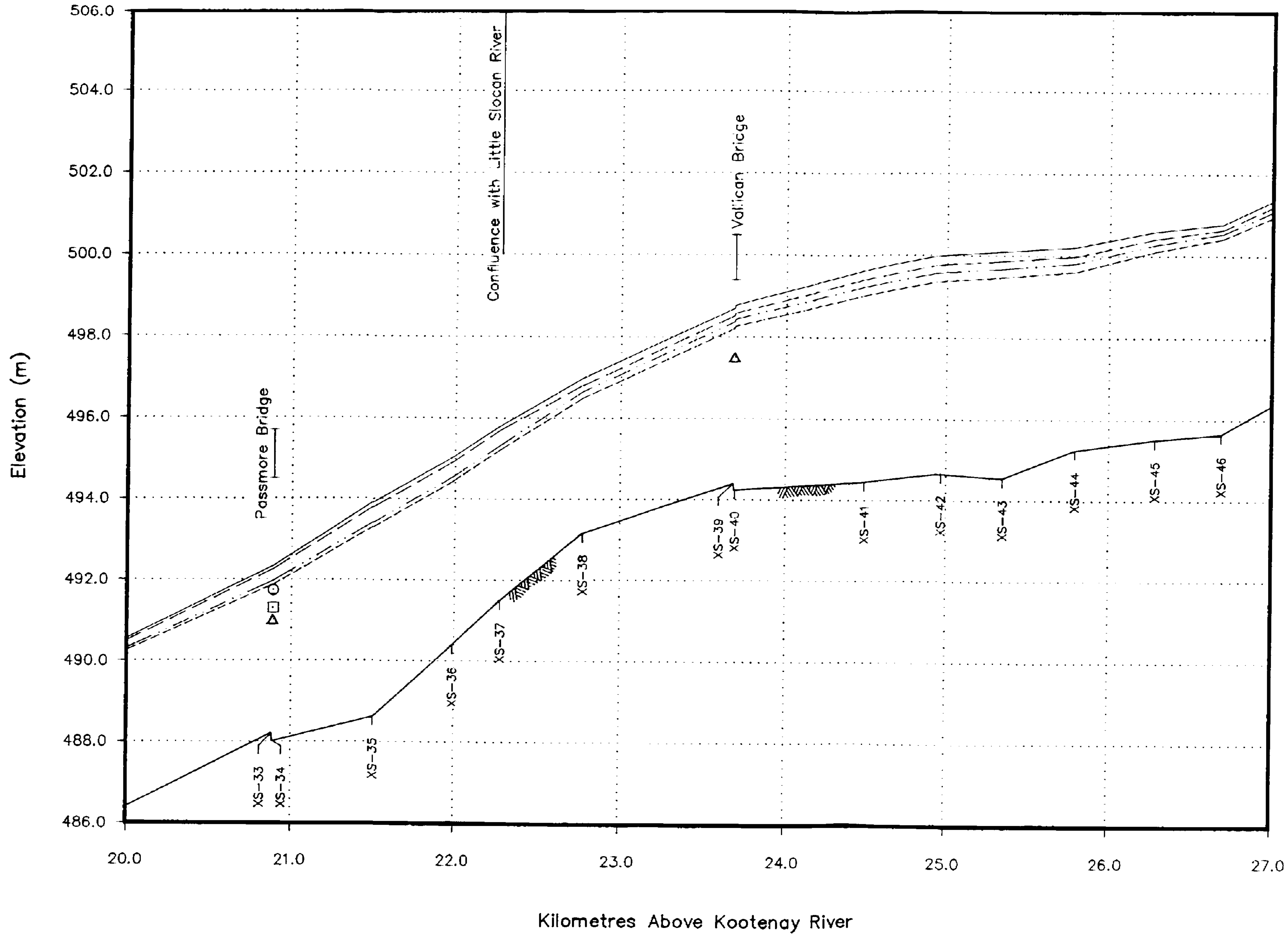
Figure 7



Notes

1. The water surface profiles were computed using a standard step backwater model assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross section locations shown on Drawing 88-26-5

Legend

- 200-Year Instantaneous Flood.
- 200-Year Daily Flood.
- 20-Year Instantaneous Flood.
- 20-Year Daily Flood.
- Thalweg
- Bridge
- 1982 Highwater Mark
- 1986 Highwater Mark
- June 5, 1986 Water Level

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Slocan River Floodplain Mapping

Flood Profiles
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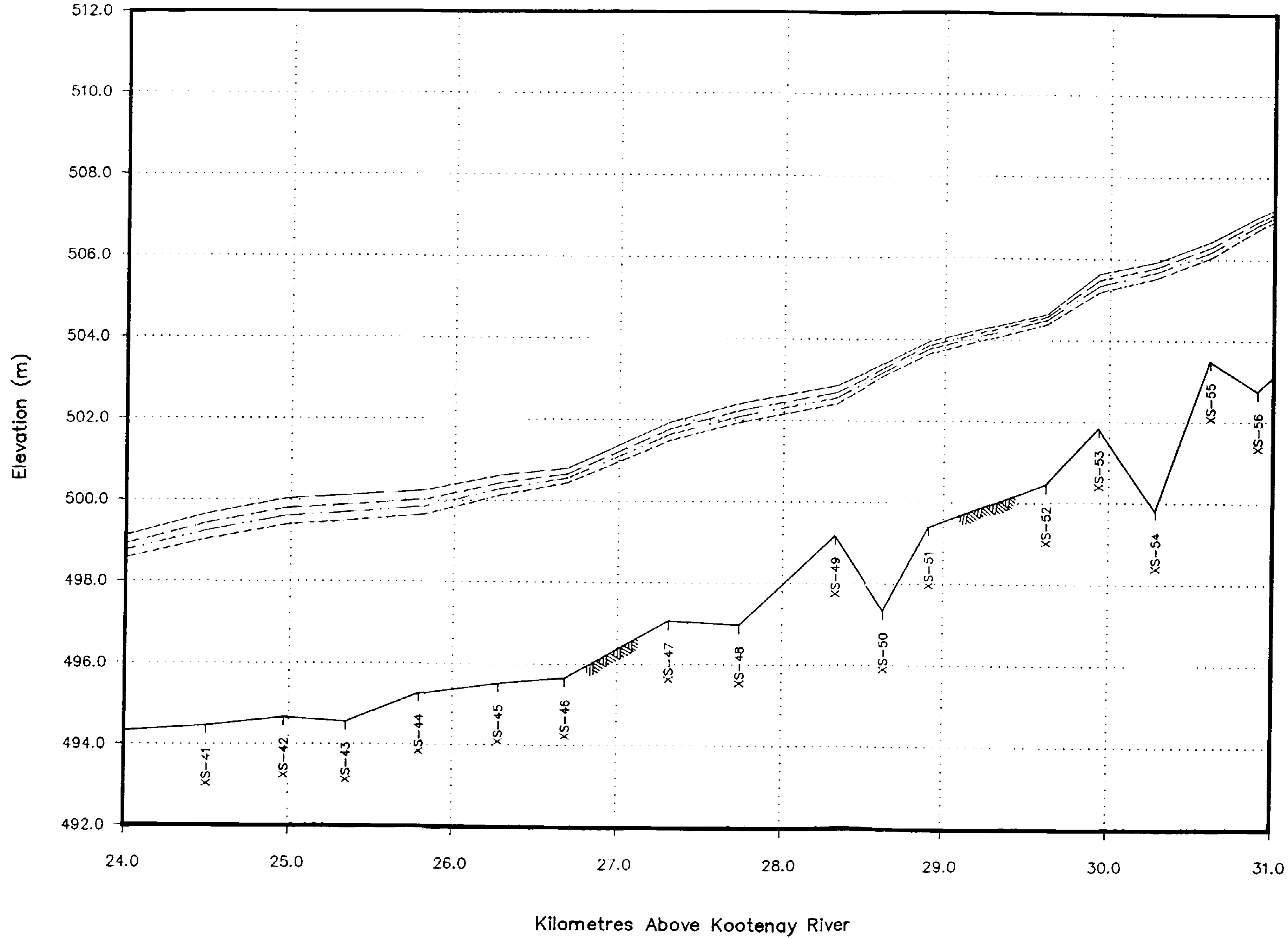
Figure 8



Notes

1. The water surface profiles were computed using a standard step backwater model assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross section locations shown on Drawing 88-26-6

Legend

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

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Slocan River Floodplain Mapping

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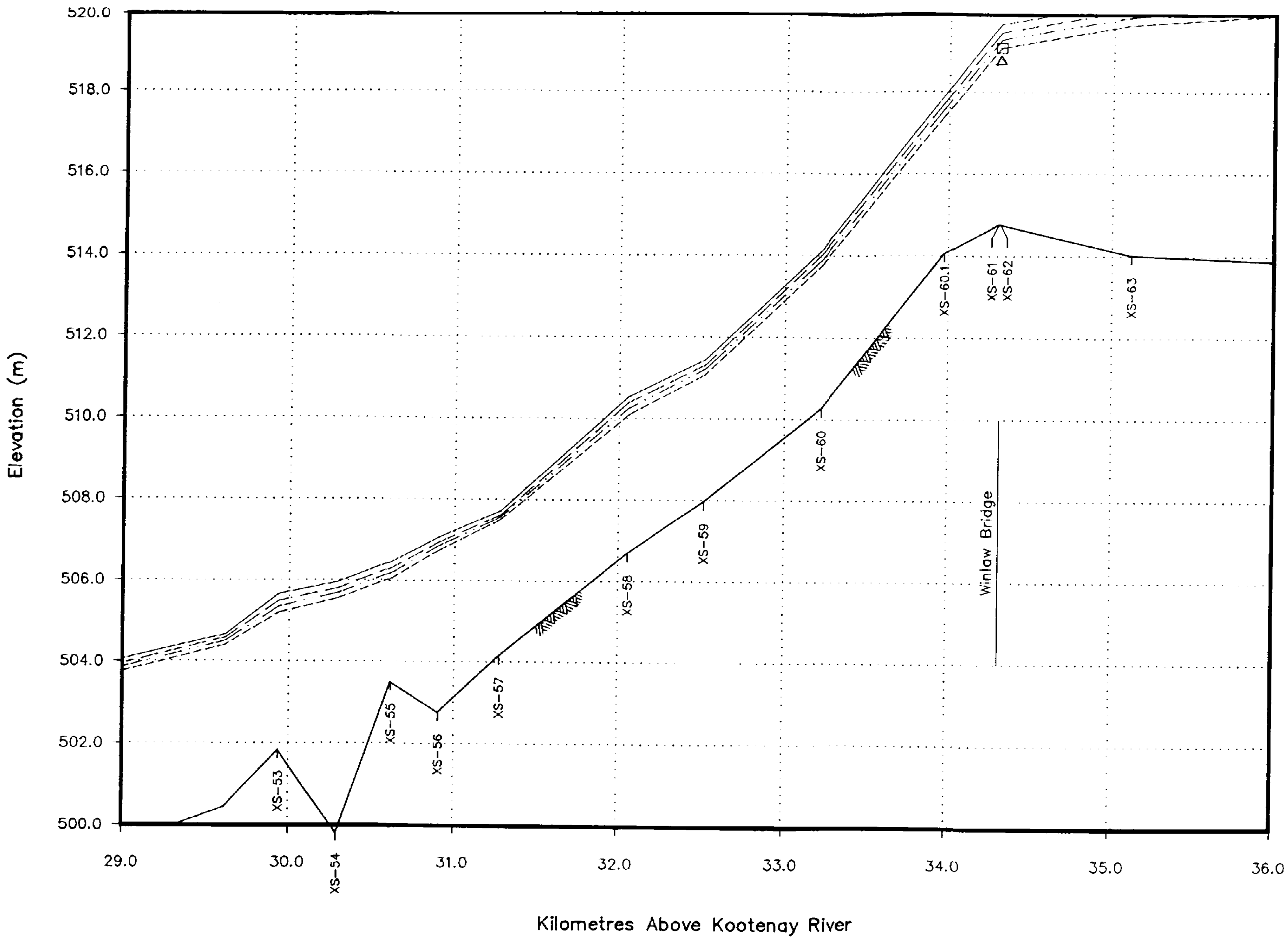
Figure 9



Notes

1. The water surface profiles were computed using a standard step backwater model assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross section locations shown on Drawing 88-26-7

Legend

- 200-Year Instantaneous Flood.
- 200-Year Daily Flood.
- 20-Year Instantaneous Flood.
- 20-Year Daily Flood.
- Thalweg
- I Bridge
- ⊡ 1986 Highwater Mark
- Δ June 5, 1986 Water Level

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Slocan River Floodplain Mapping

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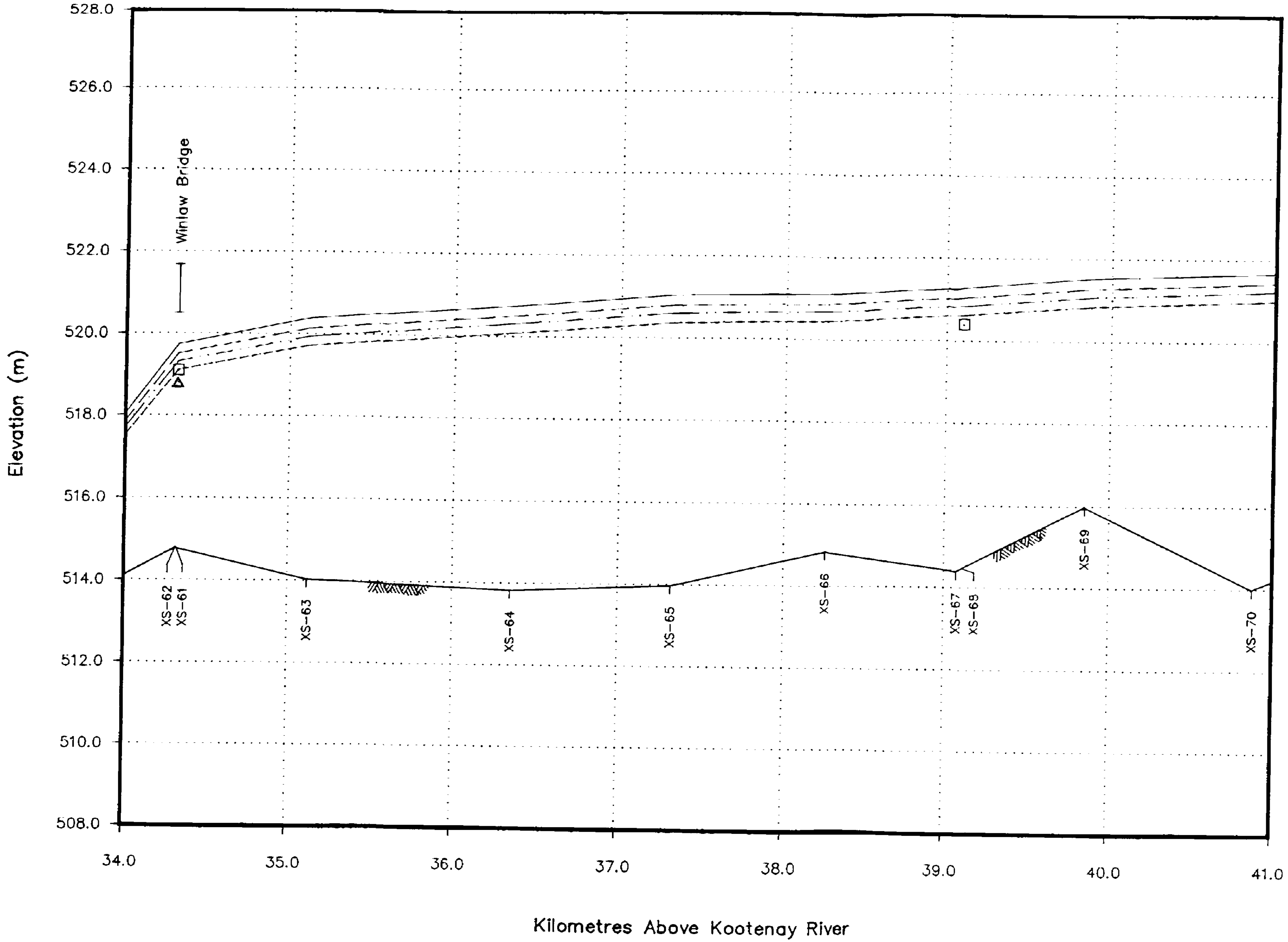
Figure 10



Notes

1. The water surface profiles were computed using a standard step backwater model assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross section locations shown on Drawing 88-26-8

Legend

- 200-Year Instantaneous Flood.
- 200 -Year Daily Flood.
- 20 Year Instantaneous Flood.
- 20-Year Daily Flood.
- Thalweg
- Bridge
- 1986 Highwater Mark
- June 5, 1986 Water Level

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Slocan River Floodplain Mapping

Flood Profiles
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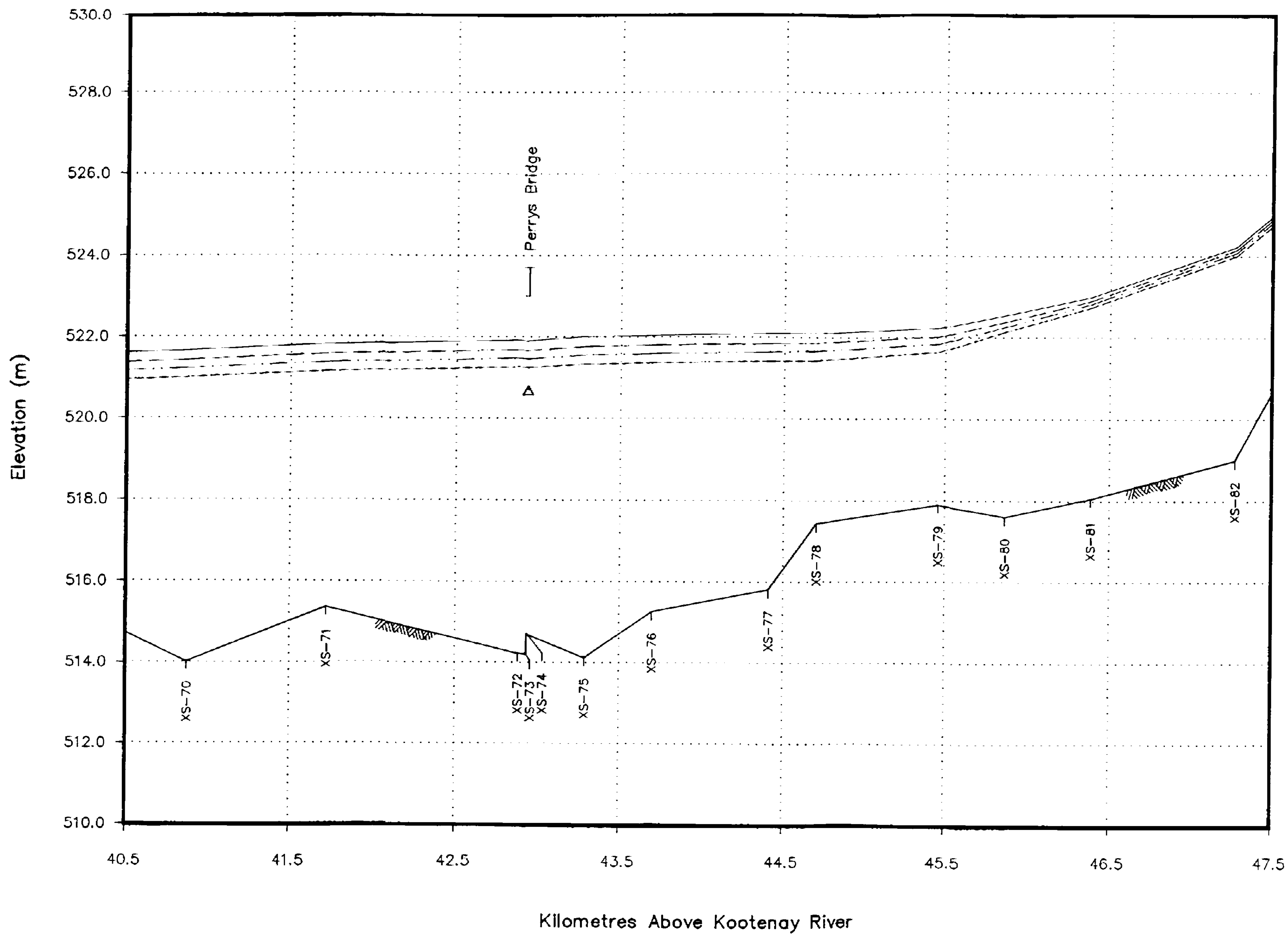
Figure 11



Notes

1. The water surface profiles were computed using a standard step backwater model assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross section locations shown on Drawing 88-26-9

Legend

- 200-Year Instantaneous Flood.
- 200-Year Daily Flood.
- 20-Year Instantaneous Flood.
- 20-Year Daily Flood.
- Thalweg
- Bridge
- June 5, 1986 Water Level

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Slocan River Floodplain Mapping

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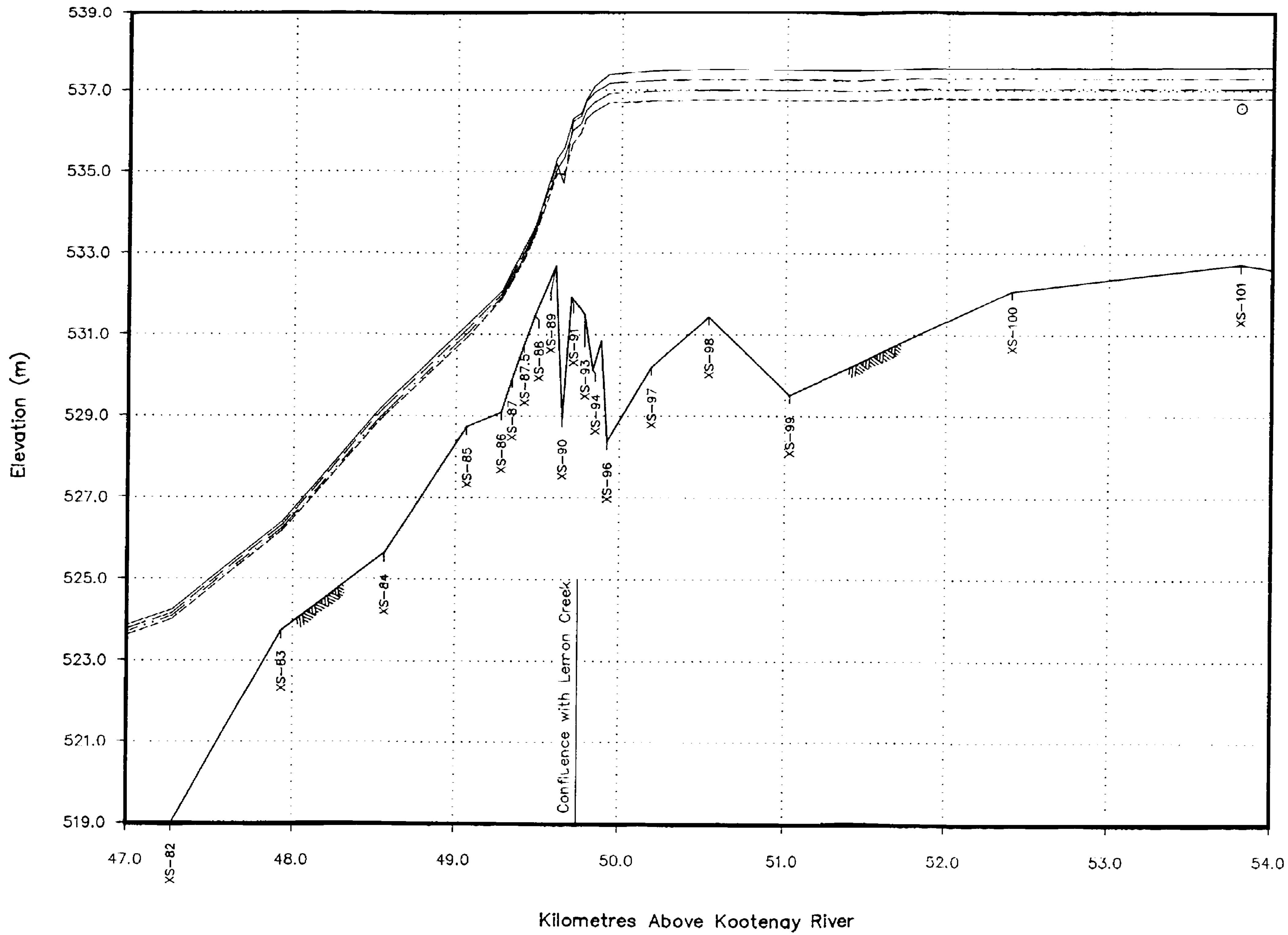
Figure 12



Notes

1. The water surface profiles were computed using a standard step backwater model assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross section locations shown on Drawing 88-26-10

Legend

- 200-Year Instantaneous Flood.
- 200-Year Daily Flood.
- 20-Year Instantaneous Flood.
- 20-Year Daily Flood.
- Thalweg
- 1982 Highwater Mark

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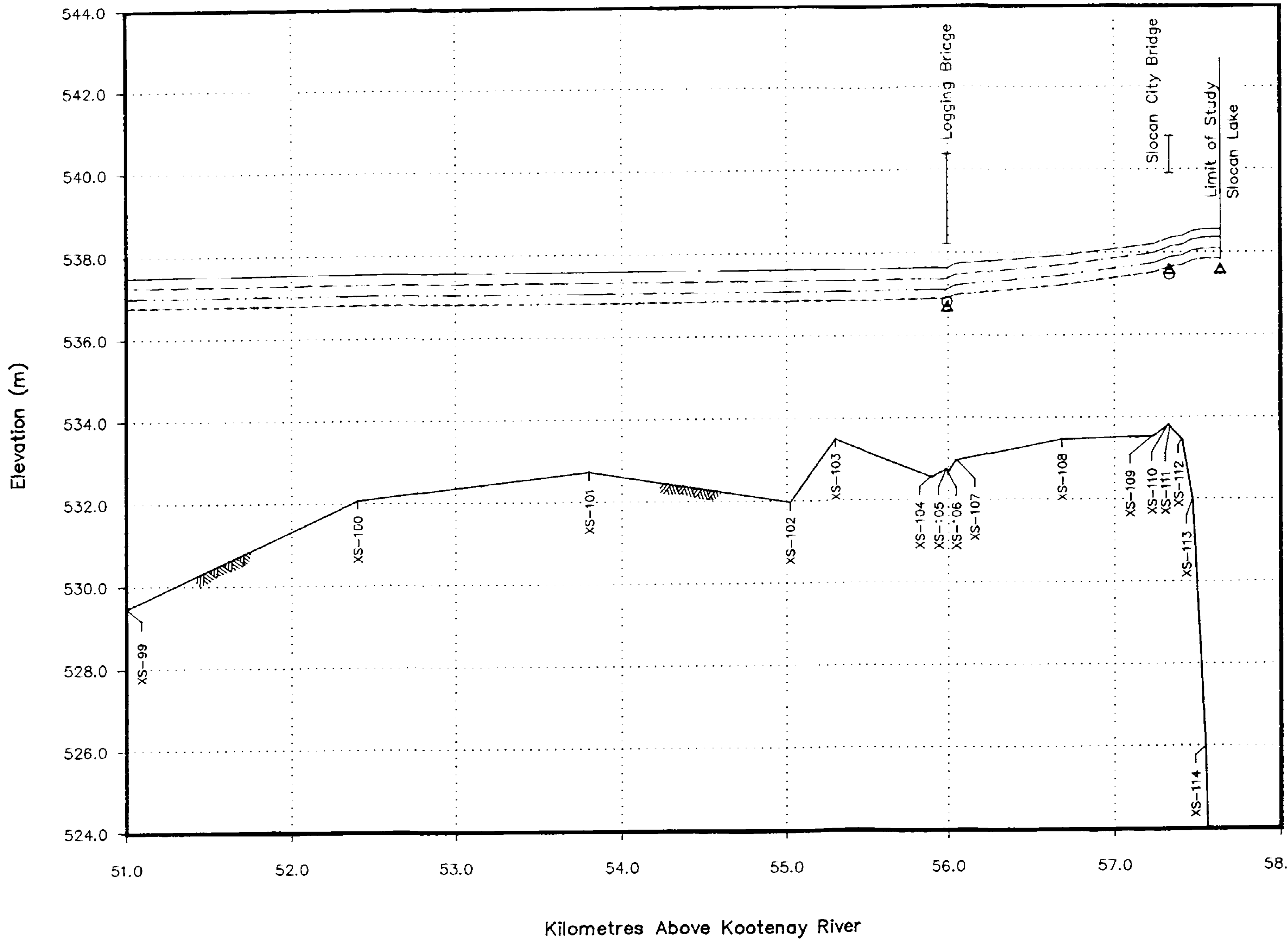
Figure 13



Notes

1. The water surface profiles were computed using a standard step backwater model assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross section locations shown on Drawing 88-26-11

Legend

- 200-Year Instantaneous Flood.
- 200-Year Daily Flood.
- 20-Year Instantaneous Flood.
- 20-Year Daily Flood.
- Thalweg
- Bridge
- 1982 Highwater Mark
- June 5, 1986 Water Level

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Slocan River Floodplain Mapping

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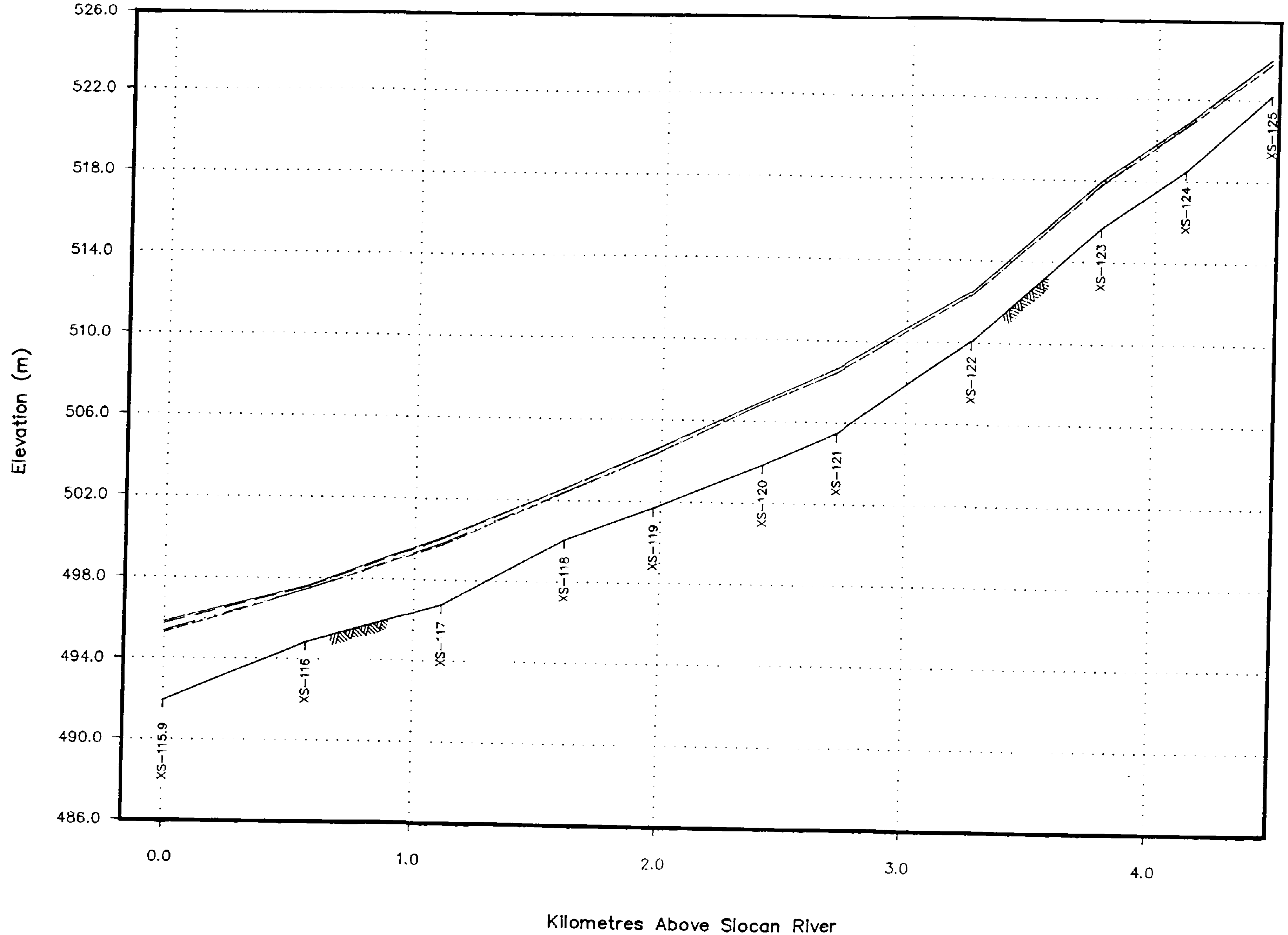
NHCV1557--012

Figure 14



Notes

1. The water surface profiles were computed using a standard step backwater model assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross section locations shown on Drawing 88-26- 5

Legend

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

British Columbia Ministry of Environment

Slocan River Floodplain Mapping

Flood Profiles
Little Slocan River

northwest hydraulic consultants

NHCV1557-013

Figure 15

APPENDIX 'A'

Province of British Columbia

Ministry of Environment

WATER MANAGEMENT BRANCH

MEMORANDUM

To R.W. Nichols
Special Projects Section
Water Management Branch

Date: March 6, 1986

File: 0323545

RE: Slocan River Area Frequency Analysis

In response to your memorandum to Mr. Coulson on the above subject dated February 3, 1986 (File No. 34-0700-Sol), I enclose a short report on the flow frequency estimates in the topic area. As you will see, the estimates were reached by a variety of methods and should be used with caution.

R.Y. McNeil

R.Y. McNeil, Head
Modelling
Hydrology Section

RYMCN/dp

Enclosure

8

W-372

NOTES ON FLOW FREQUENCY CALCULATIONS

SLOCAN VALLEY

1. Introduction

By memorandum of February 3, 1986 from R.W. Nichols, Special Projects Section, a request was made to provide 20 and 200-year return period flows for various locations along the Slocan River between its mouth and Slocan Lake and for its tributary, Lemon Creek.

2. Data Available

a) Slocan River near Crescent Valley (WSC gauge 08NJ013)
- Annual maximum daily mean discharge 1914 and 1925-85
- Annual maximum instantaneous discharge 1933 and 1935-85 except 1973

b) Slocan River at Slocan City (WSC gauge 08NJ014)
- Annual maximum daily discharge 1916-22 and 1945-68

c) Slocan Lake at Slocan City (WSC gauge 08NJ137)
- Annual maximum peak level 1916 - 22, 1931 and 1945-68

d) Lemon Creek above South Lemon Creek (WSC gauge 8NJ160)
- Annual maximum daily mean discharge 1973-85
- Annual maximum instantaneous discharge 1973-85

3. Estimated 20 and 200-Year Flows

Table 1 gives the recommended 20 and 200-year return period flows for the topic area. The following sections describe their derivation.

4. Flows Obtained Directly from Frequency Analysis

The six data sets identified in 2 (above) were analyzed by the frequency analysis program FREQAN with the following results:

a) Gauge 8NJ013. This gauge has 62 years of data and should give good frequency curves. In practice, the four greatest recorded flows are very similar (between 680 and 694 m^3/s) and this distorts the frequency curves. The Gumbel distribution gave the lowest Kolmogorov-Smirnov (K-S) statistic and the highest estimate, but did not appear to plot well at the high end of the graph. The suggested flows are the average of the log-normal, Gumbel and log-Pearson III distributions for both the daily and instantaneous flows.

b) Gauge 8NJ014. This gauge has 31 years of data, being discontinued

TABLE 1

RETURN PERIOD FLOWS

SLOCAN VALLEY

LOCATION	Drainage Area km^2	Flow m^3/s 20-year Daily	20-year Inst.	200-year Daily	200-year Inst.
Slocan River:					
at mouth	3380	665(B)	708(B)	853(B)	900(B)
at WSC station 08NJ013	3290	654(A)	694(A)	835(A)	882(A)
below Little Slocan River	3196	637(B)	679(B)	817(B)	863(B)
above Little Slocan River	2363	485(H)	536(F)	584(H)	645(F)
below Lemon Creek	2137	425(H)	471(F)	534(H)	592(F)
above Lemon Creek	1932	390(H)	434(F)	488(H)	543(F)
at WSC station 08NJ014	1660	341(A)	382(C)	426(A)	450(C)
Slocan Lake: (levels in metres)					
at WSC station 08NJ137		3.36(A)	3.56(E)	3.70(D)	3.80(E)
Lemon Creek:					
at mouth	205	75(B)	90(F)	101(B)	122(F)
at WSC station 08NJ160	178	67(G)	81(F)	91(G)	90(F)

A - Directly from frequency analysis
B - Calculated from estimate at gauging station using $q = nA^{-0.24}$
C - From Slocan Lake estimate
D - From gauge 08NJ014 estimate
E - See text. Arbitrary addition to daily
F - By correlation with daily flows
G - See text. Combination of frequency analysis and transposition
H - See text. Prorated between 08NJ013 and 08NJ014.

in 1968. None of the FREQAN distributions seemed unreasonable so the suggested daily flows are the average of all four distributions.

c) Gauge 8NJ137. The Pearson distributions had K-S factors considerably greater than the other two distributions and were rejected. The 20-year lake stage suggested is the average of the log-normal and the Gumbel, the remaining figures being derived as described below.

d) Gauge 08NJ160. With only 13 years of data, this gauge did not give very stable frequency curves, particularly for instantaneous flows. However, the daily flows estimated from the frequency analysis were very similar to those calculated for this site from gauge 08NJ013 and were therefore accepted.

5. Derived Flow Estimates

For a variety of reasons, several of the flow estimates requested could not be calculated directly from the frequency analysis - e.g. location other then gauged locations and manual gauges for which no instantaneous data are available. The following describe how the flows were estimated.

a) Main Stem Slocan River

The 1982 publication by Inland Waters Directorate "Magnitude of Floods in B.C. and the Yukon Territory" suggests a relationship between unit runoff and basin size for catchments in similar hydrologic regimes. The relationship suggested is of the form $q = nA^{-0.24}$ where q is the unit runoff in $m^3/s/km^2$, n is a constant for the particular hydrologic regime and A is the basin area in square kilometres.

If this is applied to gauge 8NJ013 for $Q=835m^3/s$ ($q = 0.254$), n can be calculated as 1.774. Theoretically, this can than be applied to basins of different sizes throughout the Slocan Valley with the unit runoff increasing as the catchment area decreases. This approach would result in an estimated 200-year unit runoff at the outlet of Slocan Lake of .299 $m^3/sec/km^2$. However, the frequency analysis of the gauge at this location suggests a 200-year unit runoff of only 0.257 $m^3/sec/km^2$ which is undoubtedly due to the attenuating effect of Slocan Lake. As a result, flows in the Slocan River at the mouth and below Little Slocan River were calculated using the above formula from the flows at gauge 08NJ013 for both daily and instantaneous flows. The daily flows above and below Lemon Creek and above Little Slocan River were prorated to account for the ratios of the various catchments that were upstream of gauge 08NJ014.

Gauges 08NJ014 and 08NJ137 use the same stage records and must, therefore, be considered together. From the published record a stage-discharge relationship could be constructed up to a gauge height of about 3.4 metres and flows of up to 350 m^3/s - flows or stages above this would require extrapolation. Using this relationship showed that the 20-year return period flow and stage selected from the frequency analyses were in close agreement. However, the 200-year lake stage of 3.90 metres suggested by the stage frequency analysis seemed to be high when compared to the 426 m^3/s 200-year flow selected from the flow frequency analysis. Accordingly, the recommended 200-year stage was reduced to 3.70m.

By examination of the records of gauge 8NJ137, the maximum daily change in lake level when the lake was rising and close to the peak was 0.2 m. This was arbitrarily added to the daily 20-year return period lake level to give the suggested 20-year instantaneous flow at gauge 08NJ014. Adding 0.2m to the 200-year return period daily lake stage would result in a flow that seemed to be too high. It was therefore arbitrarily decided that 0.1m would be added to estimate the 200-year instantaneous level and this was used to determine the instantaneous peak 200-year flow out of the lake.

b) Lemon Creek

If the equations relating unit runoff to area derived for gauge 08NJ013 are applied to the 128 km^2 upstream of gauge 08NJ160, flows of 71 and 91m^3/s are calculated for 20 and 200-year return period flows respectively. This happens to coincide fairly closely with the figures suggested by the frequency analysis of the 13 years of data available (63 and 91 m^3/s respectively). The recommended figures in Table 1 are the average of the two methods. Flows at the mouth of Lemon Creek were prorated from gauge 08NJ160 using a formula of the type $Q=nA^{-0.24}$ as described in Section 5a above.

Frequency analyses of the instantaneous peak flows on Lemon Creek were inconclusive and could not be used. A very good correlation (r^2=0.98) exists between the peak daily and instantaneous flows and this relationship was used to estimate the 20 and 200-year return period instantaneous flows.

6. Conclusions

Table 1 gives the recommended flows for the various locations requested. It must be stressed however, that, as described above, many

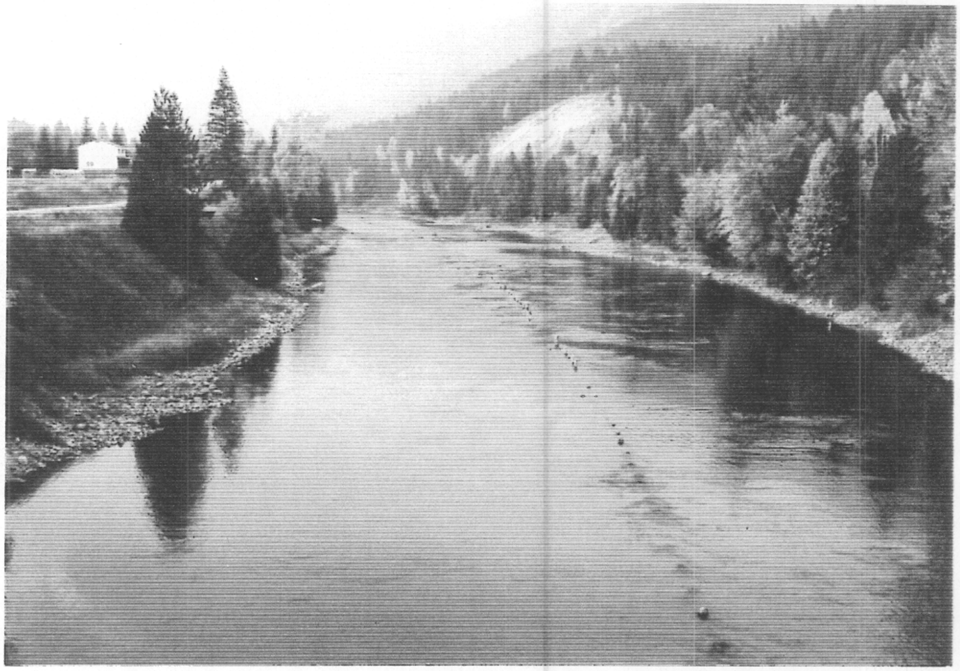
c. the figures were determined by non-rigorous methods and would be impossible to "prove". It is, therefore, stressed that the figures should be used with caution and that sensitivity analyses be conducted wherever possible when these data are used.

R.Y. McNeil, Head
Modelling
Hydrology Section

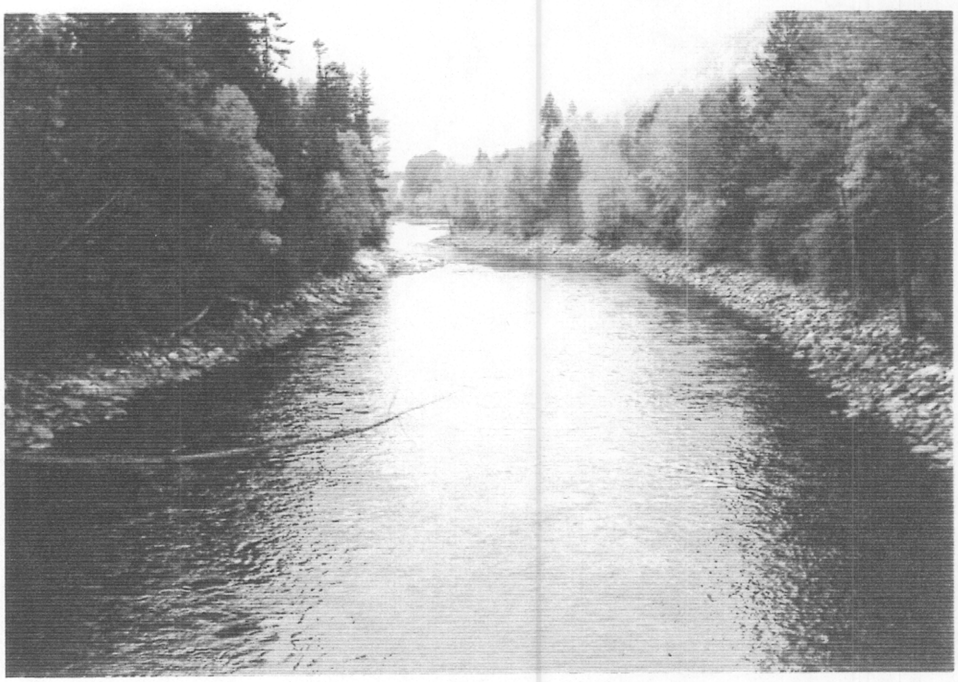
RYMcN/dp

March 1986

PHOTOGRAPHS



Slocan River - View downstream from Crescent Valley
bridge, approximately 6 km from mouth.

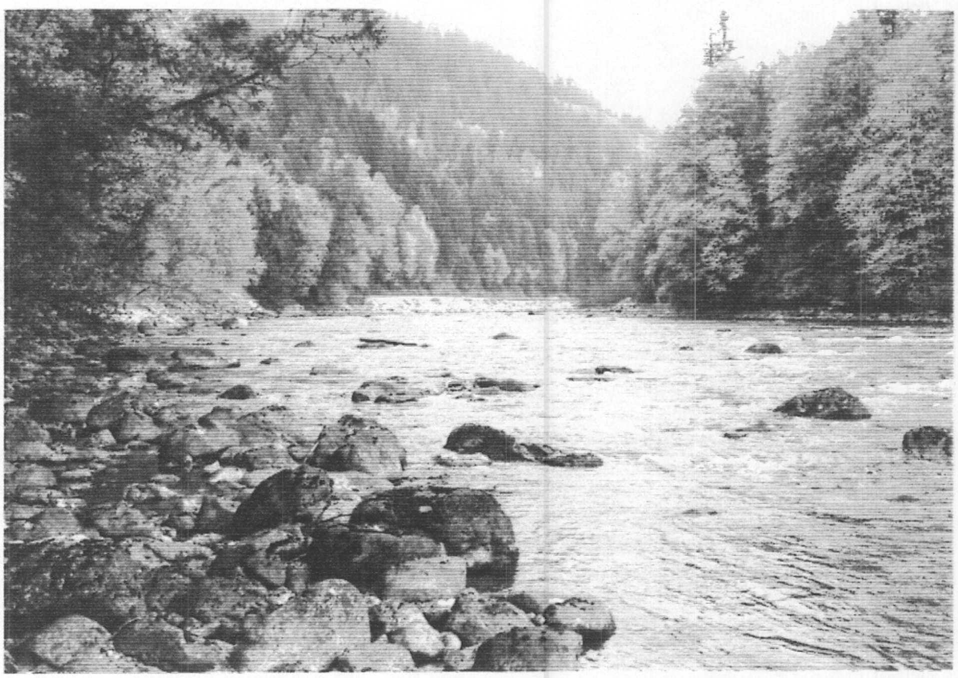


Slocan River - View upstream from Slocan Park bridge,
approximately 16 km from mouth.

Little Slocan River - View upstream from confluence with Slocan River, approximately 22 km from mouth.

Slocan River - View downstream from Vallican bridge, approximately 23.5 km from mouth.

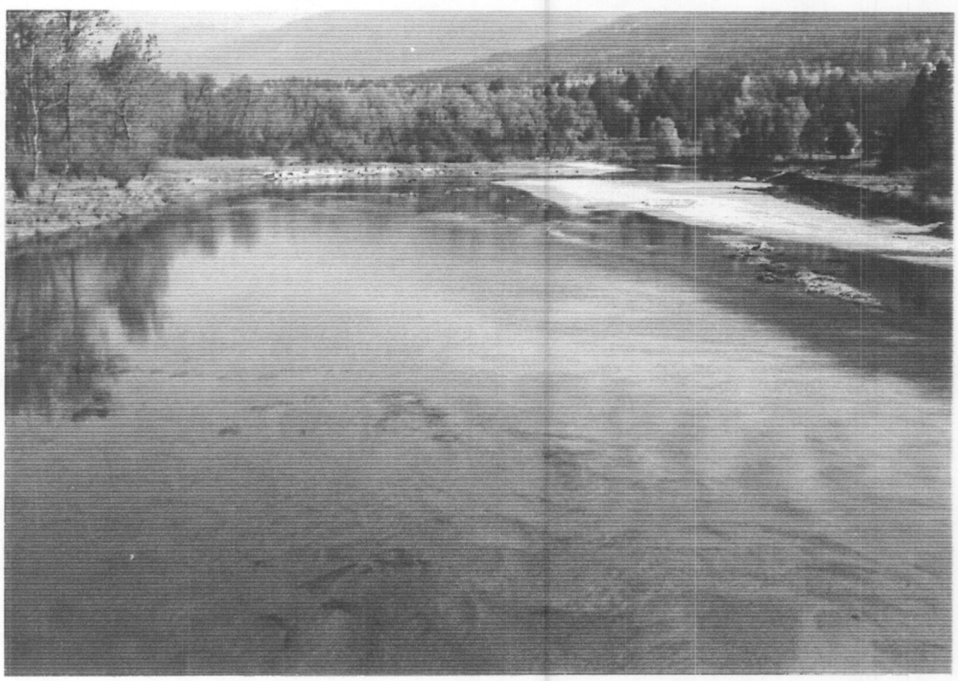
Slocan River - View downstream from left bank, approximately 32 km from mouth.



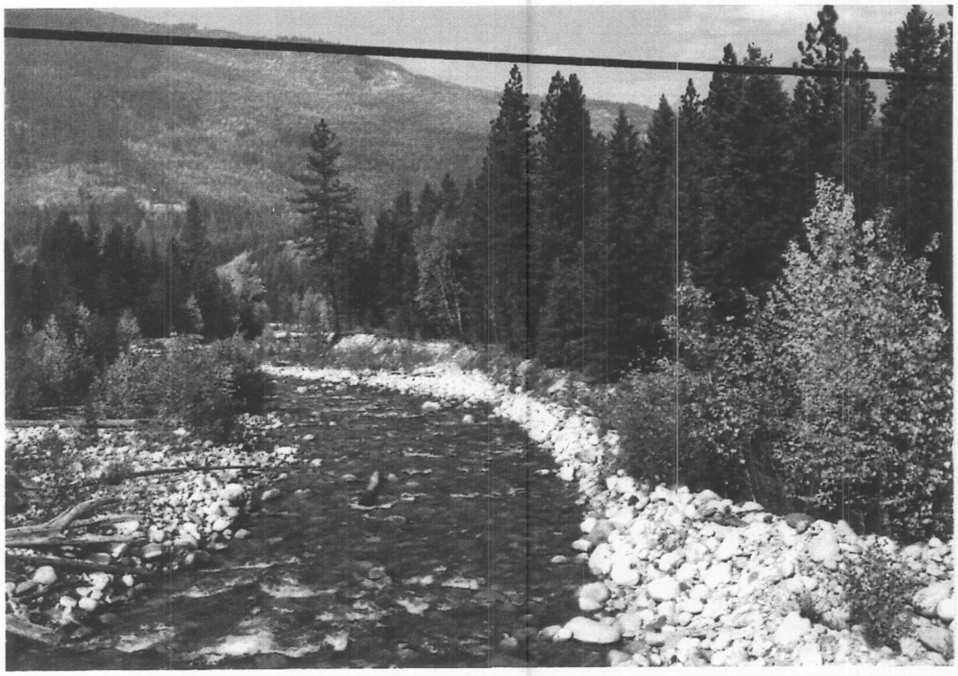
Slocan River - View upstream toward Winlaw bridge, approximately 34 km from mouth.

Slocan River - View upstream at Winlaw bridge (placed summer 1987)
approximately 34.5 km from mouth.

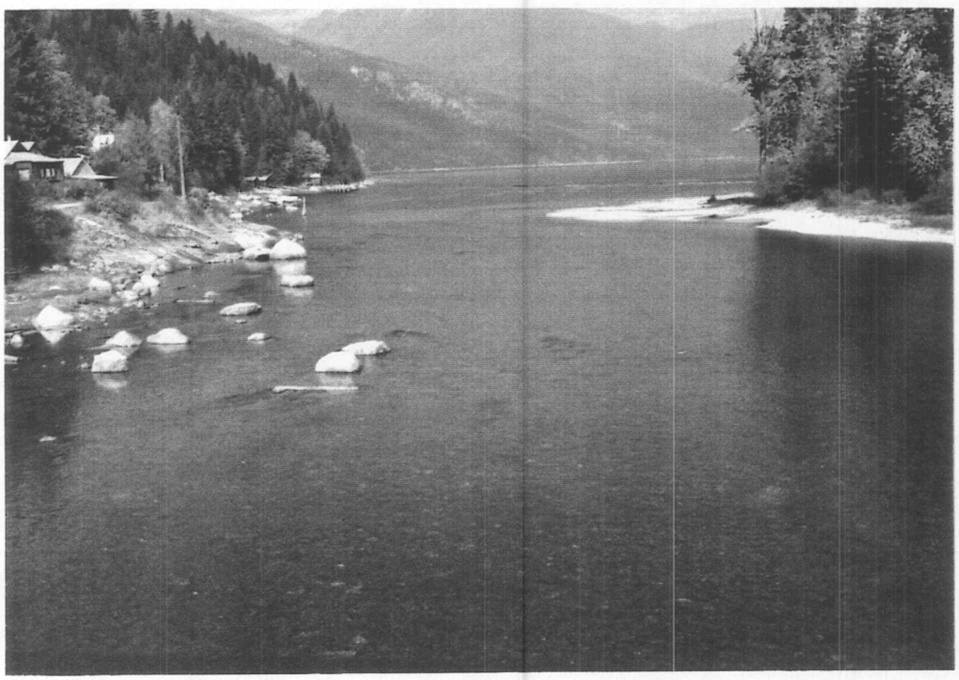
Slocan River - View upstream from site of removed Appledale bridge, approximately 39 km from mouth.



Slocan River - View upstream from Perrys bridge, approximately 43 km from mouth.



Lemon Creek - View downstream from Highway 6 bridge.



Slocan River - View upstream from Slocan City bridge toward Slocan Lake outlet, approximately 57.5 km from mouth.