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WATER MANAGEMENT DIVISION

FLOODPLAIN MAPPING PROGRAM

SIMILKAMEEN AND TULAMEEN RIVERS AT PRINCETON AND SIMILKAMEEN AND ASHNOLA RIVERS AT KEREMEOS

DESIGN BRIEF

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHS

LIST OF DRAWINGS

1 INTRODUCTION

Hay and Company Consultants Inc. were engaged by the B.C. Ministry of Environment, Lands and Parks to undertake studies and prepare floodplain maps for the Similkameen and Tulameen Rivers at Princeton and the Similkameen and Ashnola Rivers at Keremeos. This work is covered under the 1987 joint Federal/Provincial Agreement Respecting Floodplain Mapping.

The Similkameen River drains the Okanagan Range of the Cascade Mountains near the border with Washington State, Figure 1. The river has its headwaters in the United States where it is known as the Pasayten River. The Similkameen drains north towards Princeton where it is joined by the Tulameen River. This principal tributary drains the mountainous region to the west of Princeton. From Princeton the Similkameen turns east then south-east toward Keremeos. The Ashnola River joins the Similkameen just upstream from Keremeos. Downstream of Keremeos, the Similkameen turns south once more and re-enters the United States near Nighthawk.

The Similkameen River is a gravel/cobble bed stream which is fairly well incised in the upper reach near Princeton. The lower reach in the Keremeos area is highly braided and more meandering in places with numerous side channels. The river in this area has been contained by dykes within a broad floodplain.

The floodplain mapping studies described herein cover two separate reaches of the Similkameen River. The upper reach near Princeton covers 11 km of the river including 6 km downstream of the Tulameen River confluence at Princeton. The study reach also includes the first 5 km of the Tulameen River upstream of the confluence. The downstream study reach covers 25 km of the Similkameen River with Keremeos approximately in the middle. The studies also include a short 1.5 km reach of the Ashnola River which is located near the upper end of the lower study reach. The Ashnola River occupies a broad alluvial fan at the confluence with the Similkameen River. A dyke prevents the river from occupying the right side of the fan which forms part of the Ashnola I.R. 10.

Preliminary floodplain mapping was produced for the area in October 1973 based on flood levels extrapolated from air photos of the 1972 flood and observed gauge readings. The preliminary mapping covered the complete reach from Princeton to the U.S. border. Two of the map sheets in the Princeton area were subsequently revised in September 1983.

The present studies were undertaken as the preliminary mapping did not meet the specifications for engineering studies under the 1987 Agreement. The studies take cognizance of the dyking works undertaken in recent years, changes in the river regime, and the updated 1:5000 scale, 1 m contour interval base mapping of the area.

Representative photographs of the study area are included in the report with locations referenced to the survey cross sections or principal features.

2 SOURCES OF INFORMATION

This study made use of extensive river survey information supplied by Mr. R.W. Nichols of the Water Management Division, Ministry of Environment, Lands and Parks. The information package included cross section data, plots of cross sections, photographs of cross sections, VHS video tapes (3) showing river conditions at most river cross sections, bridge sketches and bridge road profiles, 1:5000 base mapping and background reports. High water mark data pertaining to the 1991 flood was also supplied. The river surveys were conducted in August and September, 1992. Base mapping is dated January 1991 based on 1987 air photography. In addition, Water Survey of Canada streamflow records were utilized as well as stage records pertaining to floods. The study also utilized 1:250,000 topographic mapping. A complete listing of data sources and references is included in Appendix 3.

3 FIELD INSPECTIONS

A field inspection was conducted by Mr. R.J. Wallwork on November 7-8, 1994 in order to establish the adequacy of the survey data base. The field inspection allowed Mr. Wallwork to become familiar with the study area and any changes which might have occurred subsequent to compilation of the river survey package. Mr. Wallwork also took site photos for possible inclusion in this report.

Mr. Wallwork met with staff of the Water Management Division's regional office in Penticton. Mr. Brian Symonds, P.Eng., and Messrs. Ray Jubb and Barry Alcock provided additional background information on both the Tulameen and Similkameen Rivers. It was related that the Similkameen River was blocked by a slide at the Similco Mine on October 5, 1992. This blockage lasted four hours, however, there was no sudden release of impounded water as the toe of the slide was comprised of boulders and course material which armoured the bed when downcutting began.

Mr. Wallwork also met with Mr. Bob Stanley in the Keremeos Village office and distributed the Floodplain Mapping Program literature. Two homeowners in the lower Cawston area related that flooding in 1972 covered their properties to depths of one to two feet (0.3 to 0.6 m). Mrs. Vesper, near the end of V.L.A. Ave., drawing No. 91-23-1, reported that the backwater of Keremeos Creek, due to high water in the Similkameen River, led to flooding of her property. She also reported that floodwater was deeper on the far side of the floodplain, furthest from the river. It was observed that local roads in this area are essentially at natural ground level. Mr. E. Marvin, at the end of Beecroft River Ave., drawing No. 91-23-1, reported that high groundwater was a problem in this area. His home is constructed on a pad of crushed rock which extends about one metre above the surrounding land. This pad was placed in order to elevate the house above river flood levels.

A final field inspection was undertaken by Mr. Wallwork on June 7, 1995, in order to check the final draft of the floodplain maps. Some minor revisions were subsequently made to the maps.

4 HYDROLOGY

4.1 Flood Frequency Studies - Methodology

The Water Survey of Canada CFA-88 computer program was utilized for the flood frequency analyses. This program utilizes several frequency distributions including the following:

1. Generalized Extreme Value Distribution (GEV Types 1, 2, or 3)
2. Three Parameter Lognormal Distribution (3-PLN)
3. Log Pearson Type III Distribution (LP III)

The selection of which results to incorporate into the studies was based on a number of considerations including the observed fit, consistency of instantaneous and daily flood estimates, and relative consistency of flood estimates versus drainage area along the study reach.

4.2 Streamflow Records

There are a number of Water Survey of Canada (WSC) stream gauging stations in the study area as listed in Table 1. It was noticed that some of the drainage areas did not appear correct as listed by WSC. The sum of the drainage areas for the Similkameen/Hedley and the Ashnola/Keremeos was found to be greater than the area for the Similkameen/Keremeos which is downstream of the confluence of the previously mentioned stations. WSC acknowledge this discrepancy but have not corrected it due to other priorities. Drainage areas were subsequently measured using 1:250,000 mapping. Not all subcatchment areas required planimetering as some of these were previously derived by the Water Management Division and were supplied to Hayco along with the 1972 historical flood data for the Similkameen. The required drainage areas along the study reach were also evaluated as these were required during the HEC-2 analysis. The revised drainage areas are listed in Table 2.

Table 1
WSC Stream Gauging Stations

Name	Station	Drainage Area km^2	Record
Tulameen River at Princeton	08NL024	1760	1951-1993 43 yr (d), 19 yr (i)
Similkameen River at Princeton	08NL007	1850	1914-17,1939-92 57 yr (d), 17 yr (i)
Similkameen River near Hedley	08NL038	5590	1965-1993 29 yr (d), 28 yr (i)
Similkameen River near Keremeos	08NL006	5960	1914-1932 18 yr (d)
Similkameen River near Nighthawk	08NL022	9190	1929-1993 65 yr (d), 60 yr (i)
Ashnola River near Keremeos	08NL004	1050	1915-18,1947-93 51 yr (d), 3 yr (i)

4.3 Flood Frequency Analysis

The frequency estimates for the various gauging stations are listed below in separate tables. In most cases, the Three-Parameter Lognormal estimates were found to give the best fit or as good a fit as any of the alternate methods. Unless otherwise noted, the 3-PLN estimates are given in the following tables.

Table 2
Drainage Areas Along Study Reach

Name	Station	Drainage Area km^2
Tulameen River at Princeton	08NL024	1760
Similkameen River at Princeton	08NL007	1850
Similkameen River below Princeton	-	3610
Similkameen River below Allison Creek	-	4190
Similkameen River near Hedley	08NL038	5590
Similkameen River above Ashnola	-	6330
Similkameen River near Keremeos	08NL006	7380*
Similkameen River above Keremeos Ck.	-	7490
Similkameen River below Keremeos Ck.	-	7700
Similkameen River near Nighthawk	08NL022	9190
Ashnola River near Keremeos	08NL004	1050

* WSC list this drainage area as 5960 km^2. Revised by Hayco.

Table 3
Tulameen River at Princeton (08NL024)
Flood Estimates (m^3/s)

Return Period Years	Max. Daily Flood m^3/s	Max. Inst. Flood m^3/s	I/D Ratio
2	196	222	1.133
5	248	292	1.177
10	280	334	1.193
20	309	372	1.204
50	344	420	1.221
100	370	454	1.227
200	395	487	1.233
500	427	530	1.241

The 3-PLN frequency distribution provided a good fit to the flood data for the Tulameen River at Princeton. The ratio of instantaneous to daily flood peaks was also consistent throughout the range in return periods. The I/D ratio increased with increasing return period as was to be expected, see Table 3 above.

It will be noted, in the following Table 4, that the maximum instantaneous flood estimates for the Similkameen River at Princeton are unrealistic. For all but the two year return period, the 3-PLN daily flood estimates are greater than the 3-PLN instantaneous flood estimates which is impossible. This anomaly is common to all of the other frequency distributions. The problem can be attributed to the relative lengths of the two sets of flood records. There are 57 years of daily flood records but only 17 years of maximum instantaneous floods. Also the record flood of 1972 was part of the maximum daily flood series but was not part of the maximum instantaneous flood series. Consequently the instantaneous flood frequency curve was much flatter than it would have been if this record flood had been included in the series. It was therefore decided that the instantaneous flood estimates for this station would be determined by factoring up the daily flood estimates by appropriate I/D ratios derived from the station records. The average I/D ratio of 1.119, based on 17 years of records, was used for the 20-year instantaneous flood estimate. The average ratio for the highest three instantaneous floods, 1.124, was used for the 200-year instantaneous flood estimate.

Table 4
Similkameen River at Princeton (08NL007)
Flood Estimates (m^3/s)

Return Period Years	Max. Daily Flood m^3/s	Max. Inst. Flood m^3/s	I/D Ratio
2	206	207	1.005
5	287	273	0.951
10	338	315	0.932
20	387	353	0.912
50	449	401	0.893
100	495	436	0.881
200	541	471	0.871
500	601	516	0.859

The 3-PLN distribution provided a good fit to the data for the Similkameen River at Hedley, however, the 1972 flood was identified as a high outlier in the daily flood series. Minor adjustments were made to the Similkameen/Hedley flood estimates, Table 5, during the subsequent regional analysis.

Table 5
Similkameen River Near Hedley (08NL038)
Flood Estimates (m^3/s)

Return Period Years	Max. Daily Flood m^3/s	Max. Inst. Flood m^3/s	I/D Ratio
2	392	441	1.125
5	519	587	1.131
10	600	679	1.132
20	676	765	1.132
50	772	875	1.133
100	843	956	1.134
200	914	1040	1.138
500	1010	1140	1.129

Table 6
Similkameen River near Keremeos (08NL006)
Flood Estimates (m^3/s)

Return Period Years	Max. Daily Flood m^3/s	Max. Inst. Flood m^3/s	I/D Ratio
2	451	NA	NA
5	620	NA	NA
10	706	NA	NA
20	773	NA	NA
50	842	NA	NA
100	884	NA	NA
200	918	NA	NA
500	955	NA	NA

The Similkameen River near Keremeos had only daily flood records available for the period 1914-1931. The frequency estimates for this station were suspect as all of the distributions were upper bounded by a value close to the maximum estimate. The estimates given in Table 6 above are for the LP III distribution which gave the largest values. The other frequency distributions resulted in extreme flood estimates which were smaller than the corresponding estimates for the upstream gauge at Hedley. It was noticed that the data displayed a strong negative skew (C.S. = -0.5292) which could account for the low estimates. A comparison of the 1914-1931 record with the longer 1914-1990 record for the Columbia River at Nicholson (08NA002) indicated that the earlier period had nearly the same average flood as the longer record, consequently the low estimates must be due to the negative skew, rather than uncertainty in the mean flood. The record for the Similkameen/Keremeos station was also relatively short, covering only 18 years. This record would be long enough to estimate the 20-year flood, however, estimates for the higher return periods were subsequently derived from a regional approach.

The Ashnola River near Keremeos had 51 years of daily floods but only 3 years of instantaneous records. The 3-PLN estimates were selected for the daily floods listed in Table 7.

Table 7
Ashnola River Near Keremeos (08NL004)
Flood Estimates (m^3/s)

Return Period Years	Max. Daily Flood m^3/s	Max. Inst. Flood m^3/s	I/D Ratio
2	67.9	NA	NA
5	105	NA	NA
10	134	NA	NA
20	165	NA	NA
50	208	NA	NA
100	244	NA	NA
200	282	NA	NA
500	337	NA	NA

The average of the three I/D ratios (1.17) was used to estimate the 20-year maximum instantaneous flood (193 m^3/s) while the highest I/D ratio was used for the 200-year flood estimate (338 m^3/s).

Table 8
Similkameen River near Nighthawk (08NL022)
Flood Estimates (m^3/s)

Return Period Years	Max. Daily Flood m^3/s	Max. Inst. Flood m^3/s	I/D Ratio
2	447	460	1.029
5	628	642	1.022
10	748	768	1.027
20	863	892	1.034
50	1010	1060	1.050
100	1120	1190	1.063
200	1240	1320	1.065
500	1390	1500	1.079

The flood estimates for the long-term Similkameen River near Nighthawk station are listed above in Table 8. These estimates are based on 65 years and 60 years, respectively, for the maximum daily and maximum instantaneous floods. The flood frequency plots for these records fitted the data well and consequently it was decided to give the most weight to these flood estimates when undertaking the regional analysis discussed below.

4.4 Regional Analysis

A regional approach was undertaken in order to obtain consistency in the flood estimates throughout the study reach. This analysis also took into account the consistency in the I/D ratios both with respect to return period and drainage area.

The 20-year and 200-year maximum daily flood estimates were plotted on log-log paper versus catchment drainage area, Figure 2. The 20-year flood estimates along the main stem of the Similkameen River were found to lie on a straight line, however, estimates for the tributaries plotted low. A line fitted through these main stem points corresponded to an areal adjustment exponent of 0.500. The 200-year flood estimates for the Princeton and Nighthawk stations were used as the basis for the 200-year trend line, corresponding to an areal adjustment exponent of 0.517. These exponents were used to develop the maximum daily flood estimates for the other locations along the study reach, both gauged and ungauged, as listed in Table 9. The formula used to develop these estimates was as follows:

$$Q_2 = Q_1 (A_2/A_1)^n$$

where Q_1 = flow at gauged location
Q_2 = flow at desired location
A_1 = drainage area at gauged location
A_2 = drainage area at desired location
n = areal adjustment exponent

The 20-year and 200-year maximum instantaneous flood estimates were somewhat more difficult to establish from the regional analysis due to the limitations in the data base. Only the long-term station at Nighthawk had sufficient records for developing the 200-year estimates with confidence. It was decided that the best approach would be to establish the estimates for the Similkameen/Princeton station based on maximum daily flood estimates, factored up by appropriate I/D ratios derived from the station records. The I/D ratios subsequently chosen were 1.119 and 1.124 for the 20-year and 200-year return periods, respectively. The areal adjustment exponents corresponding to the above maximum instantaneous flood frequency estimates were 0.4509 and 0.4836 for the 20-year and 200-year estimates, respectively, Figure 3. The flood frequency estimates derived from the above analysis are listed in Table 9.

Table 9
Design Flood Estimates

Location	Drainage Area km^2	20-Year Daily Flood m^3/s	20-Year Max. Inst. Flood m^3/s	20-Year I/D Ratio	200-Year Daily Flood m^3/s	200-Year Max. Inst. Flood m^3/s	200-Year I/D Ratio
Tulameen at Princeton	1760	309	372	1.204	395	487	1.233
Similkameen at Princeton	1850	387	433	1.119	541	608	1.124
Similkameen below Princeton	3610	532	585	1.10	764	840	1.099
Similkameen below Allison Ck.	4190	583	626	1.074	826	903	1.093
Similkameen near Hedley	5590	676	713	1.055	959	1038	1.082
Similkameen above Ashnola	6330	716	754	1.053	1023	1102	1.077
Similkameen near Keremeos	7380	773	808	1.045	1107	1187	1.072
Similkameen above Keremeos Ck.	7490	779	813	1.044	1116	1196	1.072
Similkameen below Keremeos Ck.	7700	790	824	1.043	1132	1212	1.071
Similkameen near Nighthawk	9190	863	892	1.034	1240	1320	1.065
Ashnola River	1050	165	193	1.17	282	338	1.200

It should be noted that the regional approach resulted in some minor adjustments to some of the short intermediate station estimates. For example, the Similkameen River at Hedley had 200-year estimates of 914 m^3/s and 1040 m^3/s for the daily and maximum instantaneous floods, respectively, based on frequency analysis of station records. The daily estimate was increased slightly to 959 m^3/s as a result of the regional analysis which gives more weight to the long-term station records. The instantaneous estimate was essentially unchanged, the regional approach yielding an estimate of 1038 m^3/s.

4.5 Return Period of 1972 Flood

The 1972 flood appears to have been close in magnitude to the 200-year event in the lower study reach as indicated in Table 10.

Table 10
1972 Flood - Return Periods

Location	200-Year Estimates		1972 Recorded		1972 Return Period
Ashnola River near Keremeos	282 d	338 i	170 Ed		~ 22 years
Tulameen at Princeton	395 d	487 i	374 d		110 years
Similkameen at Princeton	541 d	608 i	476 d		76 years
Similkameen near Hedley	914 d * 959 d **	1040 * 1038 **	929 d	1020 i	~ 200 years
Similkameen near Nighthawk	1240 d	1320 i	1270 d	1300 i	~ 200 years

* Table 5 ** Table 9

The 1972 floods on the Similkameen and Tulameen Rivers at Princeton had return periods of approximately 76 years and 110 years, respectively. The combination of these extreme floods resulted in a higher return period flood for the lower reaches of the river.

It therefore appears that in 1972 the lower study reach, in the Keremeos area, experienced a flood very close in magnitude to the 200-year design event while the upper study reach experienced a flood closer to the 100-year event.

The 1972 flood on the Ashnola River has a return period of approximately 22 years so the lower portion of the Similkameen River catchment does not appear responsible for the record floods in the Keremeos area, rather these floods are attributable to the large floods in the upper Similkameen catchment.

4.6 Historical Data

The 1972 flood, as discussed in section 4.5, is the flood of record in the Princeton and Keremeos area. Flood stage at Princeton was approximately 0.2 to 0.25 m higher than it was during the 1948 flood as reported by the Province newspaper, May 31, 1972. Many of the smaller creeks in the area overflowed their banks or cut new channels. Twenty Mile Creek, also known as Hedley Creek, damaged bridges and destroyed three houses. The Paul Creek Bridge, across the Similkameen River upstream of the lower study reach, was nearly lost during the 1972 flood. Floodwaters touched the lower chord of the bridge and the south end shifted by about one metre. The Penticton Herald reported that the Highways Department had considered dynamiting the bridge to prevent it from collapsing and causing a jam at other bridges down the river. Seepage and rising floodwaters threatened Princeton where dykes had to be raised in a race against the river. A wall of sandbags prevented the Tulameen River from entering the Riverside Motel, see AIII-3, item 4B.

At Keremeos, holes to 0.25 m developed in some of the dykes near the west end of the town which required emergency repairs, Province newspaper, May 31, 1972. Seepage through the dykes was also a major problem. Roads in the area were flooded and the Similkameen River spread to 0.8 km in width in the reach from just west of Keremeos to Cawston. At the Ashnola River Road Bridge, known as the "red bridge", drawing No. 91-23-5, floodwaters came within about one metre of the lower chord. Several local roads flooded in the Cawston area including V.L.A. Avenue and Coulthard Avenue, drawing No. 91-23-2. Highway No. 3 was also flooded south of Cawston.

5 HYDRAULIC ANALYSIS - SIMILKAMEEN AND TULAMEEN RIVERS AT PRINCETON

5.1 Model Calibration

The U.S. Army Corps of Engineers HEC-2 Water Surface Profiles computer program, Version 4.6.2, May 1991, was utilized in the water surface profile analysis, as implemented by Haestad Methods. The Haestad Methods version of this program, HM Version 6.52, was an extended version which allowed for up to 400 ground points (GR points) in each cross section.

The HEC-2 water surface profile model of the Similkameen and Tulameen Rivers at Princeton was developed from 37 surveyed cross sections on the Similkameen River and 22 cross sections on the Tulameen River. There is a highway bridge crossing on the Similkameen plus bridge piers from an abandoned railway crossing. On the Tulameen there are two highway bridge crossings plus two abandoned railway crossings, one of which is comprised of only the bridge piers. Portions of the riverbank are dyked on both rivers. Fifteen high water marks were surveyed on the Similkameen River by Flood Hazard Identification staff in June 1991. These high water marks were attributed to the May

1991 flood. Additional high water marks were located at the time of survey. The Flood Hazard Identification staff did not survey any high water marks on the Tulameen River, except near the confluence, though there were high water marks identified at the time of survey. In addition, flood stage readings were available for WSC gauges 08NL007 and 08NL024 on the Similkameen and Tulameen Rivers, respectively.

A skew adjustment was applied to cross section 22 on the Similkameen and to cross section 19 on the Tulameen, as these sections were not oriented perpendicular to the flow. As both the Similkameen and Tulameen cross sections were combined into a single HEC-2 model, the Tulameen cross section numbers were increased by 100 in order to distinguish them from the Similkameen cross sections. Cross sections were extended to the limit of the floodplain using the 1:5000 base mapping. The non-effective portions of the floodplain, behind the dykes, were excluded from the analysis by means of X3 cards. This approach represented conditions with the dykes in place and the overbank behind the dyke would only become effective if the dyke crest were exceeded by the calculated flood levels. A subsequent analysis with X3 cards removed was undertaken to estimate flood levels in the absence of dykes.

The model included bridge data, lower chord and minimum road elevations. The bridges were not rigorously modelled as floods were expected to pass without contacting the lower chord. This assumption, based on data from the 1972 flood, was borne out in the subsequent analyses. The contraction and expansion coefficients, 0.1 and 0.3, were increased to 0.3 and 0.5, respectively, in the vicinity of the bridges.

The calibration of the Similkameen reach of the model was conducted assuming that all of the high water marks were attributable to the 1991 flood which peaked at 284 m^3/s on May 20 at the Princeton gauge. This flood corresponded to flows of 535 m^3/s below the Tulameen confluence and 573 m^3/s below the Allison Creek confluence, as determined from the 20-year maximum instantaneous flood ratios derived in Section 4. The resulting model provided a reasonably good representation of the known flood profile, as represented by the aforementioned high water mark data, the maximum deviation being 0.12 m at cross section 19, according to trash line data. The model was within 0.02 m at the gauge, section 20.

The calibration of the Tulameen reach of the model was complicated by the fact that there had been two large floods prior to the July-August 1992 survey and it was not clear which flood had been responsible for the high water marks. The Tulameen River peaked on May 19, 1991 at 301 m^3/s. An earlier flood occurred on November 10, 1990 when the Tulameen peaked at 406 m^3/s. The approach subsequently adopted was to first estimate initial values of Manning's n from the site photos and then run the model using both the 1990 and 1991 floods to ascertain which flood was most likely responsible for each of the high water marks. Once this had been determined, the model was subsequently calibrated to match the appropriate flood and high water mark data. The resulting model provided reasonable agreement to one or the other of the floods, with deviations of 0.17 m or less with the exception of section 6 (ie. 106). Here the known high water mark corresponds to a water level less than or equal to critical depth for either of the two floods. In any event, the adopted calibration results in conservative flood level predictions at this location. The model also provides good agreement at the gauge (08NL024), section 12, for both floods, deviations being 0.03 m and 0.01 m for the 301 m^3/s and 406 m^3/s flood flows, respectively.

The adopted model had Manning's n values which varied from 0.022 to 0.056 in the channel and 0.050 to 0.120 in the overbank areas. The variability in the n values reflects channel/overbank conditions and achieved a reasonable calibration as discussed above. It should be noted that the average n value is used to determine losses between sections so the large swings in apparent channel roughness do, in fact, average out in the model calculations. Overbank roughness was varied to represent fields, lightly treed areas and heavily treed areas. The model did not result in critical depth at any of the cross sections at the calibration discharge.

5.2 Sensitivity Studies

5.2.1 Discharge

The sensitivity of the calibrated model to variations in discharge was investigated by means of a multiple flow run in which the 200-year instantaneous discharge was increased by 10%, 20% and 30% (see HEC-2 Study File: Similkameen and Tulameen Rivers at Princeton). The starting water level in each case was determined by the slope-area method, with the starting energy slope of 0.0035 derived from the model calibration run.

The profile is fairly steep in places and critical depth was indicated at several locations in the study reach, namely at sections 19, 20, 24, 26, 28, 32 and 34 on the Similkameen as well as at sections 7 and 22 on the Tulameen. Not all flows resulted in critical depth at each of the above sections.

The model was fairly sensitive to discharge, a 30% increase in flow resulted in stage increases ranging from zero at cross section 27 to 0.81 m at cross section 4 on the Similkameen River. Corresponding stage changes on the Tulameen River ranged from 0.24 m at cross section 17 to 0.74 m at cross section 7. Stage changes on the Similkameen were influenced by whether or not the overbank areas behind dykes became effective at higher discharges. Activation of these overbank areas could result in lower stage at higher flow under some conditions. The model can therefore become unstable when the calculated water levels are close to the elevation of the top of the dykes. These anomalies are evident only for the 20% and 30% flow increases. With a 10% flow increase, the stage increases at each of the Similkameen sections were positive and ranged from 0.02 m at cross section 19 to 0.26 m at cross section 3.

5.2.2 Roughness

The sensitivity of the calibrated model to changes in bed roughness was also investigated by means of a multiple "n" run. The calibrated model roughness values were increased by 20% and 40% with the 200-year mean daily discharge. Once again, the activation of the overbank areas behind dykes had a large effect on the resulting profile changes on the Similkameen River. The model was fairly sensitive to channel roughness, a 40% increase in Manning's n resulted in stage increases which ranged from 0.05 m at cross section 27 to 0.84 m at cross section 1 on the Similkameen River. Corresponding stage changes on the Tulameen River ranged from a low of 0.25 m at cross section 22 to a high of 0.60 m at cross section 12. The largest stage changes occur in the most confined reaches of the river. With a 20% increase in roughness, all but one of the stage changes at the Similkameen River cross sections were positive and ranged from a low of 0.06 m at cross section 27 to 0.51 m at cross section 13. A negative stage change of 0.10 m was indicated at cross section 28.

5.3 Designated Flood Level and Freeboard Requirements

The flood levels shown on the drawings, as listed on page 21, generally consists of the computed 200-year instantaneous peak profile plus 0.3 m freeboard, or the computed 200-year mean daily peak profile plus 0.6 m freeboard, whichever level is higher; or as deemed advisable if special conditions are apparent. Stated another way, unless the instantaneous profile is 0.3 m or more above the maximum daily profile, the maximum daily profile plus 0.6 m freeboard allowance will govern. Freeboard is provided as a contingency allowance to account for uncertainty in the flood estimates and in the flood profile calculations and for changing conditions such as bed aggradation.

The 200-year mean daily flood profile plus 0.6 m freeboard allowance was found to govern the flood profile determination throughout most of the study reach. Exceptions were at cross sections 13, 28, and 30 on the Similkameen River; and cross sections 6 to 15 inclusive, and cross section 20, on the Tulameen River. Tabulated values of the flood profiles for the Similkameen and Tulameen Rivers at Princeton, including freeboard, are listed in Appendix 1. Flood profiles for the Similkameen and Tulameen Rivers at Princeton, including freeboard, are shown on Figures 4 and 5, respectively.

The freeboard allowance added to the designated flood level therefore appears adequate to accommodate a 200-year instantaneous flow increase of approximately 14% to 59%, depending on location. The freeboard allowance would also be adequate to accommodate an increase in roughness of between 25% and 200% in conjunction with the 200-year mean daily flood. The upper limits of either of the above sensitivity test ranges should be treated with caution as results have been compromised by the previously mentioned dyke modelling anomalies.

Interpolated flood levels at one metre spacing were derived from the designated flood profiles including freeboard, Figures 4 and 5, and were used to draw flood level isograms on the enclosed floodplain maps. A separate dyke breach analysis was used to guide the extension of the flood level isograms in floodplain areas behind the river dykes. This analysis is discussed in Section 5.4.

Twenty year flood levels, including freeboard, were derived in a similar manner and noted on the floodplain maps. The dyke breach analysis did not include the 20-year flood event as it was considered extremely unlikely for such an event to precipitate a breach. In any event, only one set of flood level isograms can be shown on the drawings.

5.4 Extension of Flood Level Isograms Behind Dykes

The HEC-2 model was modified by removing all of the X3 cards which allowed flow to occupy the entire river valley including the floodplain areas behind the dykes. The dykes became, in effect, islands in the stream. Tests were conducted for both the 200-year maximum instantaneous and 200-year mean daily flood flows. The governing flood profile behind the dykes was then determined in a manner similar to that used to determine the designated flood profile in the main channel, as described in Section 5.3. It turned out that the 200-year mean daily flood profile plus 0.6 m freeboard governed the designated flood profile behind the dykes at most locations.

Interpolated flood levels at one metre spacing, including freeboard, were determined for the areas behind the dykes. The main channel flood level isograms were deflected upstream, in most cases, to reflect the lower flood levels resulting from the added conveyance of overbank areas. The exception is where breach flows could be trapped behind the dyke and pond to the crest level of the dyke where it ties into high ground further downstream. In such cases the pond level would be slightly above the downstream dyke crest level. There are two areas where this occurs, on the right bank near cross section 7 where flow could be trapped behind Highway 3 (drawing 91-22-2) and at the apex of the V formed at the confluence of the Similkameen and Tulameen Rivers (drawing 91-22-1). Elevated flood levels have been noted in both of these areas.

6 HYDRAULIC ANALYSIS - SIMILKAMEEN AND ASHNOLA RIVERS AT KEREMEOS

6.1 Model Calibration

The HEC-2 water surface profile model of the Similkameen and Ashnola Rivers at Keremeos was developed from 54 surveyed cross sections on the Similkameen River and 7 cross sections on the Ashnola River. There are three highway bridge crossings on the Similkameen River, however, the uppermost bridge is abandoned. There are no bridge crossings of the Ashnola River in the study reach which crosses an alluvial fan. The Similkameen River is extensively dyked in this reach and much of the right bank of the Ashnola River reach is also dyked. A total of 35 high water marks were identified on the Similkameen River by Flood Hazard Identification staff in June 1991. These high water marks were attributed to the May 1991 flood. Additional high water marks were located at the time of survey, including several on the Ashnola River. There are no active WSC gauges within the Keremeos study reach.

A skew adjustment was applied to cross sections 31 and 32 on the Similkameen River (drawing 91-23-5), corresponding to the "red bridge" which is not oriented perpendicular to the flow. The Similkameen and Ashnola River cross sections were combined into a single model so it was necessary to increase the Ashnola cross section numbers by 100 in order to distinguish them from the Similkameen cross sections. Once again, cross sections were extended to the limit of the floodplain using 1:5000 base mapping. Non-effective portions of the floodplain, behind dykes, were excluded from the analysis by means of X3 cards which only permitted overbank flow if the dyke crest elevation were exceeded by the calculated flood levels. A separate analysis was used to estimate flood levels in the event that the dykes were breached, as discussed in Section 6.4. Bridges were modelled using the same approach taken in Section 5.1.

The model was calibrated assuming all of the high water marks were attributable to the 1991 flood. This flood peaked at 653 m^3/s on May 20 at the gauge near Hedley which is upstream of the study reach. Likewise, this flood peaked at an estimated discharge of 732 m^3/s on May 22 at the downstream gauge at Nighthawk. There were no active gauges within the Keremeos study reach. Based on the regional analyses, Section 4, the corresponding flood at the downstream limit of the study reach below Keremeos Creek was estimated at 703 m^3/s. Just upstream of Keremeos Creek, the flood was estimated at 698 m^3/s and above the Ashnola River the flood was 672 m^3/s. The flood peak on the Ashnola River was estimated at 129 m^3/s on May 20 based on the mean daily flood flow factored by 1.17.

The resulting model provided a reasonably good approximation of the known flood profile, as depicted by the high water mark data, the maximum deviation being 0.20 m. Some anomalies were noted in the high water marks at cross sections 51 and 54 on the Similkameen and cross section 2 on the Ashnola where the deviations from the calculated profile were on the order of one metre. These were discounted as the marks represented water levels less than critical depth at these cross sections for the assumed calibration flow. A lesser flood was likely responsible for these high water marks. In addition to the above, the surveyed HWM 119 = 395.90 m at cross section 6 is suspect. A value of 396.78 m was interpolated from HWM 12 and HWM 118 and used instead.

The adopted model required the use of flow encroachments at cross sections 1 and 2 in order to limit the conveyance of overbank areas which are effectively isolated from the main channel in spite of the fact that calculated water levels might marginally exceed bank elevations for the main channel. The overbank at cross section 2 was also skewed downstream which magnified its conveyance in an unrealistic manner. Without the use of these encroachment adjustments, the model was unstable in this reach.

The Manning's n values in the Similkameen portion of the model varied from 0.022 to 0.070 in the channel and 0.060 to 0.120 in the overbank areas. As previously mentioned, the average n value is used to determine losses between sections so the large swings in apparent channel roughness will average out in the model calculations. Channel n values to 0.080 were used on the Ashnola River which is quite steep. Manning's n values for overbank areas were estimated from site photos and reference literature.

The profile is considerably flatter than the upper reach near Princeton. Critical depth was assumed only at cross section 1 on the Ashnola River where the flow enters the Similkameen River from a steep alluvial fan.

6.2 Sensitivity Studies

6.2.1 Discharge

The sensitivity of the calibrated model to variations in discharge was investigated by means of a multiple flow run in which the 200-year instantaneous discharge was increased by 10%, 20% and 30% (see HEC-2 Study File: Similkameen and Ashnola Rivers at Keremeos). The starting water level in each case was determined by the slope-area method, with the starting energy slope of 0.0013 derived from the model calibration run.

The large flood discharges resulted in critical depth assumptions at many of the cross sections in the Similkameen River study reach, namely at sections 4, 16, 19, and 21, though not all flows tested resulted in critical depth at these cross sections. As for the calibration flow, critical depth was also indicated for cross section 1 on the Ashnola River at each of the flows in the multiple flow run.

The model was fairly sensitive to discharge, at least in the upper portion of this study reach. A 30% increase in flow resulted in stage increases ranging from 0.13 m at cross section 3 to 0.93 m at cross section 41 which is upstream of a narrow, confined reach on the Similkameen River (drawing 91-23-6). Corresponding stage changes on the Ashnola River ranged from 0.16 m at cross section 6 to 0.29 m at cross section 2 (drawing 91-23-7). Similar to the upper reach near Princeton, stage changes in the lower reach near Keremeos were influenced by the activation of overbank areas behind dykes which could result in lower stage at higher flow in some cases. The model is therefore unstable when the calculated water levels are close to the elevation of the top of the dykes. These anomalies were evident for all of the flow increases above the base case, indicating that in some locations the present dyke system is just barely adequate in terms of containing the 200-year instantaneous flood.

6.2.2 Roughness

The sensitivity of the calibrated model to changes in bed roughness was also investigated by means of a multiple "n" run in which the model roughness values were increased by 20% and 40% in conjunction with the 200-year mean daily discharge. As before, the activation of overbank areas behind dykes, due to overtopping, had a large effect on the resulting profile changes. These dyke effects were found for each of the roughness tests conducted. The model was fairly sensitive to channel roughness in the upper reaches. A 40% increase in Manning's n resulted in stage increases which ranged from 0.23 m at cross section 2 to 1.26 m in the confined reach at cross section 40 (drawing 91-23-6). The preceding profile changes were in areas not affected by dyke overtopping effects between profile runs. Profile changes on the Ashnola River were in the 0.18 m to 0.33 m range for a 40% increase in roughness.

6.3 Designated Flood Level and Freeboard Requirements

The designated flood level was determined as per the methodology given in Section 5.3. The 200-year mean daily flood profile plus 0.6 m freeboard allowance was found to govern the flood profile determination throughout the study reach except for section 40 where the instantaneous profile plus 0.3 m freeboard allowance was just marginally higher. Tabulated values of the flood profiles for the Similkameen and Ashnola Rivers at Keremeos, including freeboard, are listed in Appendix 2. Flood profiles for the Similkameen and Ashnola Rivers at Keremeos, including freeboard, are shown on Figures 6 and 7, respectively.

The freeboard allowance added to the designated flood level therefore appears adequate to accommodate a 200-year instantaneous flow increase of approximately 7% to 120%, depending on location. The freeboard would also be adequate to accommodate an increase in roughness of between 14% and 104% in conjunction with the 200-year mean daily flood. The upper limits of the above sensitivity test ranges should be treated with caution as the results may have been compromised by anomalies in modelling the overbank areas.

Interpolated flood levels at one metre spacing were derived from the designated flood profiles, freeboard included, Figures 6 and 7, and were used to draw flood level isograms on the enclosed floodplain maps. A separate dyke breach analysis was used to guide the extension of the flood level isograms in areas behind the river dykes, as discussed in Section 6.4.

Twenty year flood levels, including freeboard, were derived in a similar manner and noted on the floodplain maps. Once again, the dyke breach analysis did not include the 20-year flood event as such a low return period event would be unlikely to trigger a dyke breach. Also, very little of the floodplain would be active during such an event.

6.4 Extension of Flood Level Isograms Behind Dykes

The approach taken in modelling dyke breaches was more rigorous than that adopted for the upper reach near Princeton, due to a more extensive dyke system and the fact that dykes were often present on both sides of the river. The HEC-2 model was first modified by removing all of the X3 cards which allowed flow to occupy the entire river valley including floodplain areas behind dykes. This test was only conducted for the 200-year mean daily discharge as previous analysis had shown that this governs the designated flood profile determination in the lower study reach. This analysis revealed the potential magnitude and location of dyke breaches and it also gave a good estimate of breach levels in some reaches where only one bank was dyked.

Separate left and right bank dyke breach models were then developed by reassigning the bank stations in order to simulate channel flow in the overbanks. The channel roughness values were also changed to the actual overbank n values used in the regular model. Discharges through the various reaches were varied to represent the likely magnitude of potential breaches. It was recognized that the potential breach flow behind the dyke, at any location, would be governed by the highest upstream breach flow in that particular dyke reach. Breach flows would be trapped behind the dyke and, consequently, could result in elevated water levels compared to the river. These breach water levels were checked to make sure the backwater profile did not exceed the main channel profile at the breach entrance.

The breach profiles derived in the above analysis were used to locate the interpolated flood level isograms at one metre spacing, including freeboard, in the areas behind the dykes. In some locations the lines from the main channel are deflected upstream, where they cross the dyke, and at other locations they are deflected downstream to reflect the breach profile. Elevated flood levels are also indicated where flow could be trapped behind the dykes and pond to the crest level of the dyke where it ties into high ground. Elevated flood levels may occur in these areas and are noted on the floodplain maps in such cases.

7 SPECIAL FLOOD CONDITIONS

7.1 Ice Flows

The Similkameen and Tulameen rivers are subject to ice related problems due to winter and spring break-up of the ice cover. Ice flows can damage riprap bank protection and spill over the banks and cause property damage to nearby buildings, equipment and farmland. Such an event occurred in January 1984 with the ice break-up originating in the Manning Park area of the Similkameen River, upstream of Princeton as well as in the upper reaches of the Tulameen River. Ice damage in the Princeton area resulted when flow ice spilled over the dyked river banks to depths of 1.5 m along Burton Avenue next to the Similkameen River (drawing 92-21-1). Ice flows in the river grounded on gravel bars forming 3 m thick deposits. At the highway bridge, debris was left hanging from the lower chord of the bridge, indicating the potential for a debris jam to damage or destroy the bridge. Upstream of Princeton, at the old railway bridge, the ice flows tilted the central bridge pier, the structure having been previously destroyed in the 1972 flood.

Similar damage occurred along the Tulameen River at Princeton where ice displaced riprap bank protection and necessitated extensive repairs both upstream and downstream of the old Tulameen Bridge. Ice flow damage extended upstream along the right bank past the municipal works yard. Bank repairs were also required on the left bank in the vicinity of the apartment building above the old bridge.

The 1984 ice flows also resulted in damage to bank protection and farm fields downstream of Princeton all the way to the Keremeos-Cawston area. Ice damage occurred at the Weymark, Peterson, McLeod and Lawrence properties in the reach above Keremeos. Ice flows at the Peterson property were up to 6 m thick and carried riprap onto the fields, see AIII-6, item 4C. The riprap was entirely lost along about 200 m of bank at the Lawrence property. At the Weymark property, approximately 5 km south of Princeton, ice flows destroyed fences and irrigation equipment. In the Keremeos area, ice flows damaged riprap in the vicinity of the "white bridge" (drawing 91-23-4). The Copeland, Kyle, Martin and Trotter properties also suffered ice related damage.

7.2 Ashnola Alluvial Fan

The Ashnola River enters the Similkameen River across a wide alluvial fan. The river presently occupies the right limit of the fan in the upper reach where it is contained by high ground on the right bank. A dyke prevents flow from crossing the lower right portion of the fan which is part of the Ashnola I.R. 10.

Flood conditions on an alluvial fan are, by nature, difficult to quantify as bank erosion and aggradation of the riverbed can result in unpredictable channel shifts. While an attempt has been made to quantify flood levels in this reach, caution should be exercised in their interpretation. The flood levels pertain only to the riverbed conditions at the time of the surveys and these can change dramatically as a result of channel shifts and avulsions. The floodplain maps do not show flood level isograms across the floodplain for this reason. The approximate limits of the fan are shown. Similkameen River flood levels and the right limit of the Similkameen River floodplain are shown based on calculated flood levels, freeboard included, from the Similkameen River only. The right limit of the Similkameen floodplain is shown as a dashed line where it intersects the Ashnola River alluvial fan.

8 FLOODPLAIN MAPS

The floodplain maps for the Similkameen River at Princeton are enclosed, Drawing nos. 91-22-1 and 91-22-2 (2 sheets). Also enclosed are the floodplain maps for the Similkameen River at Keremeos, Drawing nos. 91-23-1 to 91-23-7 (7 sheets). The limits of the respective floodplains are shown together with flood level isograms showing approximate lines of equal 200-year flood level (freeboard included) to the edge of the floodplain.

As noted on the drawings, the floodplain limits have not been established on the ground by legal survey and the maps depict open water conditions only. The flood levels behind the dykes were based on analysis of assumed dyke breaches at various locations. Separate dyke breaches were considered for the left and right banks in the lower reach near Keremeos. As noted on the drawings, the flood level isograms have been dashed across the area behind the standard dykes.

9 CONCLUSIONS AND RECOMMENDATIONS

The following recommendations and conclusions are based on our investigations for this study:

1. The floodplain maps prepared for the Similkameen River at Princeton, and similar maps prepared for the Similkameen River at Keremeos, as presented herein, should be designated under the terms of the joint Federal/Provincial Floodplain Mapping Agreement.

2. The floodplain maps should be reviewed and updated as required on the basis of future flood data, assessments of channel aggradation and channel shifts, or other information related to major physical changes in the floodplain.

3. A dyke safety review is recommended to assess the adequacy of the dyke freeboard in terms of the designated flood profile.

4. Dykes should be inspected for possible damage following major ice breakup events.

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Approved by: SRM Gardiner

Dr. S.R.M. Gardiner, P.Eng.

APPENDIX I

TABULATED FLOOD LEVELS (FREEBOARD INCLUDED) SIMILKAMEEN AND TULAMEEN RIVERS AT PRINCETON

SIMILKAMEEN RIVER			
Section Number	Flood Level* m	Section Number	Flood Level* m
1.000	610.67	20.000	635.51
2.000	611.37	21.000	636.68
3.000	612.29	22.000	636.96
4.000	613.66	23.000	637.01
5.000	615.12	24.000	637.33
6.000	616.41	25.000	639.20
7.000	617.72	26.000	640.45
8.000	619.71	27.000	643.10
9.000	620.27	28.000	645.08
10.000	621.88	29.000	647.49
11.000	623.86	30.000	648.95
12.000	624.97	31.000	649.96
13.000	626.88	32.000	652.06
14.000	629.08	33.000	655.34
15.000	630.65	34.000	658.20
16.000	631.27	35.000	661.29
17.000	632.12	36.000	663.82
18.000	632.91	37.000	666.58
19.000	634.25		

* Flood levels as shown on the Floodplain Mapping Drawings. Includes freeboard allowance.

TULAMEEN RIVER			
Section Number	**Flood Level* m**	**Section Number**	**Flood Level* m**
101.000	633.80	112.000	639.56
102.000	633.89	113.000	640.91
103.000	633.93	114.000	642.55
104.000	634.03	115.000	644.00
105.000	634.39	116.000	645.46
106.000	635.40	117.000	646.85
107.000	636.20	118.000	649.65
108.000	636.40	119.000	649.90
109.000	636.50	120.000	650.12
110.000	637.41	121.000	651.10
111.000	638.29	122.000	652.95

* Food levels as shown on the Floodplain Mapping Drawings. Includes freeboard allowance.

APPENDIX II

TABULATED FLOOD LEVELS (FREEBOARD INCLUDED) SIMILKAMEEN AND ASHNOLA RIVERS AT KEREMEOS

SIMILKAMEEN RIVER			
Section Number	Flood Level* m	Section Number	Flood Level* m
1.000	391.68	28.000	423.85
2.000	392.93	29.000	425.21
3.000	394.64	30.000	425.83
4.000	395.51	31.000	426.00
5.000	396.56	32.000	426.17
6.000	397.93	33.000	426.55
7.000	399.05	34.000	427.82
8.000	399.83	35.000	429.05
9.000	401.04	36.000	430.73
10.000	402.29	37.000	431.65
11.000	403.62	38.000	433.05
12.000	404.95	39.000	434.74
13.000	406.16	40.000	436.89
14.000	407.96	41.000	438.57
15.000	409.19	42.000	439.63
16.000	410.40	43.000	440.12
17.000	411.71	44.000	440.15
18.000	412.88	45.000	440.84
19.000	414.39	46.000	441.41
20.000	416.01	47.000	441.86
21.000	416.75	48.000	444.00
22.000	417.01	49.000	444.35
23.000	417.70	50.000	445.69
24.000	419.12	51.000	448.05
25.000	420.06	52.000	448.93
26.000	421.36	53.000	450.30
27.000	422.79	54.000	451.40

* Flood levels as shown on the Floodplain Mapping Drawings. Includes freeboard allowance.

ASHNOLA RIVER	
Section Number	**Flood Level* m**
101.000	446.71
102.000	448.49
103.000	449.45
104.000	451.86
105.000	453.96
106.000	456.27
107.000	461.26

* Includes freeboard allowance.

APPENDIX III

DATA SOURCES AND REFERENCES

REFERENCES

1. Barnes, H.H., 1967. Roughness Characteristics of Natural Channels, U.S. Geological Survey. Water Supply Paper No. 1849.

2. Fax transmittal (Nov. 4, 1994) from Ms. Shelly Bradford, Water Survey of Canada, re: streamflow data to 1993.

3. Hay and Company, November 16 letter to Water Management Division, re: Similkameen Floodplain Mapping, Site Visit - Survey Data Base.

4. Hay and Company, December 8, 1994 letter report to Water Management Division, re: Floodplain Mapping - Similkameen, Tulameen and Ashnola Rivers - Progress Report No. 2 - Flood Frequency Analysis.

5. Hay and Company, January 9, 1995 letter report to Water Management Division, re: Floodplain Mapping - Similkameen, Tulameen and Ashnola Rivers - Progress Report No. 2 - Flood Frequency Analysis (Revised).

6. Hay and Company, January 9, 1995 letter to Water Management Division, re: WMD comments of December 28, 1994 regarding December 8, 1994 letter report on Flood Frequency Analysis.

7. Pilon, P.J., et. al., 1985. Consolidated Frequency Analysis Package - CFA88, Water Resources Branch, Inland Waters Directorate, Environment Canada.

8. Water Survey of Canada, 1992. Surface Water Data Reference Index, Canada 1991. Environment Canada. Inland Waters Directorate. Water Resources Branch.

9. Water Survey of Canada, 1991. Historical Streamflow Summary. British Columbia to 1990. Environment Canada. Inland Waters Directorate. Water Resources Branch.

List of Available Information

Similkameen and Tulameen Rivers at Princeton

1. River Survey - Project 92 24 F056 (July/August 1992) - 2 Volumes

   A. Volume 1 of 2
      a) Two VHS video tapes showing panoramas from all cross sections. Filming starts downstream and moves upstream.
      b) Table of Contents for Volumes 1 & 2.
      c) Drawing 92-21, sheets 1 & 2, showing location and extent of surveyed cross sections and location of survey monuments.
      d) List of elevations of high water marks located by the Flood Hazard Identification Section (see 4.A below).
      e) List of elevations of high water marks located at time of survey.
      f) Monument descriptions.
      g) One 3.5 inch high density double sided disk containing GR data for all cross sections with and without decimals.
      h) Listing of GR data for both watercourses with and without decimals.
      i) Written profiles (left to right), plots (scale H 1:2000 V 1:200) and photographs for Tulameen River cross sections 1 to 22 including bridge detail where applicable.

   B. Volume 2 of 2.
      a) Table of Contents for Volumes 2 & 1.
      b) Written profiles (left to right), plots (scale H 1:2000 V 1:200) and photographs for Similkameen River cross sections 1 to 37 including bridge detail where applicable.

2. Drawings

   A. Prints of Drawing 91-22, sheets 1 & 2, base map sheets for proposed designated floodplain mapping titled "Similkameen River at Princeton", 1:5000 scale, 1m contour interval.
   B. Prints of Drawing 92-21, sheets 1 & 2, titled "Similkameen and Tulameen Rivers at Princeton, Topographic Plan Showing Cross Section Locations" (see 1C above).

3. High Water Marks

A. Binder with photographs and descriptions of 20 high water marks identified by Flood Hazard Identification staff in June, 1991. Drawings 91-22, sheets 1 & 2, and 4987, sheet 2 of 17, also included, show high water mark locations.

4. Miscellaneous**

A. One atlas of enlarged aerial photographs dated June 3, 1972 obtained during the 1972 flood event. These photos are at a scale of approximately 1"=466' and show high flood levels and the location of observed high water marks.
B. One looseleaf binder of 1972 Similkameen and Tulameen River flooding photographs and newspaper clippings.
C. One looseleaf binder of photographs of 1984 Similkameen and Tulameen River ice damage and repairs.
D. Unnumbered drawing, sheets 1 & 2, by R. J. Talbot, dated February 29, 1980, titled "Similkameen River Profile, Pasayten River to.....U. S. Border" and listing cross section and 1972 high water mark chainage and elevation.
E. Taped 1:50,000 NTS mapsheets (2) showing cross section locations referred to in 4D above.
F. Drawing 4987, sheets 1 & 2, entitled "Preliminary Floodplain Mapping, Similkameen River" dated October, 1973. The location of 1972 observed high water marks is shown.

5. Additional Background Information

The following list of information is NOT available from BC Environment unless noted.

A. Report entitled "Similkameen River Basin, An Overview of Water and Related Resources" by D. E. Sherwood, Environment Canada, Environmental Conservation Service, Inland Waters Directorate, Pacific and Yukon Region, Vancouver, B. C., 1983.
B. B. C. Ministry of Transportation and Highways (bridge crossing high water mark data, Princeton and Keremeos).
C. Report from the "Similkameen Spotlight" entitled "Floods and Ice Jams on the Similkameen River from 1948," by Dawn Johnston.
D. Previous floodplain maps and reports for the Similkameen and Tulameen Rivers (available from BC Environment).
E. Similkameen Spotlight (January 31, 1951; May 17 & 31, 1972; November 14, 1990).

6. Additional Information Sources

The following sources should be looked at by the consultant regarding background information on flooding problems in the project area:

- Brian Symonds, Water Management Division, Penticton
- Al Benson, Administrator, Princeton, and former resident of Keremeos
- Dawn Johnston, reporter, Similkameen Spotlight
- Milly Johnston, long-term resident of Keremeos

- Alice Simpson, long-term resident of Keremeos and daughter of an early developer in the Keremeos area
- Larry McKee, Manager, Engineering Structures and Environment, CP Rail, Vancouver (high water mark data from the CPR bridges on the Similkameen and Tulameen Rivers at Princeton).
- Gretchen Lind, researcher for the Keremeos Chamber of Commerce.

** Some of this information also applies to the Similkameen River at Keremeos.

List of Available Information

Similkameen and Ashnola Rivers at Keremeos

1. River Survey - Project 92 27 F052 (September 1992) - 2 Volumes

   A. Volume 1 of 2 - Ashnola River
      a) VHS video tape showing an overview of the area from various locations.
      b) Drawing 92-24, Sheets 1 to 7, titled "Similkameen and Ashnola Rivers at Keremeos, Topographic Plan Showing Cross Section Locations".
      c) Table of Contents
      d) High water mark and water level elevations obtained in June, 1991, and at time of survey.
      e) Water Survey of Canada gauge descriptions.
      f) 3 1/2" floppy disk containing GR data for the Similkameen and Ashnola Rivers with and without decimals.
      g) Listing of GR data for the Similkameen and Ashola Rivers with and without decimals.
      h) Written profiles (left to right) for Ashnola River cross sections 1 to 7 including plots (scale H 1:2000 V 1:100) and photographs.

   B. Volume 2 of 2 - Similkameen River
      a) Table of Contents
      b) Written profiles (left to right) for Similkameen River cross sections 1 to 54 including plots (scale H 1:2000 V 1:100) and photographs plus road profiles, plots and detail for 3 bridges.

2. Drawings

   A. Prints of Drawing 91-23, sheets 1 to 7, base map sheets for proposed designated floodplain mapping titled "Similkameen River at Keremeos", scale 1:5000, 1 metre contour interval.
   B. Prints of Drawing 92-24, sheets 1 to 7, as described in item 1.A.b above.
   C. Drawing 91-10, sheets 1 to 16, and drawing 91-26, sheets 1 to 9, titled "Similkameen River near Keremeos" are "as constructed" plans and profiles of the left and right bank dykes.
   D. Drawing 92-16, sheet 1, titled "Ashnola River Dyke, I.R. No. 10, Plan and Profile, As-Constructed".

3. High Water Marks

A. High water marks identified by staff of the Flood Hazard Identification Section are listed in a blue three-ring binder titled "Similkameen River at Keremeos, 1991 High Water Mark Locations". Photographs and mapsheets showing high water marks not levelled in at the time of identification are included.

4. Miscellaneous**

A. One atlas of enlarged aerial photographs dated June 3, 1972 obtained during the 1972 flood event. These photos are at a scale of approximately 1"=466' and show high flood levels and the location of observed high water marks.
B. One looseleaf binder of 1972 Similkameen and Tulameen River flooding photographs and newspaper clippings.
C. One looseleaf binder of photographs of 1984 Similkameen and Tulameen River ice damage and repairs.
D. Unnumbered drawing, sheets 1 & 2, by R. J. Talbot, dated February 29, 1980, titled "Similkameen River Profile, Pasayten River to....... U. S. Border" and listing cross section and 1972 high water mark chainage and elevation.
E. Taped 1:50,000 NTS mapsheets (2) showing cross section locations referred to in 4D above.
F. Drawing 4987, sheets 1, 2, and 8 to 12 inclusive entitled "Preliminary Floodplain Mapping, Similkameen River" dated October, 1973. Sheets 1 & 2 show the location and elevation of 1972 observed high water marks.
G. Drawing 4987, sheets 10A & 11A, entitled "Similkameen River Topographic Mapping Showing Floodplain Limits, 200 Year Frequency", dated October, 1973.

5. Additional Background Information

The following list of information is NOT available from BC Environment unless noted.

A. Report entitled "Similkameen River Basin, An Overview of Water and Related Resources" by D. E. Sherwood, Environment Canada, Environmental Conservation Service, Inland Waters Directorate, Pacific and Yukon Region, Vancouver, B. C., 1983.
B. B. C. Ministry of Transportation and Highways (bridge crossing high water mark data, Princeton and Keremeos).
C. Report from the "Similkameen Spotlight" entitled "Floods and Ice Jams on the Similkameen River from 1948," by Dawn Johnston.
D. Similkameen Spotlight (January 31, 1951; May 17 & 31, 1972; November 14, 1990).

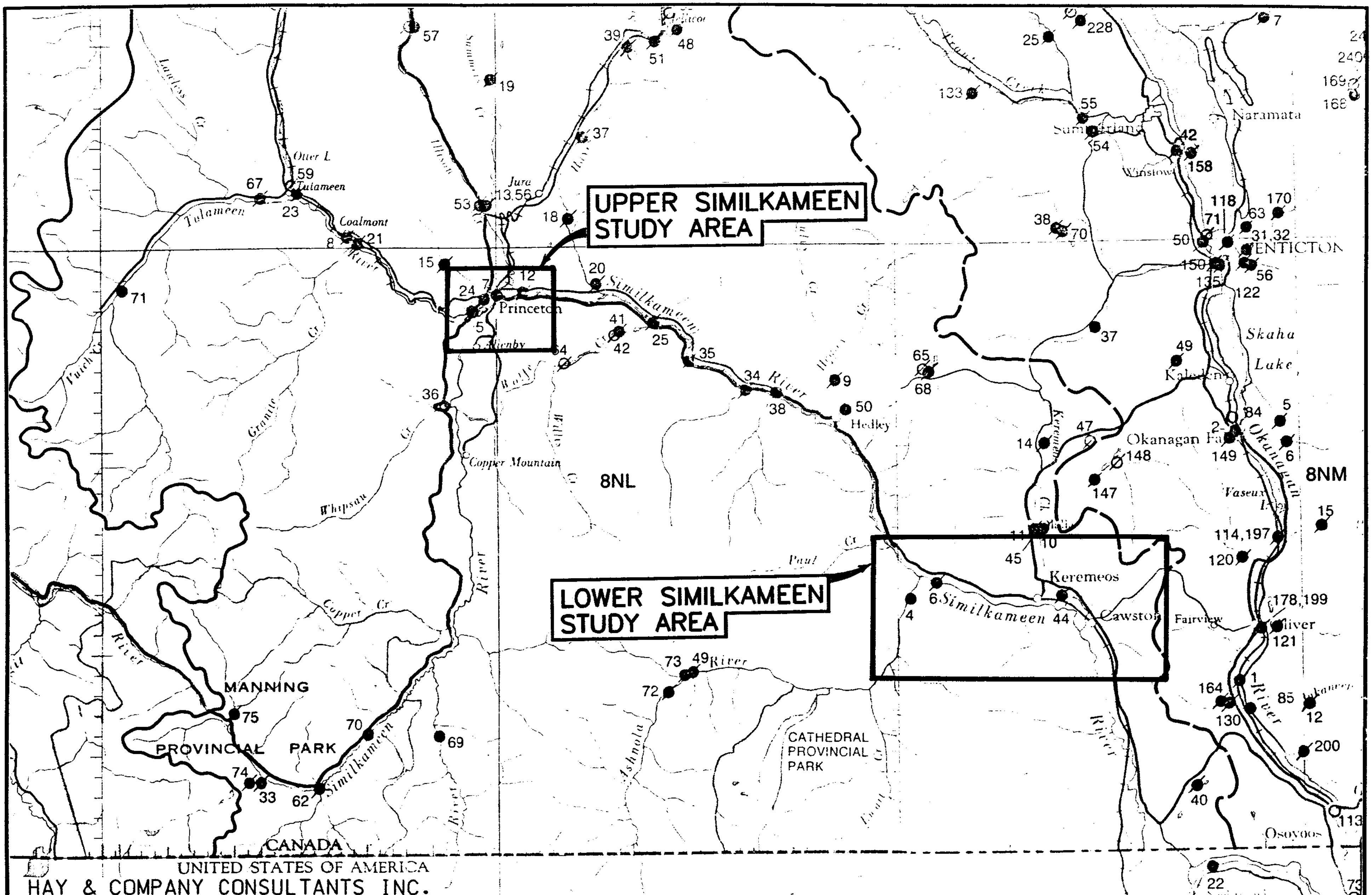
6. Additional Information Sources

The following sources should be looked at by the consultant regarding background information on flooding problems in the project area:

- Brian Symonds, Water Management Division, Penticton
- Al Benson, Administrator, Princeton, and former resident of Keremeos
- Dawn Johnston, reporter, Similkameen Spotlight
- Milly Johnston, long-term resident of Keremeos
- Alice Simpson, long-term resident of Keremeos and daughter of an early developer in the Keremeos area
- Gretchen Lind, researcher for the Keremeos Chamber of Commerce

** Some of this information also applies to the Similkameen River at Princeton.

FIGURES



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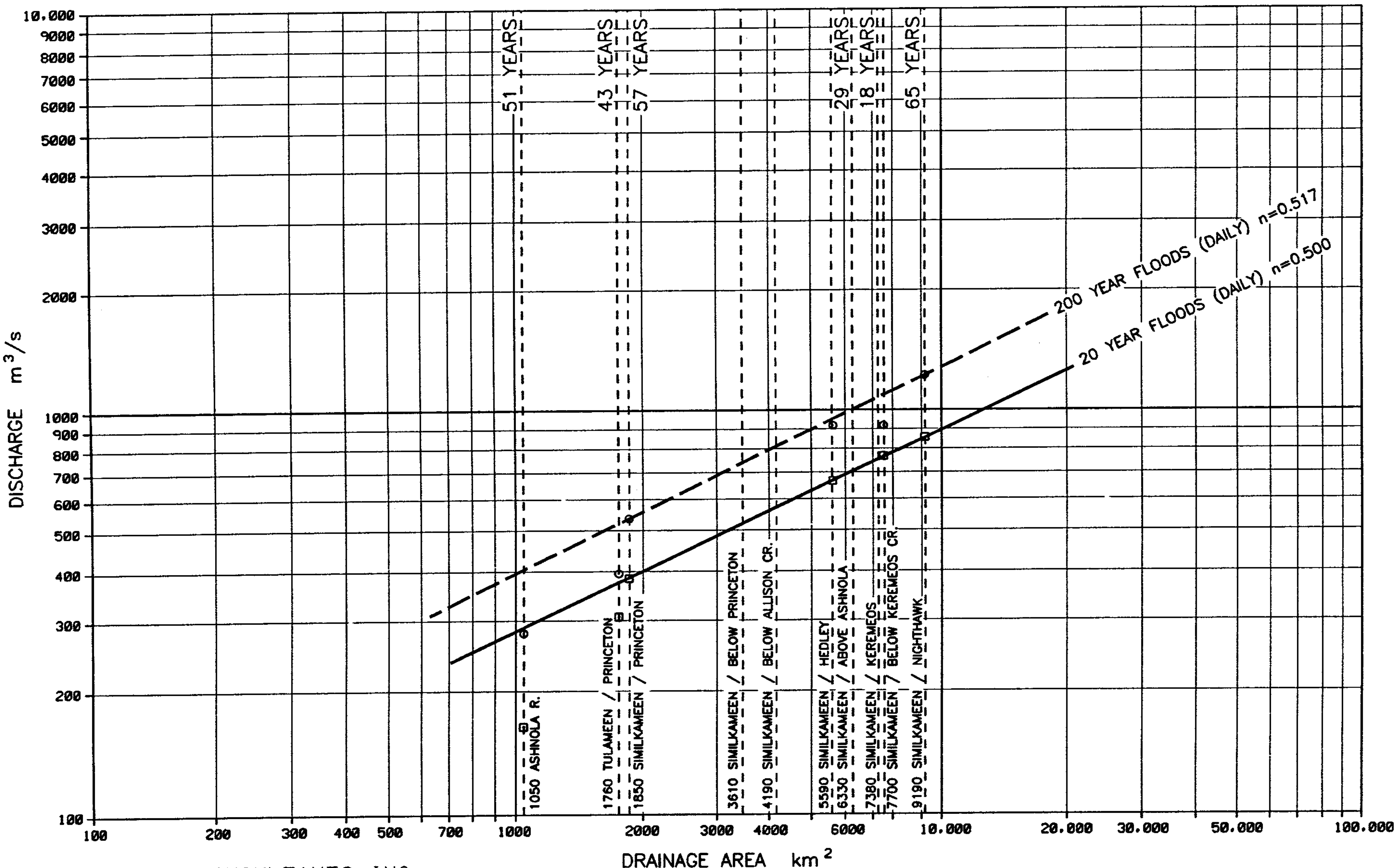
B.C. ENVIRONMENT

FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

LOCATION MAP

FIG. 1

MENV-016 /FIGS8.DGN.DGN/1995 APRIL 22



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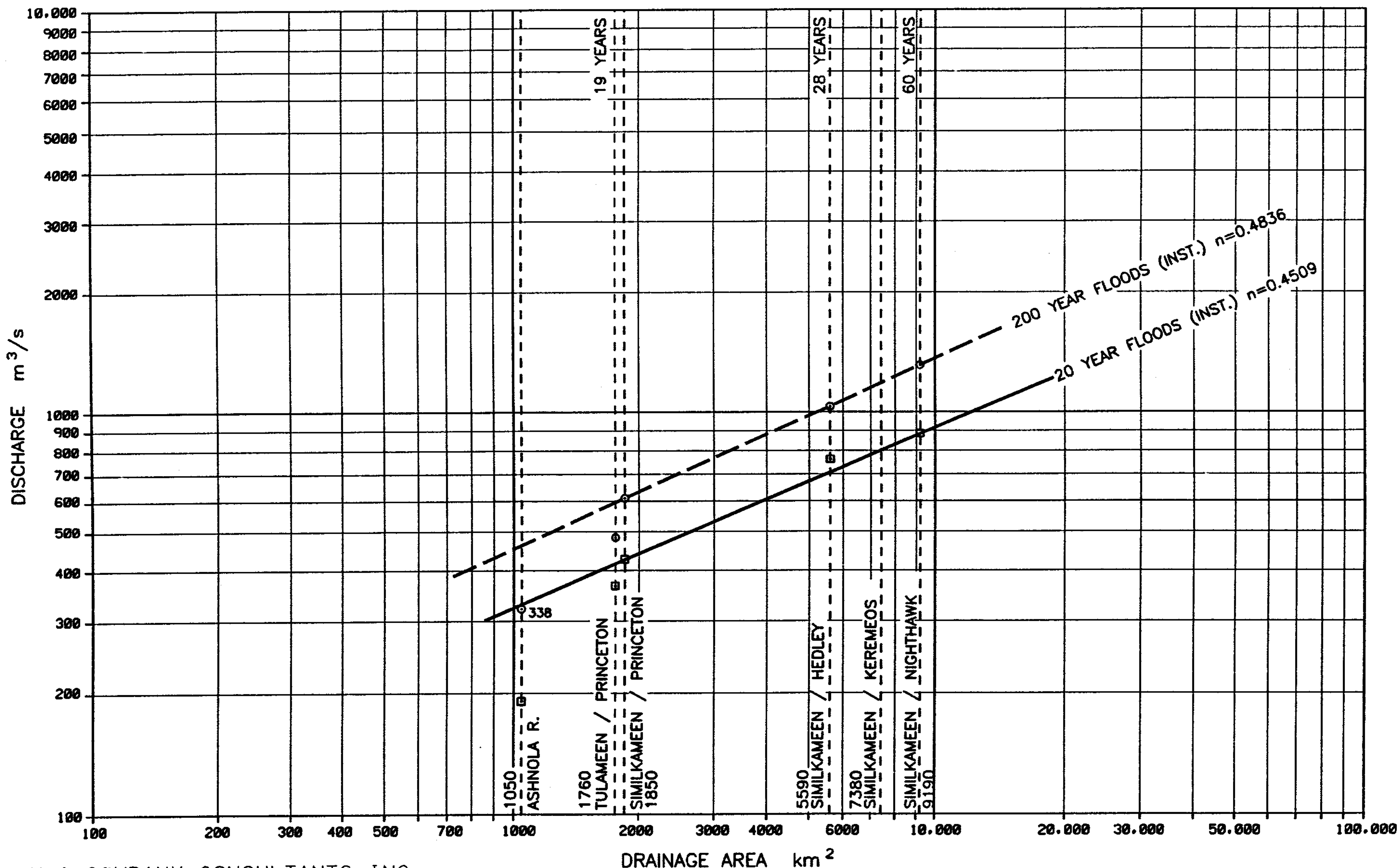
B.C. ENVIRONMENT

FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

REGIONAL ANALYSIS
MAXIMUM DAILY FLOODS

FIG. 2

MENV-016 /FIGS8.DGN.DGN/1995 JUNE 13



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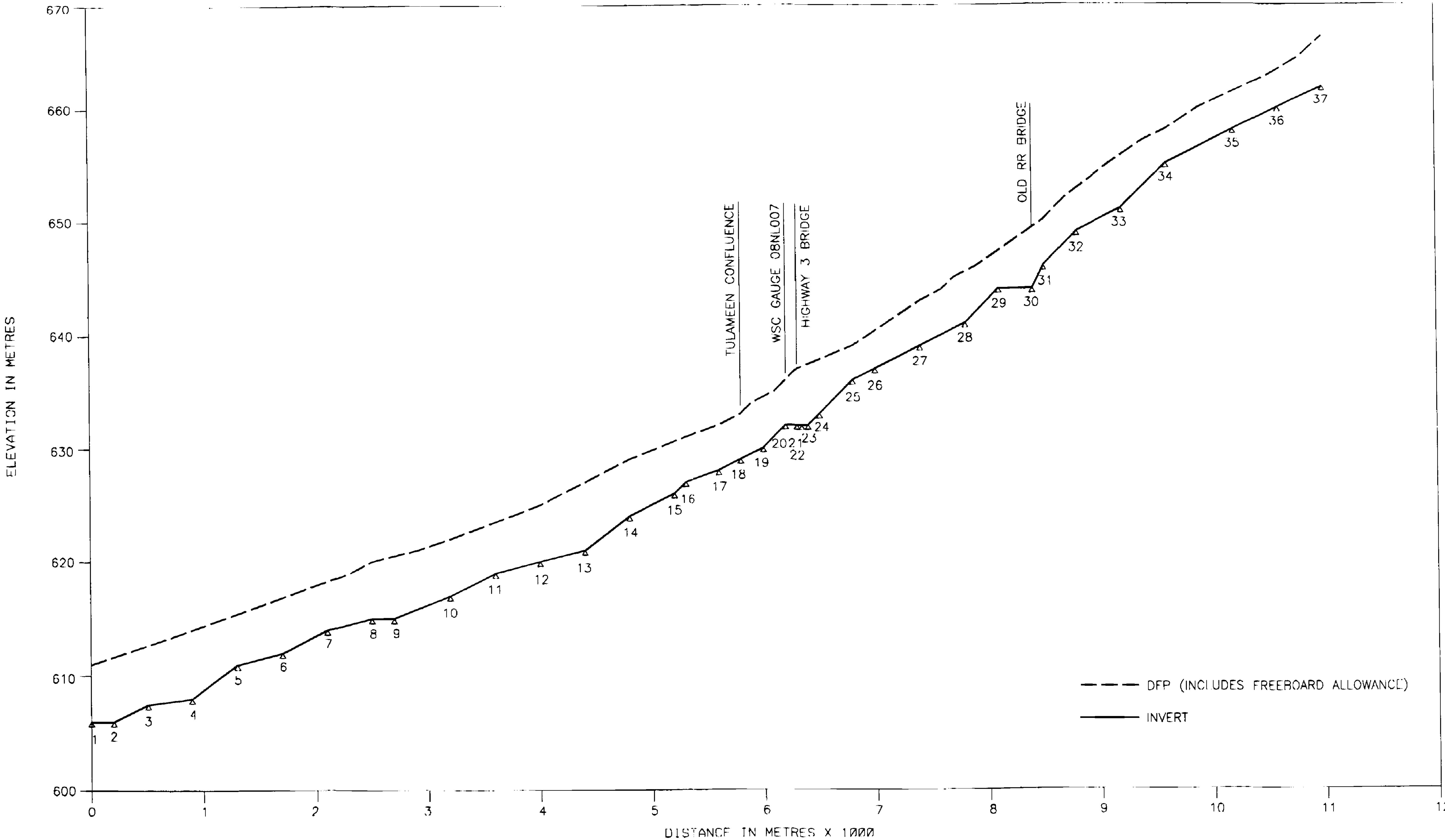
FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

REGIONAL ANALYSIS
MAX. INSTANTANEOUS FLOODS

FIG. 3

MENV-016 /FIGS8.DGN.DGN/1995 JUNE 13



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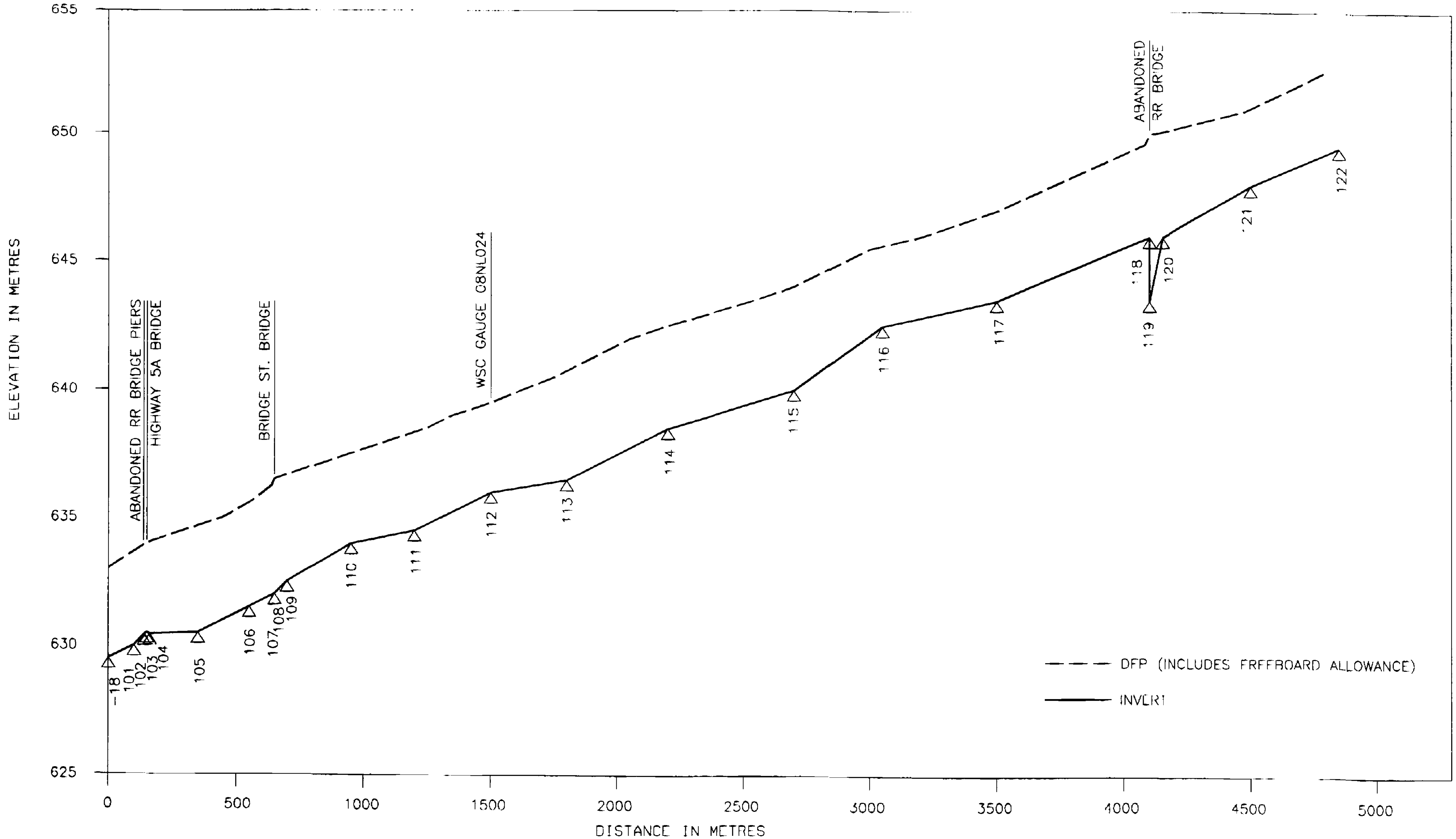
FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

SIMILKAMEEN RIVER AT PRINCETON
DESIGNATED FLOOD PROFILE

FIG. 4

CAD FILE : MEVN-016/FIGS8.DGN/1995 JUNE 13



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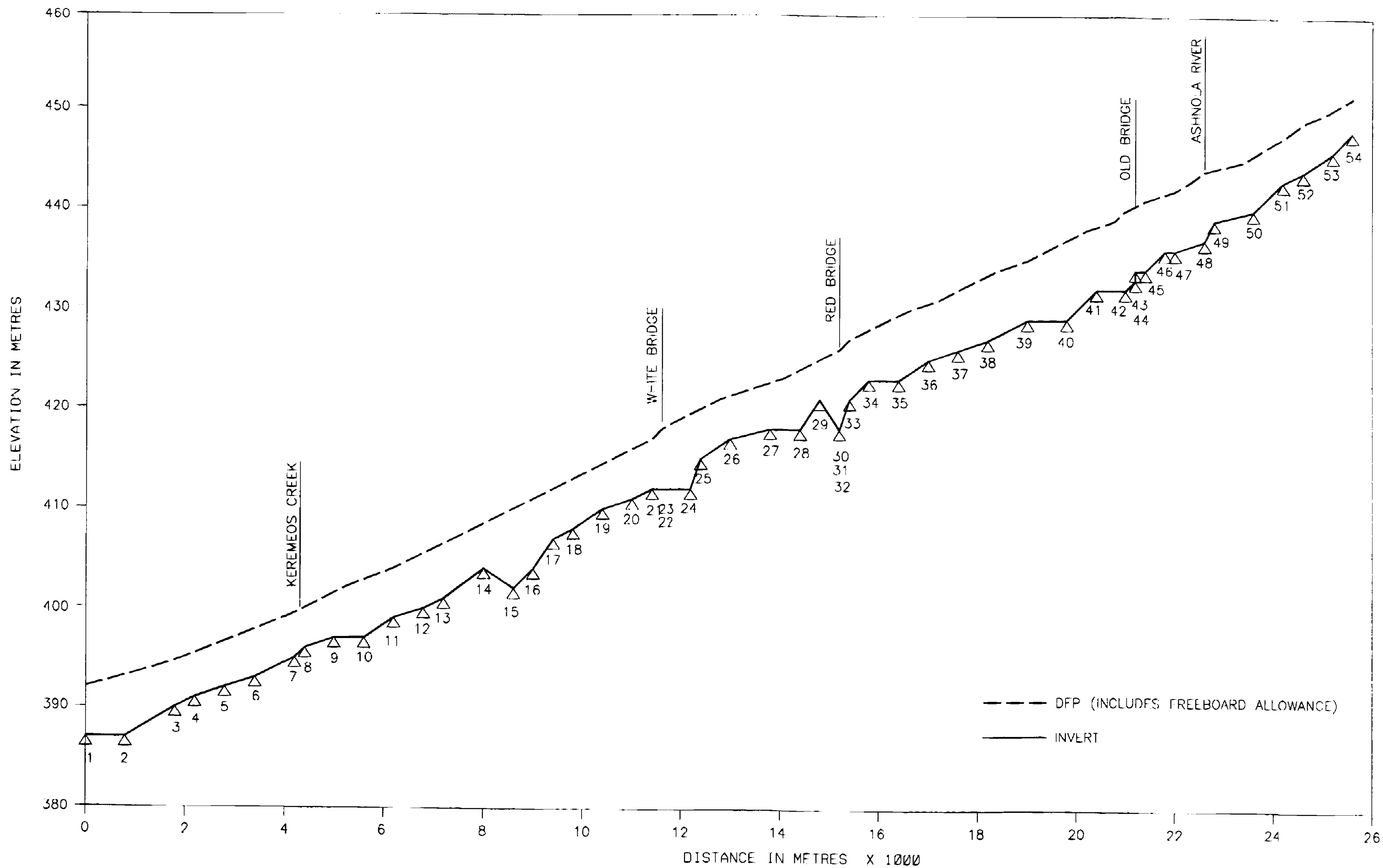
B.C. ENVIRONMENT

FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

TULAMEEN RIVER AT PRINCETON
DESIGNATED FLOOD PROFILE

FIG. 5

CAD FILE : MEVN-016/FIGS8.DGN/1995 JUNE 13



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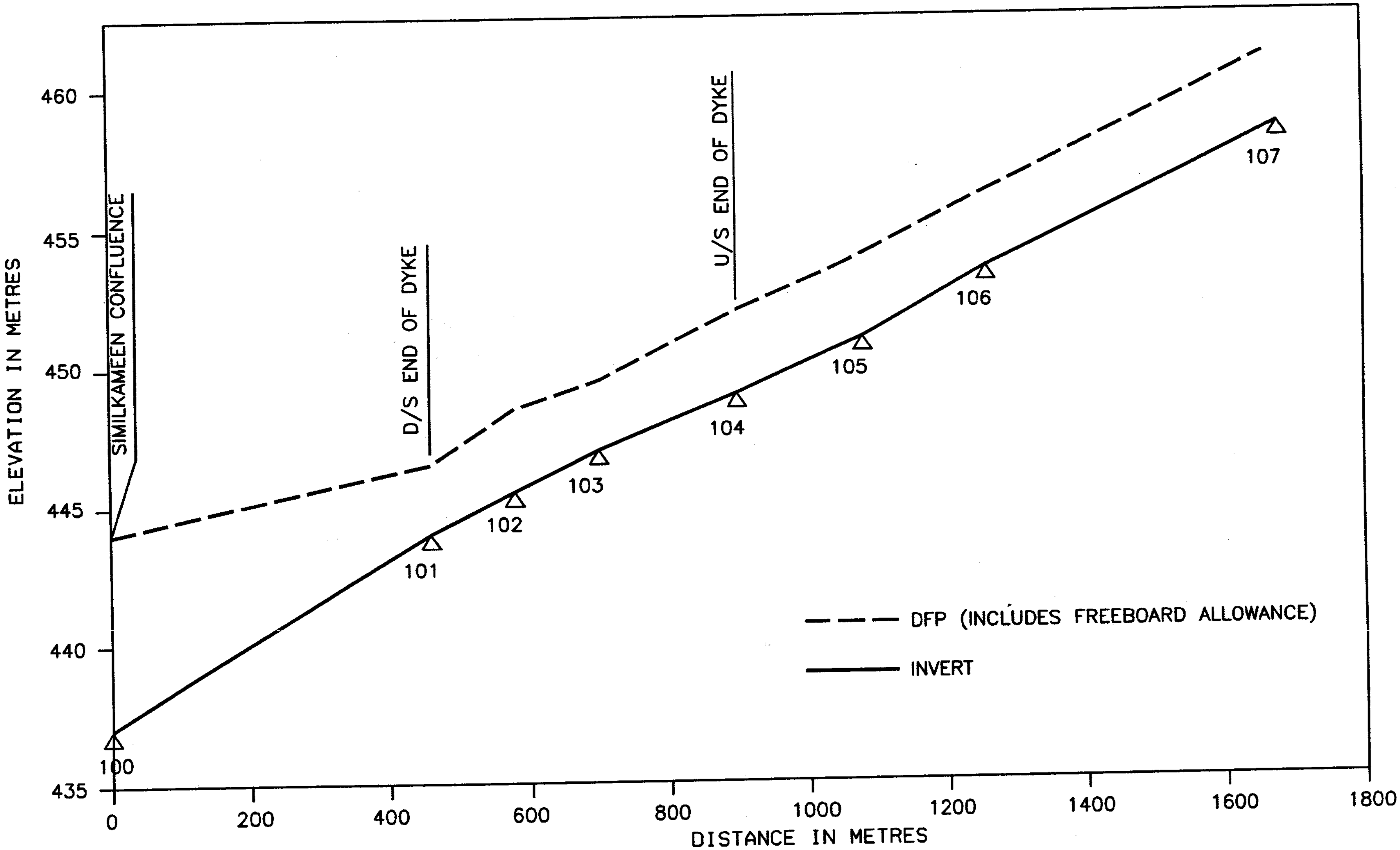
B.C. ENVIRONMENT

FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

SIMILKAMEEN RIVER AT KEREMEOS
DESIGNATED FLOOD PROFILE

FIG. 6

CAD FILE : MEVN-016/FIGS8.DGN/1995 JUNE 13



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B.C. ENVIRONMENT
FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

ASHNOLA RIVER AT KEREMEOS
DESIGNATED FLOOD PROFILE

FIG. 7

MENV-016 /FIGS8.DGN.DGN/1995 JUNE 13

PHOTOGRAPHS

PHOTO 1: SIMILKAMEEN RIVER AT PRINCETON - LOOKING UPSTREAM TOWARD HIGHWAY 3 BRIDGE

PHOTO 2: SIMILKAMEEN RIVER AT PRINCETON - LOOKING DOWNSTREAM FROM HIGHWAY 3 BRIDGE

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B.C. ENVIRONMENT

FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

PHOTOS 1 & 2

CAD FILE : MEVN-016/FIGS8.DGN/1995 APRIL 24

PHOTO 3: SIMILKAMEEN RIVER AT PRINCETON - LOOKING UPSTREAM FROM HIGHWAY 3 BRIDGE

PHOTO 4: SIMILKAMEEN RIVER AT PRINCETON - LOOKING DOWNSTREAM TOWARD HIGHWAY 3 BRIDGE

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FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

PHOTOS 3 & 4

CAD FILE : MEVN-016/FIGS8.DGN/1995 APRIL 24

PHOTO 5: TULAMEEN RIVER AT PRINCETON - LOOKING UPSTREAM TOWARD HIGHWAY 5A BRIDGE

PHOTO 6: TULAMEEN RIVER AT PRINCETON - LOOKING DOWNSTREAM FROM HIGHWAY 5A BRIDGE

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FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

PHOTOS 5 & 6

CAD FILE : MEVN-016/FIGS8.DGN/1995 APRIL 24

PHOTO 7: TULAMEEN RIVER AT PRINCETON - LOOKING UPSTREAM FROM HIGHWAY 5A BRIDGE

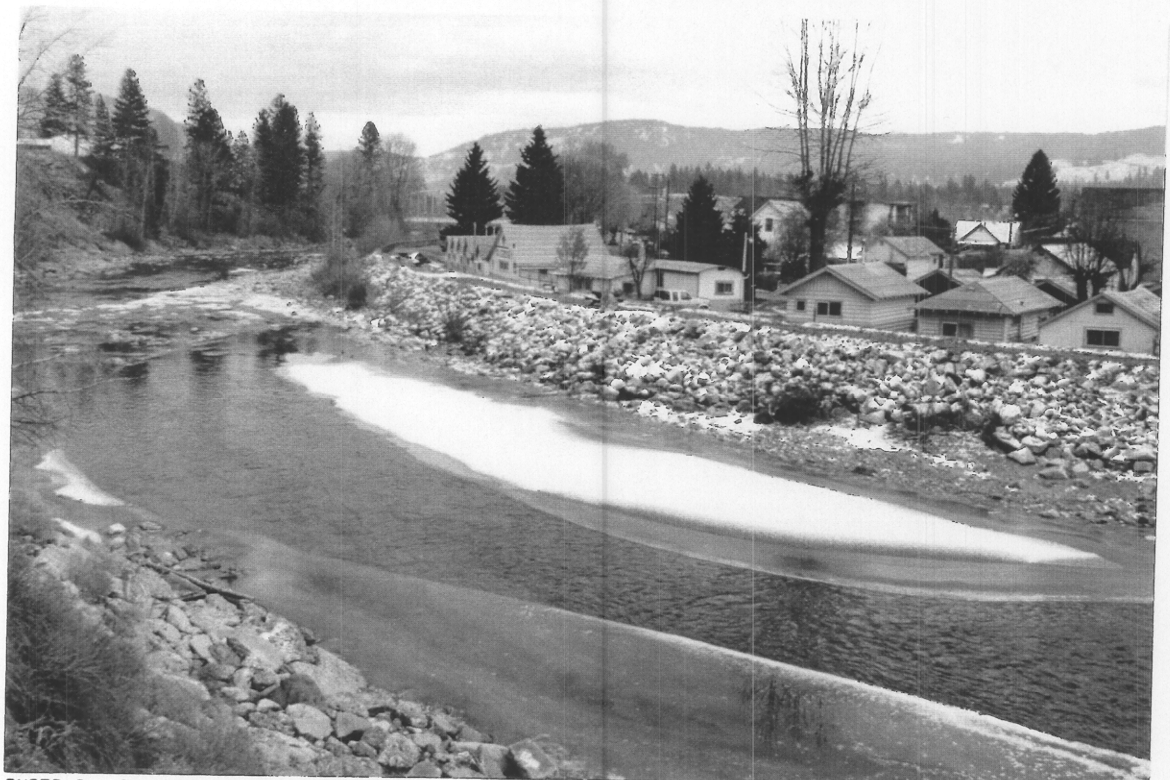

PHOTO 8: TULAMEEN RIVER AT PRINCETON - LOOKING DOWNSTREAM TOWARD RIVERSIDE MOTEL

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FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

PHOTOS 7 & 8

CAD FILE : MEVN-016/FIGS8.DGN/1995 APRIL 24

PHOTO 9: TULAMEEN RIVER AT PRINCETON - LOOKING UPSTREAM TOWARD BRIDGE ST. BRIDGE

PHOTO 10: TULAMEEN RIVER AT PRINCETON - LOOKING UPSTREAM FROM BRIDGE ST. BRIDGE

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FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

PHOTOS 9 & 10

CAD FILE : MEVN-016/FIGS8.DGN/1995 APRIL 24

PHOTO 11: SIMILKAMEEN RIVER NEAR CAWSTON - LOOKING UPSTREAM FROM CROSS SECTION 3 AT END OF BEECROFT RIVER AVE.

PHOTO 12: SIMILKAMEEN RIVER NEAR CAWSTON - LOOKING DOWNSTREAM FROM CROSS SECTION 6 NEAR END OF V.L.A. AVE.

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FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

PHOTOS 11 & 12

CAD FILE : MEVN-016/FIGS8.DGN/1995 APRIL 24

PHOTO 13: SIMILKAMEEN RIVER AT CAWSTON - LOOKING UPSTREAM FROM CROSS SECTION 7 ABOVE COULTHARD AVE.

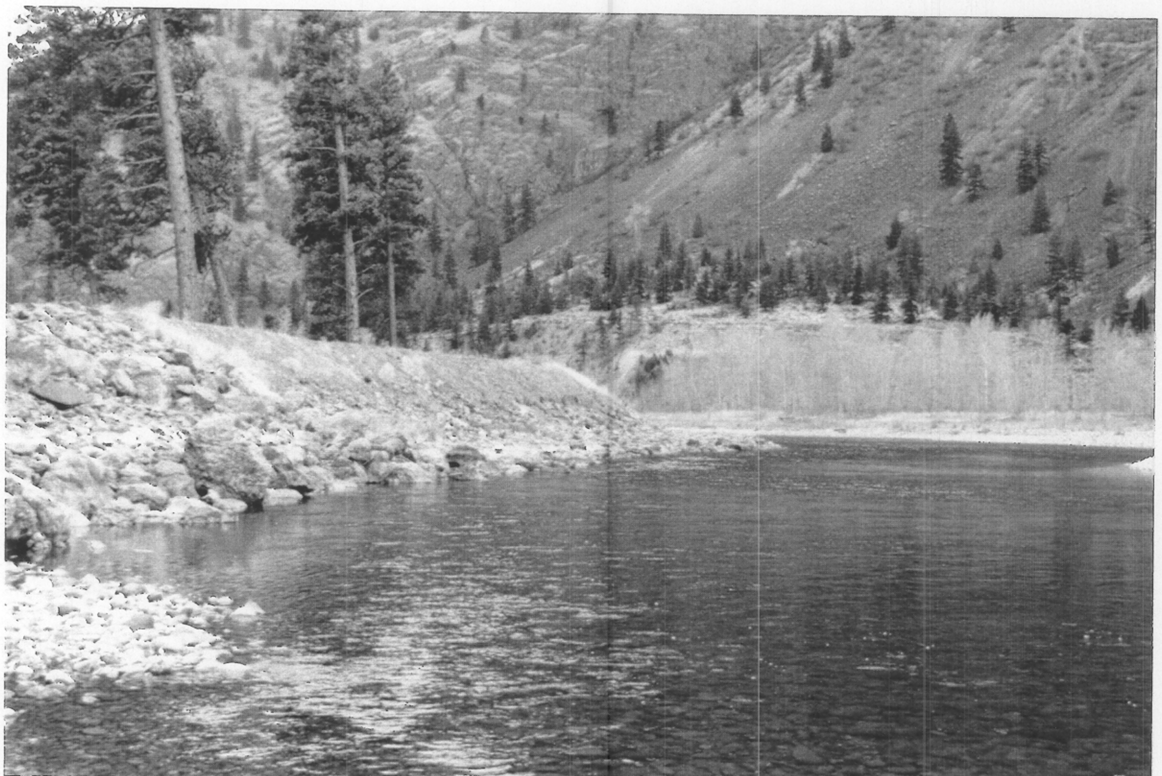

PHOTO 14: SIMILKAMEEN RIVER AT CAWSTON - LOOKING DOWNSTREAM FROM MOUTH OF KEREMEOS CREEK

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FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

PHOTOS 13 & 14

CAD FILE : MEVN-016/FIGS8.DGN/1995 APRIL 24

PHOTO 15: SIMILKAMEEN RIVER AT KEREMEOS - LOOKING DOWNSTREAM FROM CROSS SECTION 18

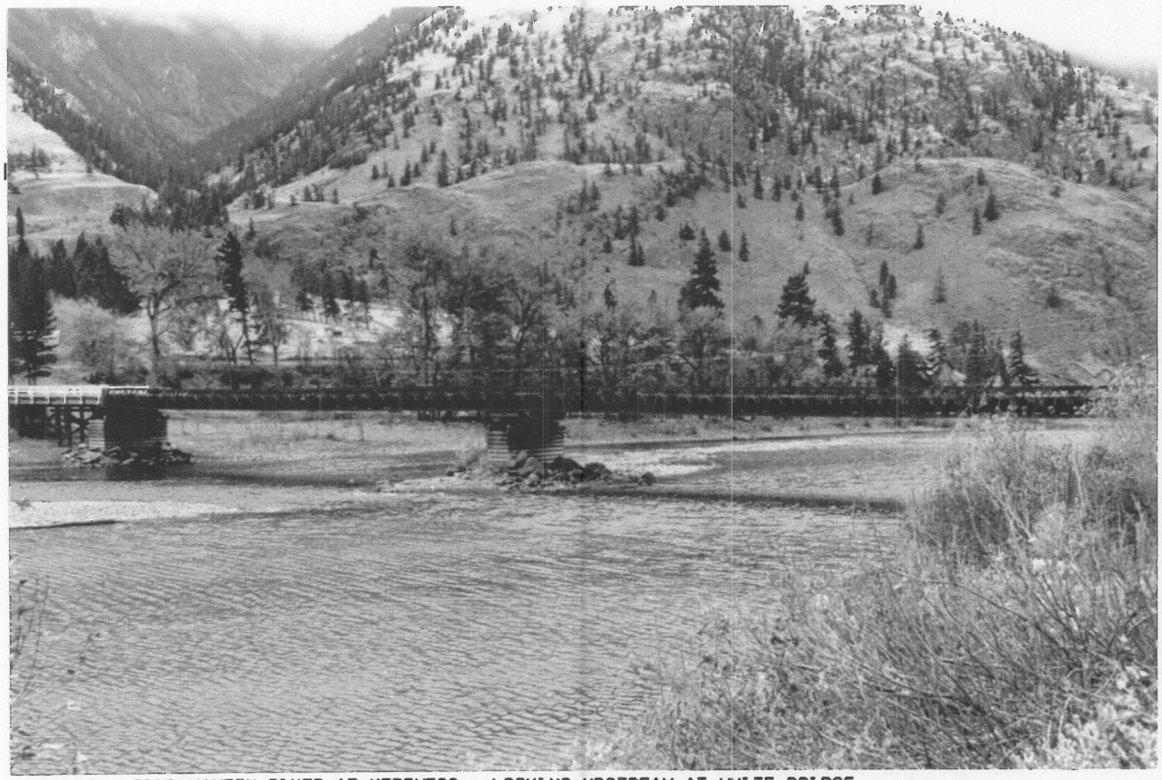

PHOTO 16: SIMILKAMEEN RIVER AT KEREMEOS - LOOKING UPSTREAM AT WHITE BRIDGE

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FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

PHOTOS 15 & 16

CAD FILE : MEVN-016/FIGS8.DGN/1995 APRIL 24

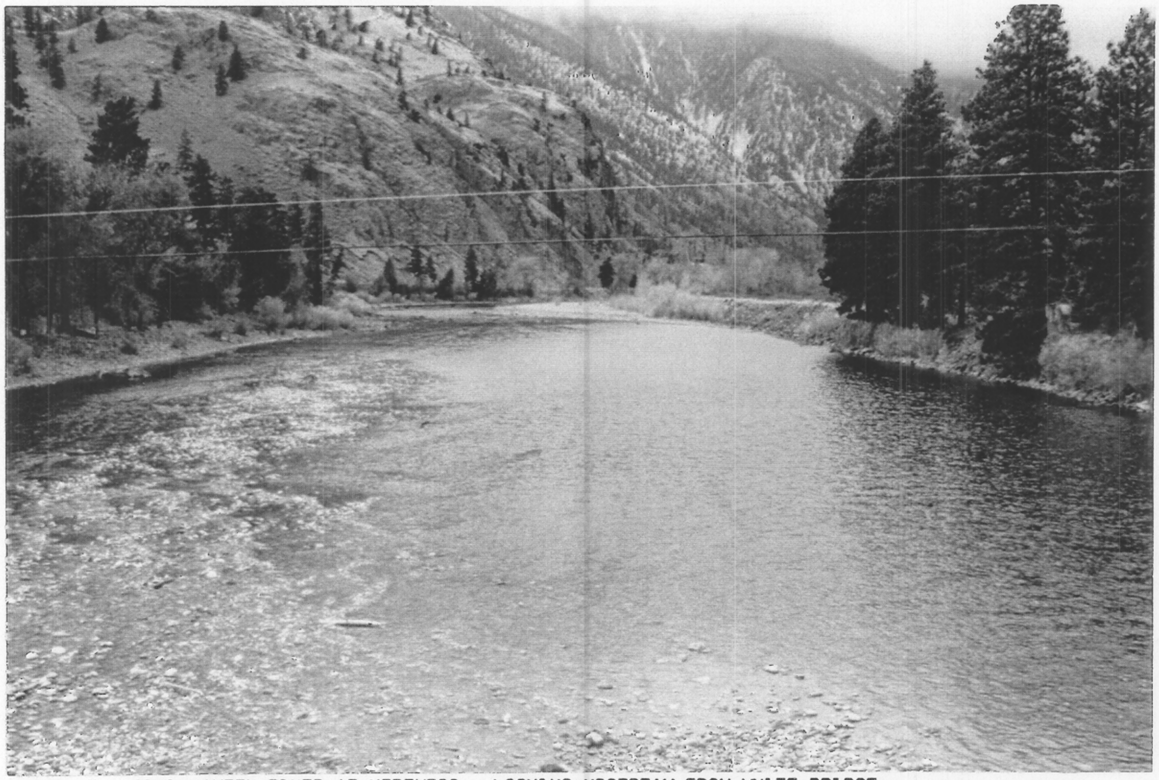

PHOTO 17: SIMILKAMEEN RIVER AT KEREMEOS - LOOKING UPSTREAM FROM WHITE BRIDGE

PHOTO 18: SIMILKAMEEN RIVER AT KEREMEOS - LOOKING UPSTREAM TOWARD CROSS SECTION 26

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FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

PHOTOS 17 & 18

CAD FILE : MEVN-016/FIGS8.DGN/1995 APRIL 24

PHOTO 19: SIMILKAMEEN RIVER AT KEREMEOS - LOOKING UPSTREAM FROM RED BRIDGE

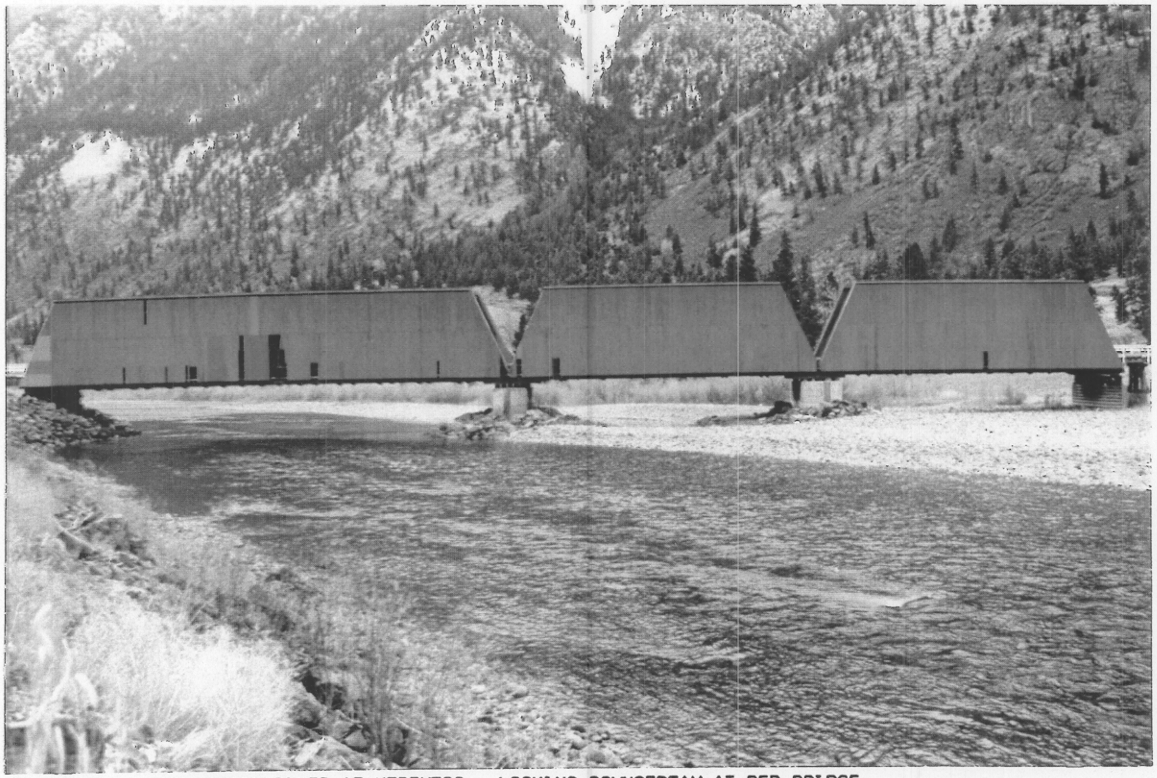

PHOTO 20: SIMILKAMEEN RIVER AT KEREMEOS - LOOKING DOWNSTREAM AT RED BRIDGE

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FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

PHOTOS 19 & 20

CAD FILE : MEVN-016/FIGS8.DGN/1995 APRIL 24

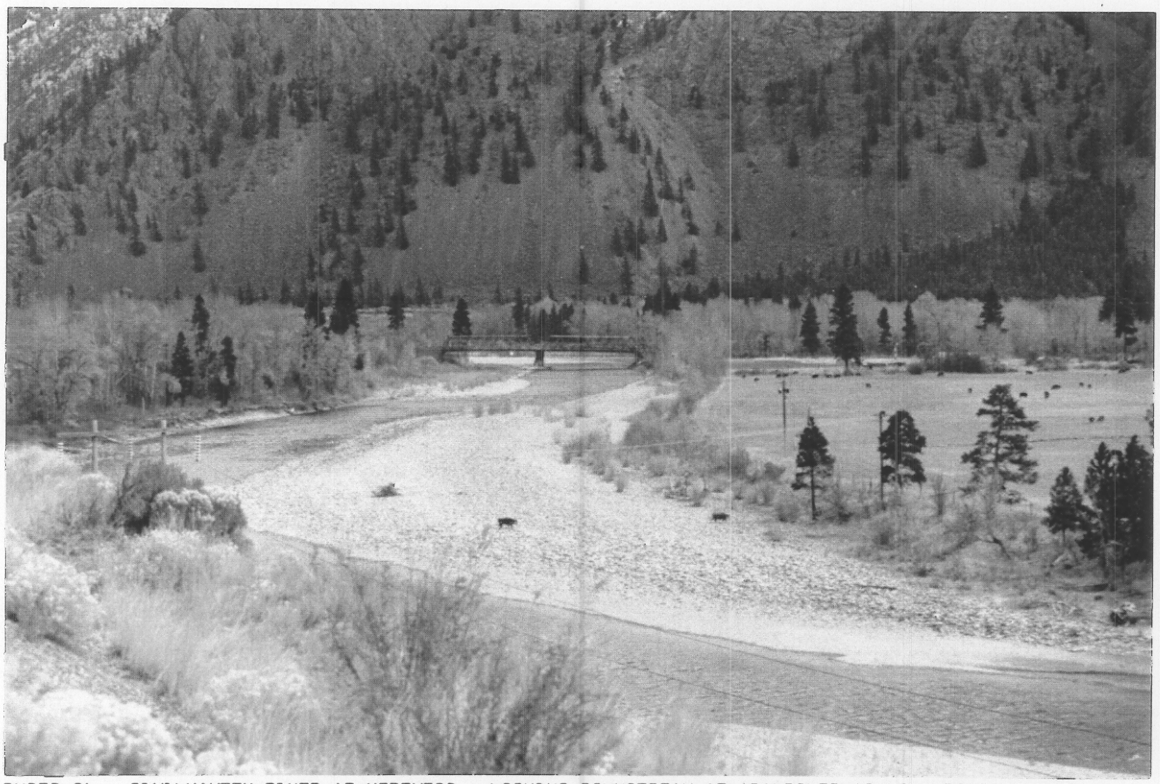

PHOTO 21: SIMILKAMEEN RIVER AT KEREMEOS - LOOKING DOWNSTREAM AT ABANDONED ASHNOLA ROAD BRIDGE

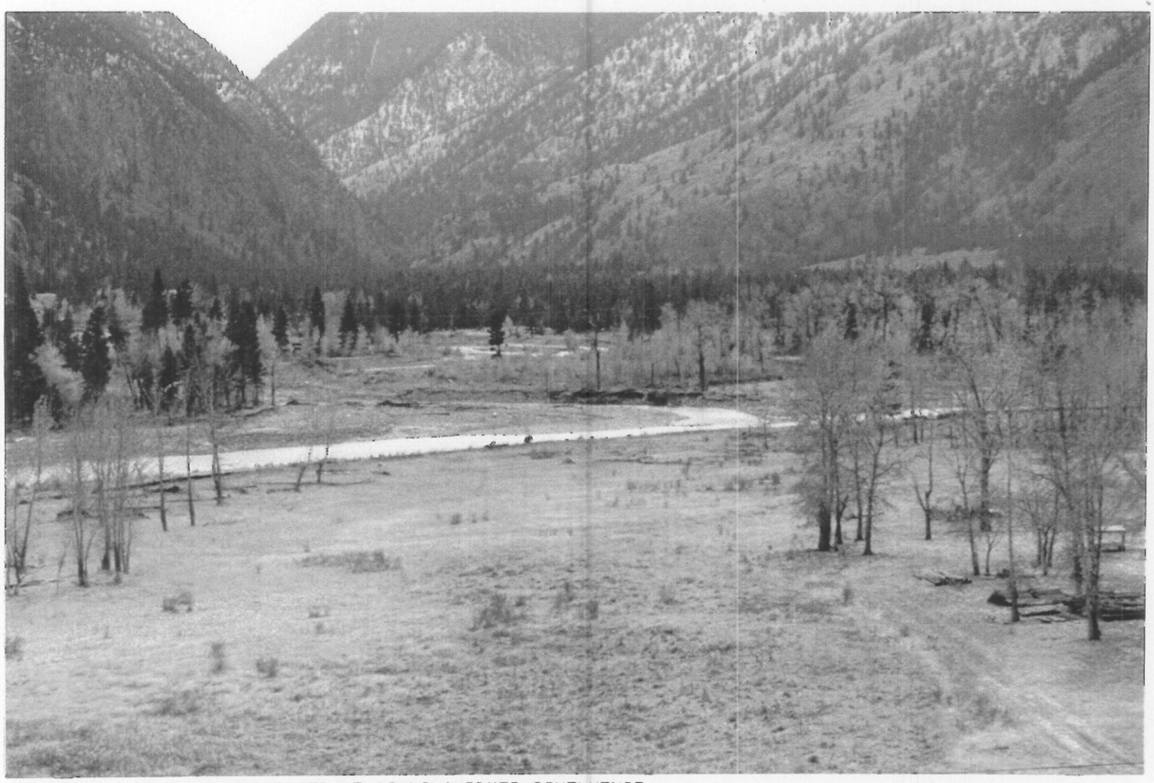

PHOTO 22: SIMILKAMEEN RIVER AT ASHNOLA RIVER CONFLUENCE

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FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

PHOTOS 21 & 22

CAD FILE : MEVN-016/FIGS8.DGN/1995 APRIL 24

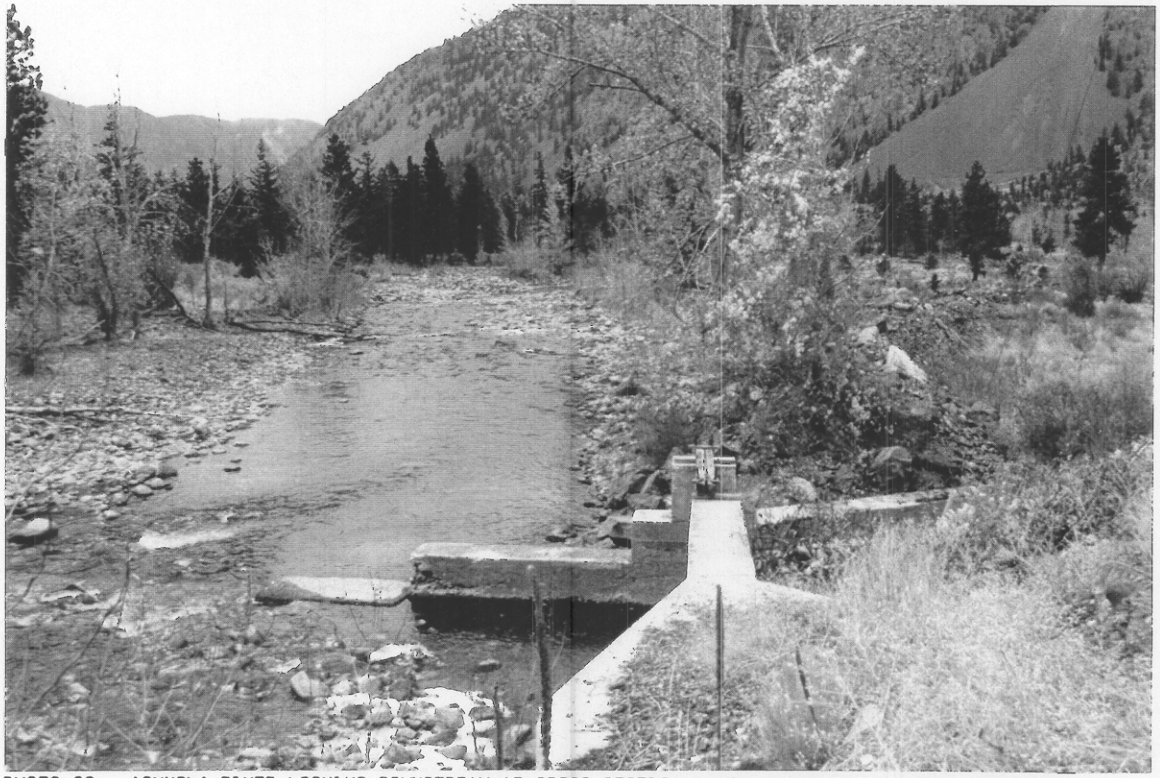

PHOTO 23: ASHNOLA RIVER LOOKING DOWNSTREAM AT CROSS SECTION 4 NEAR ABANDONED INTAKE STRUCTURE

PHOTO 24: ASHNOLA RIVER LOOKING UPSTREAM NEAR ABANDONED INTAKE STRUCTURE

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FLOODPLAIN MAPPING
SIMILKAMEEN, TULAMEEN & ASHNOLA RIVERS

PHOTOS 23 & 24

CAD FILE : MEVN-016/FIGS8.DGN/1995 APRIL 24

DRAWINGS