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MAIN REPORT

WATER INVESTIGATIONS
ALONG THE
ALASKA HIGHWAY PIPELINE ROUTE
IN THE YUKON TERRITORY

December 1978

Inland Waters Directorate
Pacific and Yukon Region
Vancouver, B.C.

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ABSTRACT

Small stream hydrology, water quality and river hydraulics along the Alaska Highway were studied by reconnaissance methods from May 1977 to September 1978. The objective was to develop estimates of baseline data for the review of the proponent's Environmental Impact Statement.

Peak flows were estimated for various return periods at representative small streams based on several techniques, including (1) Regional frequency analysis, (2) Envelope curve, (3) Channel geometry and (4) Watershed modelling. Field work for the development of these estimates included the operation of 16 crest stage gauges and the survey of stream channel geometry.

Pipeline construction will probably stress the aquatic ecosystem through (1) increased silt concentrations and (2) increased organic and inorganic loadings. To contribute to knowledge required for consideration of potential water quality problems, a short-term, two drainage basin study was undertaken of conditions existing in the southern and northern sections of the pipeline corridor. The contrasting hydrology, geology and climate at these two locations provide the required data base from which general chemical and biological process information could be extrapolated.

During 1978 high water period a pilot scour assessment was made of Donjek River and a number of typical small streams. An aerial photo and map interpretation was made of meander patterns with the objective of determining where pipeline activities may have a detrimental effect. Logarithmic relationships between suspended sediment concentrations and discharge have been developed to permit tentative estimates to be made of a stream's capability to transport sediment, and to project increases in suspended and deposited sediments that could result from increased supply during construction activity.

ETUDES HYDROLOGIQUES LE LONG DU TRACÉ
DU PIPELINE DE LA ROUTE DE L'ALASKA,
AU YUKON

RÉSUMÉ

Des expéditions de reconnaissance effectuées de mai 1977 à septembre 1978 nous ont permis d'étudier l'hydrologie des petits cours d'eau, la qualité des eaux et l'hydraulique des cours d'eau le long du tracé de la route de l'Alaska. Ces études avaient pour but de recueillir des données fondamentales estimatives devant servir à l'examen d'un Énoncé des incidences environnementales.

Nous avons évalué, à l'aide de différentes méthodes (1) des analyses de la fréquence régionale; 2) les courbes enveloppes; 3) la géométrie des chenaux; et 4) la modélisation des bassins hydrographiques) les débits maximaux correspondant à diverses périodes de retour pour des petits cours d'eau typiques. La collecte de ces informations sur le terrain a nécessité l'utilisation de 16 échelles à maxima et des relevés de la géométrie des tracés des cours d'eau.

Les incidences probables de la construction du pipeline sur l'écosystème aquatique sont: 1) une augmentation de la concentration du limon; et 2) une augmentation des concentrations de matières organiques et inorganiques. Pour ajouter aux connaissances nécessaire à la prise en ligne de compte des problèmes éventuels de la qualité de l'eau, une étude à court terme de deux bassins hydrographiques, portant sur les conditions qui existent dans les parties nord et sud du tracé du pipeline, a été mise sur pied.

Les conditions hydrologiques, géologiques et climatiques opposées de ces deux régions nous fournissent les données fondamentales à partir desquelles nous déduisons les renseignements généraux portant sur les processus chimiques et biologiques.

Pendant la période des hautes eaux de 1978, une évaluation pilote de l'affouillement a été entreprise sur la Donjek et un certain nombre de petits cours d'eau typiques. Une étude de la configuration des méandres, menée à bien à l'aide de l'interprétation de cartes et de photographies aériennes, avait pour but de déterminer les endroits où les activités liées au pipeline risquent d'avoir un effet nuisible. Les rapports logarithmiques qui existent entre la concentration des matières en suspension et le débit ont été établis afin d'évaluer la compétence d'un cours d'eau et d'extrapoler l'augmentation de la concentration des matières en suspension et de la sédimentation qui pourrait découler d'un apport plus grand de matières pendant la construction.

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INTRODUCTION

Assessment of the hydrologic impact of the proposed Alaska Highway gas pipeline is contained in the Inland Waters Directorate report dated June 3, 1977. The purpose of the present report is to present estimates of baseline data to facilitate review of the proponent's Environmental Impact Statement. Information collected from the field is limited, but was aimed at areas where data deficiencies are of greatest importance. Three disciplinary areas are involved:

Small Stream Hydrology

For consideration of mitigative measures related to erosion, drainage disruption, drainage diversions and siltation, an understanding of flood characteristics of streams is required along the pipeline corridor. However, very little baseline information exists particularly for streams with small drainage areas. Traditional methods for estimating flood-frequency characteristics at ungauged sites include the use of rainfall records, and the relationships between streamflow records and basin characteristics. These methods alone are insufficient for the Alaska Highway Pipeline route because of inadequate precipitation and streamflow records and because of their variability among subregions. Empirical and/or synthetic approaches, therefore, have to be included in generating the necessary hydrologic data. However, full reliance cannot be placed on any one particular approach; experience indicates that different approaches produce differing results with attendant wide confidence limits.

The main focus of the report is a reference on design flows for small streams based on various estimating techniques, against which estimates made by others could be compared.

Water Quality

The question that relates to water quality is whether increased suspended sediment loads in streams caused by construction and maintenance of the Alaska Highway Pipeline will degrade the quality of the river systems.

Most of the available knowledge on the effects of increased sedimentation, increased turbidity and oxygen depletions has been derived from studies of streams in temperate and hot climates and very little work has been done in cold climates.

Since needed information is required within a very short period of time, only a minimum amount of investigation could be carried out. It was considered that this could be done best on the basis of a short-term study of two representative river basins: Swift and Ogilvie Rivers.

River Hydraulics

Mitigative measures associated with river crossings are expected to require special attention during Environmental Impact Statement review particularly at rivers located along the corridor extending 150 miles south of the Alaska-Yukon border. These rivers are glacier-fed, are prone to flash flooding and are constantly changing channels; some have scour depths of over 20 feet. During 1978 high water period a pilot scour assessment was made of one large and a number of typical small streams. An aerial photo and map interpretation was made of meander patterns and areas determined where pipeline activities may have a detrimental effect.

Logarithmic relationships between suspended sediment concentrations and discharge are presented in Appendix F which permit tentative estimates to be made of a stream's capability to transport sediment, and to project increases in suspended and deposited sediments that could result from increased supply from construction activity.

PHYSIOGRAPHY AND DRAINAGE

Alaska Highway traverses five physiographic divisions in the Yukon Territory. Starting from Alaska-Yukon border they are: Yukon Plateau, Shakwak Trench, Boundary Ranges of the Coast Mountains, Cassiar Mountains and the Liard Plain (Bostock, 1967). Within these divisions lie the six main drainage basins crossed by the Alaska Highway Pipeline route: White River, Alsek River, Takhini River, Yukon River, Teslin River and Liard River. (Figure 1)

Yukon Plateau North - Location : MP 1221 - 1117

Topography : Generally flat with areas of low muskeg, laden with shallow lakes and sloughs; elevations vary between 1850 and 2400 feet.

Except for Beaver Creek, tributary streams in this area generally have a very constant discharge; increases in discharge that can be observed during summer months are attributed to the melting of permafrost. Beaver Creek with its drainage area originating in the Wrangell mountains at elevations of between 7000 and 8000 feet is not typical for the area; it is violent at flood stage and its gravel banks are highly erodable.

Soils : Peat and volcanic ash overlying gravels; underlain with discontinuous permafrost.

Major Drainage Basins : White River, a tributary of the Yukon River; larger streams are glacier fed.

Shakwak Trench - Location : MP 1177 - 1036

Topography : Trench is long, narrow, generally flat (floor elevation 2400 feet) confined by the Kluane Plateau to the N.E. and the St. Elias Mountains to the S.W. Within the trench streams are glacier fed, steep and subject to flash floods; large rivers cross the Trench approximately at right-angles in the northeasterly direction.

Kluane Lake, the largest lake in the Yukon, lies within the Shakwak Trench valley floor; its west shore is characterized by high energy, gravel-fed streams whose fans are actively aggrading. The fan of the Duke River substantially controls the level of the lake.

Soils : Outwash deposits, volcanic ash and silt; alluvial fan deposits along the western shore of Kluane Lake.

Major Drainage Basins : Donjek River, tributary of White River, and Duke and Slims Rivers, tributaries of Kluane River and Kluane Lake respectively.

Yukon Plateau South - Location : MP 1036 - 996

Topography : Follows Dezadeash Valley (elevation 2500 feet) to the southern end of the Sifton Range (elevation 3500 feet), the divide between Alsek and Takhini River drainage basins.

Soils : Till, sand, gravel with local occurrences of volcanic ash and lacustrine silt.

Major Drainage Basins : Aishihik River, tributary of Dezadeash River; Dezadeash River, tributary of Alsek River (coast drainage).

Boundary Ranges, Coastal Mountains - Location : MP 996 - 815

Topography : Crosses Takhini River at elevation 2200 feet; climbs steeply to elevation 4500 feet in the Boundary Ranges; descends across Yukon River at elevation 2400 feet; continues across Yukon Plateau to Teslin River (elevation 2300 feet); follows northern shoreline of Teslin Lake and crosses Nisutlin Bay; climbs along Morley River valley to elevation 2800 feet near Smart River.

Soils : Till, sand gravel with local occurrences of volcanic ash and lacustrine silt.

Major Drainage Basins : Takhini, Teslin and M'Clintock Rivers, tributaries of the Yukon River.

Cassiar Mountains - Location : MP 815 - 751

Topography : Moderately rugged with numerous broad valleys; route climbs to 5000 feet at the divide between Swift and Rancheria Rivers and descends to 3000 feet to Rancheria River.

Soils : Sand, gravel and some till.

Major Drainage Basins : Swift River, tributary of Teslin River; Rancheria River, tributary of Liard River.

Liard Plain - Location : MP 751 - 712

Topography : Flat and at elevation of 3000 feet, with relatively deep river valleys.

Soils : Glacial till with local occurrences of silt, sand, gravel and volcanic ash.

Major Drainage Basins : Rancheria and Little Rancheria Rivers.

CLIMATE

The Coast and the St. Elias Mountains that form the western boundary of the Yukon drainage are an effective barrier against Pacific weather influences because of their continuity and height. In the east, the Rockies present a barrier against winter flow of cold polar air from Northwest Territories. However, this barrier is considerably lower and less continuous; consequently, "continental" influences are strong, causing occasional extremely cold periods in the winter. The North American record of -81°F was established at Snag.

Because of the generally rugged terrain along the Alaska Highway, consisting of mountains, plateaux and valleys, it is difficult to map the climate accurately; altitude appears to be more of a climatic determinant than latitude.

The following data* illustrate temperature and precipitation values:

	Mean Annual Temperature (^{o}F)	Mean Annual Rainfall (inches)	Mean Annual Precip. (inches)
Snag	21.5	8.68	14.16
Haines Junction	26.3	6.29	11.12
Whitehorse	30.5	5.60	10.24
Teslin	29.2	6.62	12.83
Watson Lake	26.8	8.99	17.01

SOURCES OF HYDROMETRIC DATA

Table 1 lists Water Survey of Canada gauging stations considered in the analysis. Sources for these data are the annual and historical streamflow summaries of Surface Water Data for the Yukon and Northwest Territories, and British Columbia published by Environment Canada, Inland Waters Directorate. Table 2 lists the small stream network operated by the Department of Indian and Northern Affairs in 1978. 1978 data for these stations are given in Appendix A of this report; data for stations operated in previous years are available from Department of Indian and Northern Affairs, Northern Affairs Program, Whitehorse, Y.T.

SMALL STREAM HYDROLOGY

To assure adequate pipeline design and construction at channel crossings, information on magnitude and frequency of river flows must be available. However, very little baseline data exist on which to base reliable flow predictions, particularly for streams with small drainage areas. There are 19 streamflow observation sites in the near vicinity of the pipeline route, but usefulness of data at about half is very limited because of large upstream storage and the large-sized streams on which most stations are

*Development of Power in the Yukon, Appendix 2, Hydrology, January 1975. Sigma Resource Consultants Ltd.

located. Areas where lack of hydrologic information is particularly critical are the northeastern side of the St. Elias and the southwestern side of the Cassiar Mountains. These also are the areas wherein hydrological impact of pipeline construction and operation is expected to be the greatest. Expansion of the network for the purpose of this study would not be sufficient as data from newly established stations would not be for a long enough period to provide reasonable measures of streamflow characteristics needed for calculation of peak flows. The deficiency in data led to estimation of extreme values based on a number of approaches:

1. Dimensionless ratio to the mean annual flood - - - Appendix B
2. Envelope curve, relating maximum known floods to drainage area size - - - Appendix B
3. Channel geometry versus flow characteristics - - - Appendix C
4. Kinematic Wave technique - - - Appendix D
5. Culvert size

Comparison of results are shown in Table 3. The sites are arranged in the order in which they occur starting with Snag Creek at Alaska-Yukon border to Albert Creek at B.C.-Yukon border. The data allow direct comparisons to be made of flood magnitudes at sites for which they were calculated and to provide some transfer value for estimating flood values on other or nearby streams having similar basin and channel characteristics. Details on various approaches used are given in the above Appendices.

Discussion

The majority of streamflow records on which the first two approaches are based concerns large, and in many cases, lake-controlled rivers; therefore, there is a built-in bias towards large streams. An attempt was made during 1978 snowmelt runoff to reduce this bias through operation of a network of crest-stage gauges on small streams along the highway. However, because the level of runoff was generally low there was insufficient basis on which to modify the relationships developed earlier.

Traditional methods for estimation of flood-frequency characteristics at an ungauged stream, those based principally on precipitation data and those which use relations between streamflow and basin characteristics sometimes are inadequate because of large spacial variability in precipitation, dominance of geologic factors or insufficient streamflow data from comparable basins. An approach wherein channel geometry is related to known flow characteristics at existing gauging stations provides an alternative for estimating flow characteristics at ungauged sites. This method does not require the detailed basin information needed for the traditional methods; channel size and shape are indicators of the topographic, geologic and climatic characteristics upstream. The reliability of flow predictions, however, is determined largely by the consistency of data obtained at gauging stations which is dependent on the existence of good hydraulic conditions and on satisfactory evidence of bankfull stage. Therefore, there are some streams or stream reaches where the method is not useful or could give misleading results. Examples are the ephemeral drainages along the west shore of Kluane Lake and the braided channels of Slims, Donjek and White Rivers. In addition, occasionally geographic location for a stream indicates a particular flow regime, yet the relationship for the regime does not apply because of major difference in local terrain and/or material through which the channel is cut from the overall basin characteristics. Examples are the Lubbock and Tagish streams. Thus, geographic location is not always an acceptable criterion for applicability of a particular relation.

Most culverts and bridges along the Alaska Highway appear to have adequate openings for passage of flood flows, as any overtopping that has occurred historically can be attributed to morphological problems. Accordingly, where a culvert has been in existence for sufficient number of years the calculated capacity can be a simple rational indicator of the maximum flood flow of the stream.

When there are insufficient hydrologic data for dependable flood-frequency analysis, empirical approaches are often used for determination of peak flows. Commonly, basin drainage area modified for topography and climate is the basic parameter for empirical estimates of design floods. Such empirical techniques serve a useful purpose in being a further check on the application of other methods. The Kinematic Wave Model has been used here as such an empirical technique. The method used combines the Kinematic Wave theory for determining peak flows from climatic and topographic parameters with statistical theory, and analyzes precipitation data to produce estimates of the flood frequency data for ungagued basins.

RIVER HYDRAULICS

Construction associated with stream crossings may affect the morphologic regime of the streams. The effects may be direct and short term, those caused by construction and support activities, or indirect and long term, those caused by the operation and maintenance of the constructed works.

During construction, trenching in streambeds and banks ~~may~~ will introduce sediment which ~~could~~ may be in excess of what is normally carried by the stream and to which the ecology is adjusted to tolerate. Knowledge of the related parameters will allow the determination of the optimum methods and means of construction, as well as the scheduling of the operation.

Clearing of vegetation for the right-of-way, the disturbance of soils by construction activities, the benching of slopes and other associated changes, may cause continuous inflow of sediment into watercourses. The pipeline trench, if not properly backfilled may become a surface drainage lateral, conveying large amounts of sediment into watercourses.

Improperly backfilled banks can be a potential hazard, especially in discontinuous permafrost areas. Insufficiently buried pipeline may become exposed when the streambed becomes scoured out. Breakages of the pipeline in streambeds may necessitate the placement of equipment onto the stream during sensitive times of the year. & [illegible] in [illegible] → oil leak

Pipeline construction at stream crossings could disrupt the meandering of streams, accelerate its propagation and cause excessive sedimentation.

These and other possible impacts of the pipeline on rivers and streams along its route make it imperative that river hydraulic aspects, erosion and sedimentation be well understood.

State of Knowledge

Sediment transport mechanics is a rather inexact science. What exists is knowledge in the empirical stage. So called "theories" refer to particular streams and one must be careful of where and how to apply them. In most cases, the evaluation of problems depends almost wholly on the understanding the analyser has of the stream.

Streams along the route of the pipeline belong to a wide range of categories. Moreover, particularities of the North make understanding of the sediment regimes of these streams even more complex. Most of the available knowledge has been derived from studies of streams in temperate and hot climates and very little work has been done in cold climates.

Data on the streams of the Yukon are very sparse. For most of the streams of concern there are no data, and in most cases even the hydrology of the streams is inadequate.

Since solutions must be given to problems now, or within a very short period of time, only a minimum amount of data can be collected. Several field trips have been carried out to help understand sedimentation processes of various streams. Observations that have been made can assist in determining only "ball park" figures for the parameters involved.

Available Data

Peak flows for several return periods are contained in Table 3, pages 30 to 47. Available hydrometric and sediment survey data for streams along the Alaska Highway are listed in Appendix A. Table 4 summarizes key events in the River Hydraulics field and office program.

Application of Results

A. Streambed Scour

An inherent uncertainty exists in every scour estimate because of the complexity of considerations involved; these include the adequacy of hydrometric data, the selection of design flow value, the reliability of geotechnical and morphological data such as the streambed particle size distribution and channel slope, and the incidence of localized scour such as that associated with ice jams and channel restrictions during construction. Added to these factors are the uncertainties related to the applicability of scour equations to a particular stream. The equations tend to be empirical, whose coefficients and exponents have been derived from experiments and/or field observations for particular streams.

For seasonal streams such as the high energy, alluvial bedded streams discharging into the west shore of Kluane Lake (Figures 2 and 3), the equations do not apply, because of the severe lateral migration; for these types of streams detailed information is required on the hydrologic and geotechnical characteristics for each particular site before a judicious selection of potential scour depth could be made.

Application of the scour equations to a braided stream such as the Donjek River is hazardous because lateral erosion and changes in braided patterns (Figures 4-7) are significant complements to the vertical scour or deposition. For such rivers vertical change can best be determined from soundings obtained during a passing flood. Table 5 summarizes vertical changes measured at the Donjek River during the 1978 high water period. Table 6 gives mean velocities at the points within the cross-section where vertical changes were measured.

Table 7 and Figure 8 present estimates of scour for a representative number of small streams (Figures 9-31) along the route where scour equations were considered to be generally applicable. These streams have "incised" cross-sections and are subject to relatively small changes in flow patterns. However, it is important to point out that the scour values listed are based on regional curves giving "average" channel geometry data generated for Appendix C.

Some streams will have less scour than shown; others will have greater scour. Therefore, considerable caution should be exercised when extracting calculated values from Table 7 and Figure 8.

B. Sediment

Construction activities such as trenching and gravel excavations will increase siltation in lakes and streams along the proposed Alaska Highway pipeline route; terrain disturbance such as removal of forest cover and ground vegetation will also increase sediment supply, and volume added will tend to be proportional to the land area disturbed by technological activities. In order to assess the capacity of the river systems to carry away the added sediment supply and to consider effects of sediments on stream ecosystems, it is important to present at least a condensed picture of the natural suspended sediment movements in the area of concern.

From Appendix A it is evident that available sediment survey data for Yukon Territory do not encompass a long enough period on sufficient number of streams to provide basic data needed for this purpose. Arrangements that were made in late summer of 1977 for a program of miscellaneous sampling at small stream hydrology stations were unfruitful because of the continued low level of streamflow through 1978 snowmelt period. As an alternative, the family of regression lines relating suspended sediment concentration to discharge, developed at time of Mackenzie Valley pipeline investigations*, were expanded to include a number of sites along Alaska Highway route having relatively long suspended sediment record (Figure 32), and interpretations were made in an attempt to satisfy the above purpose. The regression lines were drawn using less than adequate data; however, they are considered to be sufficiently accurate to provide a usable approximation of a stream's morphological characteristic.

Sediment rating curves relating suspended sediment to water discharge (Figure 32) is a basic tool in wide use in hydrologic practice. They are generally used in estimating suspended sediment concentrations between sampling dates.

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*G.J. Brunskill, et al. The Chemistry, Minerology, and Rates of Transport of Sediments in the Mackenzie and Porcupine River Watersheds, N.W.T. and Yukon, 1971-73.

Also, Abrahams and Kellerhalls* have suggested that with careful evaluation of available data these regression lines may be useful in predictive estimation of sediment concentrations and rates of transport of sediments resulting from terrain disturbance.

Possible interpretations of the regression lines in Figure 32 are presented below to serve as an aid in the review of the EIS.

1. It is typical that sediment concentration increases with water discharge. Rate of increase or the slope of the regression line can provide an approximation of a stream's morphological characteristic. [illegible]
2. When the line slopes steeply, it indicates that suspended sediment concentration increases rapidly with discharge, as may be in the case of a steep tributary stream with numerous rills and large surface flow areas. ? These rivers can exert a great erosional pressure on their watersheds and transport large quantities of sediment. Examples are: Donjek, White and Alsek Rivers and the alluvial streams along the west side of Kluane Lake. Such streams carry away clay, silts and fine sands considerable distances, leaving behind only gravel and boulders.

Rivers ?

3. Streams east of Whitehorse generally have lower regression line slope values. Examples are: Swift River and Liard River at Fort Liard. The watersheds have relatively low relief and thick deposits of silt and lacustrine sediments; streams here exert lesser erosive energy and have lower capability to transport sediments. Increased sediment supply due to construction disturbances generally will settle to the streambed close to the site of addition. See also Sediment Regimes, page 20.
4. Rivers with many lakes in their watersheds are usually relatively free of suspended sediment due to the settling effect in the lakes and the regression lines will slope at much less than 45^{0}. The available capacity of these streams to carry sediments between lakes may nevertheless be high. Consequently any increased sediment supply due to pipeline activities may have a considerable detrimental effect on such rivers, particularly since lake-controlled rivers tend to be productive biologically.

It must be emphasized that the above interpretations are based on minimal data detail; greater confidence can result from a program of continued monitoring of the average and above average runoff events.

*Proceedings, Canadian Hydrology Symposium, University of Alberta, Edmonton, May 8 and 9, 1973.

C. Stream Meander and Lateral Migration

Aerial photographs of the pipeline route were studied with the objective of (a) pinpointing critical areas of natural meander propogation and (b) assessing whether pipeline construction activities may cause acceleration of meander advance. Based on a comparison of aerial photographs (scale 1 inch = 3000 feet dated April 1978, and scale 1 inch = 6200 feet dated early 1950's) no rapid migration zones were detected. Nevertheless the meander and lateral migration problem warrants detailed consideration of all factors related to construction activities that could trigger lateral migration. Streams in the 150 miles east of Alaska-Yukon border are particularly susceptible; here the shape of the river cross-sections, roughly described by their width-to-depth ratio, are generally such that they accommodate increasing discharges by increases in river width rather than by large increases in river depth.

Construction activities that could subject streams to lateral migration are mainly those which involve removal or destruction of vegetation. The slumping that results from removal of vegetation leaves the area vulnerable to floods.

D. Drainage Alternation

There is a potential for the natural drainage pattern alternation at many areas along the pipeline route. This could be in the form of "channelization" of flow adjacent to and possibly within the trench. In areas of fine-grained soil such as the glacial-lacustrine deposits, backfilling with granular soils in place of the in situ material in an attempt to reduce frost-heave may create a potential pathway for downslope flow.

The numerous small, high energy streams with actively moving beds of silt, volcanic ash, gravel and boulders that descend from Kluane Range and empty into Kluane Lake have the greatest potential in creating a serious drainage problem. The streams are contained in the mountains by channel walls, but on the fans they are unconstrained and are free to shift their courses. During floods the bed material chokes the channel, causing the stream to abruptly flow out and find a new channel elsewhere, where it scours down a similar channel (Figures 2 and 3). The question is what happens when an excavation transverses the general drainage pattern of this type of surface material, generally underlain with permafrost. Added to this knowledge gap is the general lack of hydrologic understanding of the area.

WATER QUALITY

Alaska Highway pipeline is expected to cross some 250 streams in an area of Canada for which little scientific information is available on the aquatic environment. Water quality and microbiological studies have in general been limited to spring and summer months; also, tacit assumptions exist indicating that only little biological activity occurs during the winter, and that the aquatic system would be least stressed by man's activities during this season. In order to adequately understand possible impacts of the pipeline construction and to be able to assess the proponent's mitigation measures it was considered necessary to acquire a better understanding of water quality and biological processes in the area. Thus, a 12-month study of two Yukon watersheds was carried out between October 1977 and August 1978. Pipeline construction may cause a number of water quality problems, among which are :

a) Increased sedimentation : The aquatic environment will be subjected to widespread disturbance because of many and repeated river crossings; turbidity and sedimentation will likely be increased at many stream crossings.

b) Alterations of surface and groundwater flow : Trenching may cause changes in both surface and groundwater flow regime.

The objectives of the study were:

1. To gain an understanding of water quality processes and conditions, particularly during the winter;
2. To establish cycles, trends, and sources of variability in water chemistry and biology;
3. To relate water chemistry to hydrology, geology, and biology;
4. To determine microbial (algal and bacterial) activity and productivity.

Degree to which these objectives could be met was limited by the available time period, the logistic problems associated with winter water sampling and the available manpower resources. Thrust of the study was consequently directed to achieving a qualitative understanding of the potential environmental problems; it was not designed to meet baseline data requirements for an environmental impact assessment.

Location of Study Area

The study was conducted in the Swift and Ogilvie River basins located in the south-eastern and north-central parts of the Yukon Territory respectively (Figures 33, 34 and 35). General conditions of the two watersheds are summarized below.

PARAMETERS & CONDITIONS	SWIFT RIVER	OGILVIE RIVER
Location:		
coordinates	130°45'-132°W/59°45'-60°15N	137°30'-138°30'W/65°-65°45'N
geographic location	Southeastern Yukon Territory	Northcentral Yukon Territory
Hydrologic Parameters:		
size of watershed	3870 km^2 (to mouth at Teslin Lake)	7220 km^2 (to Blackstone R. confluence)
maximum relief	1410 m	1190 m
discharge record	22 years	5 years
maximum discharge	15200 cfs (6.11.64)	23400 cfs (5.31.75)
minimum discharge	205 cfs (3.26.69)	20 cfs (2.12.75)
Water Supply:		
source	surface run-off and ground-water discharge in head-waters	surface run-off and ground-water discharge all along bedrock channel
Geological Parameters:		
bedrock geology	igneous and metamorphic	sedimentary rocks
dominant bedrock type	granodiorite	limestone
geomorphological setting	well-rounded mountainous terrain	structurally controlled mountainous terrain
dominant surficial material	till, alluvium, peat	colluvium,alluvium, peat
Soils:		
dominant type	regosol, brunisols, gleysols and organic	regosols, cryosols, and organic
Vegetation:		
dominant tree cover	white and black spruce & lodgepole pine	stunted black spruce in protected areas (tundra)
approximate tree cover	60 %	25 %
Climatic conditions:		
temperatures (max-min)	-42°C to +32°C	-47°C to +31°C
precipitation (max-min)	450 to 660 mm	290 to 350 mm
approx. time of freeze-up	mid to end of October	early October
approx.time of break-up	beginning of May	late May

The Swift River basin was selected because it was thought to be representative of watersheds in the southeastern Yukon region. The Ogilvie River basin was chosen to provide an extreme example of a drainage system in a permafrost environment having substantial winter groundwater discharge; a satisfactory study basin for this purpose could not be found in the northern portion of the Alaska Highway route.

Discussion of Results

A. Hydrological Conditions During Winter

Despite consistently cold temperatures ranging from -25° to -50°C, sections of open water were encountered in both rivers. Selective groundwater discharge was found to be the cause of open water sections in the Ogilvie River system, while ice collapse, accelerated flow, and to a lesser extent, groundwater were responsible for open water sections in the Swift River. A great variety of ice types and ice thicknesses were observed in both systems; ice types which included block ice, layer ice, cavernous ice, and aufeis, ranged in thickness from 25 to greater than 180 cm. Groundwater sources and regimes differed greatly between the two basins resulting in drastically different flow rates and ice build-up.

B. Dissolved Oxygen

A progressive decrease in dissolved oxygen concentrations was observed as the winter advanced, and oxygen replenishment did not occur until ice break-up had taken place. Oxygen depletion was found in a great variety of stream conditions in both watersheds, reaching levels as low as 3ppm. This suggests that oxygen depletion is a natural process caused by a change in the balance of a number of factors, including algal and microbial respiration, groundwater, chemical oxygen demand under conditions of reduced temperature, river flow, light input, and reaeration.

C. Trends in Water Chemistry and Biology

Both Ogilvie and Swift Rivers displayed annual cycles in many microbial, chemical and physical parameters. They are summarized below together with apparent causes for their variations. Complete details are given in Appendices E and F.

(a) Those parameters for which the concentration increased throughout the winter to reach maximum annual concentration at thickest ice cover immediately prior to break-up.

Parameter	Apparent cause for variation
Specific conductance, alkalinity Ca, Mg, Na, Si, SO_4 $N(NO_3 + NO_2)$	Increased contribution of saline groundwater, reduced input of surface water, and transfer of salts during freezing from solid to liquid phase

(b) Parameters which were consistently low or decreased as winter progressed to increase abruptly during spring high water.

Parameter	Apparent cause for variation
Iron, total phosphorous some trace metals	In part related to flow and sediment transport
Dissolved oxygen	Ice break-up allowing reaeration aided by turbulent flow

(c) Parameters which showed a decrease during early winter, followed by a slight increase in late winter and reaching maximum concentrations in late spring (following ice break-up) and early summer.

Parameter	Apparent cause for variation
Microalgal and bacterial standing crops and activities, organic and inorganic nutrients, non-filterable residues (Table 8)	Physiochemical parameters; most significant are: available light for microalgae and DOC for bacteria.

D. Sources and Magnitude of Variability in Water Chemistry

Cross-sectional and short-term variations were found to be significantly smaller than either spatial or seasonal for most of the chemical parameters. Seasonal variations for such parameters as specific conductance, pH, magnesium and silica were found to be greater than spatial variations in the Ogilvie River system, while the reverse was the case for specific conductance, pH, hardness, calcium and sulphate in the Swift River system. Differences in hydrological and drainage basin characteristics are thought to be responsible for the contrasting results. Annual maximum and minimum observed values in water chemistry are shown below.

	Annual Maximum		Annual Minimum		
Parameters	Ogilvie River	Swift River	Ogilvie River	Swift River	Units
Specific conductance	789.0	204.0	45.0	23.0	mhos/cm
pH	8.4	8.2	2.8	7.0	
hardness	396.0	113.0	26.0	9.2	mg/l
Ca	105.0	19.7	8.8	3.1	"
Mg	37.5	6.9	0.9	0.6	"
Na	15.4	2.1	0.2	0.7	"
K	1.1	0.8	0.2	0.2	"
SO_4	223.0	5.9	16.7	1.7	"
Cl	19.3	0.4	1.0	0.2	"
Si	6.6	10.6	1.8	4.9	"

Note: Excluding springs and lake water samples; including tributaries.

E. Point Versus Non-Point Sources in Water Chemistry

Swift River is controlled by non-point sources, and local differences within the watershed are attributed to differences in the bedrock composition and surficial materials. Tributaries have a localized effect on chemistry of the main stream but since influence is consistent throughout the year it is implied that the basin is controlled by relatively uniform drainage conditions. A number of point sources dominate the Ogilvie River system; the most important is a black shale formation in Engineer Creek which contributes substantial quantities of salts, nutrients, and metals to the system. In places sulphur and calcium sulphate precipitates were observed. Siderite is formed in alkaline sections, and acid water is produced through pyrite oxidation in several localized areas. The latter process is responsible for dissolution of large quantities of iron and sulphate.

F. Groundwater Conditions

Relative groundwater contribution in the two river systems differ drastically. The water supply in the Swift River basin is controlled by headwater springs, snow melt and summer precipitation. Flow is regulated by a series of high mountain lakes with little evidence of groundwater seepage in lower sections of the basin. The Ogilvie system in contrast is greatly influenced by groundwater in numerous portions of the basin. Groundwater stored in limestone quifers in the Ogilvie basin is forced to flow along the tilted bedding plane and emerges to the surface at places where bedrock formation crosses the riverbed. In these sections open water was found in the winter and overflows from that source were responsible for build-up of icings downstream. Groundwater contribution could best be differentiated from stream flow in late winter when water chemistry could be used as a sort of fingerprinting technique to locate and identify different groundwater sources. At least five such source areas were identified and each could readily be differentiated on the basis of the chemical composition as can be seen below.

Ogilvie Sampling Stations (Figure 34)	pH	Spec. Cond. mhos/cm	Ca mg/l	Mg mg/l	Na mg/l	Si mg/l	SO_4 mg/l	Cl mg/l
# 3	8.0	355	55	12	2.4	2.8	35	1.6
#14	8.0	456	64	16	7.4	3.6	62	4.5
# 6	8.1	560	75	22	11.8	3.7	90	11.8
#15	7.7	789	97	38	15.4	5.1	147	19.0
#13	7.6	1800	152	85	124.0	11.0	350	150.0

G. Sediment Regimes

No quantitative comparison of the sediment regime in the two rivers was possible because a continuous sediment record could only be obtained for the Ogilvie basin; also, Swift River runoff was one of the lowest in the 20 years that the gauging program was in operation. Because of the somewhat moderated flow caused by numerous lakes it is implied that scour and consequently sediment transport is significantly lower in the Swift than in the Ogilvie River. In addition the more extensive vegetation cover and the absence of permafrost contribute to the decreasing rate of surface run-off and increasing infiltration rates. As a result spring snow melt and summer storms transport less sediment. In contrast the Ogilvie River responds very quickly to atmospheric events and overland flow is favoured because of permafrost, sparse vegetation, little soil cover, and steeper slopes. Based on daily sampling suspended sediment concentrations varied from less than 1 mg/l to 277 mg/l over the 1978 spring and summer period.

H. Biology

Generally, the Ogilvie River appears to be the richer of the two ecosystems with regard to (1) standing crops of microalgae, bacteria and benthic invertebrates, (2) microbial productivities and bacterial gl$\overset{u}{\text{o}}$cose heterotrophic activities and (3) concentrations of organic and inorganic elements and compounds of biological interest (e.g. DOC, TIC, NO_3, NH_3, Ca, SO_4, Mg, Na and K). The higher nutrient levels have resulted in an apparently more productive microbial ecosystem in the Ogilvie as compared to the Swift River.

I. Interactions Between Physico-Chemical Parameters and Microbiology

Relationships between various physical and chemical parameters and planktonic and benthic microflora of both the Ogilvie and Swift Rivers appear to be the following:

(1) The year-round microalgal standing crops and productivities observed in both ecosystems appear to be mainly regulated by available light levels whereas bacterial glucose heterotrophic activities correlate best with dissolved organic carbon (DOC). That is, the levels of energy available to biological systems (light-algae, organic matter (DOC) - heterotrophic bacteria) appear to greatly regulate levels of microbial standing crops and activities.

(2) A portion of total inorganic carbon (TIC) which increases in the waters of both rivers under ice cover during winter is probably due to both ~~microbial and~~ macroorganism heterotrophic respiration. In a similar fashion, the decreased DO levels which were observed in both rivers in winter also appear to be at least partially due to microbial respiration.

J. Summary of Water Quality in the Swift and Ogilvie Rivers

IMPORTANT DIFFERENCES	OGILVIE RIVER	SWIFT RIVER	CAUSES
Hydrological regime	great fluctuations in flow	naturally regulated flow	Differences in water retention caused by permafrost & vegetation cover, presence of lakes
Source of chemical variability	seasonal > spatial	spatial > seasonal	Differences in groundwater contribution in winter
Major ion concentrations	hard water, high HCO_3, high Ca, low Si	soft water, low Ca, low Mg, high Si	Differences in bedrock geology
Sources of ionic contribution	point sources (Fe, SO_4)	Non-point sources (Ca, CO_3)	Presence or absence of zone of mineralization causing acid drainage
Groundwater contribution	numerous sources dominant in winter	no evidence in lower part of basin, mainly headwater springs	Differences in geological structure
Microalgal and bacterial standing crops	higher standing crops	lower standing crops	Higher nutrient levels in the Ogilvie River
Bacterial heterotrophic activities	higher heterotrophic activities	lower heterotrophic activities	Higher nutrient levels in the Ogilvie River
IMPORTANT SIMILARITIES			
Winter DO depletions	somewhat variable	consistent	Probably caused by ice cover, microbial respiration, groundwater contribution and lack of reaeration

K. Addition of Streambank Materials

Assessment of streambank materials additions (which would tend to be displaced into rivers during trenching and backfilling activities) upon microalgal and bacterial activities was done by experimentally adding streambank materials to Swift River water and noting the effects upon various microbial processes. Significant influences were noted when between 0.10 and 10.0 grams of materials were added per litre of river water. These materials tended to increase microbial productivities and biological oxygen demand of the waters, as can be noted in the tabulations below.

Influences of Three Swift River Streamside Soil Horizons on
Biological Oxygen Demand of Swift and Ogilvie River Waters
(Sampled 10 March 1978)

		Swift River Water		Ogilvie River Water	
		Days of Incubation at ± 1°C			
Sediment Addition		21	51	21	45
None		0.4*	1.7	0.0	0.4
0.01 g/l	LFH**	0.5	1.3	-	-
0.10 g/l	LFH	1.7	9.3	0.0	0.8
1.00 g/l	LFH	4.5	10.3	1.2	4.4
10.00 g/l	LFH	10.5	10.8	9.6	10.4
0.01 g/l	Ae***	0.9	1.7	-	-
0.10 g/l	Ae	1.0	2.6	0.0	0.6
1.00 g/l	Ae	3.1	9.9	0.3	1.8
10.00 g/l	Ae	9.4	10.7	9.4	10.1
0.01 g/l	Bm(t)****	0.7	1.1	-	-
0.10 g/l	Bm(t)	0.7	1.4	0.0	0.6
1.00 g/l	Bm(t)	1.4	5.9	0.3	1.0
10.00 g/l	Bm(t)	5.5	10.4	1.9	6.4

* all values expressed as mg O_2/l

** leaf, ferment and humus horizon

*** leached mineral horizon

**** mineral horizon

Influence of Two Streamside Soil Horizons on Planktonic Algal (mg C/m^{3}day)
and Heterotrophic (mg C/m^3/day) Productivities of Swift River

Sediment Addition		Algal Productivity (23 June 1978)	Heterotrophic Productivity (7 August 1978)
None		1.4	3.0
0.10 g/l	Bm(t)*	3.3	8.1
1.00 g/l	Bm(t)	1.4	4.9
10.00 g/l	Bm(t)	16.8	20.0
1.00 g/l	LFH**	6.1	27.7

* mineral horizon

** leaf, ferment and humus horizon

Interpretation of Results

A. Winter Depletion of Dissolved Oxygen

Severe dissolved oxygen depressions were found during the winter in both study basins (Figures 36 and 37). The depressions occurred in the majority of stations despite a great variety of stream conditions, and were most extensive in late winter during maximum ice cover and when salt concentrations in water were the highest. These findings are in agreement with Alaska findings published by Schallock and Lotspeich (1974), which suggest that dissolved oxygen depletion is a widespread phenomenon in these northern areas.

A number of factors appear to be responsible for the depletion process, and based on the present study it appears that ice conditions are not the only cause of the depressions; other factors such as groundwater contribution, reaeration, and respiration interact and affect oxygen concentrations. Groundwater release which often produces stretches of open water during the winter does not necessarily produce higher dissolved oxygen concentrations.

Because of low oxygen values the biological system is under stress particularly during late winter; disturbance of the ecosystem at that time could reduce oxygen values even further and thus create critical conditions. It is evident therefore, that timing of construction is critical.

B. The Use of Water Chemistry in Determining Groundwater Sources

Groundwater sources can best be identified in late winter when the proportional contribution to the river is greatest. Sources can be identified by evidence of open water sections and by analysis of chemical composition of the water. The latter method was used as a sort of "fingerprinting" technique not only to differentiate between groundwater sources but also between groundwater and surface flow. The identification of the groundwater discharge areas and the knowledge of their proportional contribution to stream flow during the winter are valuable in detailing route location for the pipeline.

C. The Use of Geological Structure in Determining Groundwater Discharge and Icings

Geological structure in the Ogilvie River basin was found to control groundwater flow. The river has cut through a series of folded and partially eroded anticlinal - syncline structures, leaving a number of steeply dipping limestone beds exposed in the river bed. The limestone beds act as aquifers and groundwater flow is forced along the structural bedding plane and is eventually released into the river at those points where the structure crosses the river. Open water sections in the winter were found to coincide with these groundwater release areas in three out of four cases, and icings were found immediately below the open water sections. These icings significantly reduce the flow in the downstream direction and force the water to periodically overflow or to find its way into new aquifers. Streambed scour during break-up is greatest below such icings and knowing their location is important in route location of the pipeline.

D. Bedrock Geology as Indicator of Toxicity and Corrosion

Bedrock composition greatly influences water quality. Differences in bedrock geology were responsible for altering water chemistry in several tributaries in the Swift and Ogilvie Rivers. The black shale formation in Engineer Creek (a major Ogilvie River tributary) for example, was identified as a major source of salt and metals. Excavation through such areas could tap heavily mineralized groundwater aquifers and cause toxicity problems. This formation also produces localized acid drainage which in places was observed to have pH values of 2.8, despite the otherwise alkaline conditions. It is thought that acid is produced through oxydation of pyrite in the black shale formation; in the process sulfuric acid is produced which not only increases metal solubility but also acts as an effective corrosive agent. This chemical reaction caused disintegration of galvanized culverts within one year of installation. The knowledge of the existence of such areas is of significance for pipeline location and construction.

E. Microbial Productivities

Numbers and productivities of both planktonic and benthic algae and bacteria were maximal in late spring (following ice break-up) to early summer and minimal in winter in the Ogilvie and Swift Rivers, with greater proportions of these microbial biomasses and activities occurring in the stream bottom as compared to overlying water. In both rivers algal productivities tended to be greater than bacterial productivities.

F. Effects of the Addition of Streambank Materials

Perturbation of Swift and Ogilvie River waters with streambank materials tended to increase bacterial activities and productivities (by increasing dissolved organic carbon (DOC) concentrations) whilst decreasing algal activities (by decreasing light penetration into the water). An example of this was noted in the Ogilvie River on 23 June, 1978. Heavy rainfall naturally perturbed this river with non-filterable residue (117 mg/litre river water) within 2 days, which resulted in heavy turbidity and little light penetration. Hence, photosynthesis was not detectable although phytoplankton numbers were high. However, bacterial planktonic productivities and glucose heterotrophic activities greatly increased (Table 8) probably due in part to increased DOC loadings. Thus, the different responses of algae and heterotrophic bacteria must be taken into consideration when appraising the effects of trenching and backfilling operations upon these trophic levels.

Table 1 WATER SURVEY OF CANADA GAUGING STATIONS CONSIDERED IN THE ANALYSIS

W.S.C. No.	Name	Record Length (Yrs.)	Drainage Area (sq.mi.)
A. Yukon Territory			
08AA001	Aishihik River near Whitehorse	29	1,660
08AB001	Alsek River above Bates River	3	6,250
10MD002	Babbage River below Cariboo Creek	3	588
09AH003	Big Creek near Mouth	4	674
09AG001	Big Salmon River near Carmacks	20	2,610
08AA003	Dezadeash River at Haines Junction	25	3,280
10MD001	Firth River near Mouth	4	2,240
10AB001	Frances River near Watson Lake	16	4,950
10AD002	Hyland River at Mi. 67.4 Nahanni Rge. Rd.	3	211
08AA004	Kathleen River near Haines Junction	6	249
10AB003	King Creek at Mi. 13 Nahanni Rge. Rd.	3	5.3
09EA003	Klondike River above Bonanza Creek	12	3,010
09CA002	Kluane River at Outlet of Kluane Lake	26	1,910
10AA001	Liard River at Upper Crossing	19	12,900
09AA007	Lubbock River near Atlin	16	684
09AB008	M'Clintock River near Whitehorse	22	597
09EA004	North Klondike River near Mouth	4	423
09FC001	Old Crow River near the Mouth	3	5,370
10MA002	Ogilvie River at Mile 123 Dempster Hwy.	4	2,090
10MA001	Peel River above Canyon Creek	13	10,200
09BC001	Pelly River at Pelly Crossing	24	18,900
09BC002	Pelly River at Ross River	20	7,670
09BC004	Pelly River below Vangorda Creek	6	8,490
09FB001	Porcupine River below Bell River	4	13,900
09FD001	Porcupine River at Old Crow	17	20,900
09BA001	Ross River at Ross River	16	2,800
10MB001	Snake River above Iron Creek	5	1,070
10MB003	Snake River near the Mouth	2	3,440
09BB001	S. MacMillan River at Mi. 249 Canol Rd.	4	385
09DC002	Stewart River at Mayo	29	12,100
09DD003	Stewart River at the Mouth	15	19,700

Table 1 WATER SURVEY OF CANADA GAUGING STATIONS CONSIDERED IN THE ANALYSIS
(Cont'd)

W.S.C. No.	Name	Record Length (Yrs.)	Drainage Area (sq.mi.)
09DD002	Stewart River at Stewart Crossing	14	13,500
09AA011	Tagish Creek near Carcross	11	31
09AC004	Takhini River at Outlet of Kusawa Lake	21	1,570
09AC001	Takhini River near Whitehorse	30	2,700
09AE001	Teslin River near Teslin	31	11,700
09AF001	Teslin River near Whitehorse	19	13,700
10AA002	Tom Creek at Mi. 21.7 Robt. Campbell Hwy.	4	168
09AA009	Watson River near Carcross	15	452
09AA012	Wheaton River near Carcross	18	337
09AH001	Yukon River at Carmacks	27	33,600
09EB001	Yukon River at Dawson	31	106,000
09AB009	Yukon River above Frank Creek	26	12,000
09CD001	Yukon River above White River	20	58,400
09EB002	Yukon River at Stewart River	9	97,300
09AB001	Yukon River at Whitehorse	35	7,500
B. British Columbia			
09AA006	Atlin River near Atlin	28	2,630
09AA014	Fantail River at Outlet of Fantail Lake	20	289
09AE004	Gladys River at Outlet of Gladys Lake	17	737
10AD001	Hyland River near Lower Post	24	3,650
09AA010	Lindeman Creek near Bennett	22	92
09AA008	Pine Creek near Atlin	19	269
08BB002	Sloko River near Atlin	18	165
09AE003	Swift River near Swift River	19	1,280
09AA013	Tutshi River at Outlet of Tutshi Lake	19	366
09AA015	Wann River near Atlin	18	104

Table 2 SMALL STREAM NETWORK - ALASKA HIGHWAY - 1978

Operated by Department of Indian and Northern Affairs

Name	Drainage Area (sq. mi.)	Remarks
Snag Creek at MP 1208.0	380	Water stage recorder; seasonal daily discharge
Dry Creek at MP 1184.0	52	Crest-stage; miscellaneous discharge measurements
Sanpete Creek at MP 1178.4	29	
Long's Creek at MP 1156.0	44	Water stage recorder; seasonal daily discharge
Burwash Creek at MP 1103.9	65	
Unnamed Creek at MP 1082.5	3.4	Crest-stage; miscellaneous discharge measurements
Silver Creek at MP 1053.6	18.6	
Bear Creek at MP 1022.3	30	
Marshall Creek at MP 1005.6	83	
Mendenhall Creek at MP 968.0	293	Water stage recorder; seasonal daily discharge
Stoney Creek at MP 956.0	19	Crest-stage; miscellaneous discharge measurements
Deadmans Creek at MP 822.3	84	
Logjam Creek at MP 751.1	33	
Partridge Creek at MP 736.4	24	Water stage recorder; seasonal daily discharge
Spencer Creek at MP 695.3	62	Crest-stage; miscellaneous discharge measurements
Big Creek at MP 674.0	405	

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY

Cubic Feet Per Second

STREAM & RAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Snag Creek	1208.0	2.33-year	see Appendix A	2,670	1,020	2,060	-		Generally swampy low ground; pipeline trench could induce toxic waters to clear creek channels. Widespread discontinuous permafrost; considerable frost heave potential because of poorly drained silty sand and volcanic ash.
		50-year		4,830	3,200	4,420	-		
		100-year		5,610	3,650	5,410	-		
380	8.5	Max. Daily		-	-	-	6,010		
		Culvert Cap.	-	-	-	-	-	Bridge	
Beaver Creek	1200.7	2.33-year	see Appendix A	3,800	6,830	3,750	-		Beaver Creek originating in the Wrangell mountains at elevations of 7000-8000 feet is not typical for the area; it is violent at flood stage and its gravel banks are highly erodable.
		50-year		6,880	12,600	8,080	-		
		100-year		7,980	13,900	9,880	-		
737	15.8	Max. Daily		-	-	-	10,300		
		Culvert Cap.	-	-	-	-	-	Bridge	
Enger Creek (Niggerhead)	1195.8	2.33-year	-	-	533	340	-		See Snag Creek
		50-year	-	-	977	731	-		
		100-year	-	-	1,080	894	-		
52.4	23.6	Max. Daily	-	-	-	-	1,180		96" dia. x 108'; Replaced in 1962
		Culvert Cap.	-	-	-	-	-	600	
ry Creek	1184.0	2.33-year	see Appendix A	150	887	338	-		See Snag Creek
		50-year		272	1,610	728	-		
		100-year		315	1,780	891	-		
52.2	31.0	Max. Daily		-	-	-	1,180		
		Culvert Cap.	-	-	-	-	-	Bridge	

* Miles along the proposed pipeline route

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY
Cubic Feet Per Second

STREAM & RAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Sanpete Creek	1178.0	2.33-year	see Appendix A	-	618	201	-		See Snag Creek
		50-year		-	1,120	432	-		
		100-year		-	1,230	529	-		
		Max. Daily		-	-	-	745		
29.4	36.7	Culvert Cap.	-	-	-	-	-	850	12'-10" x 8'-4" Pipe Arch x 70' long; installed in 1961
White River	1169.2	2.33-year	only 4 years of record	-	-	-	-		Subject to severe scour. Glacier dammed lakes could have substantial effect on hydrology. Discontinuous permafrost is widespread, an aufeis and frost heave are definite hazards.
		50-year		-	-	-	-		
		100-year		-	-	-	-		
		Max. Daily	-	-	-	-			
2410	43.5 to 45.5	Culvert Cap.	-	-	-	-	-	Bridge	
Koidern	1164.0	2.33-year	-	-	3,300	2,290	-		Drainage diversion from surrounding swamps and lakes is a possibility. Erosion, slumping and solifluction from induced permafrost thawing during construction along the steep gradient immediately east of Koidern River is a hazard requiring close attention; could cause deterioration in wate quality.
		50-year	-	-	6,090	4,930	-		
		100-year	-	-	6,710	6,030	-		
428	48.8	Max. Daily		-	-	-	6,620		
		Culvert Cap.	-	-	-	-	-		
Long's Creek	1156.0	2.33-year	see Appendix A	1,270	561	290	-		
		50-year		2,300	1,010	624	-		
		100-year		2,670	1,120	764	-		
44.1	58.1	Max. Daily		-	-	-	1,040		
		Culvert Cap.	-	-	-	-	-	Bridge	See Koidern at MP 1164

* Miles along the proposed pipeline route

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY

Cubic Feet Per Second

STREAM & DRAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Wolf Creek	1155.5	2.33-year	-	-	-	423	-		See Koidern at MP 1164
		50-year	-	-	-	910	-		
		100-year	-	-	-	1,113	-		
66.7	58.7	Max. Daily	-	-	-	-	1,450		
		Culvert Cap.	-	-	-	-	-	Bridge	
Koidern River	1152.2	2.33-year	-	1,670	2,180	1,460	-		See Koidern at MP 1164
		50-year	-	3,020	3,990	3,130	-		
		100-year	-	3,510	4,390	3,830	-		
260	62.5 to 63.0	Max. Daily	-	-	-	-	4,400		
		Culvert Cap.	-	-	-	-	-	Bridge	
Edith Creek	1146.6	2.33-year	-	-	-	683	-		Discontinuous permafrost; frost heave potential
		50-year	-	-	-	1,470	-		
		100-year	-	-	-	1,800	-		
113	67.6	Max. Daily	-	-	-	-	2,230		
		Culvert Cap.	-	-	-	-	-	Bridge	
Donjek River	1132.8	2.33-year	see Appendix A	-	-	-	-		Concerns similar to those for White River, but permafrost and frost heave hazards are expected to be relatively minor.
		50-year		-	-	-	-		
		100-year		-	-	-	-		
		Max. Daily		-	-	-	-		
1687	80.2 to 80.8	Culvert Cap.	-	-	-	-	-	Bridge	

* Miles along the proposed pipeline route

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY

Cubic Feet Per Second

STREAM & RAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Swede Johnson Creek	1119.2	2.33-year	-	-	389	241	-		Generally the eastern termin for permafrost and frost hea problems; however, ground ic and in particular frost susceptibility can be expected throughout the route. 9'6" x 6'5" pipe arch x 60' long; installed in 1961.
		50-year	-	-	713	519	-		
		100-year	-	-	785	635	-		
		Max. Daily	-	-	-	-	878		
36.0	93.7	Culvert Cap.	-	-	-	-	-	500	
Kluane River	Outlet of Kluane Lake	2.33-year	9,410	12,000	18,200	8,920	-		Kluane Lake is the largest lake in the Yukon; its west shore is characterized by high energy, gravel-fed streams whose fans are actively aggrading.
		50-year	13,000	21,700	34,800	19,200	-		
		100-year	13,400	25,200	38,500	23,400	-		
		Max. Daily	13,600	-	-	-	22,500		
1910		Culvert Cap.	-	-	-	-	-	-	
Quill Creek	1111.6	2.33-year	-	-	303	182	-		Tailings pond at the mill may induce toxic substances into adjacent streams.
		50-year	-	-	554	392	-		
		100-year	-	-	610	479	-		
		Max. Daily		-	-	-	681		
26.4	100.0	Culvert Cap.	-	-	-	-	-	Bridge	
Burwash Creek	1103.9	2.33-year	see Appendix A	639	615	413	-		Upstream placer mining activity likely has an effe on water quality.
		50-year		1,490	1,130	888	-		
		100-year		1,820	1,250	1,090	-		
		Max. Daily		-	-	-	1,420		
64.8	106.3	Culvert Cap.	-	-	-	-	-	Bridge	

* Miles along the proposed pipeline route

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY
Cubic Feet Per Second

STREAM & RAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Duke River	1098.5	2.33-year	see Appendix A	4,440	3,830	1,430	-		The fan of the Duke River substantially controls the level of Kluane Lake. Deep scour potential; lateral stability is poor.
		50-year		7,960	7,340	3,080	-		
		100-year		9,240	8,120	3,760	-		
		Max. Daily		-	-	-	4,340		
255	110.5	Culvert Cap.	-	-	-	-	-	Bridge	
Halfbreed Creek	1089.1	2.33-year	see Appendix A	716	281	184	-		See Lewis Creek
		50-year		1,670	515	396	-		
		100-year		2,040	568	484	-		
		Max. Daily		-	-	-	688		120" Dia. pipe, 92' long; installed in 1966
26.7	118.7	Culvert Cap.	-	-	-	-	-	1100	
Lewis Creek	1087.0	2.33-year	-	-	-	-	-		Slope stability, erosion and icing combined with drainage disruption are expected to be a major concern. Estimation and design flows by conventiona means is difficult.
		50-year	-	-	-	-	-		
		100-year	-	-	-	-	-		
		Max. Daily	-	-	-	-	-		
15.7	121.0	Culvert Cap.	-	-	-	-	-	Bridge	
Unnamed Creek	1082.0	2.33-year	see Appendix A	-	-	-	-		
		50-year		-	-	-	-		
		100-year		-	-	-	-		
		Max. Daily		-	-	-	-		
3.4		Culvert Cap.	-	-	-	-	-	58.0	Timber box culvert 52" x 72

*Miles along the proposed pipeline route

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY

Cubic Feet Per Second

STREAM & DRAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Bock's Creek	1080.3	2.33-year	-	-	-	-	-		See Lewis Creek
		50-year	-	-	-	-	-		
		100-year	-	-	-	-	-		
		Max. Daily	-	-	-	-	-		
13.5	127.8	Culvert Cap.	-	-	-	-	-	1,400	14'0" x 9'8" pipe-arch x 68' long; installed in 1969.
Nines Creek	1078.9	2.33-year	-	-	-	-	-		See Lewis Creek
		50-year	-	-	-	-	-		
		100-year	-	-	-	-	-		
		Max. Daily	-	-	-	-	-		
23.5	130.5	Culvert Cap.	-	-	-	-	-	Bridge	
Congdon Creek	1071.6	2.33-year	see Appendix A	-	-	-	-		See Lewis Creek
		50-year		-	-	-	-		
		100-year		-	-	-	-		
		Max. Daily		-	-	-	-		
19.5	135.7	Culvert Cap.	-	-	-	-	-	Bridge	
Williscroft Creek	1077.1	2.33-year	-	-	-	-	-		See Lewis Creek
		50-year	-	-	-	-	-		
		100-year	-	-	-	-	-		
4.9	138.3	Max. Daily	-	-	-	-	172		
		Culvert Cap.	-	-	-	-	-	Bridge	

* Miles along the proposed pipeline route

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY
Cubic Feet Per Second

STREAM & RAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Slims River	1059.8	2.33-year	-	-	-	-	-		Unstable streambed
		50-year	-	-	-	-	-		
		100-year	-	-	-	-	-		
		Max. Daily	-	-	-	-	-		
927	146.4	Culvert Cap.	-	-	-	-	-	Bridge	
Topham Creek	1049.8	2.33-year	-	-	28	17.5	-		
		50-year	-	-	51	37.5	-		
		100-year	-	-	56	45.9	-		
		Max. Daily	-	-	-	-	83.0		
	157.5	Culvert Cap.	-	-	-	-	-	55.0	Wood stave, 3' diameter
Silver Creek	1053.8	2.33-year	see Appendix A	729	360	252	-		Unstable streambed
		50-year		1,320	663	543	-		
		100-year		1,530	731	664	-		
		Max. Daily		-	-	-	910		16'-7" x 10'-11" double pipe-arch x 69' long; installed in 1972.
18.6	154.0	Culvert Cap.	-	-	-	-	-	2,600	
		2.33-year	-	521	270	265	-		Erosion and consequent increase in turbidity are of major concern
Christmas Creek	1046.4	50-year	-	943	500	569	-		
		100-year	-	1,090	552	696	-		
		Max. Daily	-	-	-	-	953		Double 6' x 4' laminated wood box, 56' long; installed in 1954
39.8	158.1	Culvert Cap.	-	-	-	-	-	56.0	

* Miles along the proposed pipeline route

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY
Cubic Feet Per Second

STREAM & DRAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Jarvis River	1034.6	2.33-year	see Appendix A	1,270	948	1,600	-		See Christmas Creek
		50-year		2,300	1,970	3,440	-		
		100-year		2,670	2,200	4,200	-		
		Max. Daily		-	-	-	913		
288	169.8	Culvert Cap.	-	-	-	-	-	Bridge	
Bear Creek	1022.1	2.33-year	see Appendix A	869	191	203	-		See Christmas Creek
		50-year		1,570	365	439	-		
		100-year		1,820	404	537	-		Concrete culvert, double 9' x 9' Barrel, 46' long; installed in 1955.
		Max. Daily		-	-	-	755		
29.9	176.5	Culvert Cap.	-	-	-	-	-	1,700	
Pine Creek	1018.9	2.33-year	-	-	341	401	-		
		50-year	-	-	658	863	-		
		100-year	-	-	728	1,060	-		
		Max. Daily	-	-	-	-	265		
63.1	185.0	Culvert Cap.	-	-	-	-	-	Bridge	
Dezadeash River	Haines-Alaska Highway Bridge	2.33-year	5,880	5,280	5,720	14,600	-		
		50-year	10,900	9,560	12,800	31,400	-		
		100-year	11,800	11,100	14,300	38,400	-		
		Max. Daily	10,100	-	-	-	6,670		
3280		Culvert Cap.	-	-	-	-	-	Bridge	

* Miles along the proposed pipeline route

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY

Cubic Feet Per Second

STREAM & RAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Marshall Creek	1005.6	2.33-year	see Appendix A	848	412	516	-		
		50-year		1,530	774	1,110	-		
		100-year		1,780	854	1,360	-		
		Max. Daily		-	-	-	1,730		Two 16'-3" x 10'-10" pipe-arches x 100' long; installed in 1967.
82.8	192.1	Culvert Cap.	-	-	-	-	-	3,600	
Aishihik River	996.3	2.33-year	2,570	3,260	2,780	7,850	-		Flow influenced by the power dam.
		50-year	5,080	5,900	6,590	16,900	-		
		100-year	5,560	6,850	7,410	20,700	-		
		Max. Daily	5,050	-	-	-	3,820		
1,660	201.3	Culvert Cap.	-	-	-	-	-	Bridge	
Cracker Creek	987.8	2.33-year	see Appendix A	-	247	325	-		
		50-year		-	482	700	-		
		100-year		-	534	856	-		
		Max. Daily		-	-	-	219		
50.2	209.0	Culvert Cap.	-	-	-	-	-	Bridge	
Mendenhall River	968.0	2.33-year	see Appendix A	848	826	1,620	-		
		50-year		2,680	1,810	3,490	-		
		100-year		3,110	2,030	4,270	-		
		Max. Daily		-	-	-	927		
293	228.5	Culvert Cap.	-	-	-	-	-	Bridge	

* Miles along the proposed pipeline route

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY

Cubic Feet Per Second

STREAM & DRAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Stoney Creek	956.0	2.33-year	see Appendix A	438	118	138	-		
		50-year		1,020	233	296	-		
		100-year		1,240	259	362	-		
		Max. Daily		-	-	-	530		
19.4	216.5	Culvert Cap.	-	-	-	-	-	Bridge	
Takhini River	946.3	2.33-year	8,370	12,900	5,270	12,200	-		A meandering stream with man active slip-offs. S.W. of Takhini thermokarst activity suggests that the valley floor has substantial ground ice. Frost heave potential is also high.
		50-year	14,500	23,300	11,100	26,300	-		
		100-year	15,800	27,100	12,300	32,200	-		
		Max. Daily	17,200	-	-	-	5,690		
2,700	206.8	Culvert Cap.	-	-	-	-	-	Bridge	
McIntyre Creek	919.2	2.33-year	see Appendix A	600	102	117	-		Values shown here, except Channel Geometry method, are for the natural stream not including diversions from Porter Creek & Fish Lake.
		50-year		1,090	204	251	-		
		100-year		1,260	228	308	-		
16.2		Max. Daily		-	-	-	458		
(106 with diversions)	270.2	Culvert Cap.	-	-	-	-	-	440	Two 60" dia. pipes 110'long; installed in 1968.
Wolf Creek	907.0	2.33-year	-	-	346	442	-		
		50-year	-	-	713	950	-		
		100-year	-	-	800	1,160	-		
		Max. Daily	-	-	-	-	287		
69.5	277.3	Culvert Cap.	-	-	-	-	-	1,500	15'8" x 9'-7" pipe-arch x 100' long; installed in 196

* Miles along the proposed pipeline route

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY
Cubic Feet Per Second

STREAM & RAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Cowley Creek	906.4	2.33-year	-	-	344	482	-		
		50-year	-	-	713	1,040	-		
		100-year	-	-	799	1,270	-		
		Max. Daily	-	-	-	-	310		
76.7	277.9	Culvert Cap.	-	-	-	-	-	Bridge	
Yukon River	897.5	2.33-year	18,500	22,800	-	30,900	-		Storage in Marsh Lake Dam since 1926. Pondage at Whitehorse Rapids power plant since 1958.
		50-year	23,300	41,300	18,600	66,500	-		
		100-year	24,000	47,900	21,700	81,400	-		
		Max. Daily	22,800	-	-	-	13,100		
7500	285.4	Culvert Cap.	-	-	-	-	-	Bridge	
M'Clintock River	890.3	2.33-year	2,030	1,090	1,750	3,370	-		
		50-year	5,500	4,470	3,750	7,250	-		
		100-year	6,500	5,450	4,220	8,880	-		
		Max. Daily	3,980	-	-	-	9,370		
655	293.4	Culvert Cap.	-	-	-	-	-	Bridge	
Squanga Creek	849.3	2.33-year	-	-	-	1,690	-		Divide between Squanga Lake system and Michie Creek in the M'Clintock drainage is poorly defined. Possibility of water migration and introduction of toxic substances into Squanga Lake exists.
		50-year	-	-	-	3,640	-		
		100-year	-	-	-	4,460	-		
		Max. Daily	-	-	-	-	5,050		
307	329.6	Culvert Cap.	-	-	-	-	-		

* Miles along the proposed pipeline route

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY
Cubic Feet Per Second

STREAM & RAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Teslin River	836.3	2.33-year	39,500	25,700	33,200	46,300	-		
		50-year	64,800	46,500	58,000	99,700	-		
		100-year	69,300	54,000	63,500	122,000	-		
		Max. Daily	65,000	-	-	-	18,900		
11700	339.0 to 339.3	Culvert Cap.	-	-	-	-	-	Bridge	
Brook's Brook	829.7	2.33-year	see Appendix A	-	276	188	-		
		50-year		-	491	405	-		
		100-year		-	539	496	-		
		Max. Daily		-	-	-	703		
27.4	343.8	Culvert Cap.	-	-	-	-	-	Bridge	
Deadmans Creek	822.4	2.33-year	see Appendix A	1,660	684	522	-		Degradation of the estuarin environment along eastside of Teslin Lake is a possibility. Icing is also a potential problem.
		50-year		3,000	1,220	1,120	-		
		100-year		3,490	1,339	1,370	-		
		Max. Daily		-	-	-	1,760		
84.2	350.8	Culvert Cap.	-	-	-	-	-	Bridge	
Lone Tree Creek	816.8	2.33-year	-	-	179	129	-		See Deadmans Creek
		50-year	-	-	321	277	-		
		100-year	-	-	354	338	-		
		Max. Daily	-	-	-	-	499		
18.0	355.4	Culvert Cap.	-	-	-	-	-	580	10'8" x 6'11", pipe-arch x 66' long; installed in 1964

*Miles along the proposed pipeline route

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY
Cubic Feet Per Second

STREAM & RAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Tenmile Creek	813.1	2.33-year	see Appendix A	-	169	121	-		See Deadmans Creek
		50-year		-	303	260	-		
		100-year		-	333	318	-		
16.8	360.0	Max. Daily		-	-	-	472		12'-10" x 8'-4" pipe-arch x 68' long; installed in 1964.
		Culvert Cap.	-	-	-	-	-	1050 cfs	
Fox Creek	808.0	2.33-year	-	-	144	100	-		See Deadmans Creek
		50-year	-	-	257	216	-		
		100-year	-	-	283	264	-		
13.7	365.1	Max. Daily	-	-	-	-	400		
		Culvert Cap.	-	-	-	-	-	Bridge	
Hays Creek	790.5	2.33-year	-	-	247	184	-		
		50-year	-	-	440	396	-		
		100-year	-	-	485	484	-		
26.7	380.0	Max. Daily	-	-	-	-	688		
		Culvert Cap.	-	-	-	-	-	10.0	
Strawberry Creek	787.0	2.33-year	see Appendix A	-	228	169	-		
		50-year		-	407	363	-		
		100-year		-	448	445	-		
24.3	383.0	Max. Daily		-	-	-	637		11'-5" x 7'-3" pipe-arch 98 long; installed in 1968.
		Culvert Cap.	-	-	-	-	-	750	

* Miles along the proposed pipeline route

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY
Cubic Feet Per Second

STREAM & RAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Morley River	778	2.33-year	see Appendix A	2,510	5,150	3,150	-		Risk of introduction of suspended sediment is high.
		50-year		4,540	9,550	6,780	-		
		100-year		5,270	10,500	8,290	-		
608	391.2	Max. Daily		-	-	-	1,680		
		Culvert Cap.	-	-	-	-	-	Bridge	
Hazel Creek	764.1	2.33-year	-	-	218	152	-		
		50-year	-	-	384	328	-		
		100-year	-	-	422	401	-		
21.7	397.5	Max. Daily	-	-	-	-	580		12'-6" x 7'11" pipe-arch x 80' long; installed in 1958.
		Culvert Cap.	-	-	-	-	-	1,000	
Swift below Smart River		2.33-year	9,300	8,000	11,900	6,200	-		Risk of deterioration of water quality is high due to the additive effect of side creeks. Very little hydrologic information is available in this potential difficult development area. Not crossed by Highway.
		50-year	21,000	14,500	22,700	13,300	-		
		100-year	35,500	16,800	25,000	16,300	-		
		Max. Daily	15,500	-	-	-	16,200		
1,280		Culvert Cap.	-	-	-	-	-	-	
Smart River		2.33-year	see Appendix A	1,880	3,150	1,540	-		See Swift River
		50-year		3,400	5,720	3,320	-		
		100-year		3,950	6,290	4,060	-		
		Max. Daily		-	-	-	885		
277		Culvert Cap.	-	-	-	-	-	Bridge	

* Miles along the proposed pipeline route

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY
Cubic Feet Per Second

STREAM & RAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Logjam Creek	751.7	2.33-year	see Appendix A	632	525	226	-		See Swift River below Smart River
		50-year		1,470	922	486	-		
		100-year		1,800	1,010	595	-		
		Max. Daily		-	-	-	828		
33.5	414	Culvert Cap.	-	-	-	-	-	Bridge	
Screw Creek	742.1	2.33-year	see Appendix A	444	468	202	-		See Swift below Smart River
		50-year		1,030	824	435	-		
		100-year		1,260	904	532	-		
		Max. Daily		-	-	-	748		
29.6	423	Culvert Cap.	-	-	-	-	-	Bridge	
Partridge Creek	736.4	2.33-year	see Appendix A	590	399	166	-		See Swift River below Smart River
		50-year		1,370	696	358	-		
		100-year		1,680	763	438	-		
		Max. Daily		-	-	-	629		
23.9	428	Culvert Cap.	-	-	-	-	-	Bridge	
Seagull Creek		2.33-year	-	442	502	214	-		See Swift River below Smart River
		50-year	-	1,030	879	460	-		
		100-year	-	1,260	964	563	-		
		Max. Daily		-	-	-	787		
31.5		Culvert Cap.	-	-	-	-	-		

*Miles along the proposed pipeline route

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY
Cubic Feet Per Second

STREAM & DRAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Swift River 105	430	2.33-year	-	-	1,450	639	-	Bridge	See Swift River below Smart River
		50-year	-	-	2,580	1,370	-		
		100-year	-	-	2,830	1,680	-		
		Max. Daily	-	-	-	-	400		
		Culvert Cap.	-	-	-	-	-		
Rancheria River (upper crossing of hwy) 261	720.0 442.6 to 443.4	2.33-year	-	-	3,410	1,460	-	Bridge	
		50-year	-	-	6,070	3,140	-		
		100-year	-	-	6,660	3,840	-		
		Max. Daily	-	-	-	-	843		
		Culvert Cap.	-	-	-	-	-		
Carlick Creek 47.5	718.0 444	2.33-year	-	-	-	310	-	Bridge	Placer mining near confluence with Rancheria River
		50-year	-	-	-	668	-		
		100-year	-	-	-	818	-		
		Max. Daily	-	-	-	-	1,100		
		Culvert Cap.	-	-	-	-	-		
Rancheria River (pipeline crossing) 382	454	2.33-year	-	-	4,460	2,070	-	Bridge	Potential for introduction of sediment; volcanic rock.
		50-year	-	-	8,180	4,440	-		
		100-year	-	-	9,000	5,430	-		
		Max. Daily	-	-	-	-	1,150		
		Culvert Cap.	-	-	-	-	-		

* Miles along the proposed pipeline route

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY
Cubic Feet Per Second

STREAM & RAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Boulder Creek	701.9	2.33-year	-	-	450	166	-		See Rancheria River
		50-year	-	-	777	358	-		
		100-year	-	-	850	438	-		
		Max. Daily	-	-	-	-	629		
23.9	460.7	Culvert Cap.	-	-	-	-	-	Bridge	
Spencer Creek	695.3	2.33-year	see Appendix A	781	957	396	-		See Rancheria River
		50-year		1,820	1,690	851	-		
		100-year		2,220	1,850	1,040	-		
61.6	467.1	Max. Daily		-	-	-	1,360		Two 14'-5" x 10'-0", 72' long pipe-arch; installed i 1970.
		Culvert Cap.	-	-	-	-	-	1,500	
Rancheria River (lower crossing of hwy)	687.0	2.33-year	-	-	8,300	4,220	-		
		50-year	-	-	15,800	9,060	-		
		100-year	-	-	17,400	11,100	-		
		Max. Daily	-	-	-	-	2,190		
837	474.0	Culvert Cap.	-	-	-	-	-	Bridge	
Big Creek	674.1	2.33-year	see Appendix A	4,060	4,470	2,180	-		See Rancheria River at MP 454
		50-year		7,350	8,390	4,680	-		
		100-year		8,530	9,260	5,730	-		
405	487.0	Max. Daily		-	-	-	1,210		
		Culvert Cap.	-	-	-	-	-	Bridge	

* Miles along the proposed pipeline route

TABLE 3. - PEAK DISCHARGE COMPARISONS ALONG ALASKA HIGHWAY
Cubic Feet Per Second

STREAM & DRAINAGE AREA (sq. mi.)	MILEPOST & MILES* FROM ALASKA BORDER	DISCHARGE EVENT	GAUGING STATION	CHANNEL GEOMETRY	KINEMATIC WAVE	RATIO TO MEAN	ENVELOPE CURVE	CULVERT CAPACITY	REMARKS
Little Rancheria River	670.3	2.33-year	see Appendix A	4,320	6,440	3,170	-		See Rancheria River at MP 454
		50-year		7,820	12,300	6,820	-		
		100-year		9,070	13,600	8,340	-		
		Max. Daily		-	-	-	1,690		
612	490.5	Culvert Cap.	-	-	-	-	-	Bridge	
Albert Creek	643.4	2.33-year	-	-	2,970	1,430	-		
		50-year	-	-	5,690	3,080	-		
		100-year	-	-	6,330	3,760	-		
		Max. Daily	-	-	-	-	827		
255	510.0	Culvert Cap.	-	-	-	-	-	Bridge	

* Miles along the proposed pipeline route

Table 4 - KEY PROGRAM EVENTS, RIVER HYDRAULICS - 1978

EVENT		June				July				Aug.					Sept.				Oct.				Nov.					Dec.			
	(weeks)	1	2	3	4	1	2	3	4	1	2	3	4	5	1	2	3	4	1	2	3	4	1	2	3	4	5	1	2	3	4
1. Reconnaissance			+																												
2. Sediment Sampling																															
Representative Streams		+																													
Donjek River					+			+		+																					
3. Direct Scour Measurements																															
Donjek River			+		+			+		+																					
4. Cross-Sectional Surveys																															
Representative Streams																+	+														
Donjek River																+	+														
5. Bed Material Particle Size Determinations		+														+	+														
6. Air Photo Interpretations																						+	+		+						
7. Data Compilation and Report Writing																+				+		+	+	+	+	+	+	+		+	
8. Provisional Report																												+			
9. Final Report																															+

Table 5 - DONJEK RIVER AT ALASKA HIGHWAY BRIDGE

Vertical Change in Streambed at Observed Points in the Cross-Section Since June 26, 1978 Discharge Measurement

Date 1978	Discharge (cfs)	West Channel Water Level (ft.)	Distance from Initial Point[1] at Left Bank in Feet																							Middle Channel Water Level (ft.)								East Channel Water Level (ft.)									Date 1978
			267	278	300	320	340	360	380	395	397		416	420	440	460	470	480	500	540	560	580	590	600			620	650	700	780	1300	1400			1448	1470	1500	1510	1530	1550	1570	1578	
June 26	5,000	18.31	18.3[5]	15.4	14.8	14.1	13.5	15.1	14.5	14.6	14.6		17.1	17.1	17.2	17.3	17.6	18.3	18.3	18.3	17.0	16.8	16.8	17.2		18.3	15.8	18.3	18.8	19.7	19.1	19.1		17.67	17.7	15.3	12.0	11.0	11.9	12.6	15.6	17.7	June 26
27	4,980	18.20	-0.1	+0.1	-1.0	-0.2	+0.9	-0.7	+0.9	-1.5	-2.4		+0.2	+0.2	-0.2	+0.3	+0.6	-	-	-0.1	-0.3	+0.3	+0.4	+0.2		18.20	+1.3	-0.1	dry	-	-	-		17.59	-0.1	-1.0	+0.3	+0.1	+0.2	+0.3	-1.6	-0.1	27
28	5,180	18.38	+0.7	+0.4	-0.7	-0.3	+1.1	-0.3	-0.1	-0.8	-0.8		+0.4	+0.4	-0.3	+0.4	+0.8	-	-	-	-0.7	+0.7	+0.4	-0.4		18.04	+1.3	+0.5	dry	-	-	-		17.83	+0.2	-1.2	-0.1	+1.3	+0.8	+0.5	-1.6	+0.1	28
29	4,930	18.29	0.0	+0.2	-0.7	-0.4	+0.8	-0.8	-0.4	-1.1	-1.0		+0.4	+0.4	+0.1	+0.5	-0.1	-	-	-	-0.1	+1.2	+0.7	+0.1		18.00	+0.9	+0.5	dry	-	-	-		17.65	0.0	-1.8	-1.0	-0.6	+0.6	+0.1	-1.6	-0.1	29
30	5,380	18.61	+0.3	+0.3	-0.6	-0.2	+0.3	-1.1	+0.5	+0.5	+0.5	Pier - 397-416 feet	+0.6	+0.6	+0.4	+0.6	+0.1	-	-	-	+0.1	+0.5	0.0	-0.8	Pier - 600-619 feet	18.38	+0.1	+0.9	dry	-	-	-	Pier - 1405-1425 feet	18.05	+0.4	-1.2	+0.2	+2.0	-0.1	+0.6	-1.2	+0.4	30
July 17	8,700	18.71	+0.4	+1.4	-1.9	-1.4	-0.9	-1.9	-1.6	-1.4	-1.4		-0.9	-0.9	-1.0	-1.2	-1.5	-2.1	-2.4	-0.7	+0.6	+1.0	+1.5	+1.5		dry	-	-	-	-	-	-		18.05	0.0	-2.4	+0.9	+1.5	0.0	-1.7	-2.8	+0.4	July 17
18	8,840	18.75	+0.4	+1.4	-2.0	-1.3	-1.0	-2.1	-2.0	-2.4	-2.4		-1.0	-1.0	-1.1	-0.9	-1.3	-2.1	-2.4	-1.2	+0.5	+1.0	+1.5	+1.6		dry	-	-	-	-	-	-		18.20	+0.1	-2.4	+0.4	+0.9	-0.7	-1.6	-2.6	+0.5	18
19	9,100	18.49	+0.2	+1.2	-1.8	+0.5	+0.9	-2.1	-2.8	-3.3	-3.3		-1.2	-1.2	-1.3	-0.5	-1.2	-2.3	-3.0	-1.3	+0.3	+0.4	+1.1	+0.2		dry	-	-	-	-	-	-		18.15	+0.1	-2.4	-0.4	+0.4	-1.1	-1.2	-2.0	+0.4	19
20	11,900	18.94	-0.2	-0.2	-0.3	+0.6	+0.4	-2.2	-3.0	-3.6	-3.7		-1.3	-1.3	-1.4	-0.9	-1.5	-2.6	-3.0	-1.8	-0.3	-0.3	+0.2	+0.6		dry	-	-	-	-	-	-		18.90	+0.1	-3.4	-1.3	-0.3	-1.9	-3.4	-1.9	+1.2	20
21	13,200	19.08	+0.8	-0.1	0.0	+0.6	+0.4	-2.1	-3.4	-3.6	-3.6		-0.9	-0.9	-1.0	-1.2	-1.8	-2.8	-3.0	-2.0	-0.5	-0.3	+1.5	+1.9		dry	-	-	-	-	-	-		18.90	-0.1	-3.5	-1.9	-1.9	-2.1	-2.6	-2.5	-1.2	21
Aug. 2	13,400	20.69	+2.0	+3.9	+2.5	+3.9	+3.2	-0.4	-2.0	-1.2	-1.2		-2.9	-2.9	-3.0	-4.2	-4.7	-5.6	-4.7	-2.8	-0.8	-0.4	-0.4	-0.8		19.69	+3.9	+0.3	-0.1	-	-0.5	0.0		19.06	+0.4	-3.0	-2.4	-1.5	-0.8	-0.6	+0.4	+1.4	Aug. 2
3	14,700	20.93	+2.0	+3.7	+1.8	+2.6	+3.2	+0.7	-0.6	-1.8	-1.8		-0.8	-0.8	-0.9	-2.6	-3.6	-4.2	-3.3	-2.0	+0.2	+1.4	+1.4	+1.0		20.13	+0.4	+0.4	-0.1	-0.8	-0.1	+0.1		19.46	+1.8	-3.4	-3.6	-3.5	-1.8	-1.4	+0.4	+1.8	3
4	16,500	20.98	+1.8	+4.2	+1.2	+1.7	+2.2	0.0	-1.2	-2.1	-2.1		-0.9	-0.9	-1.0	-2.9	-4.1	-5.1	-4.6	-0.7	+2.0	+1.9	+1.9	+1.5		20.17	+2.8	+0.3	-0.6	-1.0	-0.4	+0.2		19.33	-0.2	-3.0	-1.8	-1.0	-1.9	-1.8	-0.3	+0.3	4
5	17,100	20.85	+1.7	+3.1	+0.8	+1.4	+2.0	-0.6	-1.8	-2.4	-2.4		-1.2	-1.2	-1.4	-3.2	-4.2	-5.4	-4.8	-0.2	+2.6	+2.4	+2.4	+2.1		20.33	-0.4	-0.4	+0.1	-0.9	+0.2	+0.2		19.33	-0.1	-2.9	-2.9	-1.4	-1.2	-2.1	-1.2	-1.0	5
6	22,800	21.49	+1.8	+3.2	+0.9	+1.2	+2.1	+0.5	-0.7	-1.8	-1.8		-1.6	-1.6	-1.7	-3.5	-4.0	-4.9	-4.5	+0.9	+4.5	+3.1	+3.7	+2.9		20.67	+2.5	0.0	-0.6	-0.5	+0.5	+1.6		20.07	+0.2	-1.0	-4.8	-3.8	-3.4	-2.5	-2.1	-0.1	6
				Water Depth at Observed Points in the Cross-Section During August 6, 1978 Discharge Measurement																																							
Aug. 6	22,800	21.49	1.4	2.9	5.8	5.9	5.9	5.9	7.7	8.7	8.7		6.0	6.0	6.0	7.7	7.9	8.1	7.7	2.3	2.0	1.6	1.0	0.3		20.67	2.4	2.4	2.5	1.5	1.1	0.0		20.07	2.2	5.8	12.9	12.9	10.7	9.6	5.3	2.5	Aug. 6

1/ Initial point is the right face of left bank abutment when looking downstream.

2/ A number of vertical changes and water depths shown in the table have been obtained by interpolation.

3/ Levels are referenced to NWHS benchmark on upstream end of west bridge abutment with assumed elevation of 50.0 feet.

4/ Maximum instantaneous observed velocity at (0.2 depth or 1.7 feet from water surface during 1978) was 10.48 feet per second on August 5, 1530 feet from west bank abutment.

5/ Streambed level.

LEGEND

Maximum vertical change in streambed

🟥 Scour

🟩 Deposition

Table **6** - DONJEK RIVER AT ALASKA HIGHWAY BRIDGE

Mean Velocities in the Vertical (ft./sec.)

Date 1978	Discharge (cfs)	Distance from Initial Point[1/] at Left Bank in Feet																												Date 1978
		278	300	320	340	360	380	395	420	440	460	470	480	500	540	560	580	590	600	620	650	700	780	1300	1470	1500	1510	1530	1550	1570	
June 26	5,000	2.4	5.5	6.4	7.2	6.6	6.3	4.2	3.4	3.2	2.3	1.0	-	-	-	2.9	0.6	3.5	3.5	3.3	-	-	-	-	1.4	3.9	3.6	3.9	3.8	0.6	June 26
27	4,980	2.6	6.2	6.2	6.3	7.5	6.1	4.4	3.1	3.9	1.6	-	-	-	-	5.5	3.3	3.6	3.8	1.9	-	-	-	-	1.5	4.4	4.2	4.7	4.8	0.8	27
28	5,180	2.3	5.7	5.9	6.6	7.1	6.8	4.6	2.8	3.2	1.6	-	-	-	-	3.3	2.7	2.8	2.8	0.6	-	-	-	-	2.0	4.2	3.8	5.2	5.0	1.0	28
29	4,930	2.1	5.5	6.1	6.9	6.7	6.0	3.3	2.4	2.4	-	-	-	-	-	3.5	-	1.4	2.0	1.6	-	-	-	-	2.2	3.3	3.2	4.3	4.4	0.4	29
30	5,380	1.8	5.6	6.2	6.4	6.6	5.9	3.8	3.3	2.8	2.0	-	-	-	-	3.5	1.8	2.3	2.8	1.8	-	-	-	-	2.1	3.5	4.8	4.9	4.1	1.2	30
July 17	8,700	1.5	4.4	4.6	4.8	4.9	3.7	2.4	2.1	2.8	3.0	3.2	3.4	3.5	4.4	4.2	3.1	1.6	-	-	-	-	-	-	4.0	7.0	7.4	7.7	6.9	0.6	July 17
18	8,840	1.5	4.6	5.2	5.2	4.8	3.9	3.3	2.5	3.1	3.5	3.8	4.0	4.7	5.1	4.8	3.6	1.8	-	-	-	-	-	-	3.4	6.8	7.4	7.6	7.5	1.6	18
19	9,100	1.8	5.3	5.8	5.9	6.1	4.5	3.4	2.6	3.2	4.5	4.3	4.2	3.5	4.9	4.4	3.5	1.7	-	-	-	-	-	-	3.3	7.0	7.9	8.1	7.5	0.6	19
20	11,900	4.8	6.2	7.0	7.2	7.0	5.4	4.3	3.6	4.4	3.8	4.2	4.6	4.7	5.1	5.0	3.8	1.9	-	-	-	-	-	-	3.5	6.8	7.7	8.0	7.8	1.1	20
21	13,200	4.0	5.8	6.6	6.8	7.0	5.8	4.5	3.0	3.6	4.0	4.5	4.9	5.1	4.9	5.1	3.8	1.3	-	-	-	-	-	-	3.7	6.8	6.5	7.5	7.5	2.0	21
Aug. 2	13,400	2.3	5.5	6.6	5.7	6.8	6.7	5.9	4.5	5.4	5.9	6.6	6.8	6.9	6.4	6.0	4.7	4.4	4.0	-	6.4	-	-	-	1.8	5.2	6.0	6.2	6.5	1.9	Aug. 2
3	14,700	2.7	6.3	6.8	7.7	7.3	6.0	6.1	4.5	6.2	5.4	6.4	6.8	7.6	6.6	5.6	3.3	1.6	-	-	-	-	-	0.9	3.1	5.4	5.7	6.4	7.8	2.2	3
4	16,500	2.6	5.8	6.2	6.3	6.4	6.1	6.0	4.9	5.9	5.7	5.8	5.8	5.3	5.0	5.6	6.6	6.3	6.0	0.9	6.1	4.7	5.6	3.0	3.1	7.0	7.5	6.5	7.3	2.8	4
5	17,100	2.4	5.3	5.9	6.0	6.1	5.9	4.9	4.2	4.5	5.0	5.2	5.2	4.7	4.1	4.6	5.3	5.1	5.1	6.5	6.5	5.1	4.5	3.8	3.2	7.3	8.5	9.4	8.2	4.0	5
6	22,800	3.2	6.4	7.7	7.6	7.4	7.2	6.7	4.4	5.3	6.4	6.8	6.9	6.1	3.6	4.2	4.8	2.9	1.0	5.0	5.1	6.8	5.4	5.7	3.6	6.7	7.1	8.9	7.8	3.6	6

NOTES

1. Initial point is the right face of left bank abutment when looking downstream.
2. Velocities shown are averages of velocities observed at 0.2 and 0.8-depth in the vertical; where depths were insufficient, velocities shown are those obtained at 0.6-depth. Angle of current correction was not applied in either case.

Table 7 - DEPTH OF CHANNEL SCOUR COMPUTED BY BLENCH AND LAURSEN EQUATIONS

No.	Stream	Drainage Area (sq.mi.)	Milepost	Miles From Alaska Border Along Pipeline Route	Stream Bed Particle Size (mm)	BANKFULL CHANNEL			FLOOD CHANNEL - 50 YEAR FREQUENCY					FLOOD CHANNEL - 100 YEAR FREQUENCY				
						Surface Width (ft.)	Mean Depth (ft.)	Discharge (cfs)	Surface Width (ft.)	Mean Depth (ft.)	Discharge (cfs)	Scour Depth (Blench) (ft.)	Scour Depth (Laursen) (ft.)	Surface Width (ft.)	Mean Depth (ft.)	Discharge (cfs)	Scour Depth (Blench) (ft.)	Scour Depth (Laursen) (ft.)
1	Snag	380	1208	8.5	20	73.0	6.5	2,670	77.0	8.4	4,830	3.1	3.6	78.0	8.8	5,610	4.0	4.6
2	Beaver	737	1200.7	15.8	30	129	4.0	3,800	135	5.2	6,880	3.3	2.2	138	5.4	7,980	4.0	2.8
3	Long's	44	1156	58.1	20	48.9	5.2	1,270	51.3	6.7	2,300	1.0	0.7	52.0	7.1	2,670	1.4	1.2
4	Koidern	260	1152.2	62.5	10	76.0	5.2	1,670	79.8	6.7	3,020	1.0	1.1	81.3	7.1	3,510	1.4	1.6
5	Burwash	64.8	1103.9	106.3	30	31.0	2.2	363	35.3	4.9	1,490	1.8	1.4	36.0	5.4	1,820	2.4	1.9
6	Duke	255	1098.5	110.5	100	265	1.9	4,400	278	2.4	7,960	1.5	0.7	283	2.6	9,240	1.7	1.0
7	Halfbreed	26.7	1089.1	118.7	30	27.0	0.8	407	30.8	1.8	1,670	6.4	6.0	31.3	2.0	2,040	7.4	7.1
8	Silver	38	1053.8	154	30	26.0	2.4	729	27.3	3.1	1,320	4.4	3.9	27.8	3.3	1,530	5.0	4.6
9	Christmas	39.8	1048.8	-	20	27.0	2.6	521	28.3	3.4	943	2.9	2.3	28.9	3.5	1,090	3.2	2.9
10	Jarvis	288	1034.6	169.8	20	78.0	3.7	1,270	81.9	4.8	2,300	0.5	0.2	83.5	5.0	2,670	0.9	0.5
11	Bear	30	1022.1	176.5	70	26.0	3.0	869	27.3	3.9	1,570	3.4	2.5	27.8	4.1	1,820	4.0	3.1
12	Marshall	82.8	1005.6	192.1	100	54.0	1.9	848	56.7	2.5	1,530	1.2	0.9	57.8	2.6	1,780	1.5	0.8
13	Stoney	19	956.0	216.5	50	21.0	1.5	249	23.9	3.3	1,020	2.9	2.3	23.9	3.4	1,240	2.8	2.2
14	McIntyre	16	919.2	270.2	50	32.0	2.1	600	33.6	2.7	1,090	2.2	1.7	34.2	2.9	1,260	2.6	2.0
15	Deadmans	84.2	822.4	350.8	30	50.0	3.3	1,660	52.5	4.3	3,000	4.2	3.9	53.5	4.5	3,490	5.0	4.6
16	Morley	608	778	391.2	5	90.0	7.6	2,510	94.5	9.8	4,540	0.9	2.0	96.3	10.3	5,270	1.6	2.8
17	Smart	277	-	-	5	86.0	7.1	1,880	90.3	9.2	3,400	0.0	0.4	92.0	9.7	3,950	0.1	1.0
18	Logjam	33.5	751.7	414	30	31.9	2.0	359	36.3	4.4	1,470	2.1	1.6	37.0	4.9	1,800	2.6	2.1
19	Screw	29	742.1	423	30	33.0	2.1	252	37.6	4.6	1,030	0.1	0.0	38.3	5.2	1,260	0.3	0.0
20	Seagull	31.5	-	-	30	50.0	2.8	251	57.0	6.2	1,030	0.0	0.0	58.0	6.9	1,260	0.0	0.0
21	Spencer	61.6	695.3	467.1	30	35.8	1.5	444	40.8	3.3	1,820	3.7	3.3	41.5	3.7	2,220	4.4	4.0
22	L. Rancheria	612	670.3	490.5	10	125	5.4	4,800	131	7.0	8,690	5.0	5.6	134	7.3	10,100	6.0	6.7

BLENCH FORMULA $Y = \frac{0.212q^{4/5}}{d^{1/5}} - D$

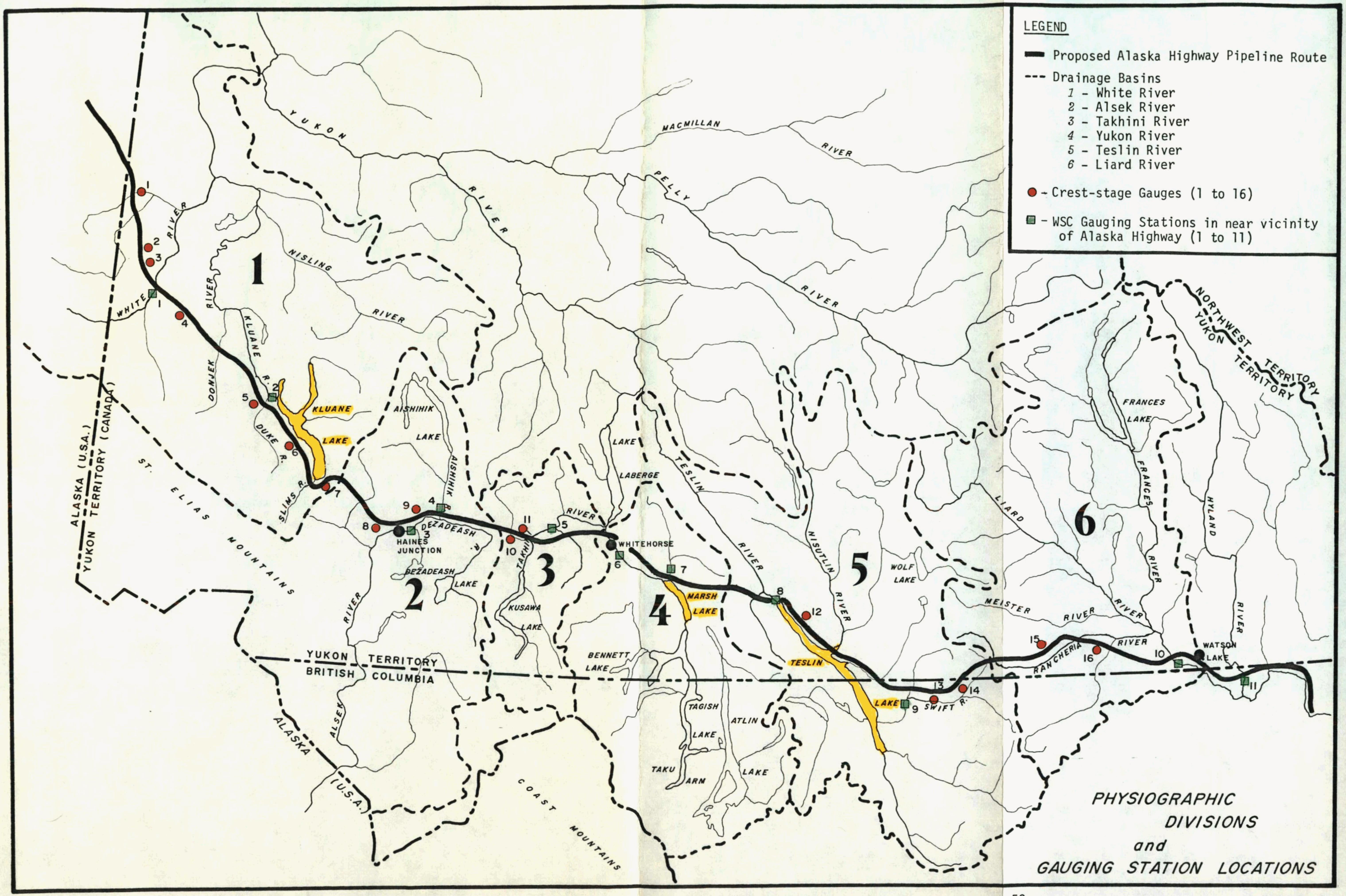
LAURSEN FORMULA $Y = 0.13 \left(\frac{q}{d^{1/3}}\right)^{6/7} - D$

Where Y is depth of scour in feet,
q is discharge in cubic feet per second per foot of channel width,
d is mean bed material particle size in feet,
D is mean depth.

Table 8 - Microbial Standing Crops and Activities and as Various Physico-chemical Parameters of Biological Interest

RIVER		DATE OF SAMPLING					
		4-10 Oct. 1977 Fall	10-20 Dec. 1977 Early Winter	22-30 Mar. 1978 Late Winter	15-26 May 1978 Spring	17-30 June 1978 Summer	1-8 Aug. 1978 Summer
Ogilvie	Units						
Phytoplankton	cells/ml	150.4	1.2	13.6	189.7	198.3	85.1
Periphyton	cells/cm^2	496,000	32,556	659,439	179,674	1,546,787	968,258
Planktonic bacteria	cells/ml	2.4 x 10^3	2.5 x 10^2	9.0 x 10^2	1.5 x 10^4	7.0 x 10^3	1.6 x 10^3
Epilithic bacteria	cells/cm^2	-	-	3.6 x 10^5	-	-	3.8 x 10^6
DOC	mg C/l	4.2	1.2	1.6	11.2	8.5	2.5
TIC	mg C/l	35.1	38.8	47.0	8.2	19.7	34.8
DO	mg C/l	9-15	8-12	6-11	12	11-12	10-12
Non-filterable residues	mg/l	3.6	2.5	1.3	100	132	2.4
Temperature	°C	0.3	-1.0	-0.2	0.8	7.7	14.9
Phytoplankton productivity	mg C/m^3/day	-	0.8	0.2	17.4	ND*	12.8
Bacterialplankton productivity	mg C/m^3/day	-	1.8	1.5	25.5	70.2	1.6
Periphyton productivity	mg C/m^2/day	-	-	80.2	-	-	56.4
Epilithic productivity	mg C/m^2/day	-	-	0.4	-	-	0
V$_{max}$	mg glucose/l/h	533.1 x 10^{-9}	40.9 x 10^{-9}	NLU**	3742.8 x 10^{-9}	13086.6 x 10^{-9}	1774.8 x 10^{-9}
Swift							
Phytoplankton	cells/ml	119.9	1.6	2.4	152.3	61.4	45.2
Periphyton	cells/cm^2	142,875	3,016	30,230	165,077	286,423	722,787
Planktonic bacteria	cells/ml	6.5 x 10^2	3.2 x 10^2	9.9 x 10^2	1.0 x 10^3	3.9 x 10^2	1.9 x 10^3
Epilithic bacteria	cells/cm^2	-	-	1.4 x 10^5	2.1 x 10^5	5.7 x 10^4	9.1 x 10^3
DOC	mg C/l	1.4	0.9	0.8	5.0	4.1	1.8
TIC	mg C/l	12.6	13.8	17.0	10.1	9.4	12.2
DO	mg/l	11-14	9-12	3-8	14-15	10-13	10-11
Non-filterable residues	mg/l	2.0	1.7	1.7	5.2	2.6	4.5
Temperature	°C	0.0	-0.5	-0.2	5.0	9.0	12.0
Phytoplankton productivity	mg C/m^3/day	-	4.4	1.8	21.6	1.9	10.1
Bacterialplankton productivity	mg C/m^3/day	-	1.3	ND***	0.9	0.7	3.9
Periphyton productivity	mg C/m^2/day	-	-	0.1	23.7	-	282.0
Epilithic productivity	mg C/m^2/day	-	-	0.1	0.01	-	0
V$_{max}$	mg glucose/l/h	230.7 x 10^{-9}	38.9 x 10^{-9}	NLU	3628.9 x 10^{-9}	1390 x 10^{-9}	8297.1 x 10^{-9}

*No detectable activity because of extremely heavy turbidity due to heavy rainfall
**Non linear uptake
***No detectable activity



PHYSIOGRAPHIC DIVISIONS and GAUGING STATION LOCATIONS

FIGURE 1

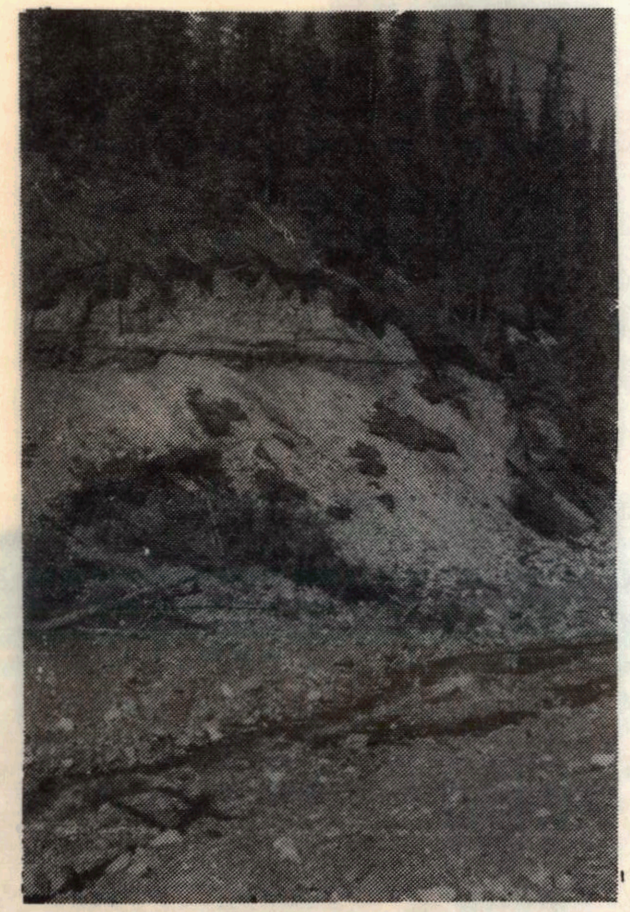
FIGURE 2

ALLUVIAL DRAINAGE
WEST SHORE OF
KLUANE LAKE

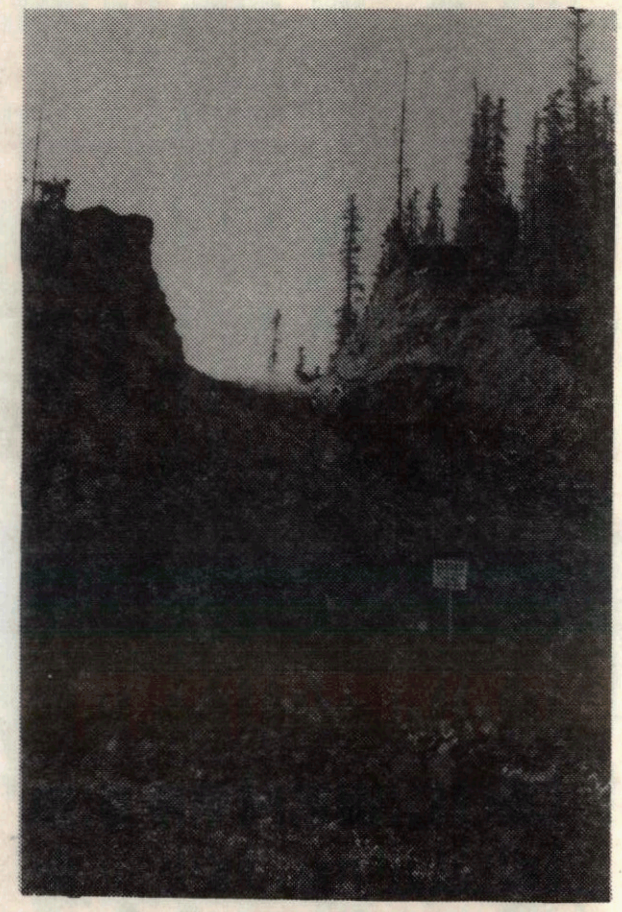
FIGURE 3

FLUVIAL FANS, WEST SIDE OF KLUANE LAKE

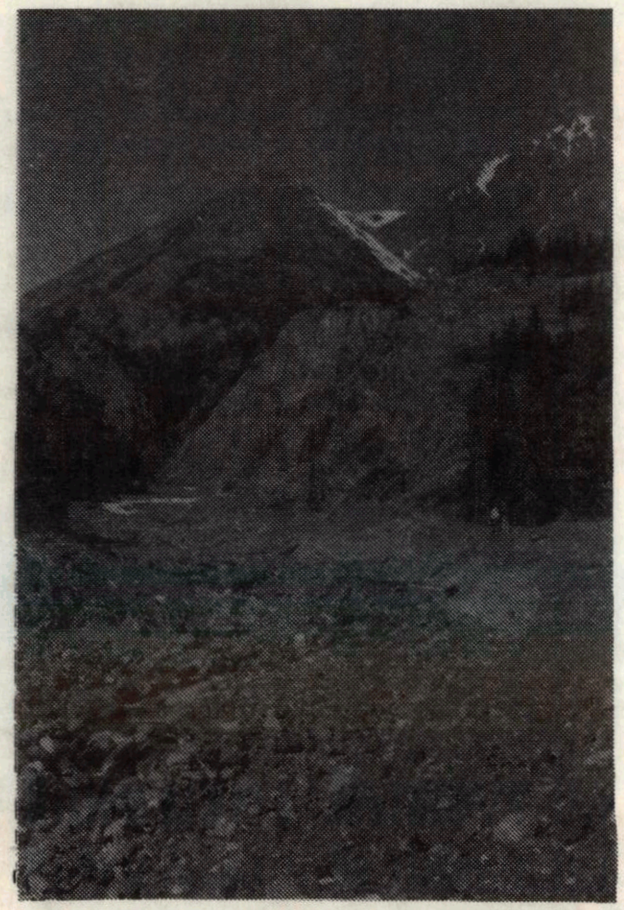
looking downstream towards Kluane Lake
Williscroft Creek (pipeline mile 137)



typical bank
condition



8" dia. pipeline
crossing

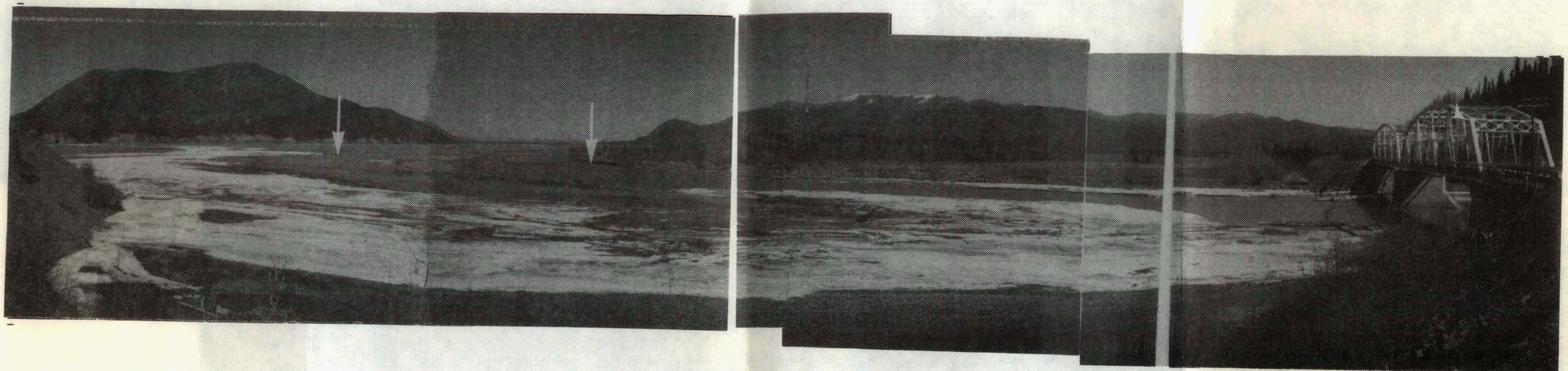


looking upstream
(note washout of
8" dia. pipeline)

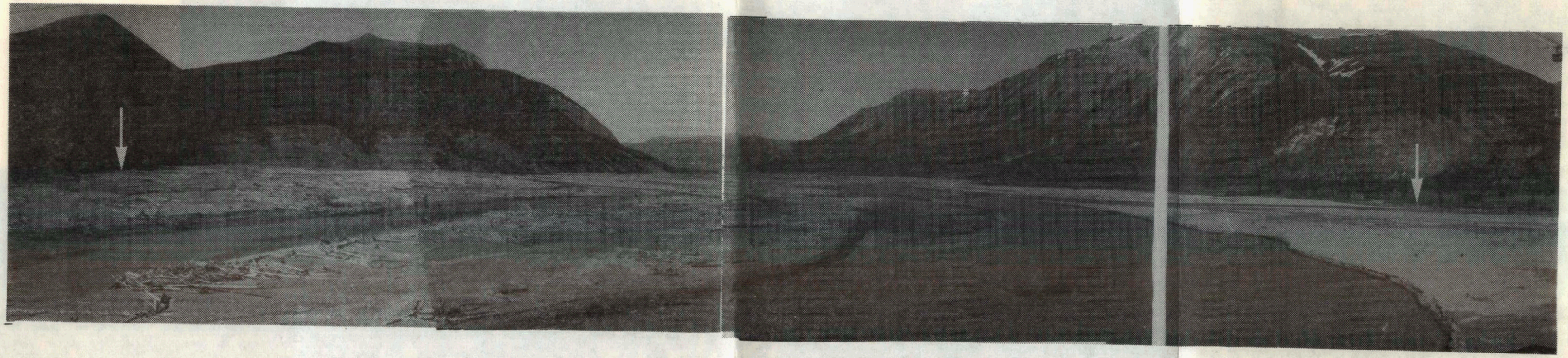
FIGURE 4

DONJEK RIVER AT
ALASKA HIGHWAY BRIDGE

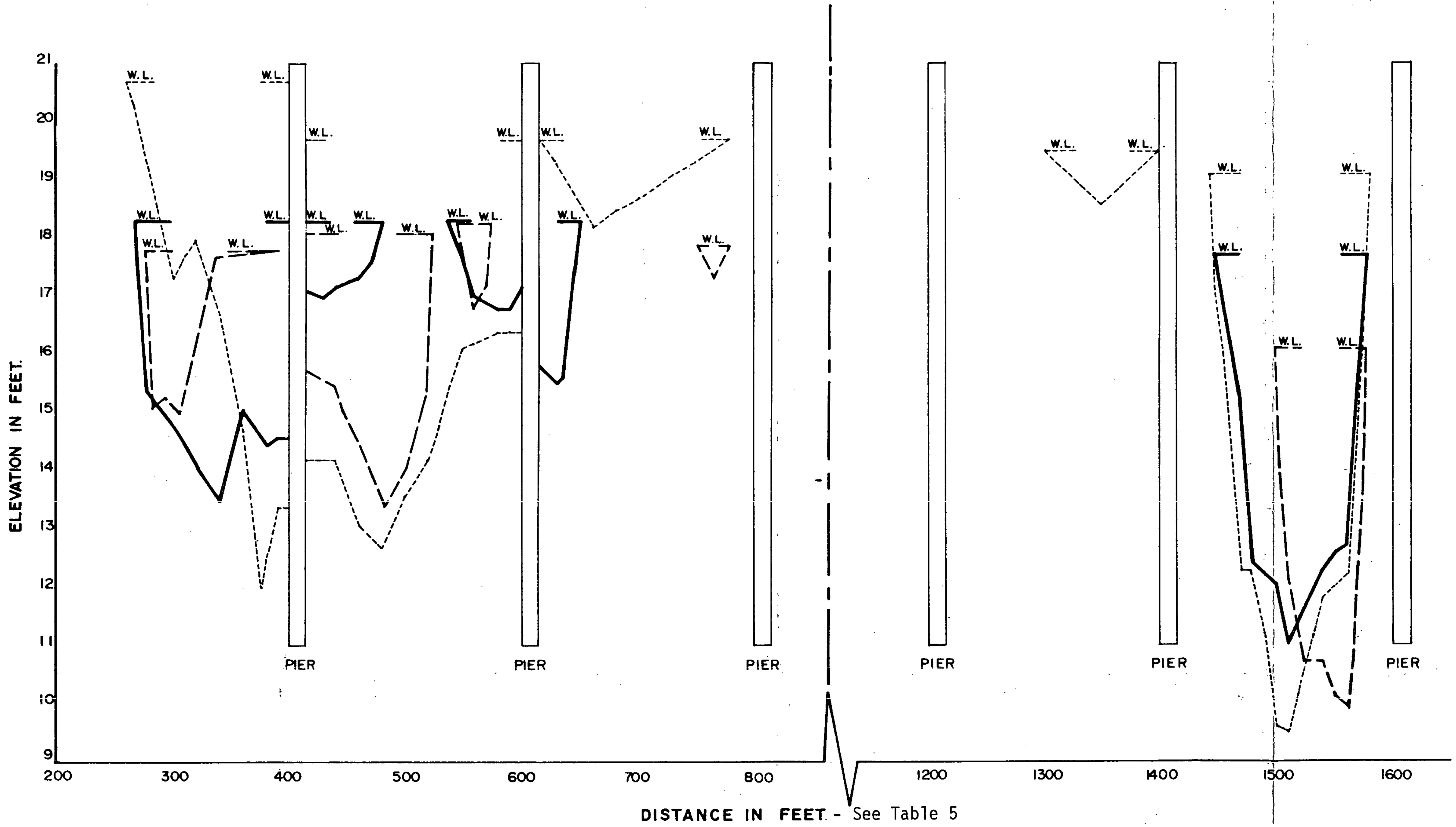
FIGURE 5



White River crossing site (see arrow)



Donjek River crossing site (see arrow)



NOTES:

1. Elevations are referenced to NWHS benchmark on upstream end of west bridge abutment with assumed elevation of 50.0ft.
2. Peak discharge for 1978 occurred Aug.6th. at approximately 22,800 c.f.s.
3. Aug.2nd. measurements showed maximum observed scour for summer 1978.

LEGEND:

——— River cross-section on June 26th. prior to freshet (5,000 c.f.s.)

--------- River cross-section on Aug.2nd. prior to peak. (13,400 c.f.s.)

— — — River cross-section on Sept.17th. following freshet.

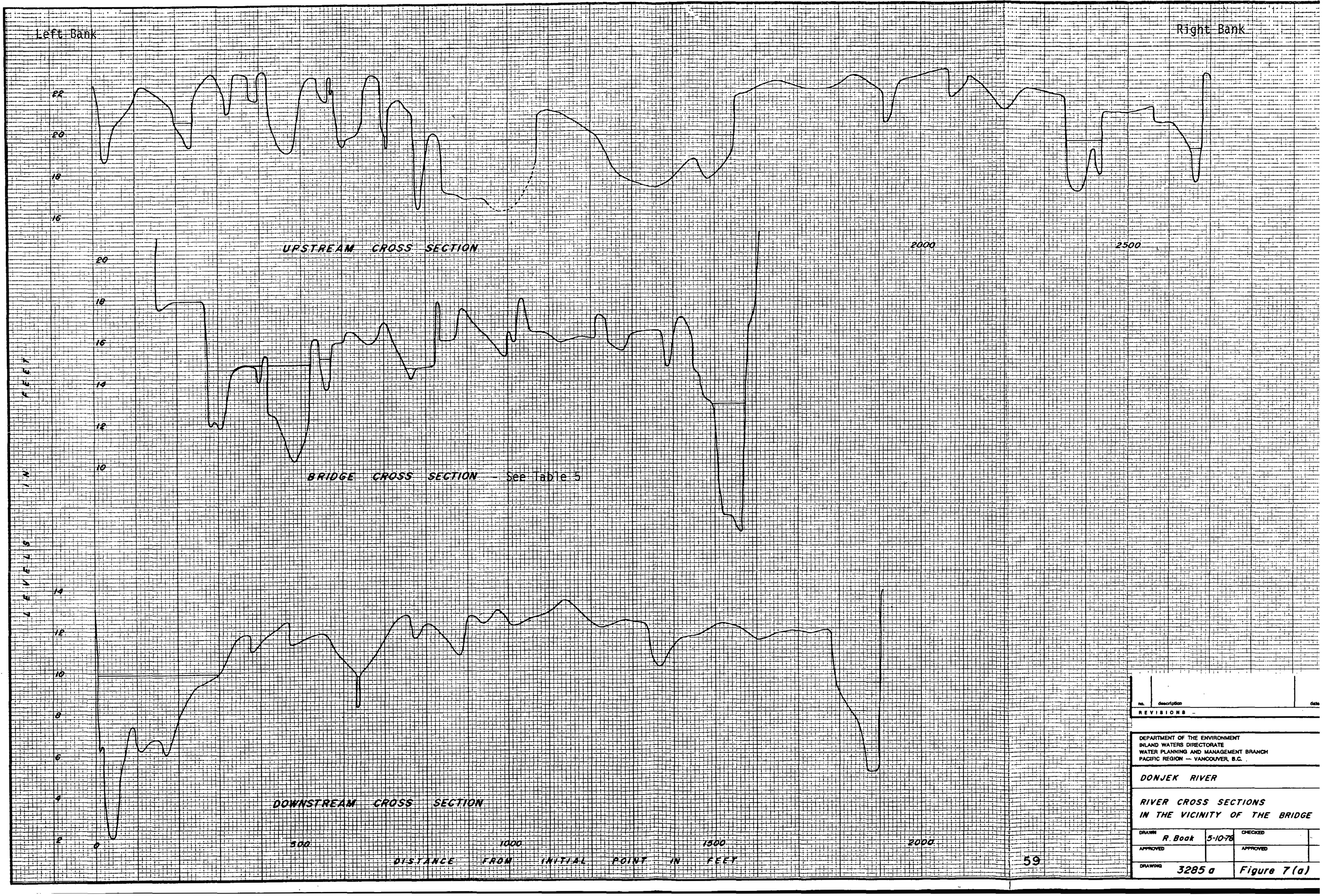
no.	description	date
REVISIONS		

DEPARTMENT OF THE ENVIRONMENT
INLAND WATERS DIRECTORATE
WATER PLANNING AND MANAGEMENT BRANCH
PACIFIC REGION — VANCOUVER, B.C.

DONJEK RIVER AT ALASKA HIGHWAY

CROSS-SECTIONS OF RIVER BED
SHOWING EFFECT OF SCOUR
SUMMER 1978

DRAWN V. Lipscombe		CHECKED	
APPROVED		APPROVED	
DRAWING		FIGURE 6	



no.	description	date

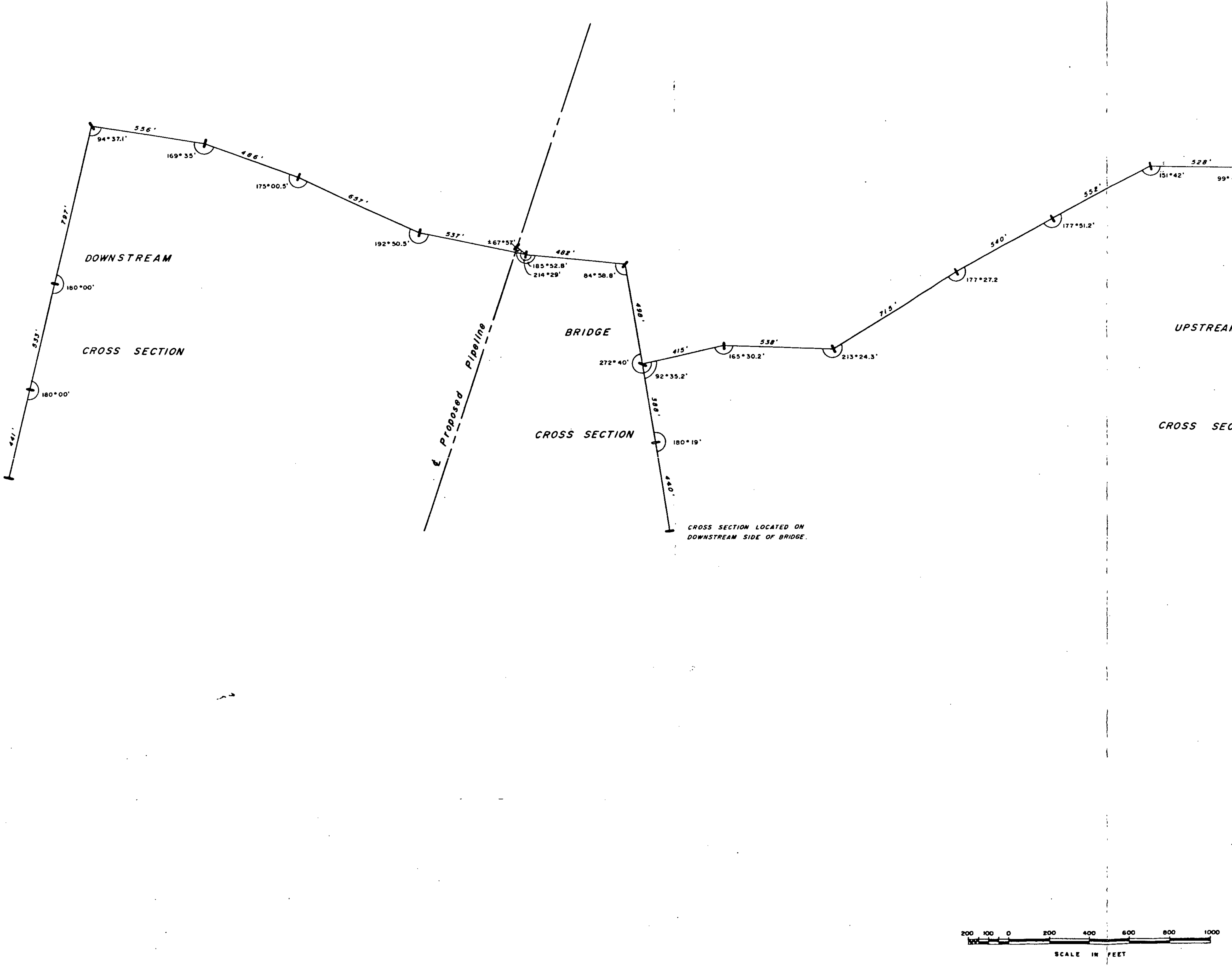
REVISIONS -

DEPARTMENT OF THE ENVIRONMENT
INLAND WATERS DIRECTORATE
WATER PLANNING AND MANAGEMENT BRANCH
PACIFIC REGION — VANCOUVER, B.C.

DONJEK RIVER

RIVER CROSS SECTIONS
IN THE VICINITY OF THE BRIDGE

DRAWN		CHECKED	
R. Boak	5-10-76		
APPROVED		APPROVED	
DRAWING 3285 a		Figure 7(a)	



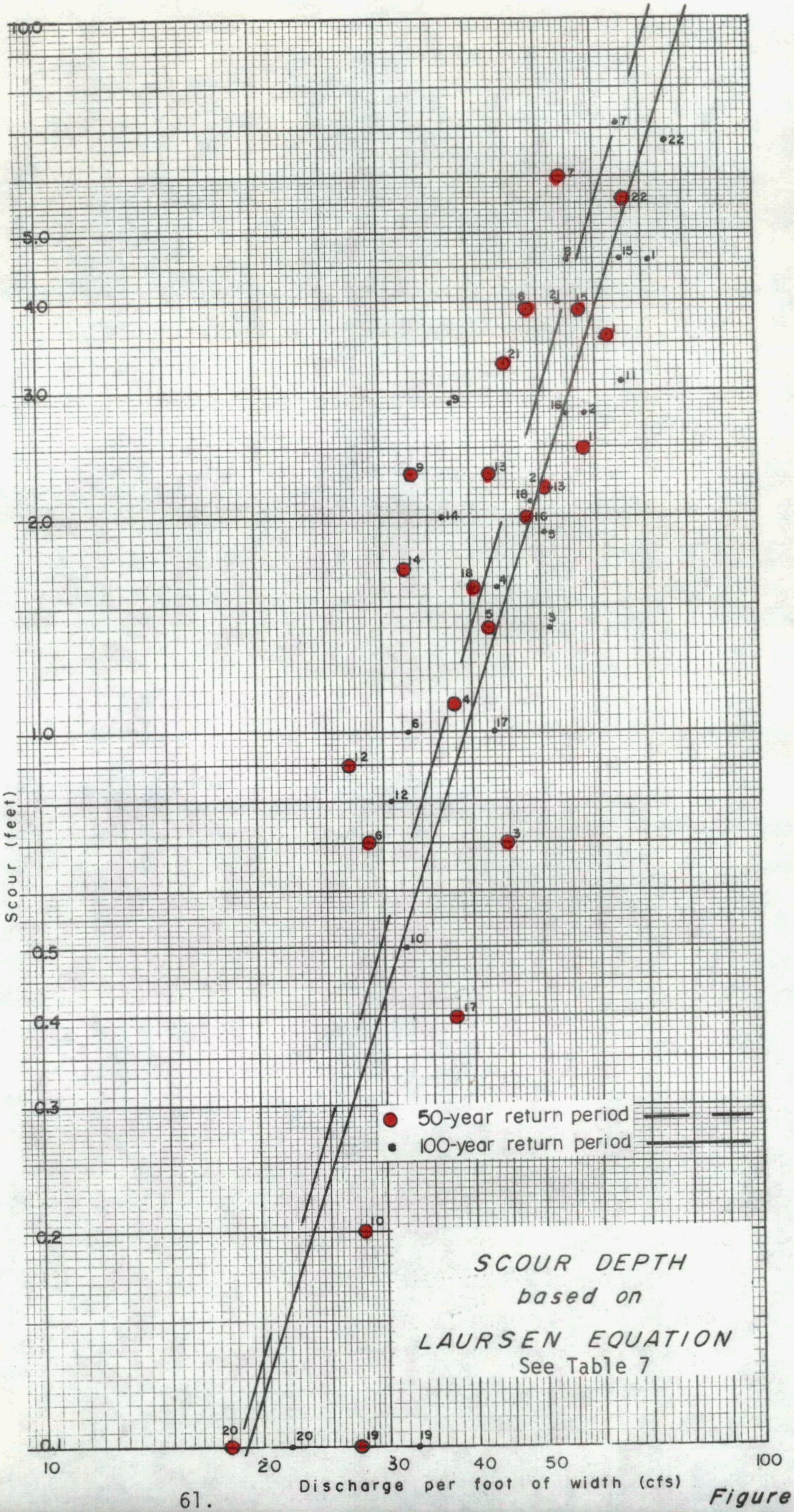
no.	description	date
REVISIONS		

DEPARTMENT OF THE ENVIRONMENT
INLAND WATERS DIRECTORATE
WATER PLANNING AND MANAGEMENT BRANCH
PACIFIC REGION — VANCOUVER, B.C.

DONJEK RIVER

TRAVERSE LOCATING RIVER CROSS SECTIONS IN THE VICINITY OF THE BRIDGE

DRAWN R. Boak	4-10-78	CHECKED	
APPROVED		APPROVED	
DRAWING 3285		Figure 7(b)	

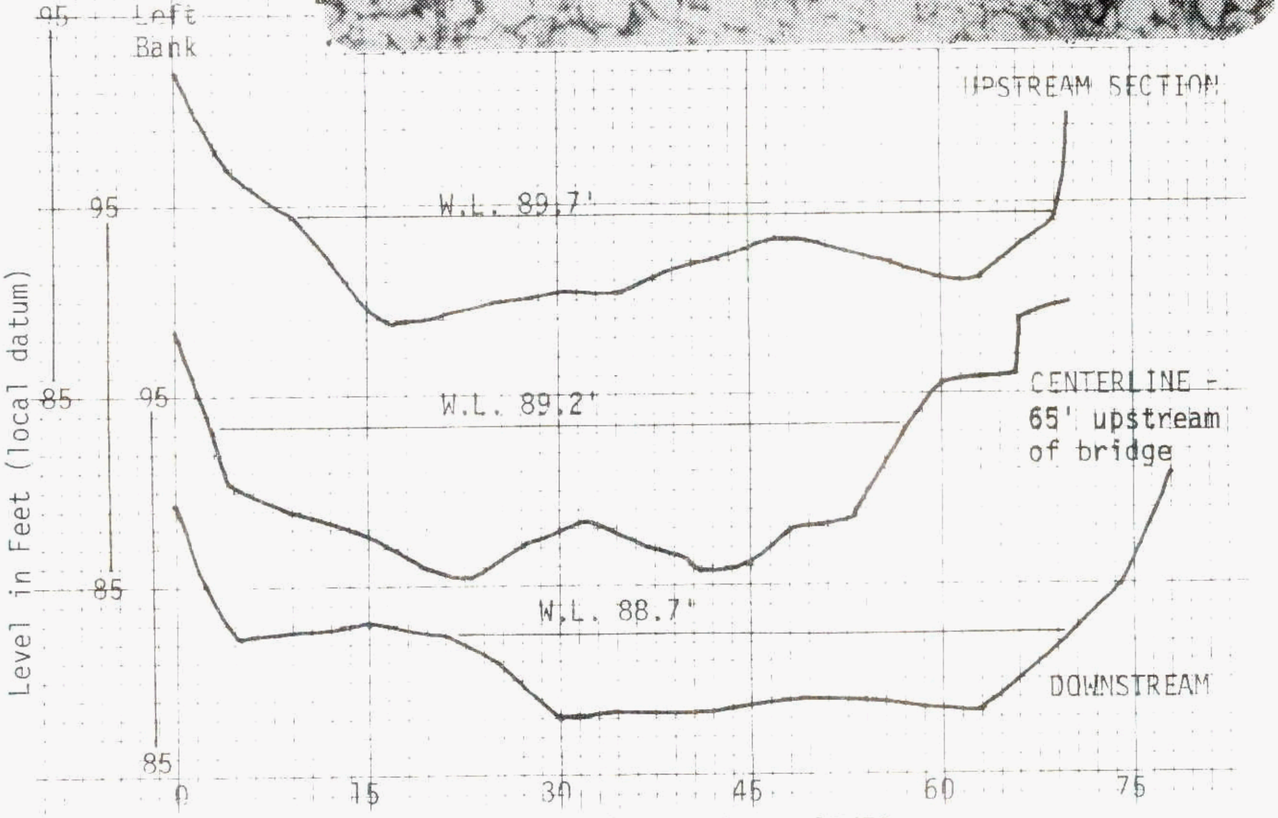


SCOUR DEPTH
based on
LAURSEN EQUATION
See Table 7

Figure 8

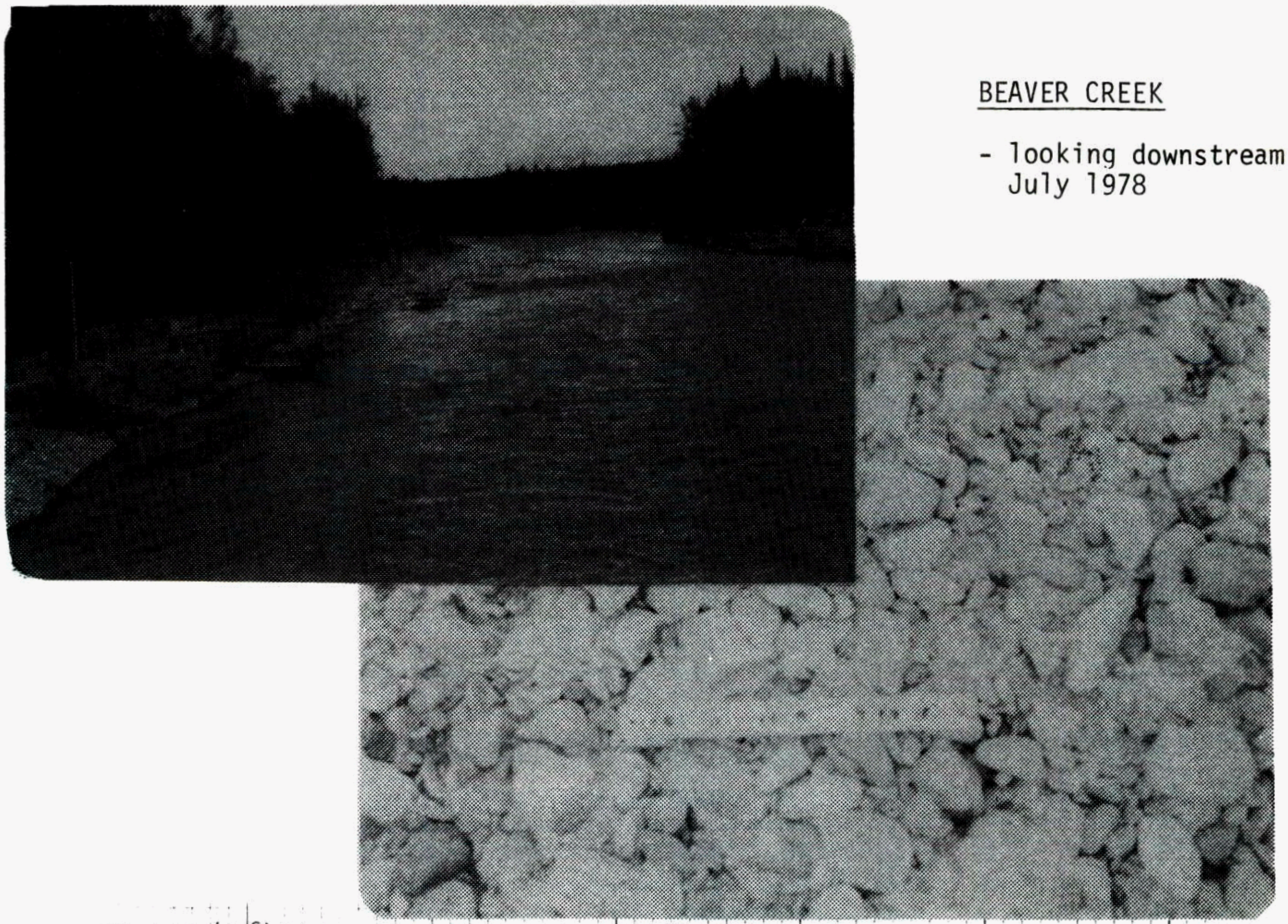
SNAG CREEK

- looking downstream
  Sept. 1978



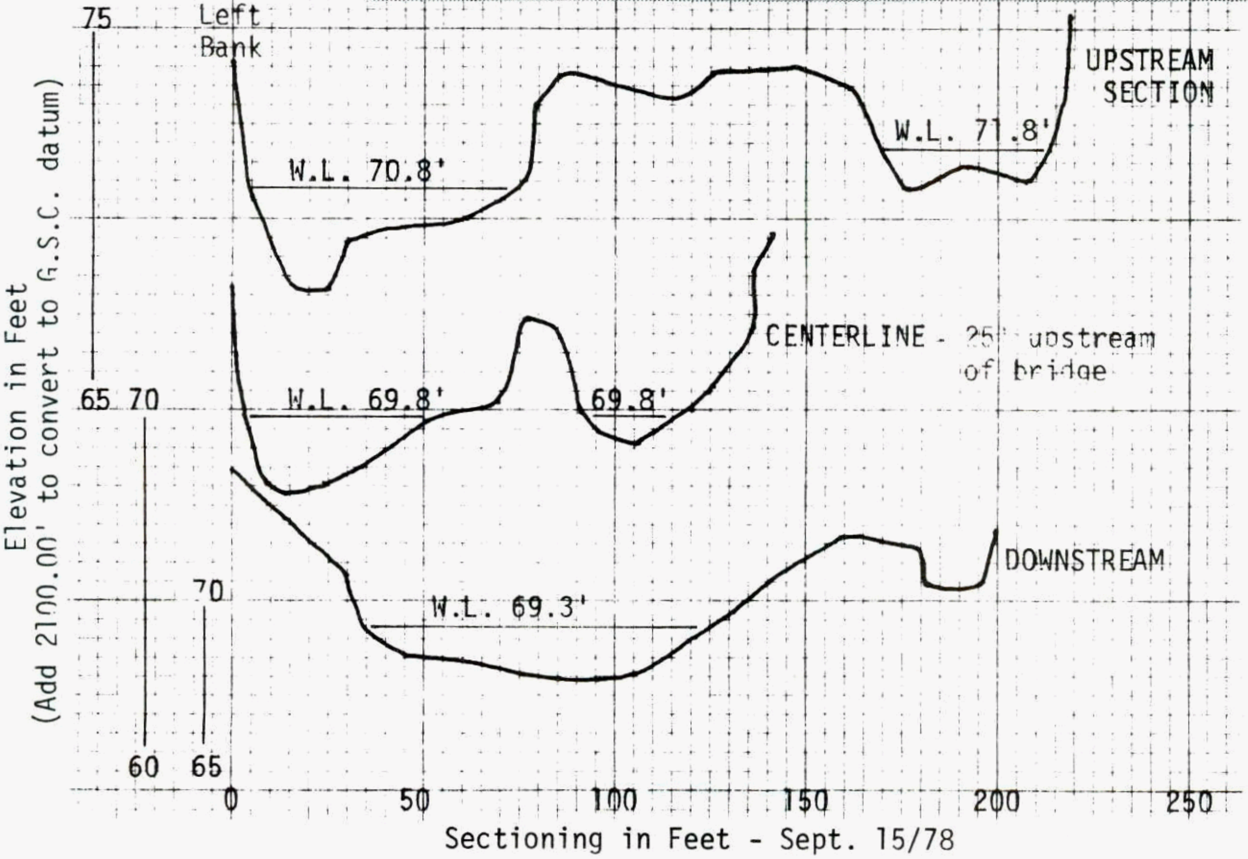
B.M. - 6" spike in d/s pile under bridge, right bank - 100.00' local datum.

Figure 9



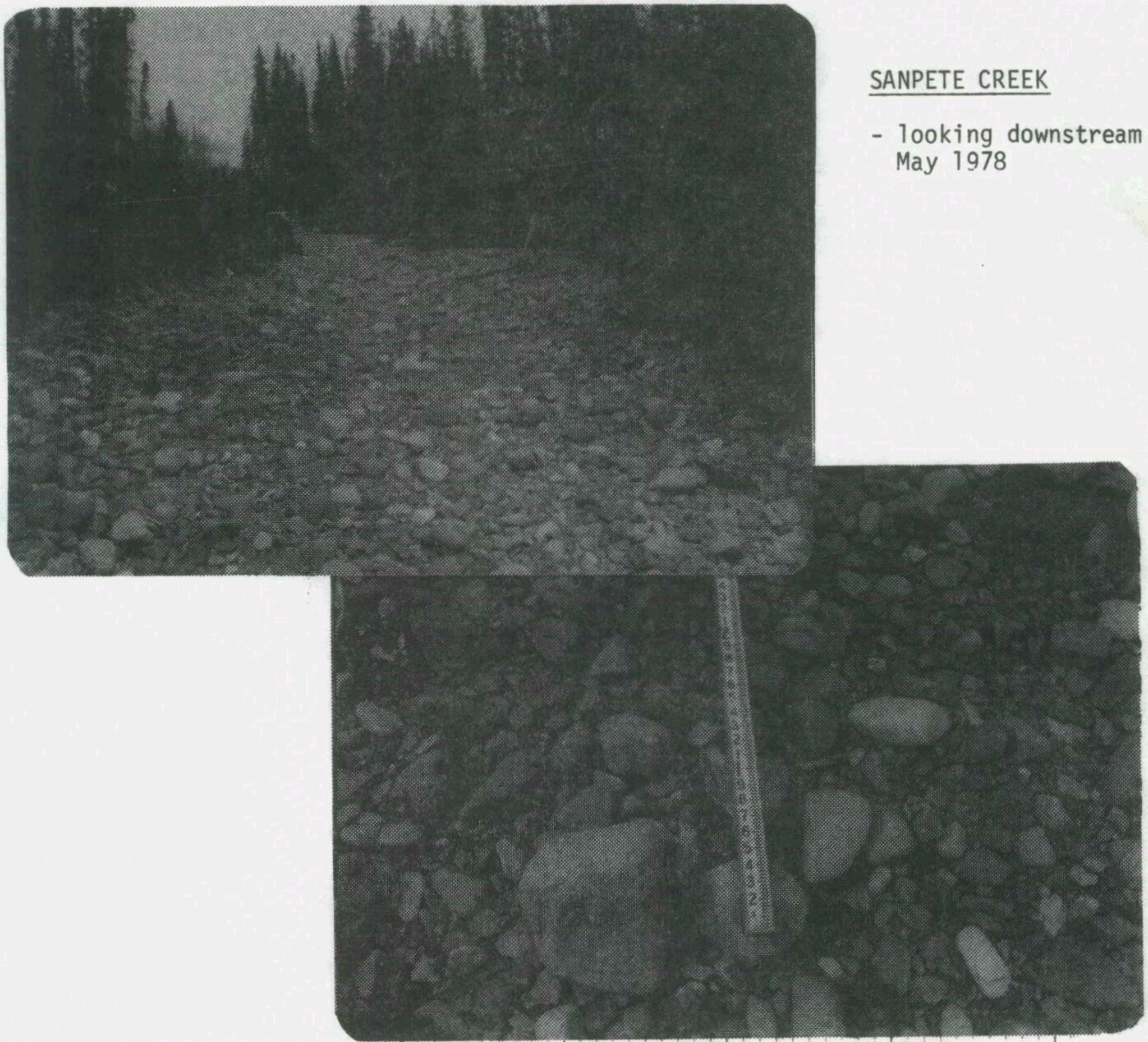
BEAVER CREEK

- looking downstream
  July 1978



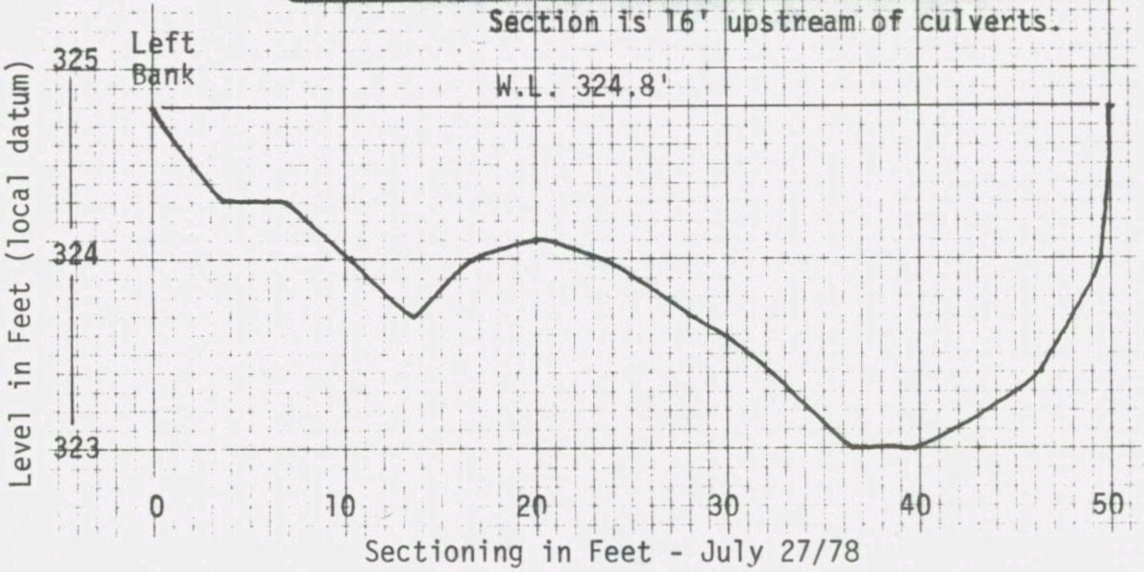
B.M. - Topog. Survey of Canada No. 64J19 located on the bridge - 2186.68' G.S.C.

Figure 10



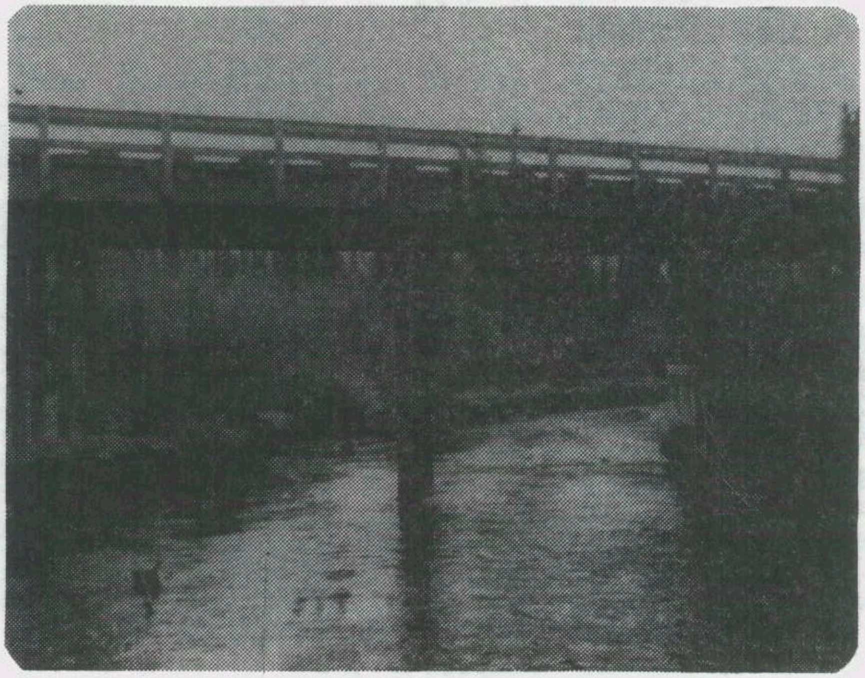
SANPETE CREEK

- looking downstream
  May 1978



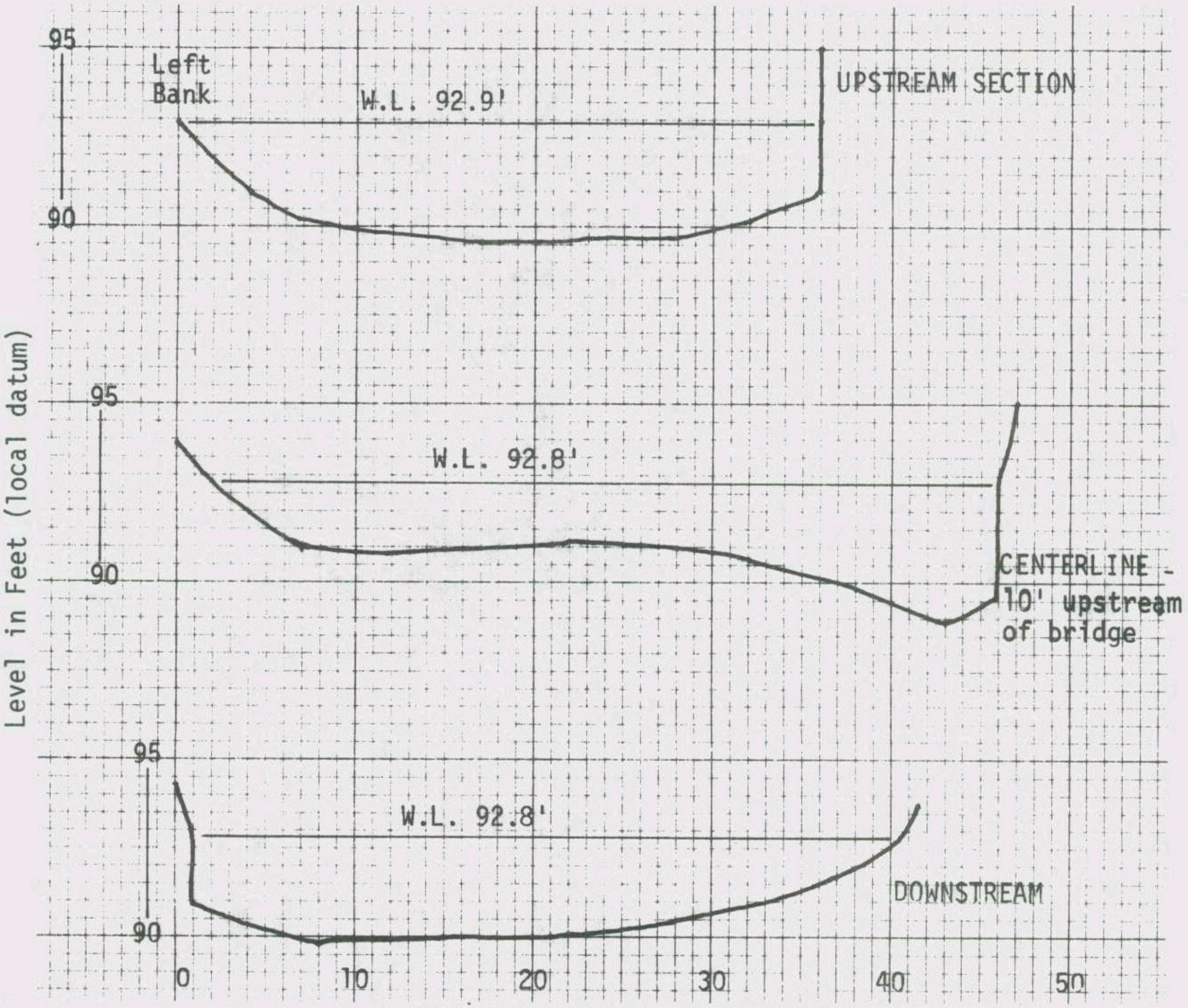
B.M. - Head of 6" spike in base of 12" poplar, 130' downstream of culvert, 40' inshore of right bank - 328.08' local datum.

Figure 11



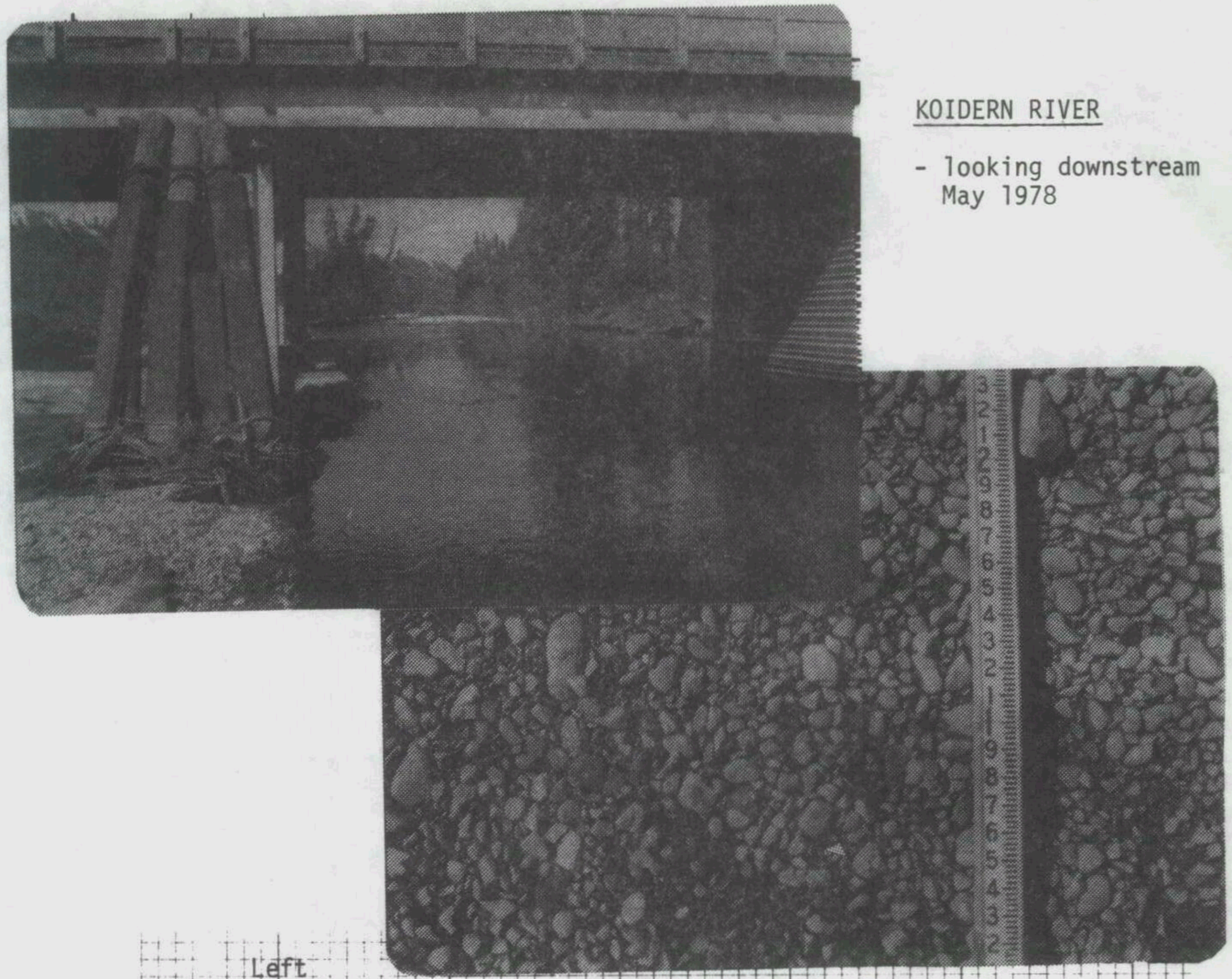
LONG'S CREEK

- looking downstream
  May 1978



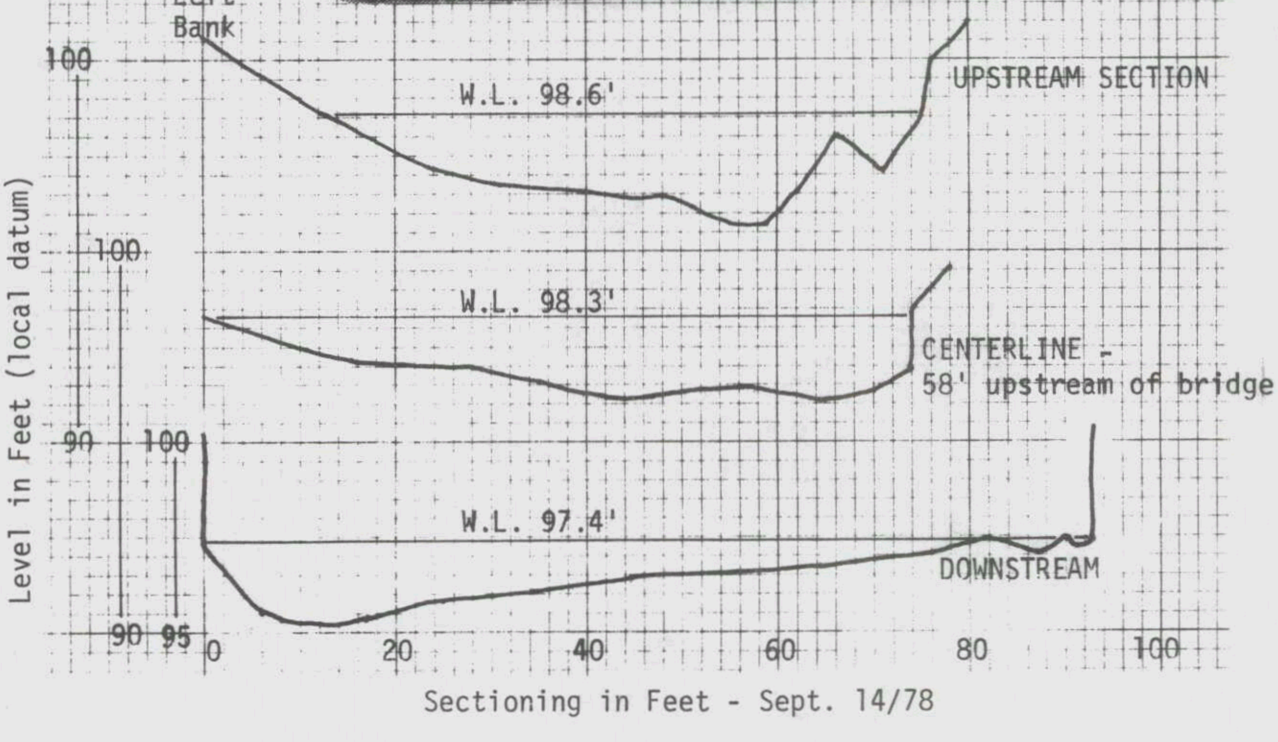
B.M. - 6" spike in spruce tree on right bank approx. 150' upstream of bridge - 100.00' local datum.

Figure 12



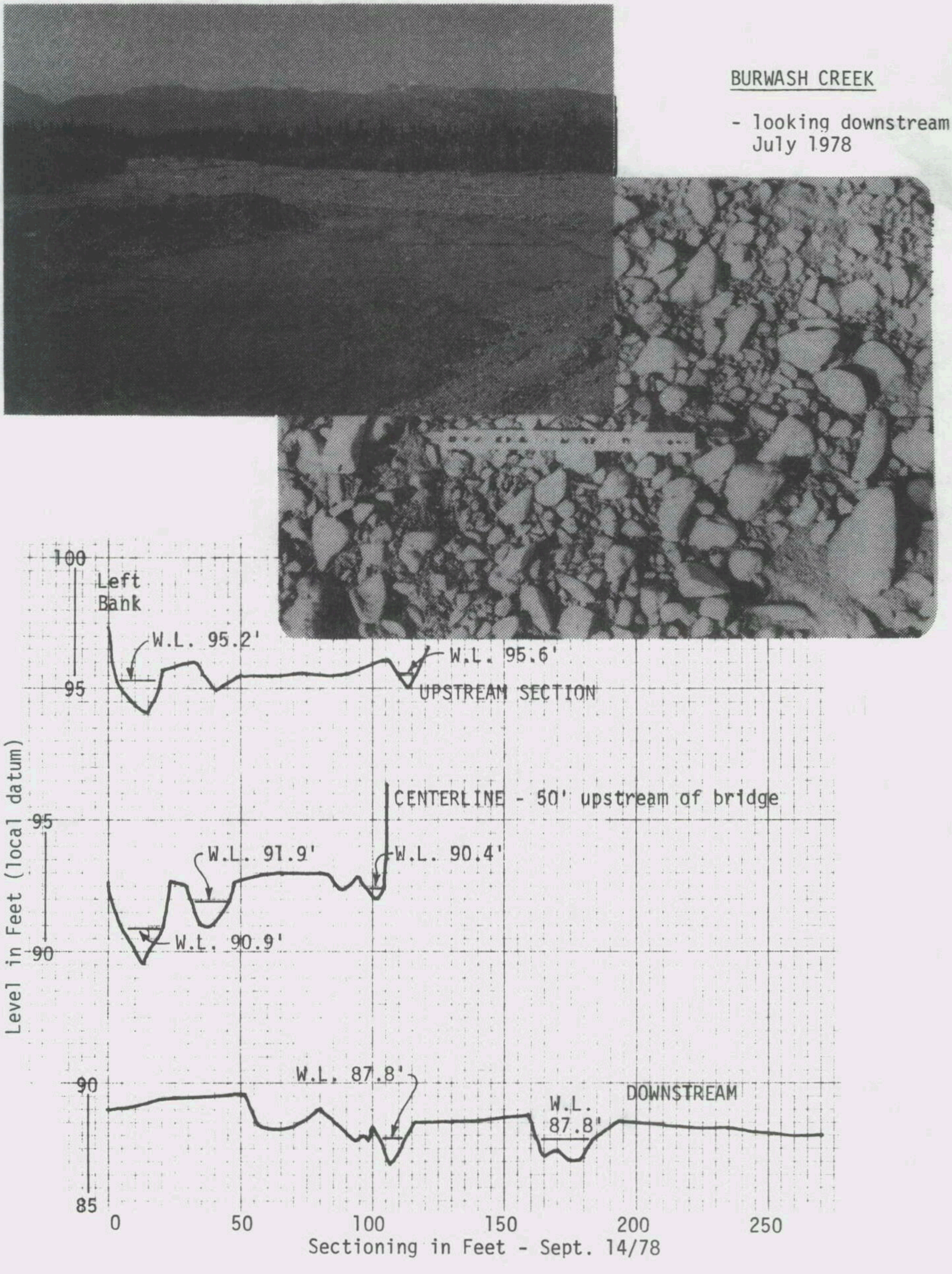
KOIDERN RIVER

- looking downstream
  May 1978



B.M. - Spike in pile on left bank under bridge - 100.00' local datum.

Figure 13

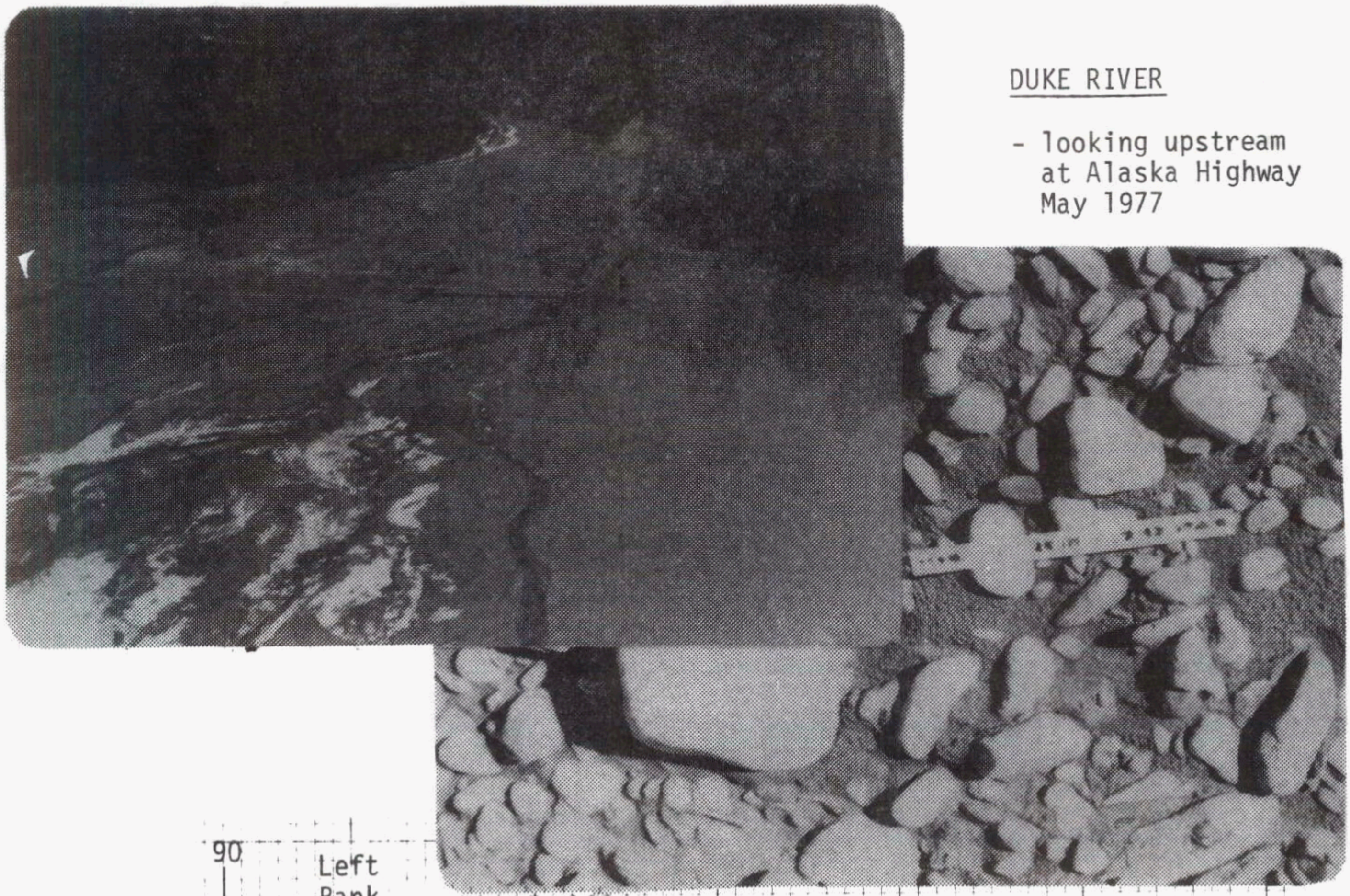


BURWASH CREEK

- looking downstream
  July 1978

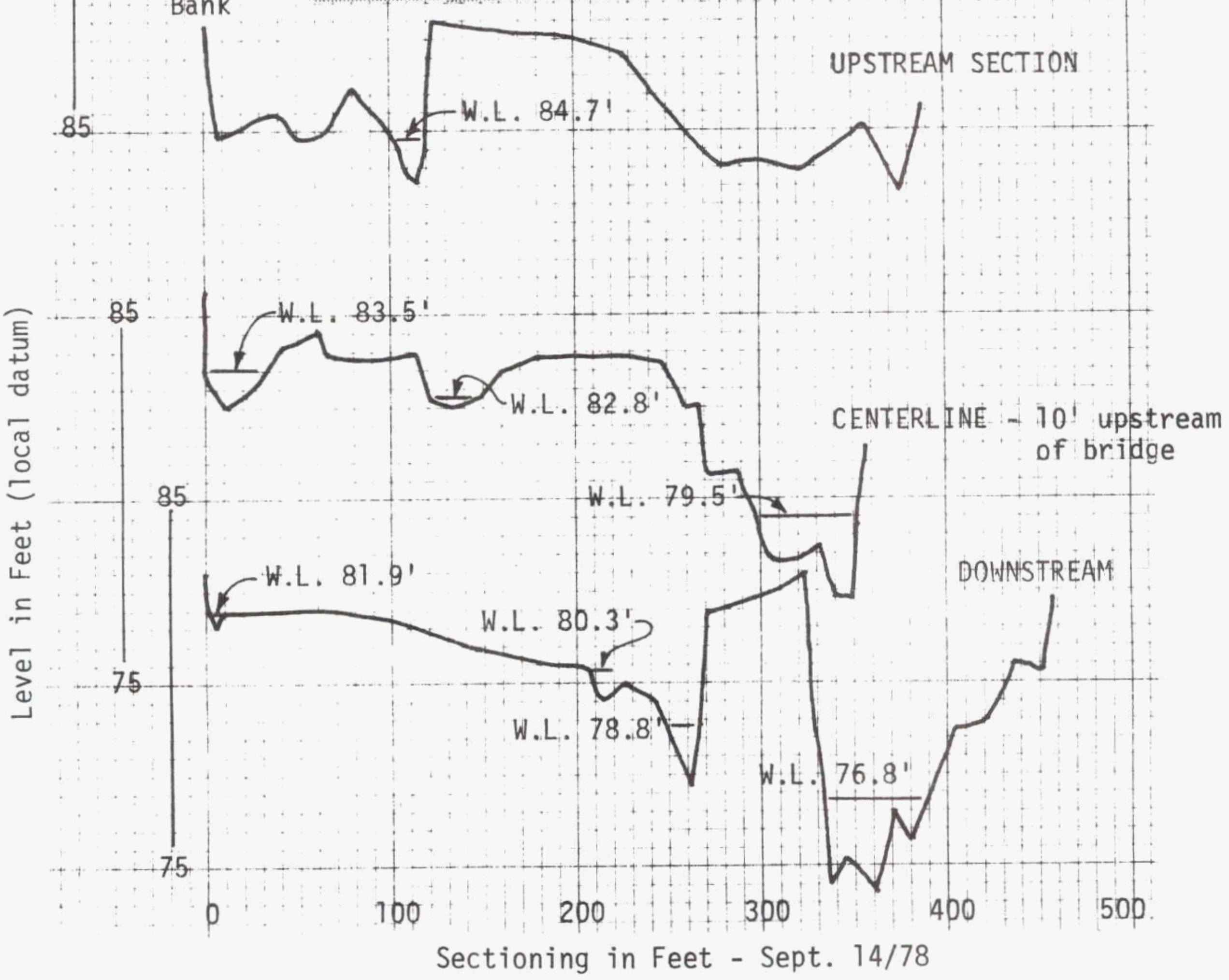
B.M. - G.S.C. 78Y559 - 100.00' local datum.

Figure 14



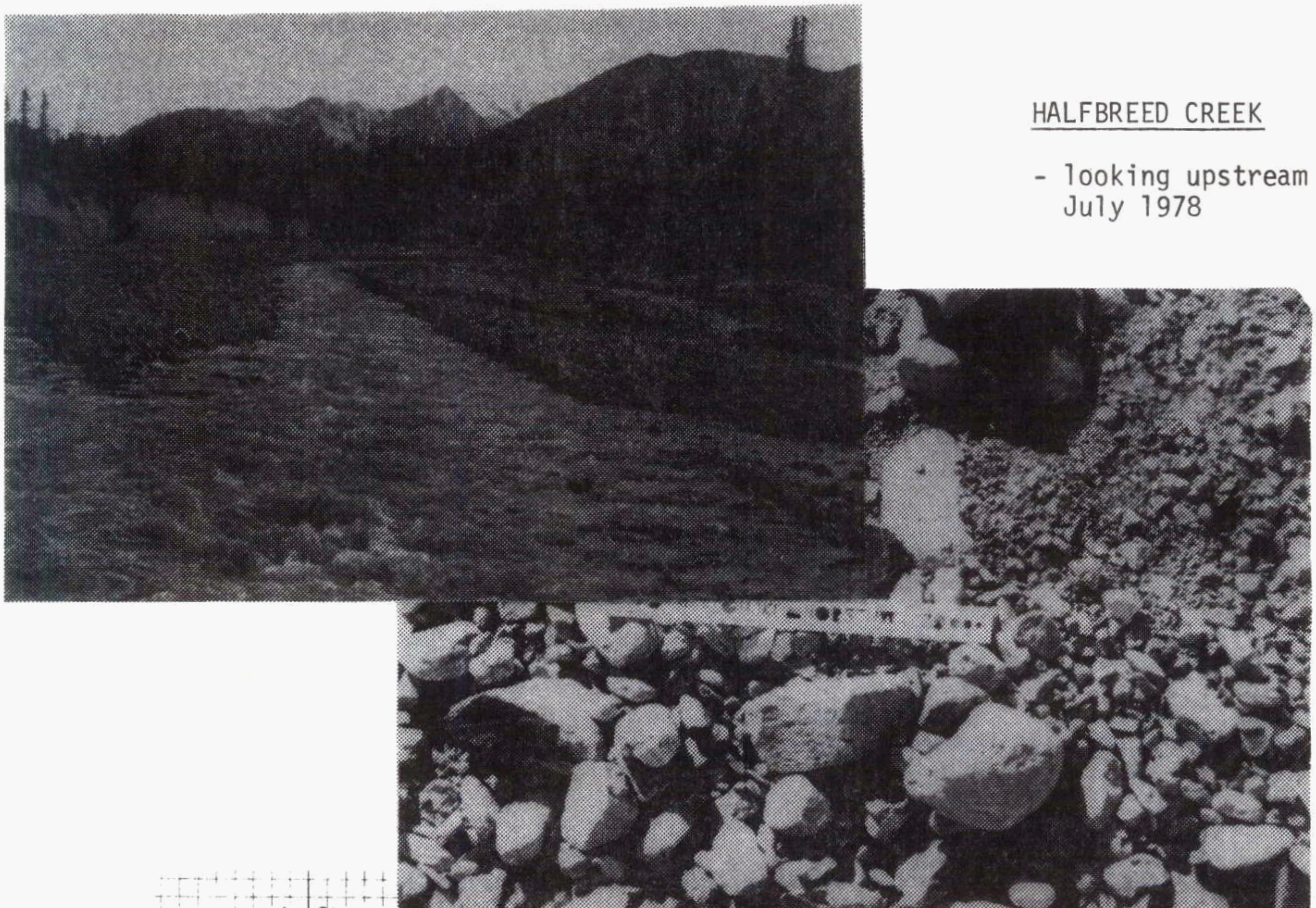
DUKE RIVER

- looking upstream
  at Alaska Highway
  May 1977



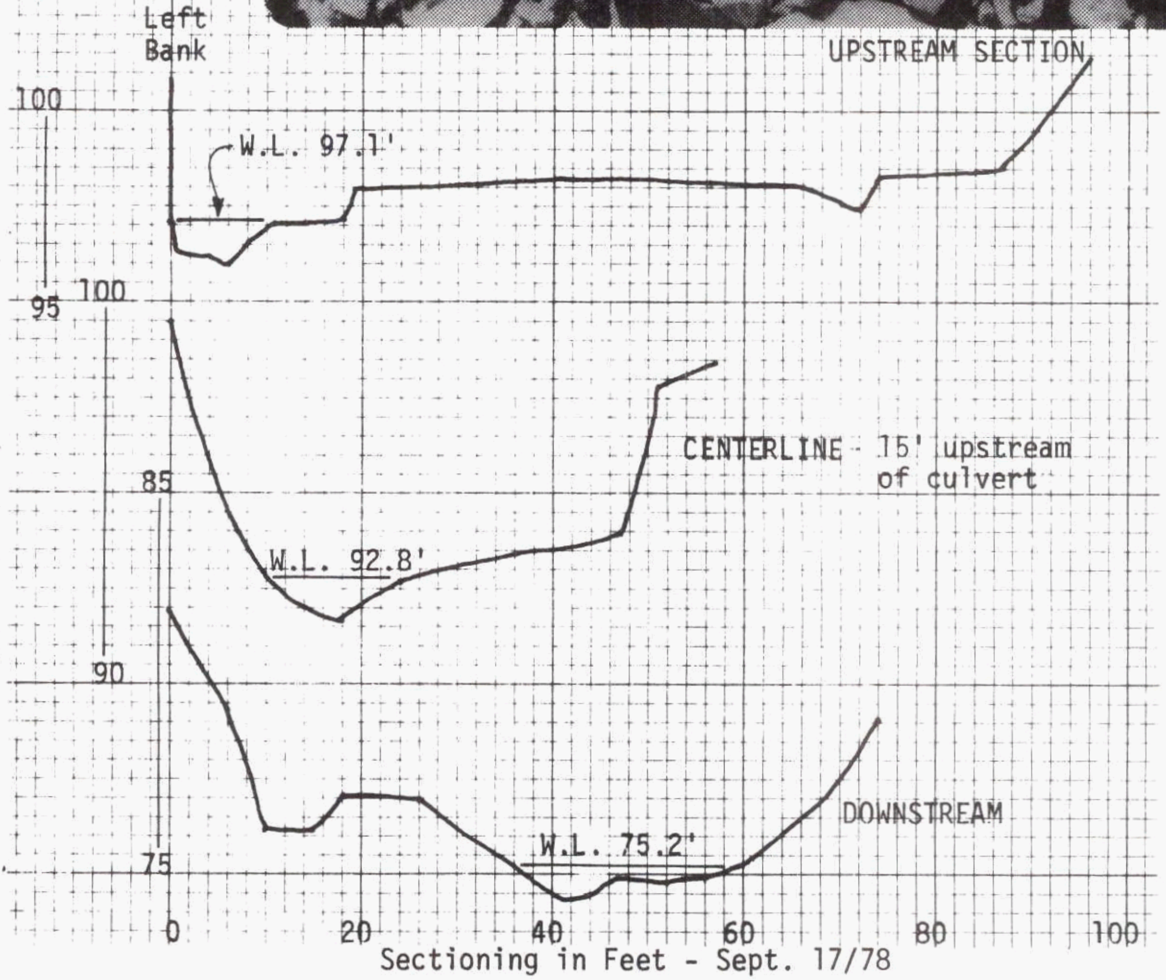
B.M. - G.S.C. 78Y556 - 100.00' local datum.

Figure 15



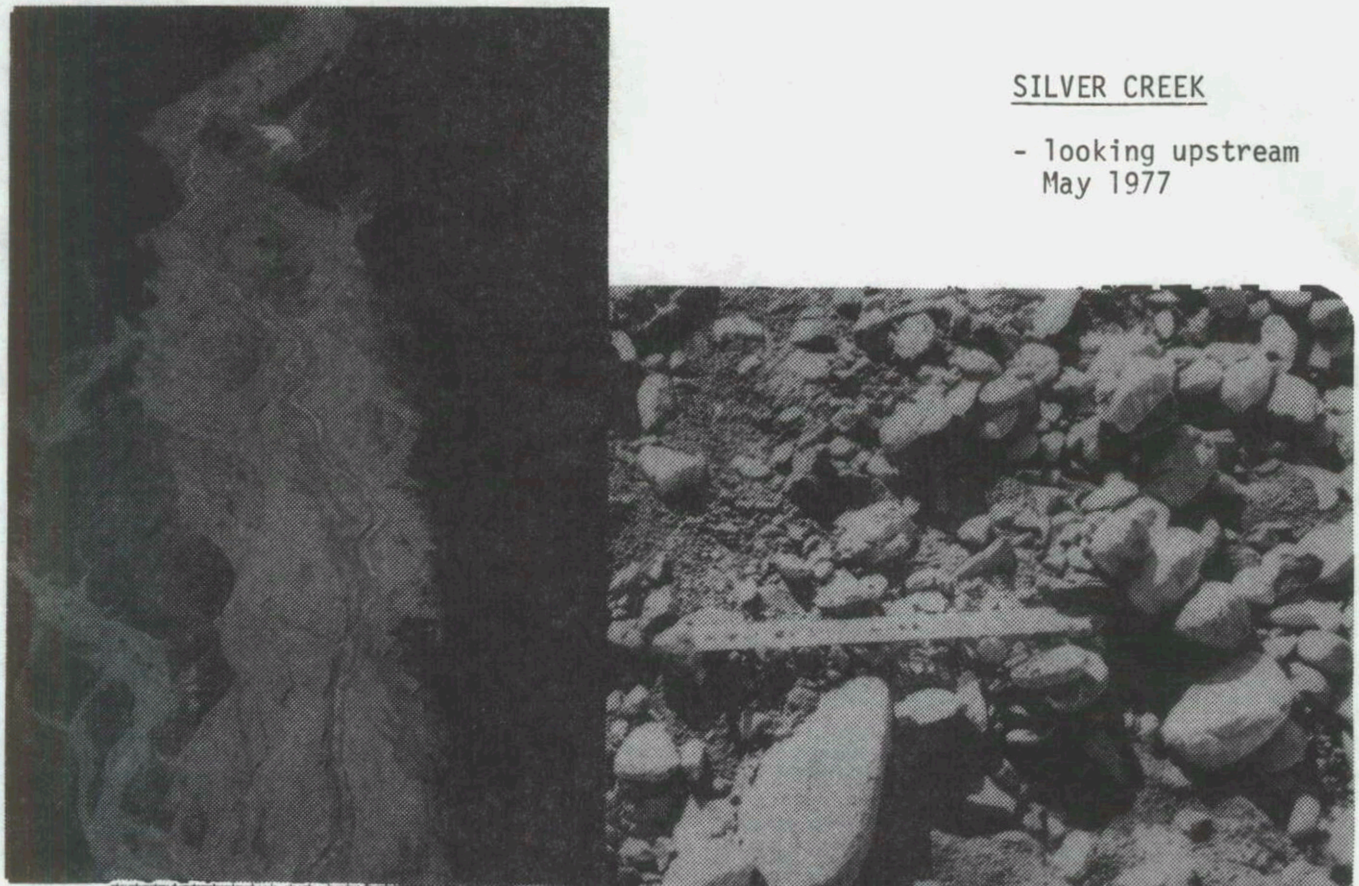
HALFBREED CREEK

- looking upstream
  July 1978



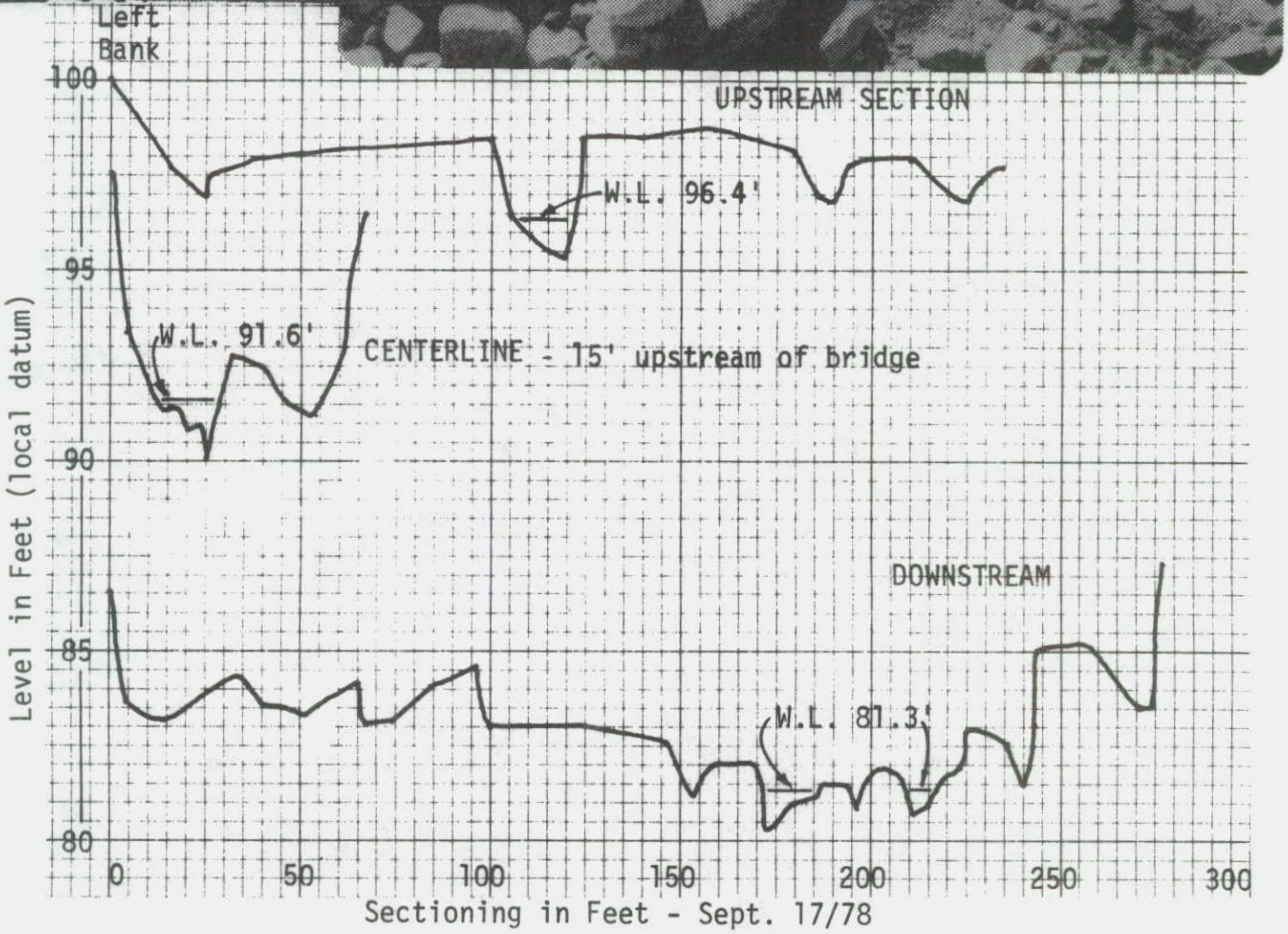
B.M. - Painted bolt on downstream end of culvert - 100.00' local datum

Figure 16



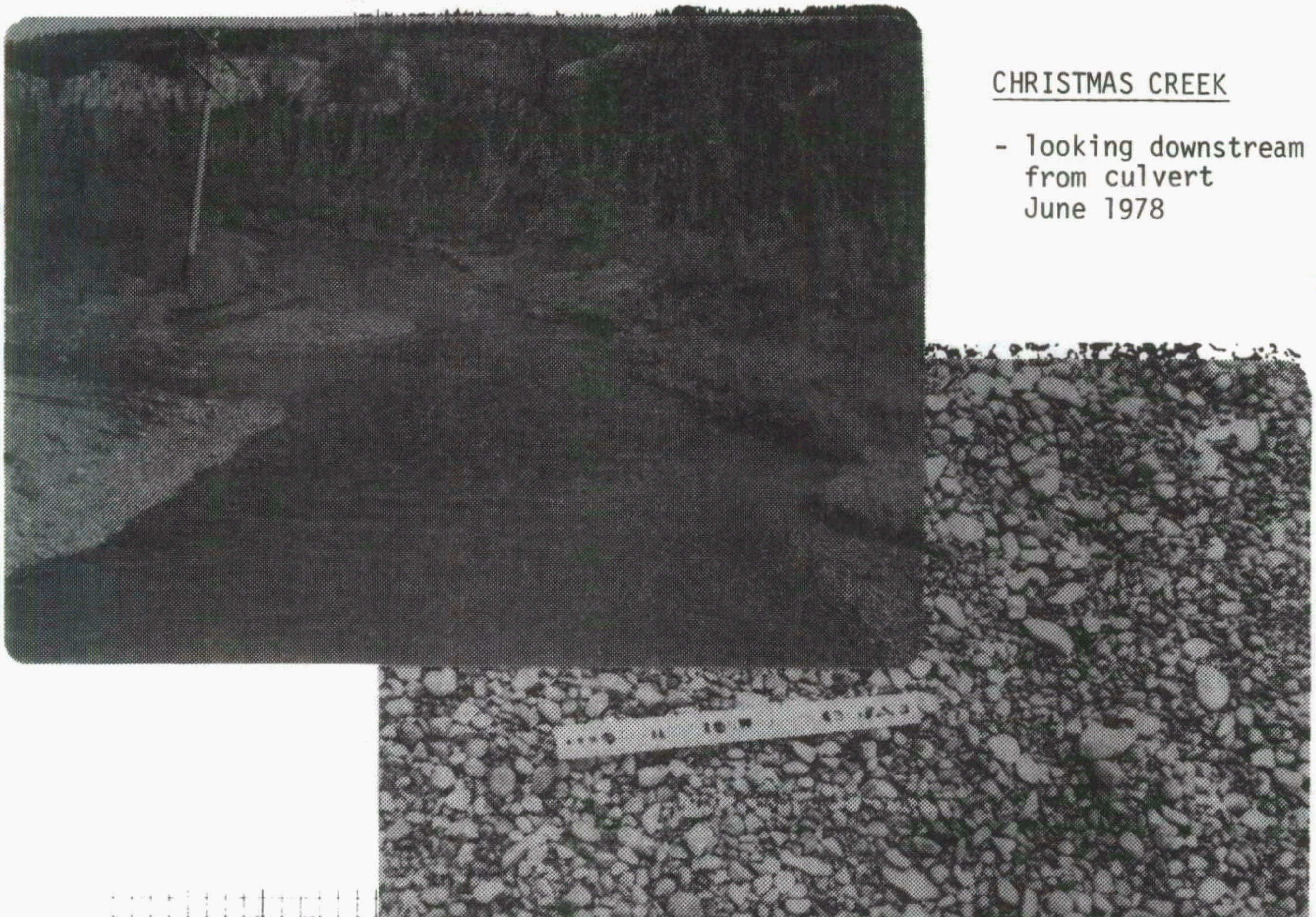
SILVER CREEK

- looking upstream
May 1977



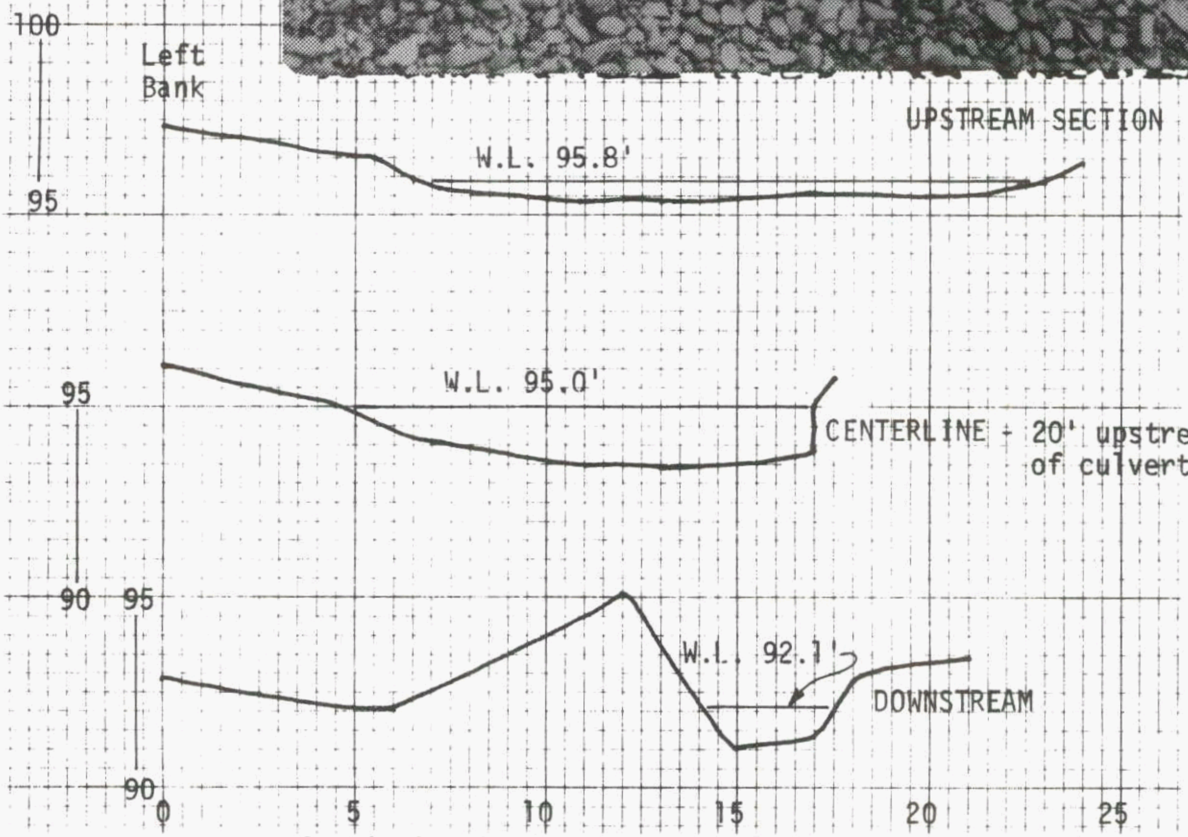
B.M. - Head of 7" spike in base of 18" spruce, 20' downstream from gauge, 60' inshore of right bank - 100.00' local datum.

Figure 17



CHRISTMAS CREEK

- looking downstream from culvert June 1978

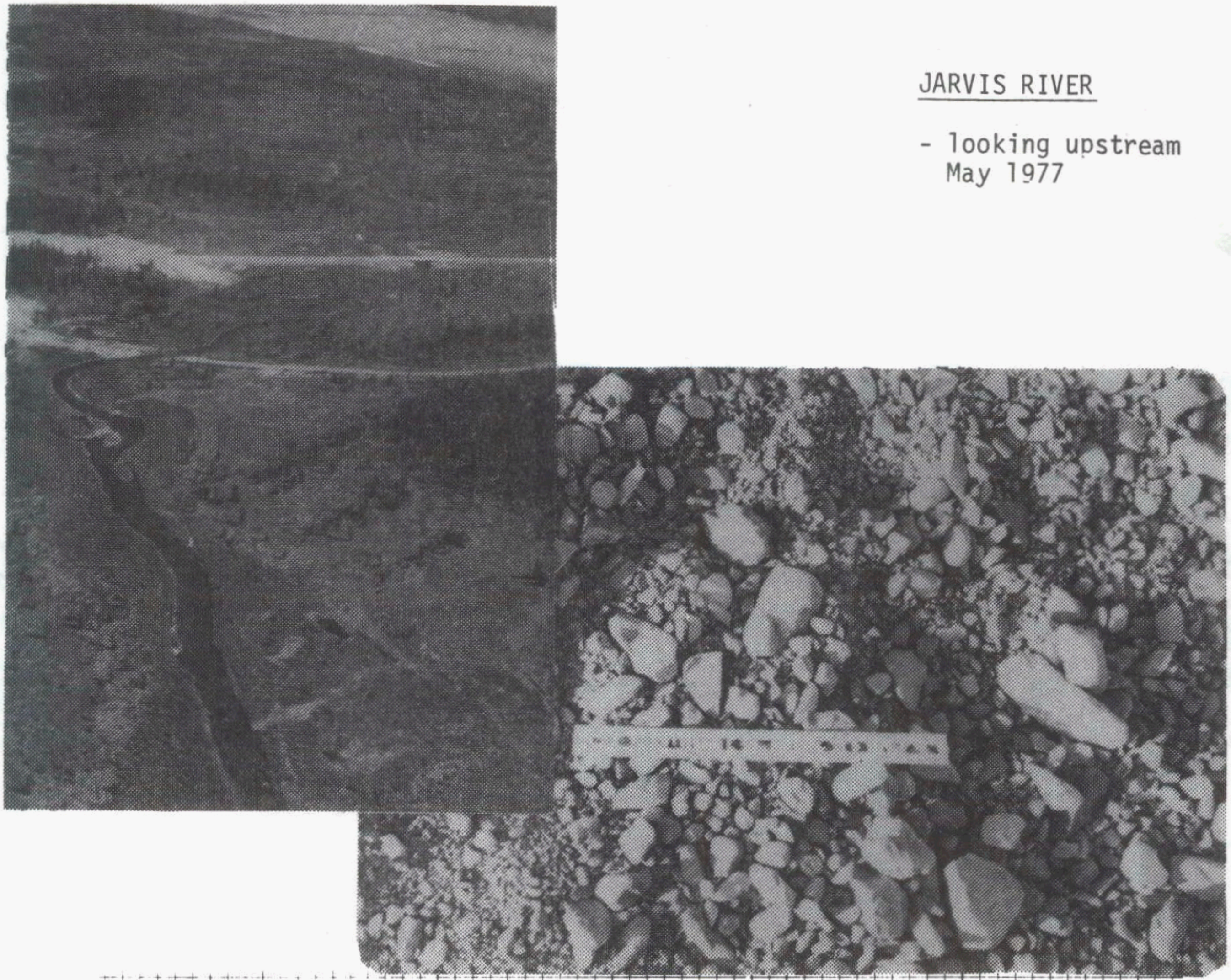


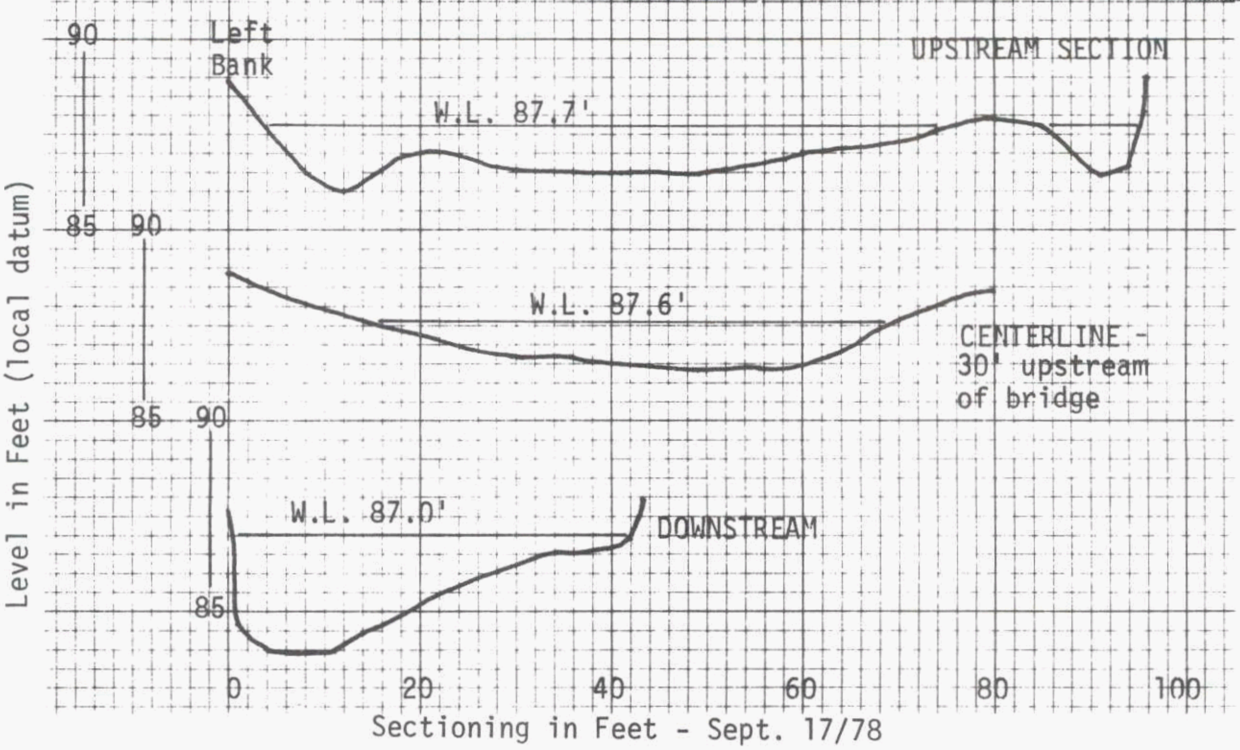
B.M. - Lag bolt with washer stamped W.S.C., in stump on right bank 230' upstream of culvert - 100.00' local datum.

Figure 18

JARVIS RIVER

- looking upstream
May 1977



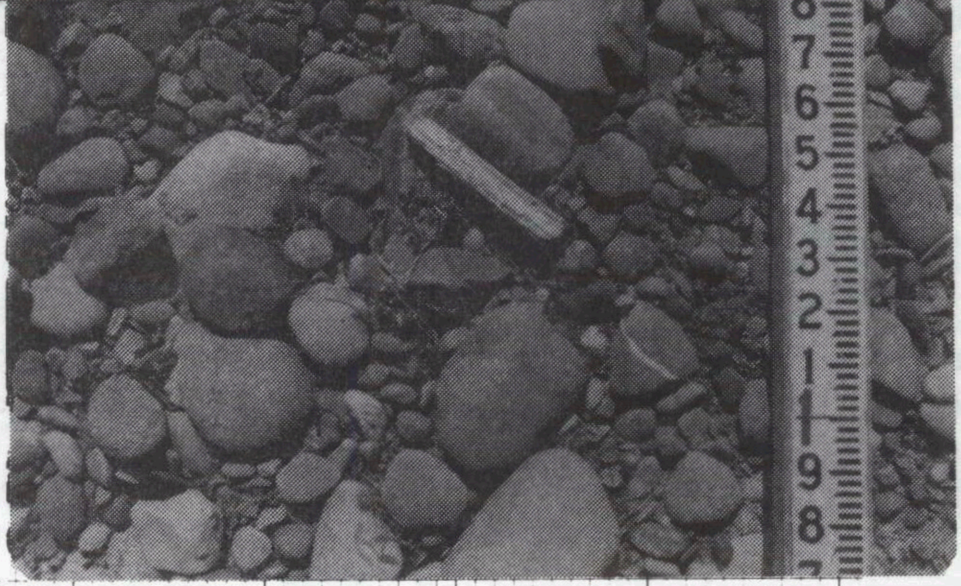


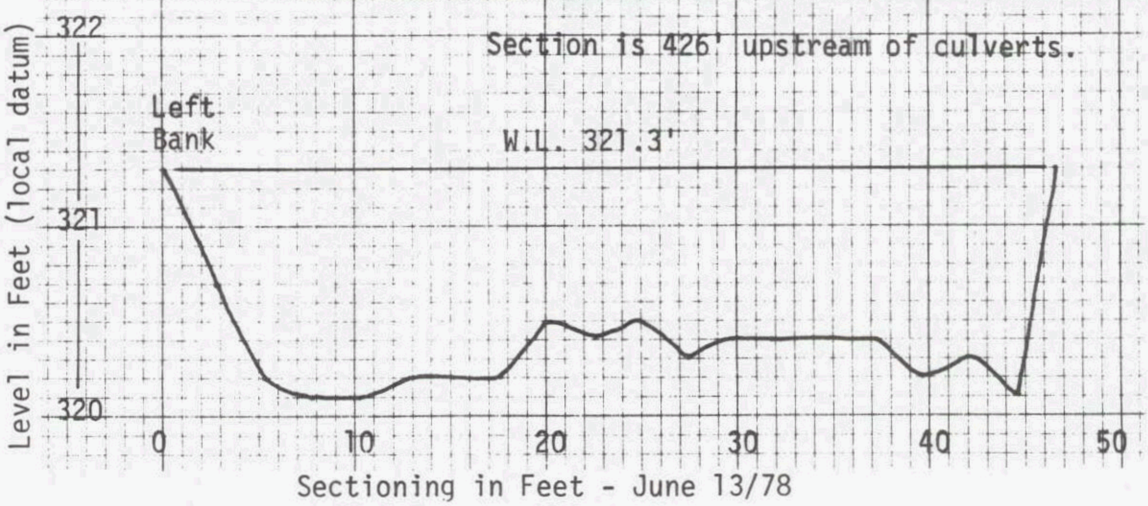
B.M. - Iron pin in downstream side of bridge (east) - 100.00' local datum

Figure 19

MARSHALL CREEK

- looking upstream
  May 1978



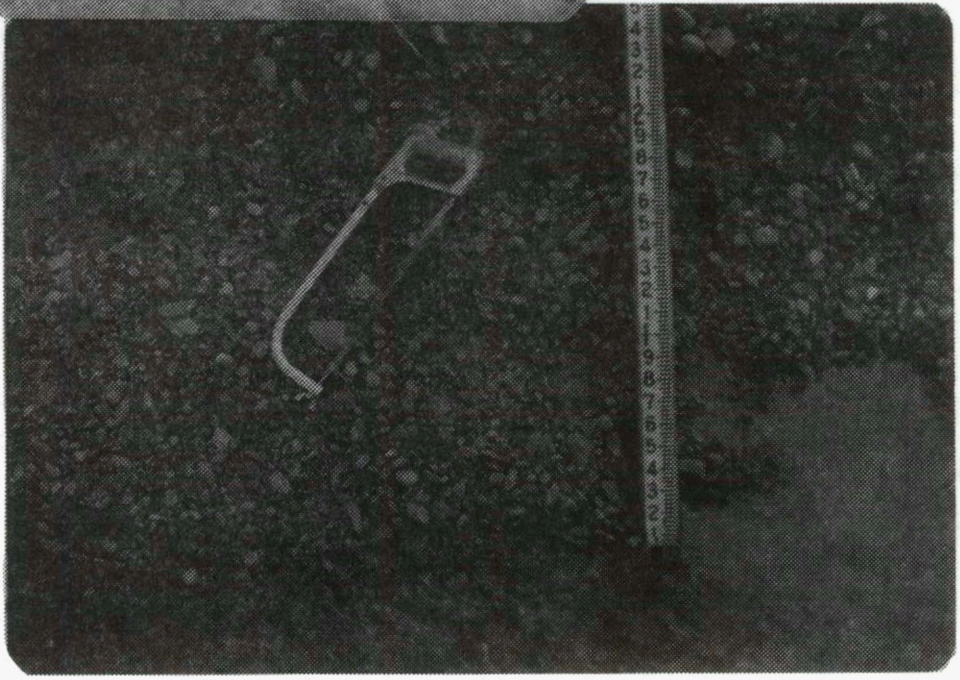


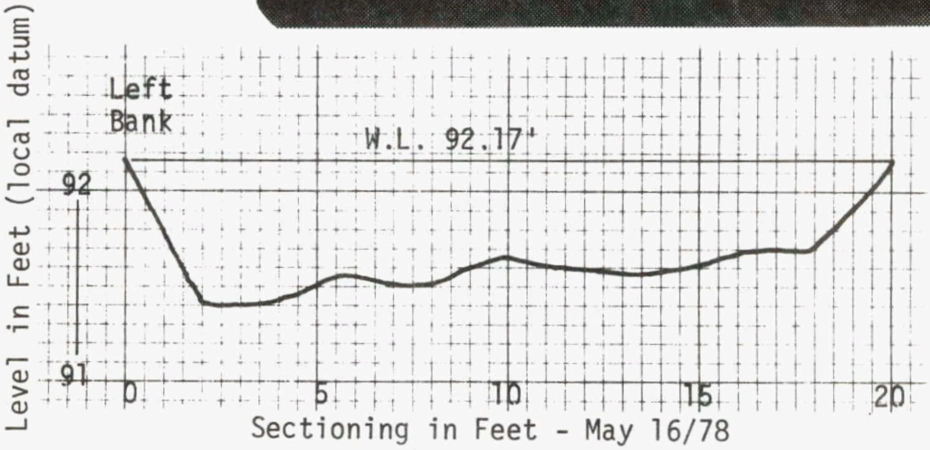
B.M. - Head of 6" spike in 10" spruce 460' upstream of culverts, 30' inshore from right bank - 328.08' local datum.

Figure 20

CRACKER CREEK

- looking downstream
  May 1978

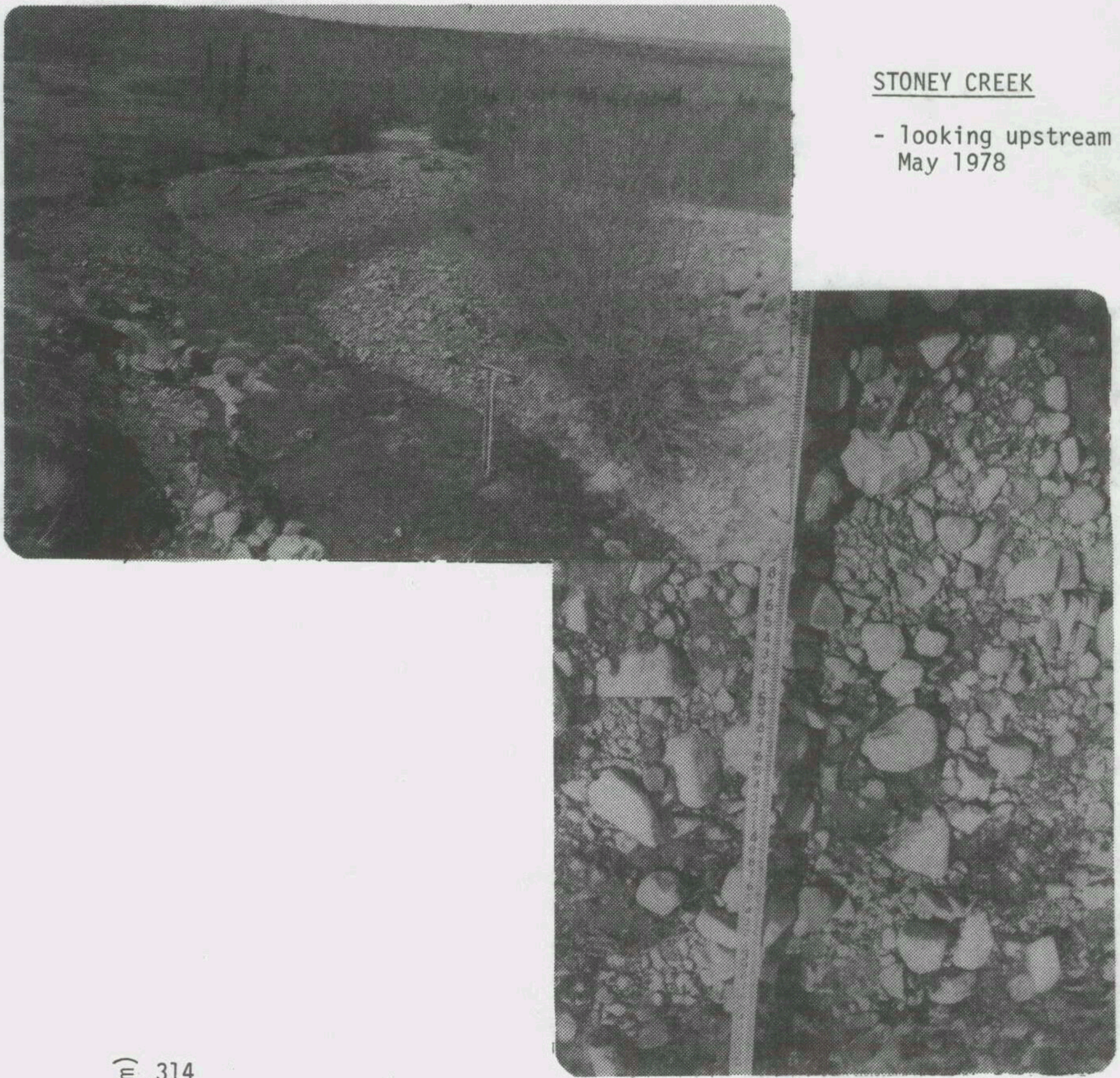




Section is 500'
upstream of bridg

B.M. - Located on upstream left bank abutment of bridge, NE corner, approx.
1 foot above road level - 100.00' local datum.

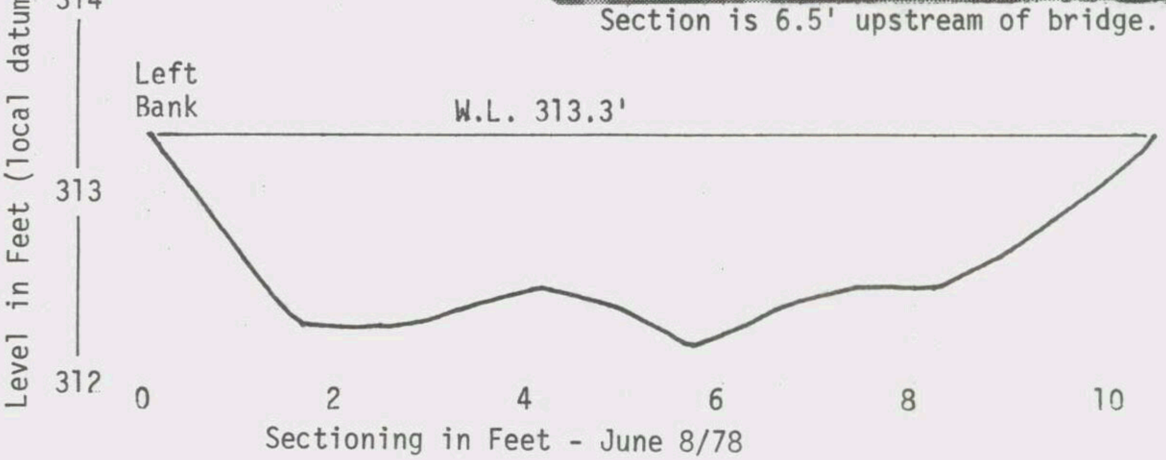
Figure 21



STONEY CREEK

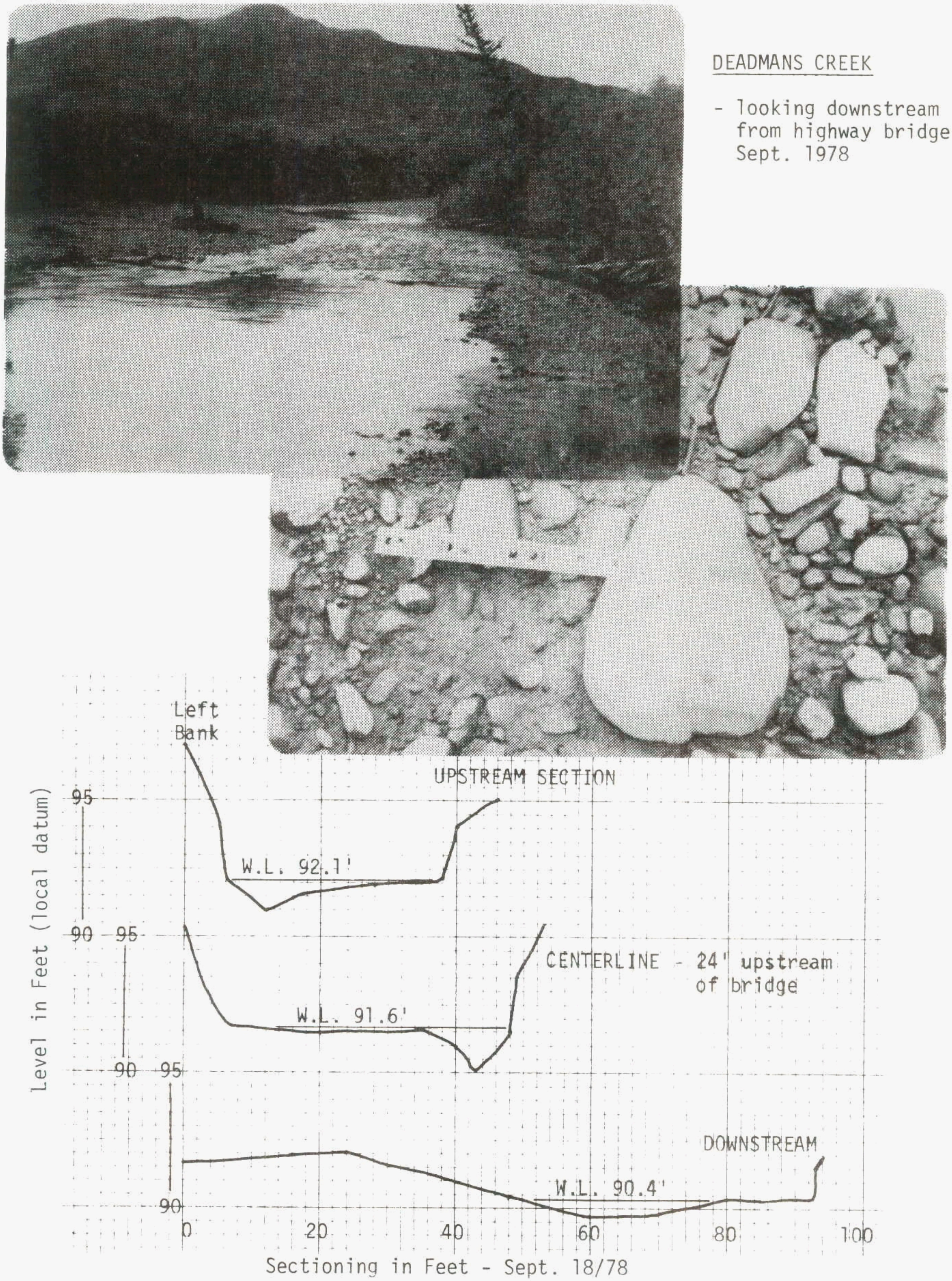
- looking upstream May 1978

Section is 6.5' upstream of bridge.



B.M. - Head of 7" spike in base of 8" spruce, 630' upstream of bridge, 60' inshore from right bank - 328.08' local datum.

Figure 22

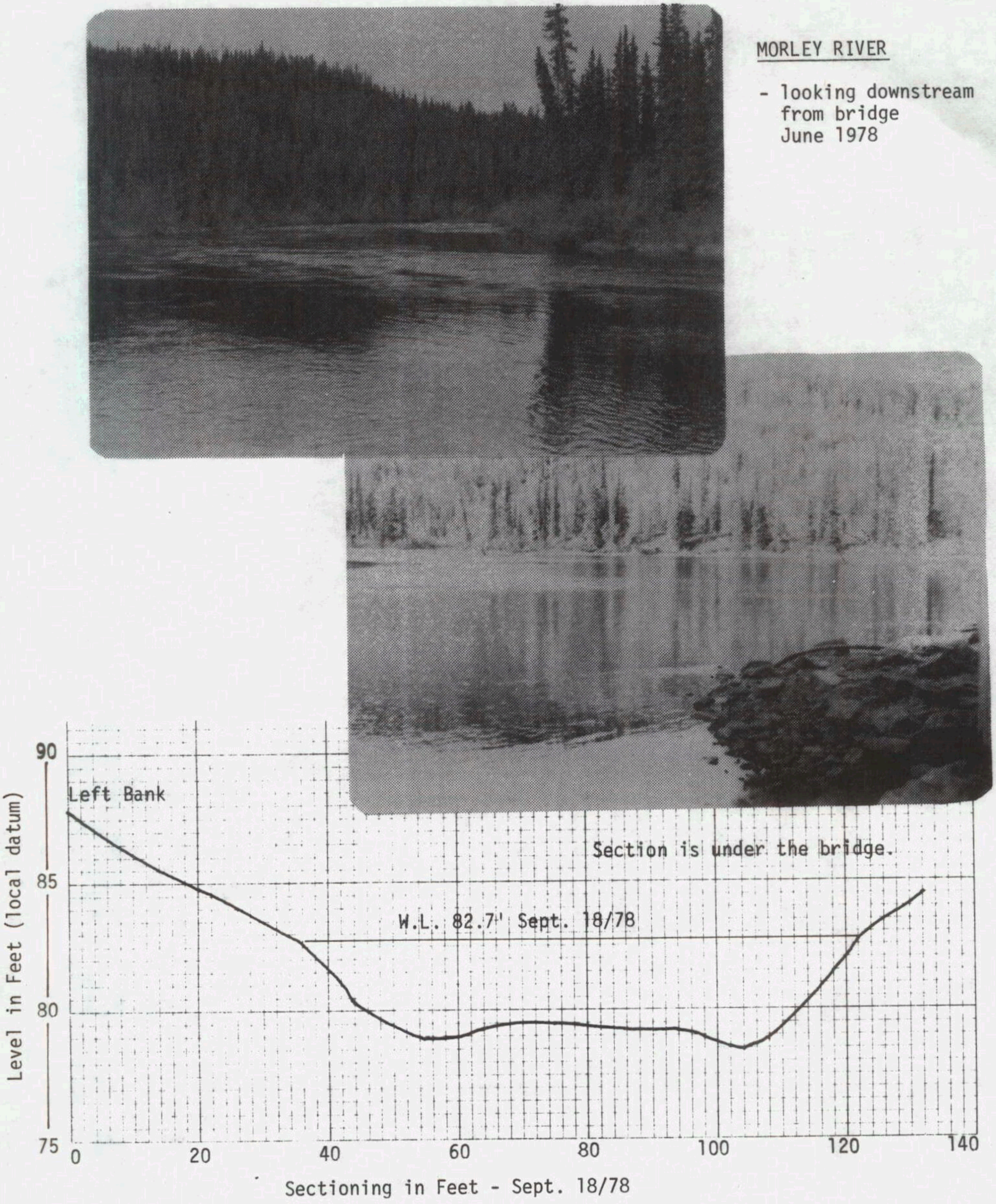


DEADMANS CREEK

- looking downstream from highway bridge Sept. 1978

B.M. - 7" spike in 10" spruce, 5' upstream of gauge, 20' inshore of right bank - 100.00' local datum.

Figure 23

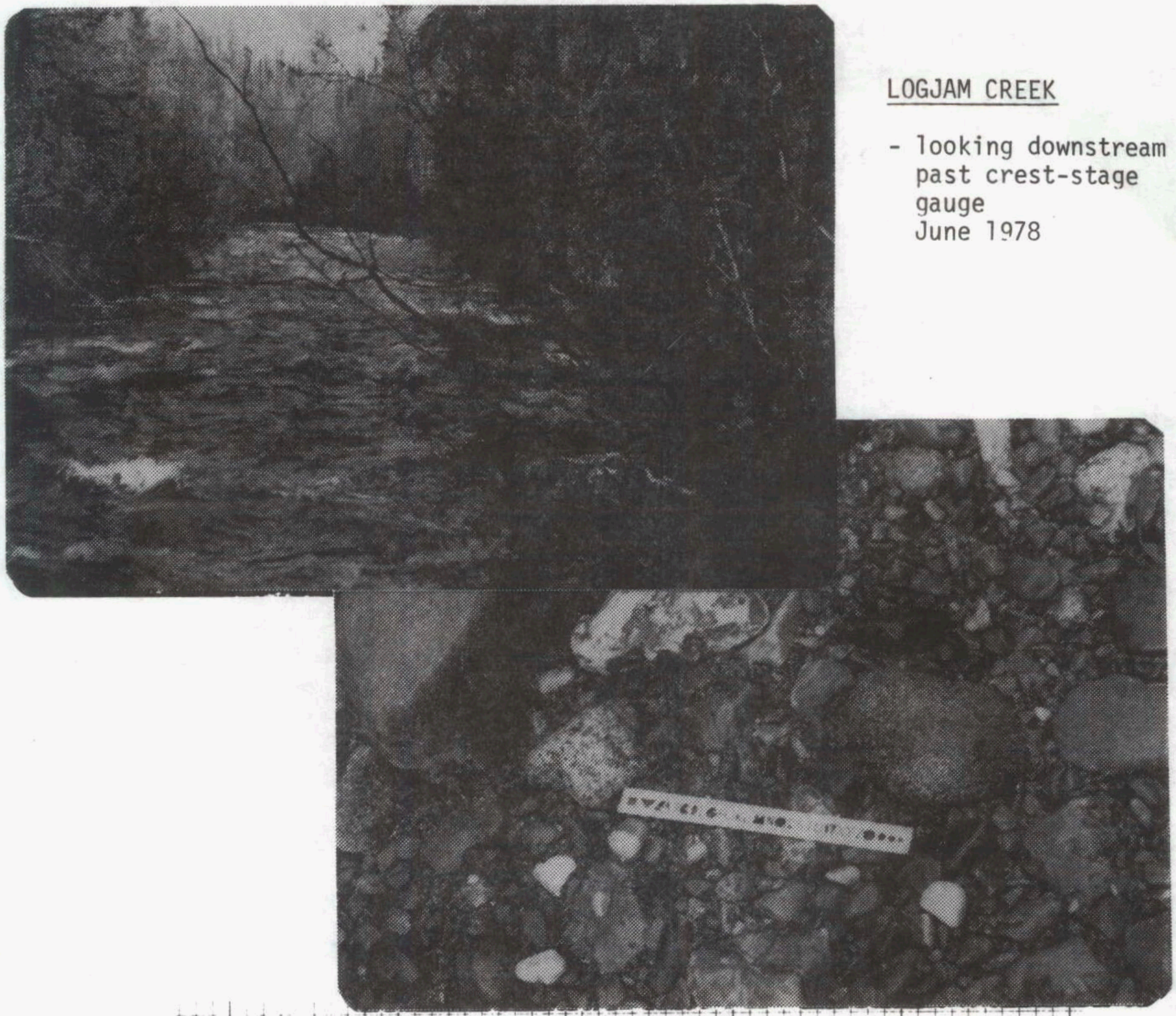


MORLEY RIVER

- looking downstream
  from bridge
  June 1978

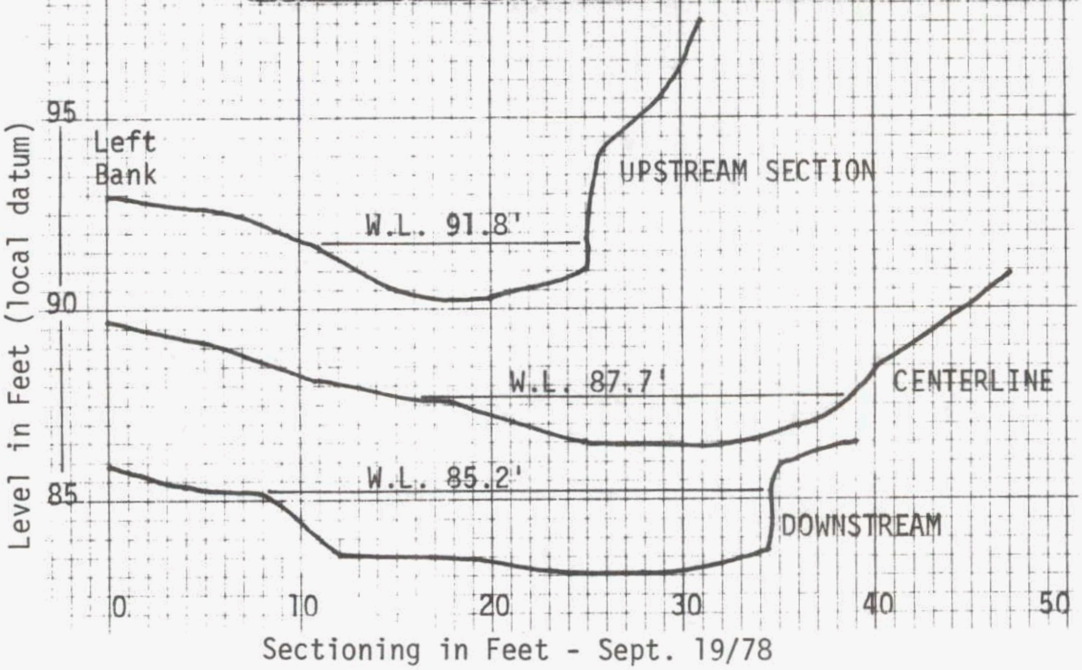
B.M. - G.S.C. 240-F - 100.00' local datum.

Figure 24



LOGJAM CREEK

- looking downstream past crest-stage gauge June 1978

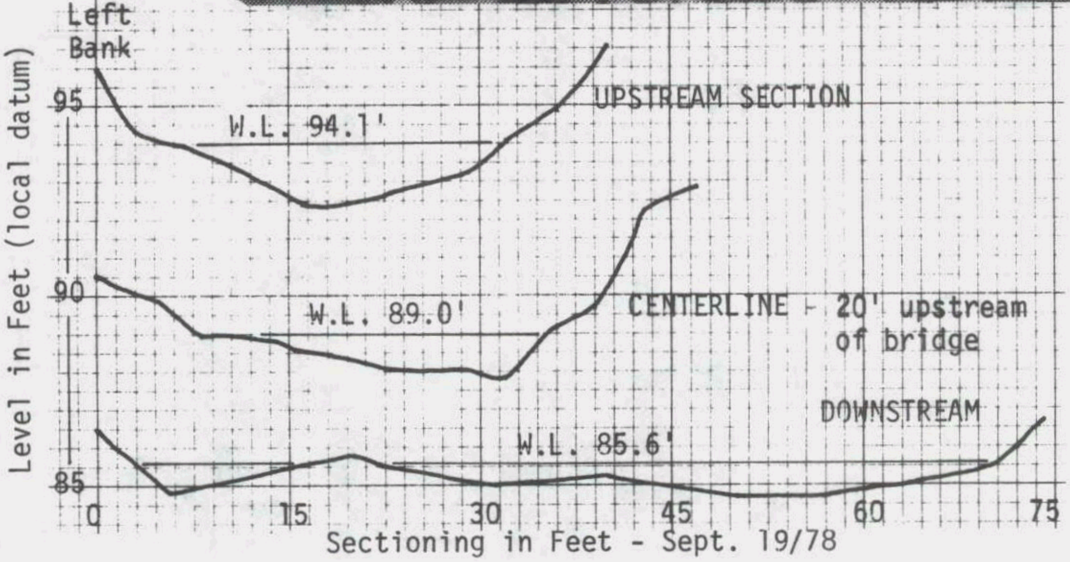


B.M. - G.S.C. 251-F - 100.00' local datum.

Figure 25

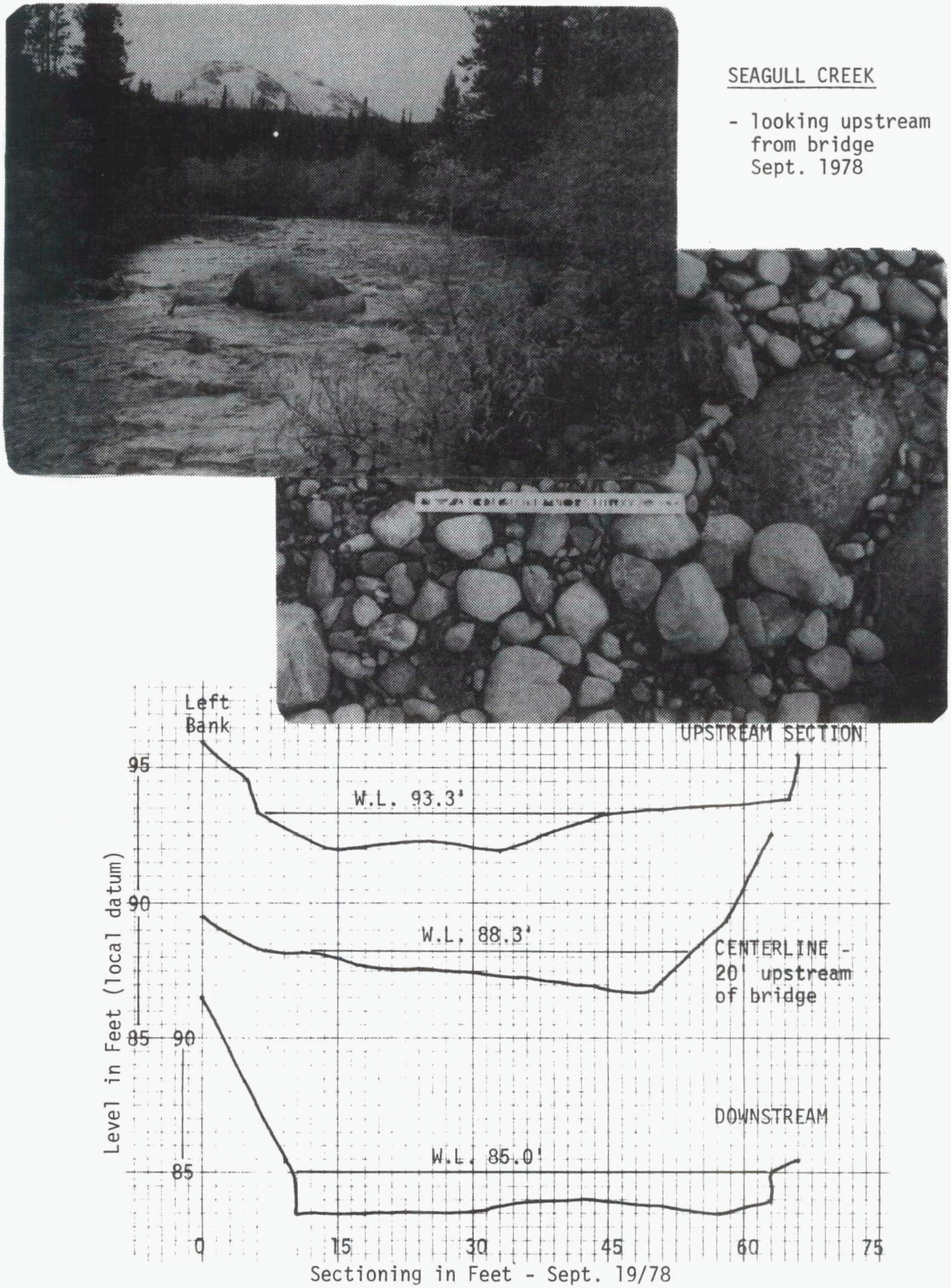
SCREW CREEK

- looking downstream from bridge Sept. 1978



B.M. - G.S.C. 255-F - 100.00' local datum.

Figure 26



SEAGULL CREEK

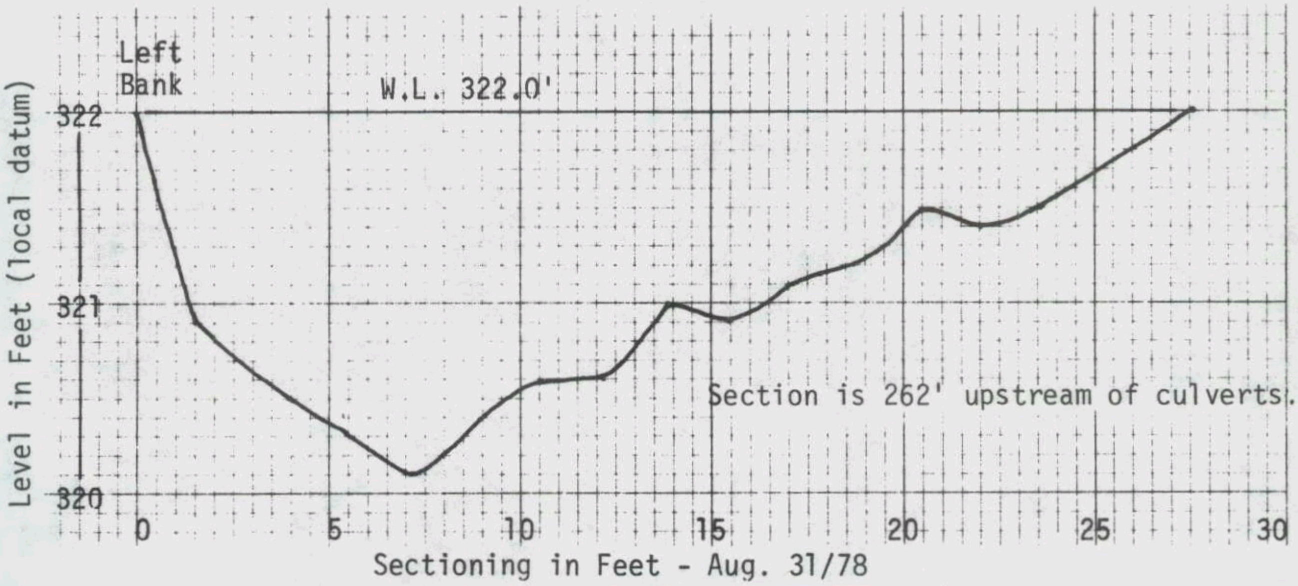
- looking upstream from bridge Sept. 1978

B.M. - G.S.C. 258-F, in top of concrete ballast wall of southwest abutment - 100.00' local datum.

Figure 27

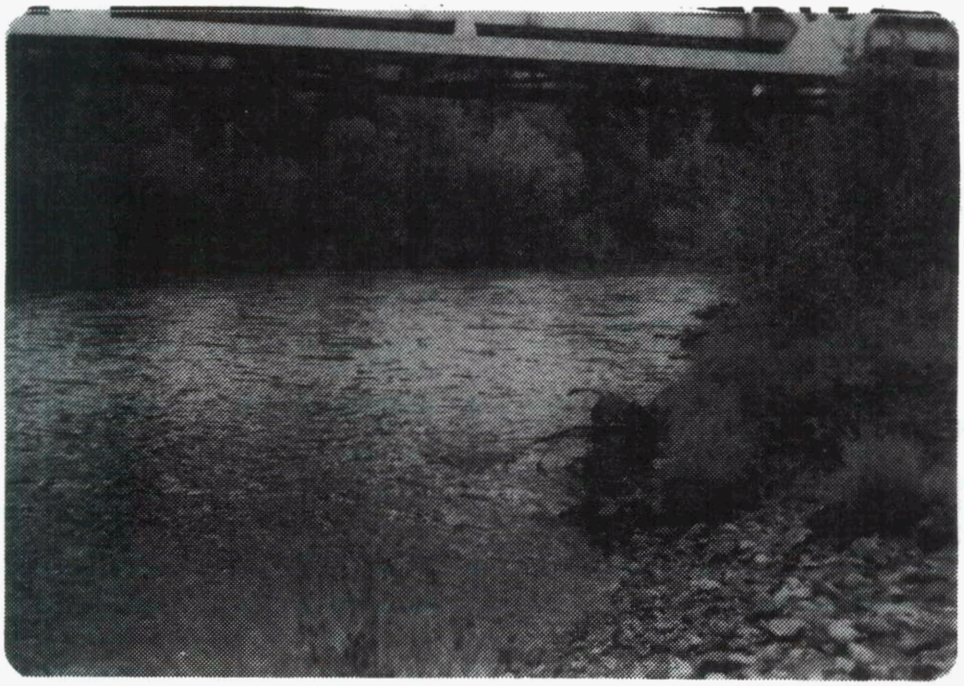
SPENCER CREEK

- looking upstream
  June 1978



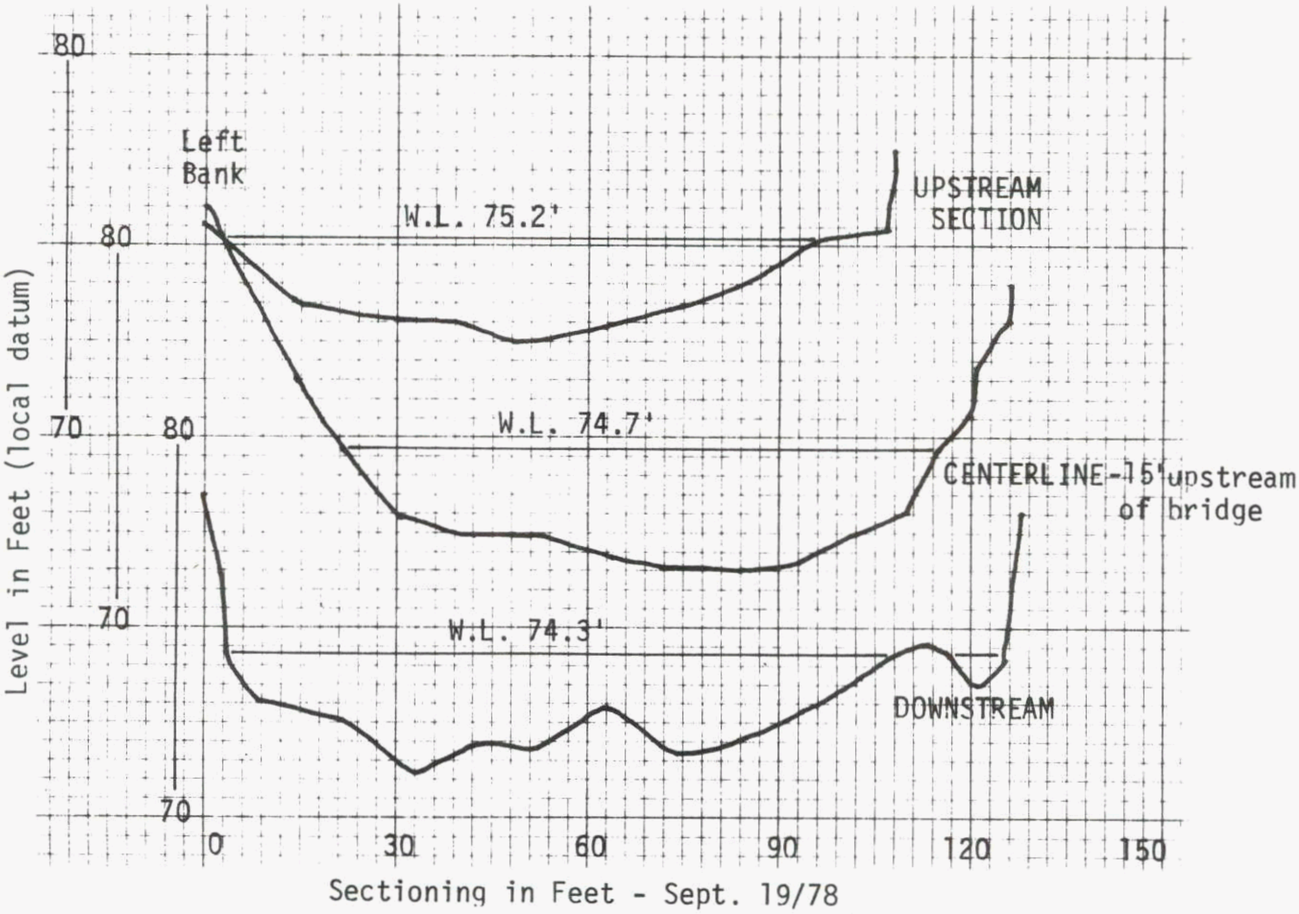
B.M. - Head of 6" spike in base of 8" poplar, 10' inshore of left bank, 650' upstream of upstream end of culverts - 328.08' local datum.

Figure 28



LITTLE RANCHERIA RIVER

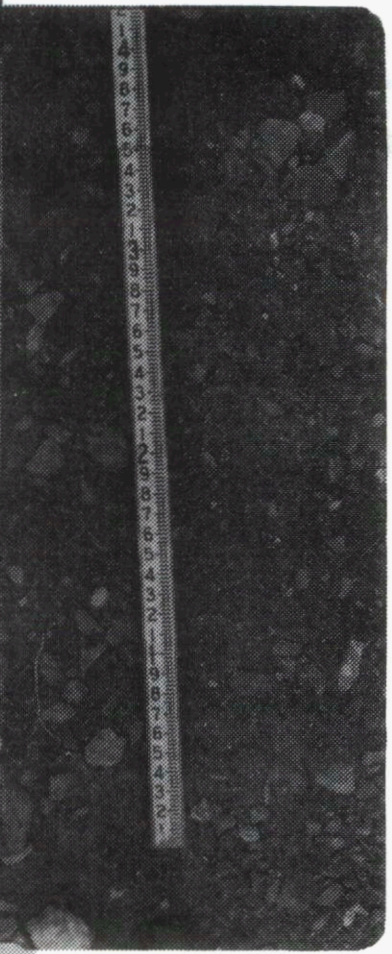
- looking downstream
  Sept. 1978



B.M. - Painted corner on upstream side of left bank abutment - 100.00' local datum.

Figure 29

Nines Creek

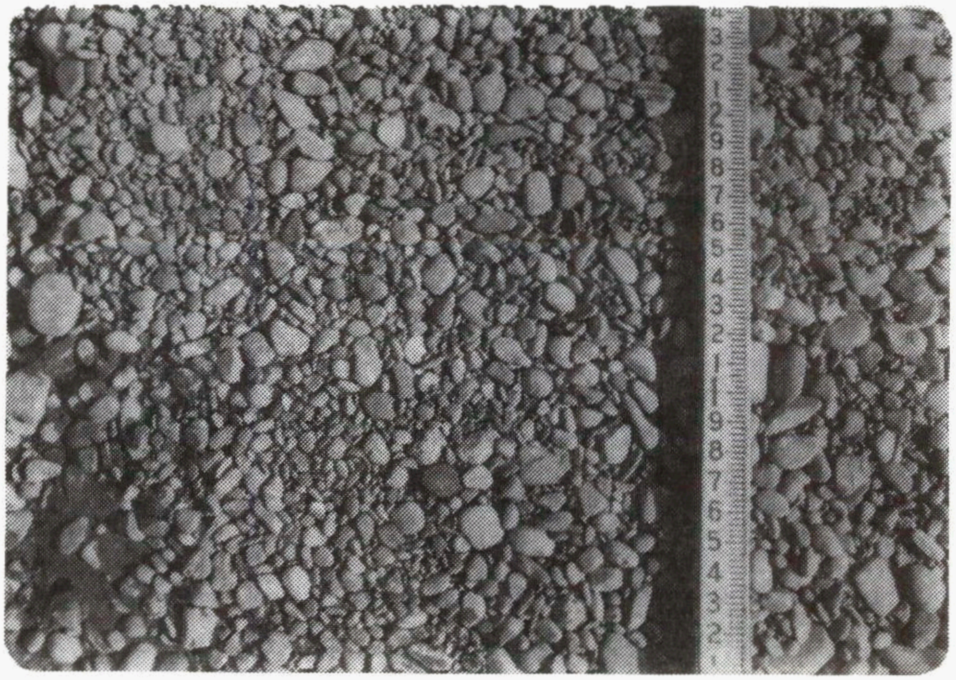


Nines Creek

Dezadeash River

BED MATERIAL - MISCELLANEOUS LOCATIONS

Figure 30

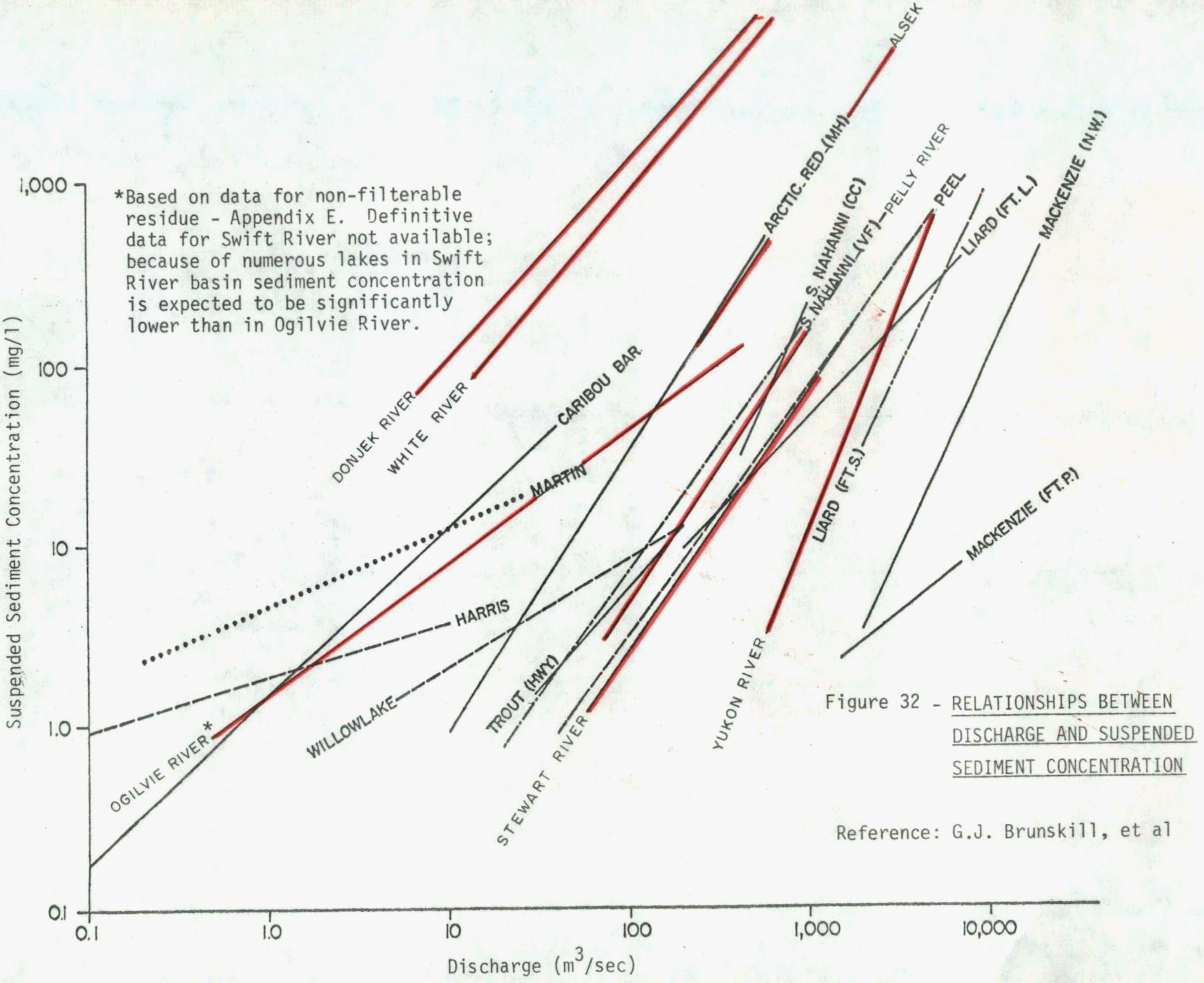


Aishihik River

Takhini River

BED MATERIAL - MISCELLANEOUS LOCATIONS

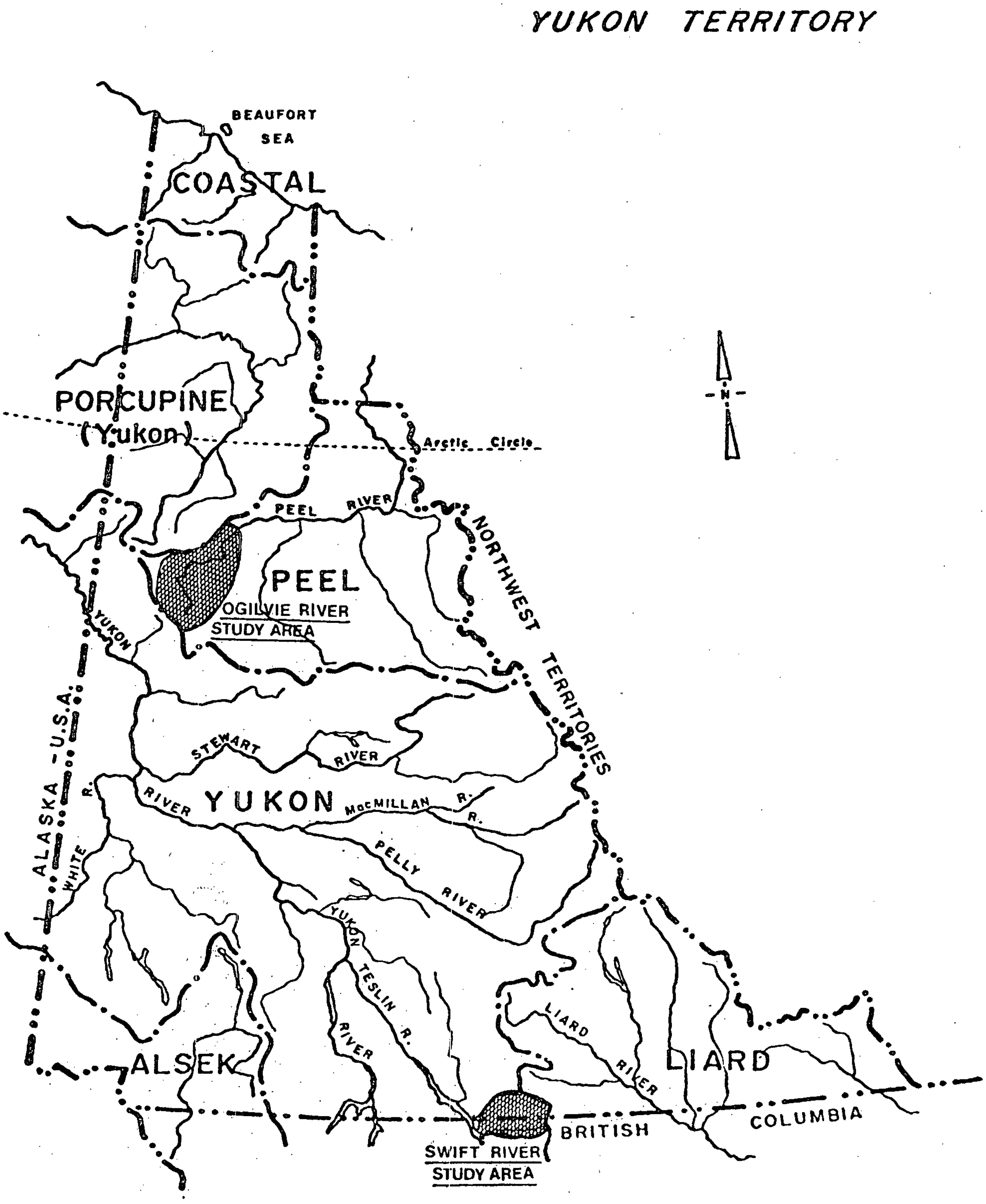
Figure 31



*Based on data for non-filterable residue - Appendix E. Definitive data for Swift River not available; because of numerous lakes in Swift River basin sediment concentration is expected to be significantly lower than in Ogilvie River.

Figure 32 - RELATIONSHIPS BETWEEN DISCHARGE AND SUSPENDED SEDIMENT CONCENTRATION

Reference: G.J. Brunskill, et al



LOCATION OF STUDY AREA

Figure 33

SWIFT RIVER DRAINAGE BASIN, YUKON TERRITORY

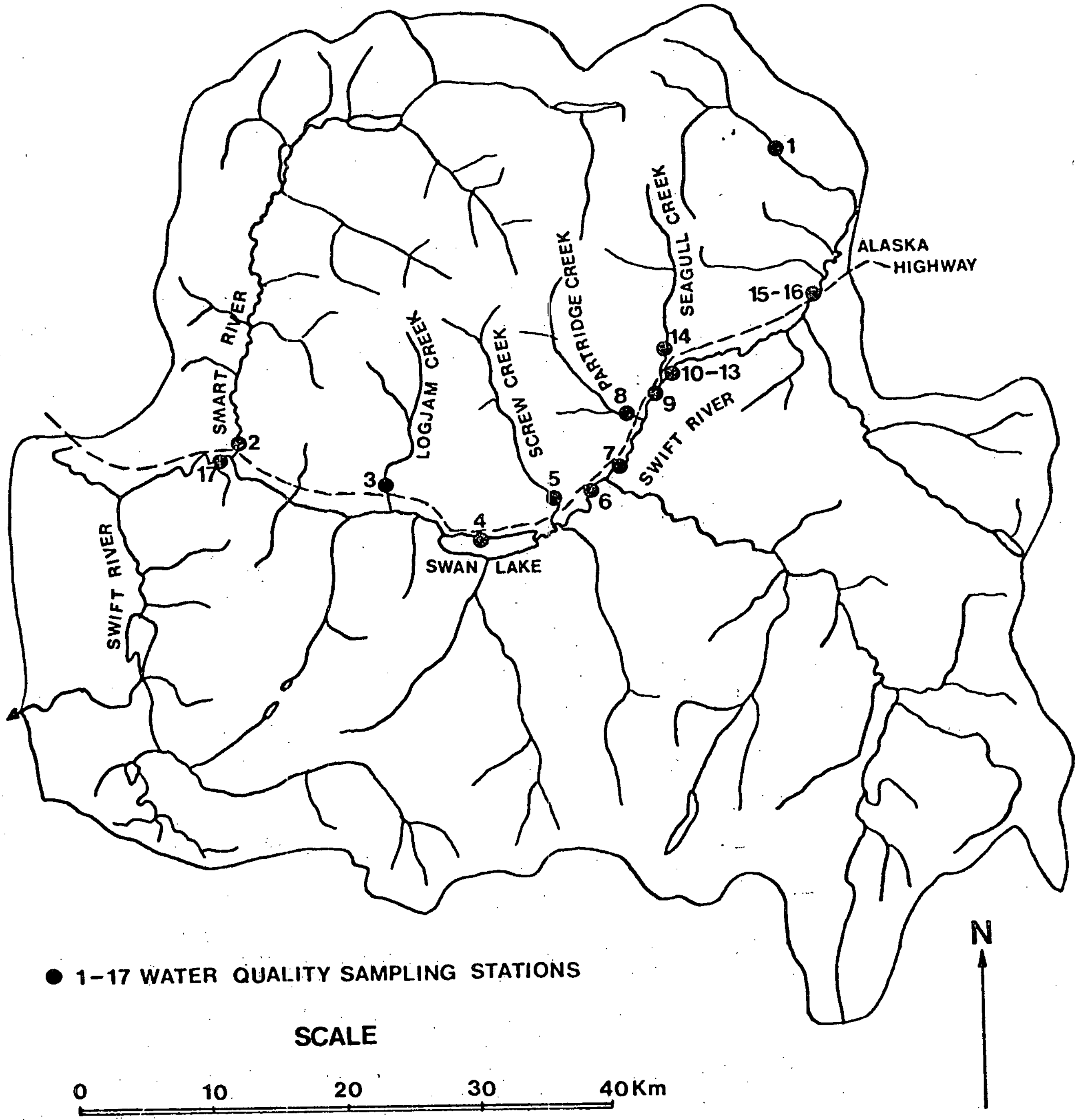


Figure 34

OGILVIE RIVER DRAINAGE BASIN , YUKON TERRITORY

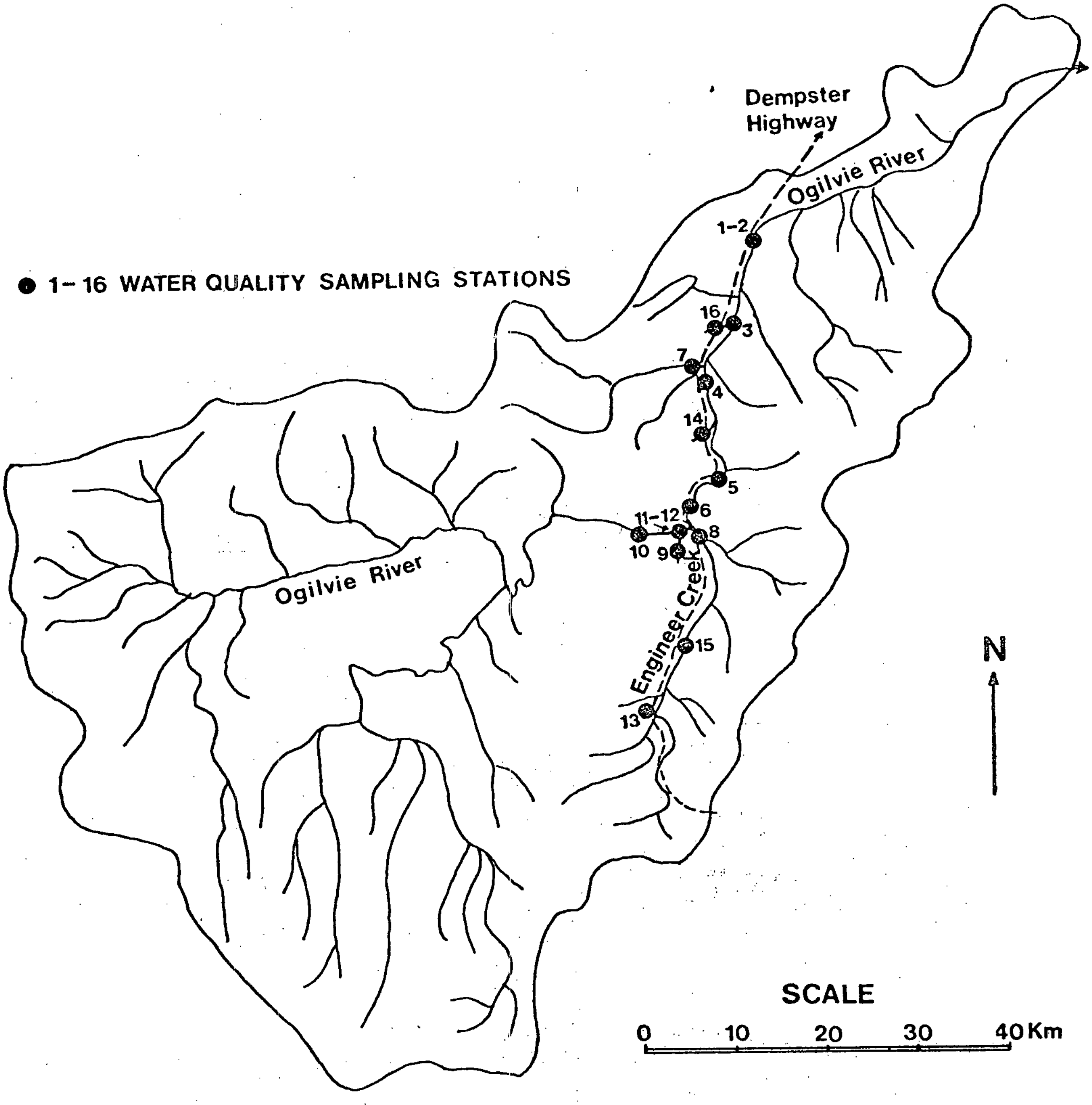


Figure 35

SEASONAL VARIATIONS IN DISSOLVED OXYGEN IN THE SWIFT RIVER BASIN, YUKON TERRITORY: 1977-1978.

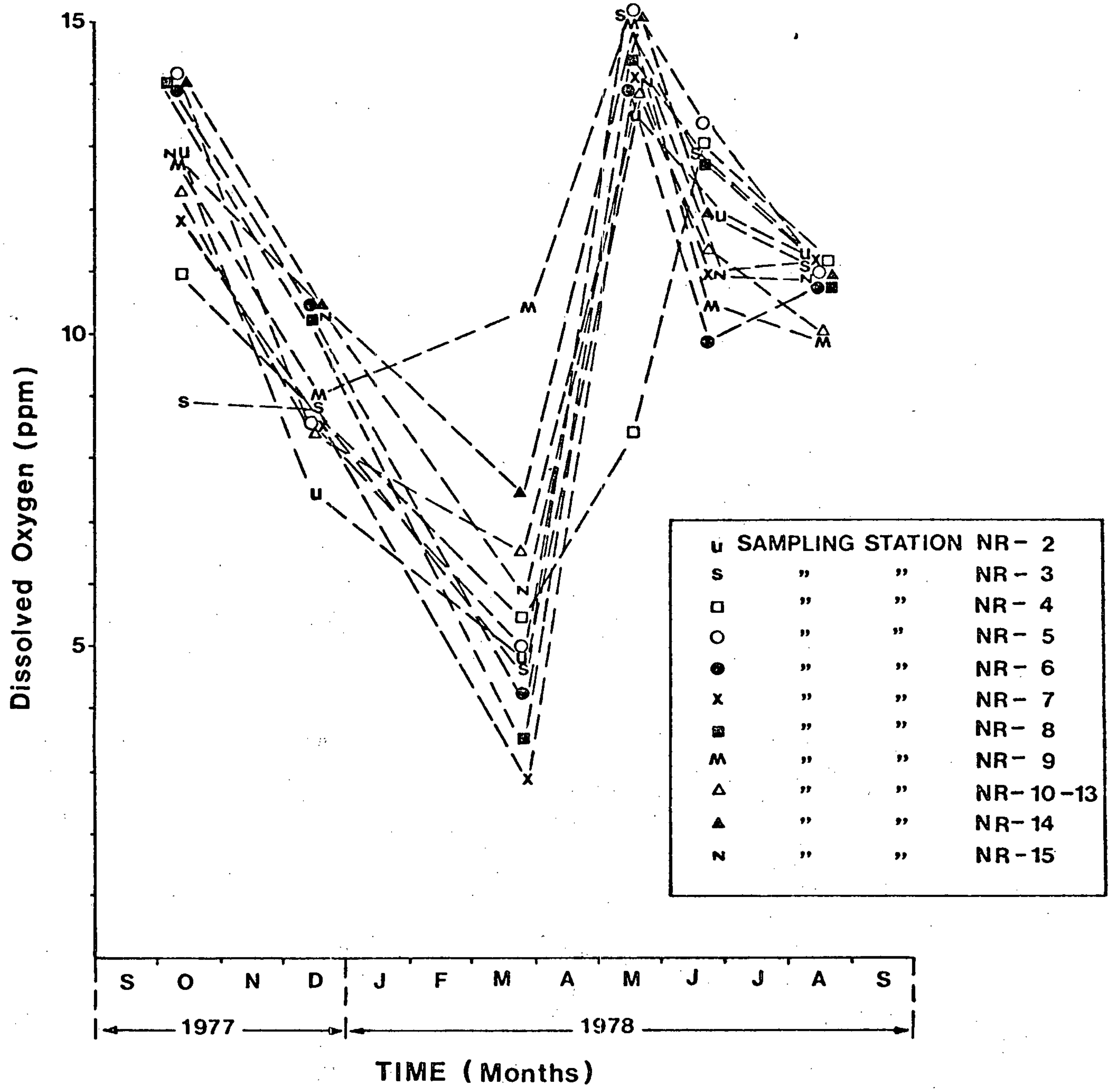


Figure 36

SEASONAL VARIATIONS IN DISSOLVED OXYGEN IN THE OGILVIE RIVER BASIN, YUKON TERRITORY : 1977 - 1978.

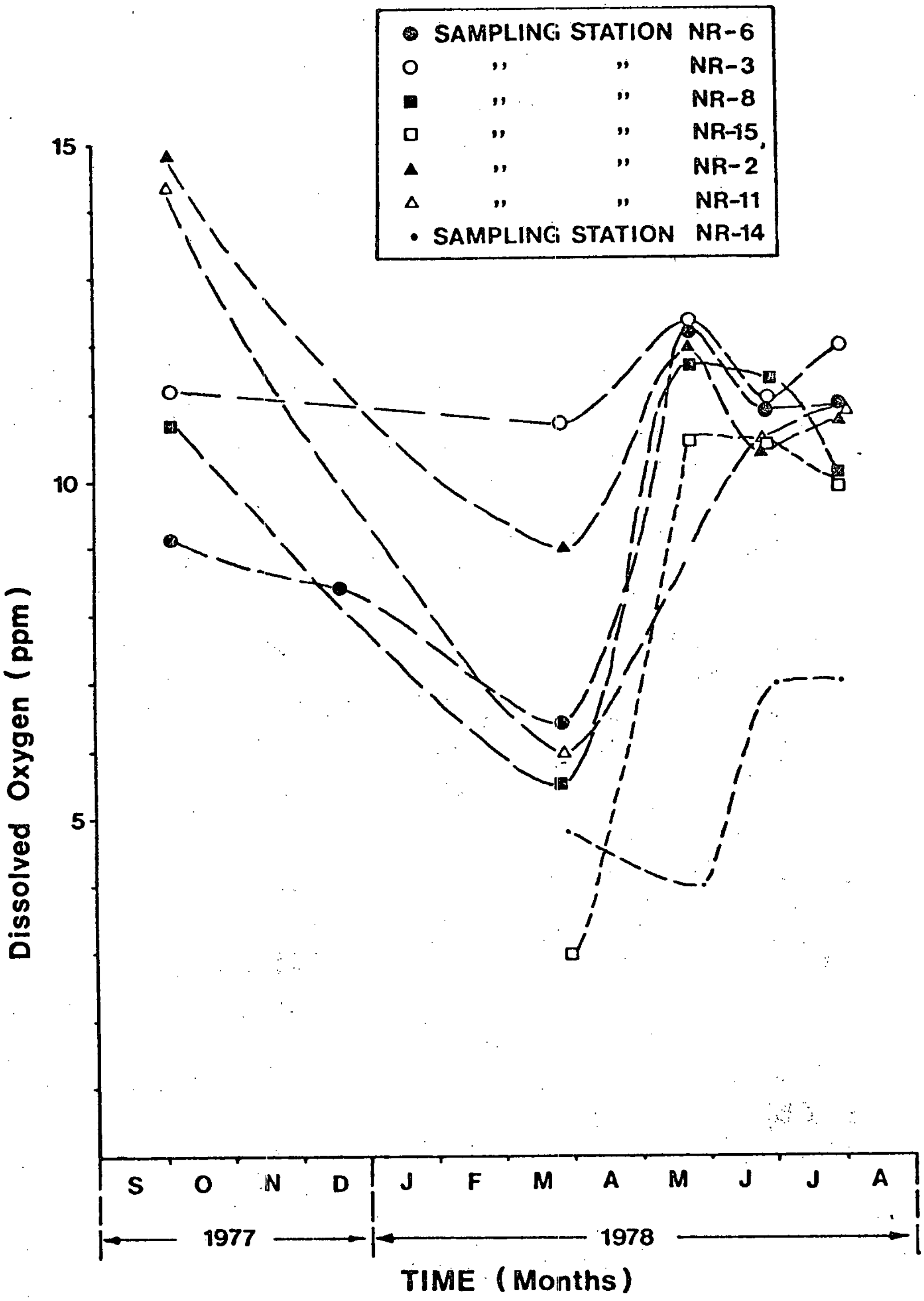


Figure 37