NORTHWEST ALASKAN PIPELINE

RIVER AND FLOODPLAINS CROSSINGS

DESIGN CONSIDERATIONS AND PROCESSES

A PRELIMINARY REPORT

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Northwest Alaskan

PIPELINE COMPANY

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A PRELIMINARY REPORT

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TABLE OF CONTENTS

VOLUME I

Page

Page

Page

1.0 SUMMARY

The following report is the second in a series of reports leading to the final design of all stream and floodplain crossings along the proposed Northwest Alaskan Pipeline Route.

The report presents the design considerations which will form the basis for developing final design criteria. The design criteria will be finalized once the stipulations of the lease and Grant of Right-of-Way have been established.

The report also outlines the design process that will be used for all major stream crossings.† The description of the design process has been separated into three major stages: Stage 1 involves development of the design criteria, basic stream analysis including office and field data collection and data assessment, and government review as necessary. Stage 2 involves preliminary design and government review and comment. Stage 3 involves final design and government approval. In-house approvals are assumed to be a part of both preliminary and final design and are included within the design process.

In Stage 1, specific field programs which must be initiated during the spring and summer of 1978 are described. This report presents their purpose, scope, description of work, manpower, scheduling, and other details pertinent to the implementation and completion of the various early field programs.

Volume II of this report contains all appendices. These include a glossary of terms, stream lists including all crossings, a list of USGS quadrangle maps covering local stream drainage basins from Delta Junction to the Yukon border, an identification of those USGS quadrangle maps covering four major drainage divisions, preliminary and partial specifications for both aerial and hydrographic surveys, and preliminary river crossing data sheets and aerial photographs. The data sheets included in the last appendix classify crossings as major or minor and give qualitative information influencing their design.

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†Major stream crossings are those where the potential for floods, scour, bank migration, or environmental damage is sufficient to require a detailed investigation and/or specific design considerations. Except for crossings of "unclassified" streams (those with drainage areas of less than a few acres), all crossings will be considered "major" until individually classified "minor." (See Section 5.1, page 53)

2.0 INTRODUCTION

The intent of the hydrologic program is to 1) gather enough data to assess hydrologic processes which could impact the gas pipeline at river crossings, 2) assemble and evaluate these data and use them to establish specific river crossing designs, and 3) provide design documentation required for the permitting processes.

To this end it is necessary to develop a reliable predictive model of stream behavior. This model must predict both the behavior of the natural stream during the large design flood and its normal behavior during the life of the project. Additionally, the model must predict the reaction of the stream to altered hydraulic conditions that may of necessity be imposed by pipeline construction.

The Northwest Alaskan Pipeline system between Prudhoe Bay and the Yukon border will cross a number of streams. Each of these crossings requires a cost-effective engineering review and design. This is the second report describing review and design considerations for stream crossings. The first report discussed the hydrologic parameters required for any general stream crossing design. The second report presents a more detailed overview of the hydrologic design of the specific crossings along the pipeline alignment. It also points out the type and amount of input needed from other design groups (e.g., geotechnical, surveying, environmental, and aerial photography) for the crossing designs. A glossary of terms used in the text is found in Appendix A (in Volume II).

2.1 Purpose

Engineering design is the product of appropriate task identification; adequate data collection; establishment of well-founded, cost-effective design criteria; and adherence to a logical sequence of design steps. The intent of this report is to outline how this principle will be applied in developing the Northwest Alaskan Pipeline stream crossings designs. Specifically, the purpose of this report is to:

1. Identify those cost-effective environmental and technical design considerations which will be used to establish the design criteria.

2. Present the sequence of activities leading to the final design including required data-gathering programs; and

3. Review all the streams to be crossed, highlighting site-specific requirements for each.

2.2 Scope

This report presents the basic work items involved in the stream crossing design for the Northwest Alaska gas pipeline. It reviews design considerations and initiates the establishment of design criteria. The design considerations will form the basis of the criteria which will be developed. The stipulations of the lease and Grant of Right-of-Way will have an influence on the finalized design criteria.

The report also outlines the proposed comprehensive field and office data collection procedure and the stream crossing design process. This design process, which consists of a series of logical steps, identifies major activities; includes a tentative classification of stream crossings; and presents qualitative crossing design information.

3.0 DESIGN CONSIDERATIONS

Good engineering design complies with pre-established criteria. These criteria are a set of rules which result in a cost-effective structure having minimal environmental impact and an acceptably low probability of failure. The importance of developing good design criteria is thus evident. Criteria are developed by recognizing conditions which could either negatively or positively influence pipeline integrity or the environment; by realizing, through experience or calculation, the extent of their influence; and by setting limits (associated with the factors considered) which, if not surpassed, assure the integrity of the design structure. The first step in establishing design criteria is the consideration of factors that will influence 1) the performance and integrity of the pipeline and 2) the integrity of adjacent structures, facilities, and property.

Those factors which must be considered in the design of stream crossings and which will become the basis for the design criteria for the Northwest Alaska Pipeline stream crossings are the design flood, design water level, design scour, design migration, river training, stream ice and drift, influence on existing structures, frost heave, and environmental concerns. Important to all these is the factor of cost-effectiveness with regard both to maintenance and initial cost. The discussion which follows elaborates on these design considerations.

3.1 Design Floods

The design of a structure or facility crossing a stream is greatly influenced by the amount of water expected to flow in that stream. This amount of water or discharge has direct influence on scour and water levels at and near the proposed structure or facility.

Depending on the type of structure, a failure will have varying degrees of impact on environmental, economic, safety, and other considerations. For this reason, not all structures are designed assuming the same design flood. That is, for example, the design flood for a pipeline may not be the same as for a bridge. For this reason the design floods for the proposed gas pipeline, access road, highway bridges, and floodplain material sites will be sized differently.

The two design floods proposed are defined below. The method of determining actual design flood magnitude is discussed in Section 4.1.1.1.

3.1.1 Pipeline Design Flood (PDF)

It seems appropriate to use a design flood of similar magnitude to that used by Alyeska. This flood is deterministically sized and does not have an associated return period. The pipeline flood is defined as "an estimate representing flood discharges that may be expected from the most severe combination of meteorologic and hydrologic events that are considered reasonably characteristic of the geographical region involved, excluding extremely rare combinations (72)." Although this is a large flood, which might imply a higher initial cost, it is recommended for the pipeline design flood because:

1. The loss of system revenue from a protracted outage at a stream crossing is very large compared to the increased costs of construction for a larger flood, especially if environmental concerns delay in-stream repairs until the following construction time-window.

2. The change in pipe burial depth at a particular unrestricted stream crossing is mostly a function of change in water depth. For any large flood on this type of stream the depth normally increases only slightly with a large increase in discharge. Therefore there is only a minimal reduction, if any, in costs for a decreased design flood size.

3. For many crossings the controlling costs will result from avoiding impact on adjacent structures, property, and the environment, as opposed to design flood magnitude.

4. Because this design flood is deterministically derived, it does not have an associated explicit return period. As such it does not psychologically imprint a "frequency of failure" and an associated environmental impact on the public mind.

5. The proposed flood is based on a concept regularly employed by the Corps of Engineers. Their flood is called a "Standard Project Flood." The use of their concept and consequent familiarity should facilitate acceptance by all government agencies.

3.1.2 Frequency Design Flood (FDF)

A 50-year flood is normally used for secondary highway bridge design (74). The stipulations will probably require use of such a design flood for permanent roads. In order to assess highway bridge impact on either gas or oil lines, bridge designs should also be checked by routing a PDF through the structure. The location of a bridge, upstream or downstream of the pipeline crossing, will influence the results of this assessment.

3.2 Design Water Levels and Velocities

Water levels and velocities are most accurately obtained by direct measurements during historic floods. However, where these measurements have not been made, the data can be approximated using hypothetical flood discharges and knowledge of the local topography. Design water levels are determined in order to provide a basis for estimating scour, determining freeboard for bridges and other structures, and defining areas where flotation control may be needed. Design water velocities are used in designing bank protection and estimating scour. As in the selection of design floods, the selection of design water levels and velocities is dependent on use.

3.2.1 Pipeline

The pipeline design water level is the level of either the pipeline design flood, spring ice jam floods, or historic aufeis levels, whichever is highest. The design water level is usually consistent with the design flood.

3.2.2 Roads

The primary design water level for permanent roads and work pads should be that resulting from routing either the 50-year flood, spring ice jams, or historic aufeis levels, whichever is greatest. The 50-year flood level is consistent with expected stipulations and standard practice for secondary roads.

3.2.3 Compressor Stations and Mainline Valve Locations

Compressor stations and mainline valves should be located far enough from streams and rivers or adequately protected so that neither their foundations nor their functions will be endangered by high water levels. Because of the importance of these facilities, the high water levels to be used in this determination are consistent with the pipeline design flood.

3.3 Design Scour

Scour considerations vary between the buried mode and the elevated mode. Buried mode considerations primarily involve the potential for pipe exposure or movement. Elevated mode scour considerations pertain to foundation undermining or movement and changes in stream alignment because of thalweg movement.

There are two additive types of scour to be considered in the design (3, 23, 34, 3 44, 45, 46, 63). The first is the general scour associated with parallel flow. The second is the local scour caused by abrupt changes in curvature of flow lines. The shapes of flow lines are affected by structures or protrusions in the stream. Pipe, pier, and abutment locations must comply with criteria related to both types of scour.

The criteria developed from scour considerations are minimum allowable depths of cover at buried crossings, and footing elevations of abutments and piers at elevated crossings. Factors that can influence scour-related criteria are 1) standard minimum depth of burial, commonly set at 4 feet, 2) codes set by the Department of Transportation for gas pipeline, 3) anticipated stipulations for this pipeline, 4) the need to ensure that no adverse influences will be imposed on existing facilities, 5) the alterations in flow conditions caused by bridges, causeways, and other works, and 6) the constructibility of the pipeline at the particular location.

Gravel removal within floodplain scour limits can control scour and bank migration (86). These changes can undermine the pipeline and other structures at river crossings and adversely impact the environment. Coordination among the stream crossing design group, the floodplain mining siting groups, and other concerned groups and agencies must be maintained.

3.4 Design Migration

Lateral stream migration is an important consideration (9) in design criteria development because it may undermine bridge abutments at elevated crossings, or expose sagbends and/or overbends at buried crossings. The solution is to design the pipeline to withstand the maximum lateral migration which may occur during one Pipeline Design Flood, or the lateral erosion that may normally be expected during the life of the project. A design to withstand one PDF is consistent with the development of the design criteria for scour. In the unlikely event that the design migration is approached, continued erosion of the bank could in some cases be prevented by placement of riprap.

3.5 Channel Control Structures

In some cases it may not be financially economical, technically feasible, or environmentally desirable to maintain the gas line at deep burial throughout the full extent of the anticipated lateral migration of the stream. In this event it may be possible to protect the pipe by means of channel control structures. These structures should be used only when the following conditions are met.

1. A specific economic analysis demonstrates cost-effectiveness.

2. The hydraulic effects on the stream do not result in unacceptable impacts on other structures or the environment (51).

3. The structures can be designed to protect the pipe and other property against the appropriate design flood. Extensive repairs after a large flood would be acceptable and must be considered in the analysis of cost-effectiveness.

4. A satisfactory method for abandonment or removal of the structures after completion of use can be developed.

5. There is continuing access for surveillance and maintenance during operation of the pipeline.

Channel control structures may be roughly divided into two groups: those designed primarily to prevent erosion, e.g., revetments, and those designed to guide the flow or promote deposition of sediment in designated areas or both, i.e., river-training structures (23, 81). The classifications may overlap. A brief discussion of the types of channel-control structures follows.

3.5.1 Revetments

Structures utilized primarily for bank protection are generally designated as revetments. There are three general types (81).

1. Blanket revetments are constructed of rock, stone-filled wire baskets, or concrete, placed to form a protective cover on the bank. Provision is usually made either to extend the blanket to scour levels or to provide for launching as the toe erodes.

2. Pervious revetments consist of open fence, pile structuring, or similar materials placed along a desired alignment, both to prevent erosion of an existing bank and to build up the bank by promoting deposition. This technique is mostly successful in streams with a high suspended sediment load.

3. Solid fence revetments consist of windrows of rock or other similar substance placed along the desired bank alignment. They may be placed either in the existing stream or along the terrace where they are allowed to slump. Solid fence revetments are usually expensive because of the large amount of rock required. Solid fence revetment designs grade into the more open type of guidebanks and revetments.

3.5.2 Training Structures

The purpose of a training structure is to guide the flow so that an effective channel will be scoured and maintained along the desired alignment. Training structures are usually more effective if they are permeable, since the permeable structure generates a turbulent zone that permits a portion of the flow and its sediment load to pass and build a deposit behind the structure (81).

River-training structures at most stream crossings along the Alyeska pipeline route have required frequent repairs. Additionally, experience gathered elsewhere, both in the U.S. and abroad, indicates river training in high bed-material load streams carries a high degree of risk (20, 30, 68, 81). Nevertheless, in some circumstances river-training structures must be utilized. Whenever they are used they will require periodic maintenance throughout the life of the pipeline. Discussed here are several general types of training structures.

1. Groins, or spurs, are short solid structures placed at approximately right angles to the bank. They are not generally recommended by the American Society of Civil Engineers as they are apt to generate more damage than they prevent (81). It is a characteristic of a groin that an eddy will form immediately downstream of its outer end. A groin must either be designed with enough freeboard to guarantee it will not overtop, or be designed to withstand overtopping.

2. Guide banks are embankments constructed more or less parallel to the stream to direct flow smoothly through waterway openings. They, like groins, create an eddy at their downstream end. They are used most successfully to guide flows through a bridge opening. They are sometimes successfully used in combination with a field of groins.

3. Pile dikes, or retards, may be either single or multiple rows of piling driven either singly or in groups into the stream-bed and connected by horizontal whalers or stringers. They generate a turbulent zone and encourage deposition of sediment.

4. Rock dikes are stone embankments, usually designed to be overtopped. Rock dikes, like pile dikes, encourage deposition. For both pile dikes and rock dikes, the action of ice must be considered. Pile dikes and rock dikes are most effective on streams with a high suspended-material load. They would not be effective on most gravel-bed streams.

All river-training structures are designed to affect the stream's prevailing hydraulic equilibrium. The effect of these stresses can sometimes be assessed by means of a mathematical model of the stream-sediment system. In some cases the effects are too complicated to model mathematically and only a physical model will give adequate results. Physical modeling is extremely expensive and requires a long lead time (probably one year). Situations requiring physical modeling should be avoided if possible.

Criteria for designing and assessing the effects of bank protection will be developed and presented in Stage 1 of the design process.

3.6 Stream Ice and Drift

There may be instances where soil type, geometry, and other conditions will render belowground installation uneconomical. In these cases the elevated mode will be used at the stream crossing. The design structures and supports for this mode must consider ice and drift conditions. The following is a review of these considerations.

3.6.1 Stream Ice

Stream ice may cause damage to pipeline-related structures or cause other undesirable results in several basic ways: ice movement during breakup, (50), ice expansion during freeze-up, main channel conveyance loss to ice anchored in the channel (32, 80), and restricted access for maintenance.

Free movement of ice in stream flow impacts exposed structures, which therefore must be designed to withstand these forces. The two most critical types of structural failure on piers are caused by ice bending and crushing. Methods of analysis are available which permit the estimation of ice forces imparted to piers. Static force conditions such as lateral forces from ice expansion during ice jams must also be considered in the design of in-stream structures.

3.6.2 Drift

Drift is the process by which any debris (usually logs and brush) is carried by a stream. When such debris is allowed to impinge upon in-stream structures, force is exerted which presents design problems. The fundamental solution for drift problems is to make bridge openings large enough to permit passage of the largest log or other debris in the watershed. This helps prevent pile-up and creation of large forces on the structure from backwater, as well as reducing the excessive scour associated with increased velocities caused by blockage of conveyance.

3.7 Influence on Existing Structures and Facilities

The proposed gas pipeline alignment will, at times, be adjacent to existing structures and facilities. This will be of particular concern because construction in a stream system may affect nearby structures. The effects may include flow regime alteration which ultimately causes erosion or deposition, either downstream or upstream from the crossing. Actual in-stream construction activity causes short-term effects, whereas the presence of in-stream structures causes long-term effects due to a change in the stream's sediment-transporting ability or resistance to flow. Procedures for assessing the effects of a crossing on adjacent structures will be developed. The effects of all construction-related activities, especially gravel mining in streambeds or floodplains, must be considered simultaneously with other assessments.

Northwest Alaskan Pipeline Company's basic philosophy regarding the installation of the gas line is that the project will not adversely affect the integrity of any existing structure or facility. Existing structures and facilities in the vicinity of the proposed pipeline stream crossings include:

1. Alyeska's oil pipeline north of Delta Junction,

2. Highway and access road bridges,

3. River-training and bank-protection structures associated with both the Alyeska pipeline and nearby bridges, and

4. Private property.

At each stream crossing, a minimum lateral and vertical spacing between the gas pipeline and existing structures or facilities will be determined so that the integrity of both the structures and the pipeline will not be adversely affected by pipeline construction and operation. The major concern is scour induced by excavating the gas pipeline ditch. The following factors must be considered in establishing a minimum spacing:

1. The mode (aboveground or belowground) of the gas pipeline with respect to the mode of the adjacent structure or facility;

2. The depth and velocity of water during construction and operation of the gas pipeline;

3. The depth of ditch required to meet minimum burial requirements;

4. The subsurface soil conditions including soil type and thermal condition;

5. The time of construction (winter or summer) and associated seasonal flood frequencies, water levels and velocities;

6. The short- and long-term changes in stream hydraulics resulting from the installation of the crossing;

7. The construction width necessary for pipeline installation and future maintenance;

8. The existing pipeline and highway river-training and bank-protection structures;

9. The location of the gas pipeline with respect to existing pipeline or bridges (upstream or downstream); and

10. The type of superstructure for existing highway and access bridges or aboveground pipeline crossings.

If river-training structures are required to protect the gas pipeline, they must not induce excessive scour or lateral erosion that will adversely affect Alyeska's river-training structures.

3.8 Frost Heave

Frost heave phenomena are important considerations which must be accommodated over a large portion of the proposed alignment. The problem exists where the pipe is buried in unfrozen frost-susceptible soils such as those existing in swampy areas and at some pipeline stream crossings.

The course granular soils anticipated at most stream crossings should not have severe frost heave problems. However, frost heave potential will need to be determined where fine-grained frost-susceptible soils are encountered. Current Northwest Alaskan Pipeline Company studies addressing frost heave problems are using computer modeling, laboratory testing, and full-scale field tests to predict the rate and magnitude of frost heave, and to establish methods to prevent it from occurring.

3.9 Environmental Considerations

Equally important with other design considerations are the effects of instream work and river training on aquatic biota and floodplain habitat (51). In assessing the impacts it will be necessary to know the existing streambed and floodplain characteristics, water quality, and biological relationships. To make certain these parameters are identified and properly considered in design, it will be necessary to maintain close liason with all environmental and technical review groups.

4.0 DESIGN PROCESS

The design process will be divided into stages so that the design of the pipeline stream crossings may proceed in an orderly and rational manner. Appropriate governmental review and input will be considered throughout the design, especially during the selection of preliminary alignment which must be established prior to initiation of the river crossing design process. This staged approach to the crossing design process is intended to facilitate coordination of the design effort and to avoid delays and additional costs caused by government rejection of basic assumptions after completion of final design. The River and Flood Plain Activities Chart, Figure 4-1, presents the various design stages. These stages are described below.

Stage 1 includes design criteria establishment, and data acquisition and assessment. Stream analyses will be made to obtain baseline data on the behavior of streams prior to construction.

Stage 2 consists of preliminary design. This is accomplished using the stream analyses and criteria developed and approved in Stage 1. Stage 2 evaluates various design alternatives based on their cost-effectiveness. A preliminary design report will be prepared and comments and review by the appropriate government agencies may be solicited. Stage 2 also includes initial application for permits from the various regulatory agencies as well as preparation of authorization-to-proceed applications.

Stage 3 will consist of the preparation of final contract drawings and specifications. These will incorporate revisions identified during the review of the preliminary design. Upon completion, final design contract drawings and specifications will be submitted to the government for permits and authorizations.

Stage 4 is the construction stage. During this period some field design changes will be necessary. The development of efficient field and office design change procedures is critical prior to the beginning of construction.

Stage 5 is the operations stage, which will require procedures for surveillance and maintenance.

Stage 6 is abandonment. Procedures will be necessary for either removing the pipeline and all related facilities or transferring maintenance responsibilities to some other entity.

RIVER AND FLOOD PLAIN CROSSING ACTIVITIES CHART

The work process in Stages 1, 2, and 3 is discussed in more detail in the following sections. Stages 4, 5, and 6 are not addressed further in this report.

4.1 Stage 1

There are three primary goals in Stage 1 of the design process. They are 1) establishment of design criteria, 2) data acquisition, and 3) analyses of streams. The following discussions address these goals. After completion of Stage 1, appropriate government review and input will be considered.

4.1.1 Design Criteria Establishment

Section 3.0 of this report presents the major design considerations relating to all stream crossings. These considerations will form the basis for development of design criteria.

The main philosophy behind the development of design criteria is the assurance of pipeline integrity, protection of adjacent property, and minimizing environmental impact. Magnitudes will be assigned to the various parameters discussed in the design considerations, thus insuring workable design criteria. These Magnitudes will be determined based on experience, field testing, government requirements, historic usage, and theoretical calculations. All magnitudes thus established will be justified in the Stage 1 report of the design process. The following discussions review the methods used to develop each criterion.

4.1.1.1 Design Floods

To optimize cost-effectiveness, the design flood size must be consistent with facility repair or replacement costs. Two basic flood sizes are proposed. The Pipeline Design Flood will be used where integrity of the pipeline and adjacent property must be assured, and a lesser "50-year" Frequency Design Flood will be used for design of less important features.

Pipeline Design Flood (PDF)

The proposed Pipeline Design Flood is derived by applying the most severe precipitation or snowmelt conditions which can reasonably be expected, excluding extremely rare combinations of events, to a mathematical model of the runoff characteristics of the particular watershed involved. It is pointed out that this flood is not developed from a classical statistical analysis of the frequency of historic floods. Sources for data used in developing the PDF, i.e. precipitation, snowmelt, and runoff, are discussed below.

1. Precipitation. The best general estimate of storm precipitation for designs of up to 400 square miles is provided by the U.S. Weather Bureau in two Technical Papers (54, 55). Additionally, precipitation and snowmelt sequences are available for floods that have been developed by the Corps of Engineers and the Bureau of Reclamation for various projects they have considered (20, 40, 52, 53, 60, 79, 83). The Hydrometeorological Branch of the National Weather Service is the federal agency responsible for developing probable precipitation for rare storms. They will be consulted for any unpublished data they may have. Data from all sources must be adjusted both spatially and temporally to fit the specific basins in question. Standard methods for such adjustments are available in the literature (74). Adjustments to published precipitation estimates will be made based on experience gained in recent years.

2. Snowmelt. For larger drainages, such as the Tanana River, the controlling flood may not be summer rainfall but rather spring snowmelt, which may be augmented by spring rainfall. Snowpack data are available from the Soil Conservation Service, of the U.S. Department of Agriculture (31) and in the previously mentioned flood studies by the Corps of Engineers. The factors causing snow melt are radiation, temperatures, albedo, winds, and rainfall. These data are available for some drainage areas in the Corps of Engineers studies already cited. Additional data have been published elsewhere (84).

3. Runoff. Mathematical models of storm runoff from a basin can be developed by a number of methods. A computer modeling method, HEC-1, developed by the Hydrologic Engineering Center (36) and adopted by the Corps of Engineers, is recommended. This modeling process consists of optimizing significant variables in a general model until a satisfactory reproduction of past flood events for drainages with known rainfall and outflow hydrographs can be obtained. The optimized variables obtained from these flood reconstitutions are then transferable to other similar drainages. This model was used by Alyeska Pipeline Service Company in deriving its design floods. It is also widely used by the Corps of Engineers and other organizations.

Frequency Design Flood

For purposes other than pipeline design, e.g., roads, bridges, and culverts, a smaller flood, based on an acceptable frequency of excedence, will be used. Various existing methods for estimating such floods have been reviewed. Critiques of these methods are presented below.

- Childers, J. M., 1970. "Flood Frequency in Alaska." U. S. Geological Survey open file report (17). This report considers flood records up to 1968 on Alaska streams and on Canadian streams draining into Alaska. Multiple regression equations for estimating flood peak magnitudes of up to 50-year recurrence intervals are presented. Drainage basin topographic and climatic characteristics, measured from existing maps, are used in these equations. The equations provided in the report have large standard errors, which are attributable to 1) the short period of record available and 2) the study's treatment of the entire state of Alaska as one hydrologically homogeneous area. Although this method is superior to others presently available, the large standard error precludes its use along the proposed gas pipeline route unless a substantial safety factor is applied. However, the USGS is currently updating this flood frequency study, regionalizing Alaska and using the currently available data. This study may be adaptable to our use if completed before initiation of the stream crossing design process.

- Berwick, V. K., Childers, J. M., and Kuentzel, M. A., 1964. "Magnitude and Frequency of Floods in Alaska, South of the Yukon River." U.S. Geological Survey. A study by the index flood method which graphically relates mean annual flood to drainage area for an average regionalized frequency curve. The method presented is not applicable north of the Yukon River. Further, the Geological Survey has recommended this method no longer be used.

- Michael Baker, Jr., Inc., Sept. 1970. "Drainage Report No. MB5 for TAPS." Michael Baker, Jr., Inc., Jackson, Mississippi. This study provided the methodology used by Alyeska Pipeline Service Company for developing design floods for culverts and bridges on its project. It is based on criteria suggested by the Bureau of Land Management, U.S. Department of Interior. The method is not statistical and no measure of its reliability is available. It uses the Chena River at Fairbanks as an index stream and adjusts this frequency curve arbitrarily, considering drainage areas, precipitation rates, and local geography. The method has not been reliable, and on the North Slope has in many cases provided an insufficiently sized design flood. This method was developed prior to publication of the statistical regression method proposed by Childers.

A method of regional frequency analysis will be adopted, consisting of a statistical approach in which data are analyzed by a multiple regression model. Most of the data required as input to this method are already available from existing records. The results are used to develop a relationship between existing regional frequency statistics and measurable map variables. An efficient method of determining the calculated statistics has been developed by the Hydrologic Engineering Center of the Corps of Engineers (39).

The major work effort in utilizing this statistical approach consists of updating flow records and preparing computer input. There are distinct advantages associated with this method. These are 1) the use of additional records now available since the completion of earlier studies and 2) the use of a hydrologically more homogeneous area.

Glacier outburst floods (jökulhlaups)

The presence of glaciers within a watershed can have a considerable effect on stream flow. One of great significance is the occurrence of glacier outburst floods, or jökulhlaups (the Icelandic term). These are caused by the sudden and occasionally catastrophic release of water impounded by ice ( ). The magnitude of these events varies but it is not uncommon for peak discharge during a jökulhlaup to greatly exceed a rainfall flood in the same watershed.

Glaciers are dynamic ice masses which constantly change their size and shape. Some glaciers, particularly surging glaciers, are more dynamic than others and have actually been observed advancing in excess of several hundred feet per day ( ). As a result, the formation of glacial lakes and other possible adverse features is often accelerated and lakes may form where none existed before. During its existence a glacial lake may go through many cycles of filling and discharging. The magnitude of these discharges is usually proportional to the accumulation period. This period may vary from a few days to several years.

The available literature ( ) does not indicate any glacier-dammed lakes threatening the proposed gas line route in Alaska. However, a field investigation to determine whether new lakes have formed or are likely to form along the alignment will be made, and recommendations will be offered on continuing investigations during the life of the project. If a potential danger exists, a method for estimating peak discharge rates will be developed.

Seasonal flood variability

In some cases, construction timing may be influenced by seasonal flooding. A review of expected seasonal flood sizes for certain streams will be required. This study is elementary and will utilize many of the data developed in the Frequency Design Flood study.

4.1.1.2 Flood Levels and Velocities

Flood levels and velocities will be determined for all stream crossings as they now exist, prior to pipeline construction. Typically, this will be done by means of a rigid-bed step-backwater process using the appropriate design floods and channel geometry as input. This will provide a design water surface and average velocities at each cross section location. The design levels will be field checked against the known flood levels (evidenced by high water marks). In a few areas, because of extensive stream alteration due to gravel mining or river training, the assumption of a rigid bed may not be warranted. In these areas a movable-bed model such as HEC-6 (38) would be used. HEC-6 raises and lowers the bed elevation by eroding and depositing material in accordance with the stress imposed by a hydrograph. This method will not be routinely used because of the great amount of basic data input required. It will be used only where large changes in channel geometry are anticipated.

The water levels resulting from ice jams or aufeis will be determined on the basis of the evidence available and the application of hydrologic engineering judgment. No reliable analytical method of estimating future aufeis levels exists at this time. However, it is known that ice jam levels tend to reach a limiting height slightly above the first floodplain terrace, and this limit is reached when sufficient conveyance around the ice jam is developed in the floodplain.

4.1.1.3 General Scour

It is difficult to analytically define the processes affecting sediment transport. These processes include scour, deposition, and lateral migration. The difficulty arises from the large number of inter-related variables affecting the behavior of stream channels. Because of this complexity no single method of estimating scour should be accepted. It is felt that scour should be estimated by a reconciliation of the four independent methods discussed below. It is noted that not all methods will apply to every stream, and that the method most applicable for each stream should be more heavily weighted in making the reconciliation.

1. Armor Development Method. A limitation on the depth of a stream may be imposed by the development of an armor layer on the bed. This layer forms when the drag force of the flow is not sufficient to remove the coarsest particles available. If the bed material consists of uniform grains, the critical shear stress

which the bed can withstand is given by Shield's entrainment function. If the bed is non-homogeneous and a sheltering effect is provided to smaller particles by the larger particles, the relationship becomes more complex. A number of procedures are available for estimating flow depth for a given bed material distribution and energy grade line (22, 29, 81, 64). All require application by an experienced hydraulic engineer. A formal procedure for estimating depth considering armoring will be developed.

2. <u>Regime Formulation Method</u>. The regime formulation method of estimating scour traces its origin to British engineers who in the late 19th century were designing and operating irrigation systems in India (81). They observed that channels constructed in alluvium tended to adjust their boundaries until a stable relationship involving depth, bed material, and velocity of flow was obtained. Canals that achieved this state were said to be "in regime." Engineers later attempting to apply these relationships to natural streams (3) found the major difference between a natural stream and an irrigation canal is that stream flows are highly variable, whereas irrigation canals tend to operate at a fixed discharge. Application of regime formulations are highly judgmental. The American Society of Civil Engineers (81) holds that "in general they are applicable only to flows at low Froude numbers, in the ripple-dune regime." Nevertheless, regime relationships, although not precise enough for design, yield a good overall check on scour. A procedure for estimating scour by regime relationships will be developed.

3. <u>Sediment Transport Relationship</u>. Methods have recently been developed which allow efficient modeling of the interactions among bed material, suspended sediment, velocity, and depth. These methods, which consider complete hydrographs and a long reach of stream, require large amounts of basic data computer time. If used, they would probably be limited to reaches that are too complicated to be reliably analyzed by simpler means. At the present time the most efficient means of applying these methods is through the use of the HEC-6 computer program model (38). This model is best suited to studying the long-term trends of scour or deposition in streams, considering changes which would result from encroachment within floodplains or gravel removal from streams.

4. <u>Evidence of Historic Scour Limits</u>. Evidence of scour limits during large floods can often be found. This evidence may consist of the following:

   a. Buried organic material may be found in boreholes.

b. Alterations of minerals in the alluvium resulting from scouring during large floods may be observed.

c. Armor layers resulting from old floods may be observed in scour holes, test pits, or sometimes in boreholes.

d. In some coarse-bed streams evidence of scour depths and armor layers may be visible at selected locations.

This evidence must be carefully correlated with that developed by analytical methods. Instructions for those logging boreholes and performing field hydrologic investigations will be developed.

4.1.1.4 Local Scour

Some of the above methods can also be used to predict scour in a limited constriction. None of them, however, can be used to predict scour caused by abrupt distortions of flow lines around bridge piers or other structures. This local scour is additive to the general scour and is more difficult to assess. Extensive literature exists (22, 35, 58, 81) and a scour assessment program best suited to the particular problems will be developed.

4.1.1.5 Lateral Migration

An alluvial stream is constantly changing its position and shape due to its own hydraulic forces acting on its bed and banks. Changes may be slow or rapid and may evolve naturally or result from man's activities. Streams are the most actively changing of all geomorphic forms. In alluvial streams it is the rule rather than the exception that banks will erode, sediment will be deposited, and floodplains will be modified with time.

Lateral erosion rates are highly variable; that is, a stream may maintain a stable position for long periods and then experience rapid movement. Most floodplain changes occur during major floods.

The design of pipeline crossings will take into account the lateral migration that might occur during the life of the project. This is accomplished by identifying the past migration for the reach of stream in question. Past lateral migration can be estimated by:

1. Comparison of historic air photos and maps (a),

2. Studies of the age of vegetation,

3. The accounts of residents and records of highway departments.

Review of the above information can indicate future migration trends with regard to directions and rates of movement. Stream alteration, caused by riparian material sites and channel control structures, must also be considered.

4.1.1.6 Channel Control Structures

An important design consideration is where and when to use channel control structures for the protection of stream banks and the pipeline from lateral migration. These structures can be used when all of the conditions set forth in section 3.5 of this report are met. If channel control structures are used, criteria must be established for the amount of freeboard above the pipeline design flood level or maximum recorded aufeis level, whichever is greater. The top width of the structure should be adequate to allow for maintenance equipment and for increasing the structure's height if necessary in the future. Riprap and filter blankets should be sized in accordance with currently existing Corps of Engineers criteria. Spacing criteria will be based upon the intended purpose of the structure.

4.1.1.7 Stream Ice and Drift

At each proposed aboveground stream crossing an analysis will be made to determine the characteristics of the stream in its natural state, or, if structures are in use, in its guided state. The analysis will include a general study to establish the nature and extent of ice conditions in the area. This evaluation will require information from various design considerations, e.g., the design flood, water levels, cost, etc. The primary concern is the maximum thickness of ice development in the stream.

Criteria will be established for drift forces and supports subjected to these forces will be analyzed accordingly. At each proposed aboveground stream crossing, analyses relevant to drift and ice conditions will be made.

4.1.2 Data Acquisition

The design of a pipeline stream or floodplain crossing requires the collection and analysis of hydrologic, hydraulic, sediment, topographic, and geomorphic data. Many data are currently available but additional data are required for basic stream analyses. Field programs have been proposed to collect these additional data. A Data Acquisition Checklist seen in Table 4-1, summarizes all data which will be collected for use in assessing design floods, water surface profiles, scour and lateral erosion.

Both field and office data need to be collected for input to stream crossing design. Field data not currently available will be collected during proposed field survey programs outlined under Section 4.1.2.1. Sources for required office data, including those related to drainage basins, stream flows and floods, meteorology, geology, geomorphology, and environmental considerations are outlined under Section 4.1.2.2.

4.1.2.1 Field Data Collection

Considerable field data must be collected in order to complete the preliminary design of the stream and floodplain crossings. Field data collection will require a number of field surveys to be conducted during the springs and summers of 1978 and 1979. This will require a well-coordinated field survey effort in order to collect the necessary data within the required time. The proposed field work includes the following:

Ice and Pre-Breakup Survey

Breakup Survey

Panel Marker Installation

Hydrologic Survey

Ground Topographic Survey

Stream Crossing Subsurface Investigation

Aerial Photography Survey

This work is described herein. For each program, the purpose, scope of work, description of work, manpower, and scheduling are presented.

The ground topographic and aerial photography surveys will require the involvement of subcontractors. The ice and pre-breakup survey, the breakup survey, panel marker installation, and the hydrologic survey can be accomplished with in-house personnel.

Ice and pre-breakup survey

Aufeis, stream ice, and drift considerations are essential in the design of both belowground and aboveground crossings. At many of the

TABLE 4-1. DATA ACQUISITION CHECKLIST

DATA SUBJECT	OFFICE ACTIVITY	RELATED FIELD ACTIVITY
1. Hydrologic Data	Obtain and organize maps, charts, reports, and photographs of: Drainage basins and areas Stream miles Local relief Run-off characteristics Landforms Soil characteristics	Investigate changes since mapping.
	Obtain original and as-built drawings of existing crossings, bridges, and other structures. Note their dimensions and grades; also their performance records, construction, and modifications.	Verify dimensions and grades. Check local evidence of and reasons for repairs and modifications. Look for scour or failure at their foundations.
	Obtain water level and discharge records from regional hydrometric stations.	Check local evidence of high water and diversion. Look for scour signs, armour layers bypass channels, etc.
	Obtain record flood levels and discharges. Check if scour records are included.	
	Obtain existing regional frequency procedures as well as procedures for obtaining deterministic floods.	

TABLE 4-1. (Continued)

DATA SUBJECT	OFFICE ACTIVITY	RELATED FIELD ACTIVITY
	Check meteorologic data for snowpack depths, precipitation intensities and duration.	
2. Local Stream Crossing Topography		
A. Ground Surveys	Use airphotos to lay out areas to be investigated by field crews. Identify property liable to be affected by backwater or scour. Identify main overflow routes.	Survey stream cross sections. Take photographs of the streams, covering areas of interest. Measure stream depths along thalweg and its lateral location within the stream. Estimate stream roughness. Measure channel slopes. Identify main overflow. routes.
B. Aerial Photography	Delineate area of photographic coverage, and contour interval required.	Fly aerial photography at crossings delineated during the office data collection.
3. Ice Conditions	Obtain dates of freeze-up and breakup. Acquire aufeis development information and behavior of ice jams. Gather ice thickness and ice temperature records. Check meteorologic records for temperatures, winds, melt seasons.	Conduct pre-breakup site investigations. Estimate aufeis and stream ice levels, delineate potential aufeis sources, identify damage to existing structures, estimate ice thickness.

TABLE 4-1. (Continued)

DATA SUBJECT	OFFICE ACTIVITY	RELATED FIELD ACTIVITY
4. Drift	Check highway records for any evidence of damage to structures due to drift.	Identify evidence of drift, debris type and size, and its effects on the stream and existing structures.
5. Geotechnical	Get information from past well logs, boring logs, and laboratory test results; also from excavations and borings associated with the construction of past structures. Type of structure foundation will reflect subsurface conditions.	Sample bed material. Locate and classify any armor layers. Describe outcrops. Take core samples to investigate subsoil below maximum anticipated scour depth.
6. Channel Processes, i.e., migration, aggrading, degrading	Compare maps and photos from different years for evidence of channel-shifting trends, movement of bars, and banklike migration. Seek reports from other parties of past erosion.	Measure scour at bends and confluences. Investigate bed forms, aggradation and degradation trends.
7. Land Usage	Determine existing usage from real estate and state records and future usage from Alaska State permits office.	Check existing usage by inspection, e.g., unrecorded mining operations.

TABLE 4-1. (Continued)

DATA SUBJECT	OFFICE ACTIVITY	RELATED FIELD ACTIVITY
	Investigate operating procedures and capabilities of existing structures.	
	Investigate proposed future gravel mining.	
8. Environmental	Review data to determine fish migration timing, and spawning, overwintering, and rearing areas; waterfowl nesting areas; raptor nesting areas; historical and archeological sites; and aesthetically important areas.	Make field observation of all those items anticipated by office review.

major crossings where structures such as pipelines and highway bridges now exist, some ice and breakup data have been collected by Alyeska and others. However, there are many crossings where no information is available regarding ice forming processes and in addition, where the proposed gas line is aligned in close proximity to the oil line, it is prudent to consider the effects the Alyeska line has had on the ice conditions. This will be the first winter season in which the relatively warm oil pipeline has had an opportunity to affect water movement and ice formation. Speculation on these effects has existed since the original concept of a buried warm oil line was presented; and until the oil line attains its maximum flow rate, these effects will not be fully realized. It is expected that changes in the ice conditions induced by the construction and operation of the Alyeska line may become important design considerations for the gas pipeline.

The purpose of the survey is to collect data on ice and breakup conditions which will provide input for both preliminary and final crossing designs. The spring 1978 survey will also provide data necessary in planning a more extensive 1979 pre-breakup survey. The scope of the work involves:

- A hydrologic survey team visiting all significant stream and floodplain crossings from Prudhoe Bay to the Yukon border to observe and collect data on stream ice, aufeis, and pre-breakup conditions.

- Preparation of an "Ice and Pre-Breakup Data Report" which will be used in the development of preliminary crossing designs.

At each significant stream crossing where ice conditions may affect the design of the crossing, the survey team will:

- Look for evidence of aufeis buildup in the vicinity of the stream crossing.

- Determine, if possible, the aufeis top profile, extent, and possible source.

- Indicate required cross section locations in critical aufeis development areas. These cross sections will be made during the ground topographic survey program. Cross sections are for thickness and volume determination.

- Flag stream ice and aufeis levels in the vicinity of each crossing. Ground surveys will later determine the elevation of each level flagged.

- Take site photographs and complete field notes of conditions which exist at each significant crossing. Particular attention will be given to potentially explosive ice mounds (naleds).

The survey will occur prior to breakup in 1978 and 1979 and will take approximately one to two weeks to complete. A data report will then be prepared and, unless activities during breakup interfere, should be presented approximately eight weeks later.

Breakup survey

The purpose of this work is to investigate high stream flows resulting from spring breakup. These flows, along with high August flows due to rainfall, are the maximum flows experienced by streams throughout the year. Observation of these flows will greatly increase understanding of how specific streams behave under potential flooding conditions.

The survey will be conducted both from the air and from the ground. The scope of work includes aerial reconnaissance and photography of selected stream crossings along the gas pipeline route. A breakup report will present the data collected.

High water levels will be photographed and overflow channels noted. When possible and necessary, the aircraft will land for on-ground observations. References to water elevations will be made for later ground surveys. From the Tanana River to the border, ground transportation will be used. Breakup conditions will be observed and recorded at selected stream crossings, particularly where there are bridges, aboveground pipeline crossings, or river-training structures either existing or proposed.

The breakup survey initiates the field run-off data collection effort. As the program develops, crews will be expected to respond on short notice to measure breakup or other floods wherever these events might occur. Close liaison with meteorological personnel in Alaska will provide sufficient notice of breakup on the more major streams. A field survey crew will be immediately mobilized to wherever breakup is occurring. The survey team will attempt to perform the following tasks:

Photograph breakup conditions in the vicinity.

Determine approximate ice thickness and average size of floe ice.

Record evidence of ice jamming and/or debris build-up.

Flag ice and stage levels where appropriate.

The survey will be conducted by two in-house hydrologists in a similar manner to that described for the ice and pre-breakup study. Field scheduling will depend on weather conditions but the survey is expected during the period from May 15 to June 15 and will take 7 to 10 days to complete. However, this time period may not be continuous, depending on stream breakup chronology. When not required in the field, the hydrologists will be developing the report for the previous ice and pre-breakup survey. After completion of the field work a breakup data report will be prepared, and should be ready within eight weeks.

Panel marker installation

The purpose of the panel marker program is to install panel markers at each of the cross-section locations at selected stream crossings. The installed panel markers will provide horizontal and vertical control essential for both the hydrologic and ground topographic field surveys.

The scope of work involves installing:

Two panel markers at each cross-section, as shown on the photographs in Volume II, Appendix G, "Review of Stream Crossings."

A temporary bench mark at each panel marker.

Typically, panel markers will be installed above the high water levels at each crossing. Some clearing will be required for panel marker installation and line of sight between panel markers. Efforts will be made to locate panel markers to minimize clearing required. Panel markers will consist of two 4 foot by 10 foot strips of white raw cotton placed to form a T. This will facilitate identification of the markers. The panel markers will be secured in place using rocks and/or wooden pegs.

A temporary bench mark, consisting of a 30-inch long #4 deformed rebar with an aluminum cap upon which an identification number can be placed, will be installed at each panel marker location. These bench marks will later be tied in by the ground topographic crews.

The panel marker installation will be conducted by four crews, each consisting of a hydrologist and two laborers. The survey is scheduled to commence on June 1 and will require approximately one month to complete.

Hydrologic survey

A hydrologic survey program is scheduled for the summers of 1978 and 1979. Data gathering activities will be conducted at selected stream crossings. North of Delta Junction, particular attention will be paid to stream crossings where the gas pipeline will be in close proximity to either the Alyeska pipeline or the highway.

The purpose of the hydrologic survey will be to observe and measure hydrologic conditions at selected stream crossings. The data collected will be used in the development of stream assessments and of stream crossing designs.

The scope of work involves:

Investigating selected stream crossings from Prudhoe Bay to the Canadian border to observe and record pertinent hydrologic data (such as stage, discharge, and roughness) required for preliminary design.

Identifying specific points (see below) which will be surveyed by the ground survey crew, and maintain close liaison with that crew.

The specific responsibilities of each hydrologic survey crew will be to:

1. Investigate and record changes which may have occurred since the existing maps, charts, and aerial photographs were issued. This information will be used to determine possible changes in the stream regime and other significant changes.

2. Investigate and describe existing bridges, pipeline, and other structures in the vicinity of the proposed pipeline crossing. The items to be checked are: evidence of repairs and/or modifications, possible reasons for repair, and possible interference of the gas pipeline with existing structures and facilities.

3. Examine debris, ice marks on the stream banks, and evidence of scour, high flood levels, and past ice jamming both at the proposed crossings and at existing bridges, pipeline crossing, and other structures in the vicinity. Important features will be marked for later location by the ground survey crew.

4. Investigate overflow channels.

5. Obtain local information on past hydrologic events which have occurred at or near the proposed crossings, such as ice jams, floods, bridge failures, etc.

6. Photograph stream channels, banks, and overflow channels and identify on maps or aerial photographs the location and direction of each photograph taken.

7. Describe property which could be affected by backwater or scour.

8. Assess roughness of bed and overbank areas.

9. Determine stream velocities. These measurements will be used to verify stage-discharge relationships.

10. Photograph streambed and bank material in the vicinity of the crossing to determine the type of material and approximate sizes of coarse material in the streambed near the shoreline and along the stream banks. In some cases, grab samples will be obtained for classification.

11. Investigate surface evidence of possible armor layers which identify historic depths of scour.

12. Estimate entrance and exit loss coefficients at existing bridges and culverts, to be used in the hydraulic computations.

13. Conduct pebble counts to assess surface bed material size.

The investigtions described herein will be conducted from breakup in 1978 through the summer of 1979. Since the object of all these investigations is to develop a mathematical model of stream performance during flooding, it is desirable that observations be made during the largest actual flood possible. In-house capability should therefore be maintained to quickly deploy a hydrologic survey crew in the event of a significant flood. Liaison with Alaskan meteorological personnel will be established to provide prompt notice of flood events.

There will be a maximum of four hydrologic survey crews under one field coordinator, each crew consisting of one hydrologist, one staff engineer, and one laborer. The schedule is conditional, dependent upon a number of factors that are impossible to foretell. For this reason, deployment of crews will be left to the discretion of the field coordinator.

The proposed hydrologic surveys should begin about August 1, 1978, and will continue until freeze-up. Crew subsistence and helicopter fuel will be arranged. A data report on work completed to date will be presented approximately ten weeks after the end of the 1978 summer field season.

<u>On-call hydrologic survey team</u>. In the event of significant floods, personnel should be deployed on short notice to obtain the needed measurements. These data will be some of the most useful but also the most transient of all field information available. The crews should be prepared to coordinate fully with personnel from government agencies as well as those from Alyeska who will be gathering similar data. Data gathered

during floods are obviously more accurate than those developed by analytical methods. They also can be obtained at lower cost.

Ground topographic survey

A ground topographic survey program is scheduled to begin on or about August 1, 1978. The ground survey crews will be preceded by the hydrologic survey team, who will assist in directing their field work. A close liaison will be maintained during the survey between the hydrologic and ground topographic survey crews.

The purpose of the ground survey is to take cross sections and water surface profiles at selected locations along stream and floodplains. In addition, elevations will be determined of old high water marks and of aufeis and stream ice levels previously flagged during the ice and pre-breakup survey and the breakup survey.

The scope of work involves the following:

A ground survey team will visit selected stream crossings from Prudhoe Bay to the Canadian border. At each crossing visited the survey team will cross-section the stream as directed by the hydrologic survey team.

The surveying contractor will present the results of his surveys to NAPLINE as required by contract.

The list below delineates the responsibilities of the contractor's field crews during this survey. Suggested preliminary technical specifications for the surveying contractor are presented in Volume II, Appendix F. The ground crew will:

Cross-section the stream at pipeline crossings. The cross sections will be extended outside the stream channel in the event dense brush and vegetation prevent adequate topographic mapping using aerial photography methods. These sections will be pre-identified by panel markers for the aerial survey.

Determine elevation of high water marks and flagged stream ice and aufeis levels.

Obtain bridge and culvert geometry required for backwater computations in accordance with technical specifications.

Obtain longitudinal soundings along the thalweg of the river using an echo sounder for larger streams and/or by sounding using a heavy weight or sounding pole. If deep scour holes are found, additional soundings will be taken to define the depths and limits of the hole.

The ground topographic survey team will consist of a maximum of four crews. Deployment of the crews will be as directed by the field coordinator. Subsistence will be arranged in advance and commerical facilities will be utilized.

The proposed survey should begin about August 1 and will continue until freeze-up. The proposed locations of all in-stream cross sections at the selected crossings are shown in Volume II, Appendix G.

After the survey results are submitted by the surveying contractor, a hydrologic field data report will be prepared, which will require an additional six weeks.

Stream crossing subsurface investigations

Subsurface investigations will be required at some of the stream crossings along the proposed pipeline. The Prudhoe Bay to Delta Junction portion of the route will need borings where the pipeline deviates significantly from the Alyeska pipeline and where there is a possibility that soil conditions could change significantly. Some borings may be required near the anticipated sagbend locations in addition to some boreholes within the main stream channel. Along the Delta Junction to Yukon border portion of the route, additional subsurface investigations will also be required such as a shallow seismic survey, for which a request for proposal ("Request for Proposal to Execute a Shallow Seismic Exploration Program at Selected River Crossings Along the NAPLINE Route, from Delta Junction to the Yukon Border") has been prepared. At some crossings it may be advisable to evaluate cobble and boulder bed material.

Sampling and laboratory testing are required for the determination of the type and gradation of soils encountered within the floodplain and stream channels. Samples will be taken within the maximum predicted lateral limits of channel migration and to depths equivalent to maximum anticipated scour depth. Typically, the soils encountered in the stream channel at shallow depth are sands, gravels, cobbles, and boulders. The gradation and maximum size of the material is important in the analysis of scour potential. It is often difficult to sample granular soils and the boring subcontractor should be prepared and equipped to sample such soils. Of particular interest is the detection of armor layers in the upper 10 to 15 feet of the streambed. These layers could signify previous maximum scour depths. If large cobbles or boulder-size layers are encountered, an attempt to core through them should be made to give an indication of their size. It is recommended that a hydrologist be present during logging of all stream crossing borings to ensure that appropriate information is obtained.

Standard soil index property tests should be performed on representative soil samples within the upper 10 feet of each boring. The sampling frequency recommended for stream crossing boreholes is as follows: continuous sampling of the upper 5 feet, sampling at 2.5 foot intervals from 5 to 15 feet, and at 5 foot intervals thereafter. Additional samples should be taken at each significant stratigraphic change.

Although the majority of the boreholes are located outside the main stream channel, some borings are required within the main channel. They will probably be drilled during the winter through stream ice. All other holes can be drilled in either winter or summer, depending on scheduling or access constraints. Permits will be required for any instream activities or adjacent activities affecting the stream.

Table 4-3 is a preliminary list of the borings required at various pipeline stream crossings along the Big Delta to Yukon border segment. These locations may require revision due to pipeline realignments prior to initiation of the drilling program. The approximate station and depth of each boring is presented. The borings listed are only those required for the preliminary hydrologic design of the river crossings. Those borings located outside of the main stream channel should be included in the currently proposed drilling program scheduled for this fall. Additional borings may be required at stream crossings due to geotechnical or other design considerations.

Aerial photography surveys

Aerial surveys will be conducted at each of the proposed stream crossings to obtain photogrammetric models which will be used to 1) extend cross sections already surveyed during the ground topographic survey, 2) permit backwater calculations when necessary, and 3) develop sufficiently detailed contour maps. The limits of photographic coverage required at each crossing are delineated in Volume II, Appendix G, "Review of Stream Crossings." Photogrammetry for hydrologic purposes differs from conventional photography in that the requirements for vertical control are much more stringent than those for horizontal control. The photography must be sufficiently detailed to permit contour mapping to a 1 foot contour interval with a "C" factor of 1200. (C = flight altitude above mean ground surface elevation divided by the required contour interval.) Preliminary specifications for aerial photography are presented in Volume II, Appendix F.

Once the aerial photographic contractor has been selected, the Northwest hydrology group will approve the contractor's proposed flight lines prior to his conducting the survey, to ensure adequate coverage.

TABLE 4-3. BORINGS REQUIRED FOR PRELIMINARY STREAM CROSSING DESIGN (BIG DELTA TO CANADA)

STREAM CROSSING	APPROXIMATE LOCATION OF CROSSING (MIDSTREAM)	PROPOSED BORING LOCATIONS (APPROXIMATE STATION)	MINIMUM DEPTH (FEET)	REMARKS	SUMMER OR WINTER DRILLING	POSSIBLE WINTER DRILLING FROM ICE REQUIRED
Gerstle River**	1520 + 00	1507 + 00	50.0	West Bank	X	
		1524 + 50	50.0	Flood Plain Boring	X	
Little Gerstle River	175 + 46	1753 + 50	40.0	East Bank	X	
Johnson River	2153 + 37	2152 + 55	60.0	West Bank	X	
		2157 + 65	30.0	Mid-River		X
		2162 + 65	60.0	East Bank	X	
Berry Creek	2164 + 83	2641 + 78	40.0 or to bedrock	West Bank	X	
Robertson River	3889 + 05	3870 + 70	50.0	Toe of West Bank	X	
		3873 + 26	30.0	In River Channel		X
		3886 + 26	30.0	In River Channel		X
		3889 + 26	50.0	Toe of East Bank	X	
Tok River	5916 + 47	5915 + 47	50.0	West Bank	X	

**Some boring information is currently available at this crossing and has been considered.

TABLE 4-3. (Continued)

STREAM CROSSING	APPROXIMATE LOCATION OF CROSSING (MIDSTREAM)	PROPOSED BORING LOCATIONS (APPROXIMATE STATION)	MINIMUM DEPTH (FEET)	REMARKS	SUMMER OR WINTER DRILLING	POSSIBLE WINTER DRILLING FROM ICE REQUIRED
Tanana River	6243 + 00	6240 + 32	40.0	West Bank	X	
		6245 + 22	35.0	In Main Channel		X
		6253 + 62	75.0	East Bank, Crest of Approach Slope	X	
Scottie Creek	10098 + 30	10099 + 25	50.0	East Bank	X	

These surveys, combined with the cross-sectioning and profile surveys conducted during the field hydrologic survey program, will provide:

- Adequate topography for hydraulic computations outside of the active stream channel.
- A basis for comparison with older photography to ascertain historic rates of bank migration.
- A source of information in determining and locating potential environmental constraints on the crossing design.
- Base information for assessing possible changes in the stream regime (stream channel) imposed by construction of the pipeline.
- Cross sections for backwater computations.
- Detailed topography for training structures design if required.

A complete recommended aerial photography program will be provided by the contractor prior to commencement of the work.

4.1.2.2 Office Data Collection

Not all data required for stream crossing design will be obtained during the field survey programs. Some data are available and will be obtained from existing sources. These data include:

1. Maps, charts, reports, and photographs. These would be of the proposed stream crossings and their respective drainage basins. They would include USGS topographic and geologic maps, aerial photography, and any site photographs which are currently available. Existing aerial photographs will be collected and developed into a photo manuscript of the crossings.

2. As-built drawings. These would be of all existing structures and facilities in the vicinity of the stream crossings. Structures of particular interest include highway bridges, pipeline crossings, and river-training and bank-protection structures.

3. Water level and discharge data. This information is available from existing regional hydrometric stations which publish discharge and stage data. This information may not be available for all crossings.

4. Data regarding ice conditions. Typical data to be collected are:

a. recorded ice thickness

b. dates of breakup and freeze-up

c. recorded information on historic ice jams and their effects on existing structures such as highway bridges

d. historic aufeis conditions

5. Available geotechnical data. These include:

   a. completed Northwest Alaskan Pipeline boreholes in the vicinity of the crossing

   b. Alyeska's borehole data, if available

   c. borehole data used for the designs of existing highway bridges and other structures

   d. pile logs for highway bridges, etc.

   e. water well logs

   f. any laboratory data available from these subsurface investigations

6. Drainage basin characteristics. Drainage areas will be defined for each of the streams crossed by the proposed gas pipeline. This will be done by outlining the drainage basin divides and estimating their gradient and runoff characteristics. The drainage basins will be drawn on USGS 1:63,360 as well as 1:250,000 scale quadrangle maps. Once the drainage basins have been defined, the areas of the basins will be determined by using a planimeter.

7. Land use. Data will be collected pertaining to the present and future use within the drainage basins along the proposed alignment.

8. Meteorological data. These data will be collected from existing weather stations in the vicinity of the proposed route. Information of particular interest will include:

   a. precipitation data

   b. snow pack depths and densities

   c. seasonal temperature variations

    d. wind velocity and direction

9. Environmental data. These data include:

    a. fish migration timing

    b. fish spawning areas

    c. fish overwintering areas

    d. fish rearing areas

    e. waterfowl nesting areas

    f. wildlife impacts

    g. historical and archeolgoical sites

    h. aesthetics

    i. baseline water quality, e.g., B.O.D., turbidity, chemistry, etc.

10. Legal input. Attention will be given to stream regulation and control works at all streams crossed by the proposed pipeline.

11. Future development in the area. Data will be obtained pertaining to future structures, gravel mining permits, or future mining operations as they may have an impact on the gas line stream crossings.

4.1.3 Data Assessment

When the field and office data have been collected, they will be assessed for the Stage 1 requirements. These requirements consist of describing the behavior of the stream system as it now exists. The ultimate goal will be to determine the parameters required for preliminary design. Table 4-4 lists these parameters, their function in preliminary design, and how they are determined from basic data.

All of the determinations shown in Table 4-4, together with necessary supporting data, will be assembled into a Stage 1 report for each crossing. The reports will be circulated internally for review and approvals. Input from and review by relevant government agencies will be considered where necessary. A final Stage 1 report will then be prepared, marking the end of this stage.

TABLE 4-4. PARAMETERS REQUIRED FOR PRELIMINARY DESIGN

PARAMETER	DESIGN FUNCTION	METHODS USED IN ESTIMATING PARAMETER
1. Delineation of flooded areas	Necessary for design of flotation control	A map of the areas flooded by both historic and estimated floods will be developed. The Project Design Flood will be developed from a mathematical model of the runoff process for each major stream crossed. This method is discussed in Section 4.1.1. Frequency Design Floods will be developed by means of statistical studies.
2. Delineation of expected height of the design water surface	Necessary so that freeboard for structures may be determined	The water surface profile will be developed for each crossing primarily using a step backwater process. In complex cases, where large adjustments of the streambed are expected, a more complex movable-bed backwater program will be used (38). Profiles will be developed for the PDF, 50-year flood, and a mean annual flood. These developed profiles will be reconciled with the evidence of past flood profiles found in the field, and with historic ice jam and aufeis levels.
3. Delineation of the expected maximum scour level of the crossing	Necessary so that the depth of burial of the pipe or bridge piers may be determined	The general and local scours occurring at each section will be developed utilizing the methods described in Sections 4.1.1.3 and 4.1.1.4.
4. Delineation of the expected limits of lateral erosion	Necessary to establish sagbend setbacks	Many variables influence channel behavior with respect to lateral migration. For this reason there are no accepted analytical methods for estimating this parameter. The primary method used in this project will be the comparisons of aerial photographs taken at different periods in time to review historic migration.

TABLE 4-4. (Continued)

PARAMETER	DESIGN FUNCTION	METHODS USED IN ESTIMATING PARAMETER
5. Determination of expected water velocities	Necessary for design of river-training structures and in some scour estimation procedures	Values of average velocities at critical locations in each cross section will be developed from the backwater data. Point velocities will be determined from knowledge of the existing hydraulic relationships.
6. Determination of the environmental design and construction	Necessary for efficient protection of the environment	The environmental constraints will be identified from information furnished by the environmental group.
7. Determination of the nature of existing works on the stream	Necessary so that protection of these works may be assured and effects of works on pipeline design determined	As-built conditions of the existing structures will be determined as well as the effects the design floods are expected to have on those structures.
8. Determination of present stream regime	Required as baseline data characterizing the stream behavior prior to proposed construction	An assessment of the general stability of the stream system in the locality of the crossing will be made by investigating the dynamic morphologic features of the stream. These features include the planform, sectional geometry, meandering process, floodplain conditions, geometry of pools and bendways, and ongoing erosional processes. Comparisons will be made with standardized morphological relationships available in the technical literature (23, 41, 85). A formal process of stream regime determination will be developed from the above considerations.

4.1.4 Government Review--Stage 1

The steps leading to final government approval have been partially described in the preceding discussions. In summary, review of the preliminary alignment and appropriate government input into the basic stream analysis will enable us to proceed with the preliminary design (Stage 2) with confidence that it will be acceptable to the government.

4.2 Stage 2

The primary objective of Stage 2 is to compare alternatives to arrive at the most cost-effective design considering integrity of the pipeline, adjacent property, and the environment. The input to this stage will be 1) the Stage 1 reports, 2) criteria for pipe and bridges developed by others, and 3) cost data. The design process is shown graphically in Figure 4-1.

4.2.1 Preliminary Design

Preliminary design consists of application of criteria, development of alternatives, and comparisons of costs and effects to the extent necessary to define the most cost-effective type of crossing. It does not include development of details or preparation of contract drawings. The process of developing a preliminary design will consist of development of reasonable design alternatives; evaluation of the costs, reliability, and effects on other property and the environment; and selection of the best design.

4.2.1.1 Design Alternatives

For most crossings a number of possible design alternatives will exist. These may be roughly categorized and described as follows:

Buried crossings. Unconstricting buried crossings are those where the completed crossing will not exert any significant effect on the stream flow regime. The pipe would be buried below scour depth and the sagbends would be located outside of the present flood channel.

Two possible methods of assuring protection of the sagbends produce two further alternatives. The sagbends may be located outside of the limits of lateral migration identified in Stage 1, or the sagbends may be located within the limits of lateral migration but at or shoreward of the existing bank line. In the first case, the depth of scour for pipe burial would be as estimated for the natural stream in Stage 1; in the second, additional local scour for impingement on the revetted bank must be considered. The effects of bank revetment on other property must also be considered.

Constricting buried crossings are those where a deliberate decision to constrict flood flows by means of training structures has been made. Constriction will require extensive protection and will result in increasing flood stages and velocities. Significant additional scour in the constriction can be expected and there may be ancillary effects on neighboring properties.

Elevated crossings. Unconstricting elevated crossings are those which exert no significant effects on flood flows. If piers or abutments are outside of the active channels they could be designed with no further hydrologic input than provided in Stage 1. If piers or abutments are located in an area of potentially significant flood flow, an assessment of local pier scour and possible abutment protection requirements must be made.

Constricting elevated crossings are those where structures associated with the crossing will constrict flood flows. In these cases, it will be necessary to assess the effects of the constriction on flood stages as well as on scour. Crossings of this type could possibly have a considerable effect on neighboring property.

Multiple alternatives. For any specific stream or floodplain crossing, a number of reasonably possible alternatives may exist. Preliminary designs, cost estimates, and an assessment of the effects on neighboring property as well as the environment should be developed for each alternative. The total costs should include initial work, maintenance, and abandonment costs.

4.2.1.2 Design Selection

After the design alternatives have been developed, a comparison of all costs and environmental requirements will be made. The assessment will also consider the designs' compatability with the construction schedule. Evaluation of the designs cannot be purely mathematical; much of the evaluation must be subjective and based on the personal experience and judgment of those making the evaluations.

After the evaluations are completed, the selection of the most cost-effective design which meets the accepted criteria for protection of the pipeline, neighboring property, and the environment will be made.

4.2.2 Government Review--Stage 2

After a preliminary design has been completed and accepted internally, a Stage 2 report for discussion with government agencies will be prepared. This report will present the preliminary design in sufficient detail to enable government reviewers to assess the acceptability of the design with respect to the existing laws, regulations, and conditions of permits. Alternatives considered should be described only to the extent necessary to show the reasons for their rejection.

4.2.3 Permit Applications

The preliminary design selected should provide an adequate basis for formal application for government permits. These conceptual applications do not require complete design data.

4.3 Stage 3

The primary purpose of Stage 3 is to produce final design; a complete set of construction drawings and documents for each major stream crossing. Input will be the final Stage 2 report plus any additional comments assembled during the intervening period. No major departures from the concepts developed in the preliminary design are envisioned. Additional comments arising out of governmental review and discussions may be incorporated in the final design.

4.3.1 Final Design Submission

After contract drawings and the associated technical documents are complete they will be submitted to the appropriate government agencies for review. Submission will be in accordance with the stipulated requirements for final design.

4.3.2 Government Approval--Stage 3

The final design should be approved without much delay, provided no significant departures from the approved preliminary designs are made. After government approvals have been received, the drawings can be released for construction. This will mark the end of Stage 3.

5.0 REVIEW OF STREAM CROSSINGS

A preliminary review has been made of all streams crossed by the Northwest Alaskan Pipeline. There were approximately 170 streams identified from alignment sheets, USGS quadrangle maps, and aerial photographs. Lists of these streams are found in Appendix B, Stream List--Prudhoe to Delta (where the gas line parallels the Alyeska pipeline), and Appendix C, Stream List--Delta to Canada (where the gas line parallels the Haines Products line). A table of USGS quadrangle maps covering drainage areas for these streams from Big Delta to the Canadian border is found in Appendix D.

During this review of stream crossings, the pipeline route was separated into four major drainage divisions. Their boundaries and relative sizes are illustrated in Figures 5-1 through 5-4. Appendix E identifies the USGS quadrangle maps covering these major divisions.

The divisions were made on the basis of major flow directions. The North Slope division includes drainage flowing northward from the Brooks Range into the Arctic Ocean; the North Yukon division includes drainage originating North of the Yukon River area and flowing southward from the Brooks Range into the Yukon; the South Yukon division includes drainage originating south of the Yukon River and flowing northward into it; and the Tanana division includes the entire Tanana River Basin upstream from the Tanana River/Delta River confluence.

Information for each stream reviewed was recorded on a "Preliminary River Crossing Data Sheet." Copies of the completed Data Sheets appear in Appendix G. Figure 5-5 is a blank Data Sheet.

The information gathered for each stream includes:

Stream classification

Stream designation

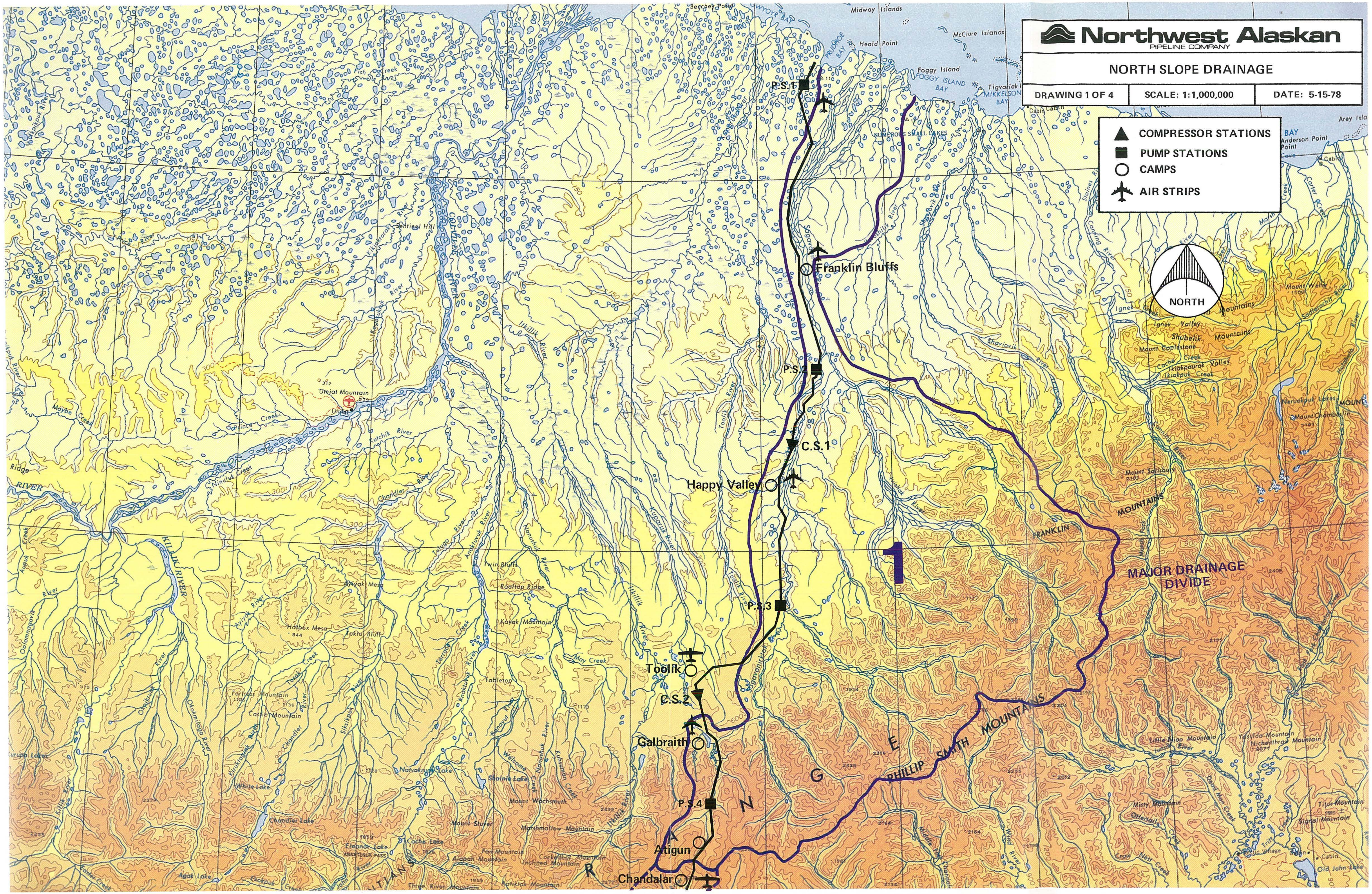
Limits of required aerial photography coverage

Tentative survey cross section locations

Recommendations for crossing mode

Proximity to existing structures

Construction constraints


Northwest Alaskan
PIPELINE COMPANY
NORTH SLOPE DRAINAGE
DRAWING 1 OF 4
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CAMPS
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C.S.1
C.S.2
Franklin Bluffs
Happy Valley
Toolik
Galbraith
Atigun
Chandalar
1
MAJOR DRAINAGE
DIVIDE
FRANKLIN
MOUNTAINS
PHILLIP SMITH MOUNTAINS
Umiat Mountain
Midway Islands
McClure Islands
Foggy Island
Heald Point
Tigvariak I.
Beechey Point
Sentinel Hill
Mount Salisbury
Mount Chamberlin
Shublik Mountains
Sadlerochit Mountains
Twin Bluffs
Rooftop Ridge
Kayak Mountain
Tabletop
Chandler Lake
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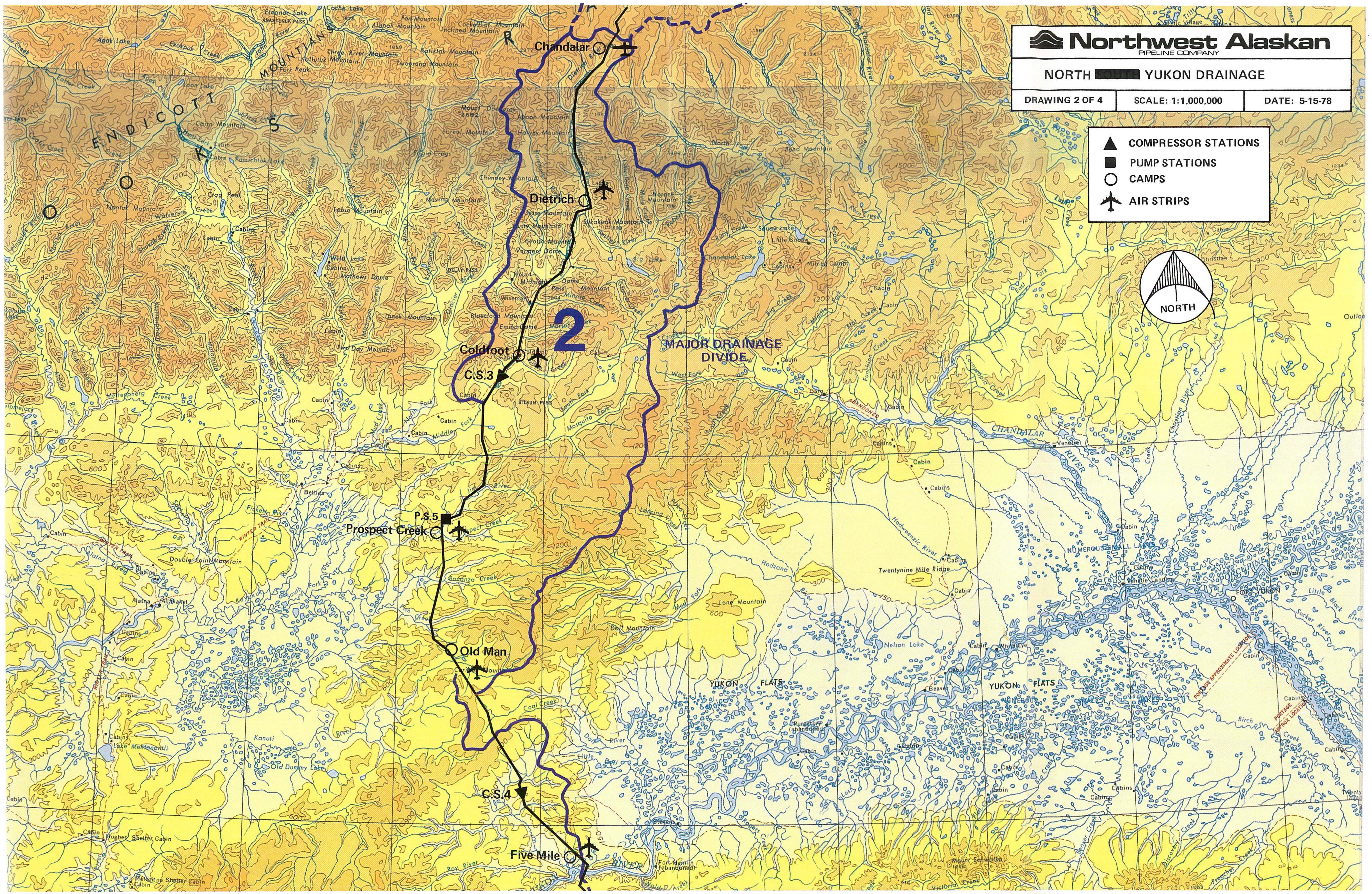
Chandler River
Colville River
Killik River


Northwest Alaskan
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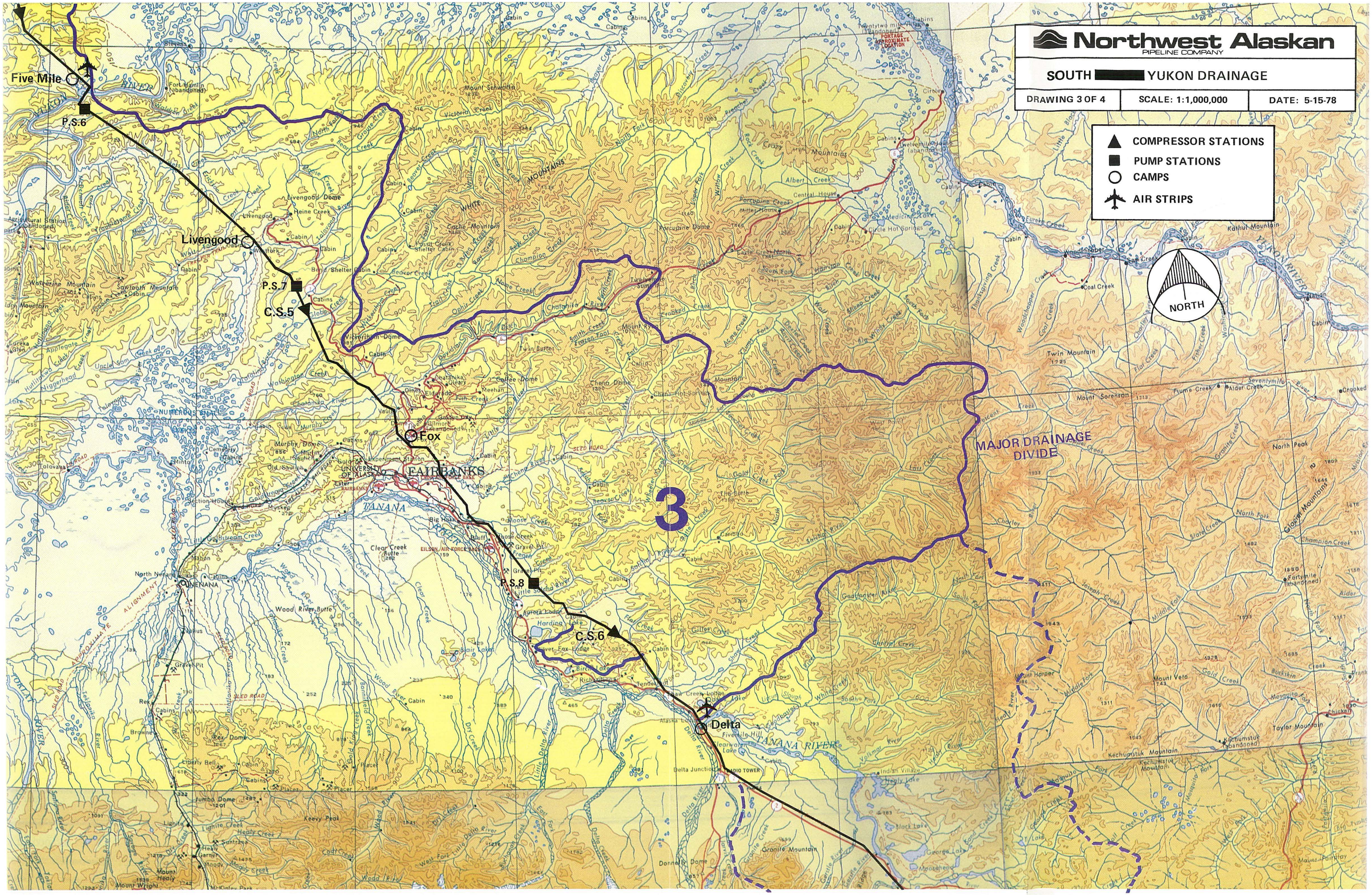
NORTH [redacted] YUKON DRAINAGE
DRAWING 2 OF 4
SCALE: 1:1,000,000
DATE: 5-15-78
COMPRESSOR STATIONS
PUMP STATIONS
CAMPS
AIR STRIPS
NORTH
Chandalar
Dietrich
2
MAJOR DRAINAGE DIVIDE
Coldfoot
C.S.3
P.S.5
Prospect Creek
Old Man
C.S.4
Five Mile
ENDICOTT MOUNTAINS
BROOKS
YUKON FLATS
CHANDALAR RIVER
Twentynine Mile Ridge
Long Mountain
Bell Mountain
Double Point Mountain
Nelson Lake
Bettles
Wiseman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CAMPS
AIR STRIPS
NORTH
MAJOR DRAINAGE DIVIDE
3
Five Mile
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Livengood
P.S.7
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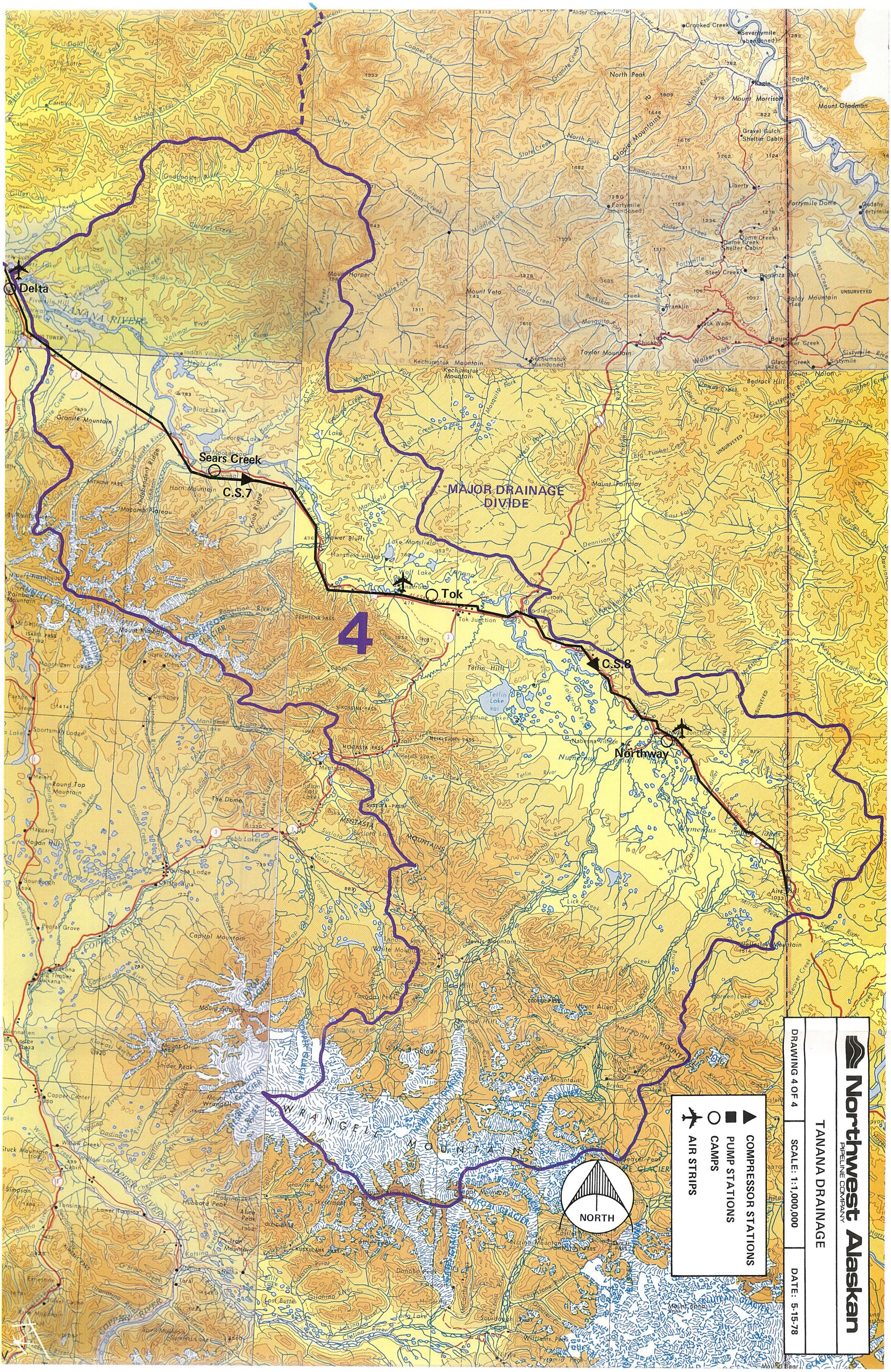
Fox
FAIRBANKS
P.S.8
C.S.6
Delta
NENANA
WHITE MOUNTAINS
TANANA RIVER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COMPRESSOR STATIONS
PUMP STATIONS
CAMPS
AIR STRIPS
NORTH
Delta
Sears Creek
C.S.7
Tok
Tok Junction
MAJOR DRAINAGE
DIVIDE
4
C.S.8
Northway
WRANGELL MOUNTAINS

FIGURE 5-5

USGS QUAD ____________ name #

TOWNSHIP & RANGE T ___ N/S R ___ E/W

SECTION ________ ___ BASELINE & MERIDIAN

ALYESKA ALIGNMENT SHEET ___ (OLD)

(SAMPLE)
PRELIMINARY RIVER CROSSING DATA SHEET

STREAM NAME: ____________ ALIGNMENT SHEET: ____ REV # ____ M.P. ____

NUMBER: ____________ CLASSIFICATION: ____________

LIMITS OF PHOTO COVERAGE:

UPSTREAM	DOWNSTREAM	WIDTH

TENTATIVE CROSS SECTION LOCATIONS: ____________

REMARKS: ____________

MODE	GAS LINE	OIL LINE	GAS LINE UPSTREAM OF OIL LINE	GAS LINE DOWNSTREAM OF OIL LINE
ELEVATED				
BURIED				
HIGHWAY/WORK PAD DISTANCE TO EXISTING BRIDGES			UPSTREAM FROM BRIDGE	DNSTREAM FROM BRIDGE
IN FLOOD PLAIN BURIAL, THE GAS LINE IS			INBOARD OF OIL LINE	OUTBOARD OF OIL LINE
DISTANCE TO EXISTING RIVER TRAINING STRUCTURES			UPSTREAM FROM X-ING	DNSTREAM FROM X-ING
DISTANCE & DIRECTION TO EXISTING MATERIAL SITES (FT.)				

CONSTRUCTION RESTRAINTS

WORKING ROOM	> ADEQUATE	ADEQUATE	< ADEQUATE	
CONSTRUCTION TIMING	SPRING	SUMMER	FALL	WINTER

STREAM MORPHOLOGY

STREAM FORM	STRAIGHT	MEANDERING	BRAIDED	INCISED		
FLOOD PLAIN	LEFT / RIGHT	ABSENT	LOW	HIGH	WIDE	NARROW
STREAM BED	CLAY	SILT	SAND	GRAVEL	COBBLE	BOULDER
BANKS	LEFT / RIGHT	RIGID	COHESIVE	RESISTANT	FREE ERODING	
REACH GEOMETRY	BENDS	CONFLUENCE	INCISED			

Stream morphology

Also included in Appendix G are copies of aerial photographs for all major stream crossings. Survey cross section locations are indicated on these photos along with the limits of required small-scale aerial photo reconnaissance.

5.1 Stream Classification

Stream crossings are classified as either major or minor depending on the anticipated problems with their designs. The following factors affect a particular crossing's classification:

Scour. The minimum stipulated burial depth is expected to be 4 feet. Experience has shown that, in general, streams with less than 5 square miles of drainage area will not scour this deeply unless flow is complicated by bridges or other structures.

Lateral erosion. Streams which show tendencies to widen excessively or to develop cutoff channels must be studied sufficiently to determine probable limits of lateral migration.

Bridges and road embankments. Road embankments and bridges are typically designed for lesser floods than the pipline. Therefore, the bridge and highway would probably fail in a large flood. The consequence of these failures should be evaluated with respect to integrity of the pipe.

Oil pipe. The proximity of the Alyeska oil pipeline may require special stream design. This may arise from two conditions: the elevated support structure and construction pad may constrict or divert flows in the vicinity of the gas pipe, or the gas pipe or its associated works may constrict or divert flow so as to endanger the oil pipe. The problem is accentuated because the construction modes of the oil and gas pipes may be different.

Environmental considerations. Areas of known environmental concerns which may require a structural solution have been identified for mapping. Examples of this type of concern are fish overwintering or spawning areas.

Because some of the problems are not totally apparent at this time, stream classifications may change as the design process develops. All crossings are assumed major at the outset of design. As evidence proves them to be of minor importance, they are appropriately classified as minors. It is expected that as design progresses the large majority of these streams will be considered minor.

5.2 Aerial Photography Requirements

The locations and extent of aerial photography required are shown on the photographs in Appendix G. Technical requirements for photography are given in Appendix F.

Aerial photography has been requested for each major stream crossing where hydraulic calculations are anticipated. The extent of required coverage generally includes the floodplain width and determined distances up and downstream from the pipe. These distances are based on data requirements for backwater calculations, and measurement of cutoff assessment.

A rule of thumb for backwater computations is that the computations should start ten channel diameters downstream of the area of interest. Thus the length of the photographed section is roughly proportional to stream width. For many areas the controlling factor for the extent of photography is the need to consider potential cutoffs or diversions.

History shows us that, during large floods on alluvial fans, streams tend to switch channels rapidly. This occurs because of deposition of sediment in the active channels. For these areas the extent of our basic photo coverage must be large enough to include all channels into which the present stream may switch.

5.3 Stream Cross-Sectioning Locations

The approximate locations of required cross sections are indicated on the photos of Appendix G. Technical requirements for these sections are provided in Appendix F.

The sections are obtained in order that we may perform backwater computations to obtain design floodwater levels. The locations of the sections are determined by hydraulic requirements. All sections must be located so that the water surface will be level throughout the section. The spacing of cross sections is highly dependent on the use to which the results will be put and the importance of local conditions. Cross sections should be obtained at the following locations:

1. At sharp changes in bed slope.

2. At points of contraction and expansion.

3. In tributaries immediately above a confluence and in the main stream immediately below a confluence.

4. At enough points between locations that have different roughness characteristics to provide a reasonable transition.

5. Immediately above and below control sections.

6. In areas where the energy slope change by a factor of two.

Cross sections should be extended to an elevation above the design water level.

Location of cross sections for bridges is difficult to pinpoint because it is necessary to visualize current directions for complicated flow patterns and position flow sections perpendicular to the flow. A procedure for locating bridge sections and measuring bridge geometry is given in Appendix F. The location of cross sections is critical and should be done by an experienced hudrologist.

The adopted procedure is to obtain as much cross section as possible from aerial photographs. Portions that are under water or obscured by vegetation will be obtained by conventional ground survey methods.

5.4 Suggested Alignment

The Preliminary River Crossing Data Sheets provide comments on the proposed alignment and suggest alternatives to be studied. These comments are in the section entitled "Remarks."

In some cases evaluation of alternative routes has been suggested due to the proximity of the original alignment to bridges, the Alyeska pipeline, and river training structures. The importance of these considerations is discussed.

Proximity to bridges. In many cases the presently proposed pipeline route is immediately downstream of either highway or work pad bridges. In these cases the bridge waterway opening constricts flows and greatly increases the amount of energy available to scour the bed. Additionally we must consider that the pipeline design flood is about two times as large as the floods normally used for bridge design. Thus, we must consider failure of the bridge or its approaches. A bridge upstream of the pipe may typically increase burial depths by 5 feet. If the bridge is downstream of the pipe similar but less critical problems exist.

Proximity to Alyeska pipe. In most stream crossings the gas pipe is close to the Alyeska pipe. If both pipes are buried the problem is to assure that our pipe location cannot cause extra scour or lateral migration at Alyeska's location and that our construction trenching operations do not endanger Alyeska's pipe. If our pipe is buried and Alyeska's pipe is elevated, the problem is similar to that experienced at highway bridge locations.

Proximity to river training structures. In many cases the presently proposed route is streamward (or "inboard") of Alyeska's alignment in spur fields designed to protect Alyeska's pipe. There are several considerations that arise from this:

1. Construction activities will necessitate disruption of spur fields protecting Alyeska's pipe. This brings questions of liability should a flood harm Alyeska's property.

2. Additional structures or extensions of existing structures may be required to protect the gas pipe. The existing spur dikes are designed to prevent erosion only from the oil pipe to the stream. If the gas pipe is inboard of the oil pipe, it will be necessary either to extend the existing spur field or to construct additional spurs between those existing. Alternatives may be deep burial or relocation outboard of Alyeska's pipe.

5.5 Design Constraints

The data sheets indicate some presently identifiable design constraints. As mentioned above, these constraints, i.e., proximity to existing structures and facilities, can influence the cost and therefore the alignment of the pipeline. The information given on the data sheets also includes the construction modes of both the gas and oil line, and the positioning of the gas line in the stream relative to the oil line, i.e. upstream or downstream.

5.6 Construction Restraints

The data sheets identify constraints on construction such as working room and the probable construction timing. These are largely environmental constraints stemming from fish habitats or spawning areas. Preferred seasons for construction are input from the environmental group. Another seasonal constraint would be severe weather conditions,, e.g. known periods of high stream flows.

5.7 Stream Morphology

The data sheets in Appendix G provide a rough description of the nature of the stream, the stream form, and the nature of the banks. This information aids in assessing stream migration probabilities, reveals the stream's historical behavior, and can indicate scour problems. Though not analytical enough for calculations, this information can flag crossings where scour or lateral migration may be a problem.

6.0 CONCLUSIONS

The following general conclusions have been reached in conjunction with the preparation of this report:

Our review and analysis, leading to the recommended design process, will require a major data collection, data assessment, and design effort to produce preliminary and final crossing designs.

The recommended staged approach to crossing design and government approval will result in substantial time and cost savings associated with the development of final stream and floodplain crossing designs.

Preparation for the field surveys proposed for the spring and summer of 1978 should begin immediately.

The preliminary review of all stream crossings from Prudhoe to the Yukon border indicates that, at some crossings, consideration must be given to realignment and, in a few instances, change in mode. The field surveys proposed will provide more detailed information on this subject.

At stream crossings north of Big Delta, pipeline mode, alignment, and design criteria may be impacted heavily by fish, wildlife and environmental concerns. In addition, the level of cooperation from Alyeska regarding data acquisition, their shared right-of-way philosophy, and the design restraints which they may attempt to impose on Northwest's crossing design may impact the design criteria.

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