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16.0 RIVER, STREAM AND WETLAND CROSSINGS

16.1 INTRODUCTION

This section contains the criteria to be used in the design of the river, stream and wetland crossings of the gas pipeline. The methodology that will be used to determine the pipeline design flood, compute local and general scour, design river training structures and bank protection works, determine buoyancy control requirements, and mitigate chilled pipe effects of river, stream and wetland crossings is presented here. In addition, the crossing classification system is included and parameters used to select aerial crossings are described.

Additional details relating to pipeline design flood determination, estimated scour computation, and the design approach for chilled pipe effects at stream crossings will be presented in subsequent project documents. These details will include sample calculations, specific data requirements, data collection methodology, and descriptions of the computer programs or models involved.

Specific criteria and procedures addressing field design changes and specifications, sample calculations, and design examples are not included. Criteria and methodologies pertaining to the design of aerial crossings are presented in Section 14. Criteria and procedures for the selection and design of drainage structures and erosion and sediment control can be found in Section 11. Applicable restoration criteria and procedures are presented in Section 12. Pertinent geotechnical/geothermal analysis criteria and procedures are presented in Section 21. Criteria for clearing (Section 10), workpad (Section 9), and ditch configuration (Section 13) are presented in other sections of this manual.

16.2 CODES AND CRITERIA

16.2.1 Codes

- United States Code, Title 16 – Conservation (Fish and Wildlife Coordination Act of 1934, as amended)
- United States Code, Title 30 – Mineral Lands and Mining
- United States Code, Title 33 – Navigation and Navigable Waters
- Executive Order 11988 – Floodplain Management Guidelines, E. O. 11988; 43 FR 6030
- Code of Federal Regulations, Title 18 – Conservation of Power and Water Resources
- Code of Federal Regulations, Title 28 – Judicial Administration (Part 63, Floodplain Management and Wetland Protection Procedures)
- Code of Federal Regulations, Title 33 – Navigation and Navigable Waters
- Code of Federal Regulations, Title 40 – Protection of the Environment

- Code of Federal Regulations, Title 43 – Public Lands: Interior, Part 2800, Rights-of-Way, Principles and Procedures
- Code of Federal Regulations, Title 44 – Emergency Management and Assistance (Part 9, Floodplain Management and Protection of Wetlands)
- Code of Federal Regulations, Title 49 – Transportation
- Alaska Statutes, Title 16 - Fish and Game
- Alaska Statutes, Title 38 – Public Lands
- Alaska Statutes, Title 41 – Public Resources
- Alaska Statutes, Title 46 - Water, Air, Energy, and Environmental Conservation
- Alaska Administrative Code, Title 5 – Fish and Game
- Alaska Administrative Code, Title 6 – Alaska Coastal Management Program
- Alaska Administrative Code, Title11 – Natural Resources
- Alaska Administrative Code, Title 17 – Transportation and Public Facilities
- Alaska Administrative Code, Title 18 – Environmental Conservation
- Federal Right-of-Way (ROW) Grant for the Alaska Natural Gas Transportation System Alaska Segment, Serial No. F-24538 (December 1, 1980), as such may be updated and/or amended from time to time.
- Federal Energy Regulatory Commission conditional certificate of public convenience and necessity, issued on December 16, 1977, as such is finalized
- U.S. Army Corps of Engineers (COE) Section 10/40 Permit No. 071-OYD-2-830282, Sagavanirktok River 120, January 4, 1984 (as modified September 9, 1987). This permit expires September 7, 2007. Including the following documents incorporated by reference: Onsite Federal Inspector's List of Sensitive Wildlife Areas between Prudhoe Bay and the Canadian Border along the proposed Northwest Alaska Pipeline Company Gas Pipeline Route; November 25, 1981 and List of Fish Streams between Prudhoe Bay and the Canadian border along the proposed Northwest Alaskan Pipeline Company Gas Pipeline Route; November 30, 1981.

16.2.2 Criteria

16.2.2.1 General

- Crossings will be below ground except when engineering and environmental restraints prohibit burial. Watercourse crossing construction techniques are outline in Table 16-1. Aerial crossing criteria are presented in Section 14.
- Heavy wall pipe will be used at selected stream crossings, based on engineering, environmental, or access considerations.

- Minimum depth of cover at rivers, streams, and floodplains will be 4.0 feet. An additional safety factor will be applied to the depth of cover at selected crossings.
- Sagbends will be set back from the bank of the active channel to preclude pipe exposure caused by bank migration or channel shifting. Setback distances will be based on 50-year estimates of possible bank migration, which will include evaluation of average annual bank migration and maximum annual bank loss. Bank migration evaluations will be based on field assessment and by photo comparison determination of historic bank migration.
- Setbacks will be measured horizontally from high bank (if it is discernible), tree line (if appropriate), water edge at design flood stage (if applicable), water edge at high flow, or top of bank, to the calculated center of the sagbend.
- If the crossing has two overbends and only one long sagbend (such as may be the case for very small streams), the terminus of the setback will be that point where the pipe rises above the minimum cover depth required for the crossing.
- River, stream, floodplain and wetland crossings will be designed so that they are fully compatible with existing adjacent facilities, i.e., other pipelines, river training works, roads and bridges. River training structures will be designed such that unacceptable backwater effects do not endanger existing facilities upstream or by increased channel velocities downstream.
- Where practical, natural deflection free bending may be employed to install the pipeline at river or stream crossings. Where this technique is used the radius of curvature in the pipe will be limited to preclude wrinkling or buckling of the pipe. The setback distance will be measured to the point where the pipe rises above the design elevation of the crossing or above the minimum cover depth required for the crossing.
- Use of horizontal directional drilling (HDD) to place the pipe beneath rivers, streams, or floodplains will be considered. Where an HDD is used to install a crossing, no portion of the pipeline will be higher than the predicted extent of bank migration and scour.
- Where an HDD is used to install a crossing, the radius of curvature in the pipe will be limited to preclude wrinkling or buckling of the pipe.
- COE Permit No. 071-OYD-2-830282 contains 28 Special Conditions that establish restrictions on the methods, locations, and schedule of construction to protect surface waters and wetlands.

16.2.2.2 Crossing Classifications

All proposed stream crossings will be classified as Class A, Class B or Class C. The crossing classification serves as an indicator of the design complexity, difficulty of construction and potential impact to pipeline integrity or the environment.

Class A crossings will require extensive design effort or construction activity to ensure pipeline and environmental integrity. The following characteristics may lead to a Class A crossing classification:

- Requirement for extensive river training structure
- Presence of high, unstable banks
- Anticipation of high or environmentally sensitive flow conditions during construction
- Deep burial or excessive excavation of the banks

Class B crossings will require moderate design effort and construction activity to ensure pipeline and environmental integrity. The following characteristics may lead to a Class B crossing classification:

- Fish stream crossings requiring workpad crossing structure, e.g. culverts
- Stream crossings adjacent to existing highway culverts of special concern
- Stream crossings requiring special erosion/sedimentation control measures
- Stream crossings exhibiting extensive armoring or restoration efforts including fisheries concerns
- Stream crossings exhibiting potentially detrimental proximity to adjacent structures

Class C crossings will be crossings of small stream exhibiting minimal construction difficulty and minimal potential for impact to pipeline and environmental integrity. The design and construction of Class C fish stream crossings will include such factors as construction scheduling which includes environmental timing, construction methods, the use of temporary structures which provide for fish passage and restoration treatment as described in Section 12.

Crossings of small drainages or rills which do not exhibit design or construction complexities beyond those identified for normal design will not be classified as stream crossings for project design purposes. Those crossings which have minimal scour potential, nominal restoration requirements and no stream associated environmental concerns will fall into this category. Design of these crossings will be performed in accordance with criteria and procedures for drainage and erosion control, see Section 11.

16.2.2.3 Hydrology

- The pipeline crossings will be designed to withstand the effects of a 200-year return period flood.
- Scour depths will be computed based on flow conditions predicted during the design flood.
- Scour depths will be computed utilizing regime theory, tractive force, competent velocity, or other appropriate approach. Results will be compared with evidence of historic scour and/or results of water/sediment routing analyses performed for the larger streams.

- Floodplain erosion will be assessed based on river regime, floodplain vegetation and soil type. Burial depth and/or utilization of river training structures will be specified to prevent exposure of the gas pipeline.

16.2.2.4 Bank Protection and River Training Works

- Bank protection and river training works will be utilized based on economic comparison with deep burial, considering resultant integrity of the gas pipeline, adjacent facilities and environmental concerns.
- Structure type will be selected based on specific protection requirements, material availability, potential effects on adjacent facilities, and environmental concerns.
- Hydraulic analysis of pre- and post-construction conditions will be performed at bank revetment or river training work locations to assess potential impact on adjacent facilities. Factors to be assessed include scour, water surface elevation, flow velocities, bank erosion, and channel switching.
- Structure height requirements will be based on a site-specific analysis. Freeboard (the height of the structure above the design water surface elevation) will take into account ice jamming, debris accumulation, aufeis and waves.
- Width of guide banks will allow for design flows to pass without endangering downstream facilities by scouring or by creating undesirable backwater effects.
- Spacing between adjacent river training structures will be selected based on site-specific evaluation.
- Revetments will be terminated in areas protected from erosive currents or will be keyed-in to the bank at their termination point.
- Where scour is anticipated, toes of river training structures will be protected by extending the armoring layer to the scour elevation or by providing a launching apron.
- Riprap design for revetments and channel stabilization aprons, not immediately downstream of culverts, will be based on the tractive force methodology adopted by the Federal Highway Administration, or other appropriate methods.
- Riprap design for channel stabilization aprons that are immediately downstream of culverts will be based on the U.S. Army Corps of Engineers Hydraulic Design Criteria.
- Riprap will be classified based on size. For a given class of riprap, the riprap layer thickness will not be less than 1.5 times the spherical diameter of the upper limit median stone size or 1.0 times the spherical diameter of the upper limit maximum stone size.

16.2.2.5 Buoyancy Control

- Pipe flotation calculations will determine buoyancy control requirements. The calculations will compare the buoyant force on the pipeline to the external forces required to keep the pipeline from floating. Elevated fluid specific gravities will be used in the calculations where appropriate to account for higher buoyant force generated in sediment-laden waters or where warranted based on other considerations.
- Where forces resisting flotation (pipe weight, overburden, soil strength) are 105 percent or more of the buoyant force (calculated using appropriate specific gravity), buoyancy control will not be required. Where the forces resisting flotation are less than 105 percent of the buoyant force, buoyancy control measures will be required.
- Potential buoyancy control measures include increased pipe wall thickness, concrete coating, bolt-on weights, saddle weights, screw anchors, or saddlebag weights. Where buoyancy control measures are used, the forces resisting floatation are 105 percent of the buoyant force, calculated using an appropriate specific gravity.

16.2.2.6 Environmental

- Location of crossings and related structures have been selected to minimize impact to the environment, including sensitive fish and wildlife habitats, riparian vegetation, visual resources, antiquities and cultural resources, and restoration considerations.
- Staging areas will be located and sized to meet construction requirements while minimizing the environmental disturbance to streams. Siting will avoid unique or sensitive vegetation and wildlife areas where practical, minimize impacts to visual quality and minimize loss of riparian vegetation. Vegetative buffers will be maintained, where practical, between staging areas and stream banks.
- The crossings will be designed and constructed to assure free passage and movement of fish in streams, rivers and other waterbodies during anticipated flow conditions.
- Temporary blockage of fish passage will require site-specific design details. Details of fish passage criteria for culverts and other crossings are presented in Section 11.
- Cuts through stream banks will be approved in writing by the Alaska Department of Natural Resources (AKDNR) and designed to minimize erosion and prevent slope failure.
- Excavated materials to be used for backfill may be temporarily stockpiled in floodplains if approved in writing by the AKDNR as long as:

  - Stockpiling does not result in fish entrapment, blockage of fish passage or detrimental sedimentation into adjacent waterbodies.
  - Excess material is removed prior to spring breakup.
  - Stockpiling does not result in excessive vegetative damage or require excessive restoration.

- Stream crossing activities will be planned to minimize alteration of the natural stream, surface water and groundwater hydrology.

  – Approximate original conditions of the stream channel in disturbed areas of fish streams will be restored insofar as practical following pipeline installation. Restoration is discussed in Section 12.

  – Following gas pipeline installation, the armoring layer will be restored where practical in those streams having armored streambeds.

- Potential effects on streams caused by the presence of a chilled gas pipeline will be minimized, where practicable, such that:

  – Temperatures of the surface water are not depressed so as to pose a threat to the biological regime of the stream.

  – Stream breakup is not retarded so as to detrimentally affect fish migration.

  – Stream freeze-up is not accelerated so as to detrimentally affect fish migration or over-wintering.

  – Potential inducement of aufeis does not damage nearby facilities or riparian habitat or displace channels.

  – Blockage or diversion does not significantly decrease groundwater flow to downstream fish over-wintering areas.

- Stabilization of stream banks is to be completed as soon as practical after pipeline installation. In consultation with Alyeska, any TAPS river training structures that may have been disturbed will be structurally restored as mutually agreed by the Project and Alyeska. Restoration will likely take place prior to breakup, if structures were breached in the winter or promptly following backfilling of the proposed pipeline during the open water season. Winter restoration may require rework as soon as the structural fill is thawed.

  – Disturbed banks requiring armoring will be armored to the discernible top of bank, or design flood stage elevation if applicable.

  – Criteria for restoration are presented in Section 12.

  – If TAPS structures are to be breached during the flood prone season, a contingency plan will be developed, in consultation with Alyeska, to ensure the integrity of TAPS.

- In problem run-off areas temporary settling basins or other forms of sedimentation control will be constructed to minimize siltation of streams.

- Diversion operations will be sequenced to minimize fish entrapment and siltation, to avoid sensitive periods where practical, to minimize interruption of fish migration, and to minimize potential impact on adjacent facilities.

- Temporary diversion structures will be removed.

- Permanent stream diversions will be avoided unless approved in writing by the AKDNR.
- Pumping or fluming of surface flows may be used on actively flowing streams to prevent blocking flow during construction. Adverse impacts on TAPS facilities will be minimized. Alyeska will be consulted as to possible impacts and plans for rehabilitation of any impacts. Minimization techniques that will be used include:

  – Temporary embankment and/or sandbag/membrane dams may be used to collect stream flow for pumping or fluming operations.

  – Pump intakes will be screened to prevent the intake of fish. Mesh size and intake velocity will be set at each crossing in accordance with ADF&G guidelines based on species/age of fish present during construction.

  – Flows from both pumping and fluming will be discharged on energy dissipaters as needed to minimize erosion and siltation.

  – Discharge from pumping operations may require passage through temporary settling basins during sensitive fish periods and/or to meet water quality standards or variances to the standards. This will be determined on a site-specific basis.

16.2.2.7 Workpad at Stream Crossings

Workpad stream crossings will be designed on a site-specific basis in accordance with criteria and methods set forth in this section, as well as in Sections 9 and 11.

16.2.2.8 Aerial Crossings

The pipeline will be buried at most stream crossings. However, serious constructional, environmental, and economic concerns may preclude a buried crossing, and lead to the choice of an aerial crossing. The design of pipeline aerial crossings will be in accordance with the criteria presented in Section 14.

16.2.2.9 Wetlands

- Wetland construction will be performed in winter whenever possible
- The minimum depth of cover in wetlands will be 2.5 feet measured to the top of the pipe (or insulation) except where buoyancy control measures, bend requirements, or other considerations require additional cover.
- Design and construction will provide adequate cross drainage to assure fish passage in designated fish habitats, to provide compatibility with third party drainage control systems, to minimize alteration of natural sheet flow conditions and to minimize erosion and resulting sedimentation. Efforts will be made to avoid upslope ponding and downslope dewatering.
- Siting of ancillary pad areas in wetlands will be avoided where practical.

- Where highly compressible material is encountered, site-specific methods will be developed and employed to minimize construction impact.

16.2.2.10 Stream Crossing Locations

- Where practical, stream crossings have been located in straight reaches of channels to minimize risk of erosion and bank migration.
- Where practical, the pipeline alignment is perpendicular to the stream channel to minimize crossing length, damage to banks and channelization.
- Where practical, crossing locations have been selected to avoid multiple channel crossings. When unavoidable, multiple channels will be crossed where spacing and orientation of the channels are conducive to minimizing environmental impacts.
- Where practical, crossings have been located where the banks are low and stable. Ice-rich soils and other thaw unstable soils have been avoided where practical.
- Where practical, crossings have not been located in reaches where the stream is deep, where the current is fast, or where river training structures will be required.
- Where practical, crossing sites have been selected to avoid sloughs, backwaters, high water channels, springs, seepages and side channels.
- Where practical, crossings have been located where terrain adjacent to the crossing site is stable. Preferably, crossing sites will require minimal vegetative disturbance, and provide construction staging and temporary spoil storage.
- Where practical, crossing sites have been selected to avoid sensitive fish habitats, such as spawning, over-wintering, or rearing areas. Measures will be taken to minimize potential for downstream siltation.
- Where practical, heavily vegetated stream banks and vegetated islands have been avoided.
- Where practical, crossings have been located to maximize construction access.
- Where practical, crossings have been located to avoid islands, shoals, narrows, sharp bends, river confluences and other areas of flow constriction which are subject to potential ice jam formation and debris accumulation.
- Where practical, crossings have been located to minimize potential effects to other facilities, such as roads, bridges, other pipelines and existing river training structures.
- Practical considerations for aesthetic values have also been a part of site selection criteria, especially where extensive clearing, excavation or use of permanent structures may be required.

16.3 DESIGN PROCESS

The amount of data acquisition, and the level of analysis and design required for each river, stream, and wetland crossing will vary depending on the length of crossing, environmental sensitivity, socioeconomic significance, potential impact on integrity of the ANGTS pipeline, potential impact on integrity of other structures, and other relevant considerations. The process to follow in designing crossings is described below. Final design documents for river, stream, and floodplain crossings and for wetland crossings will reflect the significance, sensitivity and the level of design effort.

16.3.1 Data Acquisition

The design of water crossings requires the collection and analysis of hydrologic, geotechnical, environmental, hydraulic, sedimentable, topographic and geomorphic data. Available aerial photography (historic and recent), as-built, or construction drawings of existing facilities and published reports will be assembled and reviewed. Information on stream channel geometry, local topography, subsurface stratigraphy, river ice, aufeis conditions, and environmental concerns such as fisheries, wildlife, visual resources and water quality is included in the data gathered during field surveys. A summary of the data acquisition program is presented in Table 16-1.

16.3.2 Classification System

A hydrologic stream classification system will be created for the project that allows systematic categorization of each stream crossing based on stream size, morphology, hydraulic characteristics, bank characteristics, geological/geotechnical conditions, stability (with regard to scour, bank migration, and channel shifting), and other pertinent factors. Stream crossing types will be based on this physical classification as well as on environmental/biological considerations.

16.3.2.1 Hydrologic Stream Classification

The hydrologic stream classification system will be based on hydrologic and geomorphic characteristics including drainage basin size and type, channel morphology and characteristics, scour potential, bank migration and/or channel shifting potential, potential surface water effects on adjacent facilities and other special considerations. The stream classification system will serve as the basis for hydrologic data accumulation and methods of analysis. Streams crossed by the gas pipeline will be categorized based on their stability, sensitivity and risk.

– Streams that are least stable and present the highest potential risk to the pipeline during construction or operations will comprise the first group. This grouping will include streams that have significantly high scour and/or bank migration potential, streams where the presence of adjacent structures may induce detrimental backwater effects, or streams where special problems exist that may affect the ANGTS pipeline integrity.

- Subsequent groupings will include streams where scour potential, bank migration or channel shifting, etc. are progressively less problematic. A total of three or four categories are envisioned, with the final category including streams that do not pose significant risk or sensitivity.

16.3.2.2 Crossing Classification

The stream crossing classification system serves as the basis for overall crossing design analysis and design output and is based on the hydrologic assessment as well as geotechnical, geothermal, environmental, constructibility and adjacent facility concerns.

Each stream crossing will be classified according to anticipated design complexity, magnitude of construction and potential for impact to pipeline integrity or the environment. Details of topographic surveys, analysis of hydrologic, hydraulic, geotechnical and geothermal information, and assessments of environmental and adjacent facility concerns will serve as the basis for crossing classifications. See Section 16.2.2.2.

Crossings of small drainages or rills that do not exhibit design or construction complexities beyond those identified for normal design will not be classified as stream crossings for project design purposes. Those crossings that have minimal scour potential, nominal restoration requirements and no stream associated environmental concerns will fall into this category. Design of these crossings will be performed in accordance with criteria and procedures for drainage and erosion control as outlined in Section 11.

16.3.3 Design Flood Magnitude

Stream, river and floodplain crossings will be designed to withstand the effects of the design flood. The design flood frequency will be 100 or 200 years, depending on the stream and the nature of the crossing. The magnitude of the design flood discharge and the water surface elevation for the design flood will be set based one of a number of methods. These methods include using flood stage/discharge relationships if records are available or extending the record for a given stream based on statistical correlation with similar streams in the region. Other methods include regression analysis based on drainage basin area for streams of similar type in the region, or estimates based on regional envelope curves, such as those published by Jones and Fahl ("Magnitude and Frequency of Floods in Alaska and Coterminous Basins of Canada" U. S. Geological Survey Water-Resources Investigations Report 93-4179, 1994).

Flood levels and channel velocities for stream crossings will be determined by using the Hydraulic Engineering Circular HEC-2 computer program "Water Surface Profiles", developed by the USACE, normal depth calculations, or other appropriate methods. The HEC-2 program utilizes the standard step method of computation with channel geometry and roughness as input data. If field data are not available, the roughness coefficient (n) will be estimated by comparing the stream with existing published data, or other appropriate methods.

16.3.4 Scour

No single method is considered totally definitive for estimating scour. Scour estimates will be made by the methods outlined in the following sections. Since not all methods apply to every stream, the method most applicable to the stream will be more heavily weighed in the estimation of scour depths.

16.3.4.1 General Scour

General scour in alluvial channels is associated with variable flow conditions and related channel processes including bed material transport, bed form migration and channel shifting. Reliable estimation of general scour at a stream crossing is necessary in order to install the ANGTS pipeline at a safe depth. The location of a buried pipeline in relation to computed scour depth is illustrated in Figure 16-1.

The basic methods for estimating general scour are the regime method and methods utilizing water/sediment routing models.

16.3.4.2 Local Scour

Local scour occurs in non-uniform flow regions where the water sediment mixture is accelerated or decelerated around obstructions to the flow. The major causes of local scour are the fluctuations of forces such as pressure, lift, and shear acting on the bed material.

- Scour at Bridge Piers

  Local scour at bridge piers occurs because vortex systems develop. At the upstream nose of the pier, a vortex with a horizontal axis develops and wraps around the base of the pier. Downstream of the pier, a wake-vortex system with a vertical axis develops. Shear stresses associated with these vortex systems accounts for the development of scour holes at the base of bridge piers on both the upstream and downstream sides of the pier. The pier shape at both the upstream and downstream faces affects the strength of these vortex systems. A streamlined pier oriented with the flow will reduce the strength of these vortices, thereby reducing the amount of local scour that may occur at the pier.

  Local scour at piers will be estimated using the methods outlined in HEC-18, Evaluating Scour at Bridges, or using other procedures where appropriate. The computed local depth of scour will be added to the general depth of scour through the constriction to determine the lower riverbed level adjacent to a pier or pile. Figure 16-2 illustrates a combination of general and local scour at a bridge crossing.

- Scour at Embankments

  Local scour at embankments, such as abutments, guide banks or spur, is also caused by the action of vortex systems developed by flow blockage. The vortex of fluid generated by the pileup of water on the upstream edge and subsequent acceleration of flow around the nose of the embankment are the major mechanisms for local scour around embankments.

  Generalized formulae for the estimation of local scour depth at embankments relate local scour depth to the upstream depth of flow, the upstream Froude Number and the embankment configuration. Scour depths at embankments in sand bed and gravel bed streams will be estimated using the Blench Method, Modified Blench Method, or other appropriate techniques.

16.3.4.3 Special Design Considerations

Special design considerations may include alluvial fans, multiple-channel systems, areas prone to aufeis, areas where floodplain scour is expected to occur under overbank flow conditions, and potential meander cutoffs. Where any of these special considerations occurs, site-specific assessments and design measures will be necessary.

16.3.5 Bank Migration

Evaluations of bank migration are conducted primarily through aerial photograph interpretation and on-site investigations.

16.3.5.1 Aerial Photography Interpretation

Comparison of previous and current aerial photographs will be used to assess historical channel migration. For each stream crossing, superposition of the earliest available photography (between 1948 and 1955) and the most recent photography will measure channel migration distance. Migration will be determined by measuring the distance of migration between photographs normalized to the same scale and, preferably, under similar discharge conditions. Future migration rates will be considered based on this analysis. Additionally, since the most severe bank migration occurs during the comparatively short periods of high flow during large floods, comparison of photos before and after large floods will be analyzed where possible.

Recent aerial photography will also be used to delineate meander patterns that have developed over geologic time, and to recognize any stable geologic structures that may act as bank migration control points. These photos will also be used in estimating the bank migration induced by structures or other artificial regime changes.

16.3.5.2 On-Site Investigation

In conjunction with the aerial photography interpretation, site observation of the geology, vegetation and structures at the site will be used to assess the possibility of bank migration, bank incision or new channel development. Site specific cross-section surveys and discharge measurements will assist in determining whether the location of the main channel is relatively static or dynamic.

Aufeis and pre-breakup field inspection data will be used to examine the occurrence of severe ice buildups that may induce channel shifting, extensive bank scour and subsequent migration, or complete mass wasting of the banks. Past icing problems may also be detected in the observation of swales and vegetation scars.

16.3.6 Bank Protection and River Training Structures

Bank protection and river training structures are used to stabilize eroding banks and to control the flow along a pre-selected alignment.

16.3.6.1 Structure Type and Selection Parameters

The following structure types are suitable for use in arctic and subarctic streams:

- Revetments – Artificial surfaces, usually riprap, placed along channel banks or embankment slopes for erosion protection. Spur construction and layout details are shown on Figures 16-3, 16-4, and 16-5
- Channel Stabilization Aprons – Artificial surfaces, usually riprap, placed along the bed of a channel for scour protection. Channel stabilization design, construction and layout details are shown on Figure 16-9.
- Spurs – Embankments extending from a river bank into a river to direct flow away from critical zones, and prevent a significant channel from developing in the protected portion of the floodplain. Spur construction and layout details are shown on Figures 16-3, 16-4, and 16-5.
- Guide Banks – Embankments built almost parallel to a river channel to guide flow through a waterway opening. Guide bank construction and layout details are shown on Figures 16-6, 16-7, and 16-8.
- Dikes – Long embankments that are normally constructed on a floodplain or on a terrace to contain floodwaters within specified areas.
- Plugs – Plugs are embankments used to close off small secondary channels that could develop into major flow channels under high flow conditions.
- Biological Stabilization Techniques – A variety of techniques involving fertilization, seeding and plantings may be used in low-risk areas to stabilize or rebuild existing banks to resist bank migration and/or scour.
- Stabilization Using Natural Materials – Some stabilization methods make use of materials such as tree trunk/root masses, and mats or booms made of jute or other biodegradable materials. These methods are less intrusive, and may be applicable in certain low-risk applications.

The structures noted above may be used to protect the buried gas pipeline from exposure due to erosion or to minimize the length of deep burial. They may also be used at aerial crossings to improve design economy or safety.

The following factors will be considered when selecting the type of structures used for river training and/or bank stabilization.

- The type of river, i.e., braided, meandering, straight.
- Gas pipeline crossing alignment.
- The river width, depth and discharge.
- The length of reach to be protected.
- Feasible construction methods and availability of materials.
- Potential maintenance and repair considerations.

- Long-term effects on river flows and patterns and potential consequences to existing adjacent facilities.
- Navigation requirements.
- Foundation conditions.
- Economics.
- Conformance or adaptation to existing structures.
- Location of fish habitats and their seasonal uses.
- Riparian and wetland habitats.
- Risk and safety.
- Detailed design and construction methods and procedures will be prepared in subsequent phases of the project.

16.3.7 Geotechnical/Geothermal

The same geotechnical/geothermal considerations that apply to the ANGTS pipeline mile-by-mile design also apply to the design of river, stream and wetland crossings. These include slope stability, thaw plug stability, thaw settlement, liquefaction and frost heave. These considerations are addressed in detail in Section 21.

Site-specific geotechnical/geothermal design work will be carried out as appropriate in the final design phase of the project. Site-specific geotechnical information, concerns and recommendations will be developed for the design of critical or sensitive stream crossings. Geotechnical/geothermal evaluations, assessments and analyses will be incorporated into the stream crossing design via the following activities:

- Selection of the crossing construction technique.
- Habitat protection and restoration.
- Design of piers or piles for aerial crossings.
- Design of protection or stabilization methods.
- Determination of backfill requirements for buoyancy control measures.
- Assessment of bank and/or slope stability.
- Design of cut slopes and final grades.
- Design of civil restoration requirements.

16.3.8 Buoyancy Control

A buried pipeline may be buoyant. If evaluations indicate the pipeline will float, buoyancy control measures will be taken. Such measures will be considered at all crossings of streams, floodplains, wetlands and areas where geotechnical/geothermal analyses indicate a potential buoyant condition during construction or operations.

Buoyancy control measures will include heavy wall pipe, concrete coating, concrete saddles, screw anchors, sandbags, and geotextile swamp weights. Buoyancy control measures used during construction include de-watering the ditch if conditions permit, or filling the pipe with water to sink it and dewatering the pipeline after backfilling. Freeze-up conditions may preclude this activity.

The specific gravity of water in sand/gravel streams is typically near 1.00. However, to account for possible suspended sediment induced by construction operations, weighting calculations in streams with fine-grained bed material will be based on specific gravity as high as 1.25.

In calculating pipeline buoyancy, the forces resisting buoyancy will be at least 1.05 times the buoyant force. Density of backfill used in buoyancy calculations will be based on site-specific conditions where possible. Results of the buoyancy control calculations will also be used to set any necessary spacing requirements.

16.3.9 Environmental

Environmental criteria will be established for water crossing designs to minimize potential adverse impacts to the natural stream morphology and regime, in addition to protecting fish and wildlife habitats in the region of the crossing. Generally, water crossing design will incorporate environmental considerations which:

- Minimize in-stream construction time.
- Minimize damage to riparian habitat.
- Provide construction timing to avoid fish migration periods, and other biologically sensitive periods, where practical.
- Protect fish habitat.
- Avoid fish entrapment.
- Conserve both natural and visual resources.
- Minimize erosion, siltation and impacts on designated water uses.
- Minimize possible adverse effects of a chilled gas pipeline on a stream's thermal and biological regime.
- Minimize alteration of the natural hydraulic characteristics of the stream.
- Minimize stream bank disturbance.

Environmental concerns will be resolved during design for each water crossing classification. The final crossing design will draw upon an environmental database for each location and upon all applicable design criteria.

16.3.9.1 Fish and Wildlife Habitat

Environmental data has been gathered along the pipeline corridor. Utilizing this data during design and construction will eliminate or minimize impacts to fish and wildlife and their habitat. Design criteria will also assure compliance with the U.S. Army Corps of Engineers and Federal Right-of-Way stipulations as well as the FERC certificate conditions. The following factors will be considered in crossing design:

- Construction activities will be scheduled, where practical, within permitted timing windows.
- In-stream construction activity will be minimized.
- Undisturbed buffer zones between stream banks and staging areas will be specified on a site-specific basis. Site selection for staging areas will be based on satisfying construction needs while avoiding, where practical, sensitive areas adjacent to and in proximity of stream banks.
- Selection of the construction method will be based in part on minimizing environmental impacts.
- Adjacent and related structures, including river training structures, workpad bridges and culverts, will be incorporated into the design of water crossings with full consideration for protection of fish and wildlife habitat.
- Crossing design and construction will minimize fish blockage.
- Details of diversion operations will be required in water crossing construction plans. Diversion operations will be planned to minimize sedimentation and effects to fish habitat.
- Diversion structures will be removed or stabilized.
- Fluming techniques may be used to maintain downstream flow or to minimize siltation.
- Dam-and-pump techniques may be used to maintain downstream flow or to minimize siltation. Temporary embankments and/or sandbag-membrane dams may be used to collect stream flow during construction.
- Embankments and dams will be removed as quickly as practical following construction of the crossing.
- Screens will be used to prevent fish from entering pumps. Screen openings will be specified in accordance with ADF&G guidelines, based on pumping conditions, and on fish size.
- Downstream flow from pumping and/or fluming will be discharged on energy dissipaters, as needed, to minimize erosion and sedimentation. Temporary sediment traps may be required.
- Fluming allows downstream fish migration. Outfalls will be designed to minimize effects to downstream migrants.
- Ancillary structures such as sediment basins, silt fences, or other forms of sediment traps will be incorporated into design to minimize sedimentation of streams during and after construction.

- Potential detrimental effects caused by the presence of a chilled gas pipeline at water crossings will be minimized by specific designs for each water crossing classification.
- Streambed, stream bank, and adjacent disturbed areas will be restored to a stable condition after gas pipeline installation. Alteration of the natural habitat will be minimized.
- River training structures will be designed to minimize potential effects to riparian habitat and fish passage.

16.3.9.2 Bank Restoration

Water crossing topographic surveys will provide data for design of crossings and subsequent restoration of the disturbed areas. Bank restoration will be geared toward both hydrological and environmental aspects.

Restricting damage to stream banks is an important design consideration in alignment selection, staging area siting and construction planning. Ramping over stream banks, restricting clearing and necking down workpad widths at crossings are specific methods of minimizing damage to banks. Protective measures may be required to limit bank migration, to stabilize the slope and/or to minimize stream siltation.

Each water crossing is designed to assure that streambed and banks are suitably restored to allow minimal detrimental alteration to the hydrological and biological regime. The potential impact of bank restoration on adjacent facilities will be assessed and included in the crossing design.

Bank restoration requirements will be determined by an evaluation of topographic, hydrologic/hydraulic, geotechnical/geothermal and environmental concerns at each site. Disturbed fish bearing stream channels will be restored to original or better condition following gas pipeline installation.

High, steep, or unstable banks will be restored and protected as required. Armoring layers will be restored in armored stream beds following gas pipeline installation. Adverse effects to the natural riffling or aeration characteristics of streams will be avoided or minimized.

16.3.9.3 Water Quality

The primary potential impact to water quality is siltation/sedimentation during construction, and potential changes in the stream temperature caused by the presence of a chilled gas pipeline.

Siltation and sedimentation will be minimized during construction by temporary sediment basins or other forms of sediment trapping devices, by approved ditch dewatering procedures, by proper spoil storage, and by minimizing in-stream construction activity.

Thermal changes in surface and ground water will be minimized through optimized thermal/hydraulic design of the pipeline.

The design and construction of the gas pipeline will comply with State of Alaska Water Quality requirements, and where necessary, EPA requirements.

Consideration of impacts and controls can be divided into the following three general categories:

- Avoiding Potential Impacts

  Proper design and construction planning can minimize potential detrimental effects on water quality by optimizing crossing configuration and timing.

  – Scheduling of construction activities will avoid sensitive or high flow periods where practical, e.g. winter construction. Construction will be within a permitted timing window or the technique will be altered if outside the permitted timing window.

  – Stream bank cuts and fills will be designed to minimize surface disturbance.

  – Staging areas will be sited at sufficient distances from stream banks to minimize the potential for sediment to enter the water body. As well, siltation control measures will also be used to control sediment entering the waterbody. Staging areas will also be sited to minimize potential impacts to the existing protective vegetation.

  – Proper selection of materials and methods for bank restoration will minimize thaw degradation and control siltation.

- Erosion Control During Construction

  Measures to control soil erosion in disturbed areas during runoff will be outlined in an erosion control plan and Storm Water Pollution Prevention Plan. Such measures include:

  – Plugs to prevent ditch runoff into waterbodies.

  – Sediment basins to reduce sediment prior to flowing into a receiving body.

  – Stockpiling of soils to minimize potential for stream sedimentation.

  – Sediment trapping devices to intercept runoff that may be laden with sediment due to construction activities.

  – Stabilizing disturbed areas by surface protection or special grading methods.

- Sedimentation Control After Construction

  Sedimentation control practices (Section 11) and restoration measures (Section 12) will protect waterbodies from sedimentation caused by erosion of disturbed surfaces. Such measures include:

  – Armoring, vegetation, mulch, geosynthetics, or surface grading methods to reduce erosion potential of disturbed areas.

  – Diversion levees, waterbars, ditch, channels, and proper grading to minimize erosional forces of surface runoff and limit sedimentation of waterbodies.

  – Temporary and permanent sediment trapping devices including silt fences, sediment traps and sediment basins.

16.3.9.4 Visibility and Appearance

Minimize changes to the appearance of the water crossing area during construction and operation by:

- Utilizing existing topography and/or vegetation to screen the view of the crossing, staging areas and spoil storage areas.
- Minimizing the amount of clearing and disturbance at stream crossing sites.
- Minimizing visible cut slopes where practical.
- Providing line of sight buffers, where practical.
- Accelerating rates of native plant reinvasion using restoration measures described in Section 12.

16.3.10 Chilled Pipe Effects

Potential effects from operating a chilled buried pipeline at water crossings include causing aufeis formation (or increasing the potential for aufeis formation), and cooling water in the water body. The primary method for avoiding the effects of a chilled pipeline is to operate the pipeline as near as possible to the ambient ground temperature. The detailed pipeline route will be assessed to identify potential locations of concern with respect to aufeis and water crossings. The assessment will take into consideration surface water and groundwater conditions, upstream drainage areas, and proximity to adjacent facilities and fish habitats. The condition of the groundwater will be assessed based on a review of terrain type, hydrological field surveys and geotechnical investigation data.

A coupled hydraulics/geothermal model predicts the thermal profile of the pipeline and ground. A linear hydraulics model is comprised of the pipeline with two-dimensional “slices” of soil. The hydraulics model is used to predict pipeline temperatures along the route using the anticipated throughput and inlet temperature and pressure, and the properties of the gas as derived from the gas composition. However, the pressure and temperature of the flowing gas depends upon the heat flux through the pipe wall which, in turn, depends on the pipe interaction with the subsurface thermal state. The geothermal model uses a two-dimensional finite element approach to find the combined effects of the surface climatic variations and pipe wall temperature on the subsurface thermal conditions at the slice location. The result is a series of “snapshots” along the pipeline of the thermal conditions, which is in turn used to estimate the heat flux along the alignment to the flowing gas. For major streams and rivers the two-dimensional geothermal model will also include the convective thermal effects of the groundwater in addition to the heat conduction within the soil and radiation effects at the surface. The result is an accurate estimate of thawing of frozen ground, freezing of thawed ground and an analysis of potential effects on aufeis and surface water. Results of these analyses and analysis of frost heave and thaw settlement will be used to optimize the pipeline operating temperatures with regard to throughput and geotechnical conditions.

In addition to predicting the site-specific conditions at major rivers and streams, typical stream crossings will be modeled. The analysis of “typicals” will predict the potential effects from both conductive and convective heat transfer at streams of various sizes and flows, and at various pipeline operating temperatures.

Mitigative measures will be identified by the analysis of "typical" water crossings. The mitigative measures will be applied to those crossings identified as problem areas. The mitigative measures will satisfy environmental criteria as well as be compatible with requirements for adjacent facilities. For locations that are still a problem following application of the "typical" mitigation measure, further site specific analysis and mitigation will be required.

16.3.10.1 Workpad at Water Crossings

Workpad design at water crossings will depend on local site conditions and on the gas pipeline crossing requirements. Workpad crossings will generally fall into one of the following categories:

- Discontinuous workpad access utilizing alternate access, such as a crossing of the waterbody at another location. Crossings in this category will generally require a staging area on each side of the stream and approach grading on each side to permit access in and out of the river.
- Continuous workpad access by low water crossings. This method depends on stream size and configuration and fish presence as detailed in Section 11.
- Continuous workpad across cross drainage culvert. This crossing method depends on drainage design data. Standard workpad as detailed in Sections 9 and 11 will be used across the water in this case.
- Continuous workpad access maintained by temporary or permanent bridge, where practicable. Requirements for this type are covered in Sections 11 and 14.

Local site conditions, together with construction requirements and environmental constraints, govern the design of staging areas at river crossings. Generally, staging areas will be located on each side of crossings of larger streams. However, preference will be given to the use of single staging areas where practicable.

The crossing design will contain provisions for construction areas while addressing the applicable erosion, sediment control, and clearing criteria in addition to workpad construction criteria. Special designs will be required for thaw unstable bank conditions. At all stream crossings, environmental concerns will be identified and incorporated into the workpad crossing design with special emphasis on fisheries, water quality and visibility and appearance.

Larger water crossings will accommodate all interests in the workpad design. Workpad design of smaller water crossings will be governed primarily by drainage and construction requirements.

16.3.11 Aerial Crossings

The pipeline will be buried at most stream crossings. However, serious constructional, environmental, and economic concerns may preclude a buried crossing, and lead to the choice of an aerial crossing. Some of the factors that may lead to the choice of an aerial crossing are:

- Extremely high flow
- Extremely deep burial requirements
- Extremely long crossing
- Mitigative design requirements for buried stream crossings are impractical
- Geotechnical concerns including terrain stability, thaw settlement and liquefaction potential preclude a buried crossing
- Hydrological consideration including pre-existing guide banks or river training structures and deep scour preclude a buried crossing
- Mitigating potential detrimental aufeis accumulations is not feasible

Cable suspension bridges will normally be used for longer crossings. For shorter crossings, pile-supported free spans or plate girder bridges may be used.

Final design of aerial crossings will be based on detailed structural, hydrologic, and geotechnical/geothermal analyses, and considerations for environmental and adjacent facilities concerns.

16.3.12 Wetlands

Alteration of drainage patterns in wetlands will be minimized. Adequate drainage measures will be incorporated to insure preservation of wetlands. Interactions with third party drainage control systems will be considered. The effects of frost bulb growth on groundwater flow in sensitive wetlands will be minimized or avoided. Clearing of trees, brush and tall vegetation will also be minimized to reduce impacts to wetlands.

Utilization of existing access roads and temporary ice roads will minimize construction of new access roads. Some upgrading of existing access roads and their drainage control systems may be necessary.

Construction in wetlands will be primarily during the winter or shoulder months when the ground is frozen. This practice will provide firm support for equipment and enhance ditch wall stability while minimizing adverse impacts to wetlands. Construction traffic through wetlands will be minimized.

The criteria set forth in Section 11 for cross drainage, erosion control and siltation control will be met in the final design. The following measures will be used in wetland crossings:

- Equalization culverts will be included in workpad design to limit differential water levels on each side of the workpad.

- Topography, environmental site observations, surface water considerations and geotechnical data will be reviewed to assess normal water levels. These levels will be used to establish workpad thickness. Workpad design procedures are contained in Section 9.
- Clearing will be limited to the area required for safe and efficient operation of construction equipment. Clearing procedures are presented in Section 10.
- Materials and techniques utilized in restoration will be compatible with the local environment. Details of restoration are provided in Section 12. Restoration techniques will include but will not be limited to:
  - Regrading and restoring drainage patterns, where practicable.
  - Seedbed preparation through redistribution of surface materials and/or disturbed area surface scarification.
  - Passive or active revegetation.
  - Planting of cuttings, seedlings or transplants of native woody species.
  - Fertilization.

16.3.13 Depth of Cover

Depth of cover for streams, rivers, floodplains and wetlands will be specified on appropriate construction drawings based on the following analyses or requirements:

- Federal pipeline safety codes.
- Determination of scour potential.
- Assessment of future bank migration or channel shifting potential.
- Assessment of potential floodplain erosion.
- Determination of buoyancy control requirement.
- Assessment of mitigative measures for minimizing aufeis potential.
- Specific geotechnical/geothermal analyses.
- Stress analyses for bends.

16.3.14 Adjacent Facilities

River, stream, floodplain and wetland crossings will be designed to be fully compatible with existing adjacent facilities, i.e., other pipelines, river training works, roads and bridges.

Certain types of river training structures (e.g., spurs, dikes, plugs, guide banks) will only be used in those areas where the following basic hydraulic requirements can be met:

- Ensure that existing facilities, both upstream and downstream, are not endangered by shifting stream currents or increased channel velocities.

- Pass flood flows without causing unacceptable backwater effects upstream.
- Allow the passage of river ice floes, logs or other debris without endangering adjacent facilities as a result of jams and/or accumulations.

If assessment of the proposed design at a stream crossing location indicates the potential for detrimental impact to an adjacent facility, a crossing redesign, or design of protective measures for the adjacent facility which are compatible with its existing design and its operations will be utilized. Specific design requirements of adjacent structures will be considered in evaluating compatibility.

Construction activities in streams, floodplains and wetlands will be accomplished such that existing adjacent facilities are not damaged. Any adjacent facility that is damaged, modified, or disrupted as a result of gas pipeline construction activities will be restored as soon as practical to a state equivalent to the preconstruction condition.

Methods for breaching and restoring river training structures, as well as contingency plan requirements to ensure integrity of adjacent facilities while structures are breached, will be addressed in specifications and/or construction documents.

LIST OF FIGURES

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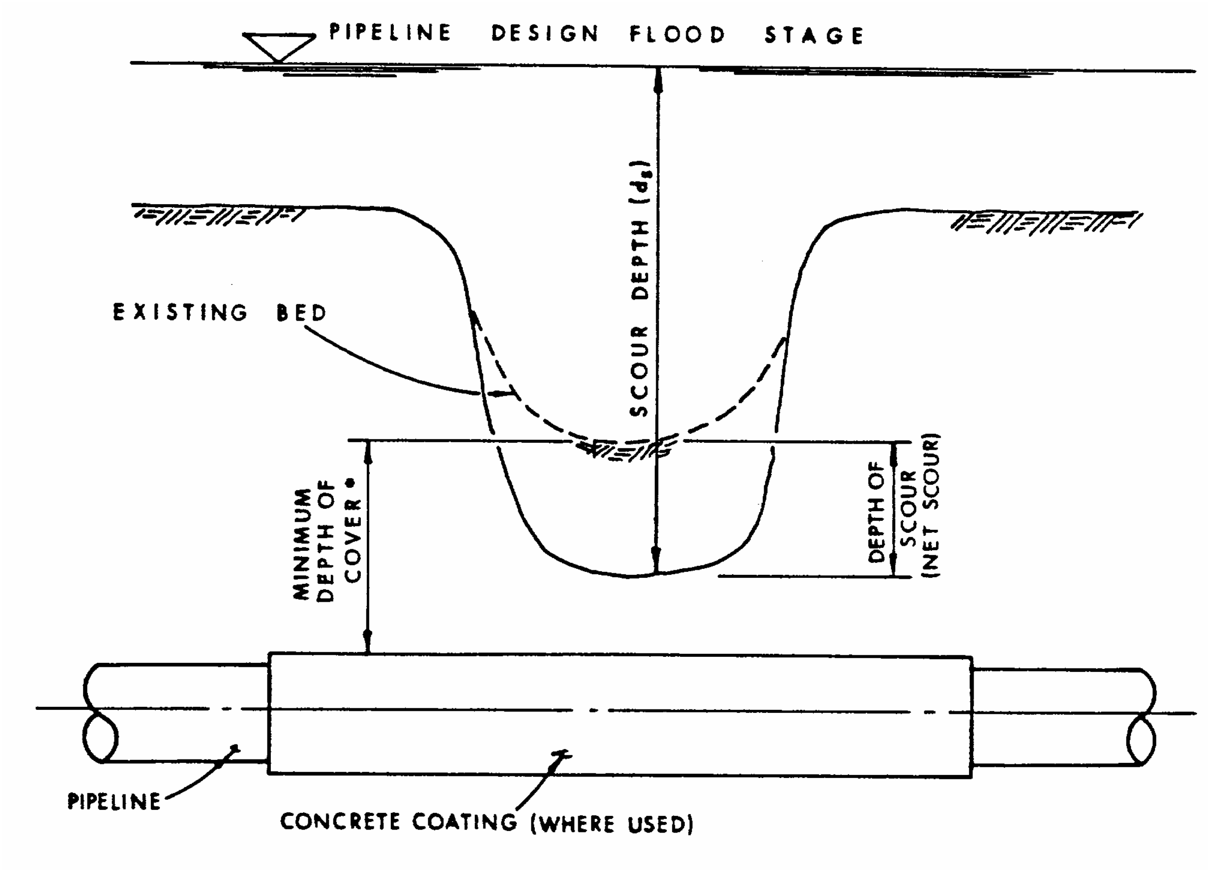

Minimum Depth of Cover = 4'-0"

Figure 16-1 Scour Definitions for a Typical River Crossing

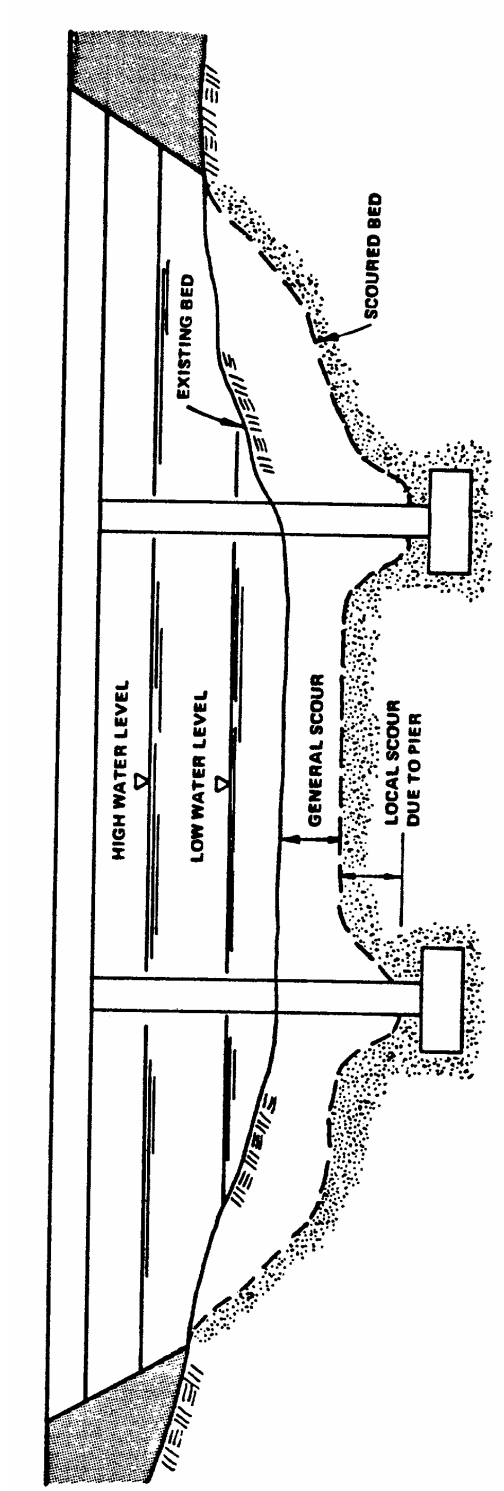

Figure 16-2 Typical Local and General Scour at Bridge Crossing

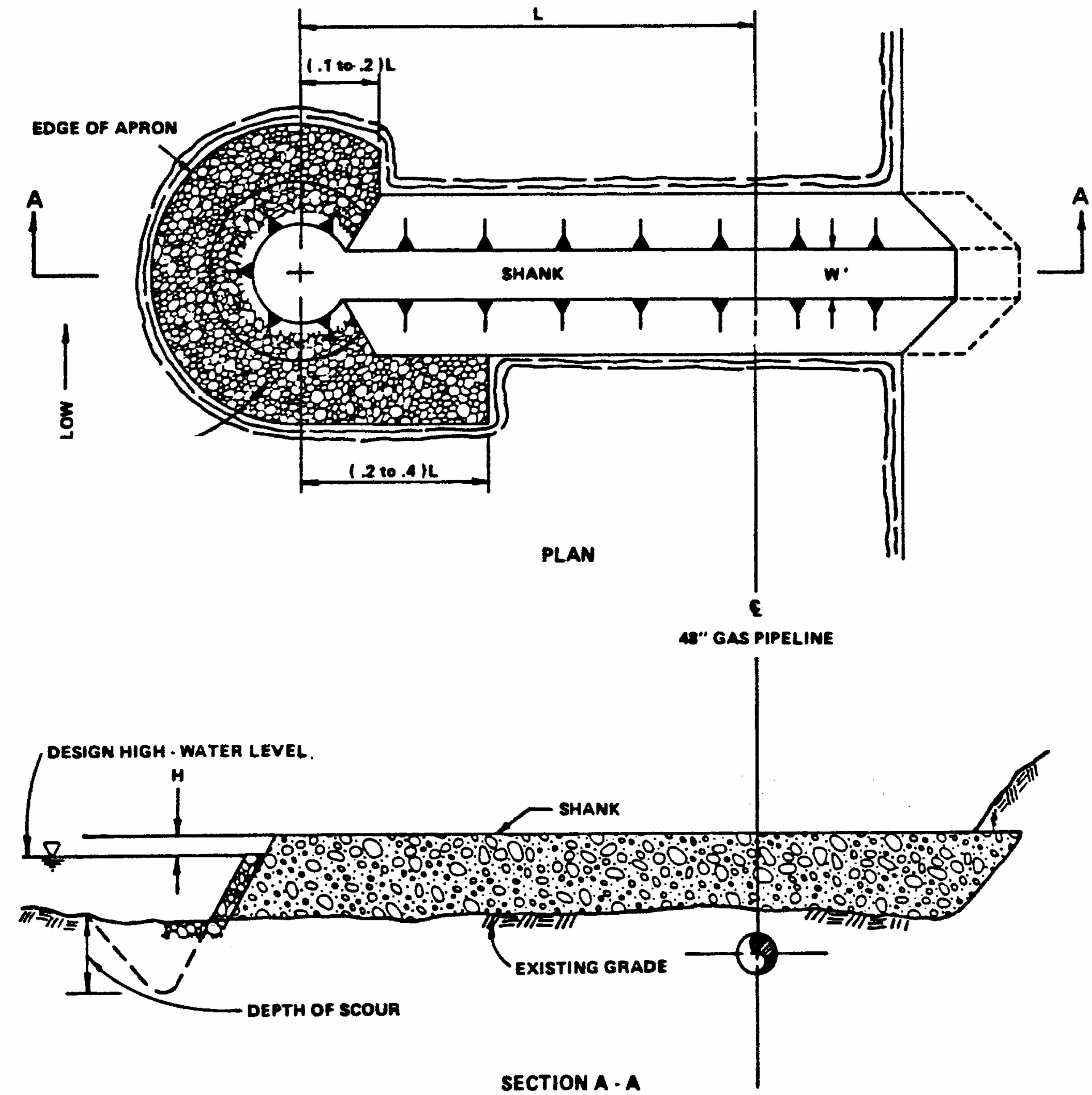

Figure 16-3 Typical Round – Nosed Spur

Notes:

1. *Dimensions L, W & H are site specific.*
2. *Vertical scale is exaggerated in section A-A.*
3. *Refer to subsection for TOE protection detail.*

TYPICAL – HEAD SPUR

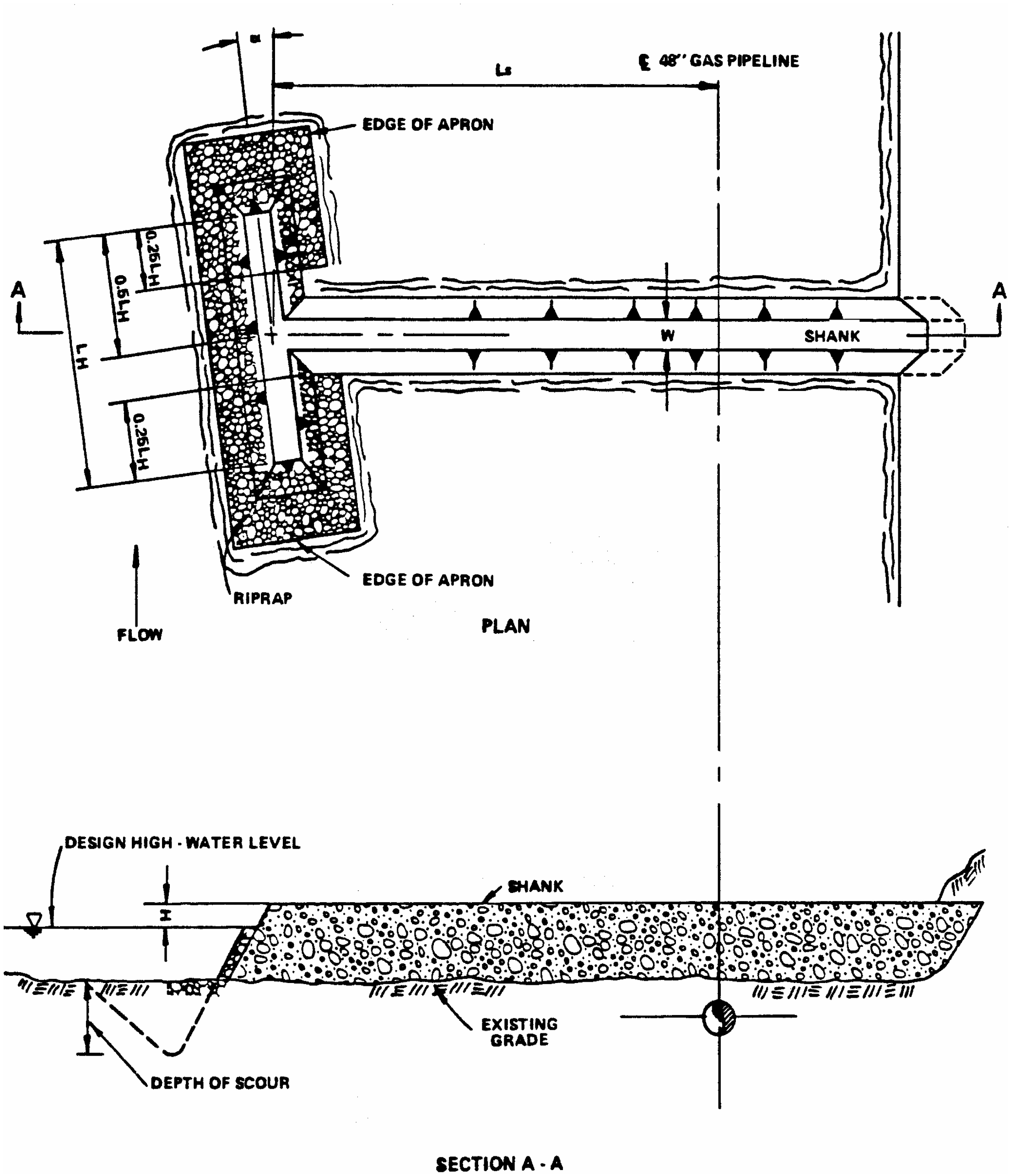

Figure 16-4 Typical Head Spur

Notes:

1. *Dimensions W, x L_H, H & L_S are site specific.*
2. *Vertical scale is exaggerated in section A-A.*

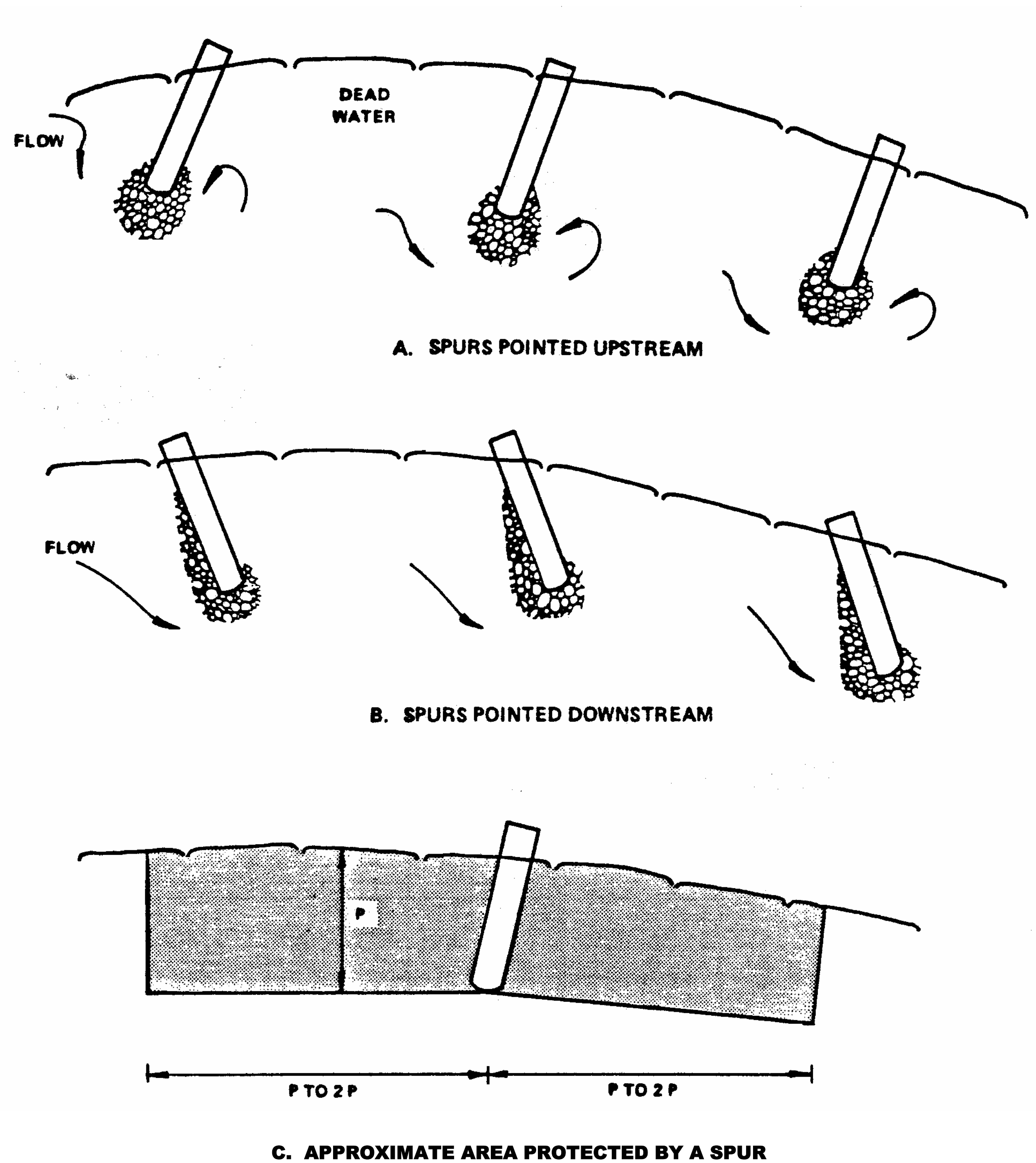

Figure 16-5 Orientation and Spacing of Spurs (After Neill, "Guide To Bridge Hydraulics "Roads And Transportation Assoc. of Canada, 1973)

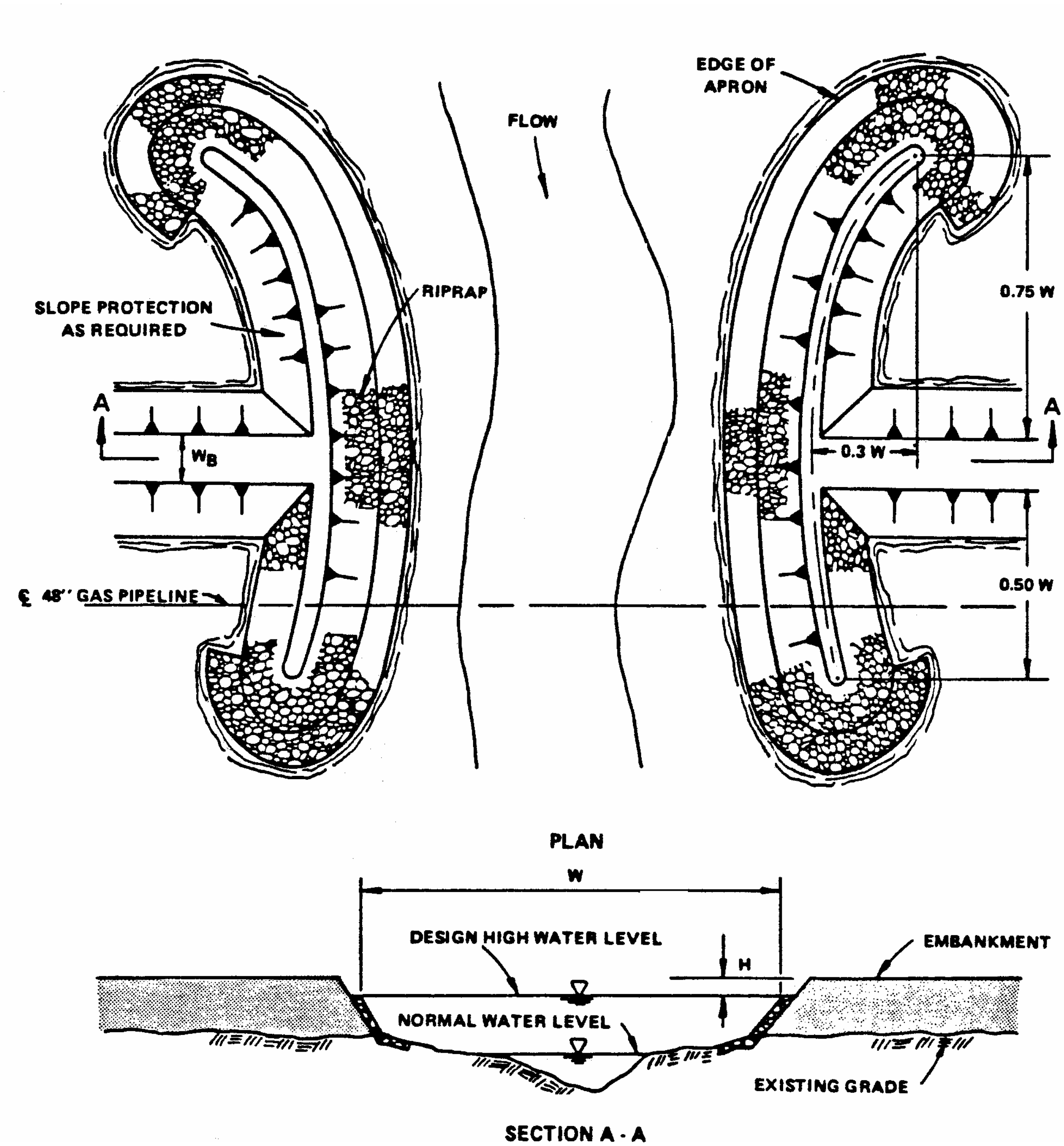

Figure 16-6 Typical Guide Bank Layout

Notes:

1. *Dimensions W, WB, & H are site specific.*
2. *Vertical scale is exaggerated in Section A-A.*
3. *Riprap sizes (embankment & apron) used are site specific.*

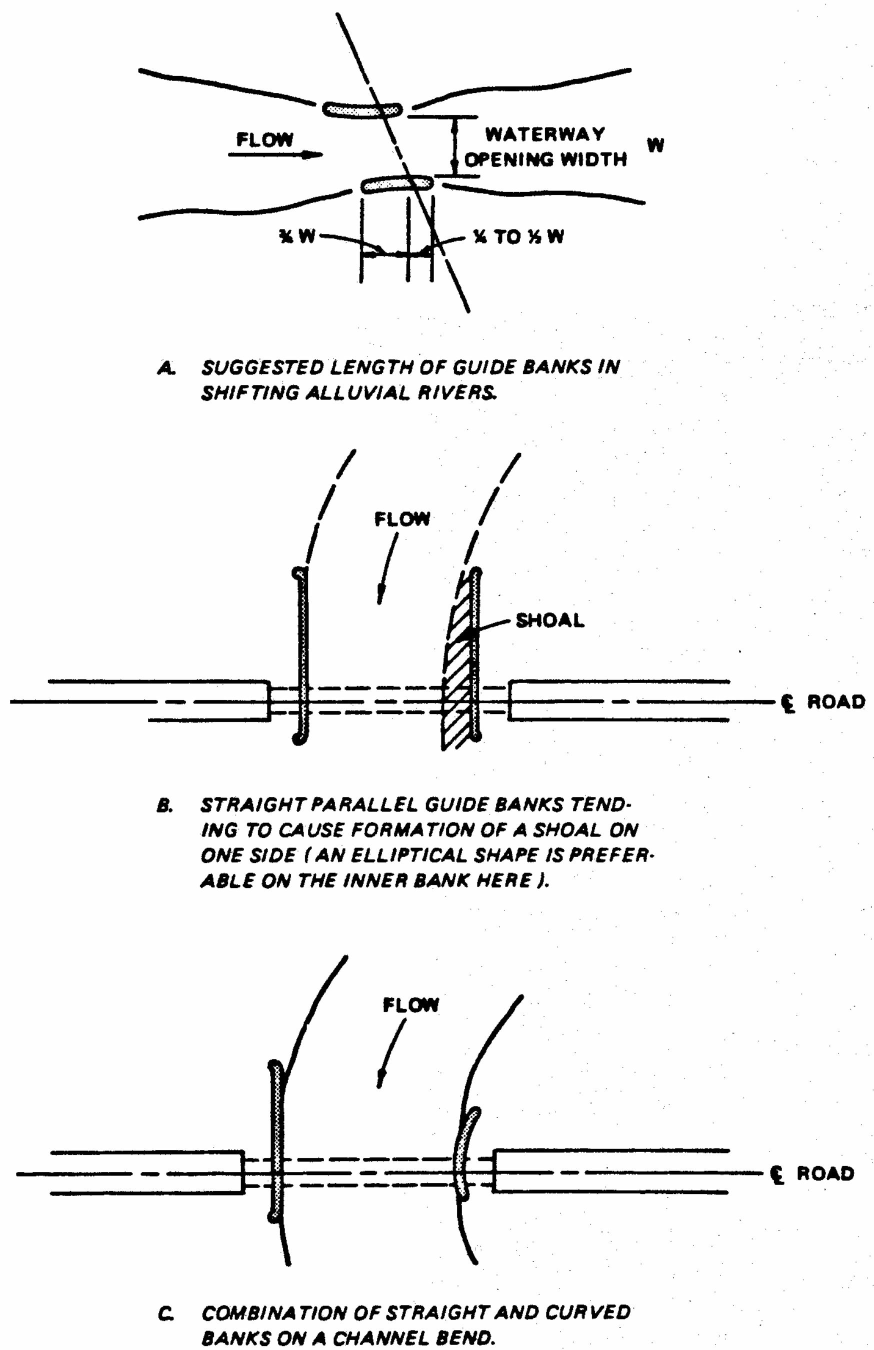

Figure 16-7 Guide Bank Layout
(After Neill, "Guide to Bridge Hydraulics",
Roads and Transportation Assoc. of Canada, 1973)

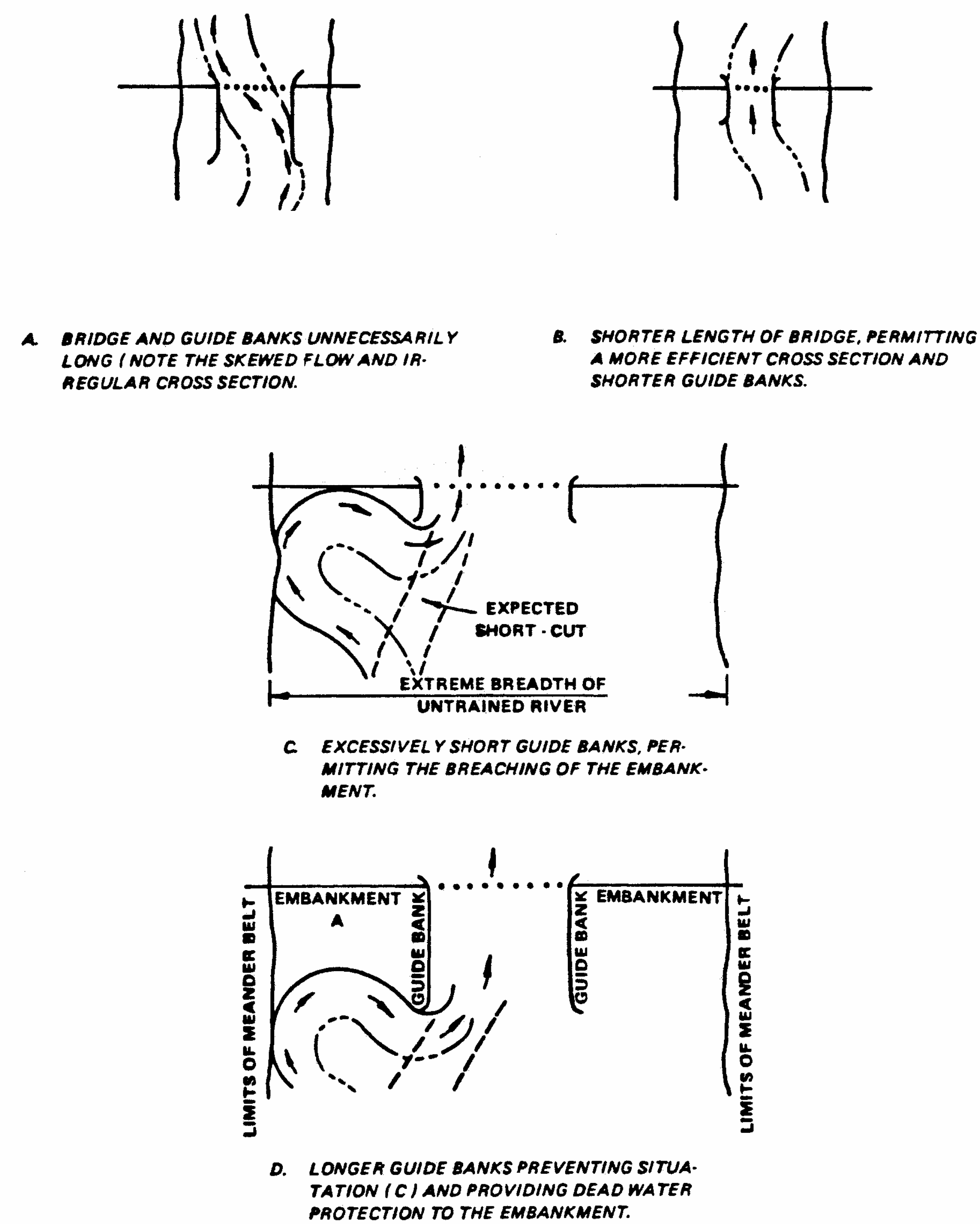

Figure 16-8 Guide Bank Length Considerations (After Neill, "Guide to Bridge Hydraulics", Roads and Transportation Assoc. of Canada, 1973)

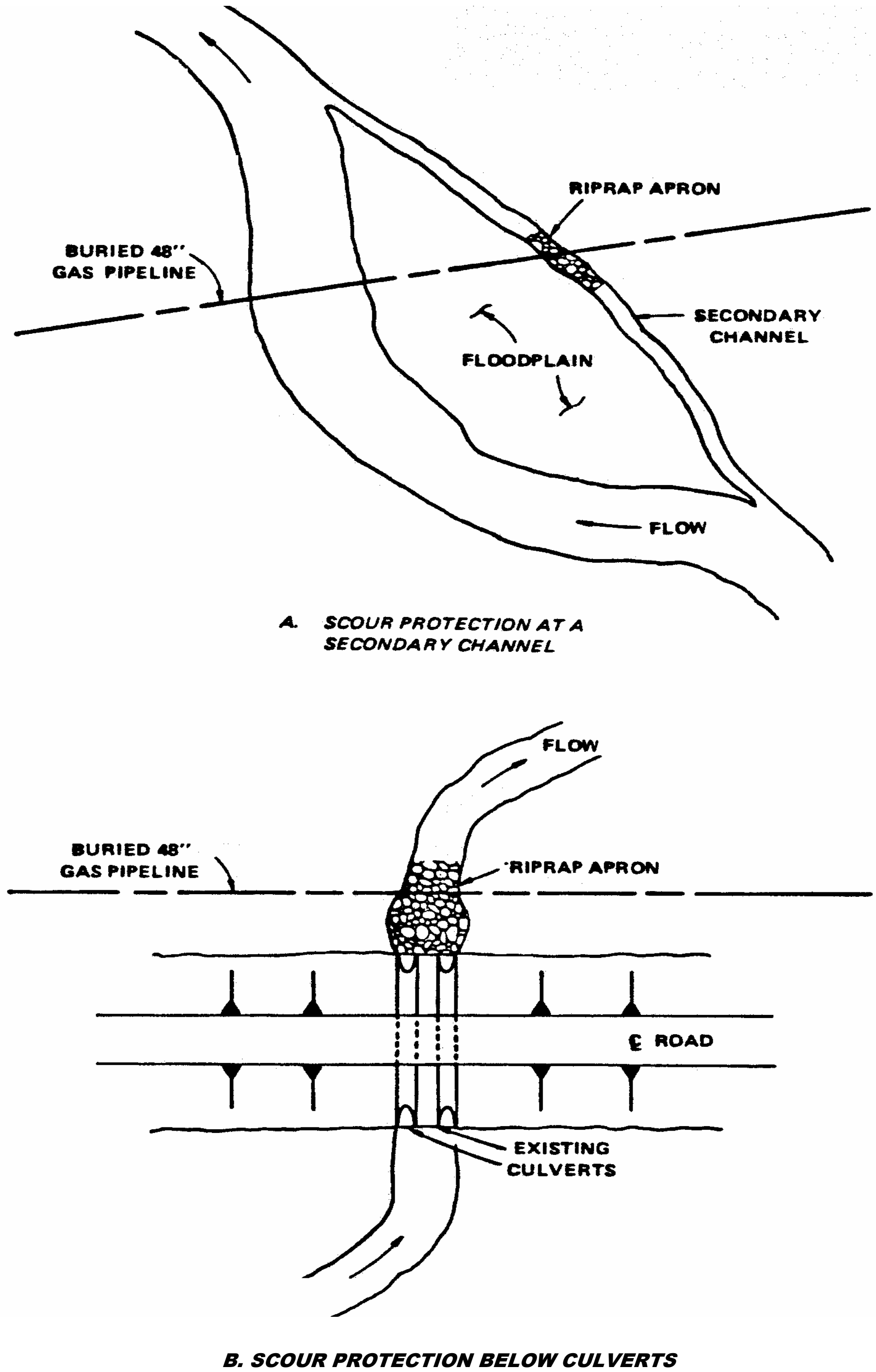

Figure 16-9 Channel Stabilization Aprons

			Environmental Considerations		Construction / Engineering Considerations		
Category	**Method**	**Description**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	**Appropriate Use**
OPEN TRENCHED	I) Plow.	▪ plow-in pipeline without pre-trenching ▪ feed or drag pipeline Into furrow behind Plow	▪ rapid construction / Installation ▪ minimizes Instrearn activity ▪ minimizes sediment release ▪ short period of sediment release ▪ maintains stream flow ▪ Maintains fish passage. ▪ minimal temporary workspace required	▪ grading of banks required ▪ potential sediment release during grading of banks ▪ sediment release during Instream work	▪ reduces Instream activity ▪ eliminates backfilling phase ▪ low cost if equipment onsite ▪ rapid construction / Installation	▪ specialized equipment ▪ need access ramps to creek ▪ problematic In boulders and bedrock ▪ depth of cover Is limited	▪ unconsolidated substrate ▪ watercourses ▪ shallow lakes or watercourses with little or no flow (<1 m) ▪ when pipeline on uplands Is also being plowed-in ▪ common for small diameter lines (<168.3 mm O.D.) ▪ where instrearn work is permitted but sediment release Is to be minimized
	II) Bucket/ Wheel Trencher	▪ trench through watercourse with bucket / wheel trencher	▪ rapid construction / installation ▪ minimizes instream activity ▪ short period of sediment release	▪ potentially high sediment release ▪ Spoil pile may block now ▪ trench Is prone to sloughing ▪ requires extensive grading of banks ▪ may block fish passage	▪ no special equipment ▪ not limited by width of watercourse ▪ low cost ▪ rapid construction installation	▪ limited by water depth (<11 m) ▪ trench is prone to sloughing ▪ trench may not be wide enough ▪ equipment has trouble on steep banks ▪ difficulty with rocky substrate or bedrock ▪ trench depth may be inadequate	▪ dry Intermittent watercourses with fine-textured substrate where wheel ditcher is being used on uplands ▪ possibly for low flow, low sensitivity streams with low banks ▪ Common for dry creeks. where sediment release is not a concern
	III) Hoe	▪ trench through watercourse with hoe from banks or instream	▪ rapid construction / Installation ▪ minimizes Instream activity ▪ maintains streamflow ▪ maintains fish passage ▪ relatively short duration of sediment release (< 24 hours)	▪ potentially high sediment release during excavation and backfilling ▪ Instream stockpiling of spoil on wide watercourses	▪ no need for specialized equipment ▪ rapid construction/installation ▪ low cost ▪ compatible with granular substrates and some rock	▪ limited to less than 20 m unless hoe works instream ▪ limited by water depth unless hoe works off barge ▪ may require several hoes working together to facilitate excavation	▪ shallow (< 1.5 m) watercourse with unconsolidated granular substrate ▪ most common method of watercourse trenching ▪ where sediment release is not a concern ▪ watercourses with low percentage of fines
	IV) Yo-Yo Dragline	▪ trench through watercourse with yo-yo bucket from either bank	▪ equipment not in watercourse ▪ spoil on banks ▪ maintains stream flow, ▪ maintains fish passage	▪ potentially high sediment release ▪ slow construction/ installation ▪ long duration of sediment release ▪ safety concern with cables strung across watercourse ▪ may require grading of banks leading to sediment release ▪ large area required for equipment	▪ permits many passes over trench ▪ cleans sloughed material from trench ▪ good for unconsolidated substrate	▪ moderately expensive ▪ inaccurate control on trench width and alignment ▪ slow construction / Installation ▪ specialized equipment ▪ trench susceptible to sloughing ▪ need large working space for equipment set up ▪ cables restrict navigational use of watercourse ▪ Incompatible with boulders or consolidated bottom material	▪ .wide and deep watercourses with soft substrate and limited navigational concerns ▪ common on larger. rivers ▪ where sediment release is not a concern ▪ watercourses with minimal bank height

Table 16-1 Pipeline Watercourse Crossing Construction Techniques
(After Table 3.1, Watercourse Crossings, Second Edition, Canadian Pipeline Water Crossing Committee, April, 1999)

			Environmental Considerations		Construction / Engineering Considerations		
Category	**Method**	**Description**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	**Appropriate Use**
OPEN TRENCHED (Cont'd)	V) Dredging	▪ dredge trench through watercourse with suction and pump slurry to banks or tanks on barges	▪ minimal sediment release during trenching ▪ maintains stream flow ▪ maintains fish passage ▪ no Instream spoil storage ▪ relies on natural sediment transport for backfill	▪ settling ponds required for slurry ▪ disposal of settled water ▪ possible mortality or Injury to fish	▪ allows deep water trenching ▪ technique for transporting to shore ▪ no instream spoil storage	▪ expensive ▪ specialized equipment ▪ settling pond must be constructed ▪ difficult In large granular substrate or bedrock ▪ trench depth may be Inadequate	▪ deep, wide rivers / lakes with fine unconsolidated substrate ▪ where sediment release Is a concern
ISOLATION	I) Flume	▪ block flow upstream of crossing and divert through pipe(s) laid In streambed perpendicular to pipeline ▪ dam downstream side of crossing area to prevent backflow ▪ flume should be pro-party sized to accommodate flow ▪ super flume Is a high capacity variation constructed out of 2 m x 3 m x 32 in steel box sections	▪ limited sediment release ▪ maintains stream flow ▪ capable of maintaining fish passage ▪ not likely to result In HADD downstream of the crossing	▪ sediment release during dam construction, removal and as water flushes over area of construction ▪ susceptible to washout /sloughing ▪ slow construction / Installation ▪ some bank and streambed disturbance may be required ▪ may dry up short reach of streambed ▪ potential icing problem in winter may cause flooding ▪ fish salvage required from dried up reach ▪ may block fish passage if water velocity in culvert is too high ▪ potential barrier to fish if ice builds up or if poorly Installed ▪ disposal of sedimentation In water may be problematic especially if dam seals are poor	▪ relatively dry or no flow working conditions ▪ ample time for pipeline construction ▪ may be adapted for in non-ideal conditions ▪ compatible with consolidated substrates	▪ difficult to trench and lay pipe, especially large diameter pipe, under flume pipe ▪ overbends may also cause problems when laying pipe under flume ▪ difficult to Install property ▪ slow construction / Installation ▪ common usage Is for flows <1 m^3/s ▪ flow limited by flume size 2 - 3 m^3/s using multiple flume pipes or super-flume >20 m^3/s ▪ an Increased number of or size of flume pipes increases construction difficulty ▪ Specialized equipment ▪ moderately expensive ▪ difficult to seal well ▪ crossing may not stay dry In coarse, permeable substrate ▪ flume size calculations must be made ▪ too short a flume may not be sufficient for unstable trench ▪ flume pipe can be crushed or blocked during pipeline construction ▪ requires relatively long, straight channel to Install flume ▪ blasting may be difficult, If required	▪ small watercourse with defined banks and defined channel with sold, fine-textured straight substrate ▪ where sediment release and fish passage are of concern ▪ works best in non-permeable substrate

Table 16-1 Pipeline Watercourse Crossing Construction Techniques (cont.)
(After Table 3.1, Watercourse Crossings, Second Edition, Canadian Pipeline Water Crossing Committee, April, 1999)

			Environmental Considerations		Construction / Engineering considerations		
Category	**Method**	**Description**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	**Appropriate Use**
ISOLATION (Cont.)	II) Dam and Pump	▪ dam flow upstream and downstream of crossing and pump water around via hose(s)	▪ limited sediment release ▪ maintains stream flow ▪ not likely to result In HADD downstream of the crossing	▪ sediment release during dam construction, dam removal and as water gushes over area of construction ▪ susceptible to washout / sloughing ▪ slow construction / Installation resulting in extended period instream ▪ may dry up short reach of streambed ▪ fish salvage required from dried up reach ▪ barrier to fish movement ▪ potential Icing problem In winter may cause flooding ▪ some bank and bed disturbance may be required ▪ disposal of sediment-laden water may be a problem, especially if seals are poor	▪ relatively dry working conditions ▪ ample time for pipeline construction ▪ may be adapted for non-ideal conditions ▪ hose can be routed around area of construction ▪ multiple pumps can be used ▪ compatible with consolidated substrates ▪ can be used in watercourses with meandering channel	▪ size of watercourse limited to pump capacity ▪ specialized equipment and materials ▪ slow construction / Installation ▪ moderately expensive ▪ hose(s) may impede construction traffic ▪ may occur In coarse, permeable substrate ▪ susceptible to mechanical failure ▪ requires standby pump(s)	▪ small watercourse with low flow, defined banks and channel with no requirement for fish passage ▪ where sediment release is of concern ▪ works best In non-permeable substrate ▪ common usage Is for flows <l m^3/s (max. capacity of 1 pump 0.3 m^3/s)
	III) High Volume Pump Bypass	▪ Install high volume pump(s) bypass In pad upstream of crossing and pump watercourse dry, discharging down-stream of crossing ▪ construct work area sump downstream of ditch to permit "washing" of work area ▪ pump silt-laden water from sump onto well vegetated area	▪ limited sediment release ▪ maintains stream flow ▪ normal stream flow can be restored Instantly ▪ no sediment release as a result of dam construction ▪ not likely to result In HADD downstream of the crossing	▪ minor sediment release as water flushes over area after construction ▪ dries up short reach of streambed ▪ barrier to fish movement ▪ potential Icing problems in winter may cause flooding ▪ fish salvage required from dried up areas ▪ sump areas are required	▪ no dams are required ▪ flow can be regulated if necessary ▪ hose(s) can be routed around area of construction ▪ multiple pumps can be used ▪ compatibility with consolidated substrates	▪ sump(s) may need to be excavated ▪ Specialized equipment and materials required ▪ moderately expensive ▪ hose(s) may Impede construction traffic ▪ requires stand-by pump(s) ▪ susceptible to mechanical failure	▪ small to moderate ▪ watercourses with low to moderate flow (1 m^3/s) and no requirement for fish passage (max. pump capacity 0.3 m^3/s)

Table 16-1 Pipeline Watercourse Crossing Construction Techniques (cont.)
(After Table 3.1, Watercourse Crossings, Second Edition, Canadian Pipeline Water Crossing Committee, April, 1999)

			Environmental Considerations		Construction I Engineering Considerations		
Category	**Method**	**Description**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	**Appropriate Use**
ISOLATION (Coni'd)	IV) Coffer Dam	▪ install dam approximately 2/3 into watercourse surrounding work area ▪ pump area dry or work In "still" waters ▪ remove dam and repeat on other side of watercourse ▪ materials such as regular sandbags, sheet piling, oversized (1 m^3) sandbags, rock fill /median barriers, poly water structures or a combination of the above can be used	▪ maintains stream flow ▪ maintains fish passage ▪ not likely to result in HADD downstream of the crossing	▪ limited to moderate sediment release based on amount of instrearn work ▪ May dry up long reach of watercourse ▪ fish salvage required from dried-up reach ▪ increased water velocity and potential scouring ▪ possible Increased erosion an opposite bank ▪ potential washout of dam ▪ slow construction / installation ▪ extensive Instream activity with heavy equipment may be required to Install dams ▪ requires large right-of-way and terrain disturbance	▪ relatively dry or no flow working environment ▪ ample time for pipeline construction ▪ compatible with consolidated substrates	▪ source of dam materials needed (i.e., sandbags, rock fill, poly, etc.) ▪ pumping may be required ▪ expensive ▪ specialized materials ▪ difficult to make tie-in ▪ slow construction / Installation ▪ potential washout of dam ▪ safety concerns	▪ moderate to large watercourses too large for flume or pump techniques ▪ where sediment release and fish passage are of concern ▪ braided stream channels ▪ watercourses with low banks ▪ where an extended instrearn period is required
	V) Channel Diversion	▪ divert stream flow into abandoned channel or construct new channel ▪ use rockhill, sheet piling or poly water structures to divert flow ▪ channel may be lined or have a flexible stream diversion conduit installed	▪ maintains stream flow ▪ maintains fish passage ▪ not likely to result In HADD downstream of the crossing	▪ unless lined, very high sediment release when new channel Is flushed through ▪ dries up long reach of watercourse ▪ fish salvage required from dried-up reach ▪ slow construction / installation ▪ potential washout of diversion dam ▪ damage to streambank and adjacent lands ▪ possible loss of topsoil and organic matter along new channel ▪ may alter stream flow	▪ relatively dry working area ▪ ample time for pipeline construction ▪ compatible with consolidated substrates	▪ expensive ▪ source of dam (i.e., sandbags, rock fill, poly, etc,) material needed ▪ may require channel liner or conduit ▪ may require extensive preparation and channel grading / restoration ▪ specialized materials required ▪ slow construction Installation	▪ watercourses too large to flume or pump ▪ best used when new channel is dear of fine substrate and will cause little sediment release ▪ braided stream channels ▪ where sediment release and fish passage are of concern

Table 16-1 Pipeline Watercourse Crossing Construction Techniques (cont.)
(After Table 3.1, Watercourse Crossings, Second Edition, Canadian Pipeline Water Crossing Committee, April, 1999)

			Environmental Considerations		Construction /Engineering Considerations		
Category	**Method**	**Description**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	**Appropriate Use**
TRENCHLESS	I) Boring	▪ bore under water-course from bellhole on one side to bellhole on other with or without casing ▪ wet boring with pilot hole and reaming bit can also be performed	▪ no sediment release ▪ no disturbance of streambed or banks ▪ maintains normal stream flow ▪ maintains fish passage ▪ maintains vegetative buffer on either side of watercourse ▪ not likely to result in HADD	▪ pump(s) may be required to drain within the bellholes onto surrounding lands ▪ possibility of sump water causing sediment release in watercourse ▪ requires additional workspace for bellholes, spoil piles and sump(s) ▪ potential for borehole cave-in	▪ can be fast and economical under the right conditions ▪ minimizes clean-up of bed and banks ▪ road boring equipment may be available	▪ can be slow or not feasible under adverse conditions ▪ difficult with till or coarse material ▪ potential for borehole cave-in ▪ excessive borehole depth on deeply incised watercourses or watercourses with moderate or greater approach slopes ▪ with excessive seepage in course fluvial material it may be Impossible to keep hole dry ▪ seepage into bellhole, may cause sloughing ▪ possible need for specialized equipment and pump(s) ▪ limited to approximately 100 m	▪ One-textured impermeable soils ▪ low water table ▪ where streambed cannot be disturbed ▪ used most often on Irrigation ditches ▪ where fish / riparian habitat cannot be disturbed ▪ where the watercourse Is only slightly Incised and approach slopes are absent or slight
	III) Punching I Ramming	▪ ram or punch casing or pipe under watercourse	▪ no sediment release ▪ no disturbance of streambed ▪ no bank disturbance ▪ maintains normal stream flow ▪ maintains fish passage ▪ maintains vegetative buffer on either side of watercourse ▪ not likely to result in HADD	▪ pump(s) may be required to drain seepage within the bellholes onto surrounding lands ▪ possibility of sump water causing sediment release In watercourse ▪ requires additional workspace for bellholes, spoil piles and sump(s)	▪ can be quick under the right conditions ▪ minimizes clean-up of bed and banks ▪ cave-ins of borehole are unlikely ▪ larger pipe diameters can be accommodated	▪ can be slow under adverse conditions ▪ potential bellhole cave-in ahead of ram ▪ seepage into bellhole ▪ with excessive seepage In coarse fluvial material it may be Impossible to keep hole dry ▪ Specialized equipment may be required ▪ potential corrosion problems from coating stepping ▪ relatively Inaccurate ▪ limited to ~ 50 m In length ▪ excessive borehole depth on deeply incised watercourses or watercourses with moderate or greater approach slopes	▪ fine-textured impermeable soils ▪ low water table ▪ Irrigation ditches ▪ where streambed cannot be disturbed ▪ can also be used In coarse-textured substrate ▪ narrow to moderate watercourse (i.e., <30 m) ▪ where the watercourse is only slightly incised and approach slopes are absent or slight

Table 16-1 Pipeline Watercourse Crossing Construction Techniques (cont.)
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			Environmental Considerations		Construction / Engineering Considerations		
Category	**Method**	**Description**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	**Appropriate Use**
TRENCHLESS (Cont'd)	III) Directional Drilling	▪ slant drill used to drill under watercourse and, where practical, approach slopes	▪ no sediment release ▪ no bank disturbance ▪ no streambed disturbance ▪ may avoid approach slope disturbance ▪ maintains normal stream flow ▪ maintains fish passage ▪ not likely to result in HADD	▪ disturbance of chilling and target area ▪ disposal of drilling fluids ▪ fractures In substrate may release pressurized drilling fluids Into watercourse ▪ circulating drilling fluid may washout cavities under the watercourse and banks resulting In sinkholes ▪ possible spills from drilling sump(s) down towards watercourse ▪ large space requirements on flood plains	▪ eliminates clean-up arid reclamation in between entry and exit points	▪ moderately to very expensive ▪ depends on substrate/ bedrock ▪ specialized equipment ▪ slow construction / installation ▪ limited to arc that can be drilled for plot hole (10-20° entry / exit angles) ▪ limit arc that pipe can "rope" through the hole, especially large diameter pipe ▪ may take several attempts ▪ drill stem may get "stuck In the hole" and tools get lost ▪ no guarantees that drill will be successful	▪ large watercourse with sensitive habitat where no instream activity allowed ▪ areas with very unstable approach slopes ▪ high aesthetic concerns (i.e., parks)
	IV) Micro-tunneling	▪ use a small tunnel boring machine to create a tunnel for the pipe or casing	▪ no sediment release ▪ no bank disturbance ▪ no streambed disturbance ▪ no approach slope disturbance ▪ maintains normal stream flow ▪ maintains fish passage ▪ not likely to result in HADD	▪ tunnel spoil / slurry requires large areas ▪ disposal of tunnel spoil ▪ large space requirements on flood plains	▪ can be utilized in most substrates above or below the water table ▪ eliminates clean-up and reclamation in streambed and banks	▪ special equipment and crew are required ▪ limited by length of pipe to be pushed and the friction forces imposed ▪ high cost ▪ tunnel spoil / slurry may require removal or settling tanks and water treatment it chemical lubricants were used	▪ large diameter pipelines ▪ watercourse crossings with ample room for tunnel spoil storage and bellhole ▪ high aesthetic concerns (i.e.,parks)
AERIAL	I) Bridge Attachment	▪ attach pipeline to existing bridge structure	▪ no sediment release ▪ no bank disturbance ▪ no streambed disturbance ▪ maintains normal stream flow ▪ maintains fish passage ▪ not likely to result In HADD	▪ possible visual Impact ▪ safety and potential introduction of product into watercourse due to third party damage	▪ eliminates clean-up and reclamation of bad and banks	▪ potentially expensive ▪ depends on bridge design ▪ specialized crew and equipment ▪ slow construction / installation ▪ potential for third party damage ▪ regulatory approval may be delayed or denied ▪ ongoing maintenance required ▪ approach bends may prevent pigging of pipe	▪ large watercourse with sensitive habitat where no instream activity is allowed ▪ areas with very unstable approach slope ▪ high aesthetic concerns (i.e., parks) ▪ where an existing bridge has been built ▪ deep gorges /canyons ▪ urban areas where bridges are abundant
AERIAL	II) Sell-Supporting Bridge or Span	▪ construct bridge or abutments to carry pipeline	▪ no sediment release ▪ no streambed disturbance ▪ no bank disturbance ▪ maintains normal stream flow ▪ maintains fish passage ▪ not likely to result In HADD	▪ visual Impact ▪ safety and introduction of product into watercourse due to third party damage ▪ Instrearn construction required for bridge abutments	▪ eliminates clean-tip and reclamation of streambed and banks	▪ very expensive ▪ specialized crew and equipment ▪ slow construction / Installation ▪ potential for third party damage ▪ regulatory approval may be delayed or denied ▪ ongoing maintenance required ▪ approach bends may prevent pigging of pipe	▪ large watercourse with sensitive habitat with no instream activity is allowed ▪ areas with very unstable approach slopes ▪ deep gorges / canyons

Table 16-1 Pipeline Watercourse Crossing Construction Techniques (cont.)
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