River and Stream Crossings Study (Phase I) Executive Summary

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F-9806(A)

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Project Background and Work Scope

There is a growing concern within the natural gas pipeline industry that turbidity based permit requirements for pipeline water crossings may be overly conservative and difficult if not impossible to achieve. Many jurisdictions use turbidity, measured in nephlometric turbidity units (NTU), as a means of measuring and controlling sediment released during water crossing construction. Instantaneous excursions above the stated limits can result in construction delays through work stoppage orders and/or prosecution of project sponsors and contractors for violations of State water quality standards. The widespread application of single turbidity standards (27 or 29 NTU's) across the United States; the apparent lack of consideration for natural fluctuations; and, the poorly defined link between turbidity levels and adverse biological effects suggest that current standards are not based on scientifically defensible knowledge of the effects of sediment released from pipeline water crossings.

In addition to concerns over the validity of turbidity standards, the natural gas pipeline industry has noticed growing support for Horizontal Directionally Drilled (HDD) crossings as the preferred by regulatory agencies. Often HDD is viewed as the solution to all environmental problems associated with water crossing construction. Some insist that is the only allowable crossing technique for certain watercourses.

While most will agree that under the appropriate conditions HDD can be a cost effective and environmentally acceptable means of crossing construction, it should not be viewed as a panacea for addressing the environmental effects of pipeline construction. Rather, HDD should be among the suite of crossing techniques available to the industry for use as conditions dictate. Additionally, the effects of HDD crossing construction have not been well studied. A better understanding of potential environmental impacts from HDD crossings is required for balanced evaluation crossing techniques and their application to the specific water crossings.

These concerns and along with a literature review on the origin of turbidity criteria prepared by Argonne laboratories on behalf of the Gas Research Institute (GRI) were discussed at the Foundation Seminar on River and Stream Crossings[1] held in Orlando Florida September 8, 1995. Over 40 industry, research and government representatives attended this meeting. The meeting included an on-site survey of the post-construction impact of five rivers and streams that were crossed with various pipelining techniques. The following research questions were identified during this meeting.

- What are the impacts of concern associated with open-cut stream crossing methods?
- How do these concerns and scientific interpretation of criteria vary across the geographic (i.e. ecosystem) and regulatory landscape?
- How can alternative criteria for limiting sedimentation events be translated into permit guidance and conditions covering construction alternatives, methods and mitigation approaches?
- On balance, what is the role of methods such as directionally drilling in terms of overall cost effectiveness?

Golder Associates Limited (Calgary) was retained by the INGAA Foundation to undertake Phase I of the River and Stream Crossing Study intended to address these questions. The project includes five reports and CROSSING™, a personal computer-based decision and assessment support tool.

The following deliverables are included in this package:

- River and Stream Crossing Project (Phase 1), *Executive Summary.*
- CROSSING™ Beta Version 1.0 (Software) and Instruction Manual, *Stream Crossing Decision Support System Beta-Version Topical Report.*

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[1] Additional information on this meeting can be obtained by requesting the INGAA Foundation Report titled, "Pipeline River and Steam Crossing Techniques".

Three additional technical reports can be obtained with the order form in the back of this Executive Summary:

- Sediment Entrainment Due to Pipeline Watercourse Crossing Construction (Technical Report 1).

- Suspended Sediment and Turbidity Criteria Associated with Instream Construction Activities: An Assessment of Biological Relevance (Technical Report 2).

- Review of Environmental Issues Associated with Horizontal Directional Drilling at Watercourse Crossings (Technical Report 3).

Generation of Sediment at Pipeline Water Crossings

The first report, **"Generation of Sediment at Pipeline Water Crossings"**, identifies the processes of constructing pipelines across rivers and streams. Listed below is the crossing processes that were reviewed.

Project Background

Sediment generation and transport models are useful to resource managers and environmental planners for estimating the amount of sediment added to the natural stream sediment loads by the construction of pipeline water crossings; determining the spatial area of the watercourse that may be affected by elevated concentrations of suspended sediments; and in the identification of areas that may be affected by sediment deposition. However, current approaches are limited by untested judgements of the amount of sediment generated during instream construction and advanced modelling of these judgements to predict downstream suspended sediment concentrations.

Objectives and Approach

The study objective was to develop a predictive approach for determining suspended sediment concentrations downstream of open-cut pipeline water crossings. The report describes a physical based model that quantifies the relationships between basic stream characteristics (depth, flow and velocity) and suspended sediment concentrations generated during construction of open-cut water crossings of watercourses having primarily non-cohesive (sand and gravel) bed materials. Equations used in the model were developed from a literature search of recent pipeline crossing sediment transport research and sediment load monitoring data from 11 crossings of sand - gravel bottom streams in Alberta, Canada.

Selected Extracts

The first report identifies the processes of constructing pipelines across rivers and streams. Listed below are the crossing processes that are reviewed:

Review of Potential for the Generation of Suspended Sediment by Different Open-cut Trenching Techniques
(adapted from TERA 1996)

Method	Level of Sediment Generation	Applicability
Backhoe	• Substantial levels of turbidity can be generated during trenching and backfilling. • As the technique is fast, the duration of sedimentation can be limited. • Can be used in conjunction with isolation methods such as dam and pump and partial diversion if sediment concerns are high.	• Appropriate for use in all widths of shallow streams. Can be adapted, or used in conjunction with other methods for crossings of greater depth. • Best applied when sediment concerns are low or when minimizing the duration of construction is seen as the best mitigative measure.
Plough	• Overall, the degree of sedimentation is low as there is limited disturbance to the substrate and backfilling is not required. • Generation of turbidity limited to grading of streambanks.	• Shallow watercourses (<3.1 ft or 1 m) with little or no flow and soft substrates. • Low scour potential, therefore, high depth of cover not required for pipe integrity. • Applicable to watercrossings where instream activity is allowed but sedimentation is to be minimized.
Dragline (Yo-Yo)	• Method is slow, requiring numerous passes with the bucket thereby subjecting the watercourse to long periods of elevated sediment load.	• Appropriate for moderately deep (< 30.1 ft or 10 m) wide (> 60.2 ft or 20 m) watercourses with soft substrates. • Best applied when sediment concerns are low.
Dredge	• Sedimentation is limited to when the dredge is used and instream storage of spoil is not required. • Concern regarding proper settling of dredged slurry before discharge.	• Appropriate for large, deep watercourses with soft substrates. • Appropriate in areas of higher sediment related concerns since sedimentation is limited.
Bucket Wheel Trencher	• Crossings can be quickly excavated and therefore the duration of sedimentation is minimized. • Since spoil is stored instream, high sediment loads may result.	• Shallow (<3.1 ft or 1 m) watercourses with firm substrates (no cobbles, or bedrock) . • Sedimentation should not be a concern and streamflow should be absent or low.

An analytic model is developed to predict the amount and dispersion of sediment from different types of pipeline crossings and is correlated with available data from pipeline crossings. Some of the variables included in the analysis are:

- water depth;
- water velocity;
- stream width;
- stream gradient;
- size distribution of bed material;
- stream sinuosity; and
- equipment used in dredging and filling.

A survey of present state, federal and provincial standards is included and the results are analyzed. An example of the results is shown:

Table 5.5

State-specific Breakdown of Various Approaches Implemented to Minimize the Release and Effect of Sediment during Pipeline Installations Across Watercourses

(States for which no permitting information was obtained are omitted)

State	Conditions, or restrictions applied to minimize sediment release and associated effects
Alabama	• allowable increase of 50 NTU above background conditions
Colorado	• numerical limits, or turbidity monitoring absent as most construction done during low flow conditions
	• no instream timing restrictions
	• numerical suspended sediment limits for discharge of hydrostatic testing waters: 30 mg/L, 30- day average/ 45 mg/L, 7-day average.
Florida	• required to adhere to specifications for prevention, control and abatement of erosion and water pollution as stated in section 104 of the Florida Department of Transportation – Standards for Road and Bridge Construction
	• BMPs to control erosion and turbidity advocated by DEP: staked silt screens, haybales, and filtercloth, coffer dams, flume pipes and pumps, and equipment mats
	• Equipment bridges for vehicle and heavy equipment crossings of watercourse
	• Required turbidity monitoring, no elevation of background levels for Outstanding Florida Waters (OFW), or above a 29 NTU increase in other waters or exceed the parameters specified in the variance. 800m mixing zone, at end of mixing zone not to exceed 1000 NTU for more than 12 consecutive hours and 3000 NTUs for 3 consecutive hours.
	• within 5 days after the beginning of trenching, turbidity 150 m downstream of the crossing shall not exceed 29 NTUs above natural levels.
Georgia	• required turbidity monitoring before, during and after construction
	• require erosion control, revegetation and maintenance plan
	• instream construction finished within 48 hrs, no installation of flume/rock fill/gravel equipment crossings
	• during construction no numerical restrictions. If after construction turbidity is > than 20 NTU then SNGC would have to take appropriate measures to rectify the problem
Idaho	• for eight Moyie River crossings, a 50 NTU instantaneous maximum or 25 NTU averaged over 10 days. No statistical increase in stream embeddedness permitted either.
	• to prevent effects of elevated turbidity on waterfowl, construction was limited to the night.
Illinois	• no turbidity related restrictions
Kansas	• no turbidity related restrictions
	• no TSS/turbidity standards implemented
Kentucky	• no numerical standards or monitoring requirements, most crossings 24 hr open -cut during low flow or dry conditions - turbidity not an issue -
	• follow FERC guidelines for construction methods
Louisiana	• no turbidity related restrictions

State	Conditions, or restrictions applied to minimize sediment release and associated effects
Maryland	• flumed crossing • gabion and riprap on banks • trench water pumped into sediment traps • Maryland requires dry-ditch crossings of trout streams. Other techniques only considered if trenchless crossing not feasible • construction timing window
Michigan	• silt fences and haybales downstream of open cut crossing, no NTU monitoring required (except for hydrostatic testing) • no TSS/turbidity standards placed on permits by DNR or Army Corps. • use of sediment trap and sediment to control sediment during Aux Sable River crossing • emphasis on minimizing the duration of construction • 48 hour limit to instream activity after July 1st • flumed crossing with rip rap on banks • two stage coffer dam; rock rip on banks, sump dewatered and 7 day construction window
Minnesota	• instream silt fences • 48 hour instream limit
Mississippi	• no numerical standards or monitoring requirements, most crossings 24 hr opencut during low flow or dry conditions - turbidity not an issue – follow FERC guidelines
Montana	• use of coffer dams • no instream spoil storage, or equipment in watercourse
Nebraska	• no turbidity related restrictions
Nevada	• rock-dam sediment barrier downstream of open-cut
New Mexico	• no turbidity related restrictions • downstream sediment monitoring • use of concrete barriers, bladders • two-phase river crossing • temporary coffer dams not to made of materials that will cause a violation of state turbidity standards for the San Juan, Animas, and La Platta Rivers • permittee is responsible for monitoring for any turbidity plumes - if a plume is detected work will cease until it can be remedied • exposed, erodible fills will be protected from being washed away into the river during project construction and will be removed, and/or stabilized after construction.
New York	• numerical limits have been attached however not consistently: 10 NTU maximum increase outside a 300 ft mixing zone • spoil not stored instream • dam and pump, flumed and two stage coffer dam crossings • silt fences and armoring of streambanks • 48 hour limit to instream activity • construction timing windows • application of sediment mat to control downstream sediment deposition in central and western New York

State	Conditions, or restrictions applied to minimize sediment release and associated effects
North Dakota	• silt fences on exposed banks • flumed crossings • crossings during low flow, or dry conditions • minimize duration of instream activity
Ohio	• no turbidity related restrictions • numerical restrictions, or monitoring requirements rare as most streams are not of high quality.
Oklahoma	• no suspended sediment or turbidity standards being implemented
Pennsylvania	• numerical restrictions or monitoring requirements rare as most streams are not high quality.
South Dakota	• flumed crossings • minimize duration of instream activity • crossings limited to low flow. or dry conditions
Tennessee	• 50 NTU allowable increase above background levels
Texas	• no numerical standards or monitoring requirements • most crossings 24 hr opencut during low flow, or dry conditions
Utah	• no numerical limits or monitoring • construction under low flow conditions • follow conditions laid out in Nationwide Permit No. 12 • minimize the duration of instream activity • coffer dams, fluming or other foreign material not allowed in river
Virginia	• numerical restrictions or monitoring requirements rare.
Washington	• flumed crossing • 48 hour limit to instream activity after July 1st • washed backfill gravel • temporary diversion • construction window after July 15
West Virginia	• numerical restrictions or monitoring requirements rare.
Wyoming	• no numerical turbidity limits, or monitoring requirements • timing restrictions on construction; low flow, or dry conditions • flumed crossings • emphasis on minimizing the duration of instream construction and the water volume

Summary

Through the identification of dominant physical processes, four regression equations were developed to predict sediment loads in gravel rivers during the following construction phases: the entire construction period; trench excavation; trench backfill; and, river scour of the exposed trench. Fall velocity equations are applied to calculate the downstream zone of influence for various sediment particle sizes.

The sediment generation equations developed are limited in their application to watercourses with streambeds composed on non-cohesive materials. Watercourses with cohesive bed material (clay and silt) may exhibit considerably different behaviour when disturbed by instream construction and are therefore considered subject to different dominant physical processes. To expand and validate the current approach, the following recommendations for future data collection efforts are given:

- Detailed measurements of hydrologic parameters;
- Geotechnical descriptions of the streambed, or the excavated and fill material;
- Monitoring of upstream conditions to determine background levels;
- Placement of monitoring stations further downstream; and,
- Keeping detailed logbooks of construction activities.

Suspended Sediment and Turbidity Criteria Associated with Instream Construction Activities in the United States: An Assessment of Biological Relevance

The second report, "**Suspended Sediment and Turbidity Criteria Associated with Instream Construction Activities in the United States: An Assessment of Biological Relevance**" identifies the scientific evidence of the effects of suspended sediment and turbidity on benthic communities.

Project Background

Natural gas pipelines, being linear facilities, traverse streams, rivers and other natural and artificial watercourses. Instream construction activities inevitably result in the suspension of sediment into the water column. Suspended sediment has the potential to impact both the aquatic life within the receiving environment and also the habitat upon which they rely. The regulation of sediment discharged during instream pipeline construction has been accomplished through numerical turbidity restrictions, and/or through *de facto* technical requirements regarding crossing methods. Instantaneous exceedences of numerical restrictions could result in construction delays and/or the prosecution of pipeline contractors and sponsors for the violation of State water quality standards.

Objectives and Outline

The goal of this study was to evaluate the biological relevance and effectiveness of regulatory approaches used across the United States to minimize the impacts of sediment suspended during pipeline water crossings. The report is broken down into the following discussions:

- The effects of suspended and deposited sediment on aquatic biota in rivers and streams;
- A review of the impacts of pipeline water crossings on streambed conditions, benthic invertebrate and fish communities;

- The regional diversity of sediment related state water quality criteria and the degree of protection provided for coldwater and warmwater fisheries;

- The regulation of sediment release during the installation of pipelines across the United States; and,

- A framework to assess the potential impacts of proposed pipeline crossings and derive biologically defensible sediment criteria for pipeline watercourse crossings.

Where possible, these discussions were structured to reflect the diversity and regional variation in aquatic communities and sediment loads across the United States. Additionally, an annotated bibliography of literature pertaining to the effects of sediment on aquatic biota was prepared as an appendix.

Approach

The review incorporated published and unpublished literature evaluating the environmental impacts of suspended sediment to aquatic biota and case-studies specifically evaluating the impacts of pipeline construction on aquatic ecosystems. Federal, State, and Regional (California only) water quality standards for turbidity and suspended sediments were summarized from available State water quality laws as outlined in the Environmental Reporter published by the Bureau of National Affairs in Washington, D.C. Telephone interviews with resource, and permitting managers from individual State and Federal agencies verified and supplemented information gathered in the initial summary. An evaluation of the level of biological protection provided by these criteria and their applicability to pipeline installations was based on statements within State water quality legislation, previous reviews of sediment criteria, supporting scientific literature, and case-studies of pipeline water crossings.

The review of permit conditions established to regulate sediment releases from water crossing construction was accomplished through the following steps. First, the regulatory and permitting environment was characterized through a review of relevant regulatory literature and interviews with involved Federal, State and Regional agencies. Secondly, specific inquiries were made to determine whether numerical turbidity restrictions were being included as permit conditions and to identify any other regulatory approaches in use. Third, additional information on regulatory restrictions, or considerations was obtained through telephone surveys of INGAA member companies and, or through the review of previously issued pipeline construction permits.

Selected Extracts

Available scientific information is used to define criteria for the sensitivity of the benthic community. An example of the criteria of direct impact is shown below:

Table 6.2

Scale of Severity (SEV) of Ill Effects Associated with Excess Suspended Sediment as Predicted by Equations Given in Newcombe and Jensen (1996).

Equations derived from a range of combinations of sediment concentrations (1-500,000 mg/L) and exposure durations (1-35,000 hrs).

SEV	Description of effect
	Nil effect
0	No behavioral effects
	Behavioral effects
1	Alarm Reaction
2	Abandonment of cover
3	Avoidance response
	Sublethal effects
4	Short-term reduction in feeding rates; short-term reduction in feeding success
5	Minor physiological stress; increase in coughing; increased respiration rate
6	Moderate physiological stress
7	Moderate physiological stress
8	Indications of major physiological stress; long-term reduction in feeding rate; long-term reduction in feeding success; poor condition
	Lethal and paralethal effects
9	Reduced growth rate; delayed hatching; reduced fish density
10	0-20% mortality; increased predation; moderate to severe habitat degradation
11	>20-40% mortality
12	>40-60% mortality
13	>60-80% mortality
14	>80-100% mortality

In addition, the deposition of sediment can affect habitats. An equation is derived from the available pipeline crossing information:

SE = 0.637 + .74 Ln(duration in hours) + 0.864 Ln(concentration in mg/L)

Summary

Effects of Sediment on Aquatic Life in Streams and Rivers

Impacts to aquatic organisms can result from direct exposure to suspended sediment or through sediment deposition. These effects can be incurred directly or through changes in habitat suitability.

Suspended sediment effects on aquatic plant, benthic invertebrate and fish communities can be summarized as:

1. The creation of low light conditions that reduce photosynthetic activity and the visual abilities of foraging fish;

2. High rates of downstream drift by benthic invertebrates that can reduce population densities; and,

3. Behavioral and physiological effects (including mortality) to invertebrates and fish.

Additionally, sediment deposition downstream of a disturbance can impact aquatic plant, benthic invertebrate and fish communities by:

1. Smothering aquatic plants;

2. Changing the streambed conditions, thereby reducing habitat suitability for benthic invertebrates, spawning and, depending on the timing of the release, affect the incubation and development of fish eggs and fry; and

3. In-filling pools and reducing the size of riffle areas, thereby reducing the available habitat for juvenile and adult fish.

The recovery of aquatic communities is dependent on the rate at which habitat conditions improve, the availability of individuals from unaffected areas to recolonize the zone of impact and the severity of the damage incurred. Post-disturbance recovery of streambed conditions will depend on discharge rates, the duration of flushing flows, substrate and sediment types, water depth and stream gradient.

Effects of Pipeline Water Crossings

Pipeline water crossing effects are generally associated with:

1. Direct habitat alteration in the area of the crossing (including changes to the riparian zone);

2. Disruption of stream flow;

3. Direct mortality due to blasting;

4. Elevated levels of suspended sediments; and,

5. The alteration of habitats downstream of the crossing due to increased sediment deposition.

Review of case studies monitoring pipeline construction effects on downstream environments indicates that short-term impacts to aquatic life are likely to occur as a result of the suspension and subsequent deposition of sediment. Sediment deposited downstream can alter streambed composition, its embeddedness and morphology. Reductions in the density and diversity of benthic invertebrate and fish communities have been reported downstream of open-cut crossings immediately after construction. However, effects are typically short-term and recovery to post-construction conditions is generally apparent within a year.

Regulatory Review

Sediment criteria and standards have been established across the United States to protect designated uses of waterbodies as required by the Federal *Water Quality Act*. Numerical limits to regulating sediment releases are primarily limited to those based on turbidity measurement. Their application is concentrated in the western and northeastern United States. Few states identify numerical restrictions on acceptable levels of suspended, or deposited sediment.

Protection of freshwater fisheries is based on maintaining the growth, movement and reproduction of fish communities. Review of scientific literature indicates that short-term and reversible behavioral changes, or reductions in growth related to chronic exposure occur at levels higher than those prescribed by State water quality standards or guidelines. However, substantial losses in the visual ability of both coldwater and warmwater fish species can occur at turbidities lower than those cited in State standards guidelines or criteria. This suggests that many of the regulatory limits may not be adequate for the protection of fish species whose feeding and reproductive behavior is visually dependent from chronic exposure. Additionally, the deposition of sediments represents a significant risk to exposed populations. Turbidity only provides a coarse approximation of the potential for sediment deposition and does not represent a biologically relevant threshold for assessing impacts on fish habitat such as burying spawning gravels. While it is recognized that there are considerable difficulties in establishing relevant and adequate numerical limits for protecting aquatic life, the current approach may be inadequate in that it fails to incorporate differences in the nature and source of various sediment discharge events; the pathways through which harm is caused; and, the susceptibilities of different species and habitats to the resulting adverse effects.

The regulation of sediment discharges into watercourses during pipeline construction has been achieved through Best Management Practices (BMPs) and numerical turbidity limits. The application of numerical turbidity restrictions is typically limited to the south-eastern and south-western United States. The primary approach has been the application of BMPs as laid out in training materials provided by the Federal Energy Regulatory Commission (FERC). Comments regarding previous construction experiences could only be obtained for 30 states. Numerical turbidity limits had been applied in 7 states. Allowable levels of turbidity, or exceedances above background turbidity based on past experience ranged from 10 to 50 NTUs. The current application of numerical turbidity standards are questioned based on the following observations:

1. Numerical limits are based on studies evaluating effects on fish resulting from chronic exposure to low concentrations of suspended sediment. The duration of instream construction and the magnitude of increase in the sediment concentration suggests that for many crossings, potential physiological harm to fish is more likely to be acute rather than chronic.

2. Regulatory requirements based on turbidity do not adequately protect against impacts associated with sediment deposition. Sediment deposition represents a substantial threat to habitat quality;

3. The values used to develop to turbidity restrictions are often derived from studies to protect primary productivity in lakes. Also, turbidity is a poor surrogate for suspended sediment levels. Unless water crossing/ or watershed specific relationships between turbidity and suspended sediment concentration are established, measurement of turbidity do not provide reliable estimates of suspended sediment concentrations in the water course; and,.

4. The delineation of allowable mixing zones does not appear to incorporate principles of sediment transport, watercourse flow characteristics, or expected levels of sediment generation during instream construction.

If numerical restrictions are to be included as permit conditions, the following recommendations should be taken into account:

1. Use suspended sediment concentration as opposed to turbidity;

2. Derive restrictions from databases, or predictive tools that integrate the concentration and duration of exposure to suspended sediment in their determination of effects on aquatic life. The effect of increased sediment load on fish and fish habitat can be predicted by applying dose-response models generated by Newcombe and Jensen

(1996) and Anderson *et al* (1996). These multiple regression predictive models can provide threshold concentrations of suspended sediment and duration of exposure at which individual organisms or aquatic habitats will not be affected.

3. The determination, or assessment of allowable increases in suspended sediment and the size of allowable mixing zones should include predictive modelling of sediment generation at the crossing site and its transport downstream. By incorporating the physical process involved in sediment transport and the potential for sediment generation by given construction method, modeling predictions can be made to determine the degree to which downstream organisms and habitats are likely to be affected by the predicted level of exposure; and,

4. Where information is available on individual watercourses determine and incorporate the sensitivity of the existing community to the expected release of sediment.

The regulation of sediment release during pipeline water crossings has tended to follow approaches similar to those used for point source industrial discharges. Numerical limits are set on the quantities or concentrations of materials that may be released to the receiving environment. However, the short duration of sediment release during construction and the limited amount of information about the effects of short-term sediment events, suggest that this approach may not be entirely appropriate for dealing with pipeline water crossings. Discussions with representatives from many of the regulatory agencies indicated the permitting primarily focuses on the ensuring the implementation of the Best Available Technology (BAT) and Best Management Practices (BMP's) to provide appropriate protection. The benefit of this approach is its pragmatism, in that a proponent commits to constructing the pipeline crossing according to the best methods available for a specific water crossing. The most appropriate water crossing method is then selected based on site-specific conditions at the proposed water crossing location.

Review of Environmental Issues Associated with Horizontal Directional Drilling at Watercourse Crossings

The third report, **"Review of Environmental Issues Associated with Horizontal Directional Drilling at Watercourse Crossings"** identifies the critical watercourse environmental issues as a result of the horizontal directional drilling method of pipeline crossings.

Project Background

Horizontal Directional Drilling (HDD) has become a well-established construction technique for the installation of pipelines beneath watercourses, highways and other obstacles which may prevent conventional surface construction. Despite avoiding the levels of sediment generation characteristic of more conventional crossing techniques, HDD installations have the potential to cause environmental damage through inadvertent releases of drilling fluids. This is of concern as HDD technology is often applied to environmentally sensitive waterbodies.

Objectives

The objective of this report was to evaluate the potential environmental impacts associated with HDD pipeline crossings.

Approach

As the majority of the environmental concerns are related to inadvertent releases of drilling fluids, the report focused on the toxicity of drilling mud to aquatic organisms; the effects of spills or inadvertent releases of drilling fluid; and the disposal of drilling wastes. Few case studies, however, been undertaken to study the impacts of drilling fluid releases, or spills. Therefore, much of the review is based on toxicity data from bioassays of drilling mud components from oil and natural gas exploration and published literature on the effects of suspended sediment on aquatic organisms. Various advantages and disadvantages of employing HDD technology were also identified.

Selected Extracts

The report describes the process of horizantal directional drilling and identifies the need for using drilling fluids:

Table 1

Functions of Drilling Muds during Horizontal Directionally Drilling (adapted from Hair and Cebo Holland B.V. 1994)

Drilling Mud Function	Description
Transmission of Hydraulic Power	Drilling mud transmits downhole the power required to turn the drill-bit and mechanically drill a hole
Hydraulic Excavation	High velocity mud streams directed from jet nozzles onto bits or reaming tools excavate soil through erosion.
Reduction of Friction	The lubricating properties of the drilling mud reduces friction between the drill pipe and the hole wall
Cooling and Cleaning of Cutters	High velocity mud streams directed at the cutters on the drill bit cools and removes drilled spoil buildup on bit or reamer cutters
Transportation of Spoil	Excavated soil, or rock cutting suspended in the drilling mud is carried to the surface by the mud stream flowing between the hole and the drill pipe
Hole Stabilization	Drilling mud stabilizes the drill hole by building up a wall cake and by exerting positive pressure on the hole wall. This function is critical as HDD pipeline installations are typically uncased and in soft soil formations
Soil Modification	Soil along the drilling path is mixed with drilling mud which facilitates the installation of a pipeline by reducing the shear strength of the soil to a near mud condition

Several events that result in the loss of drilling fluid are identifed in the report:

- circulation losses due to drilling through highly permeable gravels;
- mud migration along rock joints, or fractures which intersect with the river bottom. Cavernous and open-fissured formations such as karstic limestone will also entrain drilling mud;
- the loss of borehole directional control resulting in the hole intersecting the river bottom, or approach slope;
- drilling mud pressures exceeding ground stress, widening existing, or creating new fractures (hydraulic fracturing) allowing for the migration of drilling muds; andsubstantially different elevations of entry and exit drill locations.

Comparisons are made between typical drilling fluids and wetland soils:

Table 3

Comparison of Mineral and Organic Soils in Wetlands

	Mineral Soil	Organic Soil
Organic content percent	Less than 20-35	Greater than 20-35
Organic carbon percent	Less than 12-20	Greater than 12-20
pH	Usually circumneutral	Acid
Bulk density	High	Low
Porosity	Low (45-55%)	High (80%)
Hydraulic conductivity	High (except for clays)	Low to high
Water holding capacity	Low	High
Nutrient availability	Generally high	Often low
Cation exchange capacity	Low, dominated by major cations	High, dominated by hydrogen ions
Typical wetland	Riparian forest, some marshes	Northern peatland, southern swamps and marshes

Taken from (Kadlec and Knight 1996)

Findings

Inadvertent releases of drilling fluids into the crossed waterbody, or the surface of approach slopes can result from;

- fluid migration along rock fractures that intersect with the river bottom;
- circulation losses into highly permeable gravels;
- inaccurate drilling of pilot holes;
- and differences in the hydraulic pressure heads at entry and exit points.

The volume of the fluid release is related to;

- the porosity and extent of the substrate transporting the material;
- the pressure exerted on the fluid by the hydraulic system;

- the viscosity of drilling mud; and

- whether mud circulation can be maintained.

The subsequent dispersion from the release point will then be a function of the energy, or sediment transport characteristics of the receiving waterbody.

The overall toxicity of HDD fluids should be low and reflective of bentonite clay, its major component. However, the freshwater toxicity of HDD drilling fluid mixtures (rather than its components separately) need to be tested before definitive toxicological statements can be made. The toxicity of inadvertent releases should be expected to be higher at extreme water temperatures, if composed of large particles sizes and when exposed to diseased, very young or other sensitive life-stages. Comparisons between HDD fluid toxicity and that of fluids used in oil and gas exploration are of limited value. This is because the drilling environments encounter during HDD are less hostile and the fluids do not require more toxic additives.

Limited work has been conducted on sub-lethal, or habitat impacts of drilling fluids releases into aquatic ecosystems. Impacts could arise if sediment loads increase above background levels and deposition occurs on sensitive habitats. Potential effects include:

1. Increased drift of benthic invertebrates (and therefore reduced densities) as a result of exposure to drilling fluid releases;

2. Reduced emergence rates of adult benthic invertebrates resulting from the deposition of drilling fluids;

3. Alterations of wetland hydrological and soil conditions due to drilling fluid release and deposition; and,

4. Behavioral and physiological changes in exposed fish and changes in habitat suitability as a result of increased water column sediment concentrations and sediment deposition.

Realized impacts will reflect the volume of the drilling fluid released, flow conditions of the receiving waterbody, and the sensitivity of resident aquatic life to suspended sediment.

Concerns related to the disposal of drilling fluids are based on potential impacts on soil conditions. These result from improper landfarming techniques and the disposal of discharge water from sump dewatering operations. Recirculating drilling fluids during HDD installations is an effective first step to reducing the magnitude of some of these problems.

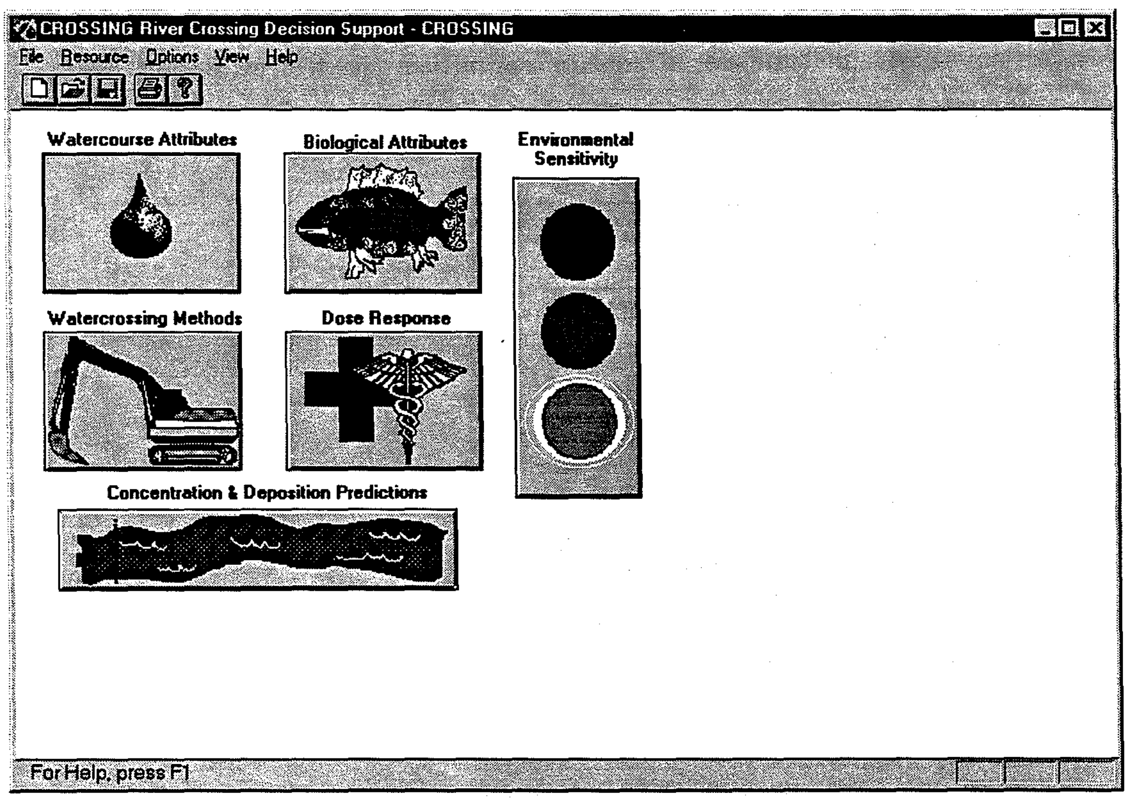
The strength of the review is limited by the lack of case-study evaluations. As HDD is often applied to environmentally sensitive water crossings, inadvertent releases and subsequent clean-up operations need to be evaluated in order to properly define impacts to receiving environments; develop appropriate clean-up technologies; and remedial strategies. Perceived gains from clean-up operations after inadvertent releases should be first evaluated in terms of potential impacts associated with organisms and contaminated sediments sensitive to physical disturbance.

CROSSING Beta Version 1.0

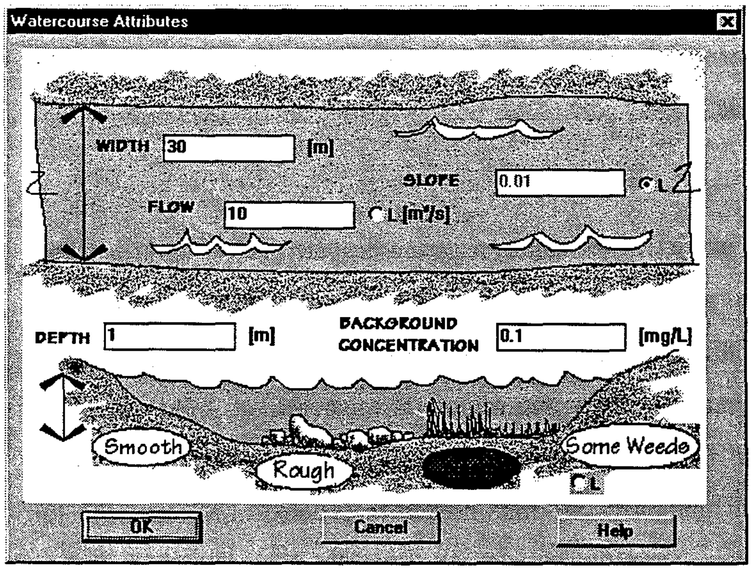
The last deliverable of the project is a Beta version of the software, "**CROSSING**" that utilizes the information from the supporting reports to form the basis of a decision support system for pipeline companies, contractors, and regulators. The software is designed to permit the users to easily utilize extensive scientific information in the decision process on how to design and approve pipeline crossings of rivers and streams.

Description:

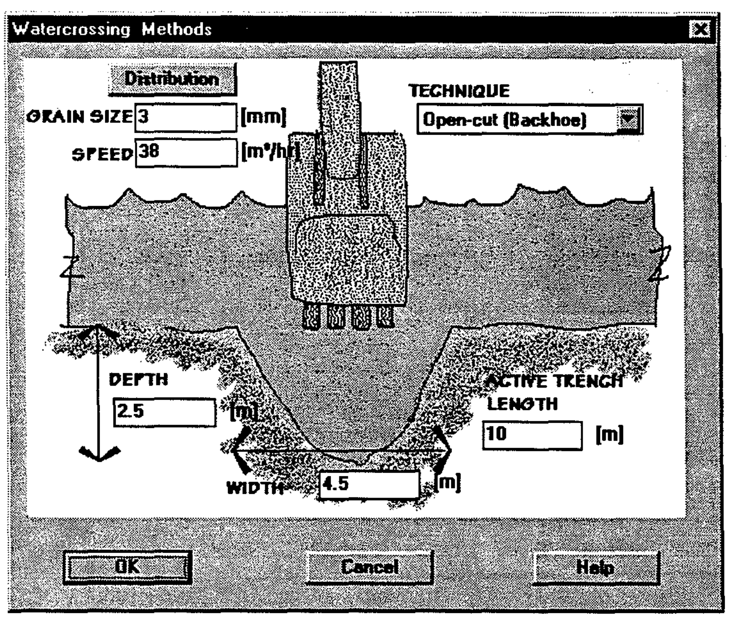
CROSSING Beta Version 1.0 is an interactive computer program designed to run on a personal computer. It is intended to operated as a decision support system for planning and evaluating pipeline stream crossings CROSSING Beta Version 1.0 provides the user with predictions of suspended sediment concentrations and sediment deposition downstream of open-cut water crossings and assesses the ecological risk to downstream fish populations. In addition, it has a graphical Windows ™ interface that minimizes the time needed to become proficient with the program.



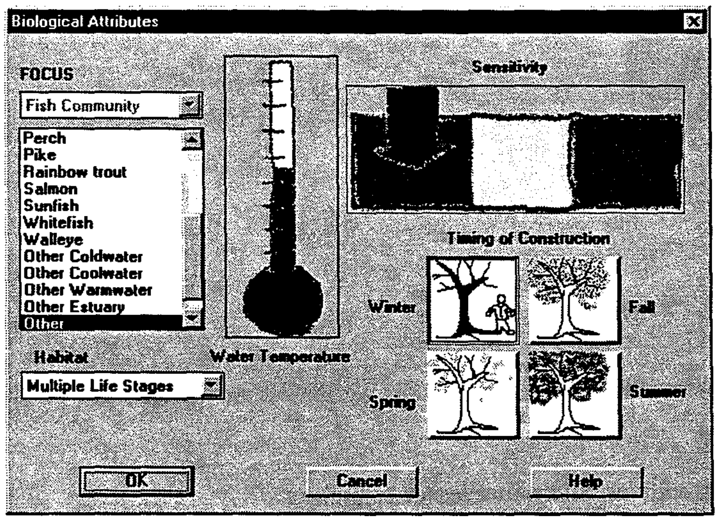
Sediment generation, and deposition predictions at defined distances downstream are based on the modeling approach described in the report "Sediment Generation at Pipeline Water Crossings". Predictions are derived from defined watercourse characteristics (stream width, depth, discharge, slope, background suspended sediment concentration, and streambed roughness) and water crossing.



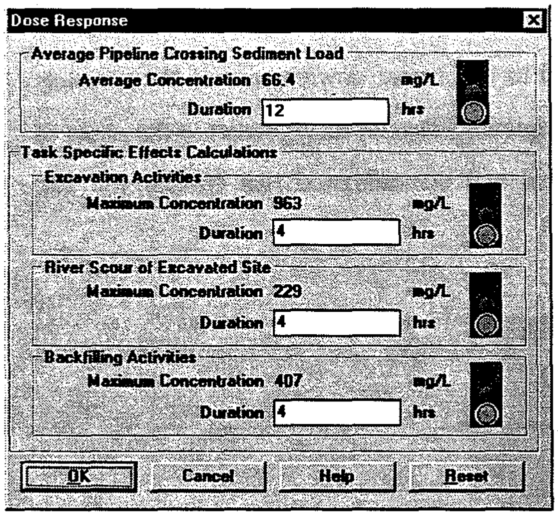
It also takes into account the attributes of crossing construction (speed of excavation, trench dimensions, and bed material descriptions).



Assessments of ecological sensitivity are based on sediment generation predictions, construction timing and the species and lifestages of fish expected to be present downstream of the crossing. Ecological sensitivity is predicted with dose-response equations developed to predict to the effect of suspended sediment on selected lifestages of salmonid and non-salmonid fish species and fish habitat.



The program takes into account the expected duration of construction activities and the period of exposure to elevated suspended sediment concentrations. The approach and dose-response equations applied in the software are discussed in an accompanying technical manual and in the report, "Suspended Sediment and Turbidity Criteria Applied to Instream Construction: An Assessment of Biological Relevance."



The following computer hardware and software is required to run CROSSING Beta Version 1.0:

- IBM®- compatible personal computer with an 80486 processor or higher;

- graphics display compatible with Microsoft® Windows™ version 3.1 or later, such as EGA, VGA or SVGA;

- 3.5-inch disk drive; and,

- hard drive with at least 8 megabytes of available memory.

Future Efforts

The ***River and Stream Water Crossings*** project is being undertaken in two phases. The reports outlined in this Executive Summary are the results of Phase I of the study. The literature review and investigation of effects of sediment generated during pipeline water crossing construction identified a number of information gaps concerning the effects of short term exposure to elevated sediment concentrations on aquatic biota, the recovery of aquatic organisms from such exposures, and our ability to make predictions about the effects of sediment released on the aquatic community. Furthermore, ability to predict the amount of sediment released during pipeline water crossings was limited by the small data set available for the development of a Sediment Generation Model.

Phase II of ***River and Stream Water Crossings*** project is intended to resolve some of the outstanding questions from Phase I. The objectives of Phase II are to: (1) test, refine and calibrate the sediment generation model specific to the construction of pipeline water crossings; (2) improve our ability to predict the zone of effect of sediment in the receiving water environment; and, (3) develop methods to evaluate the effects of sediment load, concentration, duration, and deposition on fish and fish habitat. To this end, the following project components will be undertaken as part of Phase II:

The development of a sediment release monitoring database that includes a range of water crossing methodologies and watercourse types. INGAA Foundation and GRI members are being asked to participate in this component by providing sediment monitoring data collected according to an established protocol. This database will be used to further develop and calibrate the sediment generation model and to allow for valid comparisons of the ability of different crossing methods to minimize sediment generation;

Field investigations of the effects of pipeline water crossings on stream and river fish communities. In this component, field studies will be conducted at five open cut crossings. The location of the water crossing has yet to be determined. Field experiments will focus on documenting: behavioral changes in fish in response to increases in downstream suspended sediment levels; effects of sediment load elevation on the physiology and survival of fish; and, changes in fish habitat and stream morphology as a result of sediment deposition.

The information obtained from these two components will be used to develop, a second *beta* version of the *CROSSING* decision support software. *CROSSINGS* Version 2.0 Beta will provide a more robust and universally applicable method of determining the amount of sediment generated by various crossing methods and the associated effects on the aquatic community.

Technical Report Order Form

To order any or all of these reports, please fill out and return this form to:

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Title	Qty.
Sediment Entrainment Due to Pipeline Watercourse Crossing Construction (Technical Report 1)	
Suspended Sediment and Turbidity Criteria Associated with Instream Construction Activities: An Assessment of Biological Relevance (Technical Report 2)	
Review of Environmental Issues Associated with Horizontal Directional Drilling at Watercourse Crossings (Technical Report 3)	

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