Environment Canada Environnement Canada

Canada

Method and Design for Aquatics Impacts Associated with Pipeline Crossing Construction

BY:

M. Dubé,

NWRI Contribution No. 05-341

NATIONAL WATER RESEARCH INSTITUTE

INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX

Method and Design for Assessment of Aquatics Impacts Associated with Pipeline Crossing Construction

Prepared for:

Dr. Monique Dubé
Research Scientist
National Water Research Institute
11 Innovation Blvd.
Saskatoon, SK

Prepared by:

Lucie Lévesque
Research Assistant
National Water Research Institute
11 Innovation Blvd.
Saskatoon, SK

NWRI Cont. # 05-341

March 31, 2005

Table of Contents

I. Report Objectives

The construction of pipeline crossings can result in detrimental effects on ecosystem health and functioning in streams and rivers through alteration of stream and river channels, banks, and water and sediment quality. This document reviews impacts of pipeline crossing construction on watercourses and proposes a study design to assess the impacts of the Mackenzie Gas Project (MGP) on various streams and rivers along the Mackenzie River. The MGP Environmental Impact Assessment was examined to identify the approach taken by the MGP in assessing potential impacts of crossing construction and, along with the "dominant" literature, was reviewed to identify key indicators of crossing construction impact (e.g., water quality, habitat, invertebrate and fish communities) and thresholds associated with these variables. Candidate crossing sites were selected for investigation in 2005/2006.

II. MGP Assessment: Impacts of Pipeline Crossing Construction on Watercourses

Project Design

The Mackenzie Gas Project consists of three anchor fields, a gathering pipeline system and a pipeline corridor (Imperial Oil Resources Ventures Limited, 2004a). This document focuses on the gathering pipelines and pipeline corridor, specifically the potential for impacts of construction activities on ecosystem health (as pertinent to invertebrates and fish) at watercourse crossings. The MGP selected crossing locations based on such things as bank stability and stream gradient, permafrost, streambed characteristics, and fish and fish habitat. Crossing construction methods were selected for each crossing on an individual basis. Open-cut construction was selected for channels with ephemeral flow and for channels that freeze to the bottom over winter (Vegetated, Active I and II channels). Isolated and trenchless construction were selected for perennial streams and rivers with winter spawning or overwintering habitat (Active II and Large). The latter two are the focus of this document.

MGP approach for assessment of impacts

MGP pipeline crossing construction activities are a potential source of impact at crossings due to altered suspended solids concentrations, water and sediment quality, and fish habitat, health, and abundance and distribution. Key indicators of impact (see discussion below) were selected for examination of the impact of pipeline crossing construction on valued components of hydrology, water quality and fish and fish habitat. The effects of pipeline construction on these indicators of response were assessed based on their 1) direction, whether the effects on key indicators were adverse, neutral or positive, 2) magnitude, from no to low, moderate and high effect on key indicators, 3) geographic extent, from effects on key indicators within the local study area (LSA) to the regional study area (RSA) and beyond, and 4) duration, with short-term impact

occurring over a period of less than 1 year, medium-term impact over 1 to 4 years and long-term impacts lasting from 4 to 30 years (Imperial Oil Resources Ventures Limited, 2004d,e). More detail of items 1, 2 and 3 above is given in the following sections.

Assessment of impacts on hydrology: total suspended solids

The valued component in the MGP assessment of crossing construction impact on hydrology is identified as channel morphology. Sediment (total suspended solids - TSS), concentration is a key indicator of response in channel morphology, as well as a key indicator of response in fish and fish habitat (see below). Crossing construction activities are expected to disturb banks and beds of watercourses, hence likely increase suspended sediment concentrations. Table 1 lists the MGP definitions of the direction, magnitude and geographic extent of the effects of crossing construction activities on sediment concentrations.

Estimates of total suspended solids concentrations generated by construction were made using a conservative sediment entrainment regression model (Golder Associates Ltd, 2002 in Imperial Oil Resources Ventures Limited, 2004d). The percent fines in the excavated material was a key controlling factor on the modeled TSS concentrations, which were 100 times higher for sites with bed and bank materials consisting of 15% fines compared to sites with 2% fines (See Data Tables p. 5-127, 5-129). Modeled results also indicated that deposition of sediment out of the water would be greatest immediately downstream of construction activities. Active I channels that are not frozen to the bed and that have little or no flow in winter are considered particularly susceptible to increases in suspended sediment. Though disturbed sediment concentrations will be higher in these systems than in watercourses with active flow, sediment will settle more rapidly out of the water column, limiting the geographic extent of the impact in slower flowing streams and rivers.

The MGP Environmental Impact Assessment found that crossing construction would have an adverse impact of moderate to high magnitude on suspended solids concentrations, which would persist over the short-term and over local geographic extent, producing *no significant effect*. This takes into account mitigation strategies including reclamation of bed, banks and approach slope stability, grade and contours, implementation of erosion and sediment control measures, and restriction of magnitude and duration of in-water activities.

Table 1. Definition of effects used in the assessment of pipeline crossing construction impact on sediment concentration (Imperial Oil Resources Ventures Limited (2004d), Table 5-2, pp. 5-9, 5-10).

Direction	
Adverse	Increase in mean annual concentration of sediment
Neutral	No increase in mean annual concentration of sediment
Magnitude	
No effect	No change in mean annual concentration of sediment
Low	<10 mgL^{-1} increase in mean annual concentration OR <50 mgL^{-1} increase over short-term (< 50 mgL^{-1} increase over background for Mackenzie and Liard)
Moderate	10-25 mgL^{-1} increase in mean annual concentration OR 50-100 mgL^{-1} increase over short-term (50-5000 mgL^{-1} increase over background for Mackenzie and Liard)
High	>25 mgL^{-1} increase in mean annual concentration OR >100 mgL^{-1} increase over the short-term (>5000 mgL^{-1} increase over background for Mackenzie and Liard)
Geographic Extent	
Local	Within LSA: watercourses within a 1-km-wide zone centered along the pipeline route
Regional	Within RSA: watercourses within a 30-km-wide zone centered along the pipeline route

Assessment of impacts on water (and sediment) quality

The valued components in the MGP assessment of crossing construction impacts on water quality are identified as water quality and sediment quality. Suspended sediment concentration is a key indicator of response in water quality. Crossing construction is expected to affect water and sediment quality through the disturbance of bed and banks, hence TSS concentration (see discussion above). Chemical and physical properties of water were identified as not applicable to construction activities. Chemical parameters that associate with sediment (particularly sediment high in organic matter) are, however, identified as key indicators of water quality as well. Hence other key indicators in the assessment of impacts on water quality that may pertain to construction include: a) water - dissolved oxygen (DO), total dissolved solids (TDS), nutrients (phosphorous P and nitrogen N), metals, temperature, and turbidity; b) sediment - total organic carbon (TOC), particle size, metals and polycylic aromatic hydrocarbons (PAHs). Table 2 lists the MGP definitions of the direction, magnitude and geographic extent of the effects of crossing construction activities on water and sediment quality.

The MGP Environmental Impact Assessment found that crossing construction would have an adverse impact of no to moderate magnitude on water and sediment quality, which would persist over the short-term and over local geographic extent, producing *no*

significant effect. This takes into account mitigation strategies including implementation of drainage, erosion and sediment controls, and reclamation of bed, banks and approach slope stability, grade and contours.

Table 2. Definition of effects used in the assessment of pipeline crossing construction impact on water or sediment quality as relating to the protection of aquatic life (Imperial Oil Resources Ventures Limited (2004d), Table 6-4, pp. 6-10, 6-11).

Direction	
Adverse	Increase in concentrations (reverse for DO and pH)
Neutral	No change in concentrations as compared to baseline
Magnitude	
No effect	No measurable change in quality
Low	Measurable change in concentration, but key indicator does not exceed guideline (except in locations where background values exceed guidelines, necessitating site specific evaluation)
Moderate	Increase in concentration of toxic key indicator above guideline, where baseline concentrations do not exceed guideline and where the increase is within the factor of safety[1] range (i.e., effect rating may decrease from high to moderate if the effect persists over the short-term only)
High	Increase in concentration of key indicator above guideline and beyond the factor of safety range, if applicable
Geographic Extent	
Local	Within LSA: watercourses within a 1-km-wide zone centered along the pipeline route
Regional	Within RSA: LSA and downstream to the next major stream or waterbody

[1] factor of safety range = 10 fold is applied to the LOEL for most key indicators to increase assurance

Lowest Observable Effect Level (LOEL) = lowest concentration to have an adverse effect on the most sensitive stage of the most sensitive aquatic organism (CCME, 1999).

Assessment of impacts on fish and fish habitat

The valued components in the MGP assessment of crossing construction impacts on fish and fish habitat are the top ten species of large-bodied fish found throughout the crossings and of importance to fisheries. Fish habitat, health, and distribution and abundance are the three key indicators of response in fish (proxies for these three key indicators are listed in italics in the following discussion). Crossing construction is expected to affect habitat through a) *direct* modification (i.e., stream morphology, stream bed, composition and size of bed materials, bank configuration and removal of

bank vegetation), b) alteration of *channel morphology* with bed and bank disturbance (i.e., shape, stability and makeup of bank, increased sediment input with erosion and instability) and bank subsidence (i.e., with settling of backfill), and c) alteration of *sediment deposition* with bank disturbance (i.e., erosion from bank and substrate disturbance may increase sediment load) and construction (i.e., disturbance of channel materials will affect downstream TSS concentrations). Crossing construction is expected to affect health through a) use of *explosives* with trench excavation (i.e., compressive shock wave and rapid lowering of pressures may cause hemorrhaging of organs), and b) changes in *water quality* with changes to suspended sediments (i.e., may cause stress or mortality depending on concentration and duration of exposure). Crossing construction is expected to affect abundance and distribution through changes in *habitat, health* and *water quality*. Table 3 lists the MGP definitions of the direction, magnitude and geographic extent of the effects of crossing construction activities on fish habitat, health, and abundance and distribution.

Table 3. Definition of effects used in the assessment of pipeline crossing construction impact on fish habitat, health, and abundance and distribution (Imperial Oil Resources Ventures Limited (2004e), Table 7-5, p. 7-23).

Direction	
Adverse	Effect on valued component worsening compared with baseline and trend
Neutral	Effect on valued component unchanged compared with baseline and trend
Magnitude	
No effect	No effect on key indicator(s)
Low	Effect on key indicator may affect group of fish in a population within e.g., LSA or RSA
Moderate	Effect on key indicator(s) may affect part of a regional population within LSA or RSA, altering the abundance or distribution of the valued component, and current harvesting practices
High	Effect on key indicator(s) may affect an entire population within LSA or RSA, altering the abundance or distribution such that the population will likely not return to prior levels, thereby reducing its viability and reduced sustainability of current harvesting practices
Geographic Extent	
Local	Within LSA: 100m upstream of crossing to about 45 bankfull channel widths downstream (i.e., the distance downstream where coarse silt or larger particles will be deposited)
Regional	Within RSA: catchment of each waterbody within the LSA likely to be affected

The MGP Environmental Impact Assessment found that crossing construction would have an adverse impact of no to low magnitude on bed and bank, channel morphology, sediment deposition and water quality (TSS), which would persist over the short-term and over local geographic extent, producing *no significant effect*. This takes into account mitigation strategies including reduction of the magnitude and duration of in-water activities, avoidance of habitat for sensitive fish stages unless authorized, site-specific selection of crossing technique, implementation of drainage, erosion and sediment controls, installation of temporary erosion control prior to spring breakup, reclamation and stabilization of banks, and avoidance of sensitive life stages where practical.

Mackenzie River Biophysical Gap Report

Based on the report on gaps in biophysical information pertaining to hydrocarbon-related activities in the Mackenzie Valley (Gartner Lee Limited, 2004), near the greatest knowledge and data limitations are related to fish and fish habitat. This, along with numerous physical and chemical information gaps, such as those relating to slope instability (distribution, susceptibility to thaw), baseline water quality and quantity data, abundance and distribution of fish and invertebrates, habitat sensitivity mapping, distribution of contaminants in sediments and fish, and trophic linkages along with impacts on vital rates (reproduction, growth, mortality) and abundance, have implications for not only the integrity of fish and fish habitat in the Mackenzie Valley, but for whole ecosystem structure and function at and downstream of the pipeline watercourse crossings.

III. Literature Review: Impacts of Pipeline Crossing Construction on Watercourses

Construction of pipeline watercourse crossings has the potential to negatively impact ecosystems (Zwirn, 2002). The following review examines literature pertaining to the impacts of pipeline watercourse crossing construction on watercourse ecology. The review also addresses the sensitivity of fish and benthic invertebrates (i.e., important indicators of aquatic ecosystem health) to a major stressor associated with crossing construction: sediment.

Pipeline crossing construction and fish

Construction of pipeline watercourse crossings may have detrimental effects on fish and fish habitat. The most prominent effects of construction have been associated with altered sediment-loading in response to disturbance of river and stream beds and banks. Reid *et al.* (2002, 2004) examined the effects of isolated pipeline construction on suspended sediment concentrations, sediment deposition rates, riffle habitat and fish abundance at crossings in Minnesota, Nova Scotia and Ontario. Total suspended solids (TSS) concentrations increased at all sites with construction, reaching levels of up to 1000 mg/L with installation and removal of infrastructure (i.e., dam, flume, pump) and, in

some instances, with leakage of highly turbid water from an upland sump back to the watercourse (i.e., during trenching, installation and backfilling). Though TSS concentrations increased with construction, levels typically returned quickly to background with increasing distance downstream of construction and upon completion of construction. Sedimentation rates declined rapidly with distance downstream of construction, and fine textured (silt and clay) sediment deposits were cleared quickly by flow. It was noted that any effect of increased sediment-loading on fish abundance was not greater than the effects of natural variability within the populations.

Similar effects were documented with construction of isolated pipeline crossings for the Alliance pipeline in northwestern Alberta (Reid and Anderson, 2000). TSS concentrations increased substantially with installation and removal of dams and flumes, with concentrations greatly exceeding background levels due to leakage from construction infrastructure (e.g., up to 820 mg/L over 5.5 h). Though suspended sediment concentrations increased, particle size distribution (i.e., pebble count) of bed sediments changed little at most sites. Sites with fine-textured materials were exposed to persistent plumes of highly turbid water downstream of construction, particularly in more rapidly flowing streams.

Although crossing construction may be detrimental to the health of fish and fish habitat through increased suspended sediment concentrations and increased deposition, Reid *et al.* (2002) state that the isolated construction technique more effectively mitigates these effects than does the open cut method. For example, open cut construction in an Ontario stream caused a 100% decrease in fish abundance 200 m downstream of construction, and a one year period of recovery for benthic invertebrate communities and habitat (Anderson *et al.*, 1998). Isolated crossing construction also eliminates the risk of contaminating watercourses with drilling fluids, as may occur with the horizontal directional drilling technique.

Pipeline crossing construction and *benthic invertebrates*

Pipeline watercourse crossing construction may also have detrimental effects on benthic invertebrates. Pipeline crossing construction over the winter in Hodgson Creek, NWT, altered benthic invertebrate drift density and standing crop (Young and Mackie, 1991). TSS concentrations increased from 2 to 300 mg/L, peaking at >3000 mg/L in some instances, and dropping to less than 10 mg/L within 4 days. Elevated TSS caused an increase in invertebrate drift density from 2.6 to 37.6 per 100m^3 downstream, and an increase in standing crop (with no effect on species richness or density) that lasted over 5 weeks. These effects were most apparent during construction and prior to spring breakup, with little evidence of construction impacts after passage of freshet.

Other studies have also found pipeline crossing construction to have a significant effect on benthic invertebrates. Construction of a pipeline crossing in an estuary in Ireland eliminated invertebrates from the crossing site for 1 month (Lewis *et al.*, 2002). Though species returned to pre-construction abundance, composition shifted due to altered

substrate texture. Pipeline construction in streams of southeast England increased the proportion of silt in stream substrates and, as such, shifted invertebrate species. This effect lasted for 4 years, until high magnitude storm flow scoured the bed substrates, promoting re-establishment of the original invertebrate species (Armitage and Gunn, 1996).

Sediment and fish

Fish are sensitive to increased suspended sediment concentrations and altered stream bed substrate composition (DFO, 2000; Anderson *et al.*, 1996; Newcombe and Jensen, 1996; Newcombe and Macdonald, 1991; Lloyd, 1987; EIFAC, 1965). Increased suspended sediment concentrations can have effects on fish ranging from physiological stress on individuals to effects on populations. These include: altered feeding and movement, physical damage to fish (e.g., gill damage that may lead to death), hampered egg and larvae development (e.g., degraded spawning habitat with increased siltation; reduced fry emergence; restricted dissolved oxygen and waste transport to and from eggs in redds) and reduced food abundance (e.g., decreased primary productivity and associated consumers with decreased light availability; reduced benthic productivity with decreasing bed porosity), hence increased fatality and stress, decreased growth and abundance, and reduced disease resistance and adaptive response. Depending on the sensitivity of the receiving environment (e.g., life stages, flow characteristics, substrate texture) and the magnitude of the disturbance, habitat lost in association with increased sediment loading and associated infilling of pools or embedding of coarse-grained bed materials may be recovered within 1-2 years of disturbance (Reid and Anderson, 1999 in Reid *et al.*, 2002).

Newcombe and Jensen (1996; Newcombe and Macdonald, 1991) rated the severity of sediment effects on fish. Severity of ill effects (z) of increased sediment loading as modeled for six groups of fish, generating matrix arrays of severity scores associated with various suspended sediment concentrations (y) and durations of exposure (x).

$$z = a + b(\log_e x) + c(\log_e y) \qquad (1)$$

The six groups (i.e. models) were based on species (salmonid vs. non-salmonid), life stage (eggs, larvae, juveniles, adults), and life history (estuarine, anadormous, freshwater), as well as suspended sediment particle size (<75 µm may clog gills; 75-250 µm may abrade gills). The severity of ill effects ranged from no behavioral effects, to behavioral, sublethal and lethal/paralethal effects (Table 4). Turbidity may be used as a proxy for suspended sediment concentration (or TSS) once stream-specific turbidity-suspended sediment concentration relationships have been established. For example, Lloyd (1987) found that the relationship between suspended sediment concentrations (SSC) and turbidity (T) in streams of Alaska's interior was defined as

$$\log_{10} T = 0.045 + 0.9679 \log_{10} SSC. \qquad (2)$$

Table 4. Severity of ill effect (SEV) scores associated with increased suspended sediment exposure (Newcombe and Jensen, 1996, Table 1 p. 694).

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 rate of coughing; increased respiration rate
6	Moderate physiological stress
7	Moderate habitat degradation; impaired homing
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

Sediment and benthic invertebrates

Benthic invertebrates are sensitive to increased suspended sediment loading and associated sedimentation, which may alter sediment texture and depth of accumulation. Macroinvertebrates commonly thrive in substrates consisting of coarse-grained particles (e.g., gravel), exploiting pore spaces for protection, attachment and feeding (i.e., periphyton), and oxygen (Wood and Armitage, 1997 in Roy *et al.*, 2003; Mayhood, 1998). Those that reside in coarse- rather than fine-textured substrates are the preferred food for fish (DFO, 2000). Increased sediment loading to streams may reduce invertebrate grazer productivity (i.e., reduce periphyton productivity), reduce efficiency and growth of filter feeders (i.e., clog filter apparatus), and have lethal effects on macroinvertebrates within coarse substrates (i.e., smothering, abrasion of respiratory surfaces) (DFO, 2000; Anderson *et al.*, 1996). Sediment texture has been noted to affect the composition and density of invertebrate assemblages, as substrate porosity controls exchanges of water and associated organic matter, nutrients, oxygen and biota between the stream bed substrates (and groundwater) and the water column (Malard *et*

al., 2002).

Disturbance of sediment in streams has been shown to affect benthic invertebrates in a variety of ways. Jowett (2003) found that the abundance of benthic invertebrates declined with disturbance of sediments and increased accumulation of fines, and changes to substrate texture shifted the abundance and taxa of invertebrates. Roy *et al.* (2003), through application of various indices (e.g., richness), found that invertebrate diversity in streams of Georgia, USA, varied with heterogeneity of bed substrate textures, and that invertebrate communities were sensitive to removal of riparian cover, altered turbidity, P and N concentrations, and specific conductance.

IV. Pipeline Crossing Sites

Eleven pipeline crossing sites were selected for assessment of pipeline crossing construction impacts (Table 5). The sites were selected to represent a variety of physiographic and political regions along the entire length of the pipeline, allowing assessment of impact at sites of varying physical conditions (e.g., topography, sediments, flow) and determination of cumulative impact along the length of the pipeline. Characteristics taken into consideration aside from channel type (i.e., Active I and Large) and construction method included water depth and flow characteristics, habitat (e.g., winter DO, habitat diversity), channel width, texture of bed materials, habitat diversity (i.e., number of habitat types, such as pool, run, riffle, flat), stream slope width, and bank instability, as outlined in the MGP *Biophysical Baseline Volume 3C Fish and Fish Habitat.* Channel widths, stream gradient, water velocity and depth of Large and Active I channels were compared to the median of each as calculated from data in the MGP Biophysical Baseline. Special consideration was given to sites with characteristics that made them, based on the review of literature, particularly susceptible to the impacts of pipeline construction, such as low flow velocities, high proportion of fine sediments in substrates, and slope instability. Other sites were not considered due to potential logistical constraints, such as large channel width.

1. *RPR-070 unnamed stream* is an Active I (isolate) channel within the Gwich'in region. This channel originates in an upland area east of the Mackenzie River, draining many lakes and flowing to North Caribou Lake 42 km upstream of its confluence with Norris Creek. The pipeline route crosses the channel approximately 26 km upstream of the confluence with Norris Creek. RPR-070 is narrow (i.e., less than the median). Bed materials are predominantly coarse. Low winter water depth and dissolved oxygen limit habitat for fish over the cold season. Habitat diversity is high, predominated by runs, flats, pools and riffles.

2. *RPR-099 unnamed stream* is an Active I (open cut) channel within the Gwich'in region. This stream, which is a tributary to Travaillant River, originates from a catchment with many lakes and ponds. The pipeline route crosses the channel 2 km upstream its confluence with Travaillant River, and 0.2 km downstream of a 50 ha lake. RPR-099 is narrow and of gentle gradient (i.e., less than the median), with some bank instability. Bed materials are predominantly fine. Low winter water depth and dissolved oxygen

limit habitat for fish over the cold season. Warm season flow velocities are low (i.e., less than the median). Habitat diversity is low, predominated by riffles and runs.

3. *RPR-221 Tieda River* is a Large (isolate) channel within the Sahtu region. The river drains from Yeltea Lake (65km^2) on Ramparts Plateau, through a valley with large meanders and mudslides, and on to rapids within a canyon. The pipeline route crosses the channel in the upper reaches of the canyon section, approximately 16 km upstream of the river's confluence with the Mackenzie River. Tieda River is wide (i.e., greater than the median) and of steep gradient (i.e., greater than the median), with some bank instability. Bed materials are coarse. Water is absent from the channel over the winter. Warm season water depth is low, with high flow velocity (i.e., greater then the median). Habitat diversity is moderate, predominated by runs and riffles.

4. *RPR-249 Hare Indian River* is a Large (trenchless) channel within the Sahtu region. This river (also known as Rabbitskin River), flows from a poorly drained catchment, including Coleville Hills and Anderson Plain, to the Mackenzie River near the community of Fort Good Hope. The pipeline route crosses the channel approximately 6 km upstream of the Mackenzie River. Hare Indian River is very wide and of gentle gradient. Bed materials are coarse with many fines. High winter dissolved oxygen provides habitat for fish over the cold season (no fall/winter spawning). Habitat diversity is low, predominated by runs.

5. *RPR-292 Oscar Creek* is an Active I (isolate) channel within the Sahtu region. This creek flows from Franklin Mountains, passing through Oscar Lake, a narrow canyon channel in Norman Range and a waterfall before meandering through a floodplain where it is joined by Grayling and Crystal Creeks 6 km upstream of the Mackenzie. The pipeline route crosses the channel 5 km upstream of its confluence with the Mackenzie River nearly 40 km downstream of Norman Wells. Oscar Creek is of moderate width and gentle gradient, with bank instability. Bed materials are predominantly coarse. High winter dissolved oxygen provides habitat for fish over the cold season. Warm season water is deep (i.e., greater than the median) and flow velocities high (i.e., above median). Habitat diversity is high, with runs, riffles, pools and flats.

6. *RPR-325 Jungle Ridge Creek* is an Active I (open cut) channel within the Sahtu region. The creek originates in Norman Range, flowing through small lakes and forested catchment prior to joining the Mackenzie River 35 km northwest of Tulita. The pipeline route crosses the channel upstream of the Enbridge pipeline right-of-way, approximately 9 km upstream of its confluence with the Mackenzie River. Jungle Ridge Creek is narrow and of moderate gradient (i.e. near the median). Bed materials are fine (100% silt). Low winter dissolved oxygen limits habitat for fish over the cold season. Warm season water depth and velocities are moderate. Habitat diversity is low, with runs and pools.

7. *RPR-377 Blackwater River* is a Large (trenchless) channel within the Deh Cho region. This cold, fast and clear-flowing river flows from many small lakes and streams to Blackwater Lake, through the McConnell Range (Franklin Mountains) and a deep,

wide valley to the Mackenzie. The pipeline route crosses the channel nearly 1 km upstream of it's confluence with the Mackenzie River. Backwater River is very wide and of moderate gradient, with bank instability. Bed material is predominantly coarse. High winter dissolved oxygen provides habitat for fish over the cold season. Warm season water is deep and water velocities very high (i.e., much greater than the median). Habitat diversity is low, with rapids and backwater.

8. *RPR-410 Smith Creek* is an Active I (isolate) channel within the Deh Cho region. This creek originates in Smith Ridge along the Franklin Mountains, flowing south and west where it is joined by tributaries draining lakes and ponds in wetland areas, and continuing through rapids and waterfalls upstream of the Mackenzie River, near the community of Wrigley. The pipeline route crosses the channel approximately 2.8 km upstream of the confluence with the Mackenzie River. Smith Creek is narrow and of very steep gradient (i.e., much greater than the median). Bed materials is predominantly coarse. High winter dissolved oxygen provides habitat for fish over the cold season (no fall/winter spawning). Warm season water depth is moderate and water velocities are low. Habitat diversity is moderate, with runs, pools and riffles.

9. *RPR-457 Trail River* is an Active I (isolate) channel within the Deh Cho region. The river flows from low-relief muskeg and bog terrain near Ebutt Hills, and meanders to the Mackenzue around 50 km downstream of Fort Simpson. The pipeline route crosses the channel River nearly 28.8 km upstream of the Mackenzie. Trail River is of moderate width and gentle gradient, with very high bank instability (91% of area surveyed). Bed materials are predominantly coarse. High winter dissolved oxygen provides habitat for fish over the cold season; flow is near absent. Warm season water depth and flow velocity are low. Habitat diversity is high, with runs, riffles and rapids.

10. *RPR-475 Jean-Marie Creek* is a Large (isolate) channel within the Deh Cho region. This creek flows from low-lying wetlands near Trout Lake, through a 10 km canyon and Deep and McGill Lakes before reaching a floodplain with many wetlands and flowing to the Mackenzie near the community of Jean-Marie. The pipeline route crosses the channel twice before crossing Jean-Marie Creek upstream of the Enbridge crossing, nearly 75 km upstream of its confluence with the Mackenzie River. Jean-Marie Creek is of moderate width with little bank instability. Bed materials are coarse. High winter dissolved oxygen and water depth provide habitat for fish over the cold season. Warm season water velocity is high. Habitat diversity is moderate, with runs, pools and riffles.

11. *RPR-511 unnamed stream* is an Active I (isolate) channel within the Deh Cho region. The stream originates in muskeg and flows to the Kakisa River, and on through Tathlina Lake, past Lady Evelyn Falls to Great Slave Lake. The pipeline route crosses the channel around 7.8 km upstream of its confluence with Kakisa River. RPR-511 is of moderate width and very gentle gradient (i.e., much lower than the median). Bed materials are coarse with sand. Warm season water velocities are very low. Habitat diversity is moderate with flats and riffles.

Table 5. Recommended crossings for assessment of impacts of pipeline watercourse crossing construction. The data provided in this table were gathered from the MGP *Biophysical Baseline Volume 3 Fish and Fish Habitat*, and are based on limited samples. As such, they are not intended to represent the range and variability in crossing characteristics, rather, they are for general reference and comparison of crossings.

Crossing, Region, Channel type, Method	**Winter Depth, Flow, DO**	**Warm Season Depth, Flow**	**Dominant[1] Substrate**	**Channel Width**	**Habitat Diversity[2]**	**Stream Slope**	**Instability**	**Terrain[3]**	**Fish Use[4]**
RPR-070 unnamed stream Gwich'in Active I Isolate	1 mg/L 0.22 m	1.4 m	Coarse (gravel/ cobble)	6.2 m	High				Spring/ Fall
RPR-099 unnamed stream Gwich'in Active I Open Cut	0.6 mg/L 0.2m	0.38 m 0.1 m/s	Fine (silt), some coarse	8 m	Low	0.1-2.2 m/km	present		Spring/Fall
RPR-221 Tieda River Sahtu Large Isolate		0.27 m 0.53 m/s	Coarse	14.6 m	Moderate	7.5 m/km	15%	High	Spring/Fall
RPR-249 Hare Indian River Sahtu Large Trenchless	6.8 mg/L	0.56 m	Coarse, with some fine	200 m	Low	0.3 m/km			Annual
RPR-292 Oscar Creek Sahtu Active I Isolate	10.8 mg/L	2 m 0.31 m/s	Coarse with some moderate (sand)	12.2 m	High	1 m/km	23%	Low - floodplain	Annual

Crossing, Region, Channel type, Method	Winter Depth, Flow, DO	Warm Season Depth, Flow	Dominant[1] Substrate	Channel Width	Habitat Diversity[2]	Stream Slope	Instability	Terrain[3]	Fish Use[4]
RPR-325 Jungle Ridge Creek Sahtu Active I Open Cut	1.1 mg/L 0.18 m 0.01 m/s	0.57 m 0.22 m/s	Fine (100% silt)	4.4 m	Low to moderate	5.3 m/km		Low	Spring/Fall
RPR-377 Blackwater River Deh Cho Large Trenchless	12 mg/L	1.17m 1.8 m/s	Coarse	99 m	Low	5.6 m/km	20%		Annual
RPR-410 Smith Creek Deh Cho Active I Isolate	11 mg/L	0.7 m 0.1 m/s	Coarse with some sand	6.6 m	Moderate	18 m/km			Annual
RPR-457 Trail River Deh Cho Active I Isolate	11.1 mg/L 0.21 m	0.31 m 0.51 m/s	Coarse	12.1 m	Moderate	2.2 m/km	91%	Low	Annual
RPR-475 Jean-Marie Creek Deh Cho Large Isolate	12.5 mg/L 0.67m 0.031 m/s	0.36 m/s	Coarse	30.1 m	Moderate		2%	Low	Annual
RPR-511 unnamed stream Deh Cho Active I Isolate		0.24 m 0.02 m/s	Moderate and coarse	5.6 m	Low to Moderate	0.5 m/km		Low	Annual

[1] Fine (silt), Moderate (silt/sand/gravel), Coarse (gravel/cobble) [2] Low (2 or less habitat types), Moderate (3-4 types), High (5+ types)
[3] Low (flat, low variability), Moderate (hilly, moderate variability), High (steep, high variability) [4] Annual (open-water and under-ice use), Spring/Fall (spring spawning, fall rearing)

V. Findings and Recommendations

Impacts of pipeline crossing construction on watercourses arise predominantly from increased suspended sediment concentrations and altered substrate texture and composition, and are typically short in duration. Impacts include modification of in-stream (fish and benthic invertebrate) habitat, as well as physical damage to, or stress upon, fish and invertebrates. Though the effects of altered sediment and sedimentation regimes on fish and invertebrates are well known in the literature, the effects of pipeline crossing construction on watercourse ecology are not well documented.

The MGP Impact Assessment concluded that construction of pipeline crossings would not have a significant impact on hydrology (TSS), water (and sediment) quality, and fish and fish habitat of watercourses. Tables 5 and 6 list watercourse crossings along the MGP pipeline right-of-way, key indicators of impact, and thresholds of impact to take into consideration in investigating the magnitude, duration and significance of impacts of the proposed pipeline crossing construction. Along with the various physical, chemical and biological variables (key indicators) recommended for baseline and impact monitoring, it is recommended that the following measures be taken as well: water velocity, water depth, water temperature, pH, and specific conductance (total dissolved solids-TDS).

To adequately identify the effects of pipeline crossing construction, it is recommended that site physical, chemical and biological monitoring take place 1) before construction, 2) (intensively) during construction and until suspended sediment concentrations return to background levels, and 3) after freshet. It is suggested that monitoring during and shortly after construction be carried at out varying distances downstream of construction, particularly in direct proximity to construction where impacts will be greatest. River and stream flows may have high interannual variability, such that freshet in one year may not be sufficient to scour sedimented accumulations in another year, hence it is recommended that systems with impacts persisting beyond freshet should be continuously monitored (i.e., 6 month to 1 year interval) until the impact is no longer evident.

Table 6. Recommended key indicators to measure and thresholds for assessment of impact of pipeline crossing construction on aquatic ecosystems. It is recommended that water velocity, water depth, water temperature, pH and specific conductance be measured as well.

Key Indicators	Thresholds
TSS (total suspended solids) concentration e.g., Reid *et al.* (2002), Reid and Anderson (2000), Young and Mackie (1991)	**CCME, 1999** Clear flow: max 25 mgL^{-1} increase over background over short-term (e.g., 24h); maximum average increase of 5 mgL^{-1} over background over the long-term (24h to 30d) High flow: max 25 mgL^{-1} increase over background when background is between 25 and 250 mgL^{-1}; increase of no more than 10% of background when background is > 250 mgL^{-1} **MGP: Imperial Oil Resources Ventures Limited, 2004d** Low impact: <10 mgL^{-1} increase in mean annual OR <50 mgL^{-1} increase over short-term (< 50 mgL^{-1} increase over background for Mackenzie and Liard) Moderate impact: 10-25 mgL^{-1} increase in mean annual concentration OR 50-100 mgL^{-1} increase over short-term (50-5000 mgL^{-1} increase over background for Mackenzie and Liard) High impact: >25 mgL^{-1} increase in mean annual concentration OR >100 mgL^{-1} increase over the short-term (>5000 mgL^{-1} increase over background for Mackenzie and Liard) **EIFAC, 1965** <25 mgL^{-1} = no harmful effects 25-80 mgL^{-1} = possible to maintain good to moderate fisheries, with diminished yield 80-400 mgL^{-1} = unlikely to support good freshwater fisheries 400 mgL^{-1} = only poor fisheries at best

Key Indicators	Thresholds
TSS (total suspended solids) concentration, continued	**DFO, 2000** 0 above background: no risk to fish and their habitat <25 mgL^{-1} above background: very low risk 25-100 mgL^{-1} above background: low risk 100-200 mgL^{-1} above background: moderate risk 200-400 mgL^{-1} above background: high risk >400 mgL^{-1} above background: unacceptable risk
Turbidity e.g., Roy *et al.* (2003)	**CCME, 1999** Clear flow: max 8 NTU increase over background over short-term (e.g., 24h); max 2 NTU increase above background over long-term (e.g., 30d) High flow or turbid water: max 8 NTU increase above background when background between 8 and 80 NTU; increase of no more than 10% of background when background is > 80 NTU Ratio of TSS concentration : Turbidity = approximately 3:1 for protection of aquatic organisms; will vary depending on nature of suspended sediment (see Lloyd, 1987)
Stream-bed substrate (actual and potential spawning sites) e.g., Reid *et al.* (2002), Lewis *et al.* (2002), Reid and Anderson (2000)	**CCME, 1999** Fine sediments: quantity in bed substrates should be no more than 10% particles <2 mm, 19% <3 mm, 25% <6.35 mm Geometric mean diameter (Dg): no greater than 12 mm $Dg = (d_{84} \times d_{16})^{0.5}$; d_{84} = 84th percentile particle size, d_{16} = 16th percentile particle size Fredle number (FN): no greater than 5 mm FN = geometric mean diameter / So; So = sorting coefficient = $(d_{75} / d_{25})^{0.5}$ Intergravel dissolved oxygen: minimum 6.5 mgL^{-1}

Key Indicators	Thresholds
DO (dissolved oxygen) e.g., Reid and Anderson (2000), Young and Mackie (1991)	**CCME, 1999** Warm-water biota – lowest acceptable: early life stages 6 mgL^{-1}; other life stages 5.5 mgL^{-1} Cold-water biota – lowest acceptable: early life stages 9.5 mgL^{-1}; other life stages 6.5 mgL^{-1}
Nutrients (N and P) e.g., Roy *et al.* (2003), Stantec Consulting Ltd. and Golder Associates Ltd. (2000)	**CCME, 1999** Nitrite: 60 μgL^{-1} Nitrate: Avoid concentrations that stimulate weed growth
Fish abundance e.g., Reid *et al.*, 2002	**EEM: Environment Canada, 2002** Statistical difference between measurements upstream and downstream of impact
Fish energy use (size-at-age, relative gonad size, relative fecundity) e.g., Stantec Consulting Ltd. and Golder Associates Ltd. (2000)	**EEM: Environment Canada, 2002** Statistical difference between measurements upstream and downstream of impact
Key Indicators	**Thresholds**
Fish energy storage (weight, relative liver size, relative egg size) e.g., Stantec Consulting Ltd. and Golder Associates Ltd. (2000)	**EEM: Environment Canada, 2002** Statistical difference between measurements upstream and downstream of impact

Fish survival (age) e.g., Stantec Consulting Ltd. and Golder Associates Ltd. (2000)	**EEM: Environment Canada, 2002** Statistical difference between measurements upstream and downstream of impact
Benthic invertebrate abundance e.g., Lewis *et al.* (2002), Stantec Consulting Ltd. and Golder Associates Ltd. (2000), Anderson *et al.* (1998), Armitage and Gunn (1996)	**EEM: Environment Canada, 2002** Statistical difference between measurements upstream and downstream of impact
Benthic invertebrate richness e.g., Roy *et al.* (2003), Stantec Consulting Ltd. and Golder Associates Ltd. (2000), Armitage and Gunn (1996), Young and Mackie (1991)	**EEM: Environment Canada, 2002** Statistical difference between measurements upstream and downstream of impact
Thresholds	**Key Indicators**
Benthic invertebrate diversity e.g., Roy *et al.* (2003), Armitage and Gunn (1996)	**EEM: Environment Canada, 2002** Statistical difference between measurements upstream and downstream of impact

Benthic invertebrate standing crop	**EEM: Environment Canada, 2002** Statistical difference between measurements upstream and downstream of impact
e.g., Stantec Consulting Ltd. and Golder Associates Ltd. (2000), Young and Mackie (1991)	**Wiederholm, 1984 in Stantec and Golder Associates, 2000** No effect: no change in community structure Low effect: small increase in standing crops of invertebrates; no change taxa richness; no change in trophic structure or slight shift toward scrapers and collector-gratherers Moderate effect: moderate to large increase in standing crops of grazers/scrapers, filter-feeders ad collector-gatherers; no change in standing crops of pollution-sensitive insects; shift toward collector-gatherers, scrapers and filer-feeders; no change in taxa richness Severe effect: large increase in standing crops of low DO tolerant taxa due to decay of organic material; decrease in standing crops or elimination of sensitive insects (e.g., EPT); large shift toward collector-gatherers; reduced taxa richness

References

Anderson, P.G., Fraikin, C.G.J. and T.J. Chandler (1998) Natural gas pipeline crossing of a coldwater stream: impacts and recovery. *Proceedings of the International Pipeline Conference. Vol.2.* American Society of Mechanical Engineers, June 7-11, 1998, Calgary, Alberta, p. 1013-1020.

Anderson, P.G., Taylor, B.R. and G.C. Balch (1996) *Quantifying the Effects of Sediment Release on fish and their habitats.* Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2346.

Armitage, P.D. and Gunn, R.J.M. (1996) Differential response of benthos to natural and anthropogenic disturbances in 3 lowland streams. Internationale Revue der Gesamten Hydrobiologie, 81, 2, 161-181.

Caux, P.-Y., Moore, D.R.J. and MacDonald, D. (1997) Ambient water quality criteria for turbidity, suspended and benthic sediments in British Columbia: Technical appendix. Prepared for British Columbia Ministry of Environment, Lands and Parks, Water Quality Branch, Victoria, BC.

CCME (1999) *Canadian Environmental Quality Guidelines.* Canadian Council of Ministers of the Environment, Winnipeg.

DFO (2000) *Effects of sediment on fish and their habitat.* DFO Pacific Region Habitat Status Report 2000/01.

EIFAC (1965) Water quality criteria for European freshwater fish. Water, air and soil pollution, 9, 151-168.

Environment Canada (2002) The New Metal Mining Effluent Regulations. CD.

Gartner Lee Limited (2004) Identification of the Biophysical Information and Research Gaps Associated with Hydrocarbon Exploration, Development and Transmission in the Mackenzie Valley. Final Report.

Golder Associates Ltd. (Golder) (2002) *Model Development for the Prediction of Sediment Entrainment During Open-Cut Pipeline Water Crossing Construction.* Gas Research Institute (GRI) Topical Report GRI-01/0088. Chicago, Illinois. 33pp. Prepared by Golder Associates Ltd. May 2002.

Imperial Oil Resources Ventures Limited (2004a) Environmental Impact Statement for the Mackenzie Gas Project. Volume 2: Project Description.

Imperial Oil Resources Ventures Limited (2004b) Environmental Impact Statement for the Mackenzie Gas Project. Volume 3: Biophysical Baseline. Part B Aquatic Resources: Groundwater, Hydrology and Water Quality.

Imperial Oil Resources Ventures Limited (2004c) Environmental Impact Statement for the Mackenzie Gas Project. Volume 3: Biophysical Baseline. Part C Aquatic Resources: Fish and Fish Habitat.

Imperial Oil Resources Ventures Limited (2004d) Environmental Impact Statement for the Mackenzie Gas Project. Volume 5: Biophysical Impact Assessment. Part B Aquatic Resources: Groundwater, Hydrology and Water Quality.

Imperial Oil Resources Ventures Limited (2004e) Environmental Impact Statement for the Mackenzie Gas Project. Volume 5: Biophysical Impact Assessment. Part C Aquatic Resources: Fish and Fish Habitat.

Jowett, I.G. (2003) Hydraulic constraints on habitat suitability for benthic invertebrates in gravel-bed rivers. River Research and Applications, 19, 495-507.

Lewis, L.J., Davenport, J. and Kelly, T.C. (2002) A study of the impact of a pipeline construction on estuarine benthic invertebrate communities. Estuarine, Coastal and Shelf Sciences, 55, 213-221.

Lloyd, D.S. (1987) Turbidity as a water quality standard for salmonid habitats in Alaska. North American Journal of Fisheries Management, 7, 34-45.

Malard, F., Tockner, K., Dole-Olivier, M-J. and Ward, J.V. (2002) A landscape perspective of surface-subsurface hydrological exchanges in river corridors. Freshwater Biology, 47, 621-640.

Mayhood, D.W. (1998) Some effects of natural gas operations on fishes & their habitats on Canada's Rocky Mountain east slopes. Rocky Mountain Ecosystem Coalition, Technical Report 95/1. http://www.fwresearch.ca/RMEC951.pdf. February, 2005.

Newcombe, C.P. and Jensen, J.O.T. (1996) Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management, 16, 693-727.

Newcombe, C.P. and Macdonald, D.D. (1991) Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management, 11, 72-82.

Reid, S.M., Ade, F. and Metikosh, S. (2004) Sediment entrainment during pipeline water crossing construction: predictive models and crossing method comparison. Journal of Environmental Engineering and Science, 3, 81-88.

Reid, S.M. and P.G. Anderson (1999) Effects of sediment released during open-cut pipeline water crossings. *Canadian Water Resources Journal*, 24, 23-39.

Reid, S. and Anderson, P.G. (2000) Evaluation of isolated watercourse crossings during winter construction along the Alliance pipeline in northern Alberta. Proceedings of the 7th International Symposium, Environmental Concerns in Right-of-Way Management, Calgary, AB.

Reid, S.M., Stoklosar, S., Metikosh, S. and Evans, J. (2002) Effectiveness of isolated pipeline crossing techniques to mitigate sediment impacts on brook trout streams. Water Quality Research Journal of Canada, 37, 2, 473-488.

Roy, A.H., Rosemond, A.D., Paul, M.J., Leigh, D.S. and Wallace, J.B. (2003) Stream macroinvertebrate response to catchment urbanization (Georgia, U.S.A.). Freshwater Biology, 48, 329-346.

Stantec Consulting Ltd. and Golder Associates Ltd. (2000) Cycle 2 Environmental Effects Monitoring for Athabasca River Basin Pulp Mills. Volume I: Interpretive Report.

Weiderholm, T. (1984) Responses of aquatic insects to environmental pollution. In: *The Ecology of Aquatic Insects* [Resh, V.H. and D.M. Rosenberg (eds.)]. Praeger, New York, pp.508-557.

Wood, P.J. and P.D. Armitage (1997) Biological effects of fine sediment in the lotic environment. *Environmental Management*, 21, 203-217.

Young, R.J. and Mackie, G.L. (1991) Effect of oil pipeline construction on the benthic invertebrate community structure of Hodgson Creek, Northwest Territories. Canadian Journal of Zoology, 69, 2154-2160.

Zwirn, M. (2002) Pipeline-stream crossing installations: Best management practices. http://www.wildsalmoncenter.org/pipeline-stream-english.pdf. February, 2005.

PRINTED IN CANADA ON RECYCLED PAPER
IMPRIMÉ AU CANADA SUR DU PAPIER RECYCLÉ

National Water Research Institute
Environment Canada
Canada Centre for Inland Waters
P.O. Box 5050
867 Lakeshore Road
Burlington, Ontario
L7R 4A6 Canada

National Hydrology Research Centre
11 Innovation Boulevard
Saskatoon, Saskatchewan
S7N 3H5 Canada

NATIONAL WATER RESEARCH INSTITUTE
INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX

Institut national de recherche sur les eaux
Environnement Canada
Centre canadien des eaux intérieures
Case postale 5050
867, chemin Lakeshore
Burlington, Ontario
L7R 4A6 Canada

Centre national de recherche en hydrologie
11, boul. Innovation
Saskatoon, Saskatchewan
S7N 3H5 Canada

Environment Canada Environnement Canada

Canada