PDHonline Course C378 (4 PDH)

Pipeline Construction Across Streams with Resulting Turbidity and Fishery Impacts

Instructor: H. Wayne Harper, PE

2020

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

An Approved Continuing Education Provider

Pipeline Construction Across Streams with Resulting Turbidity and Fishery Impacts

H. Wayne Harper, P.E.

EXECUTIVE SUMMARY

State water quality agencies typically impose turbidity standards on pipeline construction across waterbodies primarily because it is a widely used water quality measurement, is easy to determine in the field, and provides instantaneous feedback to regulatory personnel. However, most state water quality regulations pertaining to turbidity were originally developed for use with chronic long-term point-source discharge situations. The use of these criteria without some adjustment for the short-term nature of construction projects may be a mis-application of the basic concepts behind their original intent. Additionally, regulatory personnel will often use turbidity data to infer fishery impacts. Turbidity, however, has a lesser biological effect on fish than does its often-related measurement, suspended sediment. Portland Natural Gas Transmission System (PNGTS)/Northern Ecological Associates, Inc. (NEA) used established engineering models and grain size analysis to conduct a detailed study of turbidity and suspended sediment dynamics caused by pipeline construction across streams.

To predict total suspended sediment (TSS) distribution and transport, PNGTS/NEA developed scenarios for typical waterbody crossings by assuming representative stream characteristics including: width, cross-sectional area, bed composition, mean velocity, estimated transport distances, material lost during excavation, and the increase in suspended solids expected downstream of the crossing. PNGTS/NEA used sediment grain size analyses that were collected from representative stream crossings as input parameters in the model. PNGTS/NEA's estimates were then input into Trow's 1996 model to estimate sediment dispersion for three stream types: low, medium, and high energy. Predicted suspended sediment values were then used to determine lethal and sublethal fishery impacts using Newcombe and Jensen's mathematical model which assigns a Severity of Ill Effect (SEV) value for fish species guilds based on dose (TSS/ml) and duration (hours) of exposure. The results of this analysis were used in negotiations with state regulatory personnel to help describe potential realistic fishery impacts, rather than hypothetical effects that may be caused by elevated turbidity values.

TABLE OF CONTENTS

DESCRIPTION **PAGE**

LISTING OF TABLES

LISTING OF FIGURES

DESCRIPTION **PAGE**

1.0 INTRODUCTION

The creation and expansion of linear facilities such as pipelines and roads necessitates traversing waterbodies, such as, rivers, and streams and therefore normally requires some level of "in-stream" construction activity. Construction within a waterbody will inevitably suspend sediments in the water column. As a result, state and federal agencies often attach suspended sediment or turbidity water quality regulations to permits authorizing in-stream activity. With pipeline construction in waterbodies, crossing techniques have been developed to minimize the magnitude and duration of suspended sediment events. These modern construction techniques are in stark contrast to common methods utilized up to the 1980s. Examples of "old-school" and updated waterbody pipeline construction techniques are depicted in Figures 1 and 2, respectively. However, even with the implementation of current Best Management Practices (BMPs), any in-stream construction operations will result in a temporary increase in sediment loads and turbidity within a waterbody higher than natural background levels for at least a short time period. This technical report has been prepared to convey the following key points:

- Normal pipeline construction through waterbodies creates short-term levels of suspended sediments and turbidity greater than that allowed by most state water quality regulations;
- Case studies of recent pipeline construction projects and basic sediment transport modeling demonstrate the realistic levels of turbidity that can be expected during construction; and,
- Impacts to fisheries and aquatic biota will not be adversely affected by the short-term nature of the turbidity created by pipeline construction.

Figure 1: Pipeline Construction Near a Waterbody in the Mid-1900's

Figure 2: "Dry" Waterbody Pipeline Construction in Maine, 1999

2.0 CHARACTERISTICS OF TURBIDITY AND SEDIMENTATION

2.1 TURBIDITY

The American Public Health Association defines turbidity as an optical property of water wherein suspended and some dissolved materials such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms cause light to be scattered and absorbed rather than transmitted in straight lines. More simply, turbidity is a measure of the "cloudiness" of water or other fluids. Turbidity is measured using a nephelometric method with turbidity values presented in nephelometric turbidity units ("NTUs"). Nephelometry is a measure of light extinction measuring the light scattered at a 90° angle by suspended particles.

2.2 SEDIMENTATION

Suspended solids (or sediment) are the portion of the sediment load within a waterbody which can be transported via suspension (mainly clays, silts, and fine sands). The component of the suspended load that will settle out rapidly is defined as the settleable solids portion. Settleable solids refer to particles that settle out quickly from suspension. Settleable solids can either remain in-place indefinitely, or move downstream mainly via bedload transport processes. Suspended sediments are typically classified as silt-clay particles less than 62 microns in diameter. Conversely, particles larger than these are considered settleable solids.

2.3 Sediment Suspension During Construction

An impact of pipeline construction is the temporary generation of a plume of suspended solids and turbid water to downstream reaches of the watercourse. Levels of suspended solids increase rapidly at the onset of in-stream activity. However, pipeline installations do not generate uniform periods of high-suspended concentrations downstream. Instead, discrete peaks of high-suspended sediment concentrations occur corresponding to activities such as trench excavation, trench dewatering, and backfilling. During these time periods of peak suspended sediment concentrations, turbidity values may reach levels ranging from several hundred to several thousand NTUs. When construction stops and the streambed is no longer disturbed, suspended sediment levels typically recede to near ambient conditions. The magnitude and duration of downstream increases in suspended sediment concentrations and turbidity levels during in-stream construction are determined by:

- Size of waterbody crossing
- Construction activity
- Flow volume and velocity
- Sediment particle settling rates

3.0 REVIEW OF SEDIMENT-RELATED WATER QUALITY STANDARDS AND CRITERIA

Regulation of the input of sediment into waterbodies attributable to pipeline construction activities has been achieved through defining allowable construction methods and time frames within construction permits. In some states, numerical turbidity restrictions have been incorporated into permit conditions in order to ensure the application of permit conditions defined for a given watercrossing. These values are generally based on state water quality guidelines. However, most state water quality regulations pertaining to turbidity were originally developed for use with chronic long-term point-source discharge situations. The use of these criteria without some adjustment for the short-term nature of construction projects may be a mis-application of the basic concepts behind their original intent (Trow, 1996). Some states have recognized that during in-stream construction there are no practicable means to maintain turbidity levels to typical regulation levels developed for chronic exposure situations. Acknowledging that their water quality regulations do not appropriately address the short-term impacts associated construction activities within waterbodies; some states have modified their water quality standards and/or mixing zone criteria.

4.0 ANTICIPATED TURBIDITY DURING PIPELINE CONSTRUCTION

To document the magnitude of suspended sediments and turbidity that typically can be expected during pipeline construction, this section provides two recent case studies that review turbidity monitoring programs conducted during the construction of the Florida Gas Transmission - Phase III Expansion and the Pacific Gas Transmission - Pacific Gas & Electric Pipeline Expansion projects. The experience in these case studies, which were located in the southeast and western United States, reveals that exceedances in chronic exposure turbidity threshold levels simply cannot be avoided during construction. Additionally, sediment transport analyses for "Wet" and "Dry" waterbody crossings were performed to simulate anticipated suspended sediment and turbidity levels that can be expected in New Hampshire.

4.1 CASE STUDY 1: FLORIDA GAS TRANSMISSION - PHASE III EXPANSION

The Florida Gas Transmission Company ("FGT") - Phase III Expansion Project ("Expansion") consisted of the construction of approximately 600-miles of natural gas pipeline throughout Florida during 1994 and 1995. Following existing ROWs to the greatest extent practicable, the mainline route, which was relatively parallel to the coastline, crossed hundreds of waterbodies through Florida.

4.1.1 Surface Water Quality Regulation Variance

During the permitting process, FGT petitioned the Florida Department of Environmental Protection ("FDEP") for a variance of the existing state water quality standards for turbidity and criteria for mixing zones during the construction of its Phase III Expansion Project for Class B waterbodies (FDEP 1993). The FDEP, acknowledging the fact as stated in the petition, that "there is no practicable means known or available for the adequate control of the pollution involved (turbidity)", granted the petitioner temporary variance from the Florida Administrative Codes regulating mixing zones and turbidity. The variance issued by the FDEP to FGT for pipeline construction activities within waterbodies had the following major components:

- The mixing zone to be utilized during pipeline construction activities within waterbodies shall be expanded from 150 meters to 800 meters downstream of the crossing;
- Turbidity levels at the end of the mixing zones shall not exceed 1,000 NTUs above natural background levels for more than 12 consecutive hours;
- Turbidity levels at the end of the mixing zones shall not exceed 3,000 NTUs above natural background levels for more than 3 consecutive hours; and

- Within 5 days after the beginning of trenching, turbidity levels at sampling points located 150 meters downstream of the crossing shall not exceed 29 NTUs above natural background levels.

It should be noted that the 1,000 and 3,000 NTU turbidity values were deemed necessary by both FGT and the FDEP due to fine sediment conditions typically encountered below grade throughout many portions of Florida. Turbidity resulting from these formations can be significant as the fine sediment has extremely small particle size and mass. Although the actual turbidity values utilized in the FGT variance may not necessarily be applicable to other states, the overall framework of stratified turbidity levels, time windows, and mixing zone lengths contained within this variance reflect a mechanism that allowed the construction to proceed while providing some level of environmental protection.

4.1.2 Turbidity Monitoring Program

Throughout construction of the Expansion, FGT was required to conduct a turbidity monitoring program. As documented in the "Intent to Grant Variance" issued by the FDEP, this monitoring program consisted of the following components:

- Turbidity sampling shall take place at the end of the mixing zone and within 150 meters of the impact site (within the mixing zone), downstream of the construction activities, within the visible plume.
- Sampling at the end of the mixing zone shall be conducted twice daily, during the morning and afternoon work periods, and additionally during the daylight hours of each rainy day, during the rain event or within 3 hours following the rain event. Sampling at 150 meters shall be conducted once daily, during work periods. If any turbidity sample exceeds 600 NTUs within the mixing zone, hourly sampling shall continue at that site until turbidity levels drop below 600 NTUs.

PNGTS/NEA were able to obtain a small portion of this turbidity sampling data from the FDEP reflecting typical pipeline construction activities within minor waterbodies during October, 1994 (FGT 1994). After reviewing data from four typical streams, it has been determined that, upon initiation of construction activities, turbidity levels increased between 110 and 1,100 NTUs above background conditions. Following completion of the in-stream activities, these elevated turbidity levels quickly dropped and approached background levels between a few hours and a day. Turbidity monitoring data from two representative Expansion pipeline waterbody crossings is depicted in Figures 3 and 4.

Figure 3: **FGT-III Stream L3-60 Turbidity Data**
150-meters Downstream of Crossing

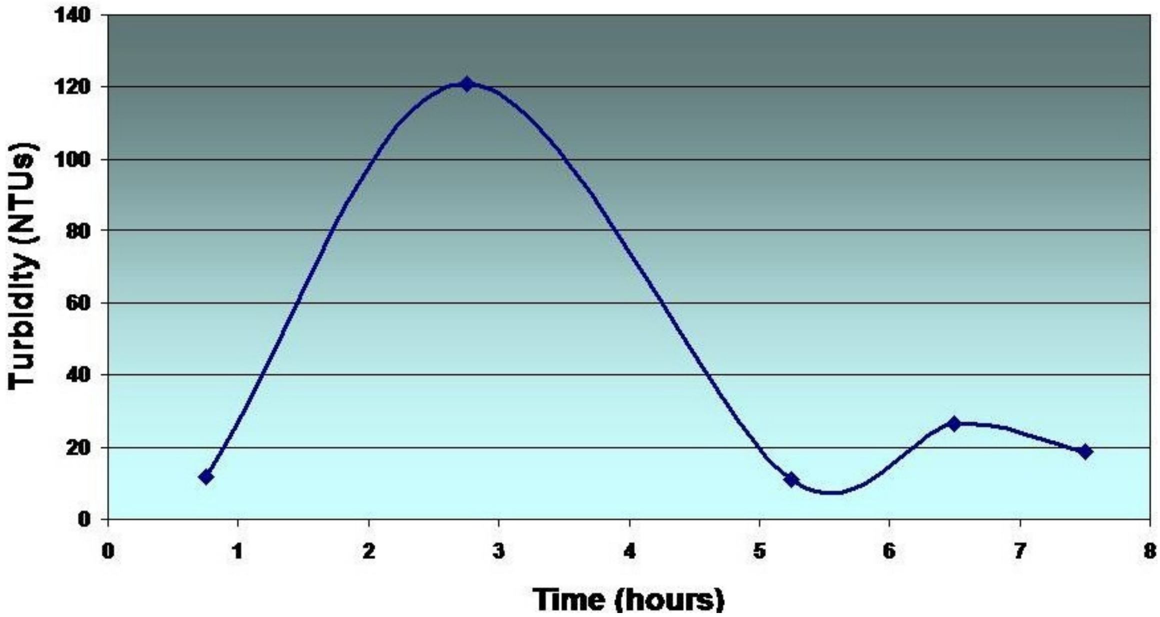
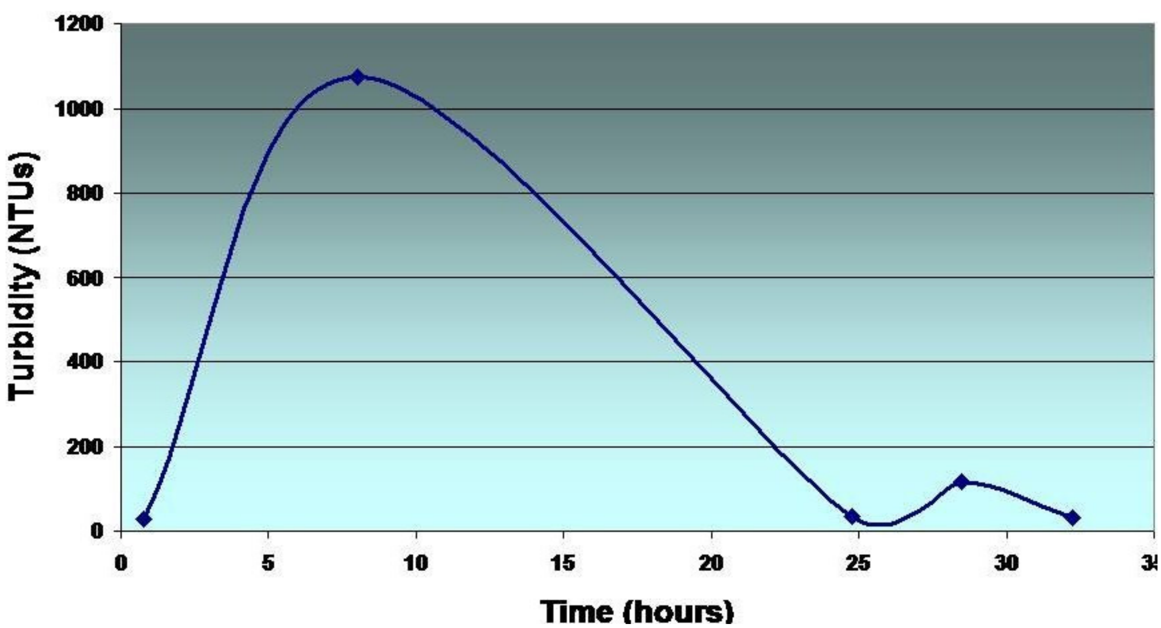


Figure 4: **FGT-III Stream L3-81 Turbidity Data**
150-meters Downstream of Crossing



4.2 Case Study 2: Pacific Gas Transmission - Pacific Gas & Electric Pipeline Expansion

During the summer of 1992, Pacific Gas Transmission ("PGT") and Pacific Gas & Electric ("PG&E") expanded their natural gas pipeline system by looping an approximate 700-mile section that ran from the Canadian-United States border near Eastport, Idaho to the Central Valley of California. The construction process involved numerous waterbody crossings including eight "wet" crossings of the Moyie River along a 13-mile section of pipeline immediately south of the Canadian-United States border in Boundary County, Idaho. The information provided in the following sections was obtained from the *Data Summary Report on Short-Term Turbidity Monitoring of Pipeline River Crossings in the Moyie River, Boundary County, Idaho: PGT-PG&E Pipeline Expansion Project, March 1994* ("Moyie-Report").

4.2.1 Surface Water Quality Regulations for Turbidity

As part of project's Section 401 Water Quality Certification, the Idaho Division of Environmental Quality ("IDEQ") established water quality monitoring requirements for turbidity, which included the following:

- Turbidity will be the water-quality parameter measured.
- Measurements will be taken immediately upstream and 600 feet downstream of the trenching activity. The upstream location will be far enough upstream to be unaffected by construction and will allow background turbidity to be measured. A best professional judgement of 600 feet downstream was determined by IDEQ as the distance required for dissipation on the basis of the permit for what the IDEQ considered to be an analogous river crossing in California (the upper Sacramento River crossing permit issued by the Army Corps of Engineers, Sacramento).
- The downstream turbidity is not to exceed background turbidity by more than 50 nephelometric turbidity units (NTUs) instantaneously or 25 NTU averaged over a 10-day period.

4.2.2 Revised IDEQ Requirements

The turbidity plumes that were generated by construction of the first two crossings of the Moyie River (#8 and #6) did not behave as anticipated by the IDEQ, and revisions to the sampling protocol were developed to better characterize the sediment plumes. The following observations were documented by the Army Corps of Engineers and the IDEQ:

- The plume was more persistent than expected, distinguishable as far as the confluence with the Kootenai River, 9-23 miles downstream from the crossing activities (depending on the crossing location).
- Poor mixing 600 feet downstream precluded representative sampling of the plume at that location.
- Turbidity levels were much higher than the IDEQ 50-NTU instantaneous standard.

In response to these sediment distribution observations, IDEQ changed the sampling protocol to obtain more representative measurements. Additionally, in response to levels of turbidity in excess of the 50 NTU standard, experimental BMPs, which are typically not utilized during pipeline construction, were developed by the construction contractor and applicable federal and state agencies before the start of each of the remaining crossings.

4.2.3 Turbidity Monitoring Results

Turbidity levels were measured from samples collected at regular time intervals utilizing automatic samplers at each Moyie River crossing. Peak turbidity levels, which can be associated with excavation and backfilling, are summarized in Table 1.

Table 1: Moyie River Pipeline Crossing Peak Turbidity Levels

Moyie River Crossing Number	Peak Turbidity Levels (NTUs) at ~ 600' Downstream of Crossing	
	Associated with Excavation	Associated with Backfilling
8	214	155
6	743	225
4	1,060	660
5	683	398
2	1,181	1,783
1	2,652	424
3	1,200	1,400

A comparison of statistical analysis results, utilizing flow weighted averages, indicates a similar turbidity level verses time pattern between the FGT and PGT/PG&E projects. Turbidity values rose quickly with the initiation of pipeline construction activities and declined with the completion of the work efforts. Within 24-hours of restoration of the stream banks, turbidity levels were generally the same as upstream background conditions.

4.2.4 Report Conclusions

Provided below is a summary of the main components of the conclusions and recommendations documented in the Moyie Report.

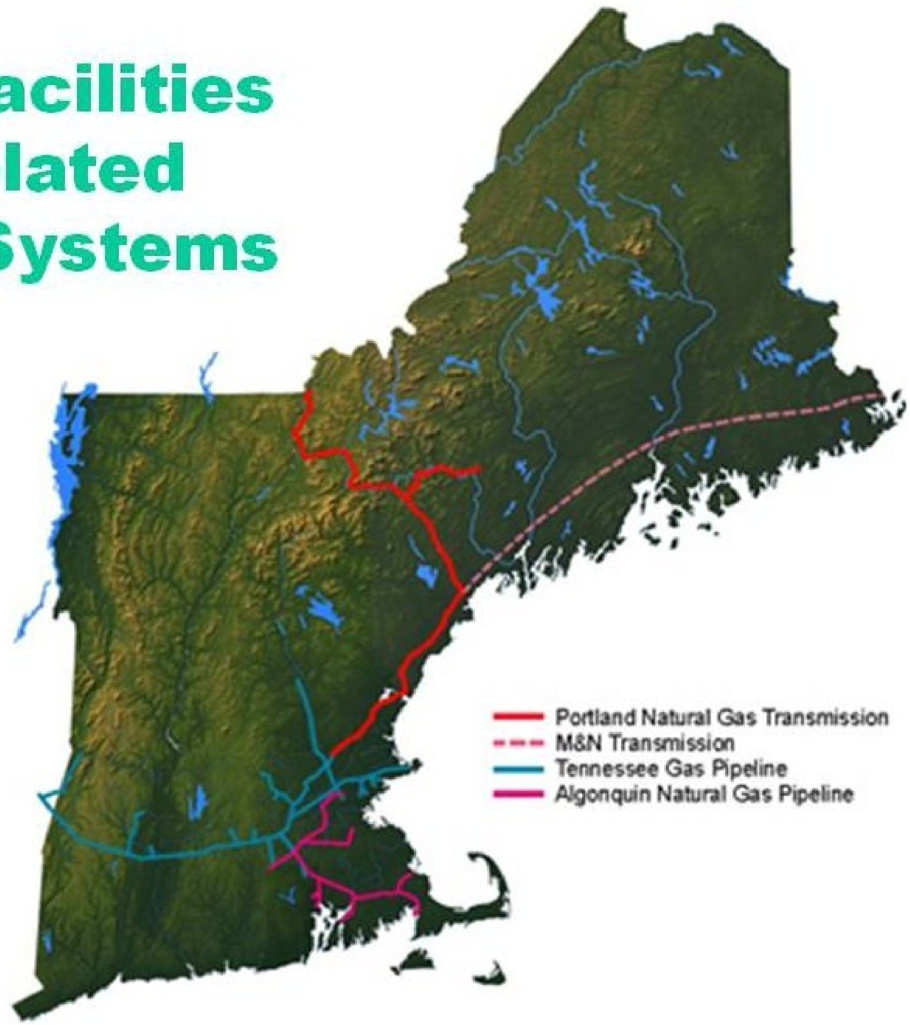
- Mixing of suspended sediments across the river cross-section was not uniform 600 feet to up to 0.5 mile downstream of the crossings. This uneven mixing presents a problem when trying to take samples representative of the overall turbidity.
- The turbidity plumes observed were extremely persistent. The plumes generated at the northern crossings (#1, #2, #3, & #4) had turbidity levels far above the IDEQ standards, even after they had traveled several river miles downstream. Less is known quantitatively about the persistence of the plumes generated by the southern crossings (#5, #6, #7, & #8), but visual observations suggest that they were as persistent as the other plumes.
- Dissolved-oxygen concentration and temperature of the water downstream of the crossing construction were not affected by in-stream construction activities.
- However, several of the "experimental" BMPs appeared to be ineffectual when field tested and were, by consensus, discarded at later crossings.

4.3 SEDIMENT TRANSPORT ANALYSIS FOR "WET" WATERBODY CROSSINGS

In an effort to assess the magnitude of sediment transport and turbidity that would occur in New Hampshire waterbodies crossed by the then proposed PNGTS North-Section Facilities and PNGTS/Maritimes & Northeast Joint Facilities (collectively herein referred to as the "Projects" – see Figure 5) using the open cut or "wet" method, PNGTS/NEA conducted sediment transport analysis using computer simulations. The computer model utilized was developed following the methodologies for sediment transport assessment as presented in the *Waterbody Crossing Design and Installation Manual - Appendix C*, ("Model") (Trow 1996). This model predicts particle transport distances, zones of deposition, depth of sediment deposition per zone, and expected suspended solids increase at downstream zone intervals. Provided in the following sections are documentation of input data development, sediment transport calculation methodologies, resulting output data, and interpretation of the results.

Figure 5:

PNGTS Facilities and Related Pipeline Systems



4.3.1 New Hampshire Waterbody Classifications

To develop scenarios of "typical waterbodies crossed" by the Projects in New Hampshire, a statistical analysis of the comprehensive waterbody crossing table was conducted. This table was presented for the applicable portions of the Projects in the permit filings that were submitted to the New Hampshire Energy Facility Evaluation Committee ("EFSEC") and Federal Energy Regulatory Commission ("FERC"). This information is summarized in Table 2.

Table 2: Summary of Waterbodies Crossed by the Projects in New Hampshire

Waterbody Type	Criteria Definition	Number of Waterbodies	Average Width (feet)	Average Depth (inches)	Average Side Slope Ratio	Average Cross-Sectional Area (ft)$^{(2)}$
Major	width > 100'	6 $^{(1)}$	237.7	38.2	1:1	786.2
Intermediate	10' ≤ width ≤ 100'	46	22.7	16.9	1:1	37.7
Minor	width < 10'	227	4.5	6.5	1:1	3.3

NOTE: Excludes the Piscataqua and Connecticut Rivers

4.3.2 Sediment Grain Size Distributions

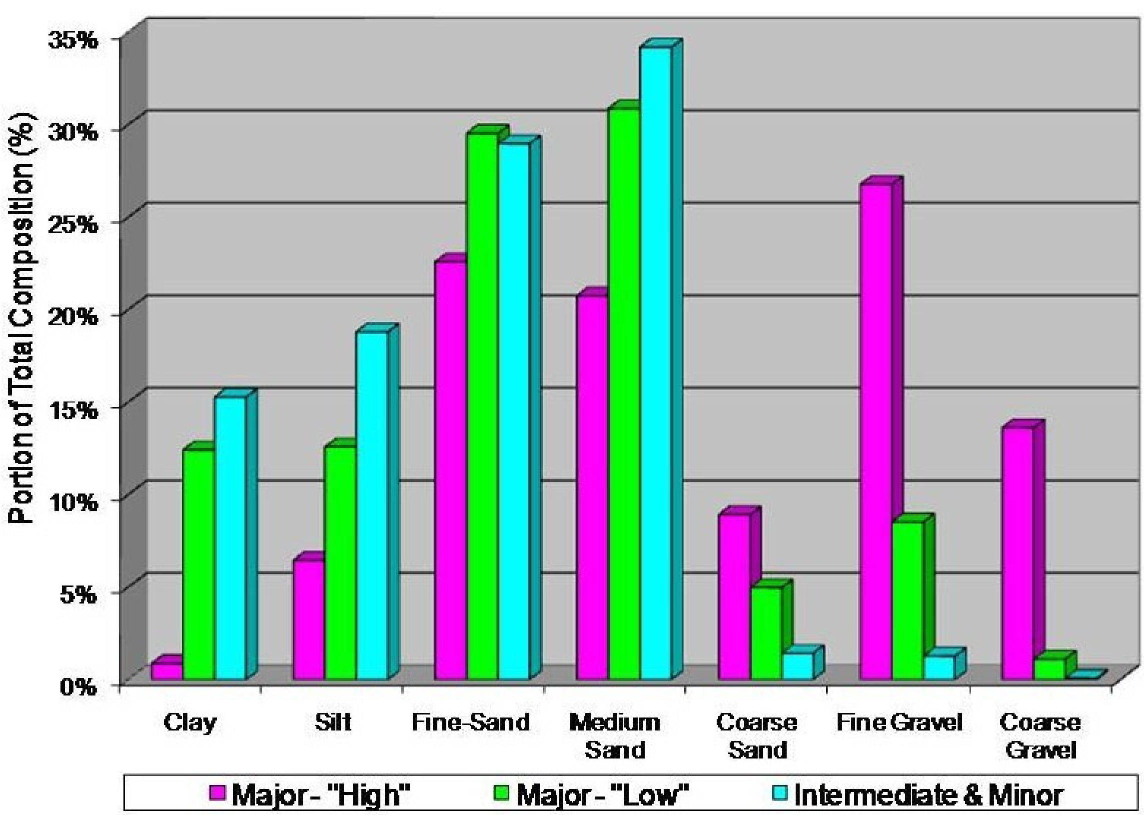
In addition to the dimensional characteristics of the waterbodies crossed, substrate composition data was also needed as input to the computer model. Since existing substrate data from within these waterbodies was not available, the PNGTS/NEA substituted substrate composition data collected during a sediment sampling program performed on several rivers in Maine during August, 1997. The waterbodies sampled in Maine have characteristics similar to those crossed in New Hampshire. In general, most waterbodies in the region have substrates consisting of glacial till with surface characteristics determined by site-specific flow regimes. Therefore, waterbodies with comparable size and flow regime types can be expected to have similar substrate compositions. During the summer of 1997, PNGTS/NEA conducted the *Maine Sediment Sampling Program* ("Program") at the proposed pipeline crossings of the Androscoggin, Presumpscot, and Great Works Rivers in Maine. Sediment grain size distribution was one of the parameters for which these waterbodies were analyzed. A summary of the particle distribution data from this Program is provided in Table 3. Comparative analysis of the size and flow regime type for these three waterbodies was also conducted for the purpose of assigning sediment grain size distributions to New Hampshire waterbody categories during computer modeling. Based on this representative comparison, each of the three major categories of waterbodies was correlated with a particle distribution as indicated in Table 3 and depicted in Figure 6.

Major "High-Energy" and "Low-Energy" waterbodies are contrasted by their substrate compositions. "High-Energy" waterbodies contain higher proportions of heavy sediment particles such as cobbles and sands, while "Low-Energy" waterbodies contain higher proportions of light sediment particles such as silts and clays.

Table 3: Summary of Sediment Grain Size Distributions

Parameters		Waterbody		
		Androscoggin River	Presumpscot River	Great Works River
Number of Crossing Locations		3	2	2
Total Number of Samples Analyzed		9	8	8
Clay Composition	0.001 to 0.075 mm	0.88%	12.41%	15.28%
Silt Composition	0.001 to 0.075 mm	6.46%	12.58%	18.80%
Fine-Sand Composition	0.075 to 0.420 mm	22.59%	29.54%	28.98%
Medium-Sand Composition	0.42 to 2.00 mm	20.76%	30.87%	34.19%
Coarse-Sand Composition	2.0 to 4.8 mm	8.91%	4.97%	1.42%
Fine-Gravel Composition	4.8 to 19.0 mm	26.78%	8.53%	1.26%
Course Gravel Composition	19 to 75 mm	13.62%	1.10%	0.07%
Computer Model Waterbody Classifications with Corresponding Sediment Grain Size Distributions		Major Waterbody "High-Energy"	Major Waterbody "Low-Energy"	Intermediate & Minor Waterbodies

Figure 6: **Sediment Grain Size Distributions**



4.3.3 Particle Settling Velocities

Settling velocities for various particle sizes were presented in the Model. However, the data provided did not cover the entire sediment grain size distribution range that was documented from the Program. Therefore, a linear regression analysis of this relationship was conducted to develop an equation to expand the range for which data were available. The resulting equation below has an R^2 of 0.9988 and a standard error of coefficient of 0.002999.

$$Y = (0.122529)\ X - 0.003806$$

4.3.4 Sediment Transport Distances

Sediment transport distances were calculated within each waterbody category for each limiting particle size utilizing the (Trow, 1996) equation;

$$L = \{(D)\ (Va)\} / Vs,$$

where:
- L = transport distance (m);
- D = depth of flow (m);
- Va= average streamflow velocity (m/s); and
- Vs = settling velocity (m/s).

Calculations for each waterbody category were generated with a range of streamflow velocities to simulate flow regimes that typically could be encountered in New Hampshire. The section of the waterbody between the "minimum particle size distance value" and the "maximum particle size distance value" for each defined particle type represents the zone of deposition for that particle type.

4.3.5 Sediment Distribution Characteristics

Utilizing the physical characteristics of each typical waterbody type, sediment transport distances, and physical characteristics of the pipeline trench, sediment distribution profiles were calculated as a function of streamflow velocity. Table 4 summarizes the physical characteristics of the pipeline trench and waterbodies, in-stream disturbance durations, and sediment loss percentages used for these calculations. Suspended solid values generated by the model are calculated as averages and do not reflect peak values associated with excavation and backfilling. Specifically, the model disperses the sediment loss volume evenly through the time period of construction disturbance within the waterbody.

4.3.6 Suspended Solids Concentration to Turbidity Level Conversions

In an effort to expand the usefulness of the Model, the final output as suspended solids concentration was converted into turbidity levels (NTUs). Although direct correlation between suspended solids and turbidity must be determined on a site-specific stream basis, streams of similar substrate composition generally have similar correlations. PNGTS/NEA obtained correlation equations (personal communication Scott Reid, Golder Associates, 1997), which are provided below, for waterbodies in western Canada that have similar glacial till substrate characteristics. These equations were developed by Golder Associates during extensive monitoring of eight pipeline construction crossings of five waterbodies. The resulting turbidity vs. suspended solids relationships from these equations were averaged and plotted. The averaging equation and plot were then modified to have a Y-intercept $\simeq$ 0, which represents suspended solids concentration of 0 mg/l equal to turbidity level of 0 NTU. This modified averaging equation is presented below;

$$NTU = \{(TSS)\,(0.880387)\} + 0.001946$$

Table 4: Summary of Pipeline Trench Physical Characteristics within Waterbodies

Characteristic Description	Value	Units
Average Trench Depth	3	meters
Average Trench Bottom Width	2	meters
Average Trench Top Width	6.8	meters
Average Trench Side-Slope Ratio (horizontal:vertical)	0.8:1	---
Average Trench Cross-Sectional Area	13.2	square meters
Average Length for Major Waterbody	72.44	meters
Average Length for Intermediate Waterbody	6.91	meters
Average Length for Minor Waterbody	1.36	meters
Major Waterbody In-stream Disturbance Duration	30	hours
Intermediate Waterbody In-stream Disturbance Duration	12	hours
Minor Waterbody In-stream Disturbance Duration	8	hours
Sediment Volume Lost from Trench at Va = 0.2 m/s	3.34 (6)	%
Sediment Volume Lost from Trench at Va = 0.4 m/s	6.67 (5)	%
Sediment Volume Lost from Trench at Va = 0.6 m/s	10.00 (4)	%
Sediment Volume Lost from Trench at Va = 0.8 m/s	13.33 (3)	%
Sediment Volume Lost from Trench at Va = 1.0 m/s	16.67 (2)	%
Sediment Volume Lost from Trench at Va = 1.2 m/s	20.00 (1)	%

4.3.7 Summary of Computer Modeling Input and Output Parametrs

As previously mentioned, sediment distribution profiles were generated utilizing the Model for typical major “high-energy”, major “low-energy”, intermediate, and minor waterbodies crossed by the proposed Projects in New Hampshire. The integral components of this analysis consisting of:

INPUT PARAMETERS

- Sediment grain size distributions;
- Particle settling velocities;
- Physical characteristics of the typical waterbody types;
- Physical characteristics of the typical pipeline construction trench within a waterbody;
- Average stream velocities representing various flow regimes;
- Proportional sediment loss ratios.

OUTPUT PARAMETERS

- Sediment transport distances for various particle sizes;
- Sediment loss proportional to average stream velocity;
- Area of deposition for various particle sizes;
- Depth of sediment for various deposition zones;
- Suspended solids concentrations at downstream distances;
- Turbidity levels at downstream distances (obtained from correlation equations).

4.4 SEDIMENT TRANSPORT ANALYSIS FOR “WET” WATERBODY CROSSINGS

The results of the modeling effort for “wet” waterbody crossings, which are summarized in Table 5, represent average values calculated over the duration of construction disturbance and documents sediments transport characteristics at distances of 6.7, 1,000, 2,000, and 3,000-feet, respectively. The 6.7-foot location represents conditions that occur at the pipeline crossing. The 1,000-foot location represents the maximum allowable mixing zone length as stipulated in the Standards and Conditions. The 2,000 and 3,000-foot locations were generated for comparison purposes and represent conditions farther downstream of the crossing point. The actual in-stream turbidity values are expected to be instantaneously higher and lower at various points during the construction process. A summary of the results are provided below:

- Turbidity levels of $\leq$10 NTUs cannot be attained 2 meters downstream of a pipeline crossing regardless of waterbody type or stream velocities (see Figure 7).
- At the end of a 1,000' mixing zone, turbidity levels range from 1 NTUs for a major “high-

energy" waterbody to 467 NTUs for a minor waterbody (see Figure 8). Turbidity levels of ≤10 NTUs can be attained at the slow to moderate stream flow regime major waterbody crossings, none of the intermediate waterbody crossings, and at only the slowest streamflow minor waterbody crossing.

- At the end of a 2,000' mixing zone, conditions improve only slightly over the 1,000' levels, with turbidity levels ranging from 1 NTUs for a major "high-energy" waterbody to 383 NTUs for a minor waterbody. Turbidity levels of ≤10 NTUs attained at all but the fastest flow "high-energy" major waterbody, the two slowest flow regime "low-energy" major waterbodies, the slowest flow intermediate waterbody, and the slowest streamflow minor waterbody.
- At the end of a 3,000' mixing zone, conditions are similar to the 2,000' levels, with turbidity levels ranging from 0.5 NTUs for a major "high-energy" waterbody to 297 NTUs for a minor waterbody. Turbidity levels of ≤10 NTUs attained at all of the "high-energy" major waterbodies, the two slowest flow regime "low-energy" major waterbodies, the slowest flow intermediate waterbody, and the two slowest streamflow minor waterbodies.

Based on the modeling results, the majority of the major, intermediate, and minor waterbodies proposed for "wet" crossings could not be crossed without exceeding the New Hampshire 10 NTU water quality standard at the end of the 1,000-foot mixing zone at some point in the construction process. This would occur despite using approved industry standard techniques and BMPs.

Table 5: Sediment Transport Characteristics Calculated at Various Distances Downstream of "Wet" Waterbody Crossing

Parameter	Major "High-Energy" Waterbody						Major "Low-Energy" Waterbody						Intermediate Waterbody						Minor Waterbody					
In-stream Disturbance Duration (hours) [1]	30						30						12						8					
Average Stream Velocity (m/s)	0.2	0.4	0.6	0.8	1.0	1.2	0.2	0.4	0.6	0.8	1.0	1.2	0.2	0.4	0.6	0.8	1.0	1.2	0.2	0.4	0.6	0.8	1.0	1.2
6.56 Feet (2 meters) Downstream of Pipeline Crossing																								
Turbidity Levels (NTUs)	11	29	48	67	86	108	20	48	78	106	135	164	92	207	357	523	705	878	235	560	972	1421	1861	2316
Suspended Solids Concentration (mg/l)	13	33	54	76	98	123	23	55	89	121	153	186	105	254	406	595	801	998	267	636	1105	1615	2115	2633
Depth of Sediment (mm)	25	46	58	77	92	110	23	43	46	48	50	68	50	88	101	89	74	61	22	78	154	198	224	243
Total Sediment Loss (metric tons)	54	107	163	217	270	325	54	107	163	217	270	325	5.2	10	16	21	26	31	1.0	2.0	3.1	4.1	5.1	6.1
1,000 Feet (304.8 meters) Downstream of Pipeline Crossing																								
Turbidity Levels (NTUs)	1	3	6	8	11	12	3	8	18	26	35	43	18	48	76	128	183	240	7	105	201	298	362	467
Suspended Solids Concentration (mg/l)	0.9	3.8	6.5	8.9	12	14	3.8	9.3	21	30	40	49	21	54	86	145	208	273	8.4	119	229	339	411	531
Depth of Sediment (mm)	<0.1	0.7	1.0	1.3	1.4	1.5	0.1	0.5	1.4	1.6	1.8	1.9	0.1	0.2	0.7	1.2	2.1	2.6	0	0.2	0.3	0.3	0.4	0.4
2,000 Feet (609.6 meters) Downstream of Pipeline Crossing																								
Turbidity Levels (NTUs)	1	2	4	6	9	11	3	7	12	20	29	37	8	37	66	95	123	153	---	15	112	209	304	383
Suspended Solids Concentration (mg/l)	0.8	2.8	4.3	6.8	9.7	12	3.1	8.5	14	23	33	42	9.5	42	75	108	140	174	---	17	127	237	346	435
Depth of Sediment (mm)	<0.1	<0.1	0.2	0.6	0.9	1.0	0.1	0.1	0.2	0.8	1.1	1.4	<0.1	0.1	0.1	0..1	0.1	0.1	---	<0.1	0.2	0.2	0.3	0.3
3,000 Feet (914.4 meters) Downstream of Pipeline Crossing																								
Turbidity Levels (NTUs)	0.5	2	3	4	6	10	2	7	11	15	22	31	---	27	55	85	113	143	---	---	22	120	218	297
Suspended Solids Concentration (mg/l)	0.6	2.6	3.8	5.0	7.3	11	2.4	7.7	12	17	25	35	---	31	63	97	128	162	---	---	25	136	248	338
Depth of Sediment (mm)	<0.1	<0.1	<0.1	<0.1	0.3	0.6	<0.1	<0.1	0.1	0.1	0.4	0.8	---	0.1	0.1	0.1	0.1	0.1	---	---	<0.1	0.1	0.1	0.1

NOTES:
- • The data provided in this table represent average values calculated over the duration of construction disturbance. Actual in-stream values are expected to be instantaneously higher at some pont during the construction process.
- * Highlighted areas indicate sediment transport regimes which exceed turbidity levels of 10 NTUs.
- * (---) Turbidity plume dissipated before reaching indicated distance downstream of pipeline crossing.
- 1 In-stream disturbance duration indicates the amount of time the equipment will actually be trenching and creating disturbance during the crossing. Actual pipe installation and restoration may take considerably longer.

Figure 7: **Calculated Turbidity Values for Various Waterbody Types and Streamflow Velocities 6.56-ft (2-meters) Downstream of "Wet" Crossing**

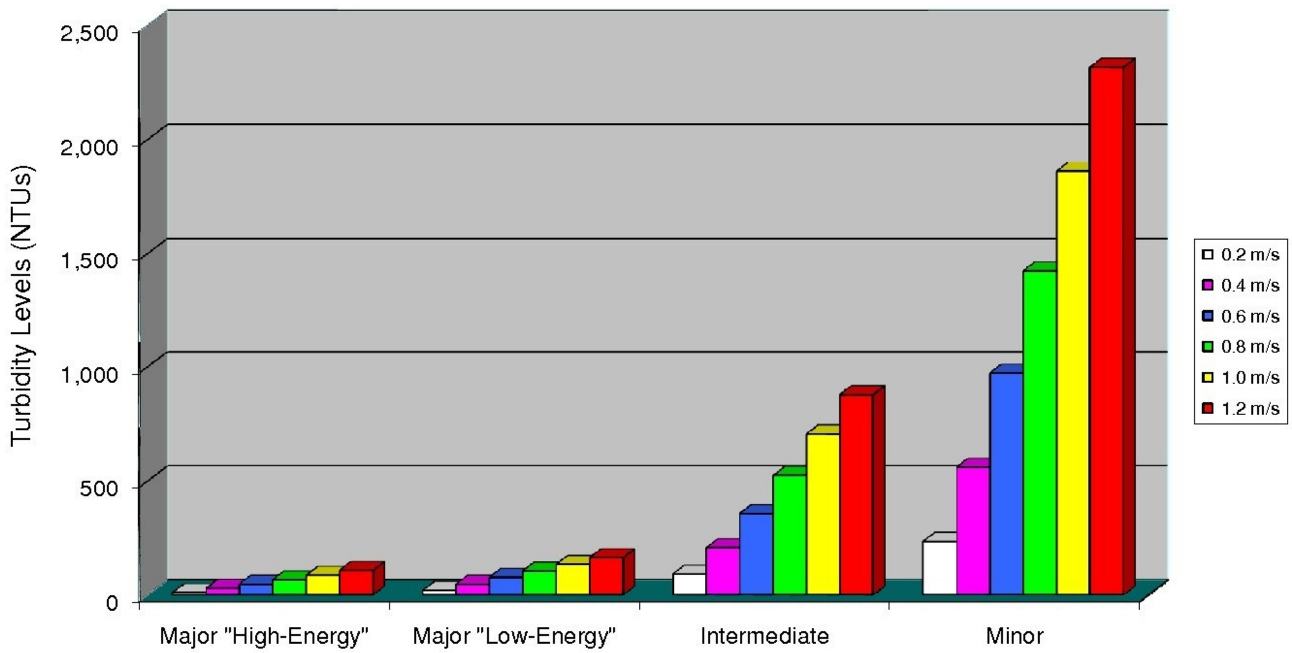
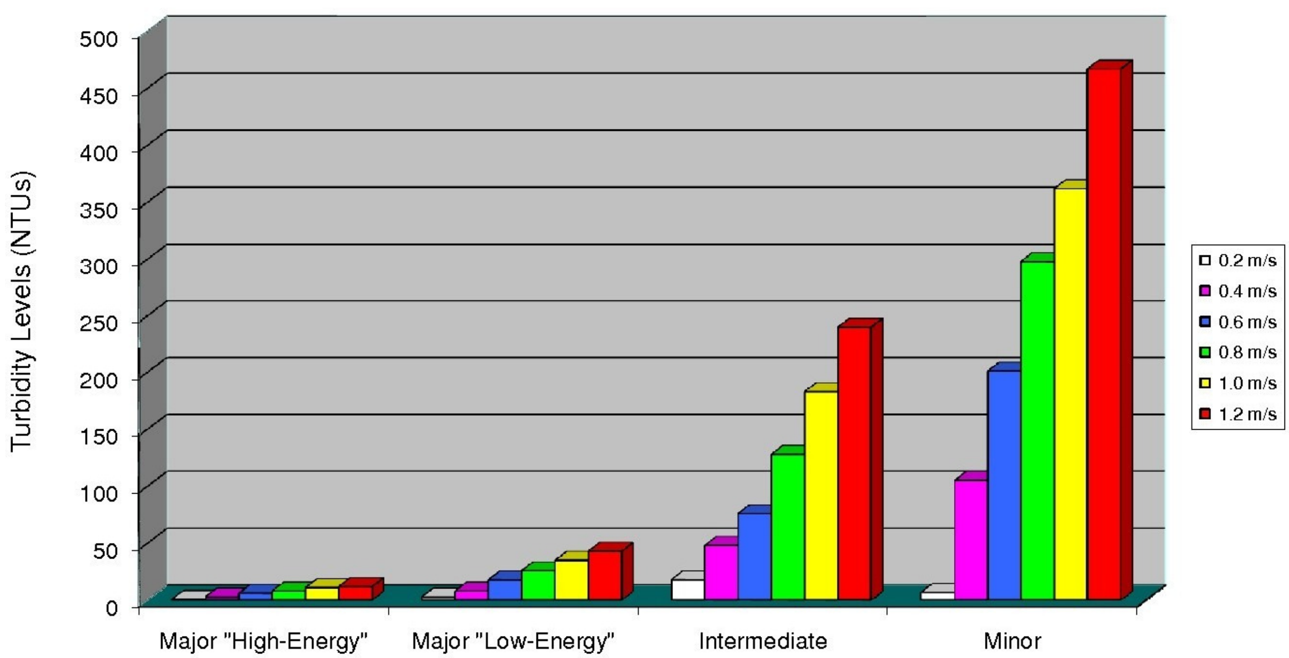


Figure 8: **Calculated Turbidity Values for Various Waterbody Types and Streamflow Velocities 1,000-ft (305-meters) Downstream of "Wet" Crossing**



4.5 SEDIMENT TRANSPORT ANALYSIS FOR "DRY" WATERBODY CROSSINGS

Certain waterbodies, typically those less than 10-feet in width may be suitable for crossing using the flumed or pump-around "dry" crossing method. To assess the magnitude of sediment transport which would occur in New Hampshire waterbodies crossed using the "dry" method, the PNGTS/NEA modified the sediment transport analysis presented in Section 4.3. Because it is impracticable to conduct a dry crossing of a major waterbody, modeling for this size class was omitted. Although it is generally infeasible to conduct dry crossings of intermediate waterbodies, turbidity levels were calculated for comparison purposes. Although the same calculation algorithms were utilized, selected input parameter values were modified to represent the "quick-flush" which occurs after a "dry" crossing is complete and water barriers around the construction work area are removed. This "quick-flush" flow regime is very different from that which occurs during "wet" crossing and is characterized by very turbulent and high energy initial impact which suspends most of the sediments in a concentrated time period. A summary of the modified input parameters is provided in Table 6.

Table 6: Summary of Modified Sediment Transport Analysis Input Parameters

Characteristic Description	Value	Units
Intermediate Waterbody "In-stream Flush" Duration	1	hours
Minor Waterbody "In-stream Flush" Duration	1	hours
Sediment Volume Lost from Trench at Va = 0.2 m/s	0.11 [6]	%
Sediment Volume Lost from Trench at Va = 0.4 m/s	0.22 [5]	%
Sediment Volume Lost from Trench at Va = 0.6 m/s	0.33 [4]	%
Sediment Volume Lost from Trench at Va = 0.8 m/s	0.44 [3]	%
Sediment Volume Lost from Trench at Va = 1.0 m/s	0.55 [2]	%
Sediment Volume Lost from Trench at Va = 1.2 m/s	0.66 [1]	%

4.5.1 Summary and Interpretation of Computer Modeling

Review of model outputs for the sediment transport characteristics between the "wet" and "dry" waterbody crossings, indicates they have very similar average turbidity values at comparable sediment transport distances. However, for "dry" crossings the volume of sediment loss and the duration of the turbidity plume is minimal in comparison. As previously stated, the results of the modeling effort for "wet" and "dry" waterbody crossings represent average values calculated over the duration of construction disturbance. It should be noted that the turbidity produced with either crossing method will have peak values associated with certain construction activities. These activities include excavation and backfilling for "wet" crossings and water barrier removal for "dry" crossings. Specifically, the modeling results for "dry" crossings, as summarized in Table 7 indicate the following:

- It is expected that New Hampshire water quality levels for turbidity can be maintained at the end of the 1,000-foot mixing zone as per the Standards and Criteria during the trenching and pipe installation;
- Minimal amounts of total sediment removal as compared to "wet" crossings; and,
- Turbidity levels will be elevated in manner similar to "wet" crossings, but only for the approximate 1-hour "quick flush" period. Specifically, turbidity levels can be expected as follows:
    - Turbidity levels of $\leq$10 NTUs cannot be obtained 2 meters downstream of a pipeline crossing regardless of waterbody type or stream velocities (see Figure 9).
    - At the end of a 1,000' mixing zone, turbidity levels range between 8 NTUs for a major "high-energy" waterbody and 129 NTUs for a minor waterbody (see Figure 10). Turbidity levels of $\leq$10 NTUs can be obtained at none of the intermediate waterbody crossings, and at only the slowest streamflow minor waterbody crossing. Results would be even less favorable at the end of a 500-foot mixing zone.

Based on these results, it may be possible to maintain the required turbidity standard during the construction process of typical minor waterbody crossing. However, the 10 NTU turbidity standard would typically be exceeded for a short period during the restoration period.

Table 7: Sediment Transport Characteristics Measured at Various Distances Downstream of "Dry" Waterbody Crossing

Parameter	Intermediate Waterbody (1)						Minor Waterbody					
Post-Disturbance "Flush-Time" (hours)	1						1					
Average Stream Velocity (m/s)	0.2	0.4	0.6	0.8	1.0	1.2	0.2	0.4	0.6	0.8	1.0	1.2
6.56 Feet (2 meters) Downstream of Pipeline Crossing												
Turbidity Levels (NTUs)	36	88	140	204	275	343	62	107	251	370	484	603
Suspended Solids Concentration (mg/l)	41	100	159	232	313	390	70	121	285	420	550	685
Depth of Sediment (mm)	1.7	2.9	3.2	1.7	3.3	2.1	0.7	2.6	5.0	7.0	8.0	8.0
Total Sediment Loss (metric tons)	0.15	0.35	0.50	0.70	0.85	1.0	0.05	0.05	0.10	0.15	0.15	0.20
1,000 Feet (304.8 meters) Downstream of Pipeline Crossing												
Turbidity Levels (NTUs)	8	19	30	50	71	94	2	14	18	78	103	129
Suspended Solids Concentration (mg/l)	8.5	21	34	57	81	107	2.2	16	20	89	117	146
Depth of Sediment (mm)	<0.1	<0.1	<0.1	<0.1	0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2,000 Feet (609.6 meters) Downstream of Pipeline Crossing												
Turbidity Levels (NTUs)	3	15	26	37	48	60	---	4	29	53	79	105
Suspended Solids Concentration (mg/l)	3.8	17	29	42	55	68	---	4.5	33	62	90	119
Dep0th of Sediment (mm)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	<0.1
3,000 Feet (914.4 meters) Downstream of Pipeline Crossing												
Turbidity Levels (NTUs)	---	11	22	33	44	55	---	---	6	32	56	82
Suspended Solids Concentration (mg/l)	---	12	25	38	50	63	---	---	6.5	36	64	93
Depth of Sediment (mm)	---	<0.1	<0.1	<0.1	<0.1	<0.1	---	---	<0.1	<0.1	<0.1	<0.1

NOTES:
- The data provided in this table represent average values calculated over the duration of construction disturbance. Actual in-stream values are expected to be instantaneously higher at some pont during the construction process.
- * Highlighted areas indicate sediment transport regimes which exceed turbidity levels of 10 NTUs.
- * (---) Turbidity plume dissipated before reaching indicated distance downstream of pipeline crossing.
- (1) Dry crossings of intermediate waterbodies are not typically feasible due to width and flow constraints.

Figure 9: **Calculated Turbidity Values for Various Waterbody Types and Streamflow Velocities 6.56-ft (2-meters) Downstream of "Dry" Crossing**

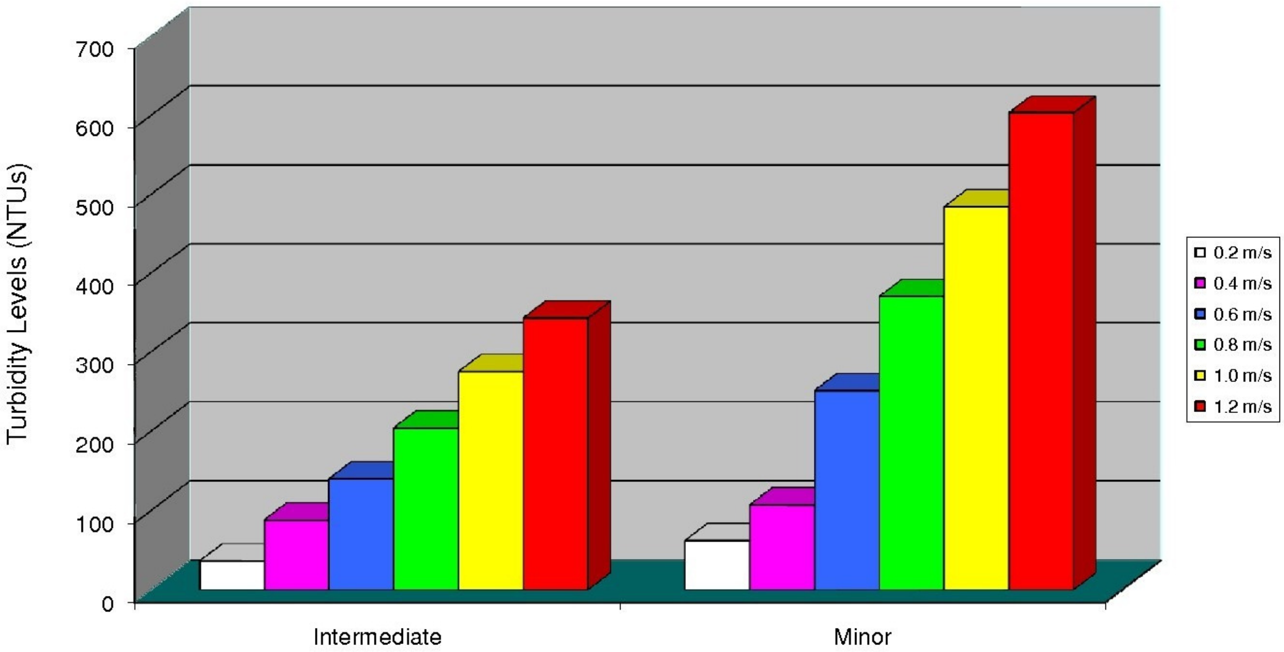
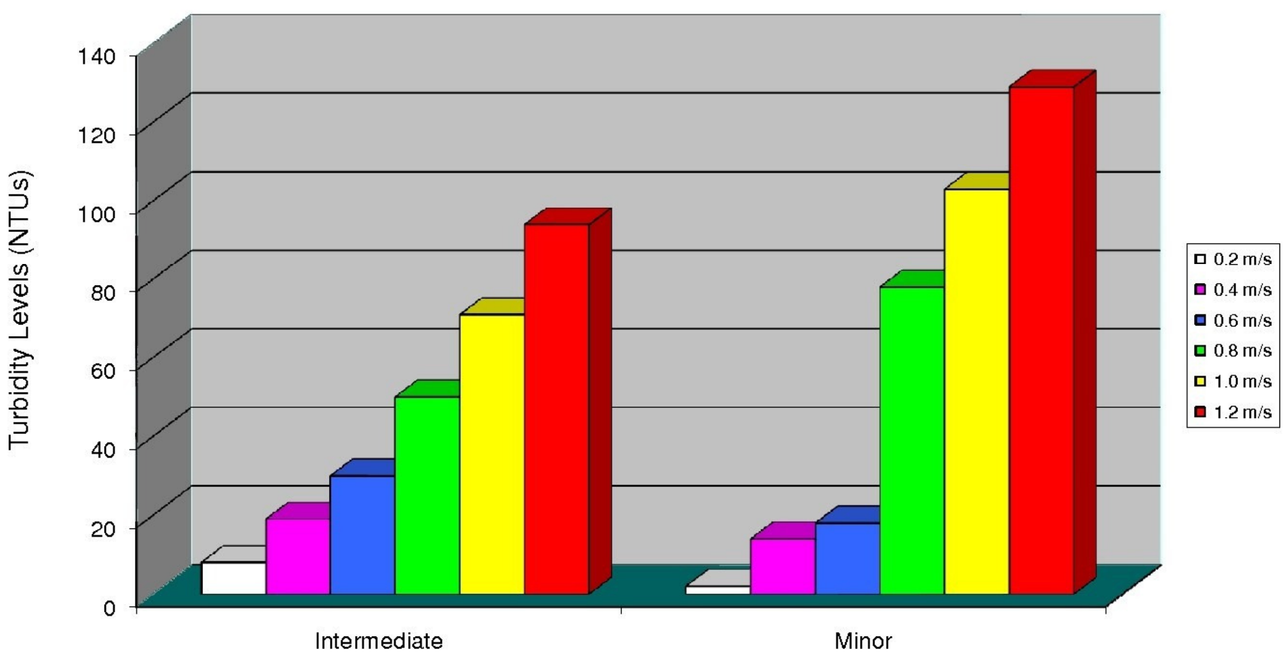


Figure 10: **Calculated Turbidity Values for Various Waterbody Types and Streamflow Velocities 1,000-ft (305-meters) Downstream of "Dry" Crossing**



5.0 IMPACTS TO AQUATIC BIOTA

This section addresses potential impacts to aquatic biota caused by suspended solids and turbidity in a watercourse. Although substantial research has been done, impacts are variable depending upon nature of pollutant, duration of exposure, type of organism, water temperature, and season of the year. This section focuses on review of several recent studies performed specifically to attempt to quantify impacts to fishery resources caused by various levels of suspended solids and turbidity.

5.1 INTRODUCTION

Studies on the effect of sediments on fish and other aquatic organisms are extensively reviewed in Anderson et al. (1996). Various studies have shown that there is no easily defined concentration of suspended sediment above which fisheries are damaged and below which fisheries are protected (Alabaster and Lloyd 1980 cf Anderson et al. 1996).

Anderson et al. (1996) indicate that the response of biological receptors to environmental stresses is complex. Many factors may influence the actual severity of effect that are caused by a sediment release episode, including:

- Characteristics of the particles suspended;
- Temperature of the water; and
- The existing stress level within the receiving environment

Despite the difficulties associated with quantifying impacts to aquatic resources, Newcombe and MacDonald (1991), Newcombe (1994), Newcombe and Jensen (1996), and Anderson et al. (1996) have developed theoretical models in an attempt to provide guidelines or criteria for the protection of fish populations.

5.2 ANALYSIS AND DISCUSSION

PNGTS/NEA utilized models and analytical techniques developed by the above-mentioned authors to attempt to quantify impacts to fisheries that may be created by construction of the proposed pipeline and its resultant suspended sediment and turbidity. The analysis attempted to evaluate impacts to fisheries that may occur immediately downstream of the construction zone and at the end of the New Hampshire Department of Environmental Services ("NHDES") proposed 1000-foot mixing zone. Suspended sediment concentrations calculated herein using sediment data from the

PNGTS Maine sediment sampling program along with anticipated exposure duration data (24, 36, and 72 hours) were used to predict the potential impact of suspended sediment episodes on fish life history stages. For each life history stage, Severity of Effect (SEV) classifications (Table 1 from Newcombe and Jensen [1996]) were estimated for each of four age class/sediment size categories and one habitat category (Anderson et al. 1996):

- Juvenile and Adult Salmonids (particle sizes 0.5-250µm)
- Adult Salmonids (particle sizes 0.5-250µm)
- Juvenile Salmonids (particle sizes 0.5-75µm)
- Eggs and Larvae of Salmonids and Non-Salmonids (particle sizes 0.5-75 µm)
- Adult Freshwater Non-Salmonids (particle sizes 0.5-75µm)
- Habitat Effects

SEV estimates were made for multiple waterbody types (Major High and Low Energy, Intermediate, and Minor), stream velocity (0.2-1.2 meters/second), and fish family (salmonid or non-salmonid) for each of the categories above using the multiple regression model developed by Newcombe and Jensen (1996). The model was run assuming the performance of a wet crossing, with periods of turbidity extending for up to 72-hours. The model was not used to predict impacts associated with the 1-hour turbidity event that would occur with a “dry” crossing. Generalized habitat effects were predicted using the multiple regression model developed by Anderson et al. (1996). Table 8 presents a 0-14 scale of the severity of ill effects in relation to four major classes of effect as presented in Newcombe and Jensen (1996). The four major classes of effect include: nil effect; behavior effects; sublethal effects; and lethal effects.

Table 8: Scale of Severity for Ill Effects Associated with Suspended Solids

SEV #	Description of Effect
Nil Effect	
0	No behavioral effects
1	Alarm reaction
2	Abandonment of cover
3	Avoidance response
Behavioral Effects	
4	Short-term reduction in feeding rates; Short-term reduction in feeding success
5	Minor physiological stress: • increase in the 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

5.3 RESULTS AND CONCLUSIONS

From the results of the modeling, moderate behavioral effects to salmonids and non-salmonids may occur due to the levels of suspended solids and turbidity created by a typical wet crossing, as depicted in Figures 11 and 12. However, no paralethal or lethal effects on salmonids and non-salmonids are anticipated 1,000 feet from the source of disturbance.

One of the assumptions of the models is that fish would remain in the turbidity plume and be subjected to the various levels of suspended sediments for extended periods of time. In reality, it can be expected that fish will display the avoidance response to the extent possible and vacate the areas of highest concentrations. Furthermore, it can be expected that peak levels of turbidity will not extend beyond 48 hours, thus fewer effects are anticipated. In the case of "dry" crossings, turbidity plumes will be extremely brief in duration (< 1 hr.), thus having an insignificant effect on fishery resources.

Figure 11: "Wet" Waterbody Crossing Severity of Effects 2-Meters Downstream for Juvenile and Adult Salmonids

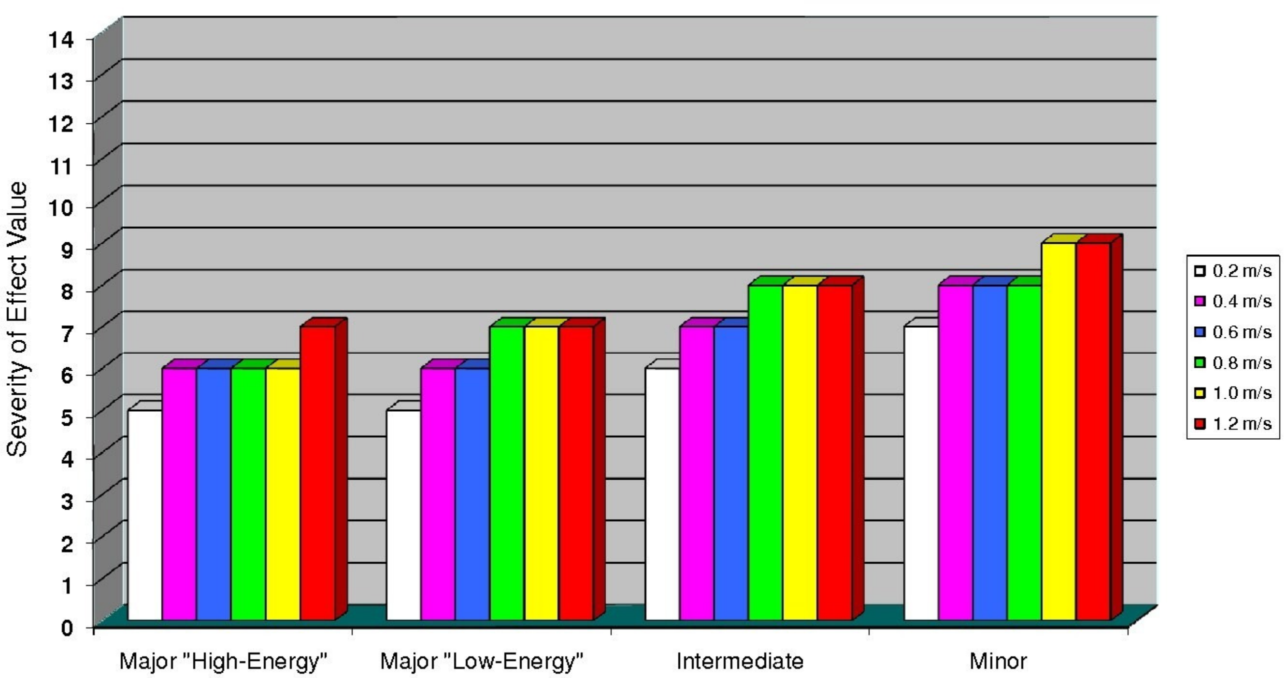


Figure 12: "Wet" Waterbody Crossing Severity of Effects 2-Meters Downstream for Adult Non-Salmonids

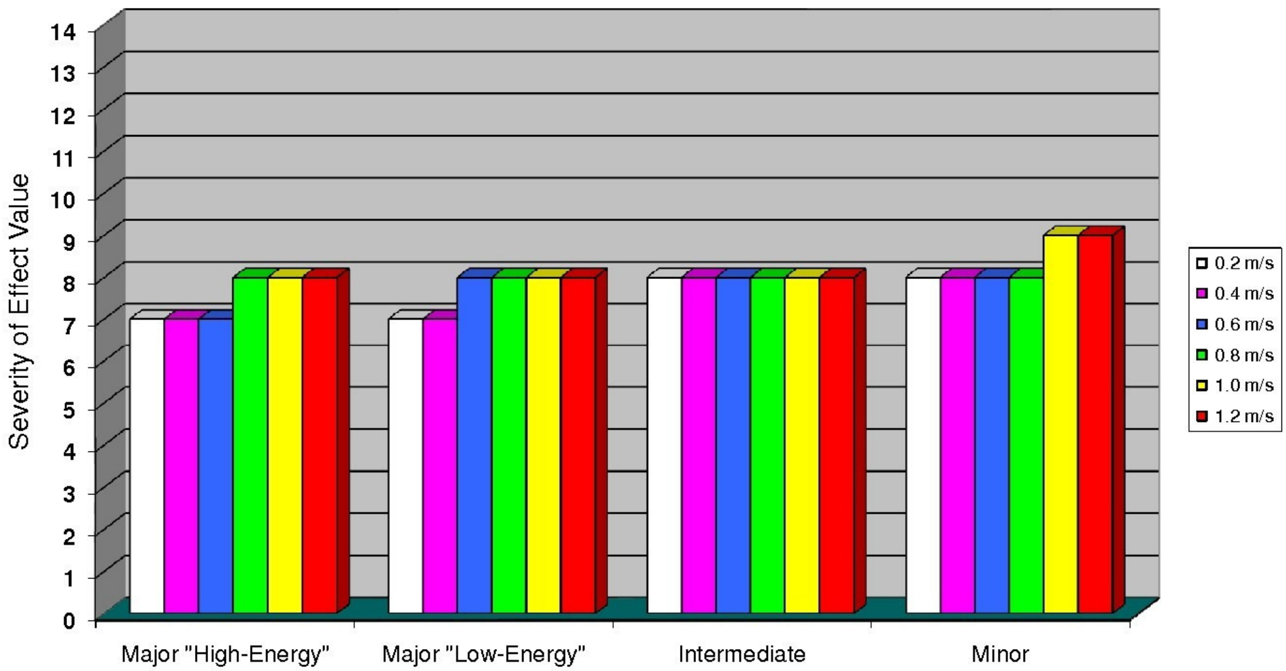
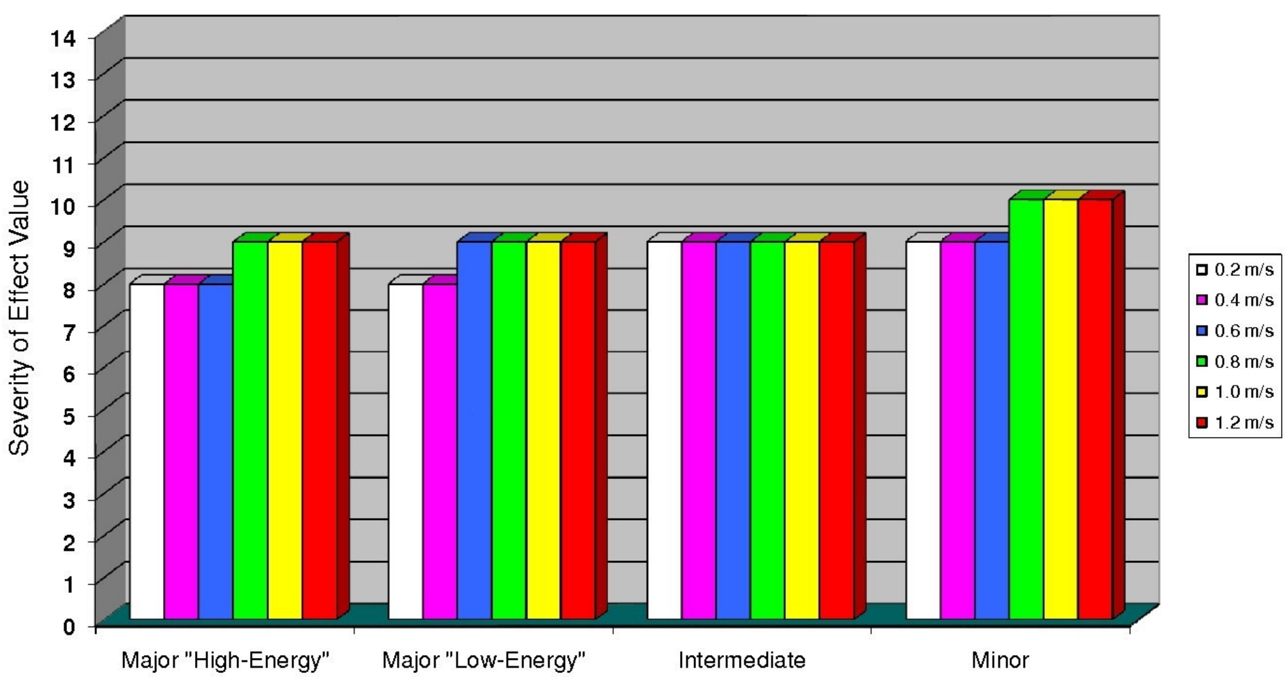


Figure 13: "Wet" Waterbody Crossing Severity of Effects 2-Meters Downstream for Fish Eggs and Larvae



Potential paralethal effects could occur to salmonid and non-salmonids eggs and larvae, as deicted in Figure 13. However, the construction window imposed by the FERC of June 1 through September 30 avoids the period when most eggs or larval fish will be present in the waterbody, thus substantially minimizing the effect of suspended sediment and turbidity and habitat degradation due to silt deposition. Furthermore, sediment transport modeling indicates minimal silt deposition particularly for "dry" crossings.

6.0 COMPREHENSIVE SUMMARY AND CONCLUSIONS

States water quality standards and criteria related to turbidity and mixing zones are primarily applicable to long-term point discharges of pollutants that have the potential to result in significant degradation of water quality. Short-term discharges associated with temporary construction activities such as pipeline construction do not fit well with the standards and criteria related to turbidity and mixing zones.

Well-documented case studies on recent pipeline construction projects show that turbidity levels during normal stream crossing activities typically exceed the states turbidity standards even when applying all appropriate Best Management Practices. Various states have recognized the difficulty of applying turbidity standards designed for long-term point discharges to the short-term disturbances caused by pipeline construction, and have attempted to identify allowable tolerances, mixing zones, and time windows to enable the construction process to proceed.

The analysis contained herein demonstrates the following basic conclusions:

- Sediment transport modeling using sediment data and stream size/flow characteristics applicable to the New Hampshire project area predict temporary turbidity levels significantly higher than the New Hampshire turbidity standard at the end of the allowed mixing zone. Even when utilizing the most protective dry crossing techniques, sediment transport modeling predicts short-term exceedances of the 10 NTU turbidity standard.
- Recent research on predicted suspended sediment and turbidity impacts to fishery resources show that impacts to fishery resources can be expected to be generally minor and short term. The sediment transport modeling predicts that the turbidity levels generated during pipeline construction of the projects were not expected to have a significant effect on aquatic resources.

7.0 REFERENCES

Alabaster, J.S. and R. Lloyd. 1982. *Finely divided solids.* Pages 1-20 in J.S. Alabaster and R. Lloyd editors. Water quality criteria for freshwater fish, 2nd edition. Butterworth, London.

Anderson, P.G., B.R. Taylor, 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. 109 pages.

Argonne National Laboratory. 1994. *Data Summary Report on Short-Term Turbidity Monitoring of Pipeline River Crossings in the Moyie River, Boundary County, Idaho: PGT-PG&E Pipeline Expansion Project*. Submitted to the Gas Research Institute. Argonne Laboratory - Energy Systems Division. Argonne, IL.

Golder Associates Ltd. 1997. *Suspended Sediment and Turbidity Criteria Associated with In-stream Construction Activities; an Assessment of Biological Relevance*. Report submitted to the Interstate Natural Gas Association of America. Golder Associates Ltd. Calgary, Alberta, Canada.

Florida Gas Transmission - Phase III Expansion Project (FGT-III). 1994. *Spreads 3b, 4, & 5: Monthly Report - November 14, 1994.* FGT-III. Tallahassee, FL.

Newcombe, C.P. and J.O.T. Jensen. 1996. *Channel Suspended Sediment and Fisheries: A Synthesis for qualitative Assessment of Risk and Impact.* North American Journal of Fisheries Management 16:693-727.

Newcombe, C.P. 1994. *Suspended Sediments in Aquatic Ecosystems: Ill Effects as a Function of Concentration and Duration of Exposure.* Habitat Protection Branch, British Columbia Ministry of Environmental, Lands and Parks. Victoria, British Columbia, Canada, 298 pages.

Newcombe, C.P. and D.D. MacDonald. 1991. *Effects of Suspended Sediments on Aquatic Ecosystems.* North American Journal of Fisheries Management 11:72-82.

State of Florida Department of Environmental Protection (FDEP). 1993. *Intent to Grant Variance - Florida Gas Transmission Company - File No. VE-03-646.* FDEP. Tallahassee, FL.

Trow Engineering Consultants Inc. 1996. *Waterbody Crossing Design and Installation Manual* Report submitted to the Offshore and Onshore Design Applications Supervisory Committee of the Pipeline Research Committee at the American Gas Association. Trow Engineering Consultants Inc. Tallahassee, FL.