University of Alberta

TURBIDITY MONITORING FOR AQUATIC ECOSYSTEM ASSESSMENT AND ITS APPLICABILITY TO MINE TAILINGS MANAGEMENT AND WATERCOURSE CROSSING CONSTRUCTION

By

Kyla L. Walker-Makowecki ©

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ABSTRACT

The measurement of turbidity in water by nephelometry can produce instant results allowing for immediate, on-site, well-informed management decisions. This study contributes to the validation of nephelometric turbidity as a valuable aquatic ecosystem monitoring tool as well as makes recommendations for solutions to reduce the incongruities in regulatory guidelines. A comprehensive literature survey and case study supported a site specific relationship between turbidity and suspended sediment with some validity of a 3 to 1 total suspended sediment to turbidity ratio. The analysis methodologies for total suspended sediment and turbidity were essential to the correlation. The field turbidity relative to the laboratory total suspended sediment provided the most consistent relationship. A comparison between on-site analysis of turbidity versus laboratory analysis conducted days after sampling demonstrated that elapsed duration between sampling and analysis may produce variable results. Limitations in the Canadian Environmental Quality Guidelines turbidity exceedence guidelines were reviewed.

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NOMENCLATURE

AOSERP	Alberta Oil Sands Environmental Research Program
AQUAMIN	Assessment of the Aquatic Effects of Mining in Canada
ASRD	Alberta Sustainable Resource Development
ASWQG	Alberta Surface Water Quality Guidelines
AWWA	American Water Works Association
CCME	Canadian Council of Ministers of the Environment
CDA	Canadian Dam Association
CEQG	Canadian Environmental Quality Guidelines
DFO	Department of Fisheries & Oceans
DWS	Downstream
EEM	Environmental Effects Monitoring
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
ICMM	International Council on Mining & Metals
ICOLD	International Commission on Large Dams
JTU	Jackson Turbidity Unit
MAC	Mining Association of Canada
MMLEG	Metal Mining Liquid Effluent Guidelines

MMLER	Metal Mining Liquid Effluent Regulations
NOAMI	National Orphaned and Abandoned Mines Initiative
NSR	North Saskatchewan River
NTU	Nephelometric Turbidity Unit
ROW	Right-of-Way
SEV	Severity-of-ill-effects
T	Transect
UNEP	United Nations Energy Programme
UPS	Upstream
USSD	United States Society on Dams

CHAPTER 1

INTRODUCTION

1.1 Background and Problem Definition

Natural Resources Canada reported approximately 190 principal metal, nonmetal and coal mines, over 3000 stone quarries and sand and gravel pits, and about 50 nonferrous smelters, refineries and steel mills operating in Canada at the beginning of 2004 (Natural Resources Canada 2004a). The waste that is generated from this mining activity can come in many forms and broadly defined categorized as dry or wet waste. The wet waste, otherwise referred to as mine tailings, produced from mining and milling activities requires comprehensive management measures often necessitating containment in the form of dams or impoundments.

There are currently 53 operating tailings disposal and effluent treatment sites listed for Canada (Canadian Mining Journal 2002). While this list is not complete, the tailings disposal types/specifications listed range from natural settling to paste backfill treatments to upstream cell constructed impoundments. For example, Syncrude Canada Ltd.'s oil sand mining operation is located approximately 45 km north of Fort McMurray, Alberta. As the world's largest producer of light, sweet crude oil from oil sand producing 81.4 million barrels in 1999, Syncrude Canada Ltd. is also one of the largest producers of mine tailings with an inventory of 360M m^3 fluid fine tails produced during the separation process of bitumen from oil sands (Matthews et al. 2000). "By 2025, Syncrude will have produced an estimated one billion cubic metres of fine tailings" (Syncrude Web Site 2000). Proper design, management and reclamation of this significant amount of waste are vital to the ongoing operation of the mine as well as to the health of the surrounding environment.

Failures associated with mine tailings have resulted in harmful environmental effects and environmental disasters. For instance, on April 25, 1998, the Aznalcóllar tailings dam, located in Spain and owned by Boliden Apirsa, failed. Approximately 1.3 million cubic metres of fine pyrite tailings and 5.5 million cubic metres of tailings were released into the nearby river systems (McDermott and Sibley 2000). Roughly 2,600 hectares of river banks and agricultural land were influenced by tailings deposition and an additional 2,000 hectares were affected by tailings water. The impact on surrounding aquatic ecosystems was devastating.

While the Aznalcóllar tailings dam disaster illustrates acute damage to aquatic ecosystems as a result of extreme dam failure, there are various other types of failures and incidents that can affect surrounding aquatic ecosystems in harmful yet less conspicuous ways. In particular, there are a number of stages and/or aspects of mining operations that can be susceptible to failures and/or incidents. Waste pre-treatment, the waste conveyance system, the liner system (unlined, single or multiple layered) (natural or synthetic) (hydraulic conductivity), geographic customization, seepage collection/ settling ponds, contingency systems and access/haulage road development can all, depending upon site-specifics, be potential sources of negative inputs to surrounding aquatic ecosystems.

One such potential input into aquatic ecosystems from mining and mine waste activities is sediment. Sediment or total particulate matter is a broad category. The Canadian Water Quality Guidelines (CEQG) (CCME 1999) for total particulate matter separates the category, for purposes of the fact sheet, into turbidity, suspended sediments, deposited sediments and bedload sediments. According to the fact sheet, "deposited sediments are those that settle out of the flow and become associated with the streambed substrate" (CCME 1999, p. 3). Bedload sediments, rather, "refers to that portion of the total sediment load that is carried by the streambed....by sliding, rolling, or saltating on the streambed" (CCME 1999, p. 2). Suspended sediments "consist of silt, clay, fine particles of organic and inorganic matter, soluble organic compounds, plankton, and other microscopic organisms" (CCME 1999, p. 1). At higher velocities, bedload sediments can be transported as suspended sediments and, similarly, at lower velocities suspended sediments can become bedload sediments.

Turbidity, on the other hand, is the "measure of the lack of clarity or transparency of water caused by biotic and abiotic suspended or dissolved substances" (CCME 1999, p. 1), and, further, the turbidity and transparency of the water is controlled by the type and concentration of suspended matter. Turbidity was described as the most predominant adverse water quality characteristic in a wide survey of fishery biologists in the United State of America (Judy et al. 1984). According to the Canadian Water Quality Guidelines, "at sites where the relationship between suspended sediment concentration and turbidity is known, turbidity can be used as a surrogate to predict suspended sediment concentrations" (CCME 1999, p. 2).

Investigation into the effects of suspended sediment and turbidity on aquatic ecosystems has shown multiple negative impacts on various organisms and biota. For example, in high suspended sediment concentrations, effects on salmonid fishes have included: death or reduced growth rate; reduced resistance to disease; interference with development of eggs and larvae; modified movement and migration; reduced abundance of food organisms available to fish; and reduced efficiency of methods used for catching fish (Newcombe and MacDonald 1991). Effects on aquatic invertebrates have included: reduced feeding efficiency (clogging of feeding structures); damage to respiratory organs; and higher predation susceptibility (scouring) as a result of induced dislodgement. Reduced biomass by light penetration reduction and growth rate reduction have been found to be potential effects of higher suspended sediment concentrations on periphyton.

Concentration in relation to duration is important in assessing the effects of suspended sediments and/or turbidity on aquatic ecosystems. Further, the effects of concentration and duration must be fitted to particular fishes as functions of taxonomic group, natural history, life history phase and predominant sizes of sediment particles (Newcombe and Jenson 1996). Currently, the Fisheries Act of Canada under Section 36 prohibits the release of any deleterious substance including sediment.

Evidence of the negative impacts of increased suspended sediment concentration on aquatic ecosystems is substantial. Therefore, with respect to the mining industry, where large volumes of sediment laden water and liquefiable sediment are present, awareness of measures and practices to prevent, control, remediate and monitor sediment is vital to the well-being of the surrounding aquatic ecosystems as well as from a regulatory perspective. The relationship between mining, mine waste management and aquatic ecosystems does not have to be detrimental. While challenging, managing mine tailings and tailings water with an approach that is beneficial or, at the least, harmless to aquatic life can be achieved with appropriate tools.

Measurement of suspended sediment requires laboratory analysis of filterable and non-filterable residues from water samples. The filtration process can be timely and expensive. For mines without in-house laboratories, results can take several days if not weeks to be produced considering analysis as well as transportation time. Even for mines with in-house analysis capabilities and extravagant monitoring budgets, the analysis process for total suspended sediments (TSS) does not facilitate prompt results thus hindering effective management.

On the other hand, the measurement of turbidity by nephelometry can produce immediate results thereby allowing mine managers to make immediate, on-site, well-informed management decisions potentially providing forewarning of more significant environmental incidents or full failures. Nephelometric turbidimeters can be relatively inexpensive portable units that measure the scattering of light through a water sample and returning "an expression of the optical properties of substances that causes light to be scattered and absorbed rather than transmitted in straight lines" (CCME 1999, p. 1).

The identification of potential and actual ecological impacts associated with mine tailings construction, operation, decommissioning and reclamation often requires aquatic ecosystem assessment. The measurement of effect on an aquatic ecosystem is complex in light of the diverse array of ecological components and variety of monitoring tools to address them. The applicability, validity, practicality, adaptability and effectiveness of turbidity as a monitoring tool in relation to mine tailings management requires examination. Further, the results of turbidity monitoring may have significant application to mine tailings risk assessment.

1.2 Objectives

The objectives of this study are based on the need to incorporate effective water quality monitoring tools in mine tailings management that are accurate, valid and credible as well as practical.

Specifically, the objectives are to:

- describe the potential effects of turbidity on the aquatic ecosystem;
- define legislative significance of turbidity;
- determine the contribution of turbidity to mine tailings management;
- demonstrate a case history in which turbidity has applicability as an effective environmental monitoring and management tool;
- examine the validity of turbidity as an indicator of total suspended sediment; and
- examine the limitations of and incongruities between the current regulations and guidelines for turbidity and the subsequent implications to environmental protection and management.

1.3 Scope

The physical and chemical properties of mine tailings are complex and, often, site specific. Numerous water quality parameters associated with tailings can be detrimental to aquatic ecosystems. For example, tailings with metals as constituents or with low ph levels could result in the bioaccumulation of heavy metals by organisms or acidification of receiving waters. Some of these water quality parameters can be, at times, associated with suspended sediment, for example, in cases where heavy metals may be attached to suspended sediment particles.

However, the scope of this study is limited to the parameter of suspended sediment and more specifically turbidity as a surrogate measurement of suspended sediment. In saying that, some attention is given, in this research, to defining and isolating suspended sediment from various other parameters such as settled sediment which can be a water velocity related result of suspended sediment or an effect all on its own. Considerable attention is given to the measurement methodology of total suspended sediments (TSS) in relation and in comparison to turbidity as part of the effort to evaluate the applicability, validity, practicality, adaptability and effectiveness of turbidity as a measurement tool. On the contrary, this research does not evaluate the acceptability of total suspended sediment (TSS) as a measurement technique.

The overall study focuses on environmental monitoring and management in mining in Canada while using some global examples for comparison and to provide further perspective. Current legislation, standards and guidelines from Canada and the Province of Alberta are examined and are supplemented with information from the United States of America. The turbidity monitoring case history concentrates on the North Saskatchewan River (NSR) in Alberta and provides quite recent data from within the past five years.

1.4 Contribution to Knowledge and Industrial Significance

This study contributes in a significant manner to effective mine management, environmental regulation and to the general body of science with respect to the further validation of nephelometric turbidity as a valuable monitoring tool.

Specifically, mine managers will benefit from the results of this study in the guidance that it offers with regard to effective aquatic ecosystem protection. Even the most elaborate environmental protection plan will not achieve its goals if the monitoring tools are ineffective and/or unattainable. By investigating and testing environmental monitoring techniques, ineffective tools can be discredited while the most useful tools can be further examined. In this specific case, nephelometric turbidity is examined as a relatively inexpensive, real-time yet precise tool for mine managers to use to achieve their environmental goals and regulatory requirements.

The study has further implications for regulators. The existing federal and provincial surface water quality guidelines address suspended sediment based on the existing body of knowledge and known or implied effects on aquatic ecosystem components. Any information that may further verify or challenge the existing body of knowledge ultimately provides for more effective regulation and law-making. Further, current legislation and/or guidelines for turbidity for the protection of aquatic life are provided by the provincial Alberta government, Department of Fisheries and Oceans (DFO) and Environment Canada. Some inconsistency exists between these bodies and the guidelines/legislation that they regulate and/or enforce. Thus, more detailed examination of these standards may provide for solutions in reducing incongruity.

1.5 Outline and Structure of Study

Chapter 1 provides an introduction of the potential significant application turbidity monitoring may have to mine tailings risk assessment. A general description of the environmental challenges facing the mining industry is provided along with specific discussion of the potential effects mine tailings may have on aquatic ecosystems. In particular, impacts of suspended sediment on aquatic ecosystems are recognized along with nephelometric turbidity as a potential tool for the measurement of suspended sediment.

Chapter 2 presents a survey of literature associated with monitoring of turbidity as a risk assessment tool in the management of mine tailings. The body of knowledge related to turbidity as a water quality indicator, effects of turbidity on the aquatic ecosystem, risk assessment, and legislation, regulations and guidelines is examined then summarized in this Chapter.

Chapter 3 addresses mine tailings management and describes the significance of turbidity to this field. Tailings and tailings management approaches are described along with some environmental aspects of tailings. Types of tailings impoundments and tailings impoundment failures are described, and a partial inventory and description of failures is provided. Potential environmental effects of failure are identified and the role of turbidity monitoring in addressing those effects is discussed.

Chapter 4 presents the background and sampling plan of a case history in which turbidity monitoring was conducted to identify and measure any potential sediment release. Results of the case history turbidity monitoring are presented.

Chapter 5 provides a discussion of the case history results and limitations demonstrated by the results. The turbidity and total suspended sediment correlation for the case history is explored. A comparison of the turbidity analysis in the field versus the laboratory is investigated. Further examined is the application of the turbidity standards provided in the Canadian Environmental Quality Guidelines for the Protection of Aquatic Life to the case history results. Within this context, the issue of point turbidity sample results versus geographically and temporally averaged results for comparison to background levels for exceedence determination is considered. Finally, the application of the case history to mine tailings management is assessed.

Chapter 6 summarizes the findings in the study and provides conclusions on the value of turbidity as an indicator of tailings release impact to the overall aquatic ecosystem. The strengths and weaknesses of the Canadian Environmental Quality Guidelines turbidity exceedence guidelines in respect to risk assessment are considered. Recommendations for future research are provided and discussed.

CHAPTER 2

LITERATURE SURVEY

2.1 Water Quality

Standards for water quality vary depending upon the use and or user of the water. The Canadian Environmental Quality Guidelines (CEQG) (CCME 1999) and separate provincial guidelines (e.g., Alberta Surface Water Quality Guidelines 1999) categorize water quality standards by uses including drinking water (human consumption), recreational (bodily contact), protection of aquatic life, agricultural use and industrial use. Depending upon use, certain indicators and endpoints may be employed to evaluate and predict water quality and establish thresholds of acceptability.

2.1.1 Indicators and Endpoints

Indicators play a vital role in water quality analysis. With the vast range of contaminants, pathogens and compounds in water, indicators and indicator organisms can provide insight into other constituents while bypassing individual analysis for each constituent. Indicators are used in numerous water quality applications including water treatment for human consumption. Accordingly, the American Water Works Association (1999, p. 2:14) lists the following criteria for the ideal indicator:

- *Should always be present when the pathogenic organism of concern is present, and absent in clean, uncontaminated watercourse*
- *Should be present in fecal material in large numbers*
- *Should respond to natural environmental conditions and to treatment processes in a manner similar to the pathogens of interest*
- *Should be easily detected by simple, inexpensive laboratory tests in the shortest time with accurate results*
- *Should have a high indicator/pathogen ratio*

- *Should be stable and non-pathogenic*

- *Should be suitable for all types of drinking water*

However, the AWWA further concludes that no indicators are ideal, and goes on to identify turbidity as "sufficiently close to the ideal indicator for regulatory consideration". Specifically, with regard to drinking water, turbidity is used as an indicator of water quality and the efficiency of the treatment process (i.e. coagulation and filtration).

In order to select an indicator, one must first identify the desired assessment endpoint and related measurement endpoint, and then determine which of the indicators are the best detectors of the endpoints. An example of such is provided in Table 2.1 in which turbidity is an indicator of the assessment endpoint, water clarity. The example provided is incomplete and does not provide a list in entirety of aquatic ecosystem components nor assessment endpoints, indicators and measurements endpoints for each of those components. The actual measurement of the indicator is connected to the ecological component and addresses the matter of a "healthy ecosystem" by established thresholds of acceptability.

Table 2.1. Examples of assessment endpoints, indicators and measurement criteria for monitoring the effects of an aggregate wash plant operation on an aquatic ecosystem.

Aquatic Ecosystem Component	**Assessment Endpoint**	**Indicator / Receptor**	**Measurement Endpoint**
Water	Water Clarity	Settled sediments	Accumulated quantities (g/24 hrs)
		Suspended sediments	Concentration (mg/L)
		Turbidity	Concentration (NTU)
	Water Quantity	Discharge	Volumes of water (m^3/sec) and (m^3/day)
Fish Habitat	Fish Habitat Quality	Fish cover	Fish cover condition (% or m^2)
Fish	Fish Distribution	Presence or absence	Number of fish

NTU – Nephelometric Turbidity Unit

2.1.2 Sediment (Suspended Sediment, Settled Sediment, etc.)

An influx of sediment into an aquatic ecosystem can be caused by numerous factors both naturally occurring and induced. From natural storm events, new road construction, unprotected stockpiles, tailings ponds to aggregate washing operations, sediment entering a watercourse can be detected as turbidity increases. Sediment can appear as a point or non-point source. Further, point sources of sediment can be measured by comparing upstream (background) and downstream sediment levels. As previously stated, the Canadian Water Quality Guidelines (CCME 1999) separates the category of total particulate matter into turbidity, suspended sediments, deposited sediments and bedload sediments.

2.1.3 Turbidity

"Water turbidity represents the degree to which light penetration is impeded by suspended material" (National Council for Air and Stream Improvement 2002). Hall and Thomas (2002) undertook a literature review of the existing information on turbidity effects on aquatic life (i.e., fish, macroinvertebrate, periphyton). The authors acknowledged the value of turbidity as an index measurement of suspended sediment, and, ultimately, siltation.

2.1.3.1 Sample Collection, Measurement and Analysis

A complete and useful data set from water quality monitoring efforts is achieved by well-defined and standardized methodology, particularly with respect to timing (temporal plan), frequency, location (spatial plan), techniques and eventually data analysis. The methods should be clearly repeatable and the indicators should be well defined in qualitative and quantitative aspects. Precise spatial and temporal plans along with explicit techniques will enhance the accuracy and validity of comparisons that would ultimately demonstrate ecosystem health or changes.

Various methods are available to measure turbidity. Jackson Turbidity Units (JTU) are determined from a visual method whereby light path length through a sample is compared to a standard suspension measure. According to the Government of British

Columbia Ministry of Water, Land and Air Protection, the most reliable method for determining turbidity is nephelometry (2004, Chapman 1996). A nephelometer detects the intensity of light scattered at one or more angles to an incident beam of light and gives values in Nephelometric Turbidity Units (NTU). A 1:1 equivalent exists between NTU and JTU when the Nephelometric method is calibrated with a suspension of formazin polymer (USEPA 1999).

A range of nephelometric turbidimeters are available. On-line or process turbidimeters monitor continuous processes such as drinking water treatment. They provide up-to-date, continuous results and are usually installed in a network fashion on a stationary water system. Laboratory, portable and pocket turbidimeters are essentially similar but offer varying limits in turbidity range. Most turbidimeters presently are made with a transmitted light detector that allows the instrument to sense attenuation of transmitted light due to color, and a ratioing algorithm compensates for this attenuation (HACH 1999).

For watercourse or waterbody turbidity measurements in which a portable turbidimeter is used in the field, samples are often collected using 500 millilitre or one-litre plastic bottles held in the water column approximately 10 to 15 centimetres below the surface with the open end facing upstream. Bottles are filled and sealed while the bottle is under water. Each sample is recorded with the date, time, location (sampling site), general weather conditions, water depth, water velocity and plume evidence or observations.

With regard to the spatial monitoring plan for turbidity, the location of the sampling may follow similar suggestions indicated by Golder Associates (1995) in "*Quantifying the Effects of Sediment Release on Fish and Their Habitats*" prepared for the Department of Fisheries and Oceans (DFO). Sampling plans need to be site-specific and may be extended geographically if necessary. The determination of the extent of the environmental effects is essential to the spatial monitoring plan. For example, in a smaller watercourse, the number of sample locations along a transect across the channel are less than for a transect across a larger watercourse. As well, spacing between transects varies with the size of the watercourse.

Background information is very useful in the development of the temporal turbidity monitoring plan. However, this information may not be available in all cases. Therefore, the timing of the sampling is generally intended to address regulatory expectations and scientific/biological expectations. As well, temporal factors are important in identifying operational problems associated with potential point sources.

The quantification of the effects of sediment release on fish and their habitats was addressed in 1995 by Golder Associates for the Department of Fisheries and Oceans (DFO). The document explores key considerations in sediment sampling program development, monitoring and data analysis, sample site selection, sampling frequency and suspended sediment measurement.

2.1.3.2 Turbidity Versus Suspended Solids Concentration

It is generally conceded that a universal turbidity versus total suspended sediment relationship is problematic (Bash et al. 2001; Duchrow and Everhart 1971; Sorenson et al. 1977) and some opposition to the use of turbidity as a substitute for suspended solids concentration exists as a result (APHA 1971; Rainwater and Thatcher 1960). "The material suspended in streamwater is composed of numerous minerals and organics, each of which may possess unique optical properties" (Gippel 1995). These various suspended materials (e.g., silt, clay, organic material, inorganic material, plankton, microscopic organisms, etc.) influence turbidity. Walling and Moorehead (1987) partially explained the site-specific nature of the turbidity and suspended solids concentration relationship by suggesting that the typical size distribution of suspended particles varies spatially. According to Brown (1980), the correlation between suspended sediment and turbidity is problematic.

A 1970 study (Pak et al.) suggested that organic particles disperse in water more easily than mineral particles, and variations in particle shape of minerals results in differential dispersion. Briggs' 1962 study indicated that incident and scattered light is partly absorbed in the presence of gilvin (water colour), so the nephelometric turbidity is reduced. By using infra-red and ratio instruments, the effects of gilvin can be avoided; therefore, the greater problem lies in when turbidity is used as an index of suspended sediment (Gippel 1995).

Gippel (1995) suggested that the turbidity and suspended solids concentration relationship was confounded by particle size, particle composition and water colour, which do not vary in a predictable way with suspended solids concentration. However, Gippel concluded that a satisfactory relationship between turbidity and suspended solids concentration could be expected in most cases and that the variances could be tolerated as the increased practicality and potential sampling frequency allowed by turbidity measurement overcomes the "greatest source of error in the estimation of stream load", infrequent sampling. High frequency temporal variations in the concentration of suspended solids in streamwater result in significant variation in replicate samples. In situ turbidity sampling may alleviate this problem. Overall, Gippel concludes that, "in many instances the error associated with estimating the suspended solids concentration from turbidity measurements would be small enough that the availability of a continuous record of turbidity would lead to better load estimates" (1995).

In light of the many advantages of turbidity measurement, scientists and regulators have attempted to determine relationships between turbidity and total suspended sediment (CCME 1999). For example, in the development of their stress index of sediment concentration and duration, Newcombe and MacDonald (1991) gathered existing total suspended sediment and turbidity data from previous studies and work. The authors then used correlations between turbidity and suspended solids concentration to convert one to the other for conformity of data. Lloyd et al. (1987) suggested the following site-specific relationship (Equation 1):

$$\mathrm{Log}_{10}T = 0.045 + 0.9679 \log_{10}SSC \qquad (1)$$

where T is turbidity (NTU) and SSC is suspended sediment concentration ($mg \cdot L^{-1}$). The model was developed to describe the decrease in primary production in shallow interior Alaskan streams caused by sediment-induced turbidity. In the study, literature was reviewed to describe effects of turbidity as well as to describe the relationship between turbidity and suspended solids concentration. Logarithmic transformation was used in regression analysis. Turbidity was established as an adequate estimator despite some inconsistency in correlations with suspended solids concentration.

A log-normal distribution is commonly used to relate turbidity and suspended solids concentration data. The CEQG (CCME 1999) reflect a 3 to 1 total suspended sediment (TSS) versus turbidity (NTU) ratio in the conversions used to develop the turbidity guidelines from the TSS guidelines; however, the guidelines do recommend site-specific relationships. In his 1995 work, Gippel identifies two relationships, linear and non-linear, between turbidity and suspended solids concentration. The correlation between TSS and NTU was higher where sediment properties were more constant, where field instrumentation versus laboratory analysis for turbidity measurement was utilized, and where there was a wide range of suspended solids concentration (Lammerts van Bueren, 1983; Gippel 1989).

2.2 Legislation, Regulations and Guidelines

The regulatory requirements for achieving a healthy aquatic ecosystem and monitoring the possible impacts are not specified in Albertan or Canadian Law. But the Alberta Environmental Protection and Enhancement Act and the Fisheries Act (Canada) do provide some expected outcomes of how industrial developments might influence the health of the ecosystem. The CEQG and ASWQG have developed guidelines of thresholds or levels of acceptability based on scientific research on the effects on various ecological components in the aquatic ecosystem. Guidelines have been the primary tool for identifying government expectations in regards to the quality of water and to the quality of the aquatic ecosystem as a whole. With that stated, the Fisheries Act of Canada expresses no tolerance in its prohibition of deleterious substances, subsequently industry could be at regulatory risk for releasing sediments.

In situations where substances are being released to the surface waters, there are specific provisions within the Alberta Environmental Protection Enhancement Act and

Effluent Limits Procedures Manual. Additionally, specific conditions on licences may have application.

In the United States of America, most states provide a fixed turbidity limit over background levels or specify limited increase of a fraction of background levels in the water quality standards (Bisson and Bilby 1982).

2.2.1 Provincial Alberta Surface Water Quality Guidelines (For the Protection of Aquatic Life)

The Alberta Water Quality Standards for suspended sediments in surface waters are described in the following way (Alberta Environment 1999):

> Turbidity:
>
> *CEQG Turbidity guideline: For clear flow - Maximum increase of 8 NTU from background levels for any short-term exposure (e.g., 24-h period). Maximum increase of 2 NTU from any Background levels for any long-term exposure (e.g., inputs lasting between 24-h and 30-d)* (Alberta Environment 1999, p. 9).
>
> *For high flow or turbid waters - Maximum increase of 8 NTU from background levels at any one time when background levels are between 8 and 80 NTU. Should not increase more than 10% of background levels when background is >80 NTU* (Alberta Environment 1999, p. 9).
>
> Suspended Sediment:
>
> *CEQG Suspended solids guideline: For clear flow - Maximum increase of 25 mg/L from background levels for any short-term exposure (e.g., 24-h period). Maximum increase of 5 mg/L from any background levels for any long-term exposure (e.g., inputs lasting between 24-h and 30-d)* (Alberta Environment 1999, p. 9).

> *For high flow - Maximum increase of 25 mg/L from background levels at any one time when background levels are between 25 and 250mg/L. Should not increase more than 10% of background levels when background is >250 mg/L* (Alberta Environment 1999, p. 9).

Further allowances are provided for wastewater for which the guidelines specify concentration to the volume of wastewater released (Alberta Environment 1999).

2.2.2 Canadian Environmental Quality Guidelines (For the Protection of Aquatic Life)

The *Canadian Environmental Quality Guidelines* (CCME 1999) (formerly the *Canadian Water Quality Guidelines* (CCREM 1987)), the *Alberta Surface Water Quality Guidelines* (ASRD 1999) and the *Fisheries Habitat Protection Guidelines* (Alberta Environmental Protection 1992) indicate that activity should not cause an increase greater than 25mg/L of total suspended sediment over the background (when less than 100 mg/L) and 10% of the background levels when the background levels exceed 100mg/L total suspended sediment. Similarly, the CEQG indicate that the turbidity levels should not be increased by more than 8 nephelometric turbidity units (NTU) above the background level. These threshold levels provide the standards that should be achieved at the time of construction or activity.

2.2.3 Canadian Fisheries Act

Some water quality parameters are identified as deleterious under The Fisheries Act of Canada and, as a result, are regulated rather than described as guidelines. Specifically, the Fisheries Act of Canada prohibits the deposit of any deleterious substance including sediment (1985):

> *Section 36(3): Subject to subsection 36(4), no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish or in any place under any conditions where the deleterious substance or any other deleterious substance that results from the deposit of the deleterious substance may enter any such water.*

Section 34(1): For the purposes of sections 35 to 43, "deleterious substance" means

(a) any substance that, if added to any water, would degrade or alter or form part of a process of degradation or alteration of the quality of that water so that it is rendered or is likely to be rendered deleterious to fish or fish habitat or to the use by man of fish that frequent that water, or

(b) any water that contains a substance in such quantity or concentration, or that has been so treated, processed or changed, by heat or other means, from a natural state that it would, if added to any other water, degrade or alter or form part of a process of degradation or alteration of the quality of that water so that it is rendered or is likely to be rendered deleterious to fish or fish habitat or to the use by man of fish that frequent that water,

and without limiting the generality of the foregoing includes

(c) any substance or class of substances prescribed pursuant to paragraph 34(2)(a),

(d) any water that contains any substance or class of substances in a quantity or concentration that is equal to or in excess of a quantity or concentration prescribed in respect of that substance or class of substances pursuant to paragraph 34(2)(b), and

(e) any water that has been subjected to a treatment, process or change prescribed pursuant to paragraph 34(2)(c).

2.2.4 Mining Legislation/Regulations

The Metal Mining Liquid Effluent Regulations (MMLER)/ Metal Mining Liquid Effluent Guidelines (MMLEG) address effluents from mine water, milling, tailings, treatment ponds, treatment facilities, seepage, surface drainage, and so on. The regulations do not apply to gold mines. The guidelines suggest a maximum monthly arithmetic mean (mg/L) of total suspended matter (TSM) of 25.0, a maximum in a composite sample (mg/L) of 37.5, and a maximum in a grab sample (mg/L) of 50.0. Ultimately, these guidelines are not legally enforceable but, rather, attempt to meet the Fisheries Act intentions associated with Subsection 36(3) (AQUAMIN 1996). Wastewater release reporting guidelines which include sediment concentration standards in relation to volume of discharge are available in Alberta (Alberta Environment 1998), and the Code of Practice for Pits (Alberta Environment 2004) provides further guidelines for water quality monitoring.

2.3 Effects of Turbidity on the Aquatic Ecosystem

Turbidity was most predominantly described as the most adverse water quality characteristic in a wide survey of United States fisheries biologists (Judy et al. 1984). Numerous studies conducted in North America and elsewhere have indicated that a major negative impact of surface disturbances on aquatic resources results from sediment entering watercourses (Kittrell 1969; MacDonald et al. 1991; Huntington 1996; Purser 1996; Van Lear 1998). Cordone and Kelley (1960) identify erosion as an insidious problem altering cold clear streams to warm turbid watercourses. Trautman (1957) as referenced in Cordone and Kelley (1960) suggests that man-made effects, such as erosion, have shifted the nature of aquatic ecosystems from "large fishes of great food value to smaller species unfit as human food, or large fishes of inferior quality as human food." The effects of sediment on the aquatic ecosystem are numerous.

Aquatic vegetation is a type of fish cover that is considered desirable for most species. Increased turbidity reduces light penetration thereby influencing the rate of photosynthesis and consequently negatively impacting the aquatic vegetation including microscopic algae, benthic algae and submerged macrophytes (Kanehl and Lyons 1992; Riviere and Seguier 1980; Hassler 1977; Gregory et al. 1993). With suspended sediment concentrations exceeding 115 mg/L, light penetration is reduced and, subsequently, so is primary productivity (Singleton 1985). Periphyton is adversely affected by suspended sediments and high turbidity, and as the growth abundance and/or species composition of periphyton is affected by sediment, various macroinvertebrate species that feed on the benthic algae (periphyton) are adversely influenced (Newcombe and McDonald 1991).

Benthic macroinvertebrates are impacted by increased suspended sediment and subsequent increased turbidity (Riviere and Seguier 1980; Van Lear et al. 1998; Schmal 1978; Starnes 1983; Lenat et al. 1981). Reduced feeding efficiency (clogged feeding structures), damage to respiratory organs and dislodgement resulting in higher predation susceptibility are noted as some effects on aquatic invertebrates (Newcombe and MacDonald 1991). Increases in suspended sediment from 40 mg/L to 120 mg/L resulted in decreases in the density of the benthic macroinvertebrates by 25% to 60% (Gammon 1970). Short-term pulses of suspended sediment, such as a 16-hour pulse at 2500 mg/L to 3000 mg/L, leads to reduced invertebrate biomass (75% in the specific case indicated) in the affected area (Slaney et al. 1977). Invertebrates are disrupted into a drift by suspended levels as low as 23 mg/L (Rosenberg and Weins 1978; Rosenburg and Snow 1973). Suspended and settled sediment adversely affects the physiology of invertebrates, specifically the respiration and digestion processes (Tsui and McCart 1981).

Water quality is subject to impacts by increased turbidity including increased biochemical oxygen demand (BOD) and reduced dissolved oxygen (DO) levels (Crunkilton 1982). Reduced dissolved oxygen may influence the potential survival of fish as well as the development of fish eggs and fry where the interstitial spaces are blocked to the dissolved oxygen (Beschta and Jackson 1979).

Effects of suspended sediment or high turbidity on fish can be both lethal and sublethal. Eggs are clearly most vulnerable and sub-lethal effects are extensive at the juvenile and adult stages; however, direct mortalities of adults appear to require persistent high concentrations of suspended sediments. The existing body of literature on the effects of sediment on fish is extensive.

Hall and Thomas (2002) undertook a literature review of the existing information on turbidity effects on aquatic life (i.e., fish, macroinvertebrate, periphyton) and focused on "references that reported turbidity effects on organisms or biological communities where turbidity is reported as either Nephelometric Turbidity Unit (NTU) or Jackson Turbidity Unit (JTU)". From the review, Hall and Thomas list the following as turbidity effects on salmon (*Oncorhynchus* sp.): increased mortality of salmonid eggs and alevins, restricted fry emergence, avoidance, impaired feeding effectiveness, reduced reaction distance, reduced growth, reduced incidence of predation, reduced human predation of fish, altered dominance hierarchies, and blood sugar level changes. In a review of literature on the effects of suspended sediments on salmonid fishes, Newcombe and MacDonald (1991) found death or reduced growth rate or resistance to disease; interference with development of eggs and larvae; modified movement and migration; reduced abundance of food organisms available to fish; and reduced efficiency of methods used for catching fish.

Wallen (1951) conducted controlled aquarium studies on warmwater fishes and the direct effects of turbidity on those fishes. Wallen found that turbidity dominated the behaviour reactions of the fishes which exemplified a pattern from commencement to death. The reactions included: "(1) momentary swimming at the surface and gulping air and water, (2) leaning toward one side or the other while remaining at the surface for several minutes, (3) floating on one side for up to 30 minutes with an occasional swimming movement and (4) floating with only occasional, feeble, opercular and pectoral fin movements until terminated by death of the fishes." Wallen also found that the maintenance of movements and water aeration enabled the avoidance of clogged gills in sublethally turbid waters. Silt coating the gills of fish was found to result in anoxemia and carbon-dioxide retention causing death rather than gill injury causing death.

Berkman and Rabeni (1987) found that fish species with similar ecological requirements had a similar response to siltation and the subsequent habitat degradation. The authors used community functional analysis to quantify the effects of sedimentation on stream fishes then related the effects to ecological characteristics of the fish fauna. Ordination, which is valuable in assessing several communities with many variables in common, was used to examine the resemblances in species composition and abundance of fish in communities. The resulting plot places similar communities closer in proximity and dissimilar communities farther away. "*The results of this study suggested that fish with similar feeding or reproductive strategies were similarly influenced by siltation*" (Berkman and Rabeni 1987). The feeding classification of fish most negatively impacted by the sedimentation were those most specialized to feed from the substratum, in particular, benthic insectivores.

Balon (1975) suggested that siltation affects reproductive behaviours of fish even more so than feeding activities. "In most cases indirect damage to the fish population through destruction of the food supply, redds and eggs, or changes in the habitat probably occur long before adult fish are harmed directly" (Mackenthun and Ingram 1967, p. 26 as quoted in Lane, unknown date). Lane makes reference to a number of studies which conclude that, at times other than storm periods (i.e. naturally high turbidity events), water velocities are insufficient to transport sediment entering watercourses resulting in damage to spawning beds as a result of silt deposition. Further, silt tends to deposit in areas that are most suitable for egg laying. It should further be noted that effects on aquatic organisms may not only be attributed to concentration of suspended sediment, rather it could be a function of particle properties such as density, size, shape and height as well as the presence of organic matter and sorptive properties (Iwamoto et al. 1978).

Numerous studies have confirmed that <25 mg/L suspended solids have no harmful effects, 25 mg/L to 80 mg/L can provide good or moderate fisheries, 80 mg/L to 400 mg/L do not provide good fisheries, and >400 mg/L result in poor fisheries. Arctic grayling (*Thymallus arcticus*) have been displaced at concentrations of 300 mg/L or greater and Arctic grayling juveniles have displayed significantly impaired growth at 100 mg/L concentrations of TSS (McLeay et al. 1987). A reduction in the survival of chum salmon (*Oncorhynchus keta*) eggs occurred at a TSS concentration of 97 mg/L (Langer 1980). Territorial behaviours of some fish species have been lost at concentrations exceeding 30 NTU (Northcote 1985). Feeding of juvenile coho salmon (*Oncorhynchus kisutch*) was reduced significantly when total suspended solids reached 300 mg/L. At concentrations of 500 mg/L to 1500 mg/L and after four or five days of exposure, fish blood chemistry, likely resulting from stress, becomes altered (Redding and Schreck 1980; Servizi and Martens 1987; Newcombe 1994). TSS concentrations as low as 270 mg/L have caused gill damage in Rainbow trout (*Oncorhynchus mykiss*) after thirteen days exposure (Herbert and Merkens 1961). Rainbow trout demonstrated more frequent fin rot after 121 days of exposure of TSS concentrations of 270 mg/L (Herbert and Merkens 1961). Coho salmon displayed increased viral kidney infections with increased TSS concentrations (Servizi and Martens 1991, 1992). Lethal effects of salmonids were reported at concentrations of TSS ranging from 500 mg/L to 6000 mg/L (Lloyd 1987). Concentrations of 500 mg/L to 1500 mg/L resulted in mortalities of young of year Coho salmon and Steelhead trout (*Oncorhynchus mykiss*) (Sigler et al. 1984).

When possible, fish may simply avoid high-silt areas (Weber and Post 1985; Suchanek et al. 1984a, 1984b). Juvenile coho salmon avoid areas with total suspended solid (TSS) concentrations of 88 mg/L (Bisson and Bilby 1982), while Arctic grayling avoid areas with concentrations greater than 100 mg/L (McLeay et al. 1987). Further, it appears that relatively high concentrations of sediment for a short period of time can be tolerated by fish (Sorenson et al. 1977) and recovery is relatively rapid when fish return to clear water (Levings 1982).

Numerous other factors influence the toxicity of a substance including frequency of sediment release episode, ambient water quality, water temperature, species and life history stage affected, presence of disease organisms and other toxicants.

2.4 Effects of Turbidity Associated with Mining

Various activities associated with mining have resulted in increased turbidities in downstream waters. Sedimentation may result from actual mining and milling activities or as a result of associated infrastructure such as erosion from road development.

The responses of Arctic grayling to laboratory experiments with sediment from Yukon placer mining was documented (McLeay et al. 1987). Simmons (1984) studied Arctic grayling caged in mined and unmined streams and concluded that dietary deficiencies may occur in the grayling in the turbid waters. Reduction in light penetration resulting in decreased predatory success (i.e. reduced feeding capability) and reduction in macroinvertebrates as a food source may be factors. Van Nieuwenhuyse (1983) found that mining-induced turbidity was directly related to the extinction of light. Following from this, Van Nieuwenhuyse and LaPerriere (1986) described a relationship between gross primary productivity and light penetration in shallow streams allowing for the comparison of primary production in streams with varying turbidities. Lower production and altered plant species composition was found as a result of turbidity from gold mining in a stream in South Africa (Hancock 1973). Turbidity was identified as the strongest statistical descriptor of reduced density and biomass of macroinvertebrates in mined streams in a study by Wagener and LaPerriere (1985). The densities and biomass of the macroinvertebrates was seen to decrease in mined streams and become almost non-present in heavily mined streams.

Leis and Fox (1996) investigated the feeding, growth, and habitat associations of young-of-year walleye (*Stizostedion vitreum*) in an Ontario watercourse affected by a 300,000 tonne gold mine tailings failure. In this study, fish were captured from both affected and unaffected reaches in the river. Comparison between the sample sets indicated that young-of-year fish in the unaffected reaches displayed on average better condition, a greater increase in mass and length, and a lesser decline in abundance than those young-of-year fish captured in tailings affected reaches. The authors conclude from the data that high mortality or increased emigration were associated with the early life stages of walleye in the tailings affected areas.

2.5 Risk Assessment and Risk Modelling

Newcombe and MacDonald (1991) compared the implicit concentration-duration response model (time frame implied) and dose concentration-duration response model (e.g. dose measured as pollution intensity) to assess effects of toxicants. The authors categorized and ranked effects into: lethal, sublethal and behavioural. Literature was analyzed for information on sediment concentration, organism exposure duration and nature of the effect. Factors that contribute to the effects of suspended sediments on the aquatic ecosystem are investigated in an effort to provide guidance on what data should be collected to characterize the environmental effects. The authors suggested an index (stress index) of pollution intensity, which is calculated by taking the natural logarithm of the product of sediment concentration (mg/L) and duration of exposure (h), as an indicator of suspended sediment effects. The units for dose are $SS \cdot h \cdot L^{-1}$, and the natural logarithm of dose is the stress index. The stress index enables quantification of the effects of concentration and duration, both of which influence the aquatic biota. Due to the large range in the product of concentration and duration, the natural logarithm of the product was utilized to compress the range and provide numbers of manageable size.

Newcombe and Jenson (1996) looked to the problem of a "lack of reliable metric" for quantification of fish response to suspended sediment and subsequent risk assessment of fish exposed to sediment pollution to demonstrate that meta-analysis can be a significant tool in habitat impact assessment. The authors tackled the limitations in existing research including the use of pooled data, wide taxonomic range and limited information about specific species and life stages normally utilized in assessment. The dose-response database was revisited to tweak models to suit particular groups of fishes as functions of taxonomic group, natural history, life history phase, and predominant sizes of sediment particles responsible for ill effects (Newcombe 1994). Taxonomy distinguished between salmonids (family Salmonidae) and non-salmonids. Life stages were classified as eggs, larvae (recently hatched fish, including yolk-sac fry, not passed through final metamorphosis), juveniles (fish, including fry, parr and smolts, that are sexually immature) and adults (mature). The study resulted in a number of reference tables that can be utilized to make inferences about severity of effects as detailed in Equation 2:

$$z = a + b(\log_e x) + c(\log_e y) \qquad (2)$$

where z is severity of ill effect (15 point scale from no effect to lethal effects), x is duration of exposure (h), y is concentration of suspended sediment (mg SS/L), a is the intercept, and b and c are slope coefficients.

There was significant variability in the data gathered in the literature; therefore, the testing of the stress index for the prediction of accurate responses of aquatic biota to suspended solids exposure was limited. Further research was recommended to fill the large number of data gaps that exist in these tables. In addition, the authors recommended further research into the area of particle angularity in relation to gill abrasion and water temperature impacts on severity of ill effect. Despite its limitations, this model is at the foundation of the TSS and NTU guidelines in the CEQG (CCME 1999).

2.6 Cumulative Effects

While the evaluation of cumulative effects of increased turbidity is beyond the scope of this study, this salient issue requires mention. The cumulative effects of sedimentation and other potentially harmful events/activities have received considerable attention in the scientific community within the past twenty years. Usually the effects are specific to particular watersheds and to the extent of anthropogenic activities in the watershed. Generally, long-term studies are required to determine the contribution of sediment and related cumulative effects.

2.7 Mitigation and Monitoring

This is a broad subject area; however, some of the general steps to effective mitigation have included avoidance of key aquatic environments temporally and spatially, reduced disturbance footprints, industrial best management practices, effective planning and implementation of erosion control devices and compensation.

Hansen (1973) explores the potential for sedimentation basins (i.e. sediment traps) to reduce sediment loads in trout watercourses. The author suggests that traditional erosion control methods such as revegetation, fencing and streambank stabilization are not very effective in reducing the gradual sheet erosion, which occurs over the entire watershed. Rather, sediment traps can be used to replace or supplement these traditional erosion control methods.

Hansen suggests that the excavated basin advantage is to trap sediment without causing coarser sediment to deposit upstream thereby leading to streambed aggradation. The basin should be located in a relatively flat gradient and a uniform distribution of flow across the basin should be targeted for best efficiency of sediment deposition.

The impacts of sediment influx into a watercourse are intensified during particularly critical fish life stages such as spawning for various species. Should fall-spawning fish species occur, eggs are usually lying dormant and incubating under the ice from September to March and are particularly vulnerable to any type of sediment (Purser 1996). Usually, spring-spawning fish have a much reduced time of vulnerability because they release eggs which will incubate in 14 to 28 days depending on water temperature and the fish species. The seasonal timing of sedimentation is an important factor in environmental management, monitoring and risk assessment.

2.8 Residual Effects

Residual effects may occur following the implementation of mitigation measures. These effects can lead to prolonged environmental degradation if not monitored and remedied. On the other hand, these effects also provide lessons on the effectiveness of mitigation measures and monitoring techniques. The accumulation of sediment, a residual effect, may be measured in downstream lakes, wetlands, flood zones, slow flowing inchannel pools and beaverdams for example. There are varying degrees of residual effects and the timeline in which the effects become measurable is activity and site-specific. While it is outside the scope of this study to examine residual effects in detail, the relation of residual effects of increased turbidity and resulting accumulated sediment to mine tailings management is important to mention.

CHAPTER 3

MINE MANAGEMENT AND TURBIDITY

3.1 Mine Tailings

Waste from mining and milling processes is and continues to be a significant focus of research by academia and organizations associated with mining as well as the mining industry itself. Generally, in the mining process, large amounts of ore have to be mined in order to recover a comparatively small quantity of metals and/or minerals. As such, a considerable amount of dry and wet waste results. The wet waste, typically referred to as tailings, is generally a slurry-like waste product of the milling process, which extracts elements of interest from mined ores.

Tailings vary in chemical and physical properties, and their makeup is interlinked with the materials being mined and the nature of the processing. Geography, geological characteristics, equipment availability, economics, relevant regulations and numerous other factors influence the course of the mining/processing plan which in turn affects the make-up of the mine tailings and the tailings management plan. As a result of the site or mine-specific nature of the waste material, the particles in the tailings must be identified in order to determine how to manage the tails. This first step of determining the origin, concentration, size and surface chemistry of the particles is crucial to the overall management vision. To further complicate the situation, it should be noted that there can often be considerable variation in tailings composition over time within the same mine.

As equipment and technology make the mining of previously unfeasible deposits now feasible, larger amounts of waste and tailings are being produced. Accordingly, larger quantities of tailings are also being disposed of and/or contained. Some of the options for disposal or containment include: disposal of dry or thickened tailings in impoundments or free-standing piles, backfilling underground mine workings and open-pits, subaqueous disposal, and the most common method, the disposal of tailings slurry in impoundments (USEPA 1994).

3.2 Mine Tailings Impoundments

Most tailings are contained in large surface impoundments otherwise referred to as tailings dams. Generally, earthfill dams are used rather than water-retention dams to form the tailings impoundments. Unlike water-retention dams, the tailings impoundments are generally built over time in a sequential fashion to accommodate increasing volumes of tailings produced during the mine life. Further, whereas retention dams generally use natural soil, raised embankments can use soil, tailings and waste rock or any combination of the three (Vick 1990). A mine tailings dam or impoundment can be an engineered waste containment system or a natural containment system (where geologic formations provide adequate containment). There are a number of types of engineered waste dams and various methods of classification for the different types. While it is not within the scope of this thesis to summarize or describe the complexities of tailings impoundment design, broadly defined, there are four types of embankment dam designs including upstream, downstream, centerline and modified centerline (ASDSO 2000).

Upstream embankments may be the most popular for tailings dams. The dam crest essentially moves "upstream" as the most recent sections of the embankment are built on top of the slurries held during the previous stage. While this is generally the most inexpensive type of embankment and, subsequently, the most common, it also can carry the greatest risk. In contrast, downstream dams are regarded as a more reliable design, consequently bearing additional cost. This design type consists of the development of a "full downstream-method embankment, similar to a water dam" (A. Gipson in ASDSO 2000). Unlike upstream and downstream embankments, which have embankment stages that move horizontally from the initial embankment, centerline impoundments stages are raised vertically. In this case, the initial embankment and subsequent stages of the embankment are one on top of the other. The modified centerline embankment is essentially a combination of upstream and centerline designs. The amount of upstream shift in this centerline-type embankment depends upon the amount of embankment needed to attain stability.

Tailings impoundments can be situated in a number of locations. Four of the most common categories for layout are: natural depression or valley, cross-valley, side-hill, and perimeter or ring-dyke (USEPA 1994; A. Gipson in ASDSO 2000). The natural depression or valley layout is somewhat self-explanatory where the tailings are deposited into an existing topographical depression. The sides of the depression or valley essentially operate as dam walls. The cross-valley design is similar to a water retention dam in that it is "constructed connecting two valley walls, confining the tailings in the natural valley topography" (USEPA 1994). This layout can be as a single impoundment or a series of impoundments. A three-sided dam built against a hillside forms the side-hill impoundment. In flat topographical areas, perimeter or ring-dyke embankments are used to contain the tailings with four constructed sides.

There are numerous factors that affect the choice of dam design including: geologic stability, potential for development of new technologies, economics, political regulations/agreements, toxicity of waste, ecological factors, life of the mine, human health risks, best management practices/intervention, amount of waste/production, climate, company vision, end land use, legal fines, labour costs, non-market values (e.g. aesthetics), investor confidence, company reputation, and levels of mill and mine capacity. According to the USEPA (1994), some factors that affect tailings design are: tailings-specific factors (e.g., composition, grain size, density, permeability, stability, seepage quantity, seepage water quality, etc.) and site-specific factors (e.g., tailings volume, surface area available, mill location, topography, hydrology, geology and hydrogeology, foundations, seismicity, etc.).

The overall role of tailings impoundments is to contain tailings and, as such, to minimize water storage and maximize solid storage (ASDSO 2000). To achieve this, impoundments can be drained, partially drained or undrained (retention). Tailings impoundments can be and are designed to perform a number of functions, including (Environment Canada 1987):

- Suspended solids removal by sedimentation
- Precipitation of heavy metals as hydroxides

- Permanent containment of settled tailings
- Equalization of wastewater quality
- Stabilization of some oxidizable constituents (e.g., thiosalts, cyanides, flotation reagents)
- Storage and stabilization of process recycle water
- Incidental flow balancing of storm water flows

Some other aspects of tailings impoundment design include liners, drains, tailings transport and deposition (e.g., single point discharge, spigotting, cycloning), decant facilities and covers (e.g., earthen, vegetative, compost, wetlands, water). While it is not within the scope of this study to identify and define them all, it should be noted that a vast array of other factors must be taken into consideration in the design of tailings dams.

3.3 Mine Tailings in Canada

As previously mentioned, Natural Resources Canada reported approximately 190 principal metal, nonmetal and coal mines, over 3000 stone quarries and sand and gravel pits, and about 50 nonferrous smelters, refineries and steel mills operating in Canada at the beginning of 2004 (Natural Resources Canada 2004a); however, does not maintain a comprehensive list of mine tailings facilities associated with the mines (J. Kwong and B. Tisch, per. comm.). Further, a comprehensive descriptive listing of the tailings facilities associated with these mines is not maintained by agencies such as the Mining Association of Canada (J. Laurie-Lean, per. comm.) or the Canadian Dam Association (B. Hurndall, per. comm.). The Canadian Dam Association (CDA) does identify 113 tailings dams in Canada as of 2002 on the CDA dam registry (CDA 2003). However, according to the executive director of the Canadian Dam Association (CDA), only large tailings dams are listed (Appendix Tables A and B). Dams less than 10 metres in height are not included in the register, dams 10 to 15 metres in height may or may not be included in the register, and whether all tailings dams that exceed 15 metres have been added or not to the registry has not been determined.

A listing of tailings facilities associated with existing mines in Canada was provided in the Canadian Mining Journal 2002 Mining Sourcebook in which 53 operating tailings disposal and effluent treatment sites were listed for Canada (Appendix Table C). The tailings disposal types/specifications ranged from natural settling to paste backfill treatments to upstream cell constructed impoundments. While this information source provides some descriptive particulars, judging by the number of listed facilities in comparison to the incomplete Canadian Dam Association registry, the Mining Sourcebook list is also incomplete.

While an incomplete quantification of tailings facilities associated with operating mines is available, increased mystery surrounds the number of tailings deposits associated with closed, abandoned and orphaned mine sites in Canada. According to Natural Resources Canada, an estimated 1000 abandoned mines exist in Canada (2004b). Campbell and Marshall in *The State of Canada's Environment* (1991) refer to approximately 6000 abandoned mine sites, yet, according to WOM Geological Associates Inc., who prepared a report on the subject for Mining Watch Canada, there are more likely tens of thousands of abandoned mine sites in Canada (2001).

> *Orphaned and abandoned mines represent potential land subsidence, violent cave-ins, and waste dump and tailings dam failures, all of which can have a critical impact on public safety and the environment* (Natural Resources Canada 2004b).

Based on the wide range of estimates available through regulatory agencies (federal and provincial), industry, consultants and non-government organizations, an accurate quantification of the number of tailings impoundments associated with orphaned or abandoned mines in Canada may not be available at this time and, further, is not within the scope of this study to calculate. Nevertheless, the significance of these tailings with regard to potential sedimentation and aquatic ecosystems should be recognized. The potential residual effects of such tailings upon abandonment could have major effects on the downstream watercourses.

The quantification of operating and abandoned tailings facilities in the United States is also problematic. There are approximately 1,000 active metal mines in the United States (Randol 1993). According to the United States Environmental Protection Agency (USEPA), many of the mines "have at least one tailings impoundment and often several impoundments grouped together in cells" (1994). Further, "EPA estimates that there may be several thousand tailings impoundments associated with active non-coal mining, and tens of thousands of inactive or abandoned impoundments". The United States Bureau of Land Management has estimated that there are between 100,000 and 500,000 small and mid-size abandoned hard rock mines in the west and 13,000 abandoned coal mines, mostly small and mid-sized in the east (UNEP 2001).

> *There are many abandoned tailings dams around the world in addition to abandoned mine sites and these could eventually pose environmental and safety problems. There is no complete inventory of tailings dams but their number is certainly in the tens of thousands. The impact of abandoned sites is significant including: altered landscape; unused pits and shafts; land no longer useable due to loss of soil, pH, slope of land; abandoned tailings dumps; changes in groundwater regime; contaminated soils and aquatic sediments; subsidence; and changes in vegetation. Results of such impacts include: loss of productive land; loss or degradation of groundwater; pollution of surface water by sediment or salts; fish affected by contaminated sediments; changes in river regimes; air pollution from dust or toxic gases; risks of falls into shafts and pits; and landslides* (UNEP 2001).

While determining the number of tailings facilities that are operational, reclaimed and abandoned is problematic, quantifying the volume of tailings is even more challenging. In the mid 1970's, ICOLD established a Committee on Mine and Industrial Tailings Dams, which prepared a Manual on Tailings Dams and Dumps, a Bibliography and a World Register of Tailings Dams, all published in 1982. "At that time, there were at least 8 tailings dams higher than 150m and 22 higher than 100m. It was estimated that tailings production exceeded 5×10^9 tons annually, far exceeding the volumes of fill involved in all civil engineering projects" (Penman 2001). Comprehensive data on tailings volumes in Canada is not available.

The lack of complete data on mine tailings impoundments, both operational and abandoned, in Canada leads to some questions about the effectiveness of environmental regulation and management.

3.4 Mine Tailings Management Approaches

There are generally four phases that need to be addressed with regard to mine tailings management including: Site Selection, Design and Planning; Construction; Operation, and; Decommissioning/ Closure/ Reclamation. Each of these phases requires unique approaches and management strategies, and as a result, each phase is associated with different levels and areas of risk. While tailings management is predominantly site-specific, certain approaches and general methodologies have become highly effective in mine tailings management for a wide range of mines all over the world. Subsequently, a number of manuals and guides have been developed to address the management phases (Vick 1990; Klohn 1980; CDA 1999; MAC 1998; Martin et al. 2002; Klohn 1972; Martin and Davies 2000).

Tailings can be problematic from a management perspective because they contain all the other constituents of the ore but the extracted metal, among them heavy metals and other toxic substances. Moreover, the tailings also contain the chemicals added during the milling process. In addition, as a result of the milling process, all these contaminants can more easily disperse into the environment than when they were in the original ore. Further, the mechanical stability of the tailings mass is very poor, due to its small grain size and the usually high water contents.

The Clark Hot Water Extraction process has been used in northern Alberta to extract bitumen from oil sands. Significant amounts of water are needed resulting in considerable amounts of fluid wastes. This waste is pumped to the settling basin where the fast-settling sand particles are used to construct mounds, dikes and other stable deposits and the leftover muddy liquid, consisting of slow-settling clay particles and water, are the fine tailings. According to the Fine Tailings Fundamentals Consortium, fine tailings are "comprised of mineral particles over 90% of which have an equivalent diameter less than 11 microns" (1995).

> *What makes tailings management so difficult is the amount of time it takes for fine tailings to settle. After a few years they reach the consistency of runny toothpaste, but it takes a few centuries for them to reach the consistency of a soft clay. The other challenge is the volume of fine tailings to manage; by 2025 Syncrude will have produced an estimated one billion cubic metres of fine tailings* (Syncrude Web Site 2000).

Due to the large quantity of fine particles in the tailings, the release water is often saturated with fines. The dissolved components found in these wastes, fine tails, are commonly released into the tails from leachable material in the oil sands/ore/mining material. These components can range in nature from heavy metals to organics such as salt. Conductivity, pH, and toxicity levels vary widely. The goal of best management practices for mine waste management is to reduce the fines in the release water by causing the fine particles to settle out more rapidly with the dense particles and, in turn, release water with low turbidity and total suspended sediments.

Historically, the freeze-thaw method has been utilized extensively in mine waste management to separate water from impurities. However, with the massive amounts of tailings requiring containment, management and reclamation, other processes such as paste technology and the composite tailings process, have been investigated, tested, and applied to reduce time requirements to reach reclamation goals and effectiveness of contaminant removal. In particular, the processes of coagulation and flocculation are continuing to increase in significance to the management and reclamation of mine waste tailings.

> "*With the addition of chemicals, fine particles in oil sands tailings become flocculated or coagulated. This process enhances the permeability of the tailings especially at relatively low solids contents (high void ratios). As a result, nonsegregating tailings undergo a significant volume reduction during sedimentation and initial consolidation which commences almost immediately after deposition with clear decant water released on top of the deposit*" (Fine Tailings Fundamentals Consortium 1995).

The production of composite tailings (CT) has had significant success in the field, and, therefore, has become the more common of tailings treatments for Syncrude. In this technique, gypsum together with dense fine tailings from the settling basin, are added to the fresh tailings slurry. "This causes the clays to aggregate and the slurry viscosity to increase. Upon deposition, natural segregation processes are reversed and the fine solids, coarse solids and water stay together forming a deposit very much like thick soup and requiring containment" (Syncrude Web Site 2000). Clean water seeps to the surface and runs off. With the release of water, the deposit becomes denser, until eventually a semi-solid or solid material is formed and the containment structures become redundant.

The rate of consolidation is dependent upon the percentage of fines content in the tailings. Mixing time and the nature of the coagulant are significant factors in determining the results, and the initial solids content affects the rate and amount of sedimentation. In the case of some trials by Suncor near Fort McMurray, Alberta, it takes up to three months to form fine tailings (FT) and approximately three years to form mature fine tailings (MFT).

In light of the costs associated with maintenance and monitoring of the tailings impoundments and the risk associated with possible dam failure, decreases in settling time are valuable and the use of coagulants/flocculants can aid the dewatering process and remove certain particles. In light of the high fines content and total suspended sediment in the fine tailings, the measurement of turbidity is essential for water released to surface flowing waters to ensure released water meets environmental guidelines and the impacts of sediment on the receiving aquatic ecosystem(s) are reduced. Further, with such large volumes and high fines content, the accidental release of fine tailings could have significant effects on surrounding aquatic ecosystems. Further, turbidity monitoring in surrounding surface waters may provide information for the early detection of tailings leaks and potential failure.

3.5 Failures Associated with Mine Tailings

> "*Engineering knowledge today is quite adequate to enable of the safe design, construction and maintenance of tailings dams. Yet throughout the world, they have failed at an average rate of 1.7 per year for the past 30 years. In many cases failure has been due to silly mistakes: a lack of full attention to detail. An exception may be due to the violent forces caused by earthquake, but even in highly seismic regions, types of construction and special provisions can be made to minimise the risk of major damage*" (A. Penman 2001).

While the rates of failure of dams may be arguable, it is apparent that poor planning, design, maintenance and monitoring are generally the origin of tailings failures (Davies 2002; UNEP 2001). According to the Swedish Mining Association, accidents in Sweden were caused by an improper design, acceptance of that design by regulators, and inadequate monitoring and dam construction, operation and maintenance (2001). Extreme events, cumulative exposure, climate change, geologic hazards and biologic effects are just some examples of factors that sometimes get missed in the tailings management scenario.

As demonstrated by the failures that have occurred in the past, the consequences of this error or neglect can be devastating physically (loss of human life), environmentally (severe land, water and air degradation) and economically.

3.5.1 Modes of Failure

Reservoir overtopping is one of the most common modes of failure of a tailings dam (Vick in Swedish Mining Association 2001). Basically, this failure occurs when excessive water is added to the impoundment. If not decanted properly and at an appropriate rate, the surplus water mixed with tailings can cause the dam to fail. Further, water derived from precipitation must also be removed. This type of failure can be a result of mismanagement in the removal of the water, underestimation of severe weather events, or damage/blocking of the discharge culvert and/or decant tower. Some examples of reservoir overtopping include: "landslide into reservoir generates a wave which overtops the dam; wave action overtops dam; perimeter bypass system fails and water enters reservoir exceeding capacity of spillway or storage, or an external creek diversion failed and water entered reservoir; pond allowed to reach crest of dam poor operations; pond allowed to reach dam by design (discharge from top end of pond to save dam height; excessive precipitation fills ponds exceeded storage capacity dam overtops; water balance not maintained (human error)" (USCOLD 2000, p. 455).

Foundation instability is another mode of failure, which can result in liquefaction (occurs only once and only applies if tailings are liquefiable) or a breach (may or may not lead to liquefaction depending upon if tailings are liquefiable). Some examples of foundation instability leading to failure include: "Karst collapse beneath dam; collapse due to mine subsidence tails escape into mine or void; sliding on weak soil or liner interface; compression of weak soils led to cracking; permafrost degradation; construction pore pressures raised and foundation moved; seepage through a poor membrane or pervious soils into groundwater system, bypassing seepage recovery systems; seismic liquefaction of foundations; seismic deformation of foundations; non seismic liquefaction of foundations" (Association of State Dam Safety Officials 2000, p. 455).

Dam instability can also result in liquefaction or a breach. Erosion, slope failure, rotational sliding, seepage issues, seismic liquefaction or deformation of dam, and settling can results in dam instability leading to dam failure.

Structural failures can include a wide range of dam-specific factors. Decant conduit failures have been identified as a cause of failure events (Association of State Dam Safety Officials, Inc. 2000). Piping, power and pumping failures along with spillway blockages are also examples of structural issues that can result in a tailings impoundment incident or failure.

Each type of failure has a different probability of occurrence depending upon the type of tailings containment structure that is being considered. For example, upstream dams are particularly susceptible to liquefaction under severe seismic ground motion (Davies 2000; WISE 2004). Further, the determination of phreatic surface location is more complex for an upstream dam than any other embankment type (WISE 2004).

The phase of the structure has an impact on the potential for failure. According to Vick (Swedish Mining Association 2001), of the 106 failures identified in the USCOLD survey of tailings dam failures and accidents (1994) "only 9 involved inactive tailings dams despite their vastly greater numbers". Overtopping was found to be the leading cause of these failures, which suggests that, "dam failure does not occur under post-closure conditions if overtopping is prevented and surface water is removed from the impoundment" (Vick in Swedish Mining Association 2001).

3.5.2 Inventory of Mine Tailings Failures

A number of sources were investigated for an inventory of reported tailings dam failures including: World Information Service on Energy; International Council on Metals and the Environment; United Nations Environment Programme, Division of Technology, Industry and Economies; International Commission on Large Dam (ICOLD), Committee on Tailings Dams and Waste Lagoons; United States Committee on Large Dams (USCOLD); U.S. Environmental Protection Agency (USEPA); various journals and; various personal communications in Canada.

USCOLD published their collection of 185 case records in 1994 which documented 172 known incidents, of which 106 were failures of tailings dams that had occurred worldwide (USCOLD 2000). UNEP included this data along with cases found by

Mining Research Services for UNEP (1996) and 12 examples known by members of the ICOLD Committee in the 2001 Bulletin entitled "Tailings Dams: Risk of dangerous occurrences: Lessons learned from practical experience". Accounting for duplication, UNEP quantified the number of known failures at 221. According to UNEP, not all incidents have been reported, and "the collected number form a subset of the actual number of tailings dam incidents that have occurred from the early 1900s to 1996."

Other efforts in summarizing or creating inventories of failures include the USEPA Office of Solid Waste 1997 "Damage Cases and Environmental Releases from Mines and Mineral Processing Sites" in which a number of tailings dam failures were identified within 62 summaries of recent mining and mineral processing damage cases from a variety of mineral commodity sectors and states. A chronological list of failures, from 1960 to present, was created by WISE (2004). The 78 failures listed on the WISE website have been gathered from sources previously described including: USCOLD 1994 compilation; UNEP 1996 compilation and; UNEP 2001 compilation. Despite these best efforts to document the inventory of failures, there are numerous unreported failures or incidents that are not included (Davies 2002).

3.5.3 Environmental Effects of Mine Tailings Failure

> *Out of a total land area of 1.01 billion ha (hectares), less than 0.40 million ha (an area less than half the size of Prince Edward Island) are used for mining in Canada. Less than 0.03% of Canada's land area has been used for mining since metal mining began more than 150 years ago* (Natural Resources Canada 2004).

While the land surface area utilized by mining may be relatively small in the larger picture of the land mass of the whole country, the environmental effects associated with mining can extend far beyond its primary location. Tailings, in particular, can have far reaching environmental effects through air, water and land, and because of its greater density, tailings can cause much greater damage than water.

For example, the tailings pond failure at the Aznalcollar mine in Spain occurred on April 24/25, 1998 when the tailings dam was breached (Eriksson & Adamek, 2000). 5.5 Mm^3 of tailings spilled across the land as well as into nearby watercourses. 4364 hectares of land were covered in tailings after the failure. Boliden utilized 250 excavators, 250 highway trucks and 26 mining trucks to remediate the northern sector of the spill. The original timeline of 5-6 months was achieved with 10Mton of tails being removed in approximately 500,000 truckloads. A secondary clean-up occurred a few months later and resulted in the removal of an additional 1Mm^3 of material (Eriksson & Adamek, 2000). By December 1999, the estimated cost to Boliden for the remediation of the northern sector of the tailings spill was 25M USD (Eriksson & Adamek 2000). This substantial cost does not take into consideration the costs to company reputation, the repair of the tailings dam and so many other costs as a result of the failure. More importantly, the cost to the environment was immense.

Ritcey (1989) lists in "Tailings Management" some of the potential environmental implications of tailings impoundments including:

- Contamination of streams by seepage of acidic waters containing high content of metals and other substances;
- Contamination of streams due to surface runoff from the impoundment area;
- Air and water contamination due to wind erosion of dried-out tailings;
- Possible risk of catastrophic dam failure and release of slimes and other substances;
- Physical and aesthetic modification to the environment;
- Difficulty in establishing vegetative cover to permanently stabilize the tailings, due to the generally unfavourable soil conditions in the presence of pyritic tailings; and
- Often deep lake or marine disposal have not been acceptable practice.

Due to the mine-specific composition of tailings, environmental effects of tailings can vary from mine to mine. Examples of the range of environmental effects that a mine and its associated tailings facilities potentially can have (without and with mitigation) are provided in the Environmental Impact Assessment (EIA) or Environmental Impact Statement (EIS) usually conducted prior to mine development through the regulatory approval process. The EIS for Voisey's Bay Mine/Mill Project in Labrador, Canada was prepared in 1997 by the Voisey's Bay Nickel Company Limited and focused the biophysical assessment on: atmospheric environment; ice; water; freshwater fish and fish habitat; marine fish and habitat; marine mammals; plant communities; waterfowl and seabirds; Caribou; Black bear; species of special conservation status and; historic resources. However, broadly categorized, ecological components that can be impacted by mining and mine waste include: soil, air, vegetation, water, aquatics and fish, wildlife and humans.

The phase of the tailings dam influences the risk of failure and the intensity of the impact on ecological factors. For instance, the risk to the environment is increased as the tailings impoundment is filled; therefore, in respect to the extent of environmental damage as a result of failure, the highest magnitude of risk is associated with the tailings dam filled to capacity. On the other hand, the risk of failure of the dam due to slope failure may be significantly influenced by precipitation and climate; therefore, the highest magnitude of risk of tailings dam failure due to slope failure may be associated with a specific time of year (rainy season).

The environmental impacts from mining activities to surrounding lands, air, water and life can be extensive if not monitored to allow for mitigation. Specifically, the potential environmental effects of mine tailings failures including, for example, full breaches and slow leakages into surrounding areas, requires attention.

3.6 Turbidity Monitoring and Mining Operations

The United States Fish and Wildlife Service have long since recognized impacts of mining on aquatic ecosystems including the creation of "turbid, unproductive waters" (Mason 1978, p. 4). In the same year, the Alberta Oil Sands Environmental Research Program (AOSERP) emphasized the effects of sedimentation on aquatic ecosystems citing "road construction, pipeline construction, general construction (urban and industrial sites), vegetation removal, overburden removal and pit excavation, tailings ponds, settling ponds, and diversion channels" as potential sources of suspended sediments (AOSERP 1978, p. v). AOSERP further identifies the role of biomonitoring in addressing sediment inputs by the mining industry and its associated industries. While portable turbidimeter technology was not advanced to the degree it is now at the time of the AOSERP report, in situ measurement of suspended sediment with light scattering (turbidity) was identified as a useful methodology.

The Assessment of the Aquatic Effects of Mining in Canada (AQUAMIN) was created to examine the environmental effects of mining and, subsequently, assess the effectiveness of the Metal Mining Liquid Effluent Regulations (MMLER). AQUAMIN recommended that total suspended matter be regulated in the revised MMLER (AQUAMIN 1996). Further the group recommended that the MMLER require mine operators to monitor key components of aquatic ecosystems including sediments with specific sampling methodology requirements being determined at the local level. The report further reiterated the importance of "fish, fish habitat, and the use of fisheries resources as defined under the Fisheries Act" to the Environmental Effects Monitoring programs for mines.

While the results were not comprehensive nor were the data completely uniform, from the review of 17 case studies in the AQUAMIN report, the following effects and conclusions were noted: water quality may be affected for many kilometres downstream; the chemical and physical properties of river sediments were influenced by tailings material released prior to construction of the tailings dams; increased levels of sediment from current and historical mining were found to have had effects on benthic communities; acid mine drainage had killed aquatic life; tailing disposal in a lake had resulted in its loss; some mines showed no observed effects; and generally older mines and those with acid mine drainage issues had more apparent effects that newer mines. Further, downstream levels that were higher than the applicable water quality guidelines were also considered to be effects.

Some previous studies have shown significant increases in suspended sediments due to mining. For example, increases of 20 mg/L to 40 mg/L of suspended sediment in a small United States stream as a result of limestone mining were found to decrease macroinvertebrate density by 5% and increases of 80 mg/L resulted in 60% density reductions (Gammon 1970 in AOSERP 1978). A coal strip mining operation in the United States was found to have raised suspended sediment levels to 3,000 mg/L eliminating benthic macroinvertebrates and reducing fish biomass (Branson and Batch 1972 in AOSERP 1978).

Aggregate mining has historically been identified as high risk for the contribution of sediment to surrounding waters in the dredging of river beds and floodplains as well as the associated washing operations (Kondolf 1998; Kanehl and Lyons 1992; Forshage and Carter 1973). A gravel washing operation in the United States which had increased suspended sediment levels to 100 mg/L resulted in 15% to 40% reductions in fish presence (Gammon 1970 in AOSERP 1978).

Tailings, a substantial source of fine sediment as detailed previously in this Chapter, have also been found to increase suspended sediment levels in surrounding surface waters thereby necessitating turbidity monitoring. Tailings have been found to reduce fry yield of eggs from 16.2% to 1.6% when 1176 mg/L to 1330 mg/L of tailings are introduced (Shaw and Maga 1943 in AOSERP 1978).

Peripheral operations to central mining, milling and waste management operations may also potentially contribute sediment to surrounding watercourses and waterbodies. For example, access and haul road construction and site development can be opportunities for the addition of sediment, and subsequently, require monitoring (Huntington 1996; DFO 1994). This was demonstrated in the Voisey Bay Nickel Company Limited operation in Labrador, Canada where increased turbidity (NTU) was measured and documented prior to the start of actual mining (L. Innes, per. comm.).

As a result of the known effects of sediment on aquatic ecosystems and the potential of sediment introduction by mining and related activities, suspended sediment monitoring is being used by the mining industry and associated industries and required by various regulatory agencies to identify sources of sediment from operations. Turbidity monitoring, as a practical methodology which provides immediate results, is a particularly beneficial tool in sediment monitoring.

> *Turbidity is used as a monitoring and regulatory parameter in the industrial, sanitation, and environmental fields, and can be used as a substitute for suspended-sediment concentration. Elevated turbidity reduces the transparency of water due to the presence of suspended and dissolved materials. Increases in turbidity can reduce biological primary production (algal growth), important to the health and balance of the aquatic ecosystem, and may aid in transporting contaminants attached to suspended particles. Turbidity can be an indicator of water suitability for fishery, drinking, industrial, and recreational uses, and has been used to evaluate the effects of mining, dredging, stream-side construction, wastewater effluent, logging, road building, and other land use activities (USGS 2004).*

CHAPTER 4

CASE HISTORY

In order to examine turbidity monitoring effectiveness, the data from an authentic project has been gathered and scrutinized. The particular project selected was not, however, a mining project, and, rather, was a bridge construction project which incorporated clay berm construction and removal in a watercourse. This project was selected for a number of reasons including: the clay material used to construct the berms had similarities to the fines in tailings with regard to the potential to create turbidity; the water quality monitoring data set was in-depth and extensive providing for increased credibility and versatility; the author worked directly on the project and conducted the majority of the analysis personally; the author did not have access to an as extensive turbidity data set from a mining project; the large Alberta watercourse depicted in the case history, the North Saskatchewan River, was indicative of watercourses surrounding various mining projects in Alberta and Canada; and, the project had direct applicability to peripheral operations associated with mining such as haul road construction.

4.1 Project Description

The Clover Bar Bridge over the North Saskatchewan River in the City of Edmonton was replaced with a new three-lane structure. The new bridge was constructed immediately south of the old bridge, which was demolished and removed (Figure 4.1). The project consisted of grading of bridge approaches, erection of a new bridge, paving of new road approaches, demolition of the old structure and approaches, reclamation of the valley and landscaping of the approach roads. U-shaped ring berms were installed on both sides of the river to isolate pier, girder and associated bridge construction activities (Gibbs & Brown Landscape Architects Ltd. 2001). Earth materials (high plastic clay) were used to construct the berms in the watercourse, subsequently requiring extensive water quality (sediment) monitoring.

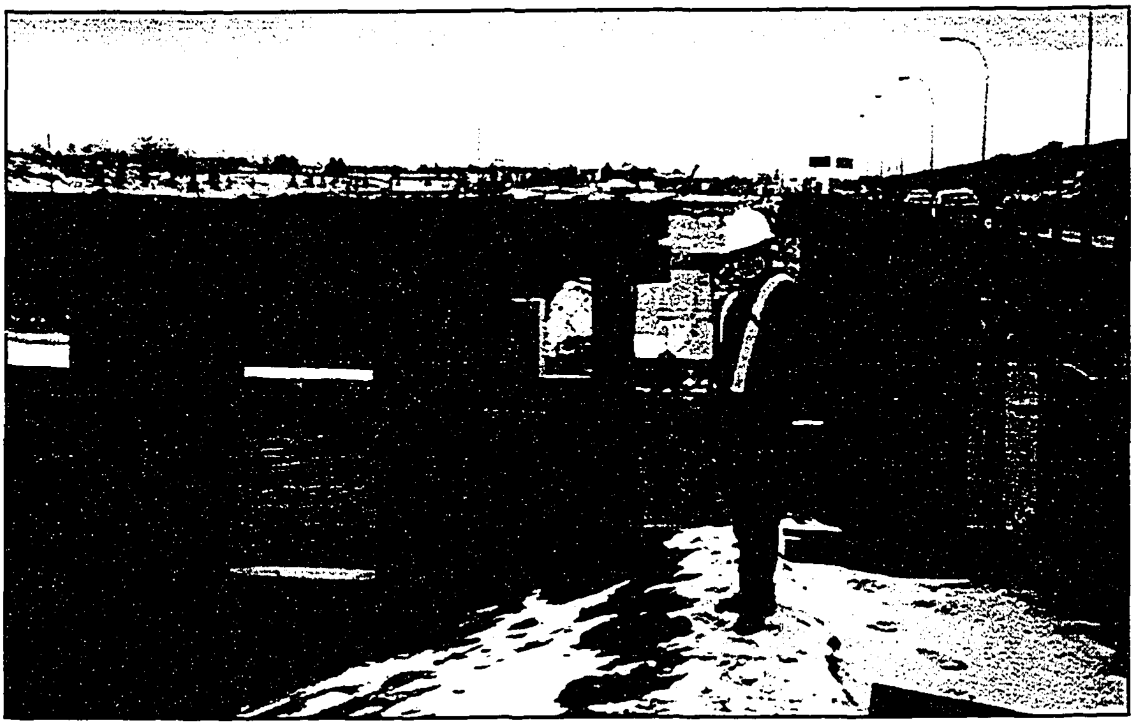

Figure 4.1. Case history project on North Saskatchewan River in Edmonton, Alberta; partially completed new bridge on left and old bridge on right; December 2000.

4.2 Site Characterization

4.2.1 Location and Climate

The site is located in northeast Edmonton in SW17–53-23-W4M and SE18–53-23-W4M where the Yellowhead Trail/Highway 16 crosses the North Saskatchewan River (Figure 4.2). Edmonton temperature (Edmonton City Centre) averages 3.9 °C annually; the July daily average is 17.5 °C; and the January daily average is -11.7 °C (Environment Canada 2004). Mean annual precipitation is 476.9 mm with 26% occurring as snow. Summer rainfall (May to September, inclusive) averages 365.7 mm. The growing season lasts 170 days.

4.2.2 Ecoregion, Topography and Soils

The case history project is located within the Aspen Parkland ecoregion (Strong and Leggat 1981). The bedrock underlying the area is the Upper Cretaceous Edmonton Formation, part of the Alberta Plains bedrock structure. The formation is composed of fine-grained interbedded bentonitic shales, sandstones and claystones with numerous coal seams (Kapthol and McPherson 1975). The surface overlying the Edmonton Formation is composed primarily of glacial till (clay, silt, and sand with pebbles and boulders) (Kapthol and McPherson 1975). This area also contains an alluvial deposit, remains of a post-glacial slough. The riverbank consists of thin colluvial cover on the slopes with mixed glacial and bedrock material in slump areas.

The landscape is generally undulating moraine in upland areas with the river valley having an approximate depth of 50 metres and a top width of 1500 metres.

The site is within the Thick Black Soil Zone of central and east-central Alberta (Soil Correlation Area 10, Pedocan Land Evaluation Ltd. 1993). The area is dominated by Eluviated Black Chernozemic soils developed on deep glaciolacustrine clays in the upland areas and calcareous Orthic and Humic Regosols on moderately fine textured colluvial material on the river banks (Gibbs & Brown Landscape Architects Ltd. 2000).

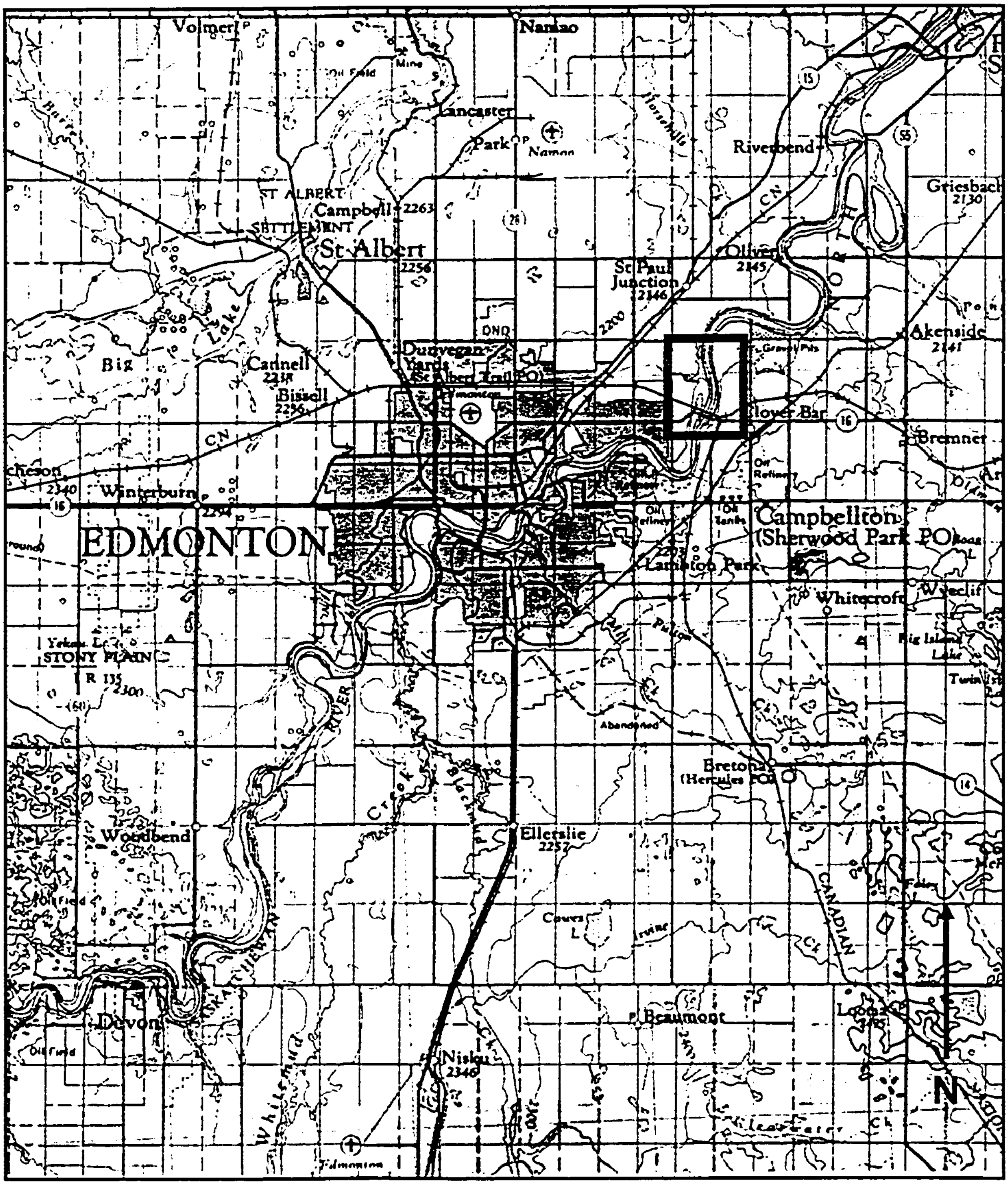

Figure 4.2. Case history water quality monitoring study area on the North Saskatchewan River near Edmonton, Alberta (1:250,000 scale).

4.2.3 Vegetation

Five vegetation community types were observed at this location including: Aspen – Tall Shrub; Riparian; Tall Shrub; Disturbed Herbaceous, and; Disturbed Riparian (Gibbs & Brown Landscape Architects Ltd. 2000). Some of the plant species present within each of the communities included:

Aspen – Tall Shrub: aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), pin cherry (*Prunus pensylvanica*), choke cherry (*P. virginiana*), red-osier dogwood (*Cornus stolonifera*), saskatoon (*Amelanchier alnifolia*), rose (*Rosa aciclaris*), twinning honeysuckle (*Lonicera dioica*), buckbrush (*Symphoricarpos occidentalis*) and high bush cranberry (*Viburnum opulus*)

Riparian: balsam poplar, willows (*Salix spp.*), horsetail (*Equisetum arvense*), prickly rose (*Rosa acicularis*), choke cherry, raspberry (*Rubus idaeus*), strawberry (*Fragaria vesca*), horsetail (*Equisetum arvense*), fireweed (*Epilobium angustifolium*), goldenrod (*Solidago canadensis*), quackgrass (*Agropyron repens*), buckbrush and Kentucky bluegrass (*Poa pratensis*)

Tall Shrub: dogwood, twinning honeysuckle, gooseberry (*Ribes oxyacanthoides*), hazel (*Corylus cornuta*), vetch (*Vicia americana*), northern bedstraw (*Galium boreale*), Kentucky bluegrass and buckbrush

Disturbed Herbaceous: Kentucky bluegrass, Canada thistle (*Cirsium arvense*), leafy spurge (*Euphorbia esula*), dandelion (*Taraxacum officinale*), rose, dogwood and saskatoon

Disturbed Riparian: Canada thistle, leafy spurge, dandelion, dogwood, choke cherry, willow, buckbrush, poplar and aspen

4.2.4 Hydrology

The North Saskatchewan River originates at the Saskatchewan Glacier located 160 kilometres west of Rocky Mountain House. It drains in an easterly aspect approximately 830 kilometres from its origin to the Alberta/Saskatchewan provincial border and has an Alberta drainage basin comprising approximately 80,000 km^2 (Alberta Environment 2004). The river eventually joins the South Saskatchewan River to form the Saskatchewan River and then joins the Nelson River, which flows into the Hudson's Bay.

Agriculture, forestry, and oil and gas developments have potential effects on the North Saskatchewan River drainage. The large amount of infrastructure is one of the major contributors influencing the water quality of the river, particularly as it relates to sedimentation.

Two Alberta dams (Bighorn Dam/Abraham Lake and Brazeau Reservoir) regulate the flows in the river. Generally, they have affected the North Saskatchewan River flows by reducing peak summer flows and increasing winter flows (Gibbs & Brown Landscape Architects Ltd. 2001). In the past, prior to 1959, the low winter flows ranged from 6.2 to 37.3 m^3/s while from 1972-1990 the winter low flow range was 20 to 94 m^3/s (Shaw et al. 1994). The 2-year flood peak for the North Saskatchewan River in this location is 1270 m^3/s.

At the case history location, the river is approximately 200 metres wide. There is little floodplain as the river covers the majority of the valley bottom. The channel bed is comprised of cobble and gravels up to 1 metre thick overlying shale/sandstone bedrock with well-defined banks. Generally, the river has a flat gradient and wide-uniform channel with the exception of the occasional riffle, pool and backwater areas.

4.2.5 Aquatic Resources

Some general information on fish presence and distribution in the North Saskatchewan River does exist (Paterson 1966; Paetz and Nelson 1992; Roberts 1974; Munson 1978; O'Neil and Chymko 1980; Allan 1984; R.L. & L. 1991 and 1999). Historical information suggests that fifteen common fish species inhabit the North Saskatchewan River near Edmonton, and these include: Northern pike (*Esox lucius*); Goldeye (*Hiodon alosoides*); Walleye (*Stizostedion vitreum vitreum*); Sauger (*Stizostedion canadense*); Mountain whitefish (*Prosopium williamsoni*); Burbot (*Lota lota*); White sucker (*Catostomus commersoni*); Longnose sucker (*Catostomus catostomus*); Shorthead redhorse (*Moxostoma macrolepidotum*); Longnose dace (*Rhinichthys cataractae*); Lake chub (*Couesius plumbeus*); Emerald shiner (*Notropis atherinoides*); Spottail shiner (*Notropis hudsonius*); Trout-perch (*Percopsis omiscomaycuc*), and; Spoonhead sculpin (*Cottus ricei*).

The information also suggests that eight species are occasionally found, and these include: Lake sturgeon (*Acipenser fulvescens*); Mooneye (*Hiodon tergisus*); Quillback (*Carpiodes cyprinus*); Flathead chub (*Platygobio gracilis*); River shiner (*Notropis blennius*); Fathead minnow (*Pimephales promelas*); Brook stickleback (*Culaea inconstans*) and Northern redbelly dace (*Phoxinus eos*).

Fish were sampled at three sampling sites in the project area during May 2 to 4, May 26, August 18 to 19, and September 29, 1999. Minnow traps (MT), electrofishing (EL), gill nets (GN), beach seines (BS) and set lines (SL) were used. A total of 374 fish including fourteen different species were captured (Table 4.1). The most abundant fish species in order of catch abundance included: Juvenile sucker species 43.9%; Emerald shiners 15.2 %; Northern red belly dace 12.8%; Goldeye 5.9%; Longnose sucker 5.6%; Brook stickleback 5.1%; White sucker 2.9%; Spottail shiner 1.9%; Lake chub 1.6%; Spoonhead sculpin 1.6%; Shorthead redhorse 1.3%; Trout perch 1.1%; Burbot 0.8%; and Sauger 0.3%.

Detailed assessments were not conducted on benthics or aquatic invertebrates. The necessity of monitoring these ecosystem components was not identified in the Environmental Impact Assessment (EIA) or by regulators.

Table 4.1. Relative abundance and species composition of fish sampled from the North Saskatchewan River in the vicinity of Edmonton in May, August and September, 1999.

Fish Species	Number of Fish Captured (1999)				% Composition
	May	August	September	Total	
Goldeye	20	2	0	22	5.9
Longnose sucker	15	5	1	21	5.6
White sucker	11	0	0	11	2.9
Shorthead redhorse	2	1	2	5	1.3
Juvenile sucker species	8	136	20	164	43.9
Emerald shiner	0	15	42	57	15.2
Spottail shiner	7	0	0	7	1.9
Northern redbelly dace	48	0	0	48	12.8
Lake chub	4	1	1	6	1.6
Brook stickleback	13	1	5	19	5.1
Sauger	0	1	0	1	0.3
Spoonhead sculpin	0	2	4	6	1.6
Burbot	0	0	3	3	0.8
Trout-perch	0	0	4	4	1.1
Total	**128**	**164**	**82**	**374**	**100.0**
	8 species	**8 species**	**9 species**		
	14 species total				

4.2.6 Sediment Characterization and Source Description

U-shaped ring berms were installed on both sides of the river to isolate pier, girder and associated bridge construction activities (Gibbs & Brown Landscape Architects Ltd. 2001) (Figure 4.3). One berm was constructed from the right bank (east side) and covered approximately 14,000 m^2 of the stream bed for four to five months. This temporary berm was removed prior to the construction of the second berm. The second berm was constructed from the left bank (west side) and covered approximately 12,000 m^2 of the stream bed for approximately four months. This was also a temporary berm and was removed at the completion of the project. Earth materials (high plastic clay) were used to construct the berms in the watercourse, thereby constituting the potential sediment source.

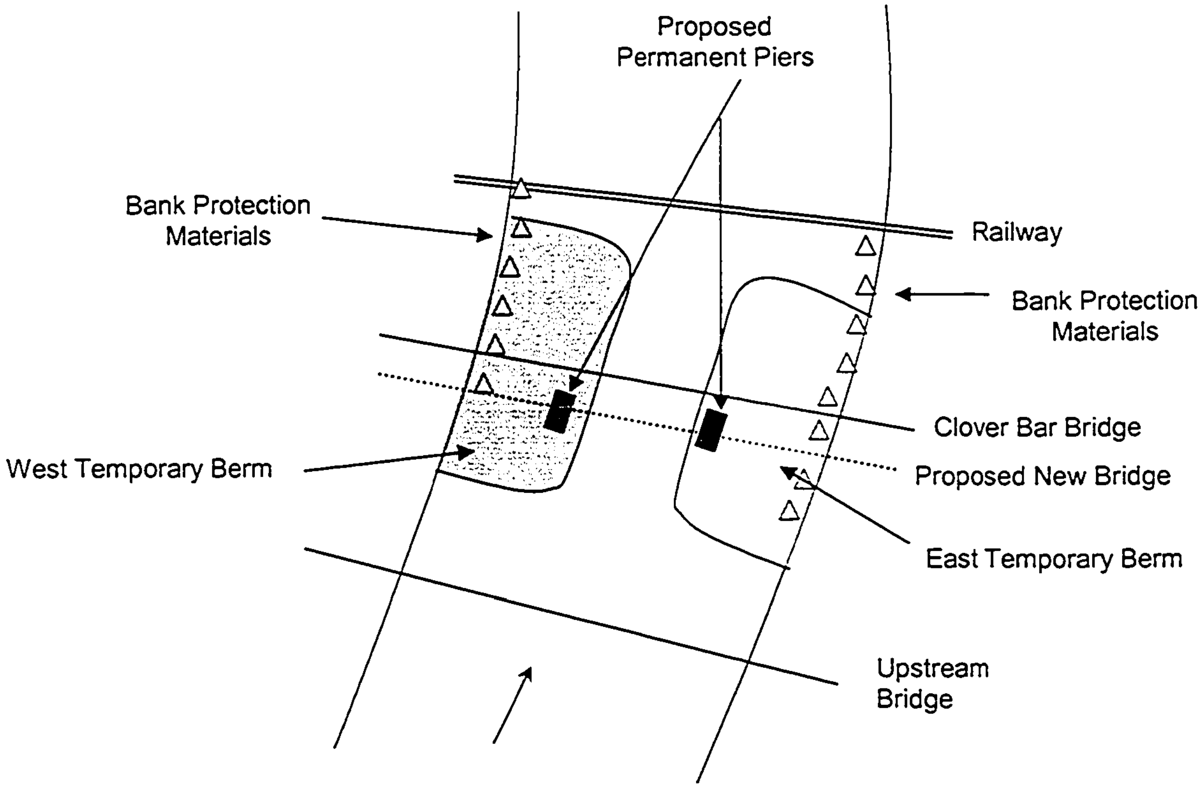

Figure 4.3. Diagrammatic view of temporary berms for construction activities associated with the case history project on the North Saskatchewan River.

4.3 Monitoring Approach

4.3.1 Baseline Assessment

Historical water quality data for the North Saskatchewan River have been summarized (Shaw et al. 1994; Mitchell 1994). In general, the authors concluded that most water quality parameters met the *Canadian Water Quality Guidelines* (CCREM 1987) recommended for the protection of aquatic life. These 1987 guidelines were subsequently integrated into the Canadian Environmental Quality Guidelines (CCME 1999). Further, they concluded that the urban and industrial influences of Edmonton and Fort Saskatchewan had a noticeable impact on the water quality of the river.

The historical background levels of suspended sediment in the North Saskatchewan River (NSR) indicated suspended solid levels ranging from less that 5 mg/L in the winter to 180 mg/L in May 1986. Generally, the spring-summer suspended solid levels were below 80 mg/L and the autumn levels were below 40 mg/L (Appendix Figure A). In May 1999, the total suspended sediments at the Clover Bar Bridge area ranged from 60 mg/L to 130 mg/L. Turbidity measurements in the Edmonton area in the spring-summer were generally below 20 NTU, while in the autumn they were below 10 NTU (Appendix Figure B). In May 1999, the turbidity levels ranged from 34.1 NTU to 44.1 NTU. Although the mean monthly historical TSS levels were 200 mg/L, there are events when the measurements do exceed 2000 mg/L. Maximum levels of TSS measured during July 1999 approached 2300 mg/L. Turbidity levels of 2000 NTU were measured at the same time (M. French and J. Paran, Aqualta, per. comm.). Figure 4.4 provides a visual example of highly turbid versus low turbid river water.

Prior to construction in 1999, a baseline assessment of sediment in the NSR was conducted in three sampling site locations in the vicinity of the proposed development (T1-2, T2-3 & T3-3 in Figure 4.6). The baseline assessment was valuable in determining indicators and endpoints for the monitoring protocol that would be implemented during the berm installations and removals. Further, the assessment served to rule out other external (non-natural) sources of sediment entering the watercourse in the near vicinity of the project.

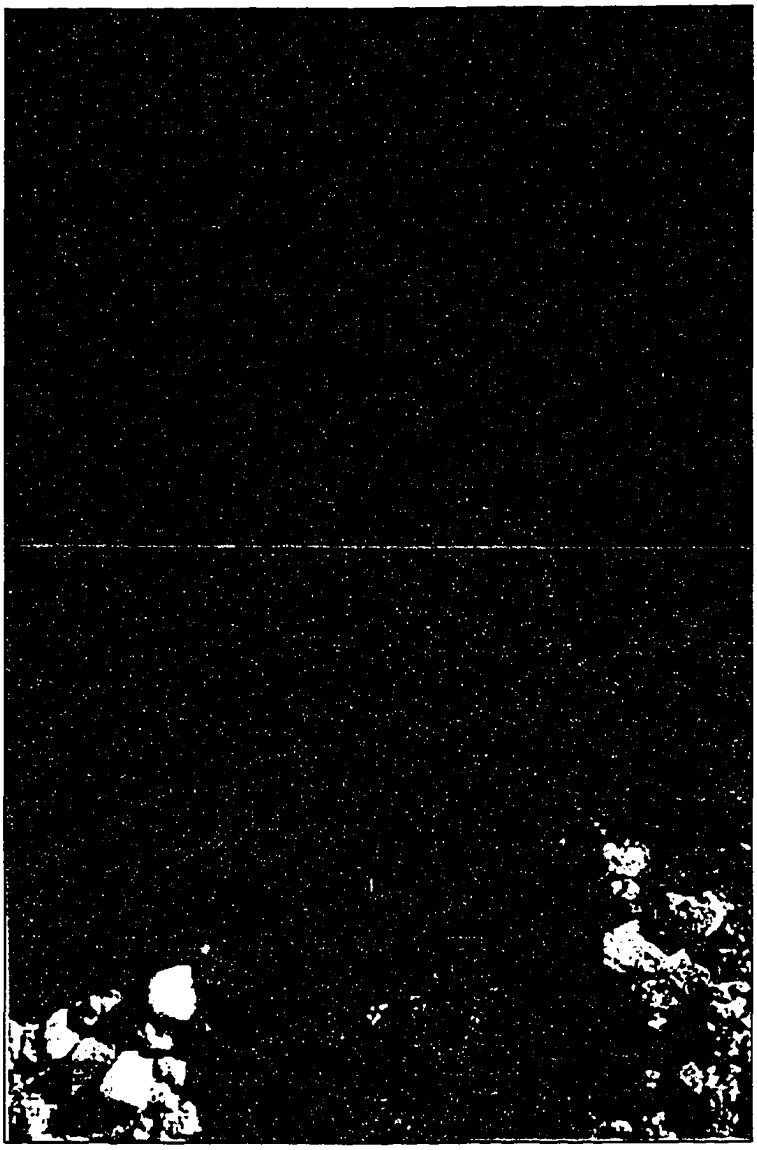

Figure 4.4. Example of highly turbid water versus low turbid water in the North Saskatchewan River near Edmonton, Alberta.

From the assessment, it was determined that the river was carrying some suspended sediment in early May 1999 (Table 4.2). The difference in results in turbidity and total suspended sediment amongst the three sites sampled in May was not statistically significant nor was there any correlation that would indicate that a source of sediment was entering between the sample locations. Similar results were noted from the August 1999 measurements of suspended sediment and turbidity. Although the overall levels of sediment were reduced from the May sampling, the comparison amongst the three sampling sites in August again verified that no source of sediment was entering the river between the various study sites. The river does carry varying amounts of sediment seasonally; therefore, spatial comparison rather than temporal comparison is more salient to identifying sediment sources.

Additional total suspended sediment and turbidity data was gathered by Aqualta in August and September 1999 (Table 4.3). This data was utilized along with the baseline assessment data and eventual monitoring data to establish a site-specific correlation between total suspended sediment and turbidity in the NSR at this location.

Table 4.2. Summary of total suspended sediments (mg/L) and turbidity (NTU) measured at the North Saskatchewan River in the vicinity of the Clover Bar Bridge near Edmonton, Alberta on May 2 and August 18, 1999.

Location	Total Suspended Sediment (mg/L)		Turbidity (NTU)	
	May 1999	August 1999	May 1999	August 1999
Sample Site #1 Upstream 200m	120	10	44.1	14.2
Sample Site #2 Downstream 100m	102	40	35.6	11.0
Sample Site #3 Downstream 250m	103	30	34.1	14.8

Table 4.3. Summary of total suspended solids (mg/L) and turbidity (NTU) as measured by Aqualta at the North Saskatchewan River in the vicinity of the Clover Bar Bridge in Edmonton, Alberta in August and September, 1999.

Date	Total Suspended Solids (mg/L)	Turbidity (NTU)
August 4, 1999	49	26
August 12, 1999	18	36.9
August 17, 1999	40	26
August 24, 1999	20	10.8
August 31, 1999	41	No measurement
September 9, 1999	4	No measurement
September 21, 1999	12	No measurement
September 28, 1999	13	No measurement

4.3.2 Field Sampling

Methods and sampling frequency followed scientifically based protocols with statistically relevant sample sizes (DFO 1995; Newcombe 1994; Newcombe and MacDonald 1991; Golder and Associates 1998; Goodchild and Metikosh 1994; Lind 1979; Newcombe and Jensen 1996; Alberta Transportation et al. 1992). Turbidity samples were collected with a 500 mL plastic bottle (Figure 4.5) and the sample was taken from approximately 15 cm below the water surface. Turbidity measurements were conducted in a mobile laboratory located at the study site. Random duplicate samples were sent to an accredited laboratory (Norwest Labs) for analysis for future comparison with the field portable turbidimeter results. For the purposes of establishing a correlation with turbidity, random total suspended sediment samples were collected with a 500 mL plastic bottle (Figure 4.5) from approximately 15 cm below the water surface. Total suspended sediment samples were analyzed both by the researcher in a temporary laboratory as well as sent to an accredited laboratory (Norwest Labs) for filtration.

4.3.3 Spatial Plan

The five sampling transects established for the monitoring were based on the baseline assessment sampling transects, site-specific regulatory criteria and on-site adaptive decision-making. Sampling for turbidity occurred along the transects at a total of 21 sampling stations of which a maximum of 5 equally spaced stations were located along each of the 5 transects (Table 4.4 and Figure 4.6). The location of the sampling followed similar suggestions indicated in "Quantifying the Effects of Sediment Release on Fish and Their Habitats" (DFO 1995). The spacing of the sampling stations was modified to account for the lower sensitivity of the waters and fish habitats located in the vicinity of this project. The sampling plan was constrained by ice build up on the banks during the winter sampling at which time sampling station numbers were reduced at certain transects.

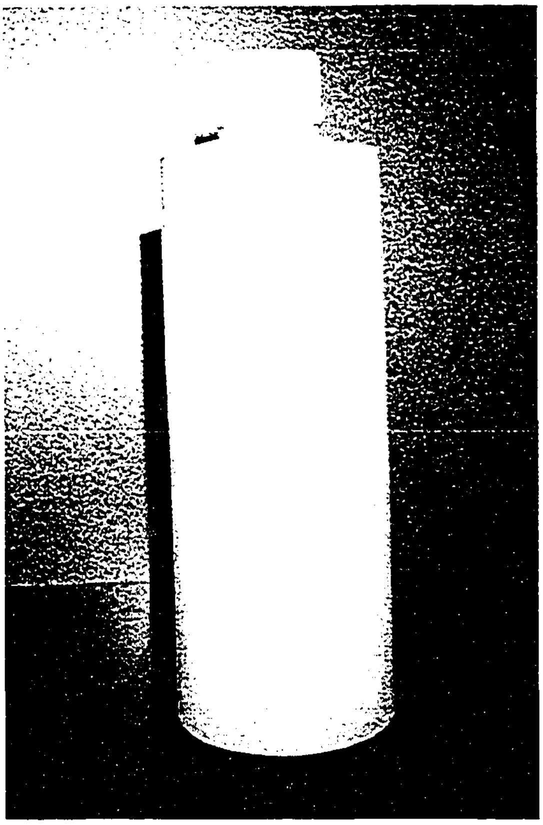

Figure 4.5. 500 mL plastic sample bottle used for sample collection for turbidity and total suspended sediment analysis.

Table 4.4. Case history transect and sampling site locations on the North Saskatchewan River near Edmonton, Alberta from August 2000 to March 2001.

Transect Number	Transect Location (from New Bridge ROW)	Maximum Number of Sampling Sites
T1	UPS 200m	3
T2	DWS 100m	5
T3	DWS 250m	5
T4	DWS 1km	5
T5	DWS 5km	3

UPS – Upstream DWS – Downstream ROW – Right-of-Way

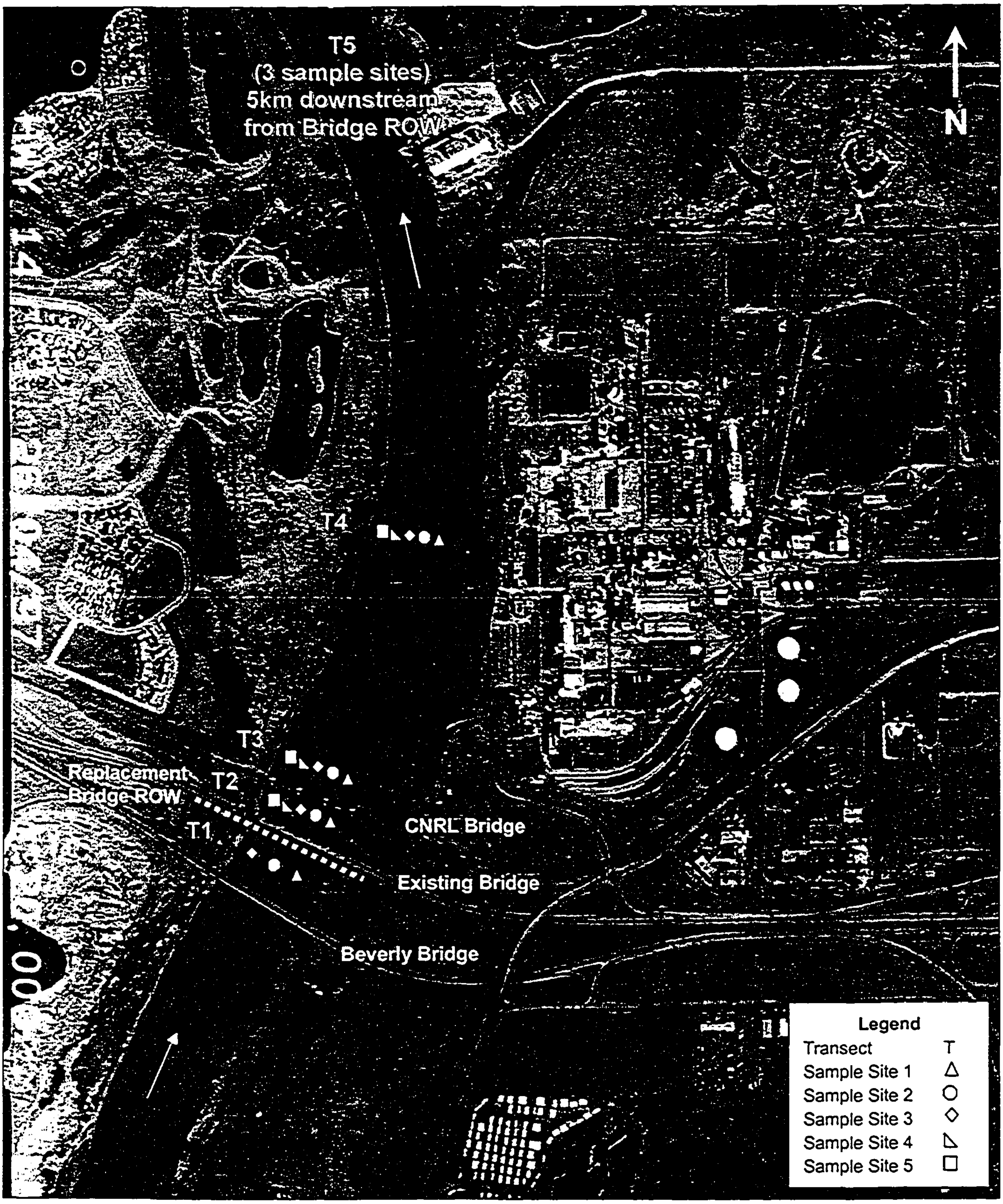

Figure 4.6. Case history transect and sample site locations in the specific study area (1:13,333 scale, 1997 aerial photograph reproduced from Alberta Environment).

4.3.4 Temporal Plan

With respect to the specific berm installation and removal activities, the main water quality monitoring periods were (Figures 4.7 to 4.11):

August 2 - 8, 2000 -	East Berm Construction
October 20 – 23, 2000 -	West Berm Construction
December 29, 2000 – January 2, 2001 -	East Berm Removal/ West Berm Construction Addition
March 23 – 27, 2001 -	West Berm Removal

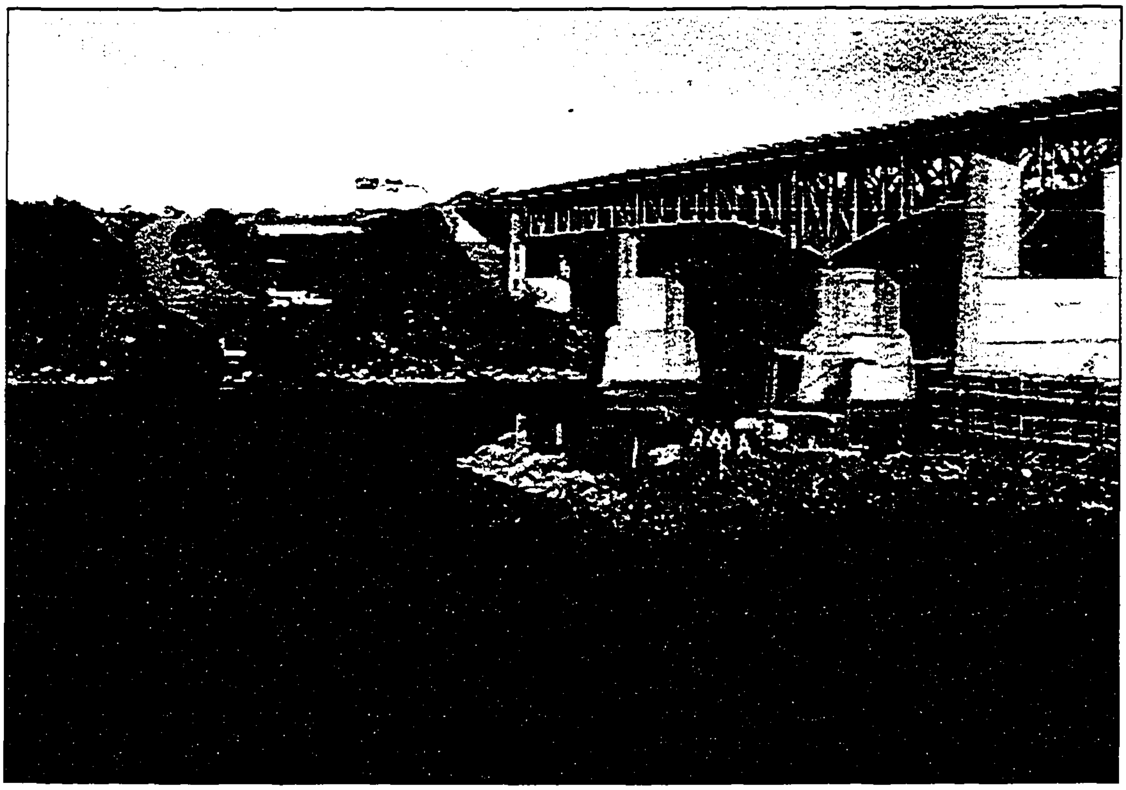

Figure 4.7. Case history project on the North Saskatchewan River in Edmonton, Alberta, west berm construction, October 2000.

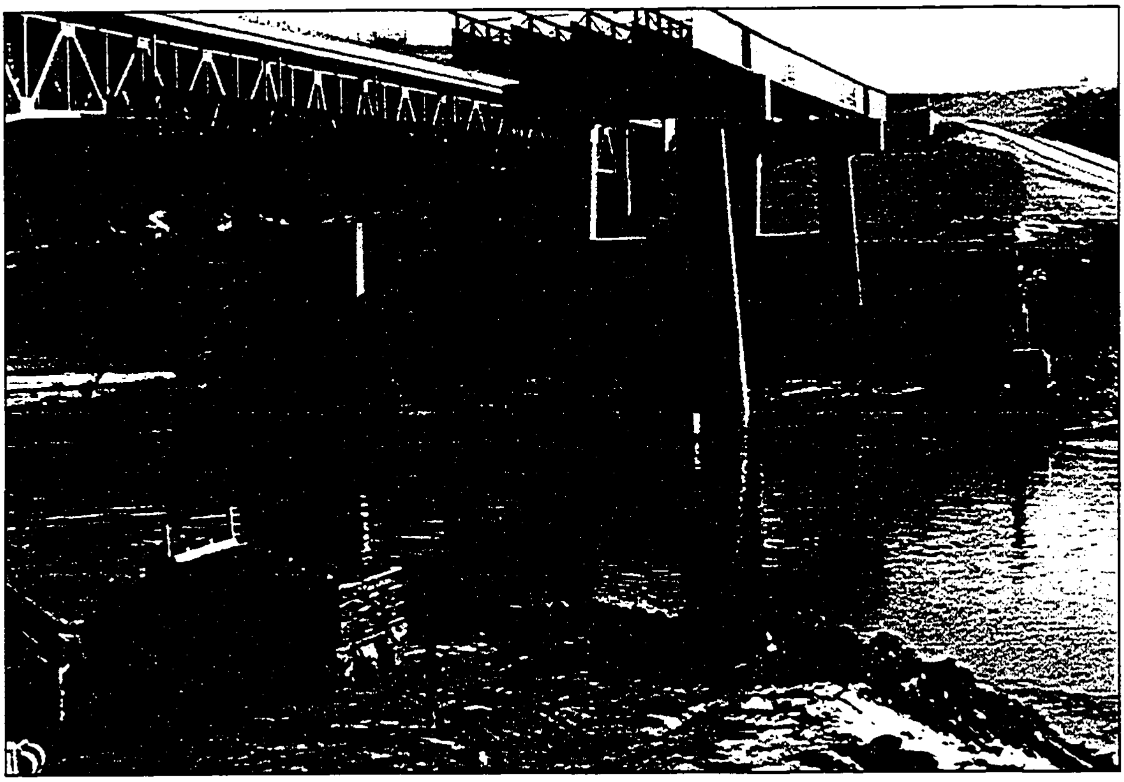

Figure 4.8. Case history project on the North Saskatchewan River in Edmonton, Alberta, east berm removal and west berm construction addition, December 2000.

Figure 4.9. Case history project on the North Saskatchewan River in Edmonton, Alberta, east berm removal, December 2000.

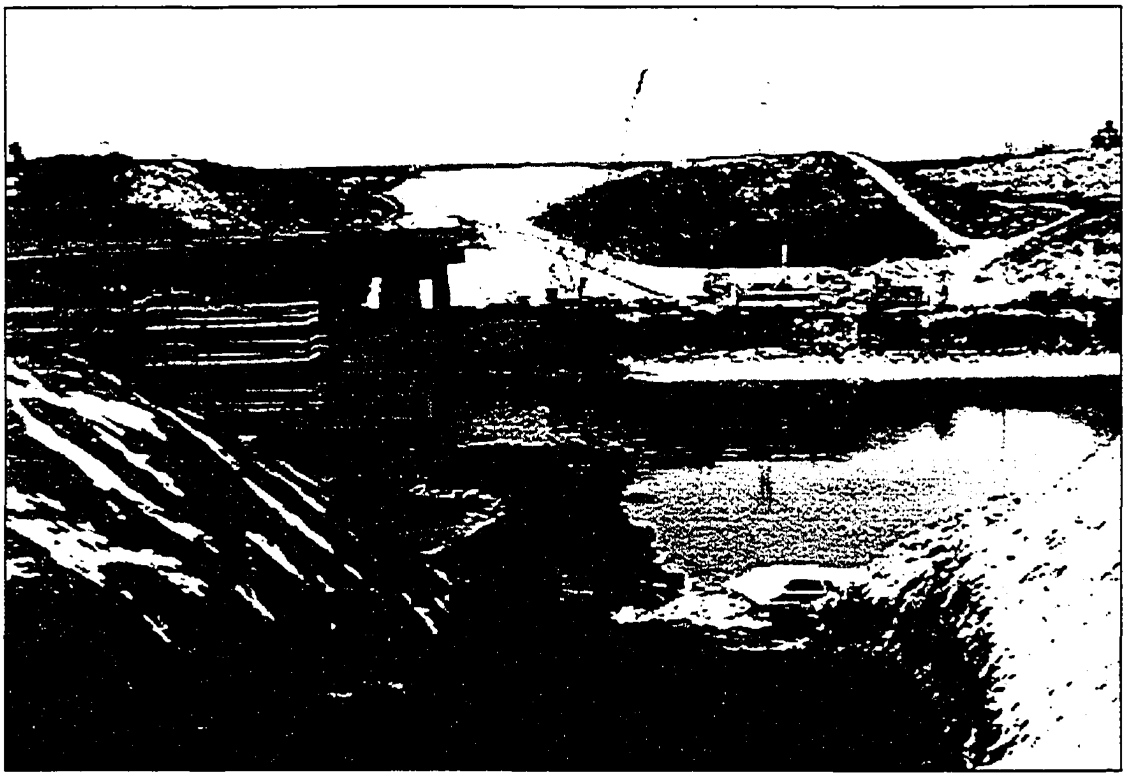

Figure 4.10. Case history project on the North Saskatchewan River in Edmonton, Alberta, west berm addition, January 2001.

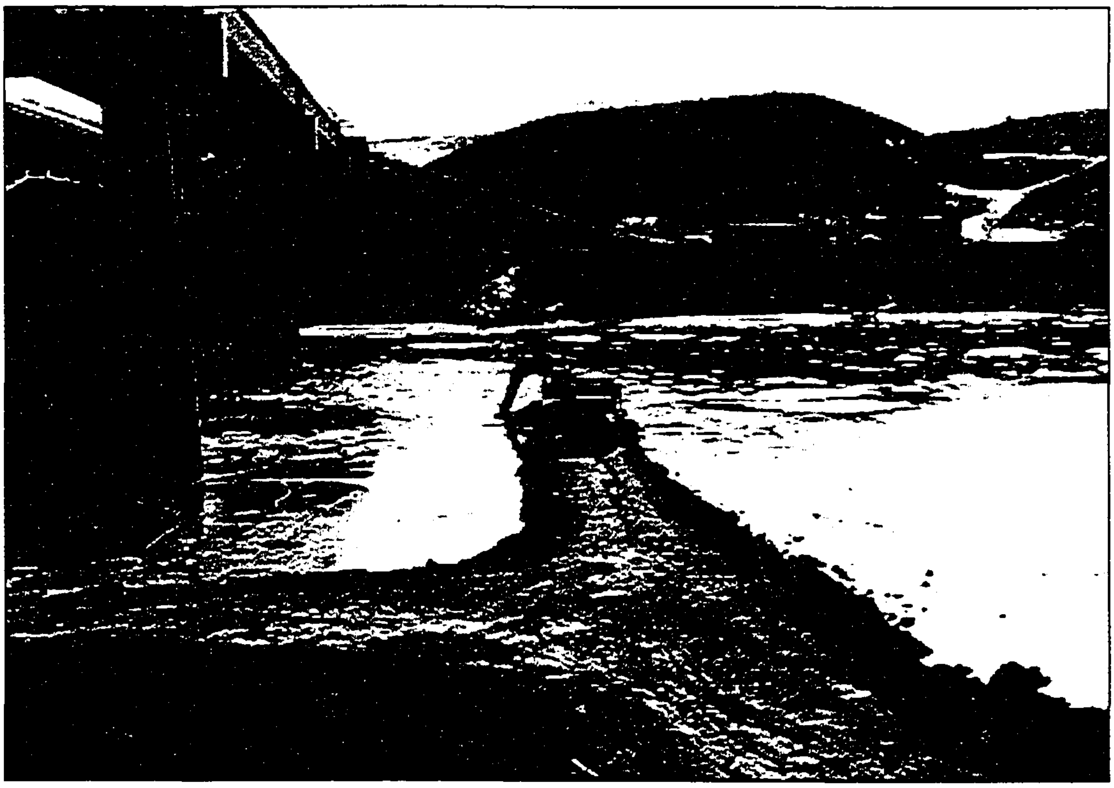

Figure 4.11. Case history project on the North Saskatchewan River in Edmonton, Alberta, west berm removal, March 2001.

An overview of the temporal and spatial monitoring plans is provided in Table 4.5.

Table 4.5. Temporal and spatial overview of water quality monitoring associated with the case history on the North Saskatchewan River from August 2000 to March 2001.

Water Quality Monitoring Date	Construction Activity	Frequency of Sampling per Day at Transects 1 to 5 (# of *Sample Suites)
August 2, 2000	East Berm Construction	3
August 3, 2000	East Berm Construction	3
August 4, 2000	East Berm Construction	3
August 5, 2000	East Berm Construction	1
August 8, 2000	East Berm Construction	1
October 20, 2000	West Berm Construction	3
October 21, 2000	West Berm Construction	3
October 22, 2000	West Berm Construction	3
October 23, 2000	West Berm Construction	2
Dec. 29, 2000	East Berm Removal & West Berm Addition	2
Dec. 30, 2000	East Berm Removal & West Berm Addition	3
Dec. 31, 2000	East Berm Removal & West Berm Addition	4
January 1, 2001	East Berm Removal & West Berm Addition	3
January 2, 2001	East Berm Removal & West Berm Addition	3
March 23, 2001	West Berm Removal	2
March 24, 2001	West Berm Removal	3
March 25, 2001	West Berm Removal	3
March 26, 2001	West Berm Removal	2
March 27, 2001	West Berm Removal	1

*Sample suites occurred at morning, midday and/or early evening.

4.3.5 Sample Analysis

Turbidity was measured on-site immediately after sampling with the HACH Model 2100P Turbidimeter (Figure 4.12). Sample temperature was maintained and samples were measured promptly after sampling. The turbidimeter was calibrated with formazin regularly and rechecked to a set of Gelex standards prior to each session of measurements. Samples were not de-gassed. Measurements were made in automatic range selection mode with triplicate readings of each sample being taken. Sample cells were cleaned regularly and coated with silicone oil to ensure the most accurate reading. Water samples were mixed thoroughly before measurement.

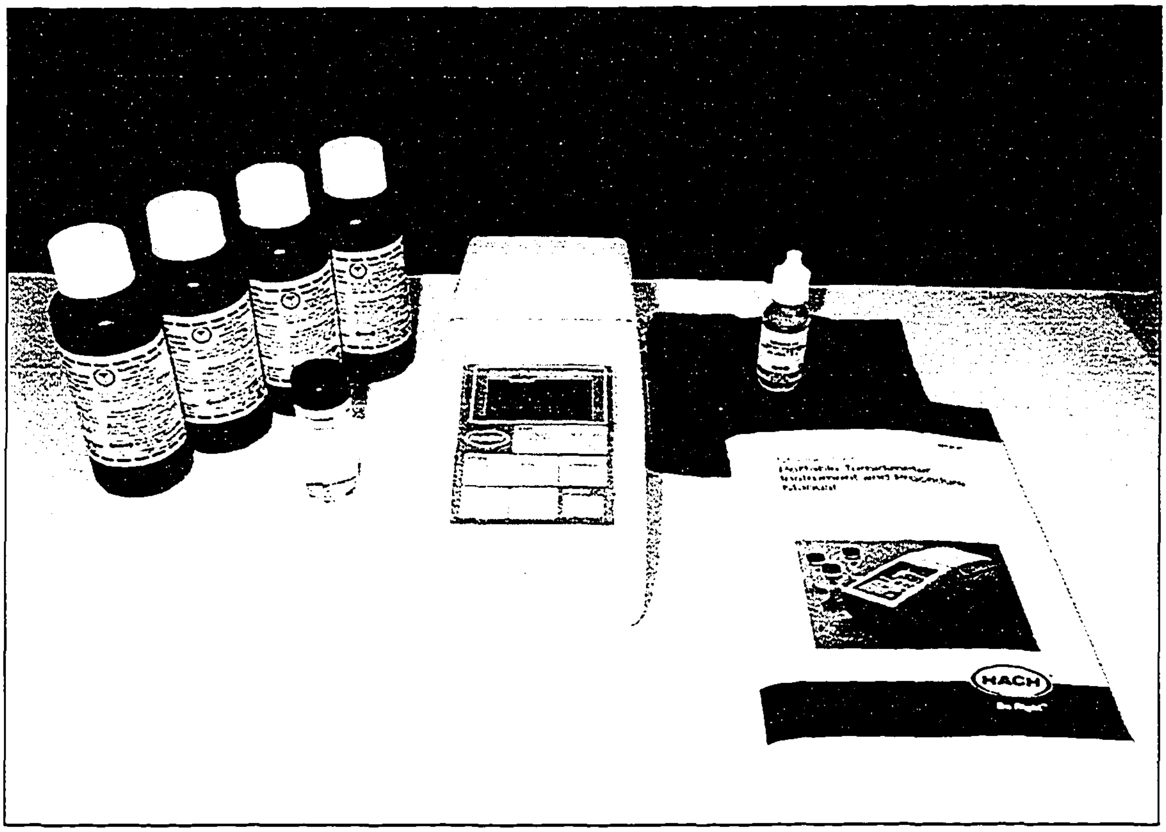

Figure 4.12. HACH Model 2100P Turbidimeter (left to right: Formazin standards, sample cell, portable turbidimeter, silicon oil and oiling cloth, operator's manual).

Random duplicate samples sent to a laboratory were analyzed for turbidity. The laboratory was fully accredited by all relevant federal and provincial agencies, including the Canadian Association for Environmental Analytical Laboratories (CAEAL) and the Standards Council of Canada (SCC). The analytical method used for turbidity was nephelometry (APHA 2130:B) with a 0.1 mg/L detection limit. Samples were held approximately 48 hours at 4°C with a standard turnaround time of 5 working days.

Total suspended sediment was analyzed at a temporary laboratory by filtering the residue of a well-mixed sample through a standard (glass) filter then drying and weighing the filter and residue. The result is a weight per volume unit (mg/L). Random duplicate samples sent to the accredited laboratory were analyzed for total suspended sediments (total non-filterable residue) by filtration (GFC), drying (105°C) and weighing with a 5 mg/L detection limit (APHA 2540:D). Samples were held approximately 7 days at 4°C.

4.3.6 Quality Assurance and Quality Control

Standard operating procedures for sample handling and data management (transfer and verification) were developed and were used for all aspects of the monitoring program.

The laboratory quality assurance/quality control (QA/QC) included basic methods of insuring confident results including:

- Periodic calibration of turbidimeter used to measure turbidity;
- Triplicate sampling to measure turbidity and other water quality parameters (to establish replication consistency);
- Analysis of random duplicate samples; and
- Use of an accredited laboratory which is certified by the Canadian Association of Environmental and Analytical Laboratories (CAEAL) to analyze some duplicate turbidity and suspended sediment samples.

Sample handling consisted of:

- Storing samples in sealed coolers to maintain a constant temperature (4 degrees Celsius);
- Completing a field data sheet that ensured a chain of custody and continuity;
- Shipping and analyzing samples as soon as possible following collection; and
- Duplicate recording of samples.

Data was recorded in hard copy and digital formats and double-checked for transcription or entry errors.

4.4 Turbidity and Total Suspended Sediment Monitoring Results

4.4.1 August 2000 East Berm Construction

The August 2000 east berm construction consisted of 5 days of water quality monitoring (August 2, 3, 4, 5 & 8, 2000). This included 235 on-site NTU measurements and 8 laboratory NTU samples, 25 researcher TSS measurements, and 8 laboratory TSS samples (Appendix Table D).

On August 2, 2000, three sample suites were conducted (Sample Suite 1 – morning, Sample Suite 2 – midday, Sample Suite 3 – early evening) at all of the sampling sites along each of the five transects (Table 4.6, Figure 4.13). Triplicate measurements were taken at and averaged for each sample site. A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for August 2 of 6.7 NTU at T2-4 which occurred during sample suite 3. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 3.2 NTU was noted at T5 during sample suite 3 (Table 4.6). When the average of all the upstream sample sites for all three sample suites (daily average) was compared with the average of all the downstream sample sites for all three sample suites (daily average), the result was a decrease in NTU from upstream (background) levels.

On August 3, 2000, three sample suites were conducted (Sample Suite 1 – morning, Sample Suite 2 – midday, Sample Suite 3 – early evening) at all of the sampling sites along each of the five transects (Table 4.6, Figure 4.14). Triplicate measurements were taken at and averaged for each sample site. A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for August 3 of 1.2 NTU at T2-5 which occurred during sample suite 1. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 0.8 NTU was noted at T2 and T5 during sample suite 3 (Table 4.6). When the average of all the upstream sample sites for all three sample suites (daily average) was compared with the average of all the downstream sample sites for all three sample suites (daily average), the result was a decrease in NTU from upstream (background) levels.

On August 4, 2000, three sample suites were conducted (Sample Suite 1 – morning, Sample Suite 2 – midday, Sample Suite 3 – early evening) at all of the sampling sites along each of the five transects (Table 4.6, Figure 4.15). Triplicate measurements were taken at and averaged for each sample site. A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for August 4 of 3.0 NTU at T2-1 which occurred during sample suite 3. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 0.3 NTU was noted at T2 during sample suite 3 (Table 4.6). When the average of all the upstream sample sites for all three sample suites (daily average) was compared with the average of all the downstream sample sites for all three sample suites (daily average), the result was a decrease in NTU from upstream (background) levels.

On August 5, 2000, one sample suite was conducted (Sample Suite 1 – morning) at all of the sampling sites along each of the five transects. Triplicate measurements were taken at and averaged for each sample site (Table 4.6, Figure 4.16). A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for August 5 of 1.9 NTU at T3-5 which occurred during sample suite 1. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 1.2 NTU was noted at T3 during sample suite 1 (Table 4.6). When the average of all the upstream sample sites for the one sample suite (daily average) was compared with the average of all the downstream sample sites for the one sample suite (daily average), the result was a decrease in NTU from upstream (background) levels.

On August 8, 2000, one sample suite was conducted (Sample Suite 3 – early evening) at all of the sampling sites along each of the five transects. Triplicate measurements were taken at and averaged for each sample site (Table 4.6, Figure 4.17). A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated no downstream sample sites exceeding upstream sample sites in turbidity. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, no downstream transects exceeded the upstream turbidity average (Table 4.6). When the average of all the upstream sample sites for the one sample suite (daily average) was compared with the average of all the downstream sample sites for the one sample suite (daily average), the result was a decrease in NTU from upstream (background) levels.

Overall, the upstream versus downstream turbidity levels during this project period exhibited little difference (Figure 4.18). Further, whether comparing the individual sample sites or the averages of sample sites along transects per sample suite or the averages of transects per day, the comparison between upstream and downstream levels were within the acceptable range of the provincial and federal guidelines.

The mean flow (m^3/s) of the North Saskatchewan River was gathered from Alberta Environment's real-time survey station (RNSASEDM) for this monitoring period and appeared to have a somewhat similar trend to the background turbidity trend (Figure 4.18).

Table 4.6. Turbidity (NTU) monitoring results for the case history during the August 2000 period.

Sampling Date	Sample Suite or Averaging Description	Turbidity (NTU) Transect Average				
		T-1 UPS	T-2 DWS	T-3 DWS	T-4 DWS	T-5 DWS
August 2, 2000	Suite 1	25.0	23.6	21.2	20.9	22.7
	Suite 2	20.2	20.7	20.7	21.2	20.3
	Suite 3	17.8	19.5	15.1	17.8	21.0
	Daily Transect Average	21.0	21.3	19.0	19.9	21.3
	Daily UPS vs. DWS Average	21.0	20.4			
August 3, 2000	Suite 1	12.8	13.3	12.9	12.8	12.3
	Suite 2	14.2	13.8	12.9	13.0	12.3
	Suite 3	12.1	12.9	12.3	12.5	12.9
	Daily Transect Average	13.0	13.3	12.7	12.7	12.5
	Daily UPS vs. DWS Average	13.0	12.8			
August 4, 2000	Suite 1	11.6	11.2	10.5	10.7	10.8
	Suite 2	10.7	10.5	10.4	10.3	10.3
	Suite 3	12.0	12.3	10.8	11.0	11.4
	Daily Transect Average	11.4	11.3	10.6	10.7	10.8
	Daily UPS vs. DWS Average	11.4	10.8			
August 5, 2000	Suite 1	22.3	21.7	23.5	21.7	21.8
	Daily UPS vs. DWS Average	22.3	22.2			
August 8, 2000	Suite 3	10.0	9.2	9.6	9.6	9.2
	Daily UPS vs. DWS Average	10.0	9.4			

Sample Suite 1 – morning   Sample Suite 2 - midday   Sample Suite 3 - early evening.
UPS – Upstream   DWS - Downstream
T – Transect   T-1 – Average of T1-1, T1-2 & T1-3
T-2 – Average of T2-1, T2-2, T2-3, T2-4 & T2-5   T3 – Average of T3-1, T3-2, T3-3, T3-4 & T3-5
T4 – Average of T4-1, T4-2, T4-3, T4-4 & T4-5   T5 – Average of T5-1, T5-2 & T5-3

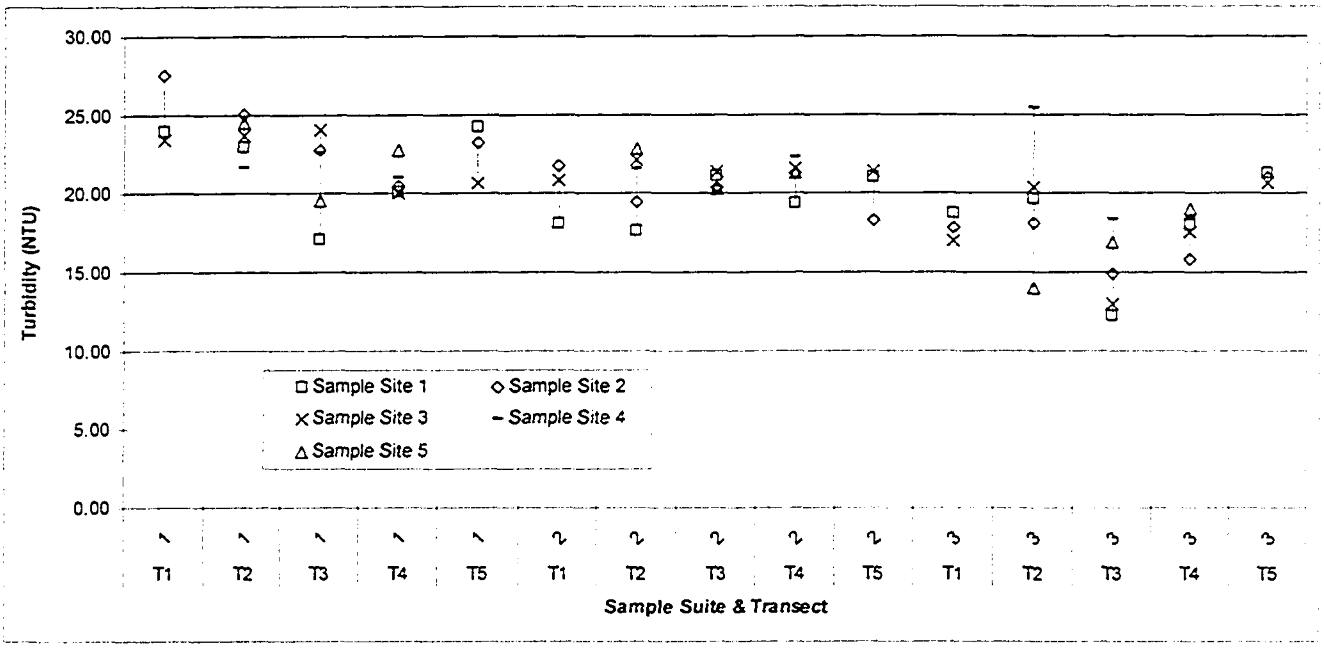

Figure 4.13. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3, T4 & T5 – downstream) for each sample suite (1 – morning, 2 – midday, 3 – early evening) on August 2, 2000.

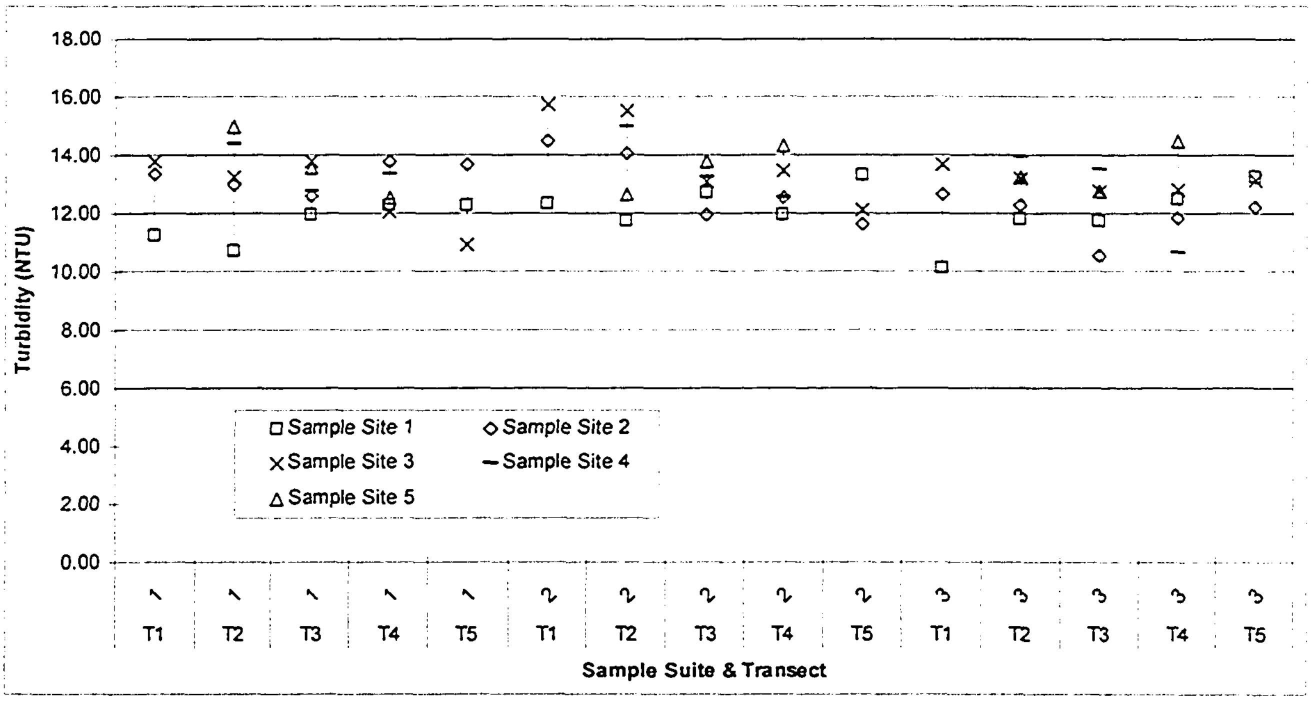

Figure 4.14. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3, T4 & T5 – downstream) for each sample suite (1 – morning, 2 – midday, 3 – early evening) on August 3, 2000.

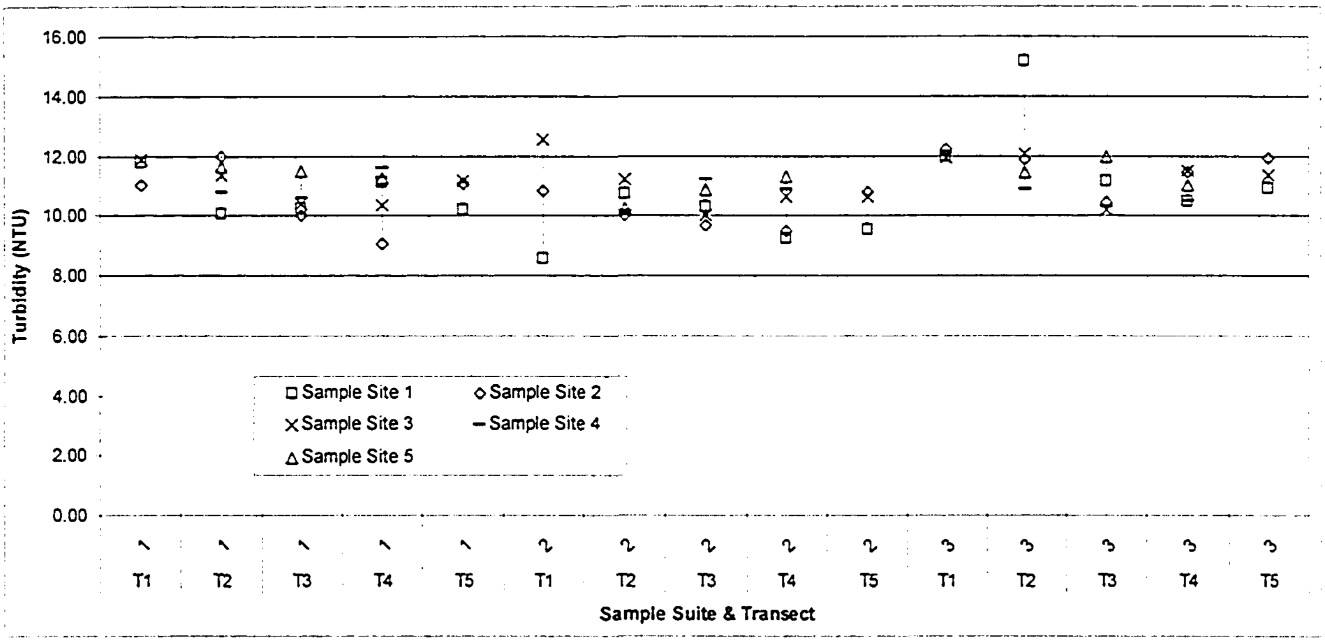

Figure 4.15. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3, T4 & T5 – downstream) for each sample suite (1 – morning, 2 – midday, 3 – early evening) on August 4, 2000.

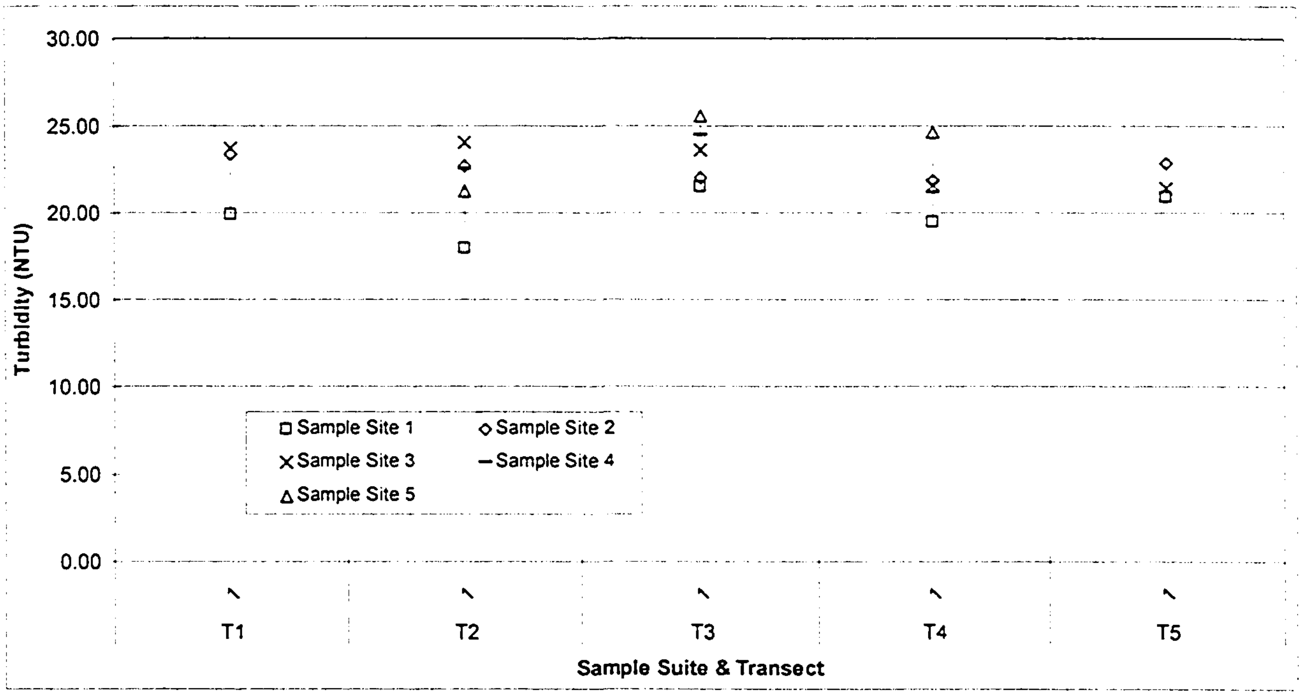

Figure 4.16. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3, T4 & T5 – downstream) for each sample suite (1 – morning) on August 5, 2000.

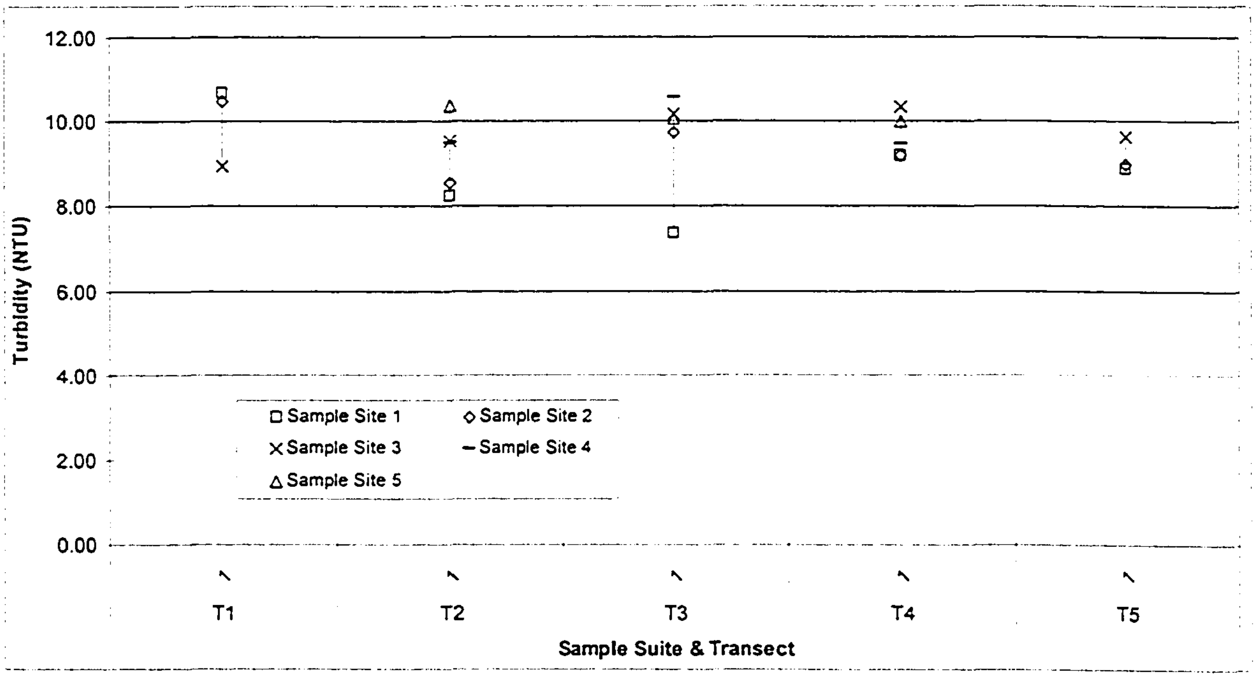

Figure 4.17. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3, T4 & T5 – downstream) for each sample suite (1 – morning) on August 8, 2000.

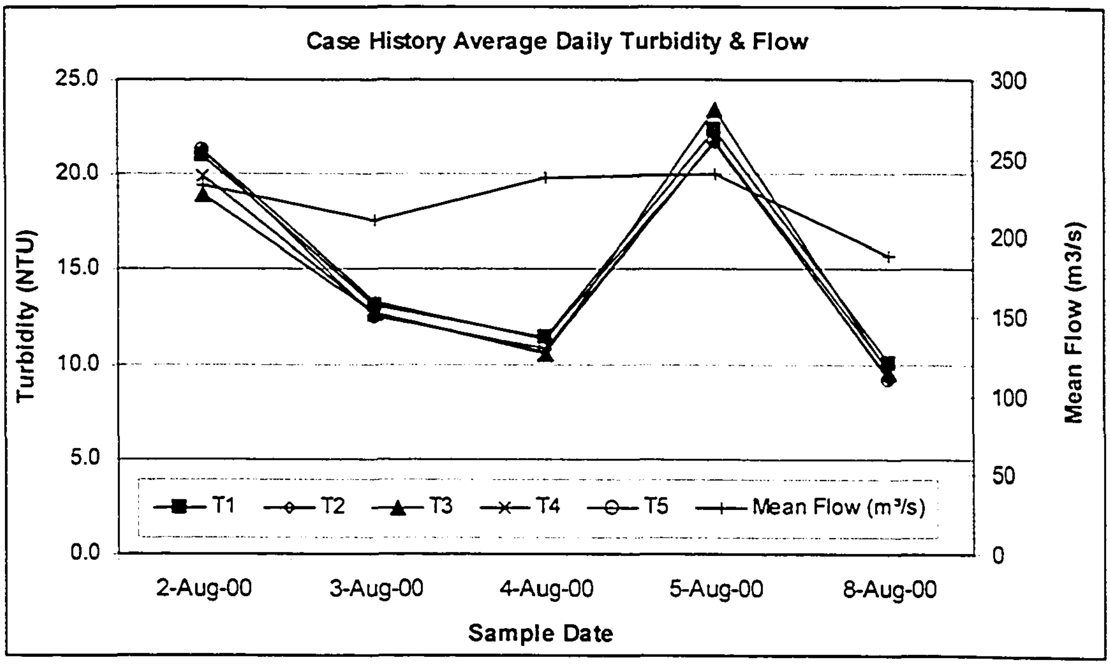

Figure 4.18. Case history daily transect average turbidity (NTU) (researcher analyzed) and mean flow (m^3/s) (from Alberta Environment's real time survey station, RNSASEDM) for the August 2000 period.

The researcher TSS levels similarly indicated little difference between upstream and downstream areas (Table 4.7). On August 2, 2000, the average TSS of the upstream transect was 60 mg/L and the average TSS level of downstream Transect 4 was 24 mg/L. On August 3, 2000, the average TSS of the upstream transect was 10 mg/L and the average TSS level of downstream Transect 4 was 8 mg/L. On August 4, 2000, the average TSS of the upstream transect was 17 mg/L and the average TSS level of downstream Transect 4 was 14 mg/L. The August 4, 2000 laboratory analyzed TSS resulted in an average upstream TSS of 17.3 mg/L and an average TSS level of downstream Transect 4 of 23.4 mg/L. These levels were within the acceptable range of the provincial and federal guidelines.

Table 4.7. Total suspended sediment (TSS) monitoring results (researcher analysis) for the case history during sample suite 2 on August 2, 3 and 4, 2000.

Sample Date	Sample Site	Total Suspended Sediment (mg/L)	
		Researcher Analysis	Laboratory Analysis
August 2, 2000	T1-1	100	
	T1-2	40	
	T1-3	40	
	T4-1	40	
	T4-2	20	
	T4-3	20	
	T4-4	20	
	T4-5	20	
August 3, 2000	T1-1	20	
	T1-2	5	
	T1-3	5	
	T4-1	20	
	T4-2	5	
	T4-3	5	
	T4-4	5	
	T4-5	5	
August 4, 2000	T1-1	40	8
	T1-2	5	18
	T1-3	5	26
	T4-1	5	16
	T4-2	5	22
	T4-3	20	25
	T4-4	20	28
	T4-5	20	26

T - Transect

4.4.2 October 2000 West Berm Construction

The October 2000 east berm construction consisted of 4 days of water quality monitoring (October 20, 21, 22 & 23, 2000). This included 231 on-site NTU measurements and 8 laboratory NTU samples, 32 researcher TSS measurements, and 8 laboratory TSS samples (Appendix Table E).

On October 20, 2000, three sample suites were conducted (Sample Suite 1 – morning, Sample Suite 2 – midday, Sample Suite 3 – early evening) at all of the sampling sites along each of the five transects (Table 4.8, Figure 4.19). Triplicate measurements were taken at and averaged for each sample site. A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for October 20 of 2.8 NTU at T2-1 which occurred during sample suite 1. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 0.3 NTU was noted at T2 and T5 during sample suite 1 (Table 4.8). When the average of all the upstream sample sites for all three sample suites (daily average) was compared with the average of all the downstream sample sites for all three sample suites (daily average), the result was no difference in NTU between upstream (background) and downstream levels.

On October 21, 2000, three sample suites were conducted (Sample Suite 1 – morning, Sample Suite 2 – midday, Sample Suite 3 – early evening) at all of the sampling sites along each of the five transects(Table 4.8, Figure 4.20). Triplicate measurements were taken at and averaged for each sample site. A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for October 21 of 1.7 NTU at T3-5 (random duplicate sample) which occurred during sample suite 3. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 0.4 NTU was noted at T2 and T4 during sample suite 2 (Table 4.8). When the average of all the upstream sample sites for all three sample suites (daily average) was compared with the average of all the downstream sample sites for all three sample suites (daily average), the downstream was 0.1 NTU higher than the upstream (background) levels.

On October 22, 2000, three sample suites were conducted (Sample Suite 1 – morning, Sample Suite 2 – midday, Sample Suite 3 – early evening) at all of the sampling sites along each of the five transects (Table 4.8, Figure 4.21). Triplicate measurements were taken at and averaged for each sample site. A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for October 22 of 4.4 NTU at T2-5 which occurred during sample suite 2. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 2.0 NTU was noted at T2 during sample suite 2 (Table 4.8). When the average of all the upstream sample sites for all three sample suites (daily average) was compared with the average of all the downstream sample sites for all three sample suites (daily average), the downstream was 0.5 NTU higher than the upstream (background) levels.

On October 23, 2000, two sample suites were conducted (Sample Suite 1 – morning, Sample Suite 2 – midday) at all of the sampling sites along each of the five transects (Table 4.8, Figure 4.22). Triplicate measurements were taken at and averaged for each sample site. A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for October 23 of 6.6 NTU at T2-5 which occurred during sample suite 1. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 2.0 NTU was noted at T2 during sample suite 2 (Table 4.8). When the average of all the upstream sample sites for all three sample suites (daily average) was compared with the average of all the downstream sample sites for all three sample suites (daily average), the downstream was 0.5 NTU higher than the upstream (background) levels.

Overall, the upstream versus downstream turbidity levels during this project period exhibited little difference (Figure 4.23). Further, whether comparing the individual sample sites or the averages of sample sites along transects per sample suite or the averages of transects per day, the comparison between upstream and downstream levels were within the acceptable range of the provincial and federal guidelines.

The mean flow (m^3/s) of the North Saskatchewan River was gathered from Alberta Environment's real-time survey station (RNSASEDM) for this monitoring period and appeared to have a highly similar trend to the background turbidity trend (Figure 4.23).

Table 4.8. Turbidity (NTU) monitoring results for the case history during the October 2000 period.

Sampling Date	Sample Suite or Averaging Description	Turbidity (NTU) Transect Average				
		T-1 UPS	T-2 DWS	T-3 DWS	T-4 DWS	T-5 DWS
October 20, 2000	Suite 1	2.6	2.9	2.8	2.8	2.9
	Suite 2	3.1	2.9	2.5	2.6	2.7
	Suite 3	2.6	2.7	2.8	2.7	2.8
	Daily Transect Average	2.8	2.8	2.7	2.7	2.8
	Daily UPS vs. DWS Average	2.8	2.8			
October 21, 2000	Suite 1	2.6	2.5	2.2	2.6	2.3
	Suite 2	2.4	2.8	2.7	2.8	2.6
	Suite 3	3.1	3.2	3.4	3.3	3.4
	Daily Transect Average	2.7	2.8	2.8	2.9	2.8
	Daily UPS vs. DWS Average	2.7	2.8			
October 22, 2000	Suite 1	3.3	3.7	3.3	3.5	3.1
	Suite 2	3.3	5.3	4.2	4.0	3.7
	Suite 3	3.9	5.0	3.9	3.8	4.0
	Daily Transect Average	3.5	4.7	3.8	3.8	3.6
	Daily UPS vs. DWS Average	3.5	4.0			
October 23, 2000	Suite 1	5.2	7.5	5.2	4.6	5.7
	Suite 2	6.3	6.9	6.2	5.3	4.6
	Daily Transect Average	5.7	7.2	5.7	4.9	5.2
	Daily UPS vs. DWS Average	5.7	5.7			

Sample Suite 1 – morning Sample Suite 2 - midday Sample Suite 3 - early evening.
UPS – Upstream DWS - Downstream
T – Transect T-1 – Average of T1-1, T1-2 & T1-3
T-2 – Average of T2-1, T2-2, T2-3, T2-4 & T2-5 T3 – Average of T3-1, T3-2, T3-3, T3-4 & T3-5
T4 – Average of T4-1, T4-2, T4-3, T4-4 & T4-5 T5 – Average of T5-1, T5-2 & T5-3

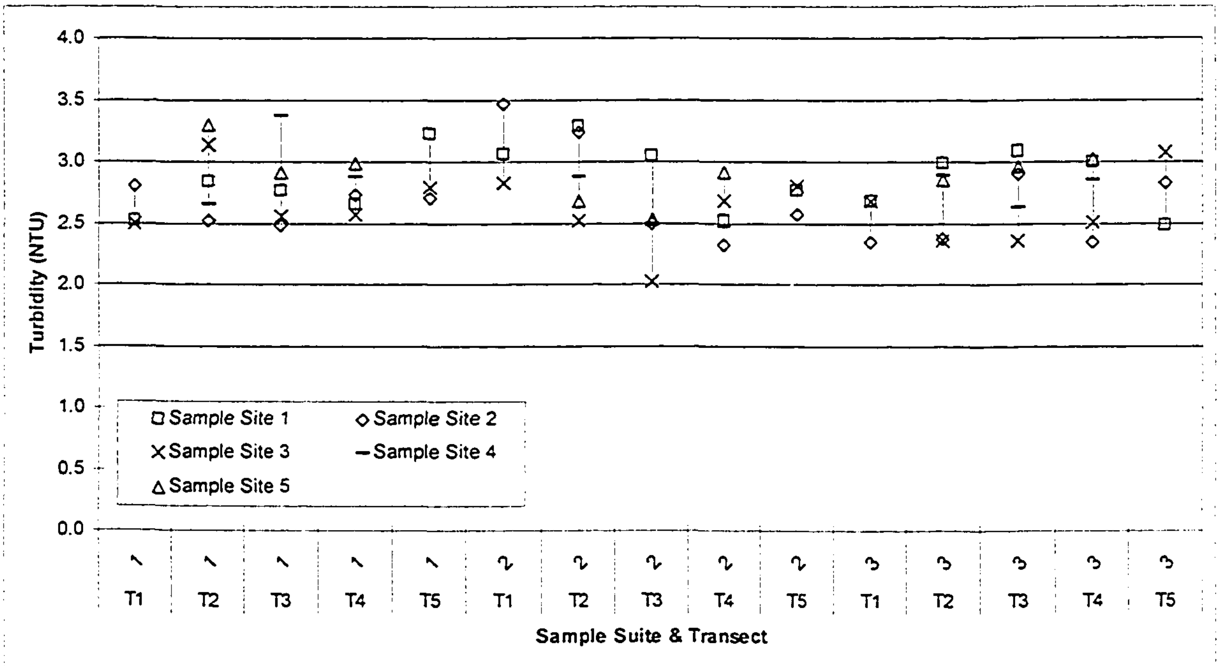

Figure 4.19. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3, T4 & T5 – downstream) for each sample suite (1 – morning, 2 – midday, 3 – early evening) on October 20, 2000.

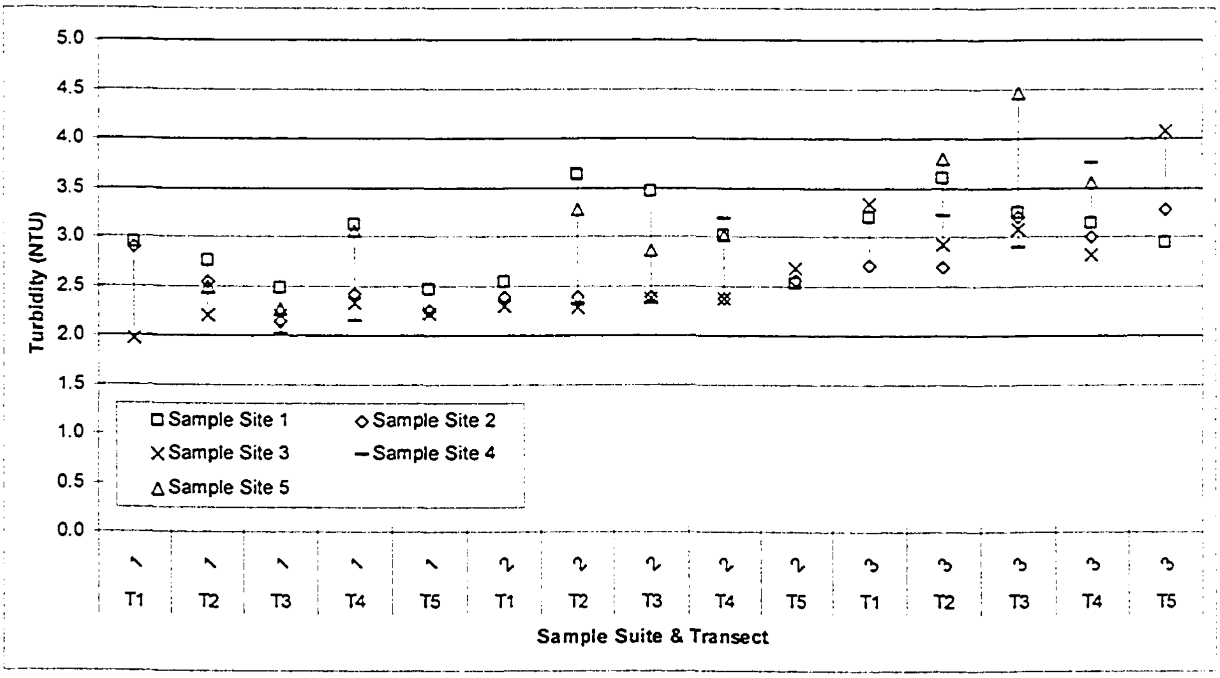

Figure 4.20. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3, T4 & T5 – downstream) for each sample suite (1 – morning, 2 – midday, 3 – early evening) on October 21, 2000.

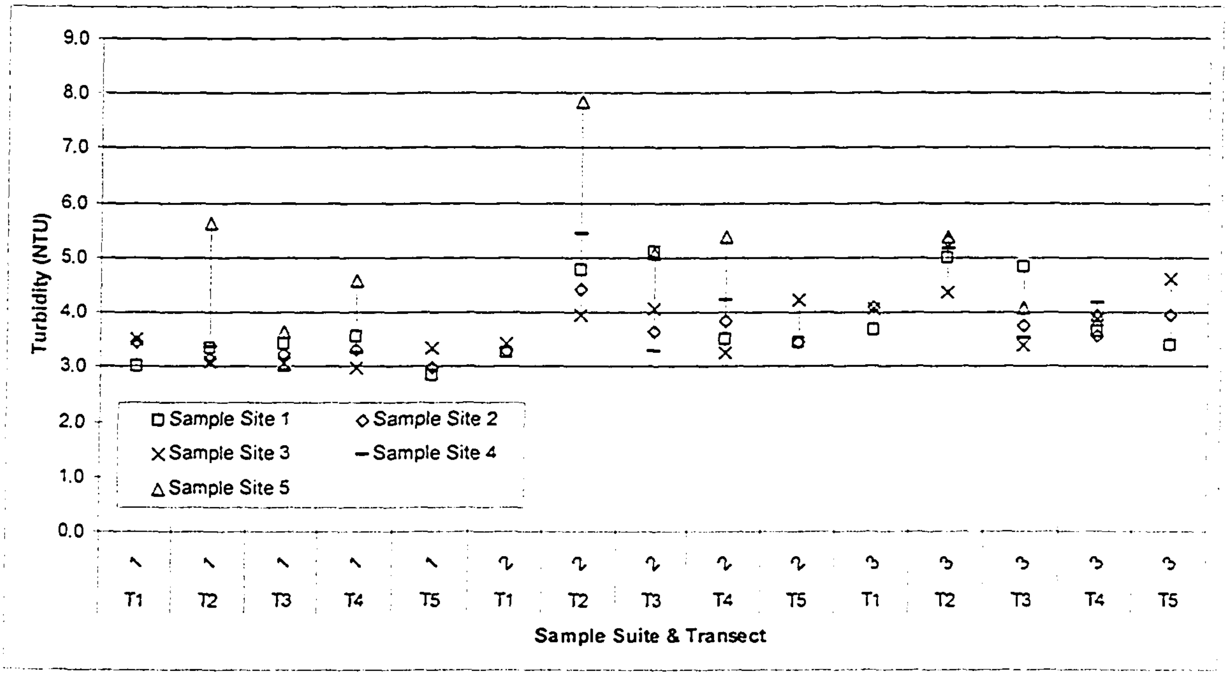

Figure 4.21. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3, T4 & T5 – downstream) for each sample suite (1 – morning, 2 – midday, 3 – early evening) on October 22, 2000.

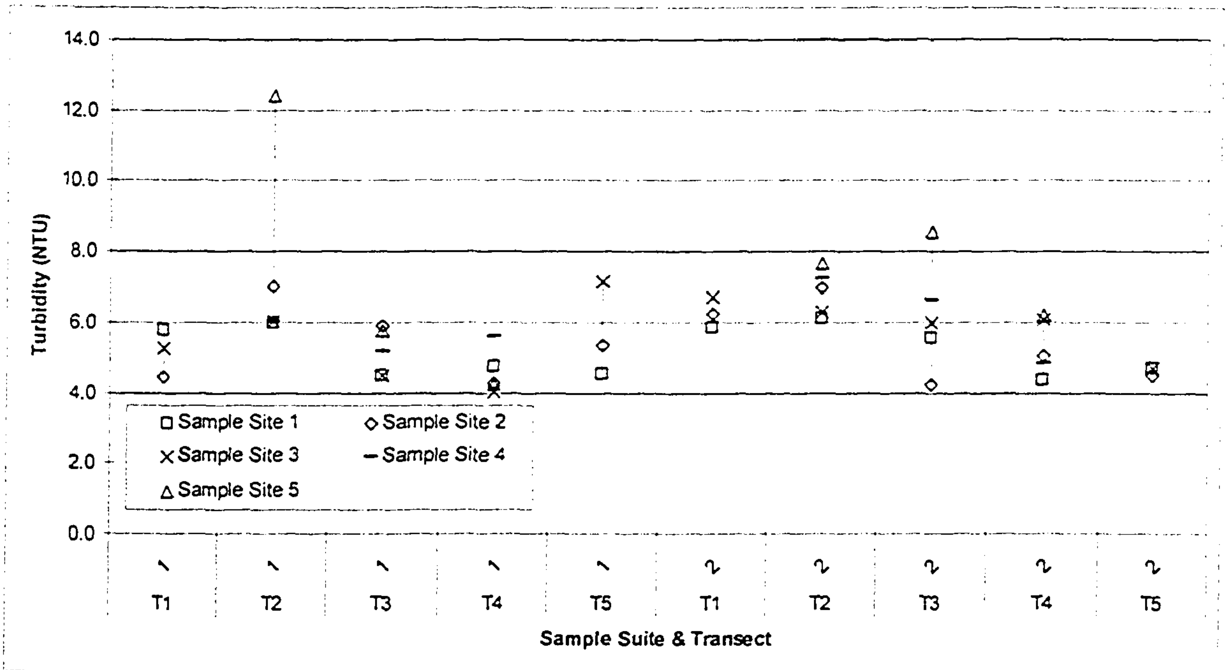

Figure 4.22. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3, T4 & T5 – downstream) for each sample suite (1 – morning, 2 – midday) on October 23, 2000.

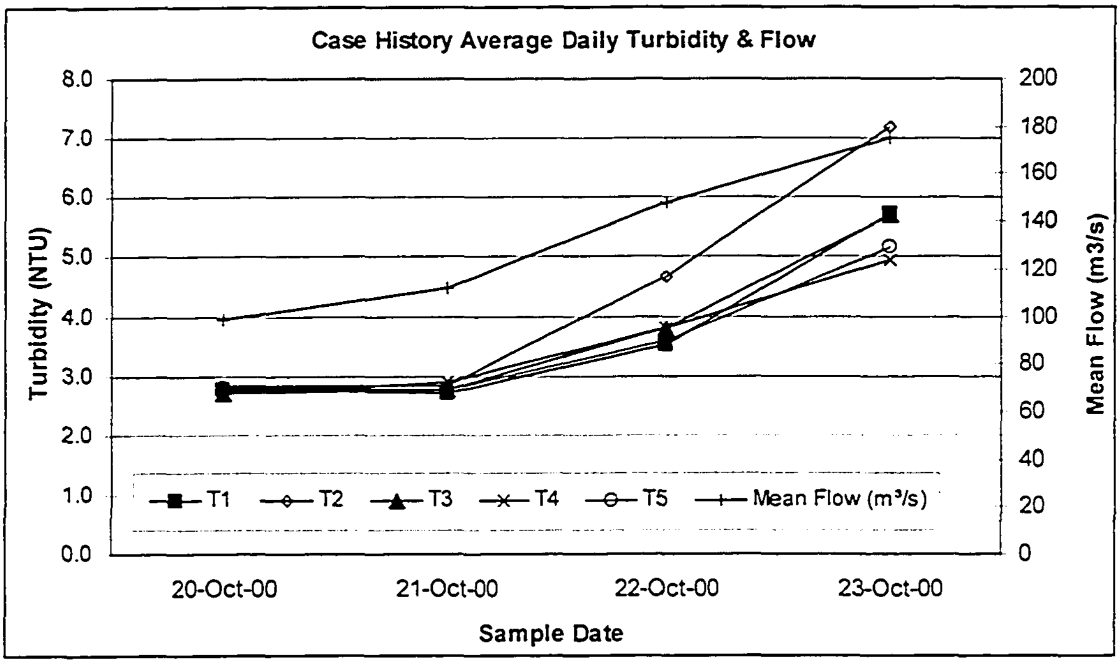

Figure 4.23. Case history daily transect average turbidity (NTU) (researcher analyzed) and mean flow (m^3/s) (from Alberta Environment's real time survey station, RNSASEDM) for the October 2000 period.

The researcher TSS levels similarly indicated little difference between upstream and downstream areas (Table 4.9). On October 20, 2000, the average TSS of the upstream transect was 0 mg/L and the average TSS level of downstream Transect 4 was 0 mg/L. On October 21, 2000, the average TSS of the upstream transect was 4 mg/L and the average TSS level of downstream Transect 4 was 6 mg/L. On October 22, 2000, the average TSS of the upstream transect was 11 mg/L and the average TSS level of downstream Transect 4 was 18 mg/L. On October 23, 2000, the average TSS of the upstream transect was 29 mg/L and the average TSS level of downstream Transect 4 was 41 mg/L. The October 23, 2000 laboratory analyzed TSS resulted in an average upstream TSS of 9 mg/L and an average TSS level of downstream Transect 4 of 9 mg/L. These levels were within the acceptable range of the provincial and federal guidelines.

Table 4.9. Total suspended sediment (TSS) monitoring results for the case history during sample suite 2 on October 20, 21, 22 and 23, 2000.

Sample Date	Sample Site	Total Suspended Sediment (mg/L)	
		Researcher Analysis	Laboratory Analysis
October 20, 2000	T1-1	0	
	T1-2	0	
	T1-3	0	
	T4-1	0	
	T4-2	0	
	T4-3	0	
	T4-4	0	
	T4-5	0	
October 21, 2000	T1-1	0	
	T1-2	0	
	T1-3	0	
	T4-1	0	
	T4-2	10	
	T4-3	20	
	T4-4	0	
	T4-5	0	
October 22, 2000	T1-1	0	
	T1-2	0	
	T1-3	0	
	T4-1	0	
	T4-2	20	
	T4-3	20	
	T4-4	30	
	T4-5	20	
October 23, 2000	T1-1	0	6
	T1-2	0	6
	T1-3	30	14
	T4-1	20	9
	T4-2	34	10
	T4-3	40	6
	T4-4	50	6
	T4-5	60	14

T - Transect

4.4.3 December 2000 East Berm Removal and West Berm Additional Construction

The December 2000 east berm removal and west berm additional construction consisted of 5 days of water quality monitoring (December 29, 30 & 31, 2000 and January 1 & 2, 2001). This included 261 on-site NTU measurements, 8 laboratory NTU samples and 32 researcher TSS measurements (Appendix Table F).

On December 29, 2000, two sample suites were conducted (Sample Suite 2 – midday, Sample Suite 3 – early evening) at all of the sampling sites along each of the four transects (T5 inaccessible due to ice conditions) (Table 4.10, Figure 4.24). Triplicate measurements were taken at and averaged for each sample site. A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for December 29 of 0.5 NTU at T3-2 which occurred during sample suite 3. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 0.4 NTU was noted at T3 during sample suite 3 (Table 4.10). When the average of all the upstream sample sites for all three sample suites (daily average) was compared with the average of all the downstream sample sites for all three sample suites (daily average), the result was a decrease in NTU from upstream (background) levels.

On December 30, 2000, three sample suites were conducted (Sample Suite 1 – morning, Sample Suite 2 – midday, Sample Suite 3 – early evening) at all of the sampling sites along each of the four transects (T5 inaccessible due to ice conditions) (Table 4.10, Figure 4.25). Triplicate measurements were taken at and averaged for each sample site. A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for December 30 of 5.8 NTU at T3-1 which occurred during sample suite 3. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 1.7 NTU was noted at T3 during sample suite 3 (Table 4.10). When the average of all the upstream sample sites for all three sample suites (daily average) was compared with the average of all the downstream sample sites for all three sample suites (daily average), the downstream was 0.3 NTU higher than the upstream (background) levels.

On December 31, 2000, three sample suites were conducted (Sample Suite 1 – morning, Sample Suite 2 – midday, Sample Suite 3 – early evening) at all of the sampling sites along each of the four transects (T5 inaccessible due to ice conditions) (Table 4.10, Figure 4.26). Triplicate measurements were taken at and averaged for each sample site. A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for December 31 of 511 NTU at T3-1 which occurred during sample suite 2. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 110.6 NTU was noted at T3 during sample suite 2 (Table 4.10). When the average of all the upstream sample sites for all three sample suites (daily average) was compared with the average of all the downstream sample sites for all three sample suites (daily average), the downstream was 24.3 NTU higher than the upstream (background) levels. This was a significant increase.

On January 1, 2001, three sample suites were conducted (Sample Suite 1 – morning, Sample Suite 2 – midday, Sample Suite 3 – early evening) at all of the sampling sites along each of the four transects (T5 was inaccessible during sample suites 1 and 2 due to ice conditions) (Table 4.10, Figure 4.27). Triplicate measurements were taken at and averaged for each sample site. A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for January 1 of 122.4 NTU at T3-1 which occurred during sample suite 3. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 27.4 NTU was noted at T3 during sample suite 3 (Table 4.10). When the average of all the upstream sample sites for all three sample suites (daily average) was compared with the average of all the downstream sample sites for all three sample suites (daily average), the downstream was 6.9 NTU higher than the upstream (background) levels. This had decreased significantly from the prior day of monitoring.

On January 2, 2001, three sample suites were conducted (Sample Suite 1 – morning, Sample Suite 2 – midday, Sample Suite 3 – early evening) at all of the sampling sites along each of the five transects (Table 4.10, Figure 4.28). Triplicate measurements were taken at and averaged for each sample site. A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for January 2 of 2.7 NTU at T3-1 which occurred during sample suite 3. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 1.0 NTU was noted at T3 during sample suite 3 (Table 4.10). When the average of all the upstream sample sites for all three sample suites (daily average) was compared with the average of all the downstream sample sites for all three sample suites (daily average), the downstream was 0.6 NTU higher than the upstream (background) levels.

The upstream versus downstream turbidity levels during this project period did exhibit significant differences particularly on December 31, 2000 and January 1, 2001 (Figure 4.29). The elevated levels persisted for approximately 12 to 18 hours. Monitoring in the morning of January 1 indicated only slightly elevated turbidity levels. Later on January 1, the turbidity levels increased again particularly at Transect 3; however, the elevated levels declined to near normal (equal between upstream and downstream transects) by the morning of January 2. The initial increased turbidity levels on December 31 were the direct result of a human error during the removal of berm materials where some clay materials were left instream and, consequently, heavy equipment entered the channel to remove these materials. As a result of the error and since the earth material being removed from the east berm was being used in the construction of the west berm, after the turbidity levels had reduced from the instream removal, the levels increased again on January 1 due to the use of the material that was likely too saturated. The increased levels were measured promptly and equipment operators were given feedback to make technique and method changes to swiftly reduce the sediment sources. Following completion of the instream work on January 2, the turbidity levels indicated little or no difference between upstream and downstream levels.

Table 4.10. Turbidity (NTU) monitoring results for the case history during the December 2000 – January 2001 period.

Sampling Date	Sample Suite or Averaging Description	Turbidity (NTU) Transect Average				
		T-1 UPS	T-2 DWS	T-3 DWS	T-4 DWS	T-5 DWS
December 29, 2000	Suite 2	3.2	3.0	2.9	2.3	
	Suite 3	2.4	2.4	2.8	2.3	
	Daily Transect Average	2.8	2.7	2.8	2.3	
	Daily UPS vs. DWS Average	2.8	2.6			
December 30, 2000	Suite 1	3.3	4.1	4.4	3.2	
	Suite 2	4.7	4.1	4.1	4.1	
	Suite 3	3.9	4.9	5.6	4.1	
	Daily Transect Average	4.0	4.4	4.7	3.8	
	Daily UPS vs. DWS Average	4.0	4.3			
December 31, 2000	Suite 1	2.8	3.2	13.6	2.8	
	Suite 2	2.9	34.8	110.6	3.0	
	Suite 3	2.5	45.6	27.0	2.7	
	Daily Transect Average	2.7	27.9	50.4	2.8	
	Daily UPS vs. DWS Average	2.7	27.0			
January 1, 2001	Suite 1	3.1	4.8	7.7	5.5	
	Suite 2	2.6	6.8	13.8	9.1	
	Suite 3	2.5	4.4	29.9	7.2	8.7
	Daily Transect Average	2.7	5.3	17.2	7.3	8.7
	Daily UPS vs. DWS Average	2.7	9.6			
January 2, 2001	Suite 1	2.3	2.8	3.2	2.9	3.0
	Suite 2	2.7	3.0	2.8	2.6	3.0
	Suite 3	2.3	2.9	3.3	3.0	3.1
	Daily Transect Average	2.4	2.9	3.1	2.8	3.1
	Daily UPS vs. DWS Average	2.4	3.0			

Sample Suite 1 – morning Sample Suite 2 - midday Sample Suite 3 - early evening.
UPS – Upstream DWS - Downstream
T – Transect T-1 – Average of T1-1, T1-2 & T1-3
T-2 – Average of T2-1, T2-2, T2-3, T2-4 & T2-5 T3 – Average of T3-1, T3-2, T3-3, T3-4 & T3-5
T4 – Average of T4-1, T4-2, T4-3, T4-4 & T4-5
T5 – Average of T5-1, T5-2 & T5-3 (Ice restrictions at times during this sampling period)

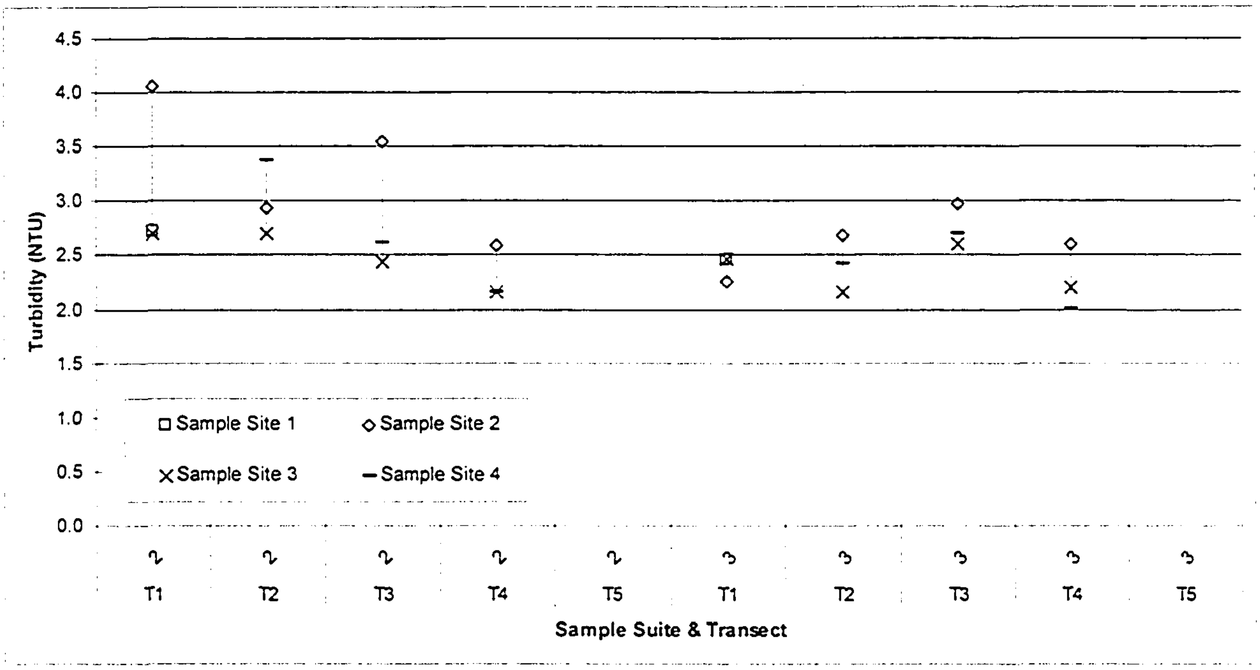

Figure 4.24. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3 & T4 – downstream) for each sample suite (2 – midday, 3 – early evening) on December 29, 2000.

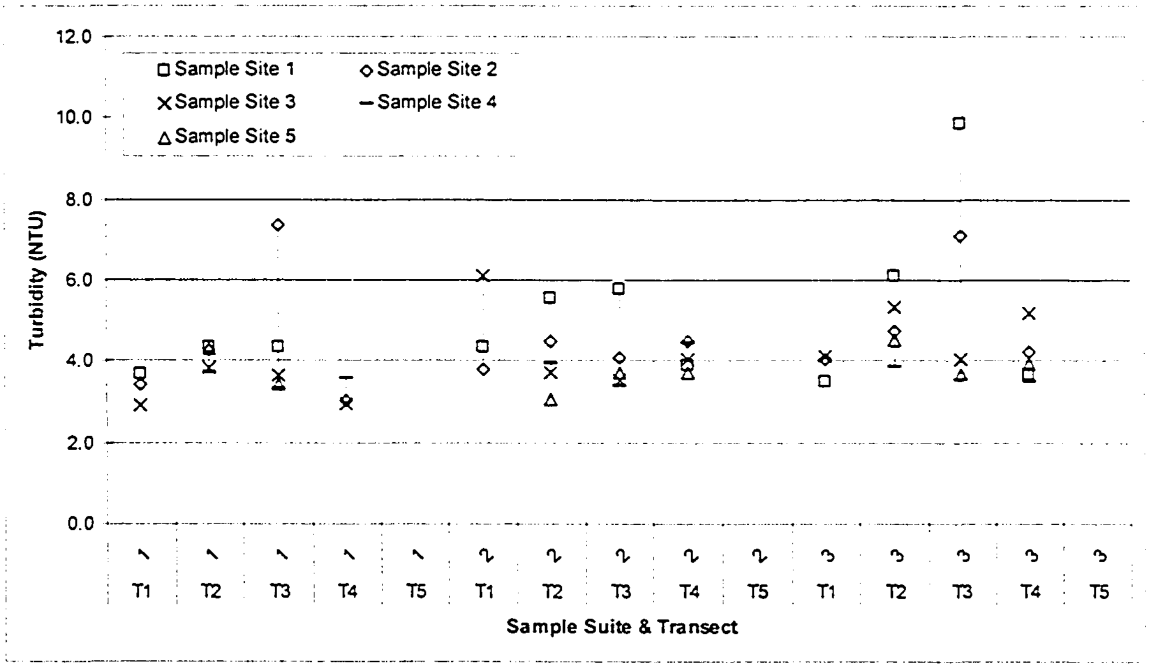

Figure 4.25. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3 & T4 – downstream) for each sample suite (1 – morning, 2 – midday, 3 – early evening) on December 30, 2000.

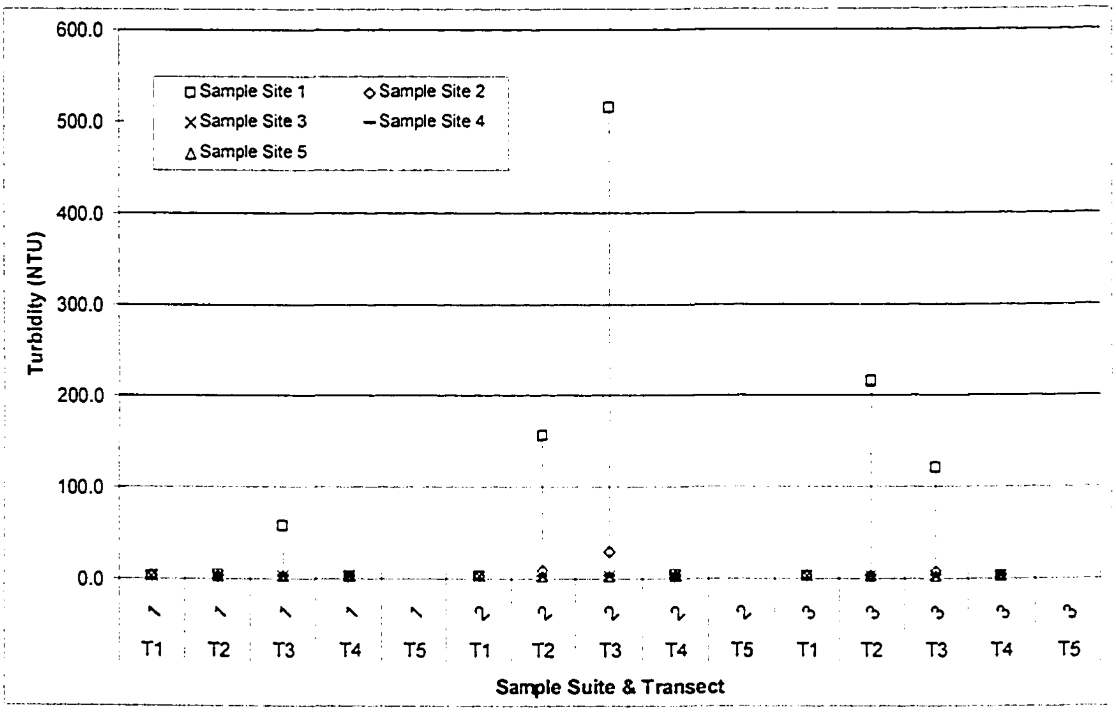

Figure 4.26. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3 & T4 – downstream) for each sample suite (1 – morning, 2 – midday, 3 – early evening) on December 31, 2000.

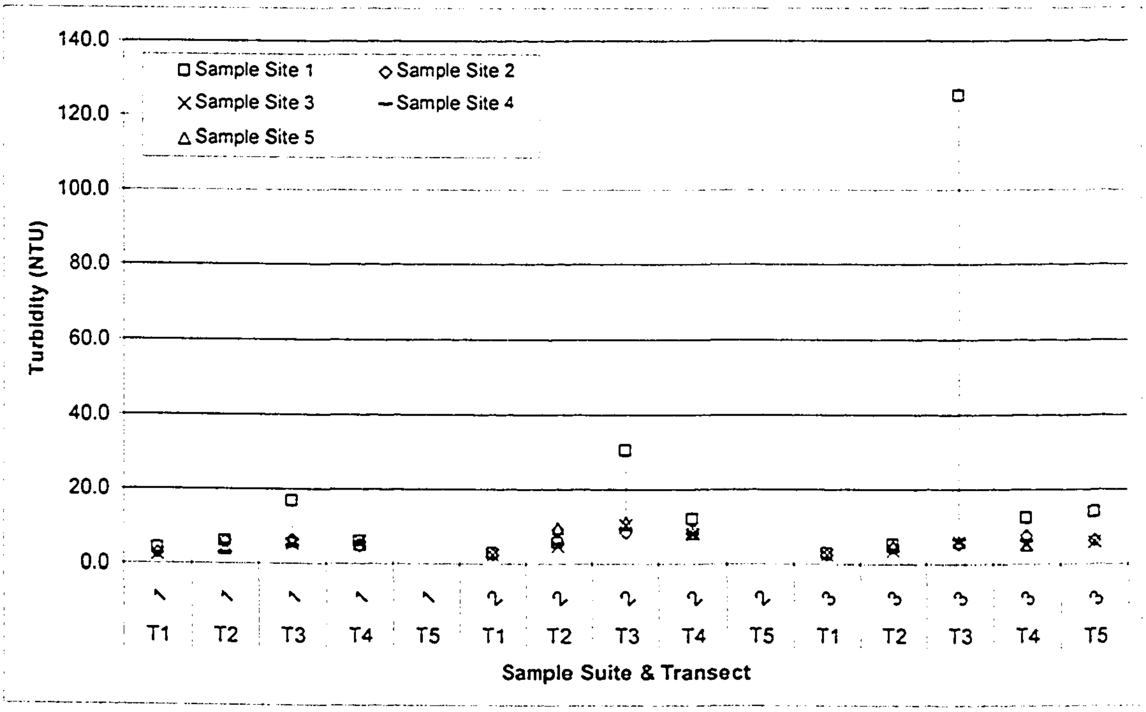

Figure 4.27. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3, T4 & T5 – downstream) for each sample suite (1 – morning, 2 – midday, 3 – early evening) on January 1, 2001.

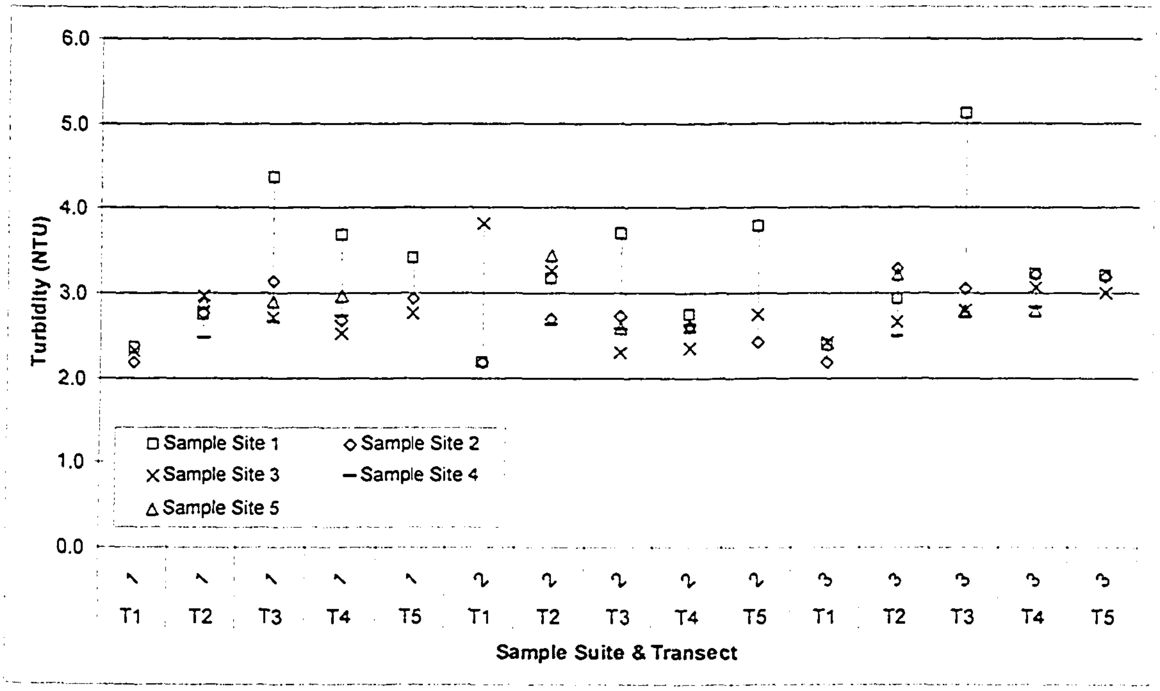

Figure 4.28. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3, T4 & T5 – downstream) for each sample suite (1 – morning, 2 – midday, 3 – early evening) on January 2, 2001.

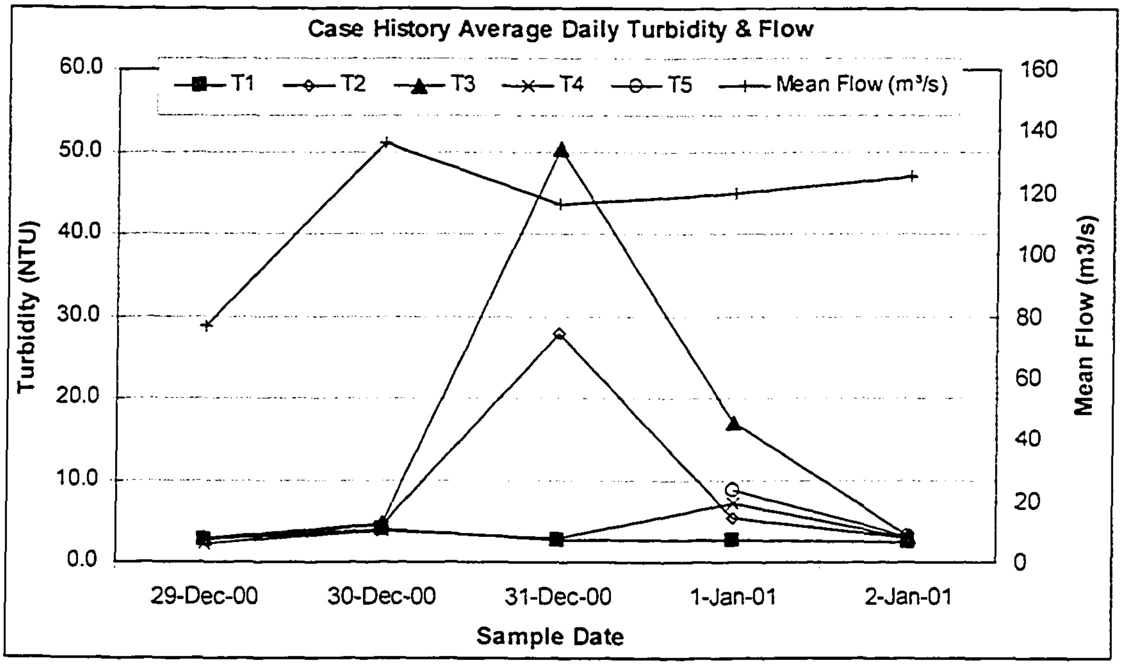

Figure 4.29. Case history daily transect average turbidity (NTU) (researcher analyzed) and mean flow (m^3/s) (from Alberta Environment's real time survey station, RNSASEDM) for the December 2000 – January 2001 period.

The mean flow (m^3/s) of the North Saskatchewan River was gathered from Alberta Environment's real-time survey station (RNSASEDM) for this monitoring period and did not appear to have a strongly similar trend to the background turbidity trend (Figure 4.29).

Overall, when comparing the averages of sample sites along transects per day, the results indicate acceptable levels based on the provincial and federal guidelines which dictate a 24-hour duration for increased turbidity. However, when comparing individual sample sites (Appendix Table F), the December 31/January 1 incident would have exceeded the 24-hour turbidity exceedence guideline at T3-1 in comparison with upstream turbidity levels.

The researcher TSS levels indicated some difference between upstream and downstream areas (Table 4.11); however, did not reflect the significant turbidity increases on December 31, 2000 and January 1, 2001. On December 29, 2000, the average TSS of the upstream transect was 23 mg/L and the average TSS level of downstream Transect 4 was 39 mg/L. On December 30, 2000, the average TSS of the upstream transect was 14 mg/L and the average TSS level of downstream Transect 4 was 33 mg/L. On December 31, 2000, the average TSS of the upstream transect was 8 mg/L and the average TSS level of downstream Transect 4 was 13 mg/L. On January 1, 2001, the average TSS of the upstream transect was 20 mg/L and the average TSS level of downstream Transect 4 was 38 mg/L. On January 2, 2001, the average TSS of the upstream transect was 43 mg/L and the average TSS level of downstream Transect 4 was 27 mg/L. These levels were within the acceptable range of the provincial and federal guidelines. No laboratory analysis of TSS was conducted during this monitoring period.

Table 4.11. Total suspended sediment (TSS) monitoring results for the case history during sample suite 2 on December 29, 30 and 31, 2000 and January 1 and 2, 2001.

Sample Date	Sample Site	Total Suspended Sediment (mg/L)	
		Researcher Analysis	*Laboratory Analysis
December 29, 2000	T1-1	36	
	T1-2	10	
	T1-3	24	
	T4-1		
	T4-2	50	
	T4-3	30	
	T4-4	36	
	T4-5		
December 30, 2000	T1-1	28	
	T1-2		
	T1-3	0	
	T4-1	66	
	T4-2	14	
	T4-3	38	
	T4-4	20	
	T4-5	28	
December 31, 2000	T1-1	14	
	T1-2		
	T1-3	2	
	T4-1	8	
	T4-2	4	
	T4-3		
	T4-4	24	
	T4-5	14	
January 1, 2001	T1-1	14	
	T1-2		
	T1-3	26	
	T4-1	40	
	T4-2	34	
	T4-3		
	T4-4	46	
	T4-5	30	
January 2, 2001	T1-1	46	
	T1-2		
	T1-3	40	
	T4-1	52	
	T4-2	22	
	T4-3		
	T4-4	20	
	T4-5	14	

T – Transect *No laboratory analysis conducted during this period.

4.4.4 March 2001 West Berm Removal

The March 2001 west berm removal consisted of 5 days of water quality monitoring (March 23, 24, 25, 26 & 27, 2001). This included 232 on-site NTU measurements, 8 laboratory NTU samples, 32 researcher TSS measurements, and 8 laboratory TSS samples (Appendix Table G).

On March 23, 2001, two sample suites were conducted (Sample Suite 1 – morning, Sample Suite 3 – early evening) at all of the sampling sites along each of the five transects (Table 4.12, Figure 4.30). Triplicate measurements were taken at and averaged for each sample site. A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for March 23 of 2.4 NTU at T2-1 which occurred during sample suite 1. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 1.5 NTU was noted at T2 during sample suite 1 (Table 4.12). When the average of all the upstream sample sites for all three sample suites (daily average) was compared with the average of all the downstream sample sites for all three sample suites (daily average), the downstream was 0.4 NTU higher than the upstream (background) levels.

On March 24, 2001, three sample suites were conducted (Sample Suite 1 – morning, Sample Suite 2 – midday, Sample Suite 3 – early evening) at all of the sampling sites along each of the five transects (Table 4.12, Figure 4.31). Triplicate measurements were taken at and averaged for each sample site. A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for March 24 of 14.4 NTU at T2-5 which occurred during sample suite 2. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 3.1 NTU was noted at T2 during sample suite 2 (Table 4.12). When the average of all the upstream sample sites for all three sample suites (daily average) was compared with the average of all the downstream sample sites for all three sample suites (daily average), the downstream was 1.2 NTU higher than the upstream (background) levels.

On March 25, 2001, three sample suites were conducted (Sample Suite 1 – morning, Sample Suite 2 – midday, Sample Suite 3 – early evening) at all of the sampling sites along each of the five transects (Table 4.12, Figure 4.32). Triplicate measurements were taken at and averaged for each sample site. A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for March 25 of 7.0 NTU at T4-5 which occurred during sample suite 3. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 1.8 NTU was noted at T4 during sample suite 3 (Table 4.12). When the average of all the upstream sample sites for all three sample suites (daily average) was compared with the average of all the downstream sample sites for all three sample suites (daily average), the downstream was 0.7 NTU higher than the upstream (background) levels.

On March 26, 2001, two sample suites were conducted (Sample Suite 1 – morning, Sample Suite 2 – midday) at all of the sampling sites along each of the five transects (Table 4.12, Figure 4.33). Triplicate measurements were taken at and averaged for each sample site. A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for March 26 of 2.2 NTU at T4-5 which occurred during sample suite 2. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 0.6 NTU was noted at T2 and T4 during sample suite 2 (Table 4.12). When the average of all the upstream sample sites for all three sample suites (daily average) was compared with the average of all the downstream sample sites for all three sample suites (daily average), the downstream was 0.3 NTU higher than the upstream (background) levels.

On March 27, 2001, one sample suite was conducted (Sample Suite 2 – midday) at all of the sampling sites along each of the five transects (Table 4.12, Figure 4.34). Triplicate measurements were taken at and averaged for each sample site. A comparison of the maximum turbidity of the three upstream sampling sites (T1-1, T1-2 & T1-3) with the turbidity measured at the individual downstream sampling sites during each sampling suite demonstrated a maximum increase for March 27 of 0.58 NTU at T2-5 which occurred during sample suite 2. When the turbidity of the sample sites along each transect was averaged and compared to the average of the upstream (T1) sample sites, the largest increase of 0.1 NTU was noted at T2 during sample suite 2 (Table 4.12). When the average of all the upstream sample sites for all three sample suites (daily average) was compared with the average of all the downstream sample sites for all three sample suites (daily average), the downstream NTU levels were less than the upstream (background) levels.

Overall, the upstream versus downstream turbidity levels during this project period exhibited little difference besides one elevated period on March 24, 2001 (Figure 4.35). However, whether comparing the individual sample sites or the averages of sample sites along transects per sample suite or the averages of transects per day, the comparison between upstream and downstream levels were within the acceptable range of the provincial and federal guidelines in light of the 24-hour duration for increased turbidity cited in the guidelines.

The mean flow (m^3/s) of the North Saskatchewan River was gathered from Alberta Environment's real-time survey station (RNSASEDM) for this monitoring period and appeared to have a similar general trend to the background turbidity trend (Figure 4.35).

Table 4.12. Turbidity (NTU) monitoring results for the case history during the March 2001 period.

Sampling Date	Sample Suite or Averaging Description	Turbidity (NTU) Transect Average				
		T-1 UPS	T-2 DWS	T-3 DWS	T-4 DWS	T-5 DWS
March 23, 2001	Suite 1	4.4	5.9	4.6	4.6	4.3
	Suite 3	7.2	7.9	7.3	7.7	7.1
	Daily Transect Average	5.8	6.9	6.0	6.2	5.7
	Daily UPS vs. DWS Average	5.8	6.2			
March 24, 2001	Suite 1	3.8	4.5	5.1	3.9	4.8
	Suite 2	5.2	8.3	5.1	6.4	6.3
	Suite 3	6.3	6.8	7.4	8.6	8.0
	Daily Transect Average	5.1	6.5	5.9	6.3	6.4
	Daily UPS vs. DWS Average	5.1	6.3			
March 25, 2001	Suite 1	3.2	3.2	3.1	3.1	3.3
	Suite 2	5.0	6.2	5.6	6.4	5.8
	Suite 3	6.6	6.7	7.8	8.4	7.6
	Daily Transect Average	4.9	5.4	5.5	6.0	5.5
	Daily UPS vs. DWS Average	4.9	5.6			
March 26, 2001	Suite 1	4.1	4.3	4.2	4.1	4.2
	Suite 2	4.8	5.4	5.2	5.4	4.8
	Daily Transect Average	4.4	4.9	4.7	4.8	4.5
	Daily UPS vs. DWS Average	4.4	4.7			
March 27, 2001	Suite 2	4.2	4.3	3.8	3.9	3.8
	Daily Transect Average	4.2	4.3	3.8	3.9	3.8
	Daily UPS vs. DWS Average	4.2	4.0			

Sample Suite 1 – morning Sample Suite 2 - midday Sample Suite 3 - early evening.
UPS – Upstream DWS - Downstream
T – Transect T-1 – Average of T1-1, T1-2 & T1-3
T-2 – Average of T2-1, T2-2, T2-3, T2-4 & T2-5 T3 – Average of T3-1, T3-2, T3-3, T3-4 & T3-5
T4 – Average of T4-1, T4-2, T4-3, T4-4 & T4-5 T5 – Average of T5-1, T5-2 & T5-3

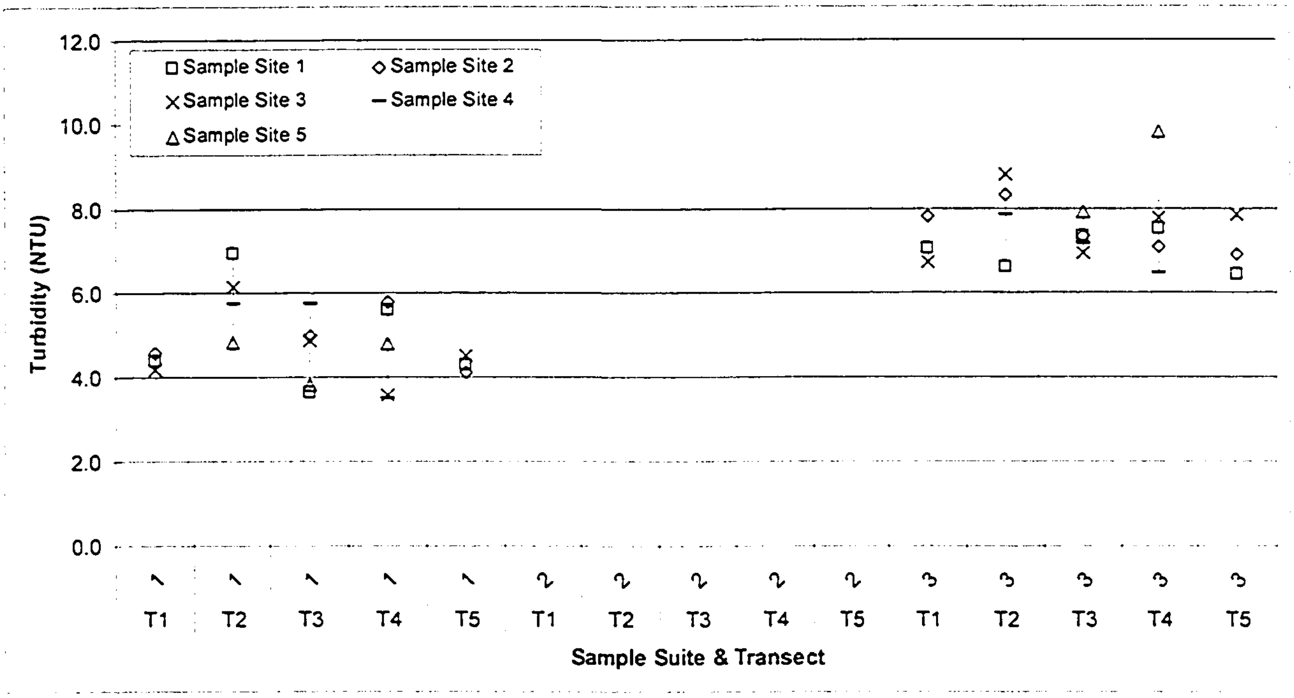

Figure 4.30. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3, T4 & T5 – downstream) for each sample suite (1 – morning, 2 – midday, 3 – early evening) on March 23, 2001.

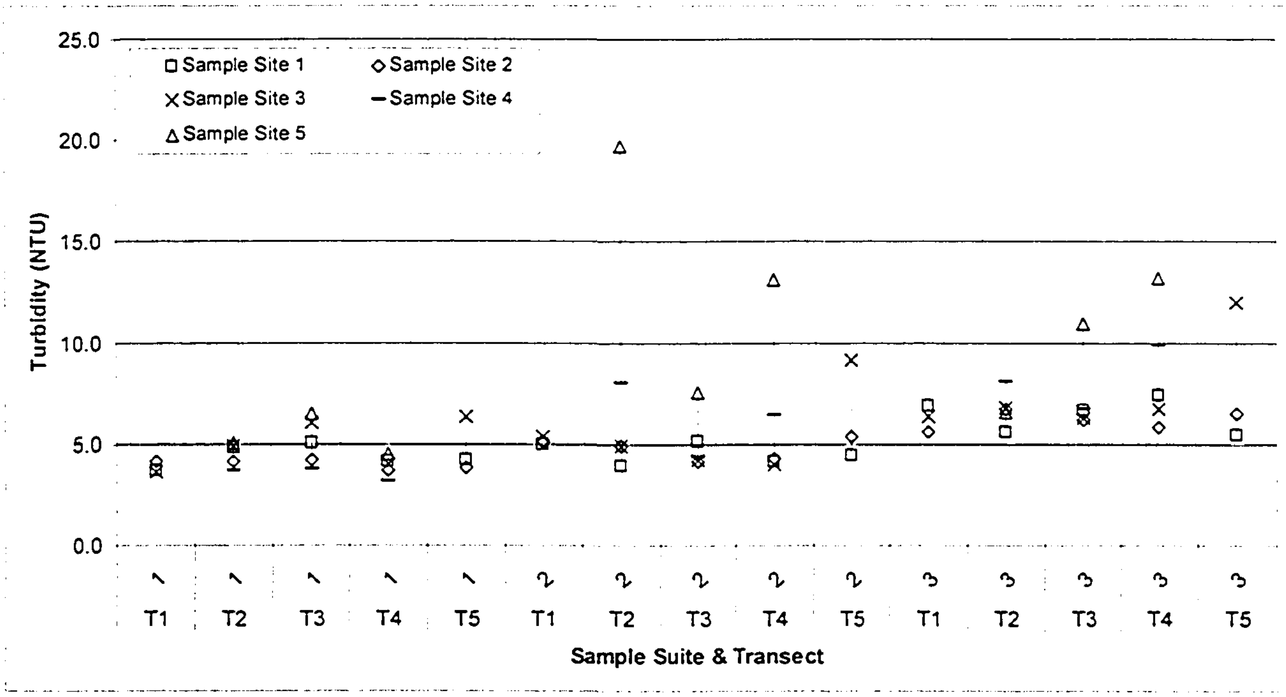

Figure 4.31. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3, T4 & T5 – downstream) for each sample suite (1 – morning, 2 – midday, 3 – early evening) on March 24, 2001.

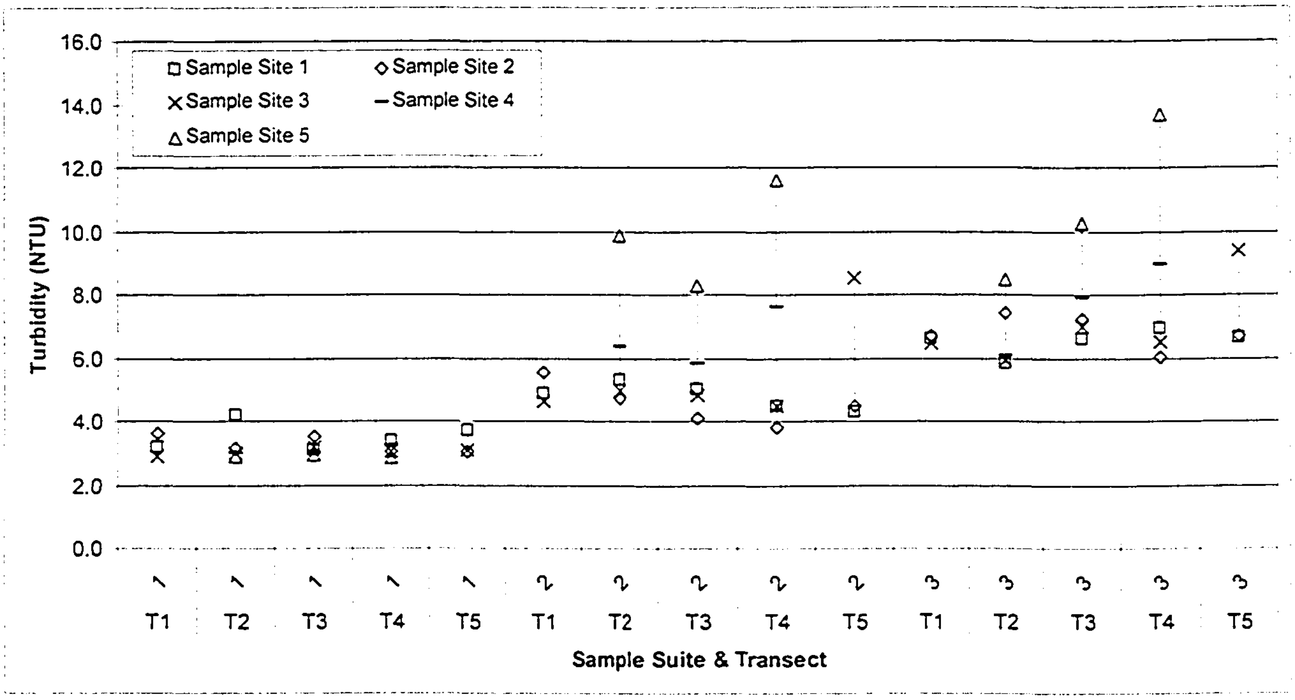

Figure 4.32. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3, T4 & T5 – downstream) for each sample suite (1 – morning, 2 – midday, 3 – early evening) on March 25, 2001.

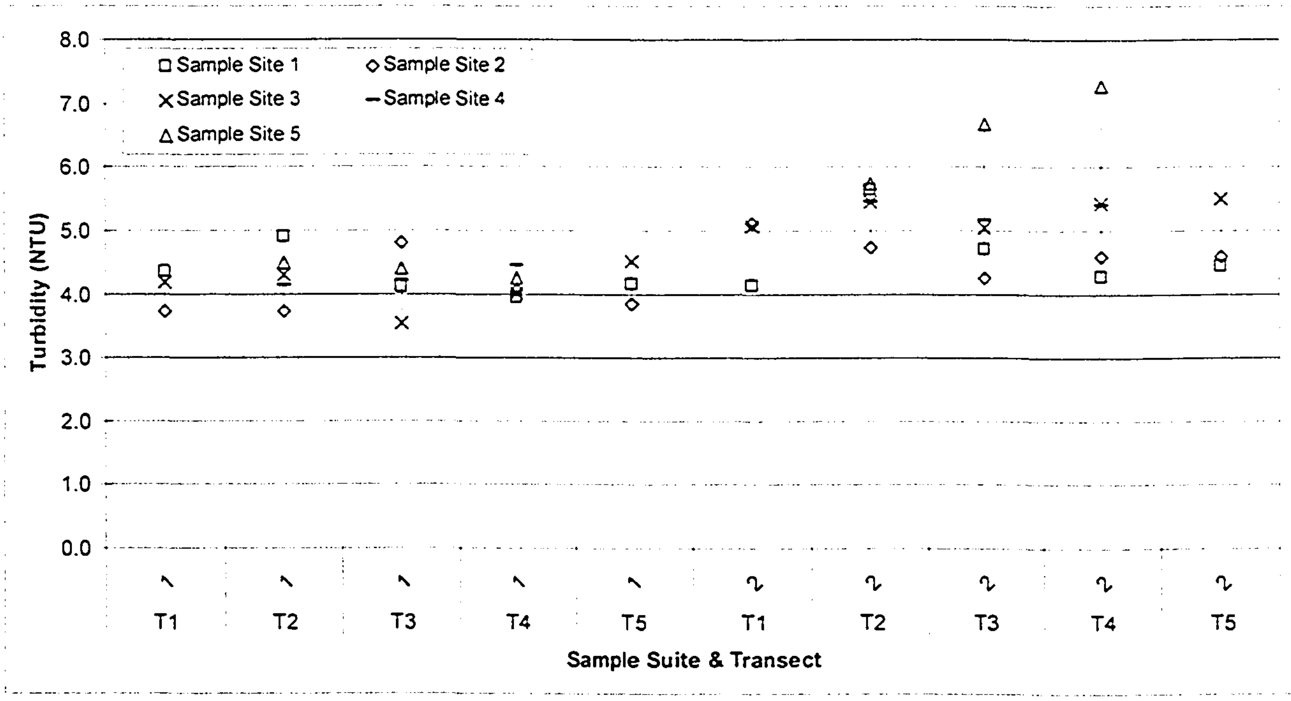

Figure 4.33. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3, T4 & T5 – downstream) for each sample suite (1 – morning, 2 – midday) on March 26, 2001.

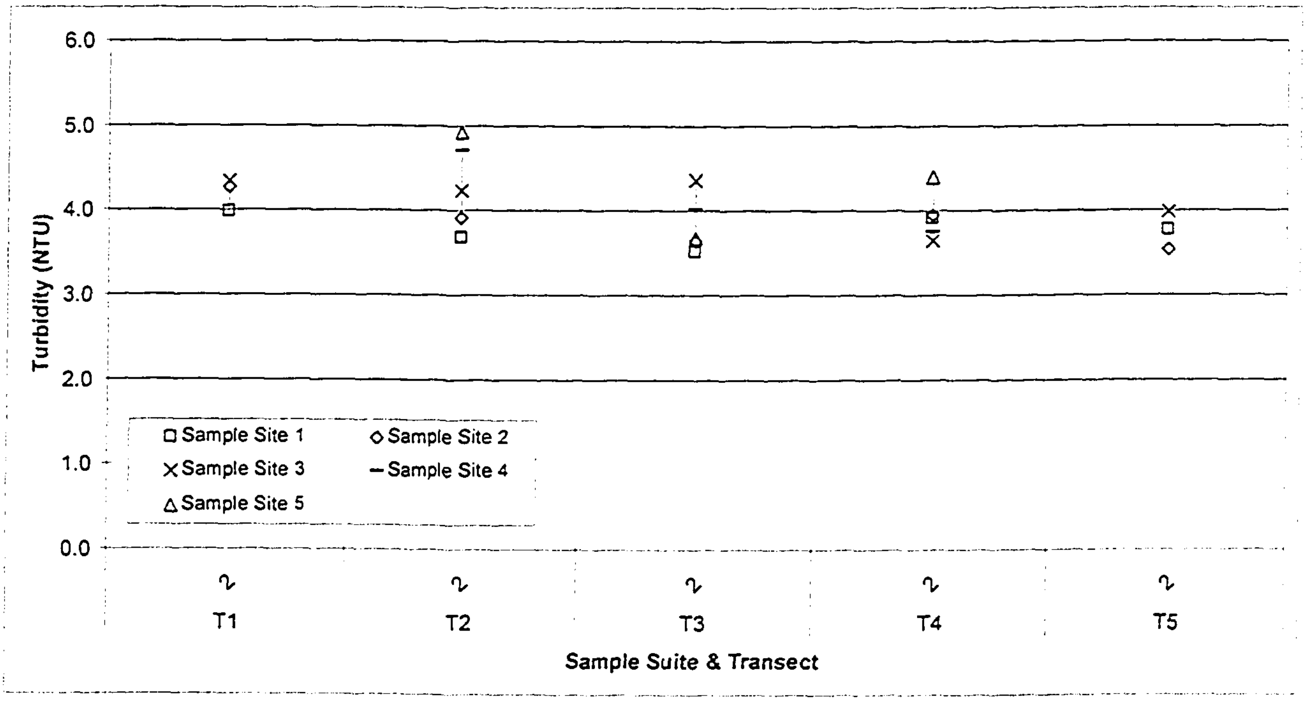

Figure 4.34. Case history turbidity (NTU) (researcher analyzed) for each sample site at each transect (T1 – upstream; T2, T3, T4 & T5 – downstream) for each sample suite (2 – midday) on March 27, 2001.

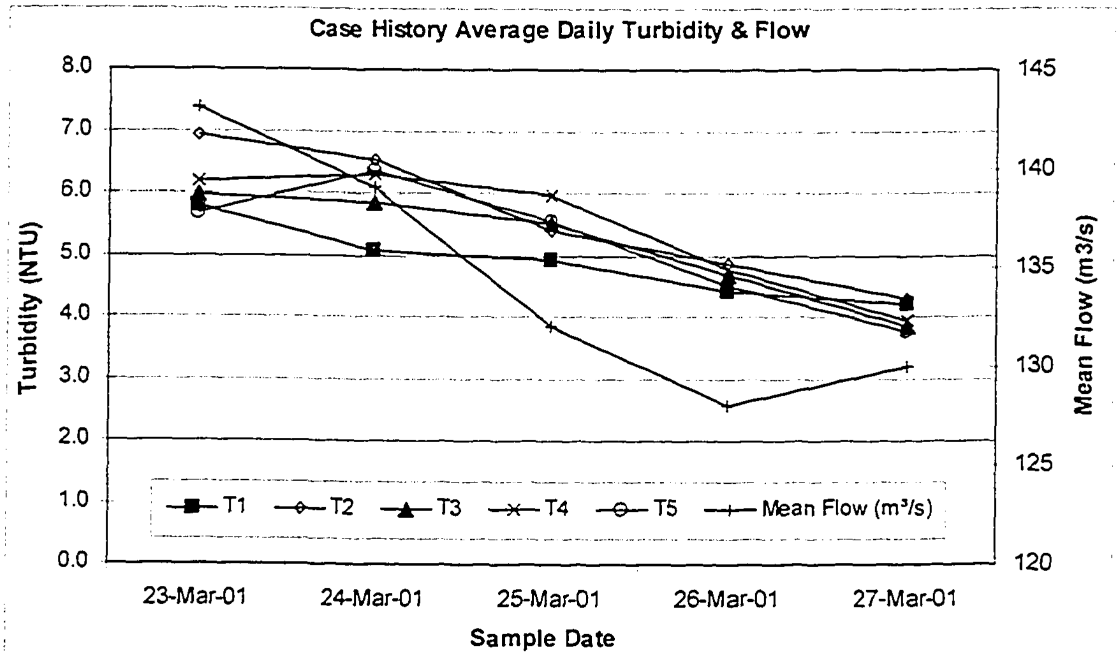

Figure 4.35. Case history daily transect average turbidity (NTU) (researcher analyzed) and mean flow (m^3/s) (from Alberta Environment's real time survey station, RNSASEDM) for the March 2001 period.

The researcher TSS levels similarly indicated little difference between upstream and downstream areas (Table 4.13). On March 23, 2001, the average TSS of the upstream transect was 39 mg/L and the average TSS level of downstream Transect 4 was 64 mg/L. On the same date, the laboratory analysis of TSS at T1-2 was 12 mg/L and 10 mg/L at T4-3. On March 24, 2001, the average TSS of the upstream transect was 20 mg/L and the average TSS level of downstream Transect 4 was 30 mg/L. On the same date, the laboratory analysis of TSS at T1-2 and T4-3 was 6 mg/L. On March 25, 2001, the average TSS of the upstream transect was 11 mg/L and the average TSS level of downstream Transect 4 was 13 mg/L. On the same date, the laboratory analysis of TSS at T1-2 was 8 mg/L and 21 mg/L at T4-3. On March 26, 2001, the average TSS of the upstream transect was 7 mg/L and the average TSS level of downstream Transect 4 was 25 mg/L. On the same date, the laboratory analysis of TSS at T1-2 was 7 mg/L and 8 mg/L at T4-3. While the March 23, 2001 TSS researcher results demonstrated a difference just slightly greater than 25 mg/L above background levels, the increase did not continue over 24 hours. Therefore, these levels were within the acceptable range of the provincial and federal guidelines.

Table 4.13. Total suspended sediment (TSS) monitoring results for the case history during sample suite 2 on March 23, 24, 25 and 26, 2001.

Sample Date	Sample Site	Total Suspended Sediment (mg/L)	
		Researcher Analysis	Laboratory Analysis
March 23, 2000	T1-1	66	
	T1-2	7	12
	T1-3	43	
	T4-1	36	
	T4-2	59	
	T4-3	56	10
	T4-4	66	
	T4-5	102	
March 24, 2000	T1-1	14	
	T1-2	22	6
	T1-3	24	
	T4-1	4	
	T4-2	13	
	T4-3	6	6
	T4-4	68	
	T4-5	59	
March 25, 2001	T1-1	8	
	T1-2	18	8
	T1-3	6	
	T4-1	10	
	T4-2	0	
	T4-3	22	21
	T4-4	22	
	T4-5	13	
March 26, 2001	T1-1	16	
	T1-2	6	7
	T1-3	0	
	T4-1	26	
	T4-2	8	
	T4-3	26	8
	T4-4	38	
	T4-5	28	

T – Transect   No laboratory analysis conducted during this period.

4.4.5 Cumulative Overview

The on-site turbidity monitored during the four monitoring periods (August 2000 – east berm construction; October 2000 – west berm construction; December 2000/January 2001 – east berm removal/west berm additional construction; March 2001 – west berm removal) is summarized in Figure 4.36.

Overall, the August, October, and March instream work displayed low levels of sediments (turbidity and total suspended sediment) that entered the North Saskatchewan River. The December/January turbidity levels did elevate above the provincial and federal guidelines for a short period of time.

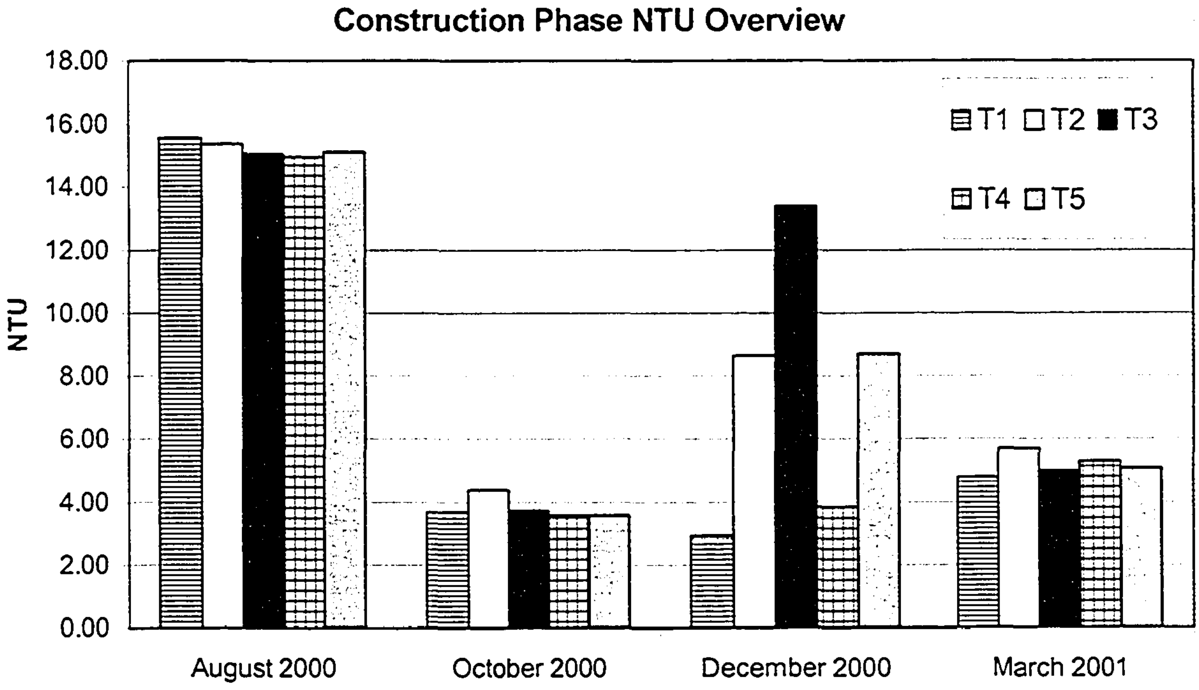

Figure 4.36. Turbidity (on-site analysis) overview for four monitoring periods of the case history project on the North Saskatchewan River in Edmonton, Alberta (values shown are averages taken for each transect over the period of the particular activity period).

CHAPTER 5

DISCUSSION OF RESULTS

The practicality of turbidity monitoring was demonstrated in the case history where turbidity monitoring was conducted across a substantial watercourse over several seasons including winter. The case history also demonstrated that clay materials can be introduced into a watercourse to create an isolated work area without exceeding environmental guidelines. However, the case history results require some discussion as they relate to the effectiveness of turbidity as a tool in mine tailings management and more specifically in regards to correlations between turbidity and TSS, laboratory versus field analysis of turbidity, point turbidity sample results versus geographically and temporally averaged results, and application of the CEQG. The following discussion examines these aspects of the effectiveness of turbidity monitoring in environmental protection and industrial development.

5.1 Turbidity and Total Suspended Sediment Correlation

The site specific relationship between turbidity and TSS was examined for the Clover Bar Bridge Construction case history. The purpose for examining the TSS/NTU relationship is to establish the site-specific relationship between turbidity and TSS and to test the validity of the current standards set by the CEQG and ASWQG that base NTU limits on TSS limits. The data used in the correlation examination included the upstream and downstream samples for which turbidity was analyzed both by the researcher on-site and external laboratory and further for which TSS was analyzed both by the researcher and external laboratory during the August, October and March periods (Table 5.1). All of the samples used in the examination were collected during the midday (suite 2) sampling.

For the case history, turbidity (NTU) samples were analyzed on-site immediately following collection and random duplicate samples for some of the sampling sites were sent to an accredited laboratory for turbidity (NTU) analysis for comparison purposes. Further, TSS analysis of random samples was conducted by the field researcher in addition to duplicate samples sent to an accredited laboratory for TSS analysis. The results of the field and laboratory NTU and TSS samples are provided in Table 5.1 and Figure 5.1.

Table 5.1. Comparison of field and laboratory results for total suspended sediment (TSS) and turbidity (NTU) measured during sample suite 2 (midday) during the case history on the North Saskatchewan River near Edmonton, Alberta.

Date	*Transect* – Sampling Site Location	Field Turbidity (NTU)	Lab Turbidity (NTU)	Field TSS (mg/L)	Lab TSS (mg/L)
4-Aug-00	T1-1	8.57	5.7	40	8
4-Aug-00	T1-2	10.83	6.5	5	18
4-Aug-00	T1-3	12.57	4.4	5	26
4-Aug-00	T4-1	9.26	2.6	5	16
4-Aug-00	T4-2	9.49	6.2	5	22
4-Aug-00	T4-3	10.63	3.6	20	25
4-Aug-00	T4-4	10.88	5.5	20	28
4-Aug-00	T4-5	11.3	3.4	20	26
23-Oct-00	T1-2	6.27	5.3	0	6
23-Oct-00	T2-1	6.14	6.3		6
23-Oct-00	T3-5	8.57	5.8		14
23-Oct-00	T4-4	4.84	5.8	50	9
23-Oct-00	T5-3	4.73	6.6		10
23-Mar-01	T1-2	7.82	6.1	38.5	12
23-Mar-01	T4-3	7.77	5.2	64	10
24-Mar-01	T1-2	5.14	4.5	20	6
24-Mar-01	T4-3	4	3.8	30	6
25-Mar-01	T1-2	5.55	3.2	10.7	8
25-Mar-01	T4-3	4.47	9	13.4	21
26-Mar-01	T1-2	5.13	5	7.3	7
26-Mar-01	T4-3	5.43	4.7	25.2	8

Field NTUs are average of triplicate readings.

T - Transect

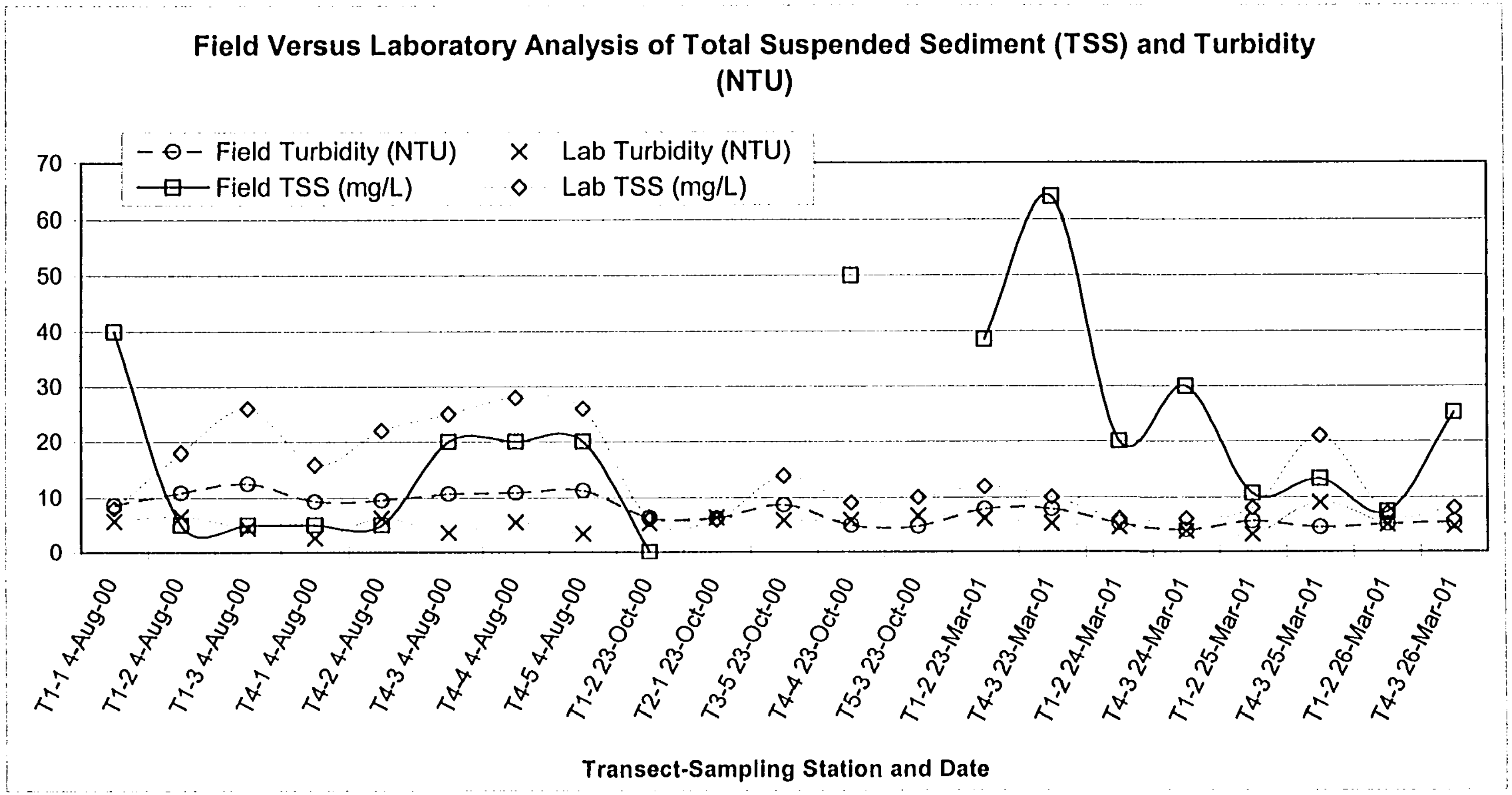

Figure 5.1. Comparison of field versus laboratory analysis of total suspended sediments (TSS) and turbidity (NTU) during sample suite 2 (midday).

For the field TSS versus the field NTU (Table 5.2; Figure 5.2; Appendix Table H), the average TSS to NTU ratio was 3.22:1. The minimum in this range of ratios was 0 and the maximum was 10.33. With the removal of the maximum outlier (10.33) from T4-4 on October 23, 2000, which was 2.09 more than the next largest ratio, the average ratio would be reduced to 2.80:1 TSS to NTU. The variance of the sample set was 11.20. Five (5) out of 18 results were less than a 1.00:1 ratio while 6 out of 18 results were greater than a 4.00:1 ratio. Therefore, 7 (38.89%) of the results were between 1:1 and 4:1 ratios. Linear regression analysis determined the correlation coefficient between field TSS and field NTU to be -0.22.

For the laboratory TSS versus the field NTU (Table 5.2; Figure 5.3 a, b, c & d; Appendix Table I), the average TSS to NTU ratio was 1.81:1. The minimum ratio contributing to this average was 0.93 and the maximum was 4.70. The variance of the sample set was 1.02. Three (3) out of 21 results were less than a 1.00:1 ratio while 1 out of the 21 results were greater than a 4.00:1 ratio. Therefore, 17 (80.95%) of the results were between the 1:1 and 4:1 ratios. Linear regression analysis determined the correlation coefficient between laboratory TSS versus field NTU to be 0.78.

For the laboratory TSS versus the laboratory NTU (Table 5.2; Figure 5.4; Appendix Table J), the average ratio was 2.94:1 TSS to NTU. The minimum ratio contributing to this average was 0.95 and the maximum was 7.65. The variance of the sample set was 5.13. One (1) out of 21 results was less than a 1.00:1 ratio while 5 out of the 21 results were greater than a 4.00:1 ratio. Therefore, 15 (71.43%) of the results were between the 1:1 and 4:1 ratios. Linear regression analysis determined the correlation coefficient between laboratory TSS versus laboratory NTU to be 0.00.

For the field TSS versus the laboratory NTU (Table 5.2; Figure 5.5; Appendix Table K), the average ratio was 4.33:1 TSS to NTU. The minimum ratio contributing to this average was 0.00 and the maximum was 12.31. The variance of the sample set was 14.48. Three (3) out of 18 results were less than a 1.00:1 ratio while 9 out of the 18 results were greater than a 4.00:1 ratio. Therefore, 6 (33.33%) of the results were between the 1:1 and 4:1 ratios. Linear regression analysis determined the correlation coefficient between field TSS versus laboratory NTU to be 0.08.

With a correlation coefficient of 0.78, the laboratory TSS to field NTU relationship was determined to be the most linear. A linear correlation was tested to determine the validity of the CEQG 3 to 1 TSS to NTU correlation. Further, since one of the premises of the effectiveness of the turbidity measure is its practicality and ease of use, linear analysis was chosen to further test the straightforwardness and practicality of the NTU correlation to TSS. Ultimately, the results of the linear analysis support previous literature which determined greater accuracy of correlations was found where field instrumentation rather than laboratory analysis for turbidity measurement was utilized (Lammerts van Bueren, 1983; Gippel, 1989a).

The results of the linear correlation graphing portrays the limitations in the field TSS analysis. The results of the field analysis (temporary laboratory) of TSS were inconsistent with the laboratory analysis of TSS (Norwest Labs). While there could be possibility of error in the laboratory analysis, it is concluded that the field analysis was subject to error and inconsistency in the analysis methodology. Despite these results, it is still believed that analysis of TSS in a temporary laboratory such as developed by the researcher, could still have merit and be more accurate with improved methods of drying and filtration.

While the field TSS versus field NTU was the closest on average to a 3 to 1 TSS to NTU ratio, the scattering of the data was greater than that of the laboratory TSS to field NTU which presented an average ratio of 1.81:1 (Figure 5.6). This suggests that the laboratory TSS and field NTU methodologies were the most accurate and consistent and that the TSS to NTU relationship for the case history location was closer to 2 to 1 rather than 3 to 1 TSS to NTU. However, when the ratios determined for field TSS versus field NTU, field TSS versus lab NTU, lab TSS versus field NTU and lab TSS versus lab NTU are all averaged, the result is 3.08:1 TSS to NTU.

In light of some recommendations for the use of a logarithmic relationship between TSS and NTU (Lloyd et al 1987), this type of relationship was tested for the laboratory TSS to field NTU (Figures 5.3c and 5.3d). Turbidity (NTU) was plotted against the natural log of TSS. The resulting scatter plots (Figure 5.3c - with the outlier and Figure 5.3d without the outlier) with a logarithmic curve demonstrated an excellent fit.

Table 5.2. Comparison of field and laboratory ratios for total suspended sediment (TSS) and turbidity (NTU) analyses during the case history on the North Saskatchewan River near Edmonton, Alberta.

Date	Transect – Sampling Site Location	Field TSS (mg/L) / Field Turbidity (NTU)	Laboratory TSS (mg/L) / Field Turbidity (NTU)	Laboratory TSS (mg/L) / Laboratory Turbidity (NTU)	Field TSS (mg/L) / Laboratory Turbidity (NTU)
4-Aug-00	T1-1	4.67	0.93	1.40	7.02
4-Aug-00	T1-2	0.46	1.66	2.77	0.77
4-Aug-00	T1-3	0.40	2.07	5.91	1.14
4-Aug-00	T4-1	0.54	1.73	6.15	1.92
4-Aug-00	T4-2	0.53	2.32	3.55	0.81
4-Aug-00	T4-3	1.88	2.35	6.94	5.56
4-Aug-00	T4-4	1.84	2.57	5.09	3.64
4-Aug-00	T4-5	1.77	2.30	7.65	5.88
23-Oct-00	T1-2	0.00	0.96	1.13	0.00
23-Oct-00	T2-1		0.98	0.95	0.00
23-Oct-00	T3-5		1.63	2.41	0.00
23-Oct-00	T4-4	10.33	1.86	1.55	8.62
23-Oct-00	T5-3		2.11	1.52	0.00
23-Mar-01	T1-2	4.92	1.53	1.97	6.31
23-Mar-01	T4-3	8.24	1.29	1.92	12.31
24-Mar-01	T1-2	3.89	1.17	1.33	4.44
24-Mar-01	T4-3	7.50	1.50	1.58	7.89
25-Mar-01	T1-2	1.93	1.44	2.50	3.34
25-Mar-01	T4-3	3.00	4.70	2.33	1.49
26-Mar-01	T1-2	1.42	1.36	1.40	1.46
26-Mar-01	T4-3	4.64	1.47	1.70	5.36
Average Ratio		**3.22:1 (TSS:NTU)**	**1.81:1 (TSS:NTU)**	**2.94:1 (TSS:NTU)**	**4.33:1 (TSS:NTU)**

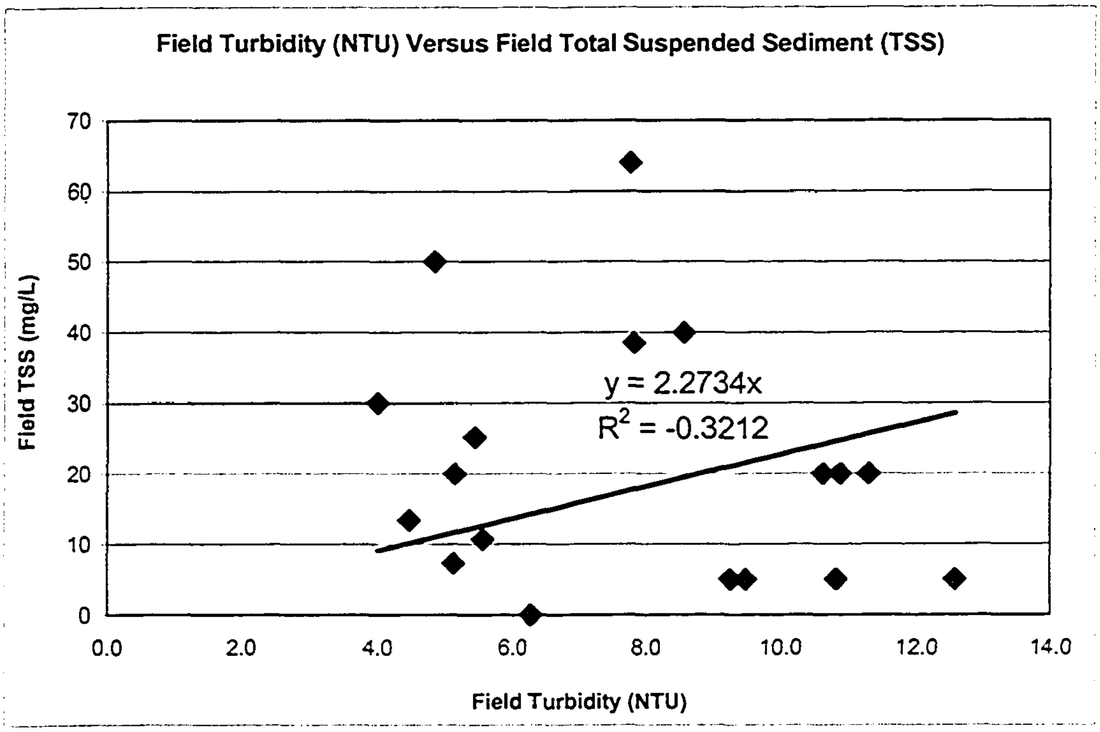

Figure 5.2. Linear correlation of case history field turbidity (NTU) versus field total suspended sediment (TSS) from various transects on August 4 and October 23, 2000 and March 23 – 26, 2001 (see Table 5.1 for data).

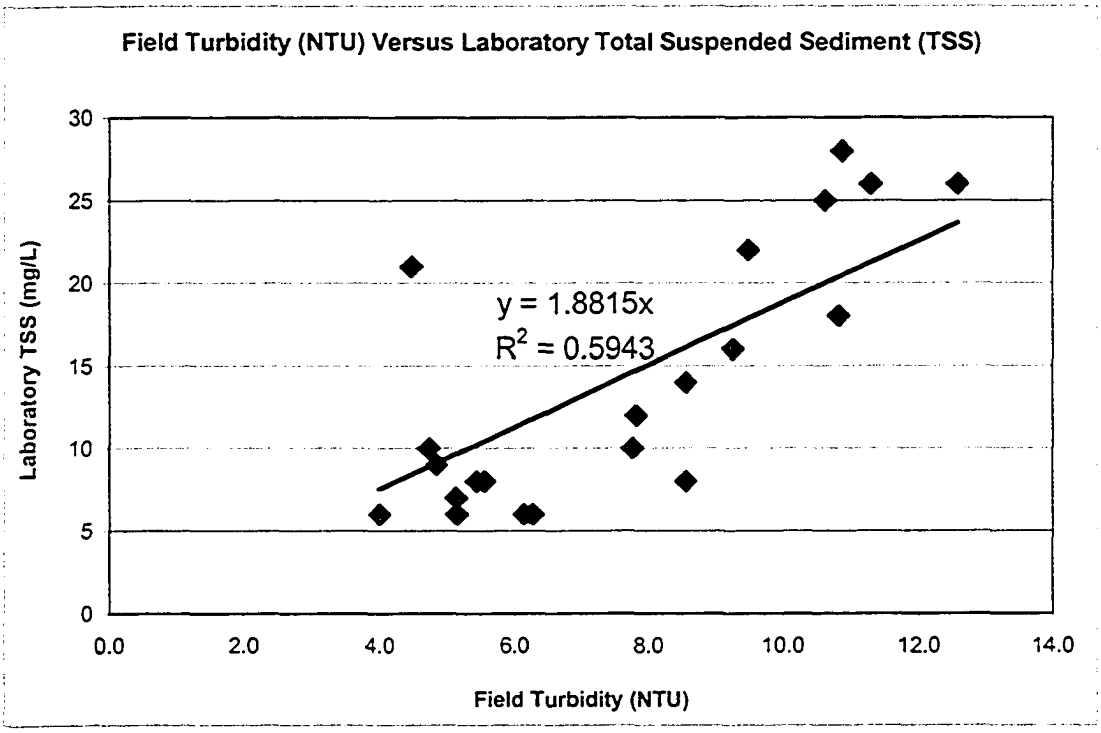

Figure 5.3a. Linear correlation of case history field turbidity (NTU) versus laboratory total suspended sediment (TSS) from various transects on August 4 and October 23, 2000 and March 23 – 26, 2001 (see Table 5.1 for data).

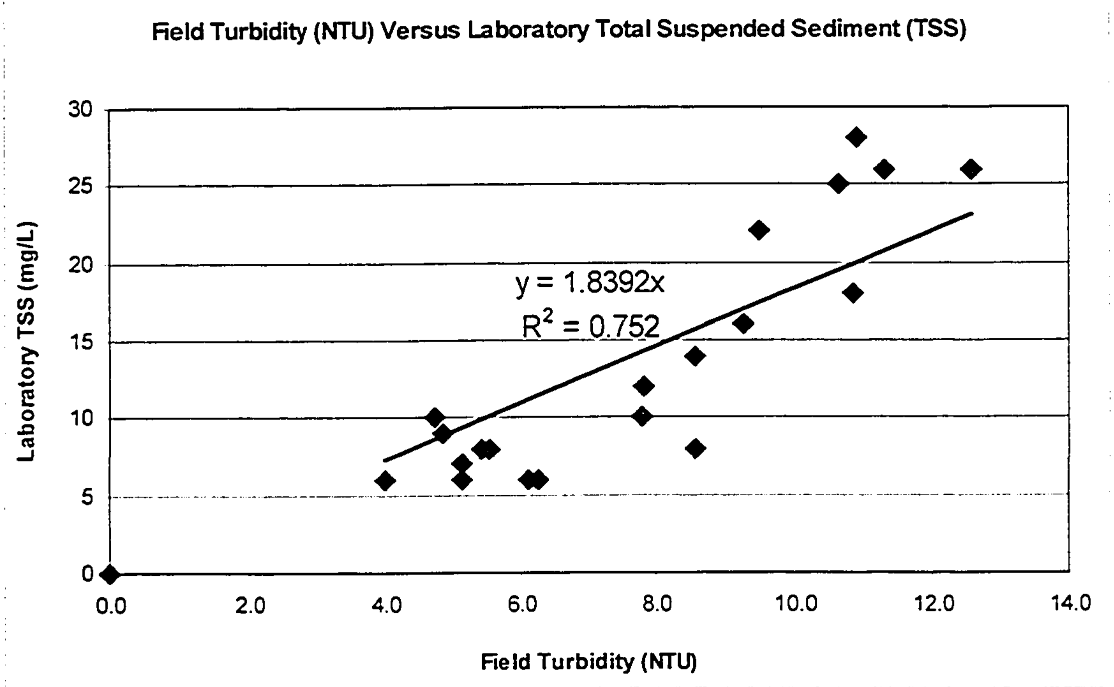

Figure 5.3b. Linear correlation of case history field turbidity (NTU) versus laboratory total suspended sediment (TSS) from various transects on August 4 and October 23, 2000 and March 23 – 26, 2001 with removal of outlier (see Table 5.1 for data).

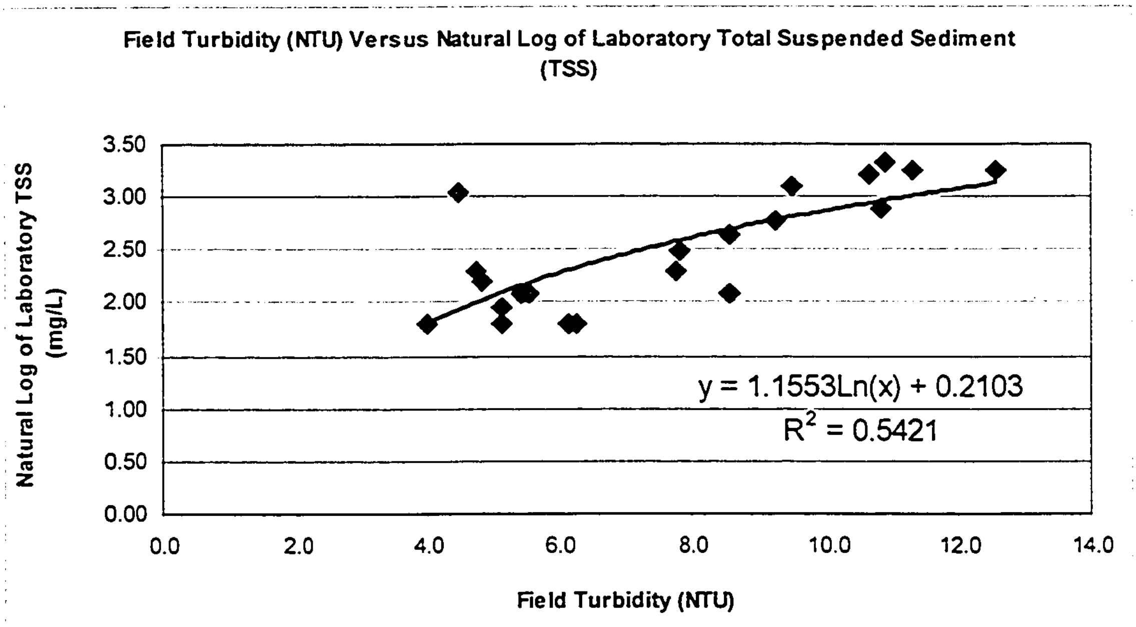

Figure 5.3c. Logarithmic correlation of case history field turbidity (NTU) versus laboratory total suspended sediment (TSS) from various transects on August 4 and October 23, 2000 and March 23 – 26, 2001 (see Table 5.1 for data).

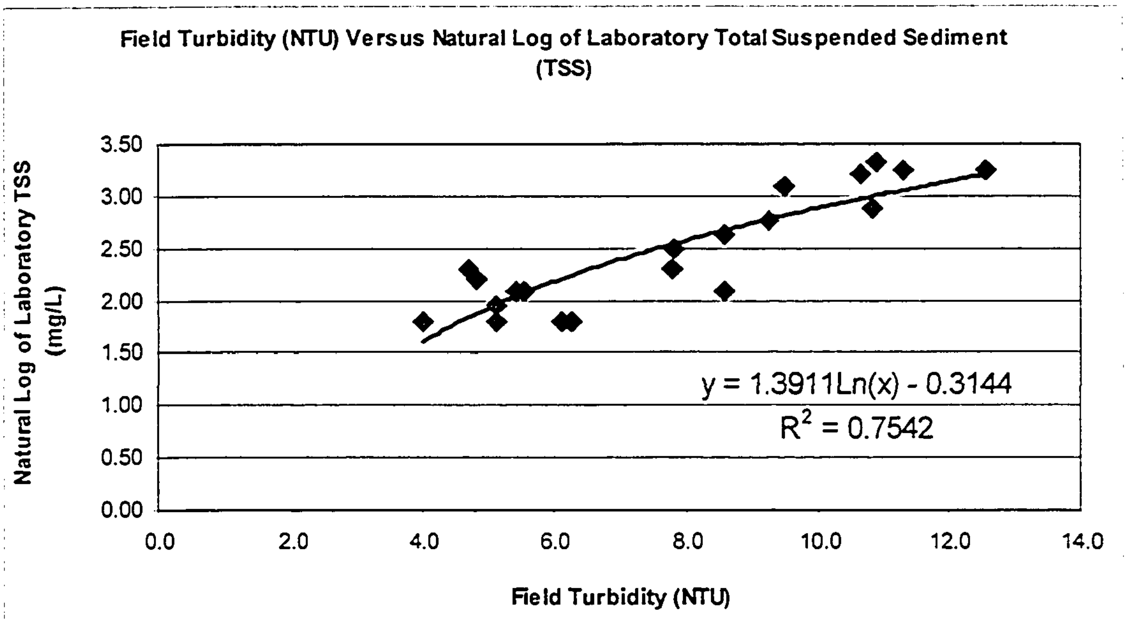

Figure 5.3d. Logarithmic correlation of case history field turbidity (NTU) versus laboratory total suspended sediment (TSS) from various transects on August 4 and October 23, 2000 and March 23 – 26, 2001 with removal of outlier (see Table 5.1 for data).

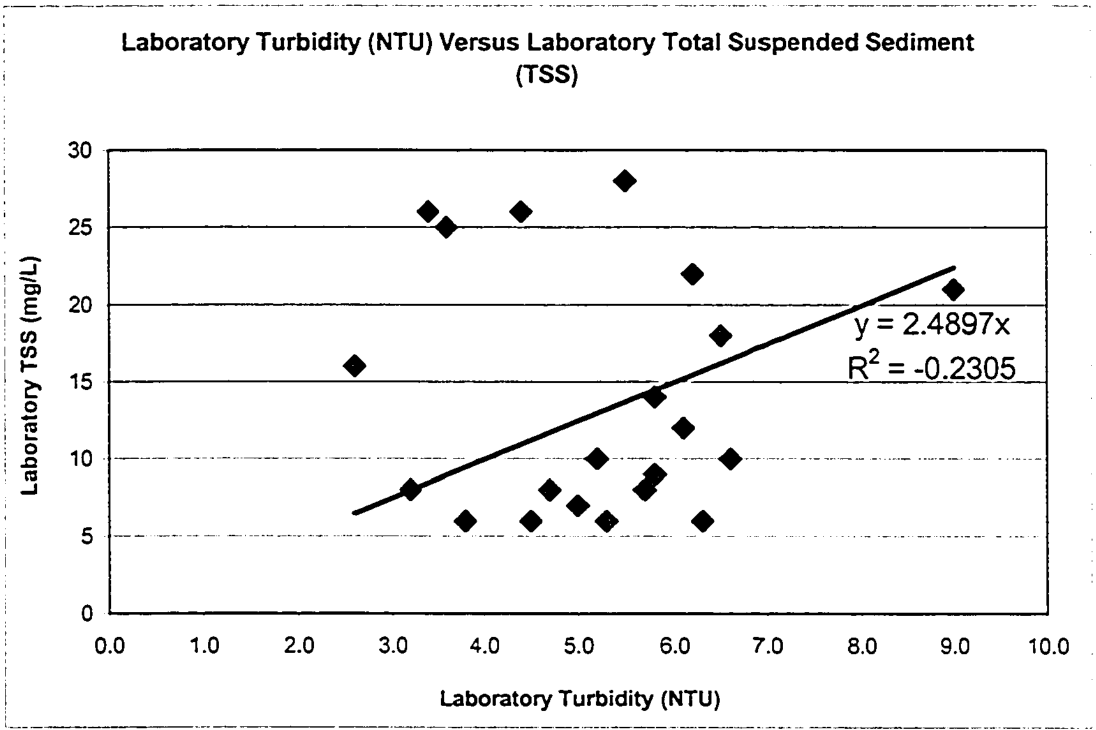

Figure 5.4. Linear correlation of case history laboratory turbidity (NTU) versus laboratory total suspended sediment (TSS) from various transects on August 4 and October 23, 2000 and March 23 – 26, 2001 (see Table 5.1 for data).

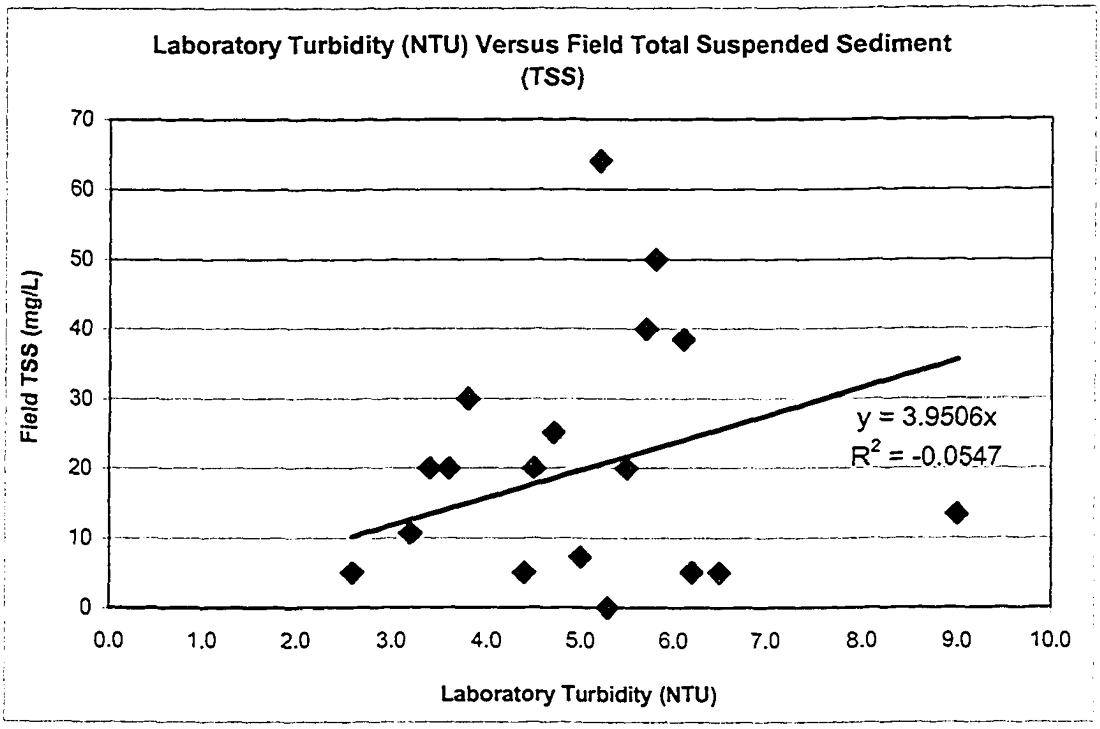

Figure 5.5. Linear correlation of case history laboratory turbidity (NTU) versus field total suspended sediment (TSS) from various transects on August 4 and October 23, 2000 and March 23 – 26, 2001 (see Table 5.1 for data).

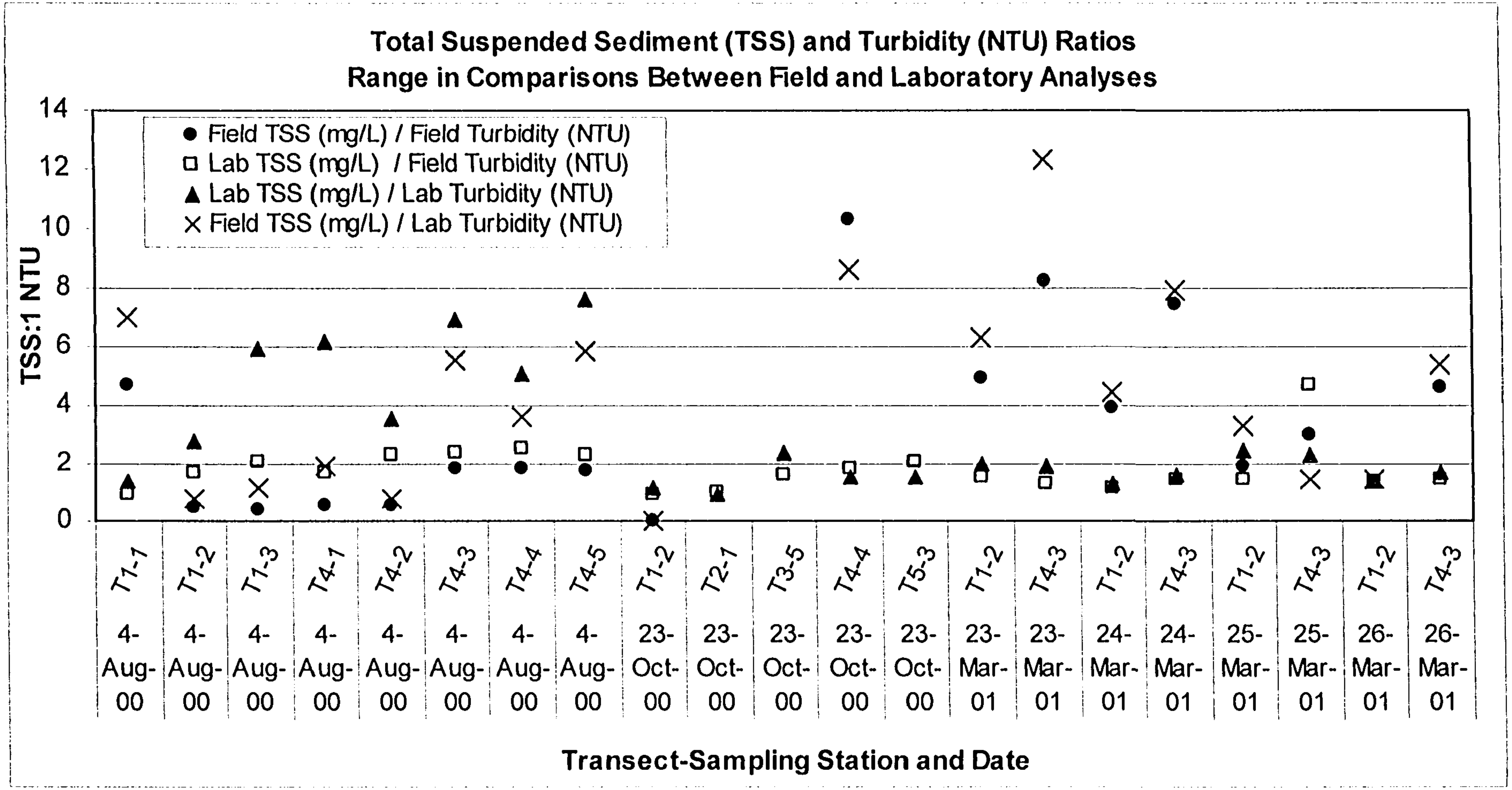

Figure 5.6. Comparison of total suspended sediment (TSS) and turbidity (NTU) ratios, range in comparisons between field and laboratory analyses.

5.2 Laboratory Versus Field Analysis of Turbidity (NTU)

Table 5.3 provides a comparison of repeated analysis of turbidity measurements of randomly selected samples gathered in conjunction with the Clover Bar Bridge Replacement Project. The samples were gathered from the August, October and March sampling periods. The data used in the examination of laboratory versus field analysis included upstream and downstream samples for which turbidity was analyzed both by the researcher on-site and external laboratory (Table 5.1). All of the samples used in the examination were collected during the midday (suite 2) sampling.

Table 5.3. Comparison of case history field and laboratory results for turbidity (NTU) from various dates and from sample suite 2 (midday) on the North Saskatchewan River near Edmonton, Alberta.

Date	Transect – Sampling Site Location	Field Turbidity (NTU)	Laboratory Turbidity (NTU)	Difference (Field NTU minus Laboratory NTU)
4-Aug-00	T1-1	8.57	5.7	2.87
4-Aug-00	T1-2	10.83	6.5	4.33
4-Aug-00	T1-3	12.57	4.4	8.17
4-Aug-00	T4-1	9.26	2.6	6.66
4-Aug-00	T4-2	9.49	6.2	3.29
4-Aug-00	T4-3	10.63	3.6	7.03
4-Aug-00	T4-4	10.88	5.5	5.38
4-Aug-00	T4-5	11.3	3.4	7.9
23-Oct-00	T1-2	6.27	5.3	0.97
23-Oct-00	T2-1	6.14	6.3	-0.16
23-Oct-00	T3-5	8.57	5.8	2.77
23-Oct-00	T4-4	4.84	5.8	-0.96
23-Oct-00	T5-3	4.73	6.6	-1.87
23-Mar-01	T1-2	7.82	6.1	1.72
23-Mar-01	T4-3	7.77	5.2	2.57
24-Mar-01	T1-2	5.14	4.5	0.64
24-Mar-01	T4-3	4	3.8	0.2
25-Mar-01	T1-2	5.55	3.2	2.35
25-Mar-01	T4-3	4.47	9	-4.53
26-Mar-01	T1-2	5.13	5	0.13
26-Mar-01	T4-3	5.43	4.7	0.73

Field NTUs are average of triplicate readings.

The average difference between the field derived NTU versus the laboratory analyzed samples was 3.11 NTU. Considering the CEQG and ASWQG guideline of less than 2 NTU above background over 30 days, an average difference of 3.11 NTU is significant. The maximum difference was 8.17 NTU while the minimum was 0.13 NTU. While the laboratory NTU measurements generally result in a similar trend as the field NTU measurements (Figures 5.7, 5.8 and 5.9), particularly between the upstream and downstream sampling locations, the majority of the field samples (17 of 21) were of higher NTU than the laboratory samples resulting in 81% of the field NTU measurements being higher than the laboratory NTU measurements.

Between sampling periods, the range between field and laboratory NTU analysis was different. During the August 4, 2000 period the average difference between field and laboratory NTU analysis was 5.70 NTU while it was only 1.35 NTU during the October 23, 2000 period and 1.61 NTU during the March 2001 period.

The difference in the NTU measurements between the field and laboratory could be attributed to variations in turbidimeters (Duchrow and Everhart 1971); however, many advances have been made in analysis equipment to result in less variance. Therefore, the difference in measurements between field and laboratory is more likely attributed to the delay prior to laboratory measurement versus the immediate measurement taken in the field. Laboratory turbidity measurements risk misleading results due to biodegradation, pH changes and settlement over time (Caux et al. 1997).

A 5-day delay period is standard for the laboratory that was used in the case history. However, samples can be analyzed any time during that period subsequently adding some inconsistency into the results. In the case of the August period where the difference was greater, it is unknown as to whether the delay period between sampling and analysis was longer than for the following two sampling phases.

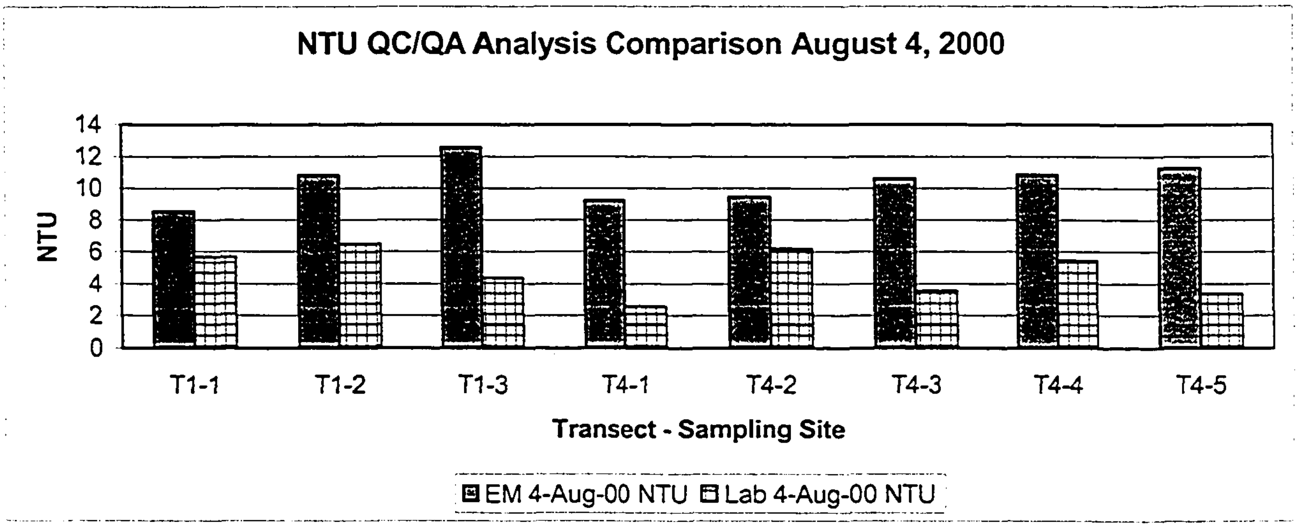

Figure 5.7. Comparison between field (EM) and laboratory (Lab) turbidity (NTU) analyses for August 4, 2000.

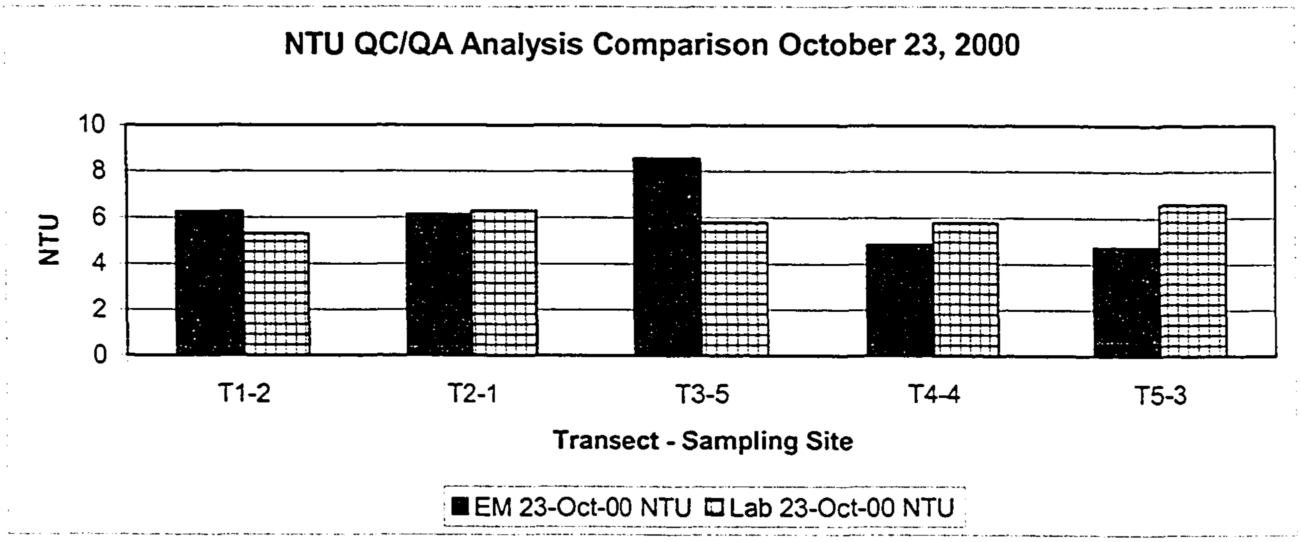

Figure 5.8. Comparison between field (EM) and laboratory (Lab) turbidity (NTU) analyses for October 23, 2000.

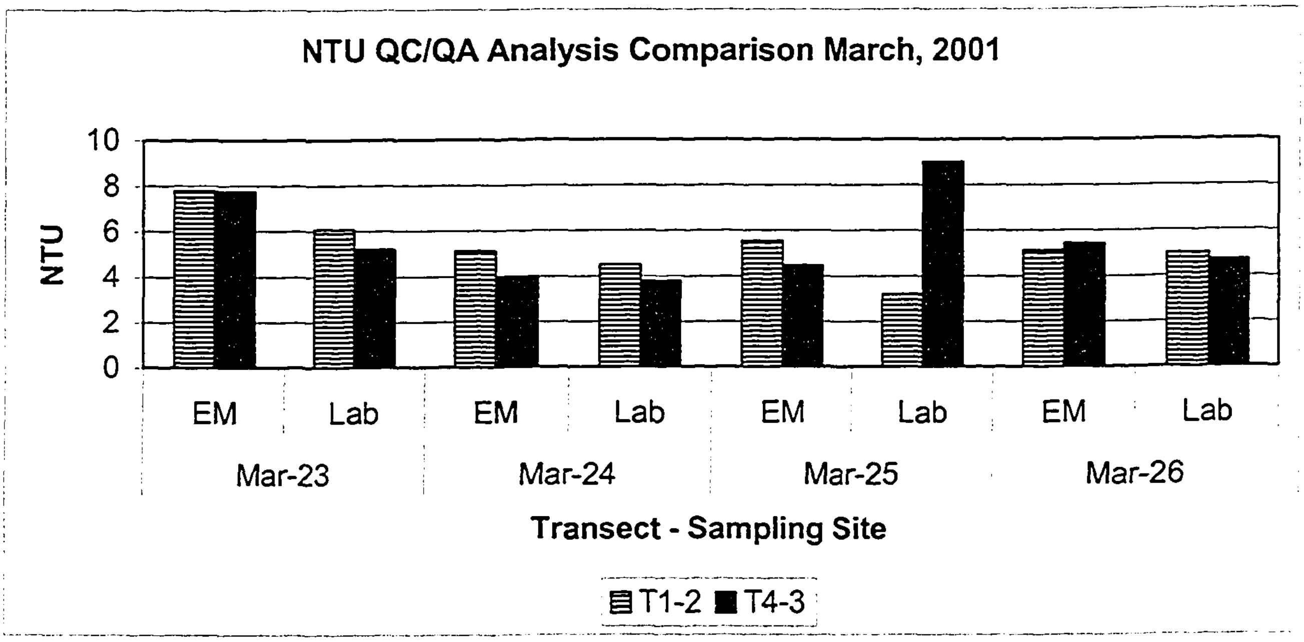

Figure 5.9. Comparison between field (EM) and laboratory (Lab) turbidity (NTU) analyses for March 2001.

Field turbidity measurements and laboratory results were compared to the NTU levels recorded at EPCOR Water Services Inc. Rossdale and EL Smith water treatment facilities. The raw (intake) water from the North Saskatchewan River was measured by EPCOR with the use of automated HACH turbidimeters. The comparison results demonstrate a high correlation with those measurements determined by the field measurements of the case history (Table 5.4 and Figure 5.10).

Table 5.4. Comparison of turbidity (NTU) measurements at EPCOR's Rossdale and EL Smith water treatment facilities to the case history field and laboratory turbidity (NTU) measurements.

Date	*EPCOR Turbidity (NTU)		Field NTU Range	Laboratory NTU Range
	Rossdale	EL Smith		
August 4, 2000	9.7	13.0	8.57 – 12.57	2.6 – 6.5
October 22, 2000	3	4	4.37 – 6.27	5.3 – 6.6
March 25, 20001	3.4	3.0	4.47 – 5.55	3.2 – 9.0

*Daily averages.

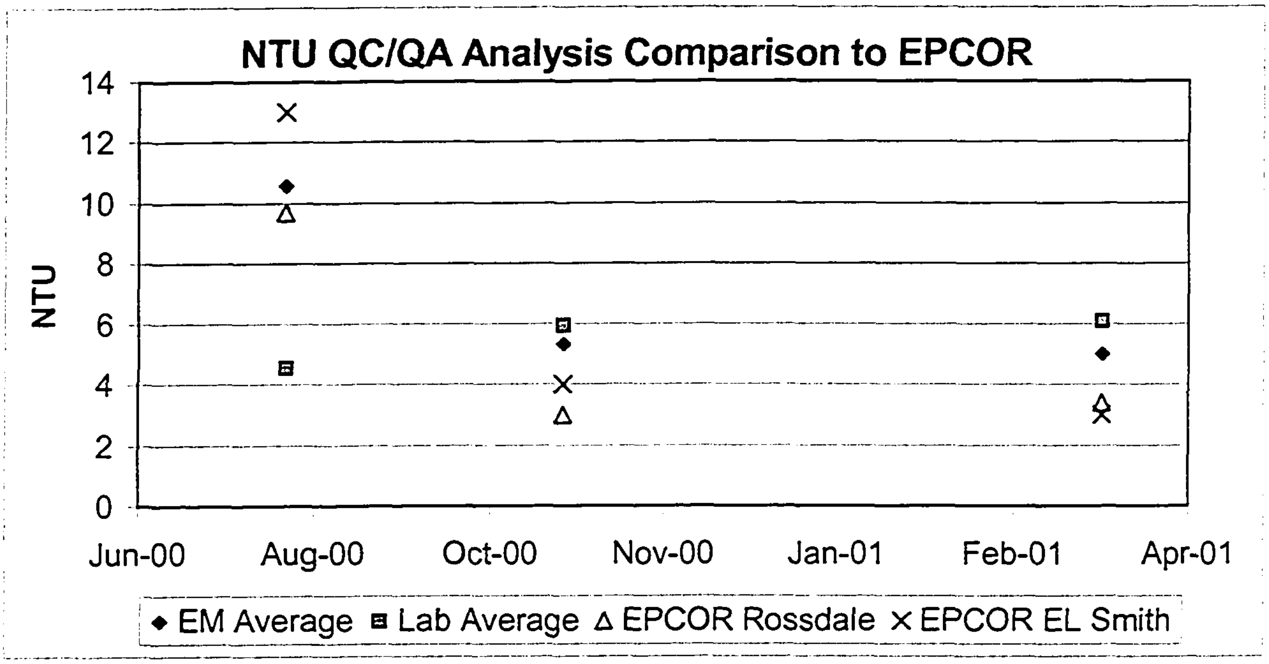

Figure 5.10. Comparison between EPCOR raw water turbidity (NTU) readings at Rossdale and EL Smith water treatment facilities and field (EM) and laboratory (Lab) turbidity (NTU) analyses during the Clover Bar Berm construction periods.

The cost to conduct field analysis of turbidity included the investment of a turbidimeter (HACH 2100P portable turbidimeter and its associated supplies approximately $1250 CND) and the cost of labour. While labour cost is variable, during the case history, the cost of the analysis would have been approximately $37.50 CND per hour. On average, the analyses of 21 samples (1 sample suite) would be conducted in less than one hour. Turbidimeters are applicable for a number of years. Laboratory turbidity (NTU) analysis at the time of this study cost approximately $11.00 CND per sample. In light of this, not taking into account labour cost which can vary widely, the capital investment of a portable turbidimeter could be recouped in less than 114 samples. During the course of the case history, 959 field turbidity samples were analyzed with the portable turbidimeter. To have had laboratory turbidity analyses of these 959 samples, the cost would have exceeded $10,500 CND. Further, laboratory total suspended sediment analysis can cost 1.6 times that of laboratory turbidity analysis at upwards of $18.00 CND per sample.

Clearly, the field turbidity analysis is far less expensive than laboratory analyses of turbidity and total suspended sediment.

5.3 CEQG Application

During the case history, the maximum differences between upstream and downstream turbidity levels (averaged across transects) ranged from 1.6 to 3.15 NTU for the August, October, and March construction periods. These were acceptable levels as stated in the federal and provincial water quality guidelines and represented low levels of sediments (turbidity and TSS) that entered the watercourse. However, the December 2000 - January 2001 turbidity levels did elevate and exceed the provincial and federal guidelines for a short period of time.

The NTU guidelines are extrapolated from the TSS guidelines "of a 25 and 5 $mg \cdot L^{-1}$ change from background for short-term and long-term exposures, respectively, according to the suspended sediment and the general turbidity correlation of 3 to 1" (CCME 1999). NTU measurements were rounded in the extrapolation.

These TSS guidelines, and subsequently the NTU guidelines, both of which have a two-pronged approach for both high and low flow periods, have largely been based on the conclusions and recommendations made by Newcombe and Jenson from the severity-of-ill-effects (SEV) concentration-response curve approach (Newcombe 1994a; Newcombe and Jenson 1996) that reports effects to biota, many of which are found in North America (CCME 1999).

> *The approach is based on the change in suspended sediment concentration causing an increase of one in a SEV score for the most sensitive taxonomic group of aquatic organisms. The steepest slope representing a change in response of one SEV score was for adult salmonids (24-48 h; slope 2.08), which represents a 24 $mg \cdot L^{-1}$ increase in suspended sediments (Caux et al. 1997). ...Based on extrapolation from the SEV analysis, a long-*

> *term exposure guideline has been set at an average suspended sediment change in 5 mg·L^{-1} (e.g., for exposures lasting 30 d). According to the SEV scale this concentration-duration exposure translates to a SEV score of five (i.e., minor physiological stress, increased rates of coughing and respiration)* (CCME 1999).

The database that was used to develop the SEV approach was formed by combining and converting data from various literature. For example, Jackson Turbidity Units (JTU), used more commonly prior to the increase in popularity of the nephelometric turbidity unit, were used to create the database thereby establishing the current TSS guideline and, consequently, the current NTU guideline. However, there is no direct relationship between JTU and NTU (Singleton 1985). Secchi disk data was also used and assumptions had to be made in order to incorporate secchi disk data into the database that formed the foundation of the TSS guideline. TSS data and NTU data were used interchangeably based on a 3:1 assumed correlation, which has been shown in the case history to be problematic from a site-specific perspective. However, there is potential for the 3:1 correlation to be applicable on a greater scale when examining a number of sites and with increased sample size and appropriate analysis methodology.

The CEQG are limited in addressing high turbidity of short duration. These events can result in increased settling of sediment thereby affecting fish eggs and benthics. Some method to assess this may be desirable. Further, flow/velocity is not taken into consideration in the CEQG, subsequently limitations in the guidelines with regard to geographical extent exist. Additional clarification of the guidelines may be warranted to ensure effective monitoring and reporting of exceedences to regulatory agencies.

5.4 Point Versus Broad Spatial Risk

A lack of clarity is evident from the CEQG in regards to the number and location of samples used to determine an exceedence in turbidity. More specifically, it is unclear as to whether a comparison between single point samples upstream and downstream versus the comparison between the average of several samples across upstream and downstream channel transects should be used to calculate the differences in NTU. This issue goes to the very heart of how geographical and temporal extent are incorporated into water quality guidelines.

For example, from the case history, the December 31, 2000 turbidity level from sampling suite 2 (midday) at Transect 3 (250m downstream) exceeded the 8 NTU difference (CEQG 1999) on a single sample averaged across the entire river channel. This exceedance was confined to Transect 3 and Transect 2 (100m downstream). The levels at Transect 4 (1000m downstream) during this time period were less than 3.0 NTU (equivalent to the upstream levels at Transect 1). The elevated turbidity levels were not only confined geographically but were also of a short duration (greater than 8 NTU above background for less than 24 hours). Likely, the turbidity levels exceeded the 8 NTU difference for approximately 15 hours. The levels were back to normal (equivalent between upstream and downstream transects) by January 2, 2001. In this example, depending upon whether point samples were used for comparison to upstream levels or whether samples were averaged across transects and sampling suites then compared to the upstream, the interpretation of whether an exceedence had occurred and the duration of the exceedence would be inconsistent.

From an examination of the case history data, the average difference in NTU between the point sample maximum and the averaged transect is 33.4 NTU (Table 5.5). With the removal of the largest value (474.50 NTU) the average difference is 8.9 NTU. This is a significant difference considering that the CEQG define an exceedence by 2 NTU difference between background (upstream) and downstream over 30 days and 8 NTU over 24 hours. From the case history data, 10 out of 19 (53%) of the comparisons had a greater than 2 NTU difference while 3 out of 19 (16%) had a greater than 8 NTU difference.

The limitations of using point sampling for CEQG exceedence determination is in its inability to characterize the total watercourse and account for mixing and dilution. While averaging samples can give context to the effect on the entire watercourse, the limitation with averaging is that one outlier (geographically confined area of high turbidity –

confined plume and confined duration) could skew the average across the whole watercourse and day thereby misrepresenting the turbidity levels in geographical and temporal extent. In the best case scenario, both approaches (point sample results versus averaged sample results) could be used to interpret effects and guide operations and monitoring decision-making. However, with regard to the reporting of exceedences, the context of geographic extent of a plume causing an exceedence should be further defined. Clearly in both cases, the duration of the high turbidity is paramount to establishing the exceedence as increased levels of sediment are tolerable for limited durations (Sorenson et al. 1977; Newcombe and MacDonald 1991; Newcombe and Jenson 1996).

This issue is particularly salient in the use of turbidity as a tool in mine management as improper plume sampling can provide skewed results, which do not adequately illustrate the sediment introduction into a watercourse. Further, it can leave managers inappropriately exposed to regulatory recourse or, on the other hand, allow them to bypass regulatory consequences for valid cases of sediment loading. While further research is required, with the existing contradiction between the regulatory guidelines and expectations (i.e. DFO zero tolerance versus CEQG), monitoring of turbidity helps to protect the proponent (i.e. mine operator). Monitoring enables the operator to slow down or halt turbidity-inducing activity thereby reducing the duration of increased turbidity levels.

Table 5.5. Comparison of turbidity (NTU) point results versus geographically and temporally averaged results from the case history on the North Saskatchewan River.

Monitoring Date	Sampling Suite	NTU Greatest Difference Between Maximum UPS & DWS Point Samples (DWS – UPS Sample Sites Shown In Parentheses)	NTU Greatest Difference Between Maximum UPS & DWS Transects (Samples Averaged Across Transect and Day) (Max. DWS Transect Shown in Parentheses)	Comparison of Maximum Point Sample to Averaged Result (Higher or Lower)	Difference Between Maximum Point Difference and Averaged Difference (NTU)
August 2, 2000	*Suite 1*	-2.47 (T2-2 – T1-2)	0.32 (T5)	Higher	6.41
	Suite 2	1.80 (T5-2 - T1-2)			
	Suite 3	**6.73 (T2-4 – T1-1)**			
August 3, 2000	Suite 1	**1.20 (T2-5 – T1-3)**	0.27 (T2)	Higher	0.93
	Suite 2	-0.23 (T2-3 – T1-3)			
	Suite 3	0.80 (T4-5 – T1-3)			
August 4, 2000	Suite 1	0.13 (T2-2 – T1-3)	-0.11 (T2)	Higher	3.08
	Suite 2	-1.08 (T3-4 – T1-3)			
	Suite 3	**2.97 (T2-1 – T1-2)**			
August 5, 2000	Suite 1	**1.87 (T3-5 – T1-3)**	1.12 (T3)	Higher	0.75
August 8, 2000	Suite 1	**-0.13 (T3-4 – T1-1)**	-0.40 (T4)	Higher	0.27
October 20, 2000	Suite 1	**0.72 (T2-1 – T1-2)**	0.07 (T2)	Higher	0.65
	Suite 2	-0.18 (T2-1 – T1-2)			
	Suite 3	0.43 (T3-5 – T1-3)			
October 21, 2000	Suite 1	0.19 (T4-1 – T1-1)	0.19 (T4)	Higher	1.46
	Suite 2	1.09 (T2-1 – T1-1)			
	Suite 3	**1.65 (T3-5 – T1-3)**			
October 22, 2000	Suite 1	2.11 (T2-5 – T1-3)	1.15 (T2)	Higher	3.25
	Suite 2	**4.40 (T2-5 – T1-3)**			
	Suite 3	1.30 (T2-5 – T1-2)			
October 23, 2000	Suite 1	**6.61 (T2-5 – T1-1)**	1.45 (T2)	Higher	5.16
	Suite 2	1.86 (T3-5 – T1-3)			
December 29, 2000	Suite 2	-0.51 (T3-2 – T1-2)	0.03 (T3)	Higher	0.47
	Suite 3	**0.50 (T3-2 – T1-1)**			
December 30, 2000	Suite 1	3.69 (T3-2 – T1-1)	0.73 (T3)	Higher	5.03
	Suite 2	0.13 (T3-1 – T1-3)			
	Suite 3	**5.76 (T3-1 – T1-3)**			
December 31, 2000	Suite 1	68.56 (T3-1 – T1-2)	36.52 (T3)	Higher	474.50
	Suite 2	**511.02 (T3-1 – T1-1)**			
	Suite 3	213.01 (T2-1 – T1-1)			
January 1, 2001	Suite 1	13.13 (T3-1 – T1-1)	14.41 (T3)	Higher	108.00
	Suite 2	27.54 (T3-1 – T1-1)			
	Suite 3	**122.41 (T3-1 – T1-1)**			
January 2, 2001	Suite 1	2.01 (T3-1 – T1-1)	0.63 (T3)	Higher	2.07
	Suite 2	-0.02 (T5-2 – T1-3)			
	Suite 3	**2.70 (T3-1 – T1-3)**			
March 23, 2001	Suite 1	**2.35 (T2-1 – T1-2)**	1.11 (T2)	Higher	1.24
	Suite 3	1.99 (T4-5 – T1-2)			
March 24, 2001	Suite 1	2.82 (T3-5 – T1-2)	1.45 (T2)	Higher	12.93
	Suite 2	**14.38 (T2-5 – T1-3)**			
	Suite 3	11.78 (T6-3 – T1-1)			
March 25, 2001	Suite 1	2.04 (T2-1 – T1-2)	1.47 (T2)	Higher	5.55
	Suite 2	6.09 (T4-5 – T1-2)			
	Suite 3	**7.02 (T4-5 – T1-2)**			
March 26, 2001	Suite 1	0.93 (T4-4 – T1-1)	0.42 (T2)	Higher	1.74
	Suite 2	**2.16 (T4-5 – T1-2)**			
March 27, 2001	Suite 2	**0.58 (T2-5 – T1-3)**	0.09 (T2)	Higher	0.49

Bolded number indicates largest value within daily set. DWS – Downstream UPS – Upstream
Sampling Suite 1 – Morning Sampling Suite 2 – Midday Sampling Suite 3 - Evening
Greatest upstream point sample was used for comparison of the point samples.

5.5 Application of Case History Results to Mine Tailings Management

Residual effects of mine tailings are a significant issue of concern. The potential for release of mine tailings over time is a potential risk to the downstream and a potential residual effect. The physical location of mine tailings could be locations/landscapes that demonstrate residual effects. The potential seepage and release water from tailings could enter surface waters and increase turbidity thereby degrading the health of the downstream aquatic environment.

The case history demonstrates that increased turbidity (i.e. December 31, 2000) can be quickly identified and corrected as a result of turbidity monitoring. The field applicability of the turbidimeter has application for mine tailings management where numerous potential receiving waters would need to be continually monitored for exposure to tailings sediment. The monitoring of tailings sediment could be a useful indicator of other substance release and, thus, could lead to more detailed assessments of other possible mining contaminant releases.

Automated turbidity monitoring (process meters) that is used in the drinking water industry (i.e., EPCOR water treatment facilities in Edmonton, Alberta) could have application for the prevention of mine tailings disasters. Process meters could be placed in suitable locations (e.g., drainage channels, surrounding surface waters and waterbodies, etc.) to continuously monitor turbidity changes. While the grab sample methodology certainly has application, automated turbidity monitoring would provide better data sets with less deviation. This would provide a more timely and clearer picture of sediment increases as a result of tailings impoundment deficiencies. The automated system would have particular applicability for slow leaks from impoundments that could signal an impending larger failure.

The examination of the case history data in regards to the current legislation and guidelines further supports the usage of monitoring tools such as turbidimeters to protect the mine manager from the inconsistencies that exist between regulatory agencies and their mandates/standards.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In this research study, the applicability, validity, practicality, adaptability and effectiveness of turbidity as a monitoring tool in relation to mine tailings management was examined. A comprehensive literature survey of previous work on turbidity as a water quality indicator, legislative significance of turbidity, potential effects of turbidity on aquatic ecosystems, turbidity in relation to mine tailings management, monitoring, mitigation and residual effects was undertaken and revealed that the measurement of turbidity is useful. This was further demonstrated in the case history that was presented. The literature survey and case history generally supported a site specific relationship between turbidity and suspended sediment, however, did show some applicability of a 3 to 1 turbidity to total suspended sediment correlation in some cases. The value of turbidity as an indicator of tailings release impact to the overall aquatic ecosystem and, subsequently, as a tool in mine management and industrial development, was explored. The strengths and weaknesses of the Canadian Environmental Quality Guidelines turbidity exceedence guidelines in respect to risk assessment were considered along with the implications to environmental protection and management. From the above components of the overall study, the following specific conclusions are drawn:

- Field analysis of turbidity (NTU) can be an effective water quality indicator.
- The environmental effects from various measures of TSS and NTU have independent scientific basis, thus, could be used independently as indicators.
- Turbidity correlates well with suspended sediment when precise laboratory methodology of suspended sediment analysis is paired with prompt turbidity analysis.
- The field turbidity results in relation to the laboratory total suspended sediment results provided the most consistent ratio with the least scattering in data and

linear correlation coefficient closest to 1. However, the field NTU to the natural log of the laboratory TSS provided a better fit than the linear correlation. Ultimately, the analysis methodology for total suspended sediment and turbidity is key to the correlation accuracy.

- The TSS/NTU relationship is site-specific; however some 3 to 1 TSS to NTU ratio validity does occur when greater sample size and different analysis methodologies for TSS and NTU are taken into account. Therefore, for industrial project monitoring for the protection of aquatic life, the 3:1 TSS to NTU ratio as proposed in the CEQG would be acceptable in cases where large data sets over various locations are being examined.

- Based on a comparison between on-site field analysis of turbidity with a portable turbidimeter versus the laboratory analysis conducted some days after sampling, the elapsed duration between sampling and analysis may produce variable results. While a similar trend in turbidity levels at sampling sites was evident, the results at individual sampling sites were different and further resulted in inconsistent ratios between TSS and NTU. The results lead to the conclusion that consistency in analysis timing after sample obtainment is salient to credible laboratory results, and that field turbidity analysis, when properly calibrated equipment is utilized, is more accurate than laboratory analysis.

- Since the CEQG guidelines for turbidity were based on the CEQG guidelines for total suspended sediments and the TSS guidelines were based on the SEV index, some potential for error exists due to the conversion between TSS and NTU data from specific studies that were used to support the SEV index.

- A contradiction exists between the Fisheries Act of Canada sediment criteria versus the Canadian Environmental Quality Guidelines for Protection of Aquatic Life and Alberta Surface Water Quality Guidelines for Protection of Aquatic Life with the Fisheries Act of Canada citing zero tolerance for sediment release and the CEQG and ASWQG citing allowable measures (i.e. 8 NTU for up to 24 hours and 2 NTU for up to 30 days in low flow conditions).

- The comparison of point turbidity sample measurements to upstream (background) levels resulted in a greater difference than the comparison of geographically and temporally averaged samples to upstream (background) levels and subsequently resulted in inconsistencies in CEQG and ASWQG exceedence interpretation. The use of geographically and temporally averaged samples for regulatory interpretation has merit in addressing mixing while the point samples may be more representative of plume characteristics.

- Sediment monitoring spatial and temporal sampling plans are site-specific and are essential to reducing residual effects.

- Reducing or halting of inchannel activities when exeedence levels are detected downstream may assist in meeting the CEQG for turbidity and total suspended sediment.

The study attempts to provide perspective into the extent of mine tailings and consequently the potential risk of increased turbidity in aquatic ecosystems as a result of the release of these tailings into the environment. However, numerous data gaps exist in the inventory and description of mine tailings which impeded the further effects and risk assessment. Some conclusions in regards to these data deficiencies are provided below. However, despite the data gaps, the overall concept of the threat of tailings as a sediment source into aquatic ecosystems was established.

- A comprehensive list of tailings impoundments in Canada does not exist or has not been verified. Further, information intrinsic to effective management of tailings facilities such as surface area, volume of tailings, composition of tailings, management approaches of tailings facilities and risk analysis of tailing facilities does not appear to have been comprehensively compiled and verified by regulators. While some of this information may be gathered for active mines, this information is all the more problematic for abandoned tailings facilities.

- A complete and reliable inventory of tailings impoundment failures is not available.

- The environmental impacts and potential residual effects from mining activities to surrounding lands, air, water and life can be extensive if not monitored and mitigated. Specifically, the potential environmental effects of mine tailings failures including, for example, full breaches and slow leakages into surrounding areas, requires attention.

6.2 Recommendations

Based on the findings in the research, the following recommendations for further study are suggested:

- The contradiction between the acceptable levels of suspended sediment and/or turbidity required by the DFO versus the CEQG/ASWQG should be reviewed and resolved.
- Turbidity can be used as an environmental health indicator for industrial projects/operations that may result in sediment entering surface waters in light of its inexpensiveness, practicality, automation capabilities and ability to provide quick results.
- Examination of other sources of sediment from mine operations (i.e. haul road construction) should be investigated for potential usefulness of turbidity monitoring to effective industrial and environmental management.
- The relationship between turbidity as an indicator of bedload and settled sediments should be explored further.
- More research is required into point turbidity samples versus geographically and temporally averaged turbidity samples for comparison to background levels for regulatory exceedence interpretation.
- Tolerable geographical extent of increased turbidity requires further examination.

- The TSS – NTU relationship is site-specific but does resemble the 3:1 TSS to NTU ratio in many cases. This relationship should be established for industrial projects; however, both measures may still be used independently to indicate environmental health.

- By using a portable field turbidimeter, it is possible to modify environmentally negative operations in a timely fashion to avoid further sediment release and to meet regulatory guidelines.

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APPENDICES

Table A. Canadian Dam Association registry list of large tailings dams exceeding 60 metres in height (reproduced from Canadian Dam Association 2003).

Name of Dam	**Height (m) Above Dam Foundation**	**Volume (10^3 m^3)**	**Gross Capacity (10^3 m^3)**
Highland Valley LL Dam	142		650 000
Brenda	137		140 000
Dyke 11A (Pond 8A) (oilsands)	120	36 000	63 000
East Tailings Plus (Pond 2/3)	105	25 000	250 000
Dyke 2 East (Pond 2/3) (oilsands)	105	20 000	
Tar Island Dyke (Pond 1) (oilsands)	100	60 000	185 000
East West Dyke: Cell 15 East (Pond 2/3) (oilsands)	95	20 000	
Dyke 5 (Pond 2/3)	95	30 000	
Similico West Dam	95		
Gibraltar	92		250 000
Dyke 2 West (Pond 2/3) (oilsands)	90	35 000	
Dyke 6 (Pond 2/3) (oilsands)	90	20 000	
Dyke 7 West (Pond 4) (oilsands)	90	20 000	
Dyke 8 (Pond 5) (oilsands)	90	45 000	270 000
Quintette	85		60 000
Similico East Dam	82		
Boundary Dyke (Pond 5) (oilsands)	80	2 000	
Afton	75		37 000
Highland Valley HH Dam	75		650 000
Bell	70		60 000
Dyke 7 East (Pond 4) (oilsands)	70	12 000	11 000
Dyke 7 North (Pond 4) (oilsands)	70	3 000	
Dyke 9 (Pond 6) (oilsands)	62	13 500	168 000
Granisle	61		

Table B. Canadian Dam Association registry list of large tailings dams exceeding 60 metres in height (reproduced from Canadian Dam Association 2003).

Name of Dam	Construction Method	Company	Completion Year	Province	Height (m)	Volume (10^3 m^3)	Gross Capacity (10^3 m^3)
Central Tailings Upper Pond North	Upstream	Inco Ltd.	1938	Ontario	23		
Central Tailings Upper Pond South	Upstream	Inco Ltd.	1938	Ontario	19		
Central Tailings A Area Dam	Upstream	Inco Ltd.	1958	Ontario	23		
Red Mountain		Inco Technical Services	1972	British Columbia	40		
Pinchi Lake		Cominco Ltd.	1975	BC	20		2 700
Cantung Pond 3		North American Tungsten	1976	NT	28		
Levack Tailings	Centerline	Inco Ltd.	1976	ON	10		
Levack Tailings Dam	Downstream	Inco Ltd.	1977	ON	14		
Central Tailings M North Dam	Upstream	Inco Ltd.	1979	ON	39		
Central Tailings M South Dam	Upstream	Inco Ltd.	1979	ON	39		
Granisle		Noranda Mining and Exploration Inc.	1982	BC	61		
Quirke Waste Management Area (Dam K1)	Centerline	BHP Billiton	1982	ON	17	153	
Giant #21B		Miramar Giant Mine	1983	NT	15		
Giant #21C		Miramar Giant Mine	1983	NT	15		
Ladner Creek		Athabaska Gold Resources Limited	1984	BC	50		
Highmont			1984	BC	35		
Giant #11		Miramar Giant Mine	1984	NT	15		
Dankoe			1984	BC	15		
Tar Island Dyke (Pond 1)	Upstream/ Centerline	Suncor Energy Inc.	1988	AB	100	60 000	185 000
Plant Access Road Dyke (Pond 1)	Centerline	Suncor Energy Inc.	1988	AB	30	5 000	
Central Tailings P Area Dam	Upstream	Inco Ltd.	1989	ON	47		
Denison Mine TMA-1 (Dam 17)	Centerline	Denison Mines Limited	1989	ON	18	230	
Brenda		Noranda Inc.	1990	BC	137		140 000
Denison Mine TMA-1 (Dam 16)	Centerline	Denison Mines Limited	1991	ON	15	150	
Levack Tailings Causway	Centerline/ Downstream	Inco Ltd.	1991	ON	13		
Bell		Noranda Mining and Exploration Inc.	1992	BC	70		60 000
Lawyers		Cheni Gold Mines Inc.	1992	BC	25		
Equity Silver		Placer Dome North America	1994	BC	30		
East Tailings Plug (Pond 2/3)	Upstream/ Centerline	Suncor Energy Inc.	1995	AB	105	25 000	250 000
Dyke 2 East (Pond 2/3)	Upstream/ Centerline	Suncor Energy Inc.	1995	AB	105	20 000	
East West Dyke Cell 15 East (Pond 2/3)	Upstream	Suncor Energy Inc.	1995	AB	95	20 000	
Dyke 5 (Pond 2/3)	Upstream	Suncor Energy Inc.	1995	AB	95	30 000	
Dyke 2 West (Pond 2/3)	Upstream/ Centerline	Suncor Energy Inc.	1995	AB	90	35 000	
Dyke 6 (Pond 2/3)	Upstream/ Centerline	Suncor Energy Inc.	1995	AB	90	20 000	
Dyke 4 (Pond 2/3)	Centerline	Suncor Energy Inc.	1995	AB	45	4 000	
Similico West Dam		Similico Mines Ltd.	1996	BC	95		
Similico EAst Dam		Similico Mines Ltd.	1996	BC	82		
Premier		Boliden Ltd.	1996	BC	41		6 000

Name of Dam	Construction Method	Company	Completion Year	Province	Height (m)	Volume (10^3 m^3)	Gross Capacity (10^3 m^3)
Nickel Plate		Homestake Canada Ltd.	1996	BC	35		11 000
Goldstream		Imperial Metals Corporation	1996	BC	15		17 000
Afton		Afton Operating Corporation	1997	BC	75		37 000
Gibraltar		Taseko Mines Ltd.	1998	BC	92		250 000
Blackdome		Claimstaker Resources Ltd.	1998	BC	32		7 000
QR		Kinross Gold Corporation	1998	BC	25		
Stanleigh Waste Management Area (Dam A)	Upstream/ Centerline	BHP Billiton	1998	ON	18	57	
Dyke 7 West (Pond 4)	Upstream/ Centerline	Suncor Energy Inc.	1999	AB	90	1 500	20 000
Dyke 7 East (Pond 4)	Upstream/ Centerline	Suncor Energy Inc.	1999	AB	70	12 000	11 000
Dyke 7 North (Pond 4)	Upstream/ Centerline	Suncor Energy Inc.	1999	AB	70	3 000	
Snip Dyke 2		Homestake Canada Ltd.	1999	BC	23		
Dyke 8 (Pond 5)	Centerline	Suncor Energy Inc.	2002	AB	90	45 000	270 000
Boundary Dyke (Pond 5)	Centerline	Suncor Energy Inc.	2002	AB	80	2 000	
Exclusion Zone Dyke (Pond 5)	Centerline	Suncor Energy Inc.	2002	AB	20	3 000	
Highland Valley LL Dam		Highland Valley Copper/Lornex	C	BC	142		650 000
Dyke 11A (Pond 8A)	Upstream/ Centerline	Suncor Energy Inc.	C	AB	120	36 000	63 000
Quintette		Quintette Operating Company	C	BC	85		60 000
Highland Valley HH Dam		Highland Valley Copper/Lornex	C	BC	75		650 000
Dyke 9 (Pond 6)	Centerline	Suncor Energy Inc.	C	AB	62	13 500	168 000
Mount Polley		Mount Polley Mining Corporation	C	BC	50		
Huckleberry		Huckleberry Mines Ltd.	C	BC	48		
Sullivan #3 Silicious		Cominco Ltd.	C	BC	41		
Bullmoose		Bullmoose Operating Company	C	BC	40	3 000	
Kemess South		Kemess Mines Inc.	C	BC	36		
Dyke 11B (Pond 8A)	Upstream/ Centerline	Suncor Energy Inc.	C	AB	30	6 000	
Sullivan Iron Dyke		Cominco Ltd.	C	BC	29		
Quinsam		Quinsam Coal Corporation	C	BC	28		
Myra Falls		Boliden Westmin (Canada) Ltd.	C	BC	25		
Fording River		Fording Coal Ltd.	C	BC	24		
Sullivan West Gypsum Dyke		Cominco Ltd.	C	BC	23		
Dyke 11C (Pond 8B)	Upstream/ Centerline	Suncor Energy Inc.	C	AB	20	3 000	13 000
Sullivan East E Gypsum Dyke		Cominco Ltd.	C	BC	17		
Sullivan #1 Silicious Dyke		Cominco Ltd.	C	BC	17		
Central Tailings R Area Dam	Upstream	Inco Ltd.	C	ON	16		
Giant #3		Miramar Giant Mine	C	NT	15		
Colomac #1 Tailings Lake (RES)			C	NT	15		
Sullivan Calcine		Cominco Ltd.	C	BC	15		
*Wagita A		Steep Rock Iron Mines Ltd.	1943	ON	18	7	

Name of Dam	Construction Method	Company	Completion Year	Province	Height (m)	Volume (10^3 m^3)	Gross Capacity (10^3 m^3)
*West Arm		Ontario Ministry of Natural Resources	1953	ON	18	220	13 262
*Fairweather		Ontario Ministry of Natural Resources	1958	ON	27	382	5 366
Lacnor Waste Management Area	Upstream	BHP Billiton	1960	ON	15	30	
Levack Tailings (Dam 1)	Downstream	Inco Ltd.	1977	ON	24		
Levack Tailings (Dam 3)	Downstream	Inco Ltd.	1977	ON	23		
Levack Tailings (Dam 2)	Downstream	Inco Ltd.	1977	ON	20		
Panel Waste Management Area (Dam D)	Centerline	BHP Billiton	1989	ON	23	44	
Panel Waste Management Area (Dam B)	Centerline	BHP Billiton	1989	ON	20	126	
Quirke Waste Management Area (Main Dam)	Centerline	BHP Billiton	1990	ON	26	237	
Denison Mine TMA-1 (Dam 10)	Centerline	Denison Mines Limited	1993	ON	38	1 500	
Stanrock TMA-3 (Dam C)	Centerline	Denison Mines Limited	1997	ON	15	49	
Stanrock TMA-3 (Dam B)	Centerline	Denison Mines Limited	1997	ON	15	99	
Stanrock TMA-3 (Dam A)	Centerline	Denison Mines Limited	1998	ON	25	248	
Stanleigh Waste Management Area (Dam B)	Centerline	BHP Billiton	1998	ON	17	76	
Interlake Dam 41 (Main Dam)	Upstream/ Centerline	Newmont Canada Limited	2000	ON	40	2 160	12 000

Table C. Tailings disposal and effluent treatment (reproduced from Canadian Mining Journal's 2002 Mining Sourcebook).

Company, Mill	Type
Agrium, Vanscoy	Natural settling
Aur Louvicourt	Submerged deposition
Barrick, Bousquet	Partially flooded tails
Barrick, Est-Malartic	Partially flooded tails
Barrick, Holt-McDermott	Natural degradation & solids retention
Battle Mountain, Golden Giant	Natural settling
BHP Diamonds, Ekati	Slurry pumped to tailings impoundment
Billiton, Selbaie	Thickened tailings
Breakwater, Bouchard-Hebert	Tailings pound & paste backfill system
Breakwater, Langlois	50% of tails used for backfill, 50% of tails are pumped to pond & stored below 1-m of water
Breakwater, Nanisivik	Open pipe discharge to lake basin for natural settling
Bullmoose	Natural settling in pond
Cambior, Doyon	Free discharge
Cambior, Sleeping Giant	Single tailings pond
Cameco, Key Lake	Sub-aqueous
Claude, Seabee	Closed circuit recycle with natural degradation & zero effluent discharge
Cogema, Cluff Lake	Natural settling
Elkview Coal	Thickened
Echo Bay, Lupin	3-stage ponding with solids retained in cells & liquid decanted for treatment
Falconbridge, Strathcona	Natural settling
Fording, Fording River	Natural settling pond
Fording, Greenhills	Closed circuit. Fine rejects tailings into pond
Goldcorp, Red Lake	CN destruction followed by 2 settling & 1 final polishing pond
Highland Valley Copper, Lornex	Slurry impoundment behind centreline dam
Huckleberry Mines	Impoundment area (TMF2) built of rock & till with 2-to-1 downstream slope and non-acid generating waste rock on downstream embankments
Hudson Bay, Flin Flon	Conventional end of pipe discharge
Hudson Bay, Ruttan	Natural impoundment (backfill plant recovers about 33% of tails for feed)
IMC Potash Belle Plaine	Tailings pond
Inco, Clarabelle	Natural settling with spigoting
Inco, Thompson	Natural settling
Inmet, Troilus	Winter: Linear discharge. Summer: spigoting & dyke raising
Lab Chrysotile, Black Lake	30" conveyir
Meston, Joe Mann	
Minto Explorations	Thickened tailings
Mount Polley Mining	Gravity flow system to banked, zero-discharge impoundment area 6 km from mill
Niobec	Upstream
Noranda, Brunswick	Natural settling Paste backfill
Noranda, Matagami	Natural settling
N.Amer. Palladium, Lac des	Peripheral discharge with centreline construction

Company, Mill	**Type**
Iles	
Northgate, Kemess	Pumped to pond
Placer Dome, Campbell	Natural settling
Placer Dome, Dome	Impoundment formed from natural topography & impermeable-core dams
Placer Dome, Musselwhite	Surface tailings impoundment
Richmont, Camflo	Dam elevation with hydraulic shovel & spigoting
Stratmin Grphite	Cycloned tails deposited behind dam
Syncrude	Base lease: Upstream cell construction Aurora lease: Upstream & centreline
Teck Cominco, Polaris	Thickened tails placed on lake bottom (sub-aqueous)
Teck Cominco, Sullivan	Natural settling
Thompson Creek, Endako	Spigot & dam deposition
TVX Gold, New Britannia	Aerial lake basin
Wabush, Scully	Slurry transport via pipes
Williams	Natural settling & effluent treatment plant

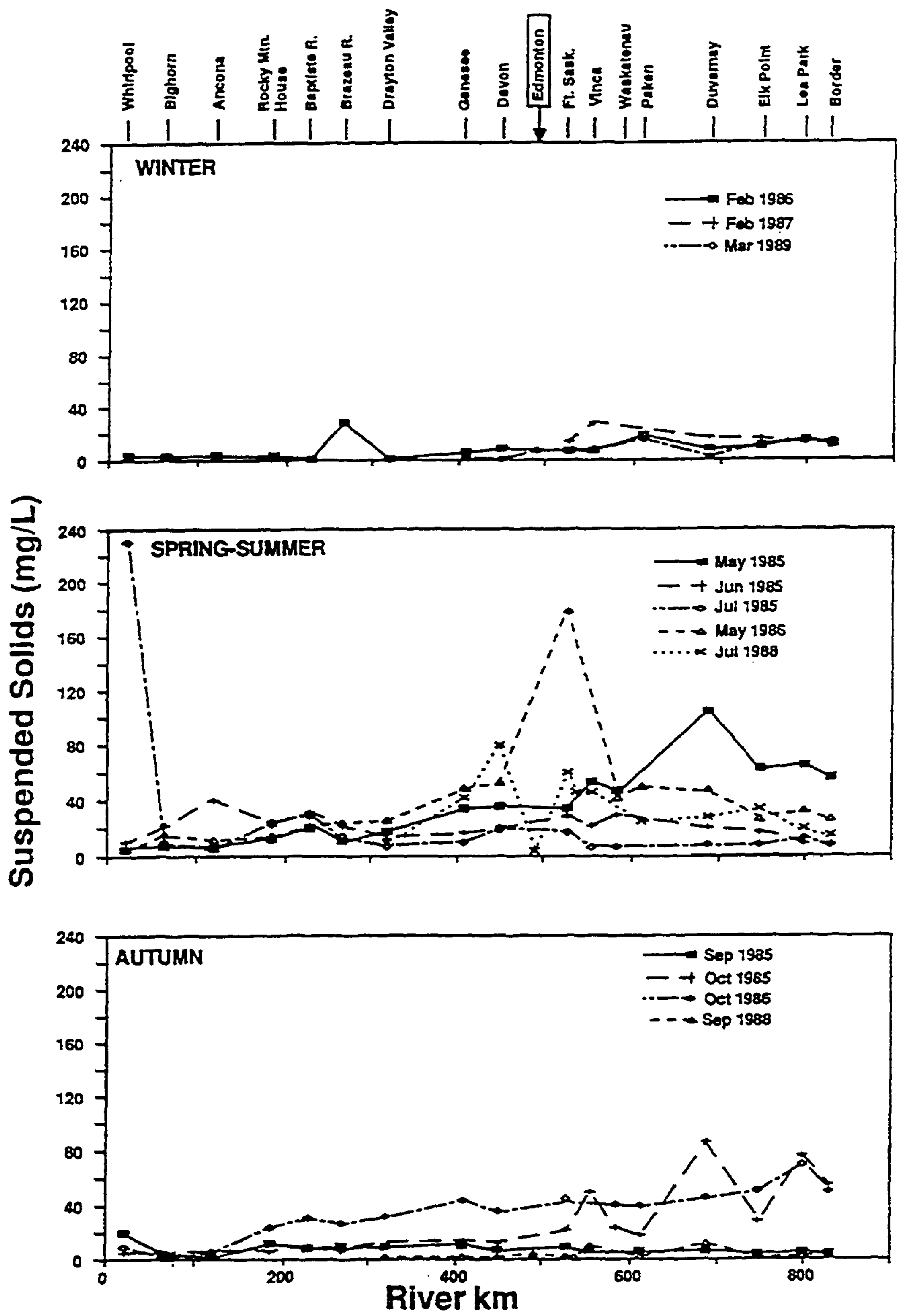

Figure A. Suspended solids (mg/L) along the North Saskatchewan River, 1985 – 1989 (Reproduced from Water Quality of the North Saskatchewan River in Alberta, Alberta Environmental Protection, 1994).

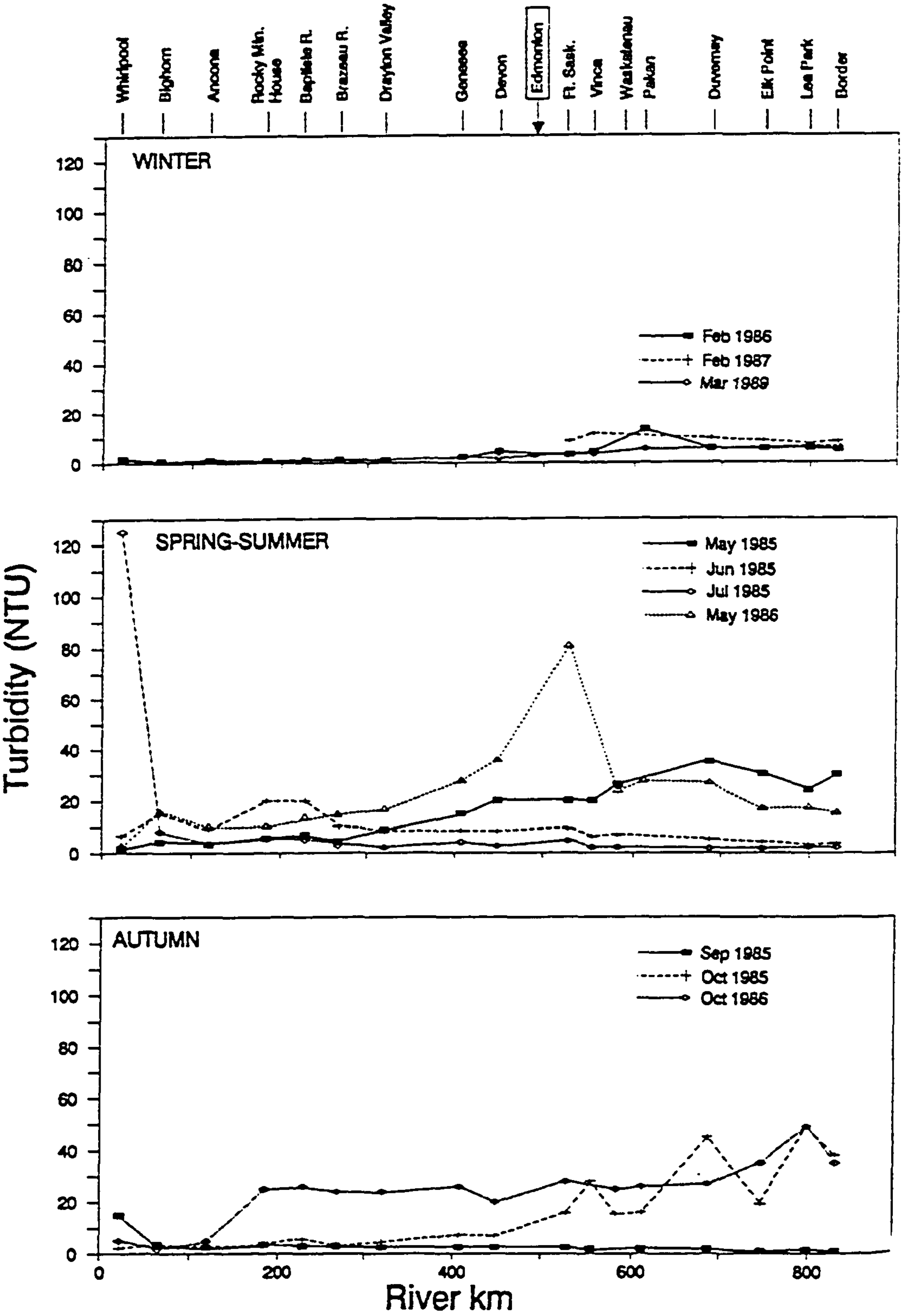

Figure B. Turbidity (NTU) along the North Saskatchewan River, 1985 – 1989 (Reproduced from Water Quality of the North Saskatchewan River in Alberta, Alberta Environmental Protection, 1994).

Table D. Case History August 2000 Raw Turbidity (NTU) Data

Day 1: August 2, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	1	25.9	23.5	22.4	23.93
T1	2	1	27.6	27.1	27.9	27.53
T1	3	1	25.5	21.9	22.8	23.40
T2	1	1	23.4	23.8	21.8	23.00
T2	2	1	26.2	25.3	23.7	25.07
T2	3	1	24.7	23.3	23.2	23.73
T2	4	1	24.8	20.4	19.8	21.67
T2	5	1	23.8	24.6	25	24.47
T3	1	1	18.4	16.6	16.3	17.10
T3	2	1	23.1	22.9	22.3	22.77
T3	3	1	25.1	23.3	23.9	24.10
T3	4	1	21.5	23.2	23	22.57
T3	5	1	19.3	20.6	18.7	19.53
T4	1	1	20	20.3	20	20.10
T4	2	1	21.7	21.4	18.4	20.50
T4	3	1	20.6	20.4	19.2	20.07
T4	4	1	21.6	20.2	21.2	21.00
T4	5	1	23.2	23.3	21.7	22.73
T5	1	1	25.7	23.1	23.9	24.23
T5	2	1	22.5	23.6	23.7	23.27
T5	3	1	21.2	21.1	19.7	20.67
R-T3	6	1	13.9	12.1	11.6	12.53
R-T4	5	1	18.3	18	16.2	17.50
T1	1	2	19.2	17.9	17.1	18.07
T1	2	2	22.6	21.8	20.9	21.77
T1	3	2	19.9	23	19.6	20.83
T2	1	2	18.1	17.8	17	17.63
T2	2	2	20	19.7	18.8	19.50
T2	3	2	22.5	22.5	21.5	22.17
T2	4	2	22.4	21.3	21	21.57
T2	5	2	24.7	23.2	20.6	22.83
T3	1	2	20.7	22	20.6	21.10
T3	2	2	21.7	20	19.4	20.37
T3	3	2	23.1	21.1	19.9	21.37
T3	4	2	20.3	20.4	19.7	20.13
T3	5	2	21	20.3	19.7	20.33
T4	1	2	22.1	19.3	16.8	19.40
T4	2	2	23.4	21	19.5	21.30
T4	3	2	22.1	22.8	19.8	21.57
T4	4	2	24.1	21.9	21	22.33
T4	5	2	22	21.4	20.6	21.33
T5	1	2	21.1	21.6	20.4	21.03
T5	2	2	18.3	18.6	18	18.30
T5	3	2	23	21.2	20.1	21.43
R-T3	1	2	21.5	21.7	20.8	21.33
R-T4	5	2	21.9	20.8	20.8	21.17
R-T5	2	2	24.4	24.4	21.9	23.57
R-T5	3	2	26.6	22.7	21.2	23.50
R-T2	3	2	19.7	19.3	20.1	19.70
R-T1	2	2	21	22.4	21.5	21.63
R-T5	1	2	21.1	19.5	19.3	19.97

Day 1: August 2, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	3	18.5	18.3	19.4	18.73
T1	2	3	18.5	18.1	16.8	17.80
T1	3	3	16.3	17.7	16.9	16.97
T2	1	3	20.2	19.9	18.9	19.67
T2	2	3	18.4	18.7	17.3	18.13
T2	3	3	20.2	21.1	19.9	20.40
T2	4	3	27.2	24.7	24.5	25.47
T2	5	3	14	13.8	14.3	14.03
T3	1	3	12.6	12.1	12.1	12.27
T3	2	3	15.2	15.5	13.9	14.87
T3	3	3	12.2	13.9	12.8	12.97
T3	4	3	19.4	17.3	18.4	18.37
T3	5	3	17.3	17.2	16.3	16.93
T4	1	3	19.1	19.1	15.9	18.03
T4	2	3	18.2	14.9	14.4	15.83
T4	3	3	17.5	18.4	16.7	17.53
T4	4	3	19.7	18.2	17.4	18.43
T4	5	3	20.1	19.5	17.6	19.07
T5	1	3	22	21.5	20.4	21.30
T5	2	3	21.8	20.6	20.7	21.03
T5	3	3	21.7	19.8	20.5	20.67
R-T4	4	3	19.1	15.8	15.2	16.70
R-T2	3	3	19.3	16.8	15.3	17.13
R-T3	5	3	16.7	14.9	14.4	15.33

Day 2: August 3, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	1	11.9	11.2	10.7	11.27
T1	2	1	13.3	13.7	13.1	13.37
T1	3	1	15	14	12.3	13.77
T2	1	1	10.9	10.4	10.8	10.70
T2	2	1	13.1	13.6	12.3	13.00
T2	3	1	14.5	12.3	13	13.27
T2	4	1	15.8	13.4	14	14.40
T2	5	1	17.8	13.9	13.2	14.97
T3	1	1	13.7	11.2	11	11.97
T3	2	1	14.1	12.4	11.3	12.60
T3	3	1	15.7	12.9	12.7	13.77
T3	4	1	12.8	12.4	13	12.73
T3	5	1	14	13.9	12.8	13.57
T4	1	1	13.4	11.9	11.5	12.27
T4	2	1	14.9	14.2	12.2	13.77
T4	3	1	13.2	12.1	10.9	12.07
T4	4	1	15.3	12.3	12.5	13.37
T4	5	1	13.8	12.6	11.3	12.57
T5	1	1	13.1	11.7	12	12.27
T5	2	1	13	15.4	12.6	13.67
T5	3	1	11.7	10.5	10.5	10.90
R-T4	1	1	15.2	12.5	10.5	12.73
R-T3	4	1	14.2	11.8	12	12.67
R-T2	1	1	12.8	12.4	10.5	11.90
R-T1	1	1	13.7	13	11.1	12.60
T1	1	2	12.3	13.1	11.5	12.30
T1	2	2	14.5	15.6	13.3	14.47
T1	3	2	17.8	15.9	13.5	15.73
T2	1	2	12	11.5	11.7	11.73
T2	2	2	14.9	14.4	12.9	14.07
T2	3	2	15.7	15.7	15.1	15.50
T2	4	2	15.6	14.4	14.9	14.97
T2	5	2	13.1	12.3	12.5	12.63
T3	1	2	14.1	12.3	11.7	12.70
T3	2	2	14.2	11.5	10.2	11.97
T3	3	2	13.2	14.3	11.7	13.07
T3	4	2	13.6	13.5	12.6	13.23
T3	5	2	14.7	14.9	11.7	13.77
T4	1	2	12.7	12.2	10.9	11.93
T4	2	2	13.9	12.5	11.3	12.57
T4	3	2	14.1	14	12.3	13.47
T4	4	2	13.6	12	12.1	12.57
T4	5	2	15.3	13.9	13.7	14.30
T5	1	2	14.6	12.8	12.5	13.30
T5	2	2	12.5	11.5	10.8	11.60
T5	3	2	11.9	13.2	11.2	12.10
R-T2	1	2	13.8	13.1	12.6	13.17
R-T3	2	2	12.2	12.1	11.5	11.93
R-T4	3	2	14.7	13.4	13	13.70
R-T5	2	2	12.9	12.7	12.6	12.73

Day 2: August 3, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	3	11.8	9.84	8.67	10.10
T1	2	3	13.9	13.3	10.7	12.63
T1	3	3	13.1	13.3	14.7	13.70
T2	1	3	13.1	11.9	10.4	11.80
T2	2	3	14.3	11.4	11.1	12.27
T2	3	3	13.1	14	12.5	13.20
T2	4	3	16.2	13.9	11.7	13.93
T2	5	3	13.1	12.9	13.7	13.23
T3	1	3	15.3	10.3	9.59	11.73
T3	2	3	10.5	11.7	9.37	10.52
T3	3	3	13.2	14	11.1	12.77
T3	4	3	15.6	13.7	11.3	13.53
T3	5	3	14	12.8	11.4	12.73
T4	1	3	14.3	11.2	11.9	12.47
T4	2	3	11.7	12.5	11.3	11.83
T4	3	3	14.3	13.4	10.8	12.83
T4	4	3	11.3	10.7	9.98	10.66
T4	5	3	16	14	13.5	14.50
T5	1	3	13.2	13.5	13.1	13.27
T5	2	3	12	12.6	12	12.20
T5	3	3	13.7	14	11.7	13.13
R-T1	2	3	14.4	13.5	11.3	13.07
R-T2	2	3	13	12.9	10.3	12.07
R-T3	2	3	10.9	10.3	9.62	10.27
R-T4	1	3	14.8	12.3	11.3	12.80

Day 3: August 4, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	1	12.9	11.8	10.7	11.80
T1	2	1	12.3	10.2	10.5	11.00
T1	3	1	12.3	10.4	12.9	11.87
T2	1	1	10.5	10.1	9.56	10.05
T2	2	1	14	10.8	11.2	12.00
T2	3	1	11.8	12.4	9.9	11.37
T2	4	1	11.5	10	10.9	10.80
T2	5	1	12.6	11.6	10.7	11.63
T3	1	1	11.2	10.5	9.08	10.26
T3	2	1	11.7	9.8	8.48	9.99
T3	3	1	11.3	9.6	10.3	10.40
T3	4	1	11.4	9.84	10.5	10.58
T3	5	1	11.7	12	10.8	11.50
T4	1	1	12.2	11	10.2	11.13
T4	2	1	10.5	9.19	7.51	9.07
T4	3	1	11.9	10	9.17	10.36
T4	4	1	12.4	11.8	10.6	11.60
T4	5	1	11.9	11.2	10.7	11.27
T5	1	1	11.5	9.49	9.59	10.19
T5	2	1	12.2	10.3	10.7	11.07
T5	3	1	11.3	11.4	10.8	11.17
R-T4	1	1	11.3	10.2	8.77	10.09
R-T3	1	1	11.3	9.25	9.86	10.14
R-T2	1	1	10.1	10.2	8.52	9.61
R-T1	2	1	9.99	9.7	8.15	9.28
T1	1	2	9.32	8.36	8.04	8.57
T1	2	2	11	11.3	10.2	10.83
T1	3	2	12.8	11.8	13.1	12.57
T2	1	2	11.9	10.4	9.88	10.73
T2	2	2	11.2	9.87	8.97	10.01
T2	3	2	12.4	11.4	9.76	11.19
T2	4	2	11.2	10.1	9.18	10.16
T2	5	2	10.5	10.5	9.73	10.24
T3	1	2	9.18	9.53	12.2	10.30
T3	2	2	11.7	9.43	7.86	9.66
T3	3	2	12.1	9.4	8.49	10.00
T3	4	2	11.2	12.5	9.94	11.21
T3	5	2	13.5	9.72	9.35	10.86
T4	1	2	10.4	8.42	8.95	9.26
T4	2	2	9.44	8.73	10.3	9.49
T4	3	2	11	10.3	10.6	10.63
T4	4	2	12.3	10.8	9.53	10.88
T4	5	2	12.6	11.1	10.2	11.30
T5	1	2	10.6	8.99	9.05	9.55
T5	2	2	11.7	10.5	10.1	10.77
T5	3	2	11.5	11	9.36	10.62
R-T4	1	2	8.71	8.75	7.37	8.28
R-T5	1	2	9.37	9.54	7.92	8.94
R-T3	4	2	12.7	12.2	9.56	11.49
R-T1	1	2	12.1	11.6	9.17	10.96

Day 3: August 4, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	3	12.4	11.8	11.8	12.00
T1	2	3	13.8	12.1	10.7	12.20
T1	3	3	13.6	12.1	10.1	11.93
T2	1	3	15.7	14.7	15.1	15.17
T2	2	3	12.8	11.9	10.9	11.87
T2	3	3	12.3	12.8	11.1	12.07
T2	4	3	11.1	11.1	10.4	10.87
T2	5	3	12	10.9	11.4	11.43
T3	1	3	12.4	11.6	9.52	11.17
T3	2	3	10.7	11.5	9.15	10.45
T3	3	3	10.6	9.38	10.6	10.19
T3	4	3	11.2	10.6	9.09	10.30
T3	5	3	12.8	12.1	11	11.97
T4	1	3	10.6	10.6	10.3	10.50
T4	2	3	13.1	11	10.3	11.47
T4	3	3	11.6	12.6	10.3	11.50
T4	4	3	11.5	8.99	11	10.50
T4	5	3	11.2	11.1	10.8	11.03
T5	1	3	11.9	10.6	10.2	10.90
T5	2	3	12.4	12.6	10.8	11.93
T5	3	3	11.8	11.4	10.8	11.33
R-T4	1	3	12.9	11.3	10.9	11.70
R-T2	2	3	12	11.5	9.46	10.99
R-T1	1	3	11.6	11.6	9.68	10.96
R-T3	1	3	10.5	11.2	9.87	10.52

Day 4: August 5, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	1	20.5	19.7	19.6	19.93
T1	2	1	23.4	23.2	23.5	23.37
T1	3	1	23.8	24.4	23	23.73
T2	1	1	18.6	18.7	16.5	17.93
T2	2	1	22.6	24.9	20.6	22.70
T2	3	1	24.9	23.8	23.5	24.07
T2	4	1	22.2	23.5	21.9	22.53
T2	5	1	22.2	21.1	20.5	21.27
T3	1	1	22.1	21.4	21.1	21.53
T3	2	1	21.7	22.6	21.7	22.00
T3	3	1	23.9	24.5	22.6	23.67
T3	4	1	24.8	24.6	24.1	24.50
T3	5	1	26.6	26.2	24	25.60
T4	1	1	19.7	20.4	18.3	19.47
T4	2	1	22.6	22.4	20.5	21.83
T4	3	1	22.8	21.3	20.7	21.60
T4	4	1	21.1	22	20.4	21.17
T4	5	1	25.9	23.4	24.6	24.63
T5	1	1	20.6	21.1	21.2	20.97
T5	2	1	23.2	24	21.5	22.90
T5	3	1	23.1	21.5	19.7	21.43
R-T4	4	1	24.6	24.2	23.5	24.10
R-T3	1	1	23.9	21.4	23.7	23.00
R-T2	1	1	18.9	19.7	17.4	18.67
R-T1	1	1	21.2	19.9	19.5	20.20

Day 5: August 8, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	3	12.6	10.5	8.98	10.69
T1	2	3	10.5	11.4	9.56	10.49
T1	3	3	8.29	10.3	8.24	8.94
T2	1	3	8.37	8.05	8.31	8.24
T2	2	3	8.99	8.77	7.91	8.56
T2	3	3	10.1	9.32	9.19	9.54
T2	4	3	10.1	8.97	9.39	9.49
T2	5	3	10.7	10.3	10.1	10.37
T3	1	3	7.82	6.7	7.57	7.36
T3	2	3	9.43	9.78	9.95	9.72
T3	3	3	10.4	12.1	8.02	10.17
T3	4	3	11.2	10.2	10.3	10.57
T3	5	3	11.1	10.2	8.89	10.06
T4	1	3	9.3	10.2	8.11	9.20
T4	2	3	9.45	9.49	8.64	9.19
T4	3	3	10.7	10.2	10.1	10.33
T4	4	3	10.4	9.48	8.49	9.46
T4	5	3	11.1	9.45	9.44	10.00
T5	1	3	7.85	9.45	9.39	8.90
T5	2	3	9.03	10	7.95	8.99
T5	3	3	9.84	9.52	9.57	9.64
R-T1	2	3	9.92	8.44	8.08	8.81
R-T2	2	3	8.07	8.37	7.68	8.04
R-T5	1	3	8.41	7.67	7.35	7.81
R-T4	1	3	9.69	8.55	7.65	8.63

Table E. Case History October 2000 Raw Turbidity (NTU) Data

Day 1: October 20, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	1	2.47	2.67	2.41	2.52
T1	2	1	2.6	3.2	2.59	2.80
T1	3	1	2.53	2.52	2.43	2.49
T2	1	1	2.79	3	2.74	2.84
T2	2	1	2.59	2.48	2.5	2.52
T2	3	1	2.38	4.58	2.43	3.13
T2	4	1	2.81	2.43	2.74	2.66
T2	5	1	3	4.03	2.85	3.29
T3	1	1	2.92	2.69	2.7	2.77
T3	2	1	2.46	2.34	2.66	2.49
T3	3	1	2.49	2.75	2.43	2.56
T3	4	1	3.8	3.18	3.13	3.37
T3	5	1	2.78	3.18	2.77	2.91
T4	1	1	2.58	2.64	2.75	2.66
T4	2	1	2.63	2.89	2.65	2.72
T4	3	1	2.56	2.51	2.63	2.57
T4	4	1	2.72	2.94	2.98	2.88
T4	5	1	3.08	2.76	3.12	2.99
T5	1	1	3.63	3.59	2.45	3.22
T5	2	1	2.63	2.77	2.72	2.71
T5	3	1	2.72	3.02	2.62	2.79
R-T1	1	1	2.68	2.57	2.42	2.56
R-T2	3	1	2.58	2.45	2.46	2.50
R-T4	1	1	2.64	2.97	2.71	2.77
R-T3	5	1	4.72	2.96	2.88	3.52
T1	1	2	3.01	2.92	3.26	3.06
T1	2	2	4.13	3.29	2.98	3.47
T1	3	2	3.1	2.54	2.84	2.83
T2	1	2	3.2	3.56	3.1	3.29
T2	2	2	3.51	3.45	2.73	3.23
T2	3	2	2.68	2.54	2.35	2.52
T2	4	2	2.43	3.48	2.71	2.87
T2	5	2	2.56	2.73	2.76	2.68
T3	1	2	3.14	2.78	3.24	3.05
T3	2	2	2.66	2.48	2.35	2.50
T3	3	2	1.98	2.1	2.01	2.03
T3	4	2	2.62	2.44	2.44	2.50
T3	5	2	2.48	2.63	2.5	2.54
T4	1	2	2.58	2.68	2.31	2.52
T4	2	2	2.24	2.38	2.34	2.32
T4	3	2	2.91	2.59	2.54	2.68
T4	4	2	2.48	2.46	2.47	2.47
T4	5	2	3	2.89	2.85	2.91
T5	1	2	2.62	2.93	2.76	2.77
T5	2	2	2.59	2.6	2.53	2.57
T5	3	2	2.96	2.78	2.67	2.80
R-T5	1	2	2.63	2.81	2.52	2.65
R-T3	4	2	2.59	2.57	2.75	2.64
R-T2	5	2	2.37	2.41	2.26	2.35
R-T1	2	2	2.47	2.28	2.71	2.49

Day 1: October 20, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	3	2.68	2.46	2.88	2.67
T1	2	3	2.58	2.24	2.23	2.35
T1	3	3	2.29	3.04	2.7	2.68
T2	1	3	3.18	2.83	2.96	2.99
T2	2	3	2.32	2.41	2.39	2.37
T2	3	3	2.39	2.46	2.24	2.36
T2	4	3	3.27	2.93	2.48	2.89
T2	5	3	3.02	2.99	2.54	2.85
T3	1	3	3.13	3.09	3.05	3.09
T3	2	3	2.62	3.05	3.05	2.91
T3	3	3	2.39	2.39	2.3	2.36
T3	4	3	2.78	2.44	2.67	2.63
T3	5	3	2.76	3.32	2.82	2.97
T4	1	3	3.11	2.96	2.92	3.00
T4	2	3	2.44	2.31	2.27	2.34
T4	3	3	2.35	2.72	2.45	2.51
T4	4	3	2.74	2.93	2.87	2.85
T4	5	3	2.71	3.08	3.27	3.02
T5	1	3	2.67	2.42	2.36	2.48
T5	2	3	3.02	2.74	2.74	2.83
T5	3	3	2.76	3.24	3.24	3.08
R-T1	1	3	2.57	2.47	2.73	2.59
R-T2	4	3	3.16	3.48	2.4	3.01
R-T4	1	3	2.99	2.48	2.85	2.77
R-T3	5	3	2.91	2.87	3.54	3.11

Day 2: October 21, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	1	3.45	2.99	2.39	2.94
T1	2	1	2.87	2.78	3.05	2.90
T1	3	1	1.99	1.92	2.02	1.98
T2	1	1	2.9	2.64	2.74	2.76
T2	2	1	3.8	1.87	1.93	2.53
T2	3	1	2.26	2.34	2.02	2.21
T2	4	1	2.5	2.4	2.35	2.42
T2	5	1	2.66	2.42	2.39	2.49
T3	1	1	2.52	2.35	2.55	2.47
T3	2	1	2.19	2.14	2.1	2.14
T3	3	1	2.47	2.15	1.99	2.20
T3	4	1	2.02	2.06	1.97	2.02
T3	5	1	2.21	2.22	2.35	2.26
T4	1	1	4.55	2.56	2.28	3.13
T4	2	1	2.85	2.2	2.2	2.42
T4	3	1	2.89	2.09	2	2.33
T4	4	1	2.3	2.06	2.06	2.14
T4	5	1	2.98	3.45	2.77	3.07
T5	1	1	2.41	2.41	2.57	2.46
T5	2	1	2.23	2.28	2.25	2.25
T5	3	1	2.15	2.26	2.23	2.21
R-T3	1	1	2.46	2.65	2.31	2.47
R-T4	3	1	2.6	2.3	2.27	2.39
R-T2	5	1	2.41	2.44	2.19	2.35
R-T1	2	1	2.33	2.2	2.26	2.26
T1	1	2	2.77	2.49	2.35	2.54
T1	2	2	2.45	2.16	2.55	2.39
T1	3	2	2.31	2.31	2.26	2.29
T2	1	2	3.26	4.01	3.6	3.62
T2	2	2	2.06	2.68	2.42	2.39
T2	3	2	2.26	2.34	2.21	2.27
T2	4	2	2.25	2.44	2.24	2.31
T2	5	2	3.37	2.95	3.5	3.27
T3	1	2	3.34	3.87	3.18	3.46
T3	2	2	2.15	2.5	2.49	2.38
T3	3	2	2.42	2.22	2.45	2.36
T3	4	2	2.63	2.19	2.13	2.32
T3	5	2	2.62	3.01	2.94	2.86
T4	1	2	3.08	3.47	2.5	3.02
T4	2	2	2.18	2.72	2.2	2.37
T4	3	2	2.38	2.35	2.39	2.37
T4	4	2	3.54	3.1	2.93	3.19
T4	5	2	2.93	3.51	2.59	3.01
T5	1	2	2.53	2.43	2.63	2.53
T5	2	2	2.68	2.51	2.47	2.55
T5	3	2	3.2	2.34	2.49	2.68
R-T3	4	2	2.49	2.12	1.89	2.17
R-T5	2	2	2.87	2.65	2.43	2.65
R-T2	1	2	2.75	3.19	3.07	3.00
R-T1	2	2	2.08	2.16	2.3	2.18

Day 2: October 21, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	3	3.52	3.14	2.92	3.19
T1	2	3	2.69	3.11	2.32	2.71
T1	3	3	3.71	3.09	3.23	3.34
T2	1	3	3.49	3.42	3.89	3.60
T2	2	3	2.65	2.92	2.52	2.70
T2	3	3	3.33	2.94	2.5	2.92
T2	4	3	2.95	3.32	3.36	3.21
T2	5	3	3.68	4.16	3.56	3.80
T3	1	3	3.23	2.99	3.52	3.25
T3	2	3	3.15	3.22	3.23	3.20
T3	3	3	3.21	3.2	2.81	3.07
T3	4	3	2.91	2.83	2.96	2.90
T3	5	3	4.33	4.62	4.45	4.47
T4	1	3	3.06	3.44	2.93	3.14
T4	2	3	2.68	3.36	2.97	3.00
T4	3	3	3.62	2.26	2.57	2.82
T4	4	3	3.78	4.08	3.4	3.75
T4	5	3	3.39	3.37	3.88	3.55
T5	1	3	3.13	2.82	2.88	2.94
T5	2	3	3.26	3.43	3.13	3.27
T5	3	3	4.38	4.37	3.5	4.08
R-T3	5	3	5.97	4.48	4.54	5.00
R-T5	2	3	3.99	3.06	3.08	3.38
R-T2	3	3	2.61	2.47	2.63	2.57

Day 3: October 22, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	1	2.89	2.85	3.32	3.02
T1	2	1	4.42	2.97	2.94	3.44
T1	3	1	4.32	3.43	2.79	3.51
T2	1	1	3.47	3.18	3.4	3.35
T2	2	1	3.32	3.18	2.96	3.15
T2	3	1	3.04	3.35	2.92	3.10
T2	4	1	3.07	3.48	3.56	3.37
T2	5	1	5.44	5.78	5.66	5.63
T3	1	1	3.27	3.62	3.4	3.43
T3	2	1	3.75	3.09	2.82	3.22
T3	3	1	3.52	3.08	2.62	3.07
T3	4	1	2.93	2.72	3.1	2.92
T3	5	1	4.02	3.45	3.48	3.65
T4	1	1	3.86	4	2.8	3.55
T4	2	1	4.14	3.04	2.73	3.30
T4	3	1	2.96	3.11	2.85	2.97
T4	4	1	3.27	3.36	3.13	3.25
T4	5	1	4.7	4.97	4.05	4.57
T5	1	1	2.86	2.94	2.76	2.85
T5	2	1	2.7	2.96	3.25	2.97
T5	3	1	3.04	3.6	3.35	3.33
R-T1	3	1	3.19	3.17	2.64	3.00
R-T4	3	1	2.91	3.03	2.5	2.81
R-T2	5	1	3.49	2.88	2.82	3.06
R-T3	4	1	3.49	2.88	2.82	3.06
T1	1	2	3.26	3.37	3.11	3.25
T1	2	2	3.36	3.35	3.12	3.28
T1	3	2	3.61	3.56	3.14	3.44
T2	1	2	4.86	4.65	4.8	4.77
T2	2	2	4.77	4.29	4.2	4.42
T2	3	2	3.68	3.9	4.24	3.94
T2	4	2	5.55	5.53	5.21	5.43
T2	5	2	7.85	7.46	8.19	7.83
T3	1	2	6.22	4.95	4.17	5.11
T3	2	2	3.56	4.11	3.27	3.65
T3	3	2	5.28	3.7	3.21	4.06
T3	4	2	3.21	2.9	3.72	3.28
T3	5	2	5.33	5.31	4.6	5.08
T4	1	2	3.74	3.41	3.4	3.52
T4	2	2	4	3.95	3.58	3.84
T4	3	2	3.35	3.42	2.98	3.25
T4	4	2	3.89	5	3.82	4.24
T4	5	2	5.78	4.78	5.6	5.39
T5	1	2	3.37	3.85	3.14	3.45
T5	2	2	3.82	3.38	3.14	3.45
T5	3	2	4.26	3.94	4.46	4.22
R-T2	1	2	5.08	4.71	4.46	4.75
R-T5	3	2	5.19	4.45	4.31	4.65
R-T1	2	2	4.45	4	3.1	3.85
R-T3	5	2	5.59	4.74	4.45	4.93

Day 3: October 22, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	3	3.54	3.75	3.72	3.67
T1	2	3	4.42	4.59	3.25	4.09
T1	3	3	4.24	3.96	3.96	4.05
T2	1	3	5.28	5.06	4.69	5.01
T2	2	3	5.84	4.95	5.13	5.31
T2	3	3	4.18	5.02	3.86	4.35
T2	4	3	6.3	4.47	4.75	5.17
T2	5	3	5.25	5.49	5.42	5.39
T3	1	3	6.12	4.64	3.74	4.83
T3	2	3	3.42	3.98	3.89	3.76
T3	3	3	3.37	2.88	3.95	3.40
T3	4	3	4	3.28	3.35	3.54
T3	5	3	4.1	4.15	4	4.08
T4	1	3	3.68	3.55	3.73	3.65
T4	2	3	3.66	3.37	3.63	3.55
T4	3	3	4.34	3.69	3.6	3.88
T4	4	3	3.58	4.8	4.14	4.17
T4	5	3	3.72	4.76	3.38	3.95
T5	1	3	3.66	3.38	3.16	3.40
T5	2	3	3.95	3.95	3.94	3.95
T5	3	3	5.47	4.23	4.11	4.60
R-T5	3	3	4.1	3.96	3.3	3.79
R-T1	1	3	4.85	3.43	3.3	3.86
R-T3	2	3	3.72	3.35	3.82	3.63

Day 4: October 23, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	1	8.44	4.56	4.37	5.79
T1	2	1	5.71	4.39	3.32	4.47
T1	3	1	5.39	5.52	4.91	5.27
T2	1	1	6.72	5.31	5.98	6.00
T2	2	1	7.47	7.83	5.76	7.02
T2	3	1	6.71	5.48	5.86	6.02
T2	4	1	6.75	6.12	5.24	6.04
T2	5	1	12.3	14.3	10.6	12.40
T3	1	1	4.48	4.19	4.84	4.50
T3	2	1	5.85	7.14	4.79	5.93
T3	3	1	4.82	4.33	4.4	4.52
T3	4	1	5.89	5.57	4.04	5.17
T3	5	1	6.8	5.42	5.12	5.78
T4	1	1	4.78	5.63	3.87	4.76
T4	2	1	4.25	4.45	4.09	4.26
T4	3	1	4.64	4.06	3.33	4.01
T4	4	1	5.16	7.09	4.62	5.62
T4	5	1	4.41	4.67	3.69	4.26
T5	1	1	5.56	3.48	4.63	4.56
T5	2	1	7.42	4.41	4.24	5.36
T5	3	1	8.97	6.65	5.85	7.16
R-T3	5	1	5.79	4.57	5.18	5.18
R-T2	1	1	5.4	4.96	4.41	4.92
R-T1	2	1	4.43	4.14	3.06	3.88
R-T4	4	1	5.86	4.89	5.23	5.33
T1	1	2	6.88	5.72	4.98	5.86
T1	2	2	7.7	6.78	4.33	6.27
T1	3	2	8.16	6.3	5.68	6.71
T2	1	2	7.9	5.12	5.39	6.14
T2	2	2	8.94	5.84	6.17	6.98
T2	3	2	6.12	6.83	5.87	6.27
T2	4	2	9.64	7.02	5.04	7.23
T2	5	2	9.44	7.07	6.54	7.68
T3	1	2	6.27	5.32	5.06	5.55
T3	2	2	4.33	4.25	4.1	4.23
T3	3	2	5.87	7.57	4.55	6.00
T3	4	2	7.55	7.21	5.17	6.64
T3	5	2	11	7.99	6.73	8.57
T4	1	2	4.53	4.99	3.64	4.39
T4	2	2	5.12	5.56	4.5	5.06
T4	3	2	5.53	6.52	6.16	6.07
T4	4	2	4.8	5.07	4.66	4.84
T4	5	2	7.46	5.89	5.21	6.19
T5	1	2	4.28	5.54	4.3	4.71
T5	2	2	3.84	5.41	4.26	4.50
T5	3	2	4.6	4.57	5.01	4.73
R-T5	2	2	6.59	5.69	4.25	5.51
R-T4	5	2	7.97	6.37	4.83	6.39
R-T1	1	2	6.35	6.41	6.22	6.33
R-T3	3	2	6.6	5.12	4.15	5.29

Table F. Case History December 2000-January 2001 Raw Turbidity (NTU) Data

Day 1: December 29, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	2	2.75	2.82	2.61	2.73
T1	2	2	4.38	3.62	4.18	4.06
T1	3	2	2.78	2.67	2.66	2.70
T2	1	2				
T2	2	2	3.02	2.96	2.82	2.93
T2	3	2	2.79	2.57	2.76	2.71
T2	4	2	3.56	3.5	3.08	3.38
T2	5	2				
T3	1	2				
T3	2	2	3.69	3.49	3.46	3.55
T3	3	2	2.46	2.27	2.59	2.44
T3	4	2	2.9	2.57	2.4	2.62
T3	5	2				
T4	1	2				
T4	2	2	2.62	2.51	2.63	2.59
T4	3	2	2.32	2.14	2.02	2.16
T4	4	2	1.96	2.34	2.16	2.15
T4	5	2				
T5	1	2				
T5	2	2				
T5	3	2				
R-T3	2	2	3.41	3.23	3.52	3.39
R-T4	4	2	2.46	3.07	2.26	2.60
T1	1	3	2.57	2.54	2.3	2.47
T1	2	3	2.38	2.2	2.19	2.26
T1	3	3	2.64	2.35	2.42	2.47
T2	1	3				
T2	2	3	3.09	2.47	2.51	2.69
T2	3	3	2.34	1.91	2.22	2.16
T2	4	3	2.46	2.14	2.67	2.42
T2	5	3				
T3	1	3				
T3	2	3	2.86	3.15	2.9	2.97
T3	3	3	2.46	2.36	3	2.61
T3	4	3	2.63	2.59	2.87	2.70
T3	5	3				
T4	1	3				
T4	2	3	2.94	2.52	2.37	2.61
T4	3	3	2.46	2.02	2.11	2.20
T4	4	3	2.16	1.94	1.94	2.01
T4	5	3				
T5	1	3				
T5	2	3				
T5	3	3				
R-T1	2	3	2.4	2.41	2.2	2.34
R-T2	3	3	2.42	2.45	2.33	2.40
R-T3	3	3	2.66	2.09	2.37	2.37
R-T4	4	3	1.8	1.77	2	1.86

Day 2: December 30, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	1	3.75	3.55	3.69	3.66
T1	2	1	3.57	3.42	3.27	3.42
T1	3	1	2.89	3.05	2.78	2.91
T2	1	1	4.96	4.2	3.89	4.35
T2	2	1	4.48	3.91	4.39	4.26
T2	3	1	3.99	3.77	3.67	3.81
T2	4	1	3.75	3.85	3.57	3.72
T2	5	1	4.99	4.25	3.73	4.32
T3	1	1	4.64	4.38	3.96	4.33
T3	2	1	7.77	6.48	7.81	7.35
T3	3	1	3.81	3.53	3.64	3.66
T3	4	1	3.37	3.52	3.06	3.32
T3	5	1	3.92	3.2	3.15	3.42
T4	1	1				
T4	2	1	3.31	2.94	2.83	3.03
T4	3	1	3.45	2.67	2.7	2.94
T4	4	1	3.93	3.37	3.38	3.56
T4	5	1				
R-T1	2	1	3.53	3.68	2.66	3.29
R-T3	2	1	5.36	5.2	4.43	5.00
R-T4	4	1	2.47	2.2	2.42	2.36
		1				
T1	1	2	3.87	3.85	5.32	4.35
T1	2	2	3.31	3.74	4.27	3.77
T1	3	2	6.15	6.12	6.11	6.13
T2	1	2	5.93	5.15	5.55	5.54
T2	2	2	5.4	4.16	3.88	4.48
T2	3	2	4.45	3.42	3.23	3.70
T2	4	2	4.04	4.27	3.47	3.93
T2	5	2	3.09	2.89	3.23	3.07
T3	1	2	5.47	5.68	6.24	5.80
T3	2	2	4.39	3.61	4.26	4.09
T3	3	2	3.71	3.34	3.6	3.55
T3	4	2	3.59	3.26	3.28	3.38
T3	5	2	4.1	3.65	3.37	3.71
T4	1	2	3.9	4.06	3.77	3.91
T4	2	2	4.59	4.41	4.47	4.49
T4	3	2	4.74	3.66	3.78	4.06
T4	4	2	4.09	5.79	3.53	4.47
T4	5	2	4.2	3.58	3.39	3.72
R-T1	1	2	4.58	5.03	5.01	4.87
R-T2	2	2	4.01	4.51	3.39	3.97
R-T3	1	2	6.23	6.36	6.18	6.26
R-T4	3	2	5.07	3.83	3.28	4.06

Day 2: December 30, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	3	3.85	3.65	3.04	3.51
T1	2	3	4.13	4.16	3.83	4.04
T1	3	3	3.77	4.12	4.46	4.12
T2	1	3	7.05	5.43	5.85	6.11
T2	2	3	4.7	5.03	4.53	4.75
T2	3	3	5.18	4.9	5.94	5.34
T2	4	3	4.06	3.97	3.58	3.87
T2	5	3	5.29	3.9	4.4	4.53
T3	1	3	9.91	9.79	9.92	9.87
T3	2	3	6.34	9.38	5.61	7.11
T3	3	3	3.97	4.19	3.95	4.04
T3	4	3	3.59	3.56	3.44	3.53
T3	5	3	3.35	3.49	4.24	3.69
T4	1	3	3.84	3.78	3.46	3.69
T4	2	3	4.12	4.77	3.78	4.22
T4	3	3	4.93	5.95	4.67	5.18
T4	4	3	3.2	3.67	3.64	3.50
T4	5	3	3.74	4.45	3.66	3.95
R-T1	2	3	3	3.09	3.24	3.11
R-T2	4	3	4.56	3.58	3.75	3.96
R-T3	1	3	9.31	9.99	8.69	9.33
R-T4	5	3	4.06	4.37	3.75	4.06

Day 3: December 31, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	1	2.93	2.71	2.64	2.76
T1	2	1	2.89	2.82	2.7	2.80
T1	3	1	2.64	2.73	2.97	2.78
T2	1	1	4.21	4.36	4.29	4.29
T2	2	1	2.82	2.79	2.68	2.76
T2	3	1	2.94	2.9	2.72	2.85
T2	4	1	3.38	3.09	2.97	3.15
T2	5	1	2.88	2.65	3.88	3.14
T3	1	1	59.2	56	56.1	57.10
T3	2	1	2.8	3.02	3.03	2.95
T3	3	1	3.39	2.42	2.37	2.73
T3	4	1	2.52	2.56	2.59	2.56
T3	5	1	2.43	2.63	2.37	2.48
T4	1	1	2.69	2.68	3.26	2.88
T4	2	1	2.78	2.89	2.88	2.85
T4	3	1	2.59	2.5	2.57	2.55
T4	4	1	2.71	3.34	2.5	2.85
T4	5	1	3.35	2.81	3.18	3.11
R-T1	1	1	2.7	2.83	2.81	2.78
R-T2	1	1	5.94	5.68	5.31	5.64
R-T3	1	1	73.3	71.1	69.7	71.37
R-T4	3	1	2.8	2.5	2.43	2.58
T1	1	2	3.09	3.68	3.18	3.32
T1	2	2	2.8	2.72	2.55	2.69
T1	3	2	2.47	2.99	3.04	2.83
T2	1	2	153	158	158	156.33
T2	2	2	9.35	8.55	8.76	8.89
T2	3	2	3.05	2.82	2.8	2.89
T2	4	2	2.83	3.11	3.65	3.20
T2	5	2	2.77	2.78	2.66	2.74
T3	1	2	509	516	518	514.33
T3	2	2	30.4	29.9	29.5	29.93
T3	3	2	3.19	3.33	3.56	3.36
T3	4	2	2.68	2.7	3.12	2.83
T3	5	2	2.45	2.42	2.32	2.40
T4	1	2	4.38	4.45	4.9	4.58
T4	2	2	2.74	2.59	3.14	2.82
T4	3	2	2.47	2.39	2.75	2.54
T4	4	2	2.45	2.55	2.38	2.46
T4	5	2	2.75	2.57	2.45	2.59
R-T1	2	2	2.44	2.37	2.41	2.41
R-T2	1	2	161	166	164	163.67
R-T3	1	2	453	455	459	455.67
R-T4	4	2	2.82	3.02	2.99	2.94

Day 3: December 31, 2000			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	3	2.59	2.5	2.88	2.66
T1	2	3	2.41	2.45	2.54	2.47
T1	3	3	2.6	2.29	2.26	2.38
T2	1	3	214	216	217	215.67
T2	2	3	3.84	3.39	3.37	3.53
T2	3	3	2.99	2.61	2.94	2.85
T2	4	3	2.97	3.01	3.13	3.04
T2	5	3	3.13	2.78	2.74	2.88
T3	1	3	120	121	121	120.67
T3	2	3	7.08	6.51	6.4	6.66
T3	3	3	3.04	2.59	2.63	2.75
T3	4	3	2.64	2.55	2.44	2.54
T3	5	3	2.91	2.44	2.4	2.58
T4	1	3	3.15	2.77	2.78	2.90
T4	2	3	2.87	2.77	2.79	2.81
T4	3	3	2.41	2.54	2.5	2.48
T4	4	3	2.52	2.36	2.4	2.43
T4	5	3	3.33	2.52	2.36	2.74
R-T3	1	3	115	118	120	117.67

Day 4: January 1, 2001			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	1	4.28	3.86	4.28	4.14
T1	2	1	2.64	3.12	2.96	2.91
T1	3	1	2.58	2.33	2.26	2.39
T2	1	1	6.02	6.59	5.82	6.14
T2	2	1	6.32	5.79	5.93	6.01
T2	3	1	4.97	4.63	4.31	4.64
T2	4	1	3.11	2.98	2.76	2.95
T2	5	1	4.51	3.74	3.9	4.05
T3	1	1	17.8	15.4	16.6	16.60
T3	2	1	6.31	6.51	5.78	6.20
T3	3	1	5.25	5.1	4.71	5.02
T3	4	1	4.88	5.25	4.8	4.98
T3	5	1	5.18	6.12	6.31	5.87
T4	1	1	5.79	6.24	6.04	6.02
T4	2	1	5.23	4.7	4.65	4.86
T4	3	1	5.59	6.14	5.96	5.90
T4	4	1	5.34	5.42	5.43	5.40
T4	5	1	6.33	4.68	5.12	5.38
R-T1	1	1	2.59	2.5	2.54	2.54
R-T2	2	1	4.93	4.9	4.72	4.85
R-T3	1	1	17.1	17.2	17.5	17.27
R-T4	4	1	4.79	5.11	5.12	5.01
T1	1	2	2.74	2.56	2.69	2.66
T1	2	2	2.43	2.68	2.56	2.56
T1	3	2	2.5	2.48	2.46	2.48
T2	1	2	5.62	5.12	5.67	5.47
T2	2	2	9.24	9.79	8.86	9.30
T2	3	2	5.28	5	4.46	4.91
T2	4	2	5.19	4.98	5.15	5.11
T2	5	2	9.35	9.4	9.38	9.38
T3	1	2	30.4	30.5	29.7	30.20
T3	2	2	8.92	8.08	8.48	8.49
T3	3	2	10	10.4	10.4	10.27
T3	4	2	9.43	9.03	8.95	9.14
T3	5	2	11.2	12	10.2	11.13
T4	1	2	12.8	11.8	11.3	11.97
T4	2	2	9.92	8.78	9.32	9.34
T4	3	2	8.58	8.02	7.36	7.99
T4	4	2	8.69	7.66	7.53	7.96
T4	5	2	8.53	8.31	8.33	8.39
R-T1	2	2	2.88	2.59	2.5	2.66
R-T2	1	2	5.65	5.5	5.21	5.45
R-T3	1	2	25.5	25.9	25.4	25.60
R-T4	5	2	7.99	8.96	7.73	8.23

Day 4: January 1, 2001			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	3	2.54	2.89	3.34	2.92
T1	2	3	2.29	2.27	2.28	2.28
T1	3	3	2.26	2.69	2.12	2.36
T2	1	3	5.68	5.04	5.34	5.35
T2	2	3	4.25	4.4	4.23	4.29
T2	3	3	3.84	3.6	3.9	3.78
T2	4	3	3.83	3.58	3.39	3.60
T2	5	3	5.05	5.02	4.53	4.87
T3	1	3	129	123	124	125.33
T3	2	3	5.31	5.32	5.46	5.36
T3	3	3	6.57	6.32	5.51	6.13
T3	4	3	8.46	6.28	5	6.58
T3	5	3	6.36	5.24	6.42	6.01
T4	1	3	11.7	14	11	12.23
T4	2	3	8.89	6.74	6.88	7.50
T4	3	3	5.33	5.18	4.81	5.11
T4	4	3	5.96	5.65	6.24	5.95
T4	5	3	5.68	5.16	5.12	5.32
T5	1	3	13.9	14.8	13.2	13.97
T5	2	3	6.91	5.77	6.06	6.25
T5	3	3	5.95	5.86	5.79	5.87
R-T1	3	3	2.74	2.24	2.46	2.48
R-T2	1	3	5.63	4.61	4.33	4.86

Day 5: January 2, 2001			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	1	2.38	2.4	2.27	2.35
T1	2	1	2.26	2.2	2.11	2.19
T1	3	1	2.27	2.24	2.45	2.32
T2	1	1	2.77	2.83	2.61	2.74
T2	2	1	2.86	2.94	2.46	2.75
T2	3	1	2.79	3.21	2.92	2.97
T2	4	1	2.68	2.36	2.36	2.47
T2	5	1	2.51	3.72	2.45	2.89
T3	1	1	4.61	4.23	4.23	4.36
T3	2	1	3.39	2.88	3.13	3.13
T3	3	1	2.75	2.63	2.77	2.72
T3	4	1	2.67	2.76	2.53	2.65
T3	5	1	2.66	2.67	3.38	2.90
T4	1	1	3.58	3.83	3.66	3.69
T4	2	1	2.68	2.63	2.71	2.67
T4	3	1	2.58	2.53	2.48	2.53
T4	4	1	2.48	3.07	2.63	2.73
T4	5	1	3.37	2.78	2.74	2.96
T5	1	1	3.2	3.24	3.8	3.41
T5	2	1	2.99	3.1	2.72	2.94
T5	3	1	2.68	2.94	2.68	2.77
R-T1	1	1	2.28	2.11	2.38	2.26
R-T2	1	1	3.47	3.03	3.09	3.20
R-T3	1	1	3.59	3.79	3.52	3.63
T1	1	2	2.19	2.22	2.14	2.18
T1	2	2	2.36	2.13	2.04	2.18
T1	3	2	3.98	3.77	3.68	3.81
T2	1	2	3.43	3.27	2.83	3.18
T2	2	2	2.84	2.81	2.42	2.69
T2	3	2	3.26	3.33	3.19	3.26
T2	4	2	3.08	2.38	2.4	2.62
T2	5	2	3.8	3.16	3.39	3.45
T3	1	2	3.71	3.72	3.66	3.70
T3	2	2	2.94	2.49	2.74	2.72
T3	3	2	2.19	2.35	2.37	2.30
T3	4	2	2.49	2.72	2.52	2.58
T3	5	2	2.64	2.74	2.41	2.60
T4	1	2	2.65	3.05	2.52	2.74
T4	2	2	2.81	2.62	2.4	2.61
T4	3	2	2.45	2.28	2.32	2.35
T4	4	2	2.74	2.48	2.68	2.63
T4	5	2	2.71	2.51	2.58	2.60
T5	2	2	3.59	3.39	4.39	3.79
T5	1	2	2.4	2.4	2.47	2.42
T5	1	2	2.61	3.02	2.61	2.75
R-T1	3	2	2.31	2.05	2.23	2.20
R-T2	1	2	2.71	2.98	2.58	2.76
R-T3	1	2	3.66	3.47	3.85	3.66

Day 5: January 2, 2001			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	3	2.82	2.18	2.17	2.39
T1	2	3	2.18	2.08	2.28	2.18
T1	3	3	2.44	2.48	2.33	2.42
T2	1	3	2.85	3.14	2.8	2.93
T2	2	3	2.98	3.4	3.51	3.30
T2	3	3	2.81	2.9	2.28	2.66
T2	4	3	2.69	2.39	2.39	2.49
T2	5	3	3.58	3.16	2.91	3.22
T3	1	3	5.32	5.5	4.52	5.11
T3	2	3	2.89	3.25	3.02	3.05
T3	3	3	2.99	2.6	2.78	2.79
T3	4	3	2.58	2.95	2.58	2.70
T3	5	3	2.9	2.82	2.67	2.80
T4	1	3	3.48	3.09	3.11	3.23
T4	2	3	3.51	3.1	3.03	3.21
T4	3	3	3.42	2.82	2.98	3.07
T4	4	3	3.17	2.69	2.64	2.83
T4	5	3	2.71	2.98	2.7	2.80
T5	1	3	3.47	3.05	3.11	3.21
T5	2	3	2.71	3.36	3.49	3.19
T5	3	3	3.2	2.95	2.83	2.99
R-T1	1	3	2.12	2.27	2.44	2.28
R-T3	5	3	2.73	2.74	2.64	2.70
R-T4	3	3	2.96	2.86	2.85	2.89
R-T5	1	3	3.38	3.74	2.86	3.33

Table G. Case History March 2001 Raw Turbidity (NTU) Data

Day 1: March 23, 2001			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	1	4.33	4.52	4.38	4.41
T1	2	1	5.16	4.23	4.37	4.59
T1	3	1	4.55	3.88	4.11	4.18
T2	1	1	6.47	7.49	6.84	6.93
T2	2	1				
T2	3	1	6	6.47	5.97	6.15
T2	4	1	5.6	5.85	5.83	5.76
T2	5	1	5.07	4.55	4.94	4.85
T3	1	1	3.74	3.43	3.74	3.64
T3	2	1	4.47	5.67	4.81	4.98
T3	3	1	5.21	5	4.36	4.86
T3	4	1	5.89	5.93	5.42	5.75
T3	5	1	3.89	3.86	3.72	3.82
T4	1	1	5.2	4.8	6.81	5.60
T4	2	1	6.12	5.39	5.79	5.77
T4	3	1	3.69	3.39	3.56	3.55
T4	4	1	3.42	3.66	3.4	3.49
T4	5	1	4.65	4.28	5.48	4.80
T5	1	1	4.76	3.9	4.16	4.27
T5	2	1	4.09	4.2	4.09	4.13
T5	3	1	4.67	4.34	4.56	4.52
R-T5	3	1	5.24	3.89	4	4.38
R-T4	1	1	5.02	4.58	4.64	4.75
R-T1	1	1	5.2	4.59	5.11	4.97
T1	1	3	7.55	6.97	6.65	7.06
T1	2	3	9.13	6.63	7.71	7.82
T1	3	3	6.61	6.87	6.75	6.74
T2	1	3	7.09	6.68	6.08	6.62
T2	2	3	7.72	8.83	8.48	8.34
T2	3	3	8.42	8.61	9.37	8.80
T2	4	3	7.44	8.35	7.73	7.84
T2	5	3				
T3	1	3	7.13	7.38	7.57	7.36
T3	2	3	8.98	6.22	6.85	7.35
T3	3	3	7.12	6.96	6.78	6.95
T3	4	3	6.48	7.73	7.23	7.15
T3	5	3	7.83	8.17	7.74	7.91
T4	1	3	8.09	7.62	6.87	7.53
T4	2	3	7.56	7.16	6.51	7.08
T4	3	3	7.16	7.37	8.77	7.77
T4	4	3	6.88	6.56	6.01	6.48
T4	5	3	9.67	9.83	9.94	9.81
T5	1	3	6.78	6.53	5.95	6.42
T5	2	3	6.73	6.65	7.36	6.91
T5	3	3	8.3	7.51	7.75	7.85
R-T1	1	3	6.51	5.89	5.58	5.99
R-T2	1	3	7.71	6.72	6.32	6.92
R-T3	5	3	7.21	5.91	6.85	6.66
R-T5	3	3	8.01	4.54	6.56	6.37

Day 2: March 24, 2001			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	1	3.95	3.53	3.73	3.74
T1	2	1	3.95	4.42	4.09	4.15
T1	3	1	4.32	3.36	3.18	3.62
T2	1	1	4.88	4.71	4.93	4.84
T2	2	1	4.24	4.05	4.23	4.17
T2	3	1	4.75	5.09	4.94	4.93
T2	4	1	3.75	3.43	3.97	3.72
T2	5	1	5.15	5.06	5.03	5.08
T3	1	1	5	5.5	4.66	5.05
T3	2	1	3.84	4.25	4.5	4.20
T3	3	1	5.54	5.93	6.63	6.03
T3	4	1	3.87	3.76	3.81	3.81
T3	5	1	7.54	6.14	5.73	6.47
T4	1	1	4.51	3.51	4.48	4.17
T4	2	1	4.12	3.48	3.49	3.70
T4	3	1	4.24	4.16	3.51	3.97
T4	4	1	3.24	3.09	3.12	3.15
T4	5	1	4.58	4.69	4.27	4.51
T5	1	1	3.97	4.51	4.17	4.22
T5	2	1	4.27	3.45	3.73	3.82
T5	3	1	6.61	6.54	5.88	6.34
R-T2	1	1	5.48	5.66	5.36	5.50
R-T3	5	1	7.28	7.1	6.54	6.97
R-T4	4	1	3.78	4.51	4.03	4.11
R-T5	1	1	4.76	4.14	3.87	4.26
T1	1	2	4.56	6.05	4.28	4.96
T1	2	2	6.01	4.76	4.66	5.14
T1	3	2	5	5.25	5.8	5.35
T2	1	2	4.07	4.1	3.63	3.93
T2	2	2	5.13	5	4.57	4.90
T2	3	2	4.89	5.09	4.84	4.94
T2	4	2	8.76	7.49	7.74	8.00
T2	5	2	19.8	20.7	18.7	19.73
T3	1	2	5.76	5.06	4.55	5.12
T3	2	2	4.29	4.33	3.94	4.19
T3	3	2	3.94	4.39	4.39	4.24
T3	4	2	4.29	4.55	4.4	4.41
T3	5	2	8.1	7.58	6.94	7.54
T4	1	2	4.31	4.45	3.65	4.14
T4	2	2	4.27	4.79	3.94	4.33
T4	3	2	4.38	3.98	3.64	4.00
T4	4	2	6.66	6.54	5.99	6.40
T4	5	2	13.7	13.3	12.5	13.17
T5	1	2	4.63	4.26	4.44	4.44
T5	2	2	5.38	5.18	5.5	5.35
T5	3	2	9.51	8.99	8.96	9.15
R-T2	1	2	4.16	3.58	3.99	3.91
R-T3	4	2	6.25	6.03	6.06	6.11
R-T5	3	2	4.76	5.08	4.68	4.84

Day 2: March 24, 2001			*Triplicate Turbidity (NTU) Readings per Sample*			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	3	8	6.48	6.18	6.89
T1	2	3	5.47	5.75	5.49	5.57
T1	3	3	6.49	5.4	7.18	6.36
T2	1	3	5.17	5.52	6.08	5.59
T2	2	3	6.53	6.6	7.09	6.74
T2	3	3	6.99	6.74	6.77	6.83
T2	4	3	8.56	7.81	7.89	8.09
T2	5	3	6.24	7.03	6.55	6.61
T3	1	3	7.47	6.78	5.66	6.64
T3	2	3	6.13	5.47	6.91	6.17
T3	3	3	6.87	6.02	5.97	6.29
T3	4	3	6.11	7.98	6.11	6.73
T3	5	3	10.6	11.4	10.8	10.93
T4	1	3	7.32	6.8	7.98	7.37
T4	2	3	5.74	6.35	5.44	5.84
T4	3	3	7.59	6.39	6.14	6.71
T4	4	3	9.96	10.1	9.62	9.89
T4	5	3	12.8	12.8	14	13.20
T5	1	3	5.13	6.46	4.64	5.41
T5	2	3	6.15	6.45	6.87	6.49
T5	3	3	12.3	12.3	11.4	12.00
T6	1	3	10.5	8.24	9.07	9.27
T6	2	3	12.7	12.2	13.8	12.90
T6	3	3	17.5	18.7	19.8	18.67
R-T1	1	3	8.08	6.89	7.85	7.61
R-T2	1	3	5.99	5.48	5.89	5.79
R-T3	3	3	5.9	6.44	5.72	6.02

Day 3: March 25, 2001			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	1	3.43	3.09	2.97	3.16
T1	2	1	3.87	3.35	3.6	3.61
T1	3	1	3.17	2.74	2.75	2.89
T2	1	1	3.87	4.07	4.67	4.20
T2	2	1	3.11	3.17	3.17	3.15
T2	3	1	2.88	2.95	3.09	2.97
T2	4	1	2.82	2.89	3.29	3.00
T2	5	1	2.61	3.04	2.97	2.87
T3	1	1	2.99	3.27	2.94	3.07
T3	2	1	3.14	3.56	3.86	3.52
T3	3	1	3.23	3.21	3.08	3.17
T3	4	1	3.12	2.84	3.01	2.99
T3	5	1	3.02	3.1	2.75	2.96
T4	1	1	3.4	3.47	3.26	3.38
T4	2	1	2.95	3.25	2.9	3.03
T4	3	1	3.01	2.82	3.24	3.02
T4	4	1	3.22	3.02	3.5	3.25
T4	5	1	2.97	2.72	2.82	2.84
T5	1	1	4.03	3.82	3.26	3.70
T5	2	1	3.2	2.89	2.95	3.01
T5	3	1	3.16	3.18	2.9	3.08
R-T1	3	1	2.71	2.47	2.73	2.64
R-T2	1	1	7.64	4.22	5.09	5.65
R-T3	3	1	3.74	2.75	2.95	3.15
R-T4	5	1	2.84	3.34	2.92	3.03
T1	1	2	4.41	5.7	4.51	4.87
T1	2	2	5.57	5.45	5.62	5.55
T1	3	2	4.86	4.48	4.51	4.62
T2	1	2	5.36	5.3	5.27	5.31
T2	2	2	5.01	4.26	4.9	4.72
T2	3	2	4.6	5.07	5.18	4.95
T2	4	2	6.54	7.17	5.31	6.34
T2	5	2	10.4	9.72	9.51	9.88
T3	1	2	5.87	4.53	4.58	4.99
T3	2	2	4.46	3.66	4.19	4.10
T3	3	2	4.81	5.01	4.67	4.83
T3	4	2	6.31	6.03	5.2	5.85
T3	5	2	8.21	8.61	7.99	8.27
T4	1	2	4.68	4.29	4.51	4.49
T4	2	2	4.39	3.26	3.8	3.82
T4	3	2	4.54	4.44	4.44	4.47
T4	4	2	8.95	7.22	6.74	7.64
T4	5	2	13.4	10.5	11	11.63
T5	1	2	4.62	4.16	4.07	4.28
T5	2	2	4.47	4.87	4.16	4.50
T5	3	2	8.64	9.36	7.61	8.54
R-T2	1	2	5.47	5.09	4.77	5.11
R-T3	3	2	5.03	4.55	3.93	4.50
R-T5	2	2	5.28	5.23	4.91	5.14
R-T1	1	2	4.69	5.26	4.26	4.74

Day 3: March 25, 2001			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	3	7.28	6.6	5.98	6.62
T1	2	3	7.12	5.8	7.11	6.68
T1	3	3	5.97	6.9	6.48	6.45
T2	1	3	6.02	5.79	5.69	5.83
T2	2	3	9.55	6.62	6.12	7.43
T2	3	3	6.3	5.42	6.12	5.95
T2	4	3	6.37	6.45	5.34	6.05
T2	5	3	8.02	9.01	8.39	8.47
T3	1	3	6.05	6.43	7.39	6.62
T3	2	3	8.18	6.69	6.83	7.23
T3	3	3	7.43	6.73	6.77	6.98
T3	4	3	8.84	6.95	7.94	7.91
T3	5	3	9.16	13.5	8.1	10.25
T4	1	3	7.62	6.76	6.43	6.94
T4	2	3	6.37	6	5.73	6.03
T4	3	3	6.73	6.41	6.41	6.52
T4	4	3	8.74	9.75	8.4	8.96
T4	5	3	13.8	14.6	12.7	13.70
T5	1	3	7.65	6.7	5.62	6.66
T5	2	3	6.55	6.55	7.02	6.71
T5	3	3	10.5	9.31	8.41	9.41
T6	1	3				
T6	2	3				
T6	3	3				
R-T1	1	3	7.41	7.39	6.69	7.16
R-T3	5	3	9.05	9.01	8.7	8.92
R-T4	2	3	6.61	8.4	6.12	7.04
R-T5	2	3	7.39	10.1	6.94	8.14

Day 4: March 26, 2001			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	1	4.57	4.3	4.21	4.36
T1	2	1	3.9	3.82	3.43	3.72
T1	3	1	4.4	3.72	4.43	4.18
T2	1	1	4.8	4.87	5.02	4.90
T2	2	1	4.18	3.71	3.25	3.71
T2	3	1	4.2	4.8	3.88	4.29
T2	4	1	4.58	4.36	3.48	4.14
T2	5	1	4.79	4.07	4.59	4.48
T3	1	1	3.97	4.37	3.98	4.11
T3	2	1	4.82	4.79	4.77	4.79
T3	3	1	3.65	3.43	3.5	3.53
T3	4	1	4.79	3.79	4.06	4.21
T3	5	1	4.7	4.57	3.9	4.39
T4	1	1	3.98	4.21	3.63	3.94
T4	2	1	4.69	3.87	3.61	4.06
T4	3	1	4.45	4.03	3.59	4.02
T4	4	1	4.35	4.99	3.99	4.44
T4	5	1	4.68	4.45	3.6	4.24
T5	1	1	4.78	4.11	3.57	4.15
T5	2	1	4.75	3.85	2.96	3.85
T5	3	1	4.64	4.82	4.08	4.51
R-T1	2	1	4.44	4.39	4.25	4.36
R-T3	5	1	4.02	4.57	3.92	4.17
R-T4	4	1	5.54	5.26	5.06	5.29
R-T5	1	1	5.32	5.14	5	5.15
T1	1	2	4.01	4	4.37	4.13
T1	2	2	4.9	5.86	4.62	5.13
T1	3	2	5.06	4.99	5.16	5.07
T2	1	2	5.67	6.06	5.21	5.65
T2	2	2	4.78	4.73	4.69	4.73
T2	3	2	4.78	4.31	7.25	5.45
T2	4	2	5.02	6.07	5.26	5.45
T2	5	2	5.78	5.77	5.65	5.73
T3	1	2	4.68	4.61	4.86	4.72
T3	2	2	4.41	4.03	4.35	4.26
T3	3	2	5.58	5.07	4.48	5.04
T3	4	2	5.43	4.83	5.26	5.17
T3	5	2	7.27	7.28	5.51	6.69
T4	1	2	4.48	3.94	4.44	4.29
T4	2	2	4.9	4.32	4.51	4.58
T4	3	2	4.93	6.01	5.36	5.43
T4	4	2	6.25	4.95	5.04	5.41
T4	5	2	6.51	8.27	7.07	7.28
T5	1	2	4.57	4.32	4.44	4.44
T5	2	2	4.94	3.97	4.89	4.60
T5	3	2	6.71	4.92	4.84	5.49
R-T2	2	2	4.59	4.04	4.48	4.37
R-T3	5	2	5.57	6.18	6.34	6.03
R-T5	2	2	4.19	5.11	3.9	4.40
R-T1	1	2	4.71	4.74	4.43	4.63

Day 5: March 27, 2001			Triplicate Turbidity (NTU) Readings per Sample			Average NTU
Transect	Site	Suite	NTU	NTU	NTU	
T1	1	2	3.93	4	4.05	3.99
T1	2	2	4.51	4.18	4.12	4.27
T1	3	2	4.59	3.98	4.45	4.34
T2	1	2	3.35	3.76	3.94	3.68
T2	2	2	4.51	3.68	3.57	3.92
T2	3	2	4.56	3.8	4.34	4.23
T2	4	2	5.21	4.04	4.85	4.70
T2	5	2	4.96	4.21	5.59	4.92
T3	1	2	3.71	3.59	3.25	3.52
T3	2	2	3.63	3.96	3.36	3.65
T3	3	2	4.32	5.45	3.3	4.36
T3	4	2	4.64	3.64	3.77	4.02
T3	5	2	3.68	4.07	3.28	3.68
T4	1	2	3.58	4.28	3.89	3.92
T4	2	2	3.9	4.17	3.77	3.95
T4	3	2	3.83	3.53	3.6	3.65
T4	4	2	4.02	4.03	3.2	3.75
T4	5	2	4.39	4.13	4.71	4.41
T5	1	2	4.22	3.85	3.27	3.78
T5	2	2	3.82	3.31	3.47	3.53
T5	3	2	4.32	3.64		3.98
R-T4	4	2	3.21	3.4	2.77	3.13
R-T3	5	2	4.37	4.16	4.08	4.20
R-T5	3	2	3.92	3.99	3.15	3.69
R-T1	1	2	4.4	3.7	3.78	3.96

Table H. Linear Correlation Calculations for Case History Field Turbidity (NTU) Versus Field Total Suspended Sediment (TSS)

		x	y	X	Y	X^2	XY	Y^2
Date	Transect – Sampling Site Location	Field Turbidity (NTU)	Field TSS (mg/L)	Field NTU - Field NTU Mean	Field TSS - Field TSS Mean	Field NTU Squared	Field NTU x Field TSS	Field TSS Squared
4-Aug-00	T1-1	8.57	40	0.79	18.94	0.63	15.06	358.68
4-Aug-00	T1-2	10.83	5	3.06	-16.06	9.33	-49.07	257.96
4-Aug-00	T1-3	12.57	5	4.80	-16.06	22.99	-77.01	257.96
4-Aug-00	T4-1	9.26	5	1.49	-16.06	2.21	-23.85	257.96
4-Aug-00	T4-2	9.49	5	1.72	-16.06	2.94	-27.54	257.96
4-Aug-00	T4-3	10.63	20	2.86	-1.06	8.15	-3.03	1.13
4-Aug-00	T4-4	10.88	20	3.11	-1.06	9.64	-3.29	1.13
4-Aug-00	T4-5	11.3	20	3.53	-1.06	12.43	-3.74	1.13
23-Oct-00	T1-2	6.27	0	-1.51	-21.06	2.27	31.70	443.57
23-Oct-00	T4-4	4.84	50	-2.94	28.94	8.61	-84.94	837.46
23-Mar-01	T1-2	7.82	38.5	0.04	17.44	0.00	0.78	304.11
23-Mar-01	T4-3	7.77	64	-0.01	42.94	0.00	-0.21	1843.75
24-Mar-01	T1-2	5.14	20	-2.64	-1.06	6.94	2.80	1.13
24-Mar-01	T4-3	4	30	-3.78	8.94	14.25	-33.74	79.90
25-Mar-01	T1-2	5.55	10.7	-2.23	-10.36	4.95	23.05	107.35
25-Mar-01	T4-3	4.47	13.4	-3.31	-7.66	10.92	25.32	58.69
26-Mar-01	T1-2	5.13	7.3	-2.65	-13.76	7.00	36.40	189.37
26-Mar-01	T4-3	5.43	25.2	-2.35	4.14	5.50	-9.71	17.13
SUM		139.95	379.10			128.77	-181.03	5276.36
Mean		7.78	21.06					
Linear Correlation Coefficient	-0.22							

Table I. Linear Correlation Calculations for Case History Field Turbidity (NTU) Versus Laboratory Total Suspended Sediment (TSS)

		x	y	X	Y	X^2	XY	Y^2
Date	**Transect – Sampling Site Location**	**Field Turbidity (NTU)**	**Lab TSS (mg/L)**	**Field NTU - Field NTU Mean**	**Lab TSS - Lab TSS Mean**	**Field NTU Squared**	**Field NTU x Lab TSS**	**Lab TSS Squared**
4-Aug-00	T1-1	8.57	8	0.55	-6.22	0.30	-3.42	38.72
4-Aug-00	T1-2	10.83	18	2.81	3.78	7.90	10.62	14.27
4-Aug-00	T1-3	12.57	26	4.55	11.78	20.70	53.59	138.72
4-Aug-00	T4-1	9.26	16	1.24	1.78	1.54	2.20	3.16
4-Aug-00	T4-2	9.49	22	1.47	7.78	2.16	11.43	60.49
4-Aug-00	T4-3	10.63	25	2.61	10.78	6.81	28.13	116.16
4-Aug-00	T4-4	10.88	28	2.86	13.78	8.18	39.40	189.83
4-Aug-00	T4-5	11.3	26	3.28	11.78	10.76	38.63	138.72
23-Oct-00	T1-2	6.27	6	-1.75	-8.22	3.06	14.39	67.60
23-Oct-00	T2-1	6.14	6	-1.88	-8.22	3.53	15.46	67.60
23-Oct-00	T3-5	8.57	14	0.55	-0.22	0.30	-0.12	0.05
23-Oct-00	T4-4	4.84	9	-3.18	-5.22	10.11	16.61	27.27
23-Oct-00	T5-3	4.73	10	-3.29	-4.22	10.82	13.89	17.83
23-Mar-01	T1-2	7.82	12	-0.20	-2.22	0.04	0.44	4.94
23-Mar-01	T4-3	7.77	10	-0.25	-4.22	0.06	1.06	17.83
24-Mar-01	T1-2	5.14	6	-2.88	-8.22	8.29	23.68	67.60
24-Mar-01	T4-3	4	6	-4.02	-8.22	16.16	33.05	67.60
25-Mar-01	T1-2	5.55	8	-2.47	-6.22	6.10	15.37	38.72
25-Mar-01	T4-3	4.47	21	-3.55	6.78	12.60	-24.06	45.94
26-Mar-01	T1-2	5.13	7	-2.89	-7.22	8.35	20.87	52.16
26-Mar-01	T4-3	5.43	8	-2.59	-6.22	6.71	16.12	38.72
SUM		159.39	292.00			144.51	327.34	1213.93
Mean		7.59	13.90					
Linear Correlation Coefficient	0.78							

Table J. Linear Correlation Calculations for Case History Laboratory Turbidity (NTU) Versus Laboratory Total Suspended Sediment (TSS)

		x	y	X	Y	X^2	XY	Y^2
Date	**Transect – Sampling Site Location**	**Lab Turbidity (NTU)**	**Lab TSS (mg/L)**	**Lab NTU - Lab NTU Mean**	**Lab TSS - Lab TSS Mean**	**Lab NTU Squared**	**Lab NTU x Lab TSS**	**Lab TSS Squared**
4-Aug-00	T1-1	5.7	8	0.67	-6.22	0.45	-4.18	38.72
4-Aug-00	T1-2	6.5	18	1.47	3.78	2.17	5.56	14.27
4-Aug-00	T1-3	4.4	26	-0.63	11.78	0.39	-7.39	138.72
4-Aug-00	T4-1	2.6	16	-2.43	1.78	5.89	-4.32	3.16
4-Aug-00	T4-2	6.2	22	1.17	7.78	1.37	9.12	60.49
4-Aug-00	T4-3	3.6	25	-1.43	10.78	2.04	-15.39	116.16
4-Aug-00	T4-4	5.5	28	0.47	13.78	0.22	6.51	189.83
4-Aug-00	T4-5	3.4	26	-1.63	11.78	2.65	-19.17	138.72
23-Oct-00	T1-2	5.3	6	0.27	-8.22	0.07	-2.24	67.60
23-Oct-00	T2-1	6.3	6	1.27	-8.22	1.62	-10.46	67.60
23-Oct-00	T3-5	5.8	14	0.77	-0.22	0.60	-0.17	0.05
23-Oct-00	T4-4	5.8	9	0.77	-5.22	0.60	-4.03	27.27
23-Oct-00	T5-3	6.6	10	1.57	-4.22	2.47	-6.64	17.83
23-Mar-01	T1-2	6.1	12	1.07	-2.22	1.15	-2.38	4.94
23-Mar-01	T4-3	5.2	10	0.17	-4.22	0.03	-0.73	17.83
24-Mar-01	T1-2	4.5	6	-0.53	-8.22	0.28	4.34	67.60
24-Mar-01	T4-3	3.8	6	-1.23	-8.22	1.51	10.10	67.60
25-Mar-01	T1-2	3.2	8	-1.83	-6.22	3.34	11.37	38.72
25-Mar-01	T4-3	9	21	3.97	6.78	15.78	26.92	45.94
26-Mar-01	T1-2	5	7	-0.03	-7.22	0.00	0.20	52.16
26-Mar-01	T4-3	4.7	8	-0.33	-6.22	0.11	2.04	38.72
SUM		109.2	292			42.74	-0.95	1213.93
Mean		5.2	13.90					
Linear Correlation Coefficient	-0.0042							

Table K. Linear Correlation Calculations for Case History Laboratory Turbidity (NTU) Versus Field Total Suspended Sediment (TSS)

		x	y	X	Y	X^2	XY	Y^2
Date	**Transect – Sampling Site Location**	**Lab Turbidity (NTU)**	**Field TSS (mg/L)**	**Lab NTU - Lab NTU Mean**	**Field TSS - Field TSS Mean**	**Lab NTU Squared**	**Lab NTU x Field TSS**	**Field TSS Squared**
4-Aug-00	T1-1	5.7	40	0.91	17.79	0.83	16.25	316.37
4-Aug-00	T1-2	6.5	5	1.71	-17.21	2.94	-29.49	296.30
4-Aug-00	T1-3	4.4	5	-0.39	-17.21	0.15	6.66	296.30
4-Aug-00	T4-1	2.6	5	-2.19	-17.21	4.78	37.64	296.30
4-Aug-00	T4-2	6.2	5	1.41	-17.21	2.00	-24.33	296.30
4-Aug-00	T4-3	3.6	20	-1.19	-2.21	1.41	2.63	4.90
4-Aug-00	T4-4	5.5	20	0.71	-2.21	0.51	-1.58	4.90
4-Aug-00	T4-5	3.4	20	-1.39	-2.21	1.92	3.07	4.90
23-Oct-00	T1-2	5.3	0	0.51	-22.21	0.26	-11.40	493.43
23-Oct-00	T4-4	5.8	50	1.01	27.79	1.03	28.16	772.10
23-Mar-01	T1-2	6.1	38.5	1.31	16.29	1.72	21.39	265.26
23-Mar-01	T4-3	5.2	64	0.41	41.79	0.17	17.27	1746.13
24-Mar-01	T1-2	4.5	20	-0.29	-2.21	0.08	0.63	4.90
24-Mar-01	T4-3	3.8	30	-0.99	7.79	0.97	-7.68	60.63
25-Mar-01	T1-2	3.2	10.7	-1.59	-11.51	2.52	18.27	132.56
25-Mar-01	T4-3	9	13.4	4.21	-8.81	17.75	-37.13	77.67
26-Mar-01	T1-2	5	7.3	0.21	-14.91	0.05	-3.18	222.41
26-Mar-01	T4-3	4.7	25.2	-0.09	2.99	0.01	-0.26	8.92
SUM		90.50	379.10			39.10	36.90	5300.26
Mean		5.03	21.06					
Linear Correlation Coefficient	0.08							