canada/yukon economic
development agreement

INDIAN AND NORTHERN AFFAIRS CANADA
NORTHERN AFFAIRS: YUKON REGION

Open File 1996-2(T)

USE OF DIFFUSER SYSTEMS
for
DISPERSION OF PLACER MINING EFFLUENT

By

Forty Mile Placers, Dawson City Yukon

Canada

Yukon
Government

14-65
$500

This report is available from:
Exploration and Geological Services Division,
Indian and Northern Affairs Canada,
300 Main Street, Whitehorse, Yukon Y1A 2B5

Canada/Yukon Mineral Development Agreement

USE OF DIFFUSER SYSTEMS

for

DISPERSION OF
PLACER MINING EFFLUENT

by

FORTYMILE PLACERS

Box 460
Dawson City, Yukon
Y0B-1G0

R.J. LORIMER

Executive Summary

Placer mining involves washing stream gravels to separate and save free gold particles. Usually a placer mine must discharge excess effluent water, which contains some residual suspended fine silt and clay particles, from a settling pond back into the stream. This study examines the applicability of introducing placer effluent through a diffuser to lessen environmental impact.

A dffuser is a mechanism which introduces effluent fluid into the main current of a receiving stream so that mixing and dispersion are facilitated. A diffuser usually consists of a header pipe with one or more discharge ports. Effluent is ejected from the ports at high velocity into the receiving water. Performance of the diffuser depends on the diameter, spacing, and angle of the ports in relation to the water column.

Diffusers are used effectively in many industrial applications. Computer programs have been developed which predict the effluent plume from a diffuser, using input data from both the receiving stream and the effluent discharge. We used the CORMIX model, which was developed for the U.S. Environmental Protection Agency. This program can also be used in the design of diffusers.

We modelled two series of scenarios using receiving water data for the Fortymile River. In one series, we varied the concentration of suspended solids in the effluent. In the other series, we varied the flow rate of the effluent. In all cases from both of these series of models, the CORMIX program predicted that the effluent diffused into the receiving water rapidly. A water quality objective of 12.5 mg of suspended sediment per litre of water was achieved in a very short distance downstream of the diffuser.

We also used the CORMIX model to predict effluent behaviour in some hypothetical receiving streams. These scenarios showed that the larger the receiving stream, the better the diffusion rate. It also showed that diffusers would not be as effective on small streams where large effluent concentrations are discharged. Dilution is limited by the flow rate of the receiving water.

The CORMIX model cannot predict whether sediment from the effluent plume will settle out on the streambed. Our team hydrologist examined the question of potential sedimentation by using the following techniques: comparing background to introduced sediment levels, calculating the shear/fall velocity ratio for the sediment, comparison to flume testing, and comparison to other field investigations. He predicted that in the example of the Fortymile River using our mine effluent parameters, there would be little or no sediment deposited on the streambed from a diffuser installation.

The use of diffuser systems to disperse placer effluent into receiving water appears to be an effective way of mitigating the impact of placer mining on the aquatic environment, providing there is adequate flow in the receiving stream. Effluent is dispersed into the stream flow, reducing the possibility of sedimentation of the stream substrate.

TABLE OF CONTENTS

APPENDICES

1. INTRODUCTION

In November 1995, Fortymile Placers received financial support under the Canada/Yukon Mineral Development Agreement to do an analysis of the potential use of diffusers for dispersing placer mining effluent. The purpose of the study was to examine whether diffusers could disperse and dilute the suspended sediment in placer effluent to non-acute levels in the receiving waters. This report documents the findings of the study.

We assembled a team of professionals to conduct the study. We required expertise in the following fields: placer mining, civil engineering, environmental engineering, computer modelling, hydrology and sedimentology. The study team included the following members:

a) Placer Mining: Bill Claxton and Leslie Chapman, Fortymile Placers
b) Civil Engineering: Bob Lorimer, P. Eng. of Lorimer & Associates
c) Environmental Engineering and Computer Modelling: Leslie Gomm, M. Eng, P. Eng.
d) Hydrology, Sedimentology: Michael A. Carson, PhD.

2. STUDY OBJECTIVES AND SCOPE OF WORK

The objective of the project was to produce a report to evaluate the merit of diffuser systems as a method of mitigating the environmental impact of placer effluent discharge into stream courses.

The project consisted of the following tasks:

i) Research the available data on the use of diffusers in other industrial and mining effluent treatment applications. Compile a summary of available data and prepare a bibliography.

ii) Select the project team, and with them, design a work program.

iii) Outline the data required to design a suspended sediment effluent diffuser, and design a typical placer effluent diffuser system.

iv) With the aid of computer modelling, model the discharge plumes generated by theoretical diffusers in water courses, and then predict the effects of the discharge.

v) Prepare a report documenting the process and results of the study.

3. BACKGROUND

Placer mining involves the use of water to wash alluvial gravels in and around stream beds. Water and gravity separate the gold from the gravel. Process water is settled in large containment ponds where heavy sediment settles out and is stored. Treated influent from the containment ponds is then discharged back into the water-course. The remaining suspended sediment in this effluent though low, may have an impact on the aquatic environment.

In the Yukon, a regulatory regime has been developed to set standards for placer mining effluent discharged into water courses (receiving waters) in order to maintian water quality and protect fish and fish habitat. These effluent discharge standards are site specific and are based on scientific biologically based water quality objectives assessed on degrees of protection or risk to fish and fish habitat.

"In the YPA the water quality for a stream that supports fish and needs protection has been determined as a range in concentrations from 0 to 25 mg/L of suspended solids above natural background. This additional sediment, according to the scientific information available will not reduce the productive capacity for fish." (the Yukon Placer Authorization and Supporting Documents, June 1993. page 6)

An average suspended solid concentration of 12.5 mg/L was set as the downstream water quality objective in concert with using average values for stream flows. This averaging would account for increased dilution when flows were greater and during periods of decreased dilution. Allowable sediment discharges vary from a zero increase in concentration of sediments above background levels in the case of a sensitive stream, to 5 mg/L of settlable solids in the case of a stream with no fish or no fish of significant value.

A process has been set up whereby water quality standards on a particular stream or stream section may be deferred for a period of time to allow mining to take place if standards cannot be met. Upon completion of mining, the stream is restored and stabilized. A deferment may be granted in situations which are detailed in the Yukon Placer Authorization of June 1993.

In 1993, the Yukon Placer Committee considered an application by Fortymile Placers for a deferment of the water quality standard on the Fortymile River. Because the Fortymile has a large flow, and Fortymile Placers is the only operator on the river, it was suggested during the YPC deliberations that a higher concentration of effluent could be introduced into the river if the process water was injected directly into the current. In this manner the effluent would disperse into the stream flow quickly with little effect on the river system.

When effluent is discharged into receiving waters by passive means such as gravity outfalls, rapid mixing of the effluent and the receiving water often does not occur. This is because the effluent does not have enough momentum to create turbulence as it enters the receiving environment. If the receiving water itself is not turbulent, then further mixing is restricted. Diffusers are an effective means of overcoming this problem. They are commonly used in applications such as pulp mills, municipal sewage outfalls, and power plant cooling water systems but, to the best of our knowledge, have not been used in the placer mining industry. Diffusers cannot reduce overall sediment loadings; this being the purpose of other facilities such as settling ponds. However, diffusers can facilitate rapid dispersion of sediments by creating turbulence where the jets enter the water and by allowing the effluent to be discharged over a greater width of the receiving channel.

4. DATA REQUIRED FOR STUDYING PLACER EFFLUENT DIFFUSION

In order to predict how a diffuser will disperse effluent, knowledge of certain characteristics of both the effluent and receiving water is required. As well, the design of the diffuser will affect the behaviour of the effluent when it is discharged into the receiving water. Diffuser design for placer effluent is discussed in section 5 of this report. The required data on the effluent and the receiving water are discussed below.

4.1 Effluent Characteristics

Effluent discharged from the settling facilities can be analyzed to obtain the following data:

Discharge Rate:
The quantity of effluent discharged, commonly expressed in cubic metres per second.

Density:
The density of the effluent is a function of both the temperature of the discharge and the amount of sediment which it contains. Placer effluent has a density greater than that of the receiving water because of the sediment content. Higher effluent temperatures tend to offset this effect somewhat; however sediment content is the major factor affecting placer effluent density.

For many mines in the Yukon, the water standard for concentration of sediment in effluent is measured in millilitres per litre. If sediment concentration is measured in millilitres per litre, a conversion must be made to obtain a corresponding weight of the sediment. This conversion depends on the nature and grain size of the material present in the sediment. A field measurement of the density of the effluent is the best way to obtain density data; however work has been done in various water sheds to correlate the volume and weight measurements. An example for this correlation in the Sixtymile watershed is found in **Appendix D.**

4.2 Receiving Water Characteristics

The following information regarding receiving water is required in order to determine how effluent will be dispersed:

Water Flow Rates:
Flow rate of the receiving stream or river fluctuates over the mining season due to freshet, rainfall, and other factors. If a low average flow for the mining season is used, a conservative scenario will be modelled; at higher flow rates effluent will disperse more quickly and completely. Flow rate is normally calculated in cubic metres per second.

Water Velocity:
The velocity of the receiving water at the effluent discharge point affects the dilution rate significantly. The best way to obtain velocity data is by field measurement. Velocity is normally calculated in metres per second. Generally, the higher the receiving water velocity, the better the effluent is diffused.

Water Density:
As in the case of the effluent, the density of the receiving water is a function of temperature and background sediment load. The background sediment load may be either natural or the result of

upstream activities. By adding the density of the background sediment load to the density of water at the temperature of the receiving water, the density of the receiving water can be calculated.

Stream Profile:
The channel section where the diffuser is located should be mapped in order to predict the effluent plume accurately. As much as possible should be known about the following factors:

a) channel depth Measurements of the deepest, the shallowest, and the overall average depth of the channel are required. Again, if low flow data are used, a conservative prediction will result. Channel depths are normally measured in metres.

b)composition of the stream bed Knowing the roughness of the bottom of the stream channel will help refine the prediction of the behaviour of the effluent plume, although this is a relatively minor factor. Channel roughness is normally measured by a coefficient known as the *"Manning's roughness coefficient"*.

5. DIFFUSER DESIGN

Hydrologist/sedimentologists are able to model the effluent plume from by a diffuser by taking into account the effluent and receiving water characteristics previously discussed. There have been some computer models developed to predict the configuration of the effluent dispersion pattern from a diffuser. By using these programs, a number of scenarios testing diffuser designs can be run in order to design a suitable diffuser for a particular application. Because these programs perform the complex mathematical equations automatically, effluent plumes can be predicted relatively accurately and quickly. This modelling tool allows the diffuser designer to select and refine a design. He can change the shape of the plume by varying different elements of the diffuser design. For example, different scenarios can be run using different discharge port sizes and spacings.

5.1 Practical Diffuser Design Considerations

Diffusers can be complex pieces of equipment, designed for permanent installation in situations where large volumes of substances, some of which may be toxic, are being released. We believe that a simple diffuser design will disperse placer effluent effectively. Placer effluent consists of fine grained sediment suspended in water. While in high concentrations it may be harmful, it is not toxic in a chemical sense. It is not foreign to the aquatic environment; the receiving water also carries fine grained sediment, although in a lower concentration. The diffuser introduces the elevated sediment load into the receiving water where it is dispersed. Suspended sediment may be harmful in high concentrations particularly when introduced in the shore area of streams; if it can be dispersed and absorbed into a large stream flow, its effect will be mitigated.

We had certain objectives for the design of a diffuser for use in the Yukon placer industry. These considerations are outlined as follows:

Economy:
A diffuser suited to the placer industry should be constructed from readily available materials. Steel pipe would probably be most cost-effective.

Simplicity:
A diffuser suited to the placer mining industry must be simple in design so that it can be fabricated with basic welding and cutting equipment. In addition, simplicity of design generally promotes reliability in the field. For this reason, complex nozzle configurations which would require machining or the use of mouldings were not considered.

Reliability:
Any diffuser must perform reliably. Because of the short placer season, every hour of downtime means lost production.

Portability:
The diffuser must be easily installed and retrieved on a seasonal basis, or more often if required. Installation must be feasible without using heavy equipment in water courses which are considered sensitive.

Stability:
The diffuser must be stable in the stream bed over varying water flow conditions. During extreme seasonal floods the diffuser could be dislodged if it is not anchored adequately. The weight of steel pipe adds to the stability. Cross bars can be welded to the bottom of the pipe to maintain the vertical port orientation and to add to stability.

Durability:
The diffuser must be rugged enough to resist the abrasion caused by suspended sediment moving at high velocity. As well, it must withstand the effects of rocks and gravel being transported down the stream channel at high water.

Functionality:
The diffuser must diffuse effluent effectively while adhering to the preceding criteria. The major objective is to disperse the effluent into the stream flow as quickly as possible, and to discourage sediment from settling out on the watercourse substrate.

5.2 The CORMIX Model

We selected the Cornell Mixing Zone Expert System (CORMIX) as the best available computer program for modelling diffuser discharges. This program was developed at Cornell University, under a three year contract to the United States Environmental Protection Agency (EPA), for the analysis and design of aqueous discharges into aquatic environments. Its use is required by the EPA for any diffuser being designed for installation in U.S. waters. It has been validated in both flume modelling and by monitoring operating diffuser systems

"CORMIX is based on an expert system which attempts to mimic the way an experienced person would solve a specific mixing problem. The core of CORMIX is the flow classification system. This enables each specific discharge scenario to be classified based on length .... Once the flow has

been classified, the model assembles and executes a sequence of submodels based on dimensional analysis ... to simulate the hydrodynamic behaviour of the discharge. CORMIX summarizes the results which include any regulatory mixing zones, location of boundary attachments, and the flow trajectory and dilution." L. Gomm, "Discussion of the Use of Diffusers to Mitigate Impact on the Aquatic Environment", Appendix A. See **Appendix A** for a more complete discussion of the CORMIX model.

5.3 Using the CORMIX Model to Design a Diffuser

Because the diffuser design takes into account both the receiving water and the effluent discharge, different placer effluent diffuser designs will be required in order to respond to specific conditions. The diffuser will perform differently depending on the following diffuser design elements:

Port Diameter:
The port size must be calculated taking into account the volume of the effluent being released and the number of ports, in order to achieve an adequate discharge velocity. The smaller the port, the higher the discharge velocity; however, ports must be large enough so that they do not clog and affect reliability.

Number of Ports:
Generally the more ports there are, the better the mixing will be. However, the more ports there are, the smaller they must be to maintain a given discharge velocity. Increasing the number of ports usually makes the diffuser longer and therefore more cumbersome to install and retrieve.

Port Orientation:
The ports should be vertical or angled slightly downstream. This will give the effluent an upward trajectory, helping to overcome its negative buoyancy. However, vertical orientation in a fast watercourse can lead to unpredictable turbulence and the plume can become split and layered; this has an adverse effect on mixing. Angling the diffusers slightly downstream will introduce the effluent more smoothly. Generally, the diffuser pipe should be laid at right angles to the current direction.

Port Spacing:
The ports should be placed far enough apart so that their plumes do not intermix in the vertical jet stage. A rule of thumb is that distance between ports should be at least the height of the water column. Spacing the ports farther apart than necessary does not enhance mixing.

Port Height:
Because of the negative buoyancy of placer effluent, the port aperture should be located above the stream bed. The lower the discharge velocity, the higher the ports should be off the stream bed. Because most of the primary mixing occurs in the vertical water column where the effluent is being introduced, ports should not be higher off the stream bed than necessary to overcome negative buoyancy. As well, the higher the ports are off the bottom, the more cumbersome the diffuser is, the more difficult it is to install, and the less stable it will be.

Diffuser Placement:
Ideally, the diffuser should be placed in the main channel where the water is swiftest and deepest in order to promote optimum dilution. This is the section of the water-course that carries the highest background sediment load. Practical considerations, however, will not always allow for diffuser placement in the main current.

5.4 A Sample Design Scenario Using the CORMIX Model

To illustrate the process for designing a placer effluent diffuser, we have used our mine on the Fortymile River as an example. Our mine recirculates much of the process water but we also take water from the river for use in the gold recovery tables. This results in a discharge of approximately 500 imperial gallons per minute from the settling pond. The receiving water, the Fortymile River, is a fairly large river system, draining approximately 16,600 square kilometres.

5.4.1 Input Data

The specific effluent and receiving water parameters which we entered into the CORMIX program are outlined as follows:

Effluent:
flow rate: 500 igpm, or .0378 m^3/s

concentration of sediment: 2000 mg/L. Using the charts developed by M. Miles and Associates Ltd. on the Sixtymile River, a similar watershed geologically, (**Appendix D**, Excerpts from a report to the Yukon Placer Committee on Relationship of Suspended to Settleable Solids) we estimated that 1 ml/L of settleable solids, as measured in an Imhoff Cone, would equal approximately 2000 mg/L when discharged from our settling pond.

density: 1001.6071 kg/m^3. The CORMIX model works with density measured in kg/m^3. The effluent sediment level of 2000 mg/L, was converted to 2 kg/m^3. Temperature of the effluent is based on measurments taken in our settling pond. The density was calculated using the following formula:

density of water @ 11°C + weight of sediment = density of effluent

$$999.6071\ kg/m^3 + 2\ kg/m^3 = 1001.6071\ kg/m^3$$

Receiving Water:
stream channel width: 71 m. This width was obtained by measuring the width of the channel at low average summer water flow at the proposed diffuser location.

average stream depth: 2 m. We made field measurements at our proposed diffuser site to obtain this data on the Fortymile.

depth at diffuser location: 2.5 m. from field measurements.

flow rate: 178 m^3/s This flow rate was the number used by the YPC for establishing discharge standards on the Fortymile River in the "Yukon Placer Authorization 1993", based on Water Survey of Canada records. A flow meter is located on the Fortymile River, approximately 12 miles downstream from our mine site.

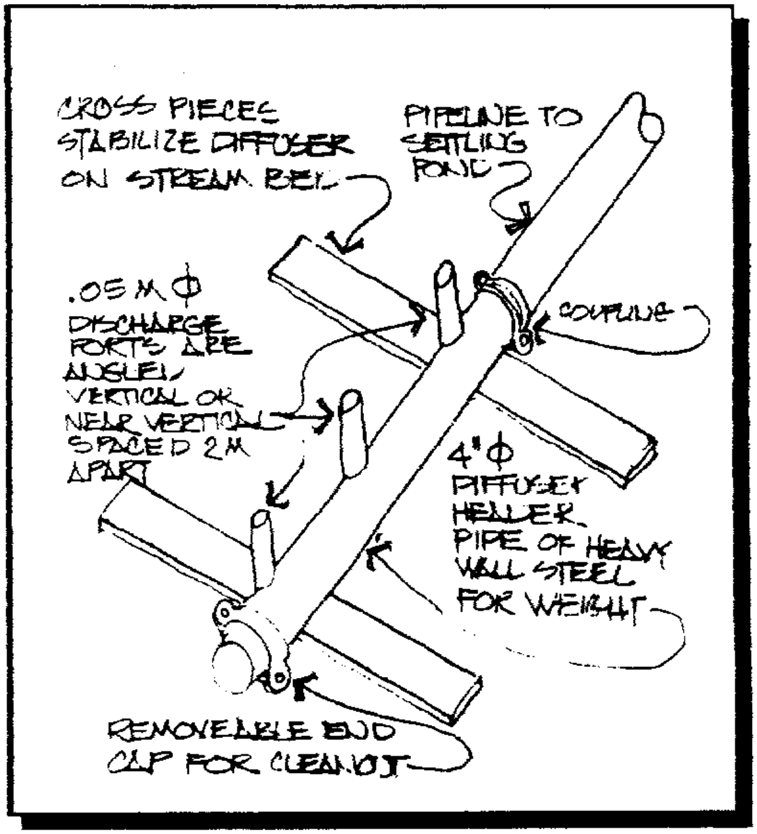
velocity: 1.2535 m/s. This velocity was calculated by the CORMIX model using flow rate and stream section profile parameters. Field measurements show this velocity to be accurate.

density: 999.7862 kg/m^3. As with the effluent, the CORMIX model works with receiving water density measured in kg/m^3. The background sediment level of 3 mg/L, was converted to .003 kg/m^3. Temperature of the receiving water is based on field measurements. The density was calculated using the following formula:

density of water @ 9^0C + weight of sediment = density of effluent

$999.7832\ kg/m^3 + .003\ kg/m^3 = 999.7862\ kg/m^3$

The important factor is the difference in density between the effluent and the receiving water, not the absolute value of the density. The effluent water is on average 2^0 C warmer than the receiving water. This temperature difference affects buoyancy slightly, although the sediment content of the effluent is the main factor which determines the density difference between the effluent and the receiving water.

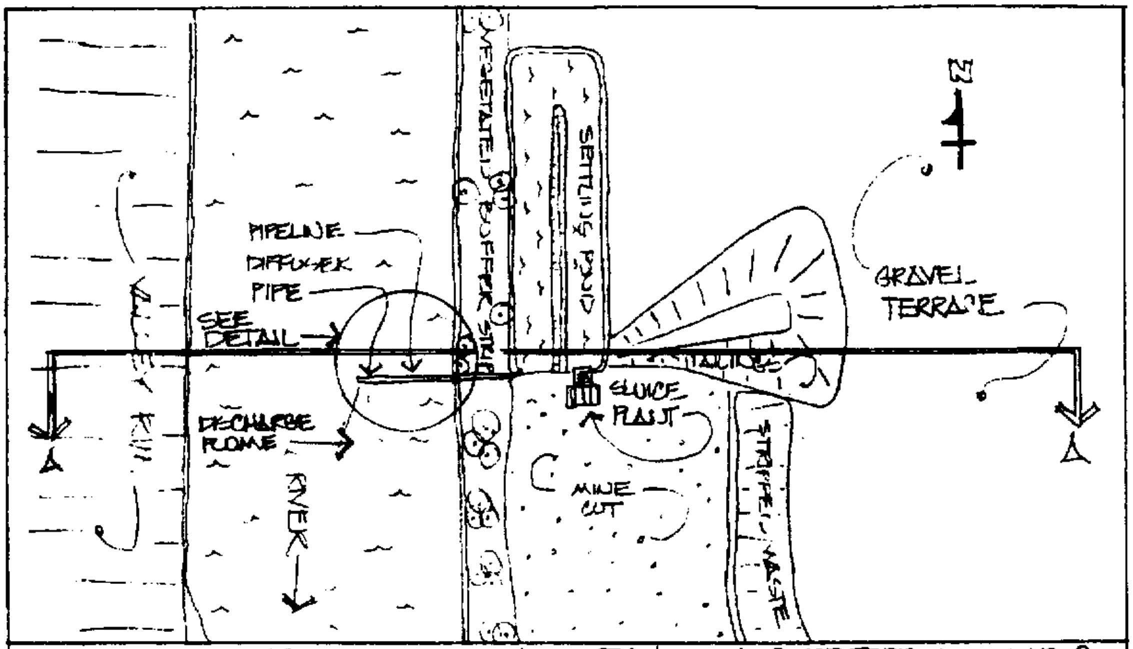


Drawing 1 - Diffuser Designed for Fortymile River

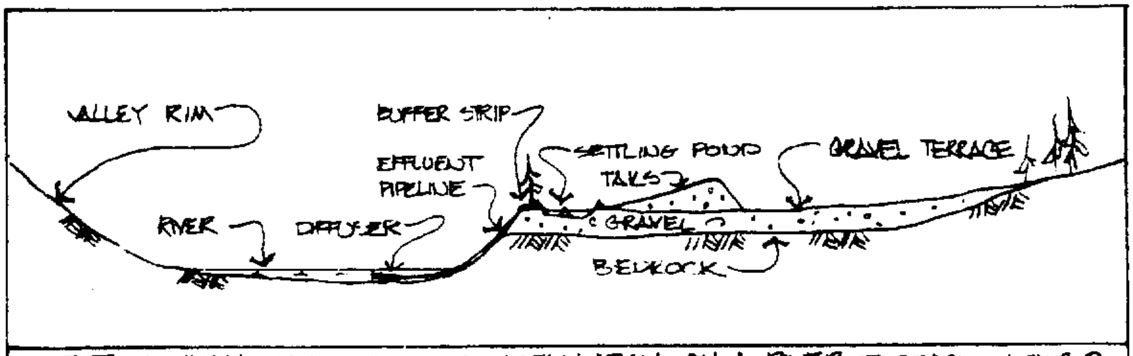
stream bed roughness: We used the Manning's "n" value of .06. This represents a relatively rough stream bottom of large boulders, up to 3' in diameter and exposed bedrock reefs, such as is found at the Fortymile diffuser site. The Manning's "n" coefficient can be found in hydrological engineering handbooks.

5.4.2 Suggested Design for a Placer Effluent Diffuser

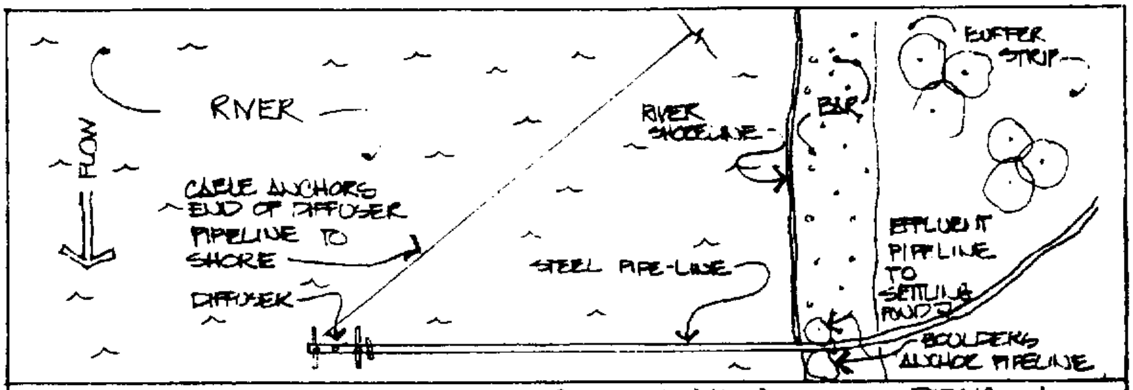
Using the above data, we ran a number of scenarios using the CORMIX model, varying diffuser port size, spacing, and orientation, to arrive at a diffuser design for our site. This design is shown in **Drawing 1**. The diffuser consists of a piece of 4 inch steel pipe 4 metres long. The inlet end is fitted with a connector to attach to the effluent



PLAN VIEW OF A DIFFUSER INSTALLATION ON A RIVER TERRACE DRWG 2.



SECTION VIEW OF A DIFFUSER INSTALLATION ON A RIVER TERRACE DRWG 3.



ANCHORING DETAIL FOR A DIFFUSER INSTALLATION DRWG 4.

Drawing 2 - Plan View of Diffuer Installation for Fortymile River pipeline. The other end is fitted with a removable end cap so that the diffuser can be flushed out if necessary. It has three ports of 0.05m diameter, spaced 2 m apart. The ports are angled downstream at an angle of 69° from the horizontal, or 21° from the vertical. The ports project 0.5m above the river bed. This simple design could be easily modified to provide good effluent dispersion over a wide range of applications. We used this basic design in our computer modelling work for a number of diffusion scenarios.

Drawing 2 shows how a diffuser could be incorporated into a mining operation, using our operation as an example. The effluent discharge pipeline from the settling pond should be located at the far end of the settling pond to allow at least four hours settling time prior to discharge. The settling pond has a baffle dividing the pond lengthwise to increase the distance between the effluent outfall pipeline and the gravel processing plant. As a result of the increased distance, there is more time for sediment to settle out before the effluent is discharged. The baffle allows the water intake pipeline and the effluent discharge pipeline to use the same right of way through the buffer strip to the river; this aids in maintaining the integrety of the vegetated leave strip.

It can be seen from the section view of the mining operation in **Drawing 3** that there is an elevation difference of approximately 40 feet between the mining operation and the water course. This elevation difference provides ample effluent discharge velocity from the diffuser ports. In an operation which does not have the necessary drop to generate effluent velocity, effluent could be pumped.

If the diffuser and pipeline are constructed from heavy wall steel pipe, the weight should be sufficient to keep it in place on the river bed. Cross pieces welded at right angles to the underside of the pipe will add to stability, and keep the ports oriented properly. The pipeline can be anchored with boulders or by other means at the shore. A cable attached to the end of the diffuser and anchored to the shore upstream will counter the effect of water current. This anchoring arangment is shown in **Drawing 4**.

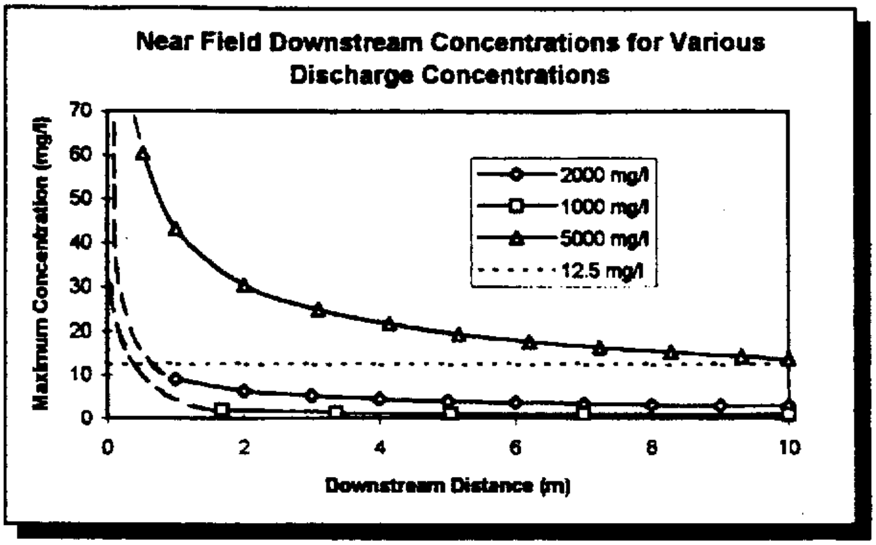
6. USING THE CORMIX MODEL TO PREDICT EFFLUENT PLUMES

Using the diffuser design which we developed, we modelled a number of different CORMIX scenarios to predict plume behaviour in various situations. We wanted to see how both effluent concentration and effluent flow rate would affect the downstream distance required to disperse the effluent. We chose to look at these two variables, effluent concentration and effluent flow rate, because they are factors which can be controlled by the placer miner. We modelled two series of scenarios to test the effect of these two variables. For these two series of scenarios we used constant data for the receiving water and for the diffuser design, so that valid comparisions could be made. We used the receiving water data for the Fortymle River because we know the actual values for the measurements required, and we assumed that a case using actual data would be more meaningful than a hypothetical case. **Appendix B** is a sample CORMIX file report on a scenario modelling an effluent discharge of 500 igpm at a concentration of 2,000 mg/L.

We also modelled a number of different scenarios for other receiving waters, with different effluent volumes and concentrations. Two of these scenarios are presented here; they are intended to provide a sort of snapshot of some of the possible results of using diffusers for dispersion of placer effluent in various situations.

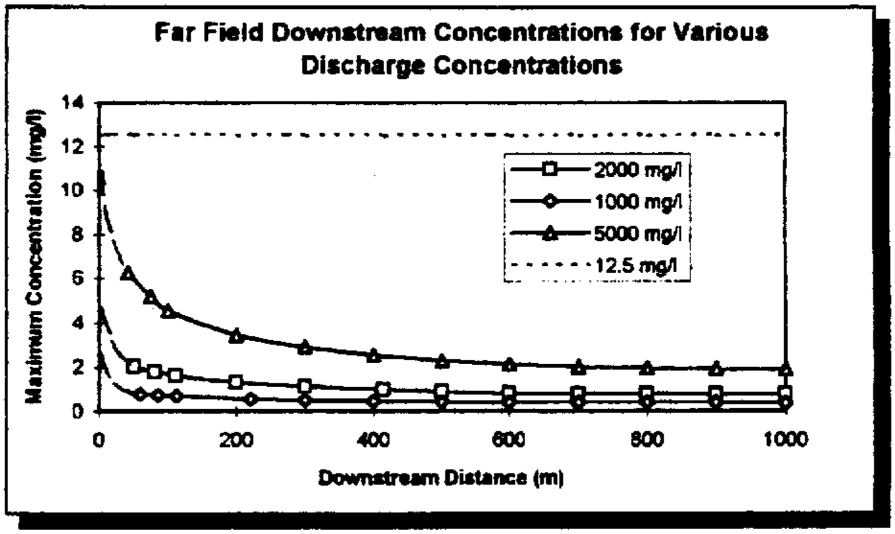
6.1 Dispersion Rate at Different Effluent Concentrations

We modelled a series of scenarios using different concentrations of suspended sediment in the effluent to illustrate how sediment concentration affects diffusion. The effluent concentrations which we used for these models were 200 mg/L, 1000 mg/L, 2000 mg/L, and 5,000 mg/L. We used constant values for the receiving water data, the diffuser design, and the effluent flowrate, as outlined in 5.4.1 above.



Graph 1

The dilution rates predicted by these scenarios in the near field are plotted on **Graph 1**. We were not able to plot the 200 mg/L scenario on the graph because diffusion was virtually instantaneous. We have marked with a dashed line the 12.5 mg/L "very low risk to fish" threshold which has been established by DFO. It can be seen that in all of these scenarios diffusion to under 40 mg/L is achieved within the first metre from where the effluent is diffused into the water course. For the 1000 mg/L and 2000 mg/L scenarios, effluent dilution to well below the 12.5 mg/L threshold is achieved in this first metre. In the 5,000 mg/L discharge scenario, dilution to below the 12.5mg/L threshold occurs at approximately 11 metres downstream from the diffuser location.

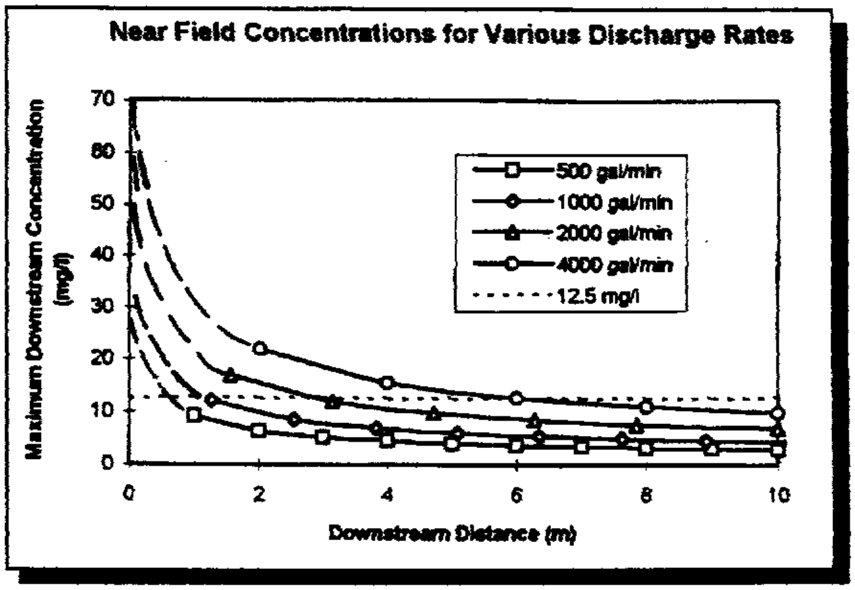


Graph 2

Graph 2, which plots the far field mixing region, shows that within the first 100 metres all of the concentration scenarios have dropped to less than 5 mg/L above background. Effluent of this concentration would not be visible in the water-column. The 1000 and 2000 mg/L concentrations have diluted to less than 2 mg/L above background within 100m. For comparison, background sediment load in the Fortymile River at low flow is 3 mg/L.

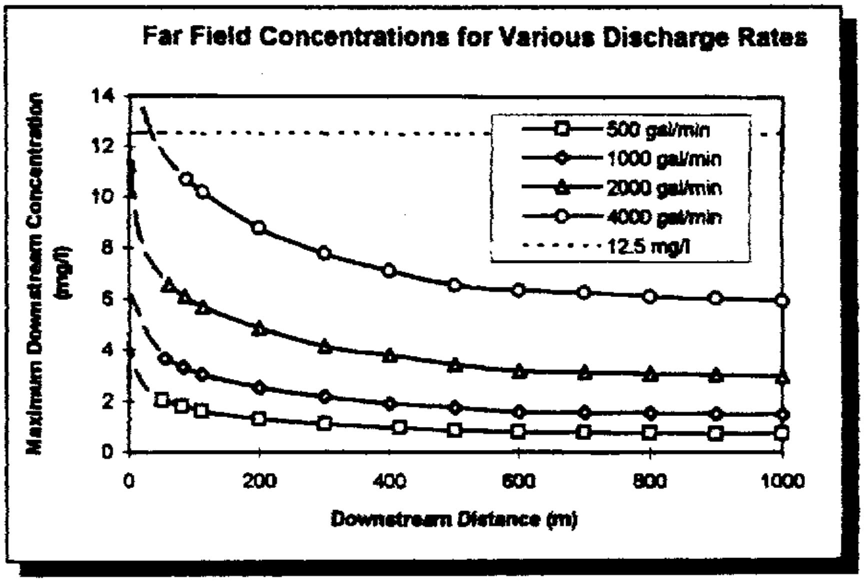
6.2 Dispersion Rate at Different Effluent Flowrates

We modelled a series of scenarios using discharge flowrates of 500 igpm (.0378 m^3/s), 1,000 igpm (.0756 m^3/s), 2,000 igpm (.1512 m^3/s), and 4,000 igpm (.3024 m^3/s). We used the receiving water data outlined in **5.4.1** above and an effluent concentration of 2000 mg/L. We used the same diffuser design for each of these scenarios, except that port diameters varied in each scenario to maintain a constant effluent discharge velocity of approximately 6.4 m/s.



Graph 3

It can be seen in **Graph 3** that all four of the scenarios which we ran in this series met the 12.5 mg/L objective within 6 metres downstream of the diffuser location. The 500 igpm discharge rate met 12.5 mg/L in less than 1m. The 1000 igpm scenario achieved the 12.5 mg/L standard at approximately 1 m. Both these discharge rates diluted to less than 4mg/L within 10 metres. The 2000 igpm scenario meets 12.5 mg/L approximately 3 metres downstream, while 4000 igpm meets this objective at approximately 6 metres downstream. **Graph 4** shows that the discharges



Graph 4

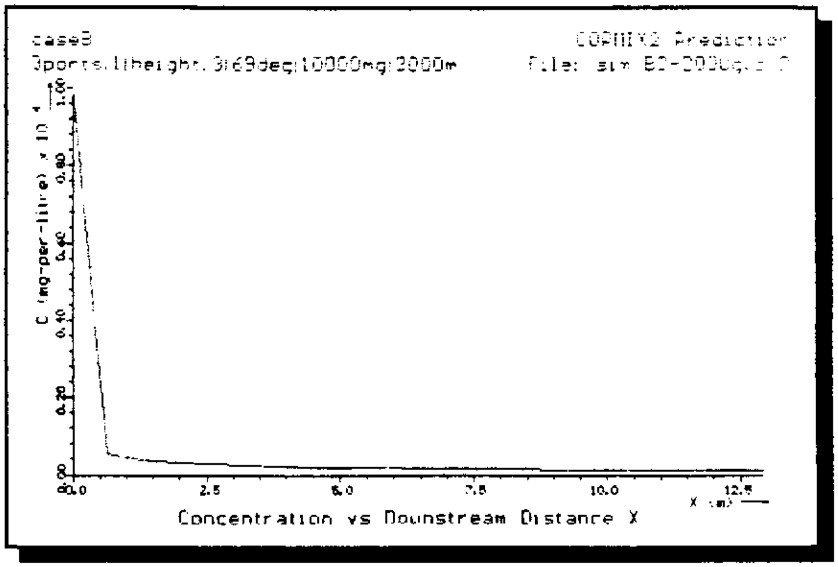
continue to dilute in the far field region.

6.3 Scenarios Using Other Receiving Waters

We used the CORMIX model to predict effluent plumes in a number of different effluent water conditions and receiving water environments. Two of these scenarios are discussed below.

6.3.1 Scenario for a Heavily Mined Creek

We chose effluent water and receiving water parameters for a scenario which reflects conditions found on a hypothetical but typical mining creek. The diffuser design used was similar to that described in 5.4.2, except that a 0.1 m port diameter was used. The parameters are outlined as follows:



Graph 5

Effluent Characteristics:

flow rate: 2000 igpm (.1512 m^3/s)
concentration of suspended sediment: 10,000 mg/L
density: 1009.6071 kg/m^3 at 11^0C

Receiving Water Characteristics:

flow rate: 24 m^3/s
velocity: 1 m/s
background sediment load: 50 mg/L
density: 999.8332 kg/m^3 at 9^0C
streambed roughness: Manning's n .06
channel width: 24 m
average channel depth: 1 m
depth at diffuser location: 1 m

Graph 5 shows the concentration in the effluent plume in the near field. The effluent concentration fell from 10,000 mg/L to 500 mg/L in less than 1 metre. The concentration was 100 mg/L at approximately 175 metres from the diffuser location. Maximum dilution to 63 mg/L was achieved at a distance of approximately 1000 metres. The concentration did not drop below 63 mg/L because this is the maximum dilution possible, given the limitation of the flowrate of the receiving water. This case demonstrates that there are limits to the *effectiveness of a diffuser system*.

6.3.2 Scenario for a Small River

This case for another hypothetical mining operation represents a large creek, or small river. Again the diffuser design is similar to that described in section 5.4.2, except that the port diameter is 0.07m. The parameters established for this case are as follows:

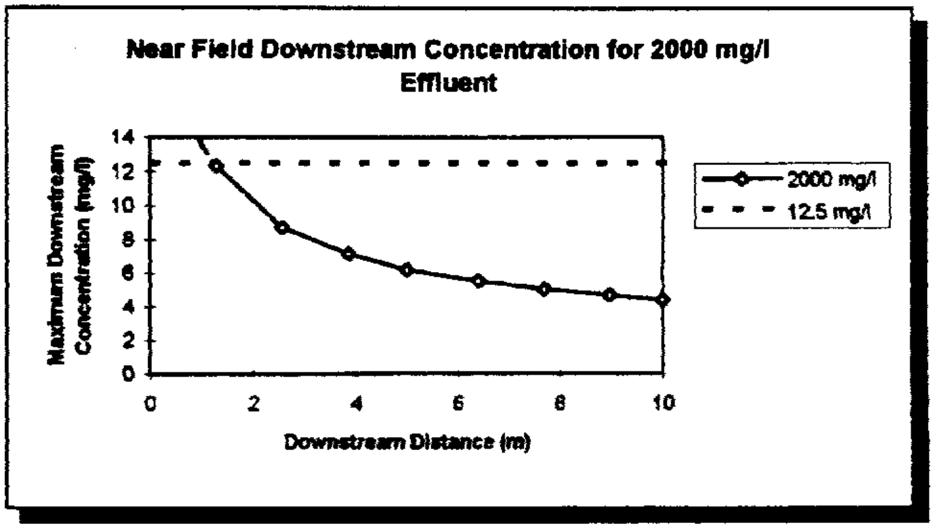
Effluent Characteristics:

flow rate:	1,000 igpm (.0756 m^3/s)
concentration of suspended sediment:	2,000 mg/L
density:	1001.6071 kg/m^3 at 11°C

Receiving Water Characteristics:

flow rate:	80 m^3/s
velocity:	1.5 m/s
background sediment load:	25 mg/L
density:	999.8082 kg/m^3 at 9°C
streambed roughness:	Manning's "n" .06
channel width:	44 m
average channel depth:	1.5 m
depth at diffuser location:	1.5 m

Graph 6 depicts the dispersion/ distance relationship for the effluent discharge plume. The 12.5mg/L objective is achieved in approximately 1metre. At 25 metres the effluent has dispersed to 2.7mg/L above background. This case indicates that diffusers are most effective when used in streams with larger flow rates such as this. A flow rate of 80m^3/s, while less than half of that modelled in the Fortymile River scenarios, was still ample to allow effective diffusion.



Graph 6

7. BEHAVIOUR OF SEDIMENTS DISPERSED BY A DIFFUSER

Most of the suspended material in placer effluent settles out in the settling pond which is an inherent feature of any placer mining operation. However, the effluent still carries some fine suspended material when it is discharged from the pond into the water course. These fine sediments give the effluent a specific gravity slightly greater than the receiving water. While the CORMIX model can predict the behaviour of the effluent plume taking into account this negative buoyancy factor, it cannot determine if or how sediment particles will fall out of suspension. Sedimentation on the stream bed caused by fine effluent particles must be predicted by other means.

There are various ways that hydrologists can predict the behaviour of suspended sediments introduced into a receiving stream flow. These methods are discussed below.

7.1 Comparison of Background to Introduced Sediment Levels

When examining the effect of introducing elevated suspended solids loads into a water course, background sediment load must be considered. Background sediment loads for some rivers have been monitored by Water Survey of Canada. Where these values are not available, an estimate can be made. By using the sediment load born by a similar river, and calculating the drainage area of the watershed being analyzed, the sediment loading can be estimated. The gross sediment load in a river during a season can be compared to the sediment load introduced through the diffuser, to give an idea of the impact that the introduced sediment will have.

Using the Fortymile River and our mining operation as an example, we compared the mean annual sediment load to the sediment load introduced by a diffuser. A rough estimate of mean annual sediment yield is 50 tonnes per square kilometre per year (based on sediment data from measuring stations on other similar rivers). Assuming this value and multiplying by 16,600 km^2, the area of the Fortymile River basin, the mean annual suspended load is approximately 830,000 tonnes. Dr. Carson says in "Diffusion of Settling Pond Suspended Sediment in Yukon Rivers" in **Appendix C**, *"... a diffuser operating for 90 days, with a flow rate of 0.0378 cubic metres per second and a sediment concentration of 1,000 mg/L, ..., the sediment added to the river would be 294 tonnes, assuming operation for 24 hours pre day. This amounts to about 0.035% of the estimated mean annual suspended sediment load. Operation for only 12 hours per day would reduce the load to 147 tonnes, or less than 0.02% of the estimated mean annual load."*

7.2 Theoretical Aspects of Suspended Sediment Settling

"The propensity of suspended sediment to settle to the river bed depends, in the first instance, upon two parameters: the settling velocity of sediment in still water (w) and the intensity of the upward mixing of the water. The latter is usually represented by the shear velocity of the flow (V^*). The ratio of V^* to w is dimensionless. It can be considered an index of the ease of sediment

suspension by the flow. The higher is the value, the easier it is for the river to keep sediment in suspension.

There appears to be no standard approved value of V/w that is universally accepted as the minimum value to keep sediment is suspension, but various workers have suggested that settling begins when actual values are less than 1.0 whereas sediment stays in suspension when value is greater than 1.0. Moir (1989), p.31-32), in developing a computer model for sediment transport in Yukon rivers, adopted this value."* M. A. Carson.

The V* value for different water bodies will be different depending on their physical characteristics. We calculated the V* value for the Fortymile River to be between 14 and 17. Dr. Carson's analysis of the possibility for sedimentation on the Fortymile River is concluded by the following comment, *"...it appears that little if any sediment should settle out in the Fortymile River from the proposed diffuser."*

7.3 Investigating Sediment Settling By Flume Modelling

Laboratory investigation using flumes to model scenarios is a valuable tool for predicting how sediment will behave in a water course. Because of the complex dynamics acting on steam flows, theoretical analysis is not 100% accurate. Analyzing actual flows in flumes will help refine theoretical predictions. It was beyond the scope of this study to conduct flume modelling. However we were able to compare results of flume modelling done on the Athabasca River for diffusion of pulp mill effluent to diffusion of placer mining sediment on the Fortymile River. This discussion is included in Appendix C. Some of Dr. Carson's conclusions regarding this comparison are as follows:

- *"... less than 25% of the diffuser sediment would have been expected to settle out on the bed of the Fortymile River."*
- *"...no significant settling would be expected near the diffuser."*
- *"...the fully dispersed sediment concentration in the river from the diffuser would be about 0.2 mg/L."*

Dr. Carson sums up the comparison of actual flume modelling for the Athabasca River, applied to the Fortymile River as follows: *"... settling of the diffuser sediment should be minimal on the Fortymile River, provided that the diffuser is itself not located in an area of low shear velocity."*

7.4 Analyzing Results from Similar Field Investigations

It is useful to study similar field investigations on other streams to help determine how effluent will disperse in a water course being investigated. We have compared the Athabasca river where pulp mill effluent is being diffused, to the Fortymile River where placer effluent diffusion is being studied. It should be noted that in the case of the Athabasca diffuser, a tremendous volume of complex effluent including chemicals, pulp fibre, bacteria, and other material foreign to the river is being diffused.

Based on the Athabasca experiences, Dr. Carson has suggested that approximately 19% of the sediment load introduced by the diffuser would settle out in the 27 kilometre reach of the Fortymile River downstream from the diffuser location. He concludes that *"Under normal conditions, this minuscule amount would be expected to be flushed from the bed during the following spring freshet."*

Hydrologists can use data from similar investigations to construct a hypothetical worst case scenario. In order to asses risk, it is useful to consider a scenario which magnifies parameters beyond the normal conditions which would be encountered. For example, considering a worst case scenario for the Fortymile River, Dr. Carson concludes, *"Application of the rate of settling from that study to 60 days of low flow on the Fortymile River indicates, as a worst case, an average amount of deposition of less than 0.03 mm on a strip of near bank bed of 20 m width over the full length of the river downstream, assuming diffuser operation for 10 hours per day. "*

8. CONCLUSIONS

Diffusers have been used successfully to introduce effluent into receiving water to mitigate environmental impact in other industries. We have not found any reason to suggest that diffusers could not perform well in the placer industry in the Yukon. Both the CORMIX model and the analysis by Dr. M. A. Carson support the idea that diffusers would help to rapidly and effectively disperse placer effluent into receiving streams.

The overall effectiveness of a diffuser is dependent on the amount and concentration of effluent being discharged along with the flow rate and velocity of the receiving water. Diffusers dilute effluent more completely where the ratio of effluent to receiving water is large. For example, if there are a number of miners with large scale operations on a small creek, the total volume of water in the creek will become saturated with sediment, even if the effluent is introduced with diffusers. On the other hand, a large stream with fewer operators, can disperse the suspended sediment so that, this sediment is quickly diluted to levels equal to or less than the background sediment level of the stream. In all the cases which we modelled for the Fortymile River, sediment was quickly dispersed into the stream flow.

It is important that a diffuser be properly designed for the conditions in which it will be used. While a piece of pipe projecting into the active stream channel would act as a diffuser, a properly designed diffuser will achieve superior effluent dispersion; however a diffuser need not be complicated in order to perform well. The CORMIX model facilitates designing a diffuser and predicting its effluent plume.

Diffusers should be used in conjunction with effective settling facilities. The lower the sediment concentration in the effluent, the more rapid and complete the dilution will be in the receiving water. When used in the appropriate situations, diffuser would be an effective in reducing the effects of suspended sediment discharge from placer mining on the aquatic environment.

We believe that a field test of a diffuser system for placer effluent diffusion should be undertaken. This study has shown that risk is minimal, and the potential for lessening environmental impact of placer effluent is great.

9. BIBLIOGRAPHY

McCorquodale, J.A., Zhou, S.P., Jhong, Z., Moawad, A., Yuen, E.M., and Rajaratnam, N. "Near Field Modelling in the Connecting Channels of the Great Lakes" for Ontario Ministry of the Environment. July 1992.

Hodgson, J. "Turbulent Jet Discharge in Rivers". PhD Thesis, Department of Civil Engineering, University of Alberta, 1991.

Wright, S.J. "Mean Behaviour or Buoyant Jets in a Crossflow". ASCE Journal of the Hydraulics Division, Vol. 103, No. HY5, pp 499-513, 1971.

Fischer, H.B., List, E.J., Kon, R.C., Imberger, J., and Brooks, N.H. "Mixing in Inland and Coastal Waters, Academic Press, New York, 1979.

Yotsukura, N. and Sayre, W.W. "Transverse Mixing in Natural Channels, water Resources Research, Vol. 12, No. 4, pp 695-704, 1976.

Tsanis, I.K. and Valeo, C. "Mixing Zone Models for Submerged Discharges", Computational Mechanics Publications, Southampton, U.K., 1994.

Doneker, R.L., and Jirka, G.H. "Expert System for Hydrodynamic Mixing Zone Analysis of Conventional and Toxic Submerged Single Port Discharges (CORMIX1)", United States Environmental Protection Agency, Publication No. EPA/600/3-90/012, 1990.

Akar, P.J. and Jirka, G.H. "CORMIX2: An Expert System for Hydrodynamic Mixing Zone Analysis of Conventional and Toxic Multiport Diffuser Discharges", United States Environmental Protection Agency, Publication No. EPA/600/3-91/073, 1991.

The Yukon Placer Authorization and Supporting Documents, Government of Canada, 1993.

ACKNOWLEDGEMENTS

We would like to acknowledge the following people and groups for their support of the application to do this study:

Steven Morison, Director Mineral Resources, DIAND

John Kowalchuk, Geo-Science Office

Canada/ Yukon Mineral Development Agreement Technical & Management Committees

We would like to acknowledge the assistance of the following people who provided background information for this study:

Water Survey of Canada Staff, Whitehorse

DIAND Library Staff, Whitehorse

Al Rothwell, Placer Inspector, DIAND, Dawson City

William LeBarge, Geological Services, DIAND, Whitehorse

Barry Chillibeck, Environmental Engineer, DFO, Vancouver

Mike Miles, Miles and Associates Ltd. , Victoria

I. K. Tsanis, Professor of Civil Engineering, McMaster University

We would like to thank our project team, Bob Lorimer, Leslie Gomm, and Dr. Mike Carson for their hard work on the study and their thoughtful approach to the subject.

We would particularly like to thank David Latoski, Chief, Placer Unit, DIAND, Whitehorse, for his help in his role as technical advisor to the project and editor of the report.

APPENDIX A

THEORY OF EFFLUENT DIFFUSION

by
LESLIE GOMM M. Eng., P.Eng.

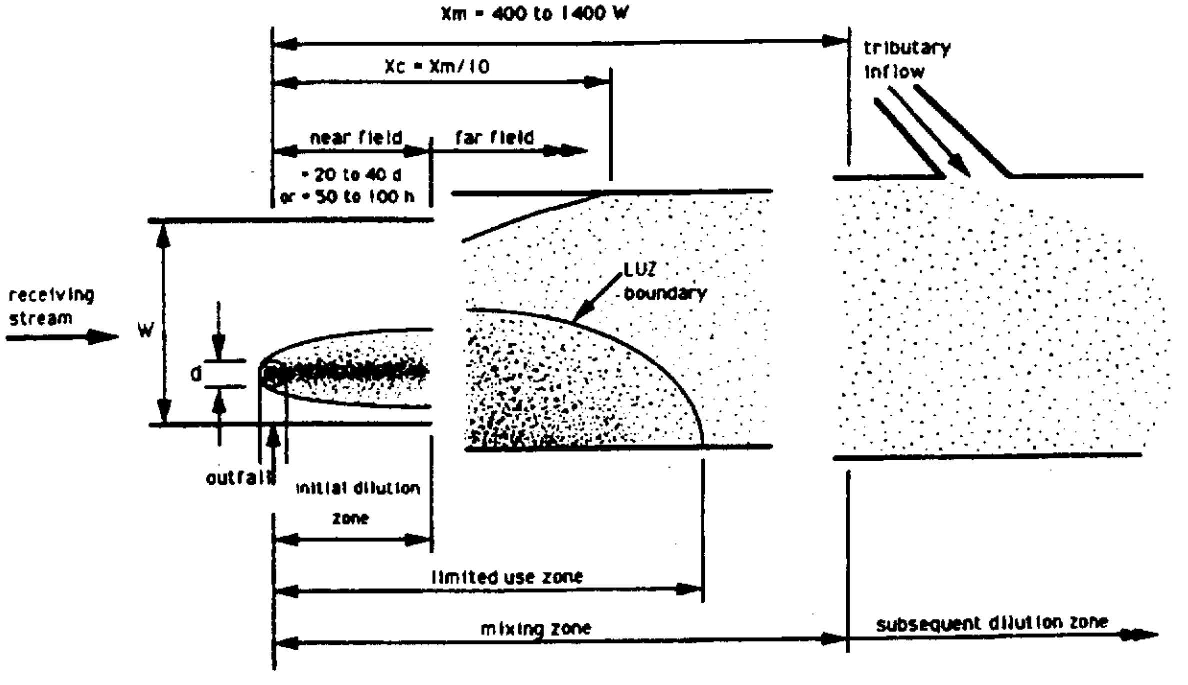
for
FORTYMILE PLACERS

THEORY OF EFFLUENT DIFFUSION

by Leslie Gomm P. Eng., M. Eng.

Downstream of point source discharges, the mixing of the effluent with the receiving water is not instanteous, sometimes taking several hundred meters before complete mixing is achieved. Within this mixing zone, pollutant concentrations may exceed water quality guidelines and pose a potential hazard to aquatic biota. Maximizing the dilution in the region near the mixing zone reduces the extent of this zone, minimizing environmental impacts. There are two distinct types of point souce discharges, passive discharges and diffuser discharges. A passive discharge has no initial momentum compared to that of the ambient receiving water. A diffuser discharge has a substantial amount of momentum associated with it, typically much higher than that of the receiving water. The mixing of a passive discharge is primarily by the turbulent nature of the river into which it is being discharged. A diffuser discharge mixes initially due to the momentum and turbulence of the discharge itself and later by the turbulence of the river, with the former being controlled by the actual design of the discharge system. The use of properly designed diffusers provides an effective means of maximizing the dilution.

For a discharge in a flowing environment, near the jet exit, the discharge is controlled by the inital conditions of the discharge. This is called the Near-Field region (see **Figure 1**). Inital characteristics such as momentum flux, buoyancy flux and geometry dominate the jet dilution and trajectory. Within the near field region, complete vertical mixing is achieved, typically within a



[Hodgson, 1991]

Figure 1 - Receiving Stream Regions

distance equal to 50 to 100 times the river depth. The buoyancy of the discharge (positive or negative) can increase this distance due to a density stratification developed in the receiving water. A significant amount of mixing can be achieved in the near field, with an initial dilution on the order of 100 or more. (Yotsukura et al, 1976)

The design of a diffuser can be manipulated to minimize the length of the near field region and maximize dilution within this region. This can also eliminate buoyancy problems. A diffuser consisting of one or more high velocity ports, can enhance the vertical mixing compared to a passive discharge. The turbulent nature of the diffuser (jet) dominates the mixing process in the near field. It is this turbulence that is controlled by the diffuser design.

Farther downstream, the initial conditions no longer dominate the mixing. This region is called the Far-Field. The far field region occurs after vertical mixing has occurred. At this point, ambient conditions such as turbulence and residual buoyancy effects begin to domintate. In this region, the turbulence of the receiving water dominates the mixing process. This can not be controlled in the same way that the near field mixing can be controlled. The far field region extends until the discharge has completely mixed across the entire river. Downstream of the mixing zone, further dilution occurs due to increased stream loading from run off and incoming tributaries.

The behaviour of a discharge is governed by three factors: jet parameters, environmental parameters relating to ambient conditions, and geometrical parameters. Environmental parameters include density stratification, flow velocity and turbulence. Important geometrical parameters are depth of submergance and angle of the discharge relative to the ambient flow. Significant jet parameters are initial volume, momentum and buoyancy fluxes which are defined as follows:

$$Q = VA$$
$$M = QV = V^2A$$
$$J = g_o'Q$$

where Q = inital volume flux
A = area of port
M = initial momentum flux
J = inital buoyancy flux
g_o' = initial effective gravitation acceleration

Depending on the importance of the inital momentum and/or buoyancy of the discharge, they may be classified as pure jets, pure plumes and buoyant jets. A pure jet has no buoyancy associated with it and the flow is driven solely by its initial momentum. A pure plume has no initial momentum and the discharge is driven by either a positive or negative buoyancy resulting from a density difference between the discharge fluid and the ambient. Positive buoyancy acts vertically upwards while negative buoyancy acts downwards. Buoyant jets are driven by both momentum and buoyancy and are typical of many environmental discharges. In general, initially the momentum dominates the discharge flow until it diminishes relative to the ambient current and then buoyancy effects begin to dominate the mixing process. Therefore the discharge initially behaves as a jet and then as a plume.

The following five length scales have been derived for buoyant jets discharging into uniform environments (Fischer et al, 1979). These length scales are used to quantify the behaviour of different discharge scenarios.

$L_Q = Q/M$ = characteristic length scale
$L_M = M^{3/4}/J^{1/2}$ = jet-plume transition length scale

$L_m = M^{1/2}/U_a$ = jet - crossflow length scale
$L_b = J/U_a^3$ = plume - crossflow length scale

The first two length scales pertain to discharges in quiescent receiving waters while the latter two are used to identify various regions for discharges into river. These must be modified to the following equations for use with diffusers.

$l_Q = q^2/m = B_D$ = outlet slot length scale
$l_M = m/j^{2/3}$ = slot jet - plume transition length scale
$l_m = m/U_a^2$ = slot jet - crossflow length scale
$q = Q/L_D$ = slot flow rate = flow per unit length of diffuser
$m = M/L_D$ = slot momentum flux per unit length of diffuser
$j = J/L_D$ = slot buoyancy flux
L_D = diffuser length

These length scales are on the same axis as the discharge is oriented. For example, if the jet is vertical, these length scales refer to a vertical distance above the jet exit. For a buoyant jet in a cross flow, if $L_m > L_b$, the jet is momentum dominated and buoyancy effects will be negligible in the region near the jet exit. L_m is the point at which the discharge will change from being dominated by the jet characteristics to being dominated by the crossflow. L_M is the point at which the buoyant jet will switch from jet-like to plume-like behaviour.

Wright (1977) used these length scales and dimensionless analysis in conjuction with experiments to develop empirical relationships for jet trajectory and dilution which are commomly used. These scales are also used to determine the dominant process in the discharge mixing. For example, consider a discharge of placer effluent into a northern river in summer.

Effluent Characteristics	Ambient Characteristics
density = 999.78 kg/m^3	density = 1000.78 kg/m3
velocity = 4.8 m/s	velocity = 1.25 m/s
port diameter = 0.10 m	river depth = 2.5 m

The length scales for this discharge scenario are:

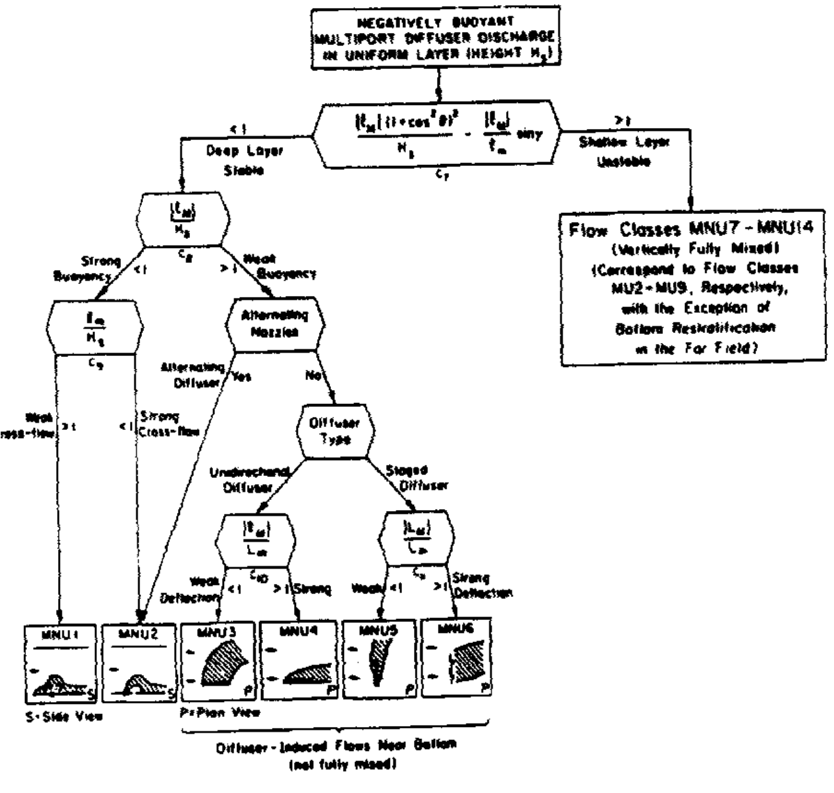
$L_Q = 0.09$ m
$L_M = 14.47$ m
$L_m = 0.34$
$L_b = 0.00$

The discharge is momentum dominated (jet) because $L_m > L_b$. The jet effects dominate the jet trajectory until the height above the discharge is greater than L_m (0.34 m), after which the crossflow dominates. The effects of buoyancy within this region are negligible because the depth of the river (D) is substantially less than the jet-plume transition length scale ($L_M = 14.47 > D$). If this discharge had not been through a high velocity diffuser, the value of L_M would be essentially zero, as the jet momentum would be negligible. In this case, undesirable buoyancy effects may influence the discharge mixing, most likely resulting in the plume attaching to the bottom of the river immediately downstream. This would set up a density stratification which would minimize mixing and dilution. Therefore to minimize these buoyancy effects, a diffuser should be used.

DESCRIPTION OF THE CORMIX MODEL

Under contract to the US EPA, the Cornell Mixing Zone Expert System (CORMIX) was developed by Cornell University for the analysis and design of aqueous discharges into aquatic environments. CORMIX1 is used for positively and negatively buoyant submerged single port discharges. CORMIX2 is used for submerged multiport (>3) discharges and CORMIX3 for surface buoyant discharges. In CORMIX1 and CORMIX2 the jet must be highly submerged with an effective diameter small compared to the depth of the river. CORMIX3 was not used for this application. All models can deal with stagnant or flowing ambients with or without density stratifications.

There is a wide range of models available for predicting mixing zones, ranging from simple analytical formulae to complex numerical solutions of differential equations. CORMIX is based on an expert system which attempts to mimic the way an experienced person would solve a specific mixing problem. The core of CORMIX is the flow classification system. This enables each specific discharge scenario to be classified based on the length scales that were described previously. A possible discharge classification for this modelling exercise can be seen in **Figure 2**. Once the flow has been classified, the model assembles and executes a sequence of submodels based on dimensional analysis similar to that developed by Wright (1977) to simulate the hydrodynamic behaviour of the discharge. CORMIX summarizes the results



(McCorquodale et al, 1992)

Figure 2
Negatively Buoyant Submerged Multiport Discharges

which include any regulatory mixing zones, location of boundary attachments, and the flow trajectory and dilution.

Both laboratory and field data are continually being used for model validation. An extensive study looking a the suitablility of a variety of models for mixing was carried out by McCorquodale et al, 1992. Of the models evaluated, CORMIX was the only one that has been developed to deal with positively and negatively buoyant discharges in flowing ambients. They investigated the specific use of CORMIX1 and CORMIX2 for use in connecting channels of the Great Lakes. This study found that the use of CORMIX1 and CORMIX2 was restricted to discharges that have a ratio of the depth of ambient to pipe diameter (D/d) greater than 3 as well as the vertical distance of the jet exit above the river bed less than 1/3 of the ambient depth. Essentially, the jet must have a large submergence.

When compared to actual field data from a mixing study carried in the Lesser Slave River in Alberta (Hodgsen, 1991), CORMIX1 developes the same dilution trend but underestimated the measured dilution, resulting in a more conservative result. By underestimating the dilution, the contaminant concentration is overestimated. CORMIX1 was also compared to field data from the Ingleside STP in the St. Lawrence River for three measured effluent cases and provided a reasonable estimate of the dilution. CORMIX2 was compared to two field studies, the Domtar diffuser (27 ports) in the St. Lawrence River and the Algoma diffuser in the St. Marys River (5 ports). There was agreement between the CORMIX2 output and the field dilution data for each case, verifying the use of this model for these cases.

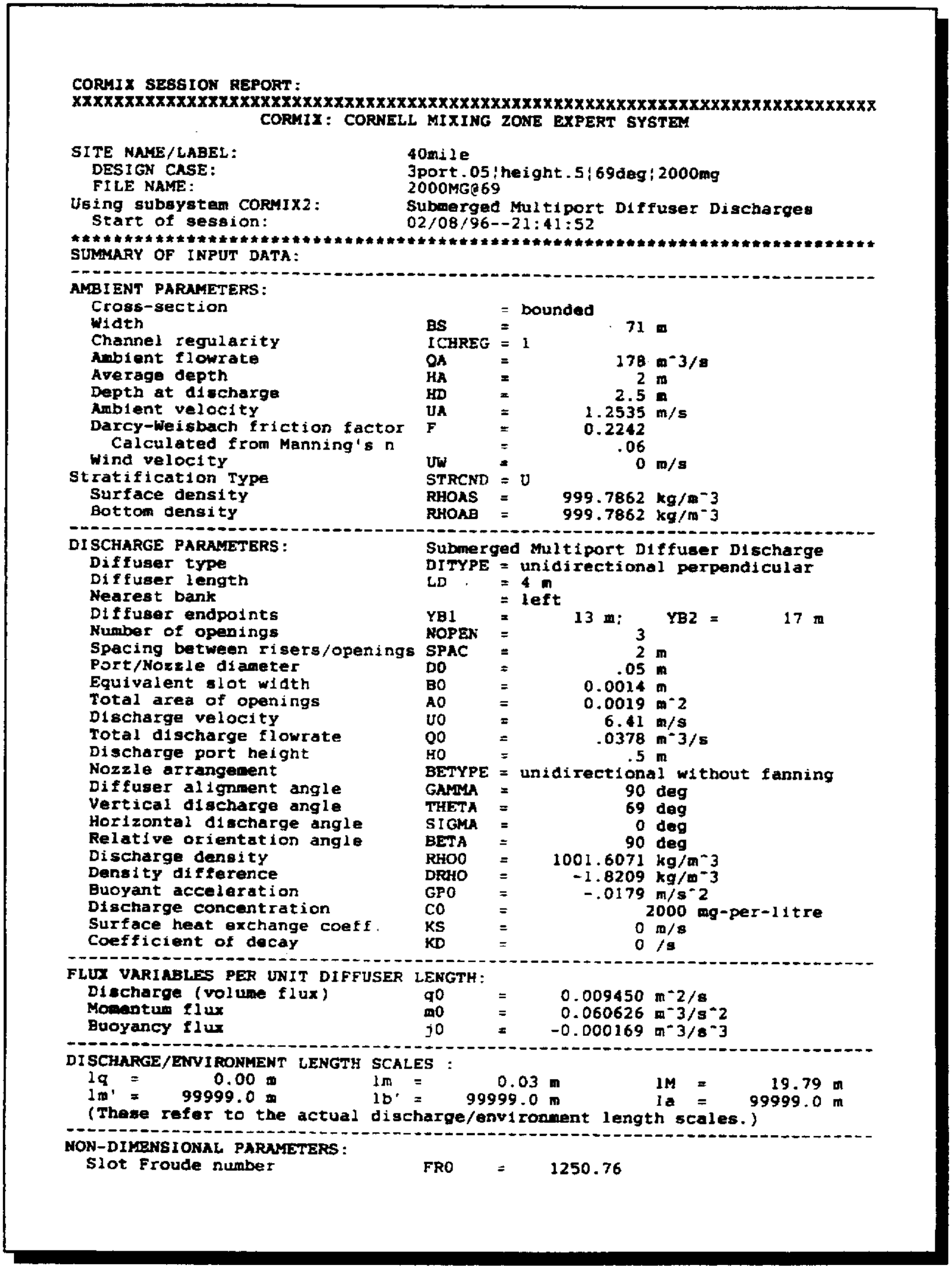
It should be noted that, as with the use of any model, there are limitations to its use and the accuracy of the results. Many assumptions are made when using this and any other model, which simplify the case being tested from reality. Some of these limitations and shortfalls are:

- the effects of secondary currents on mixing due to wind or channel geometry have not been consider in CORMIX and,
- CORMIX2 does not deal with multiport diffusers with only two ports.
- models tend to present conservative results by underestimating dilution as discussed above
- there is an accuracy of ±50%for hydrodynamic modelling.

Results of any modelling exercise should not be taken as given but should be used as a comparison tool for the evaluation of various scenarios. Once the optimal discharge configuration has been determined, the best evaluation tool is a field mixing study using tracers such as chloride.

APPENDIX B

SAMPLE CORMIX PREDICTION REPORT

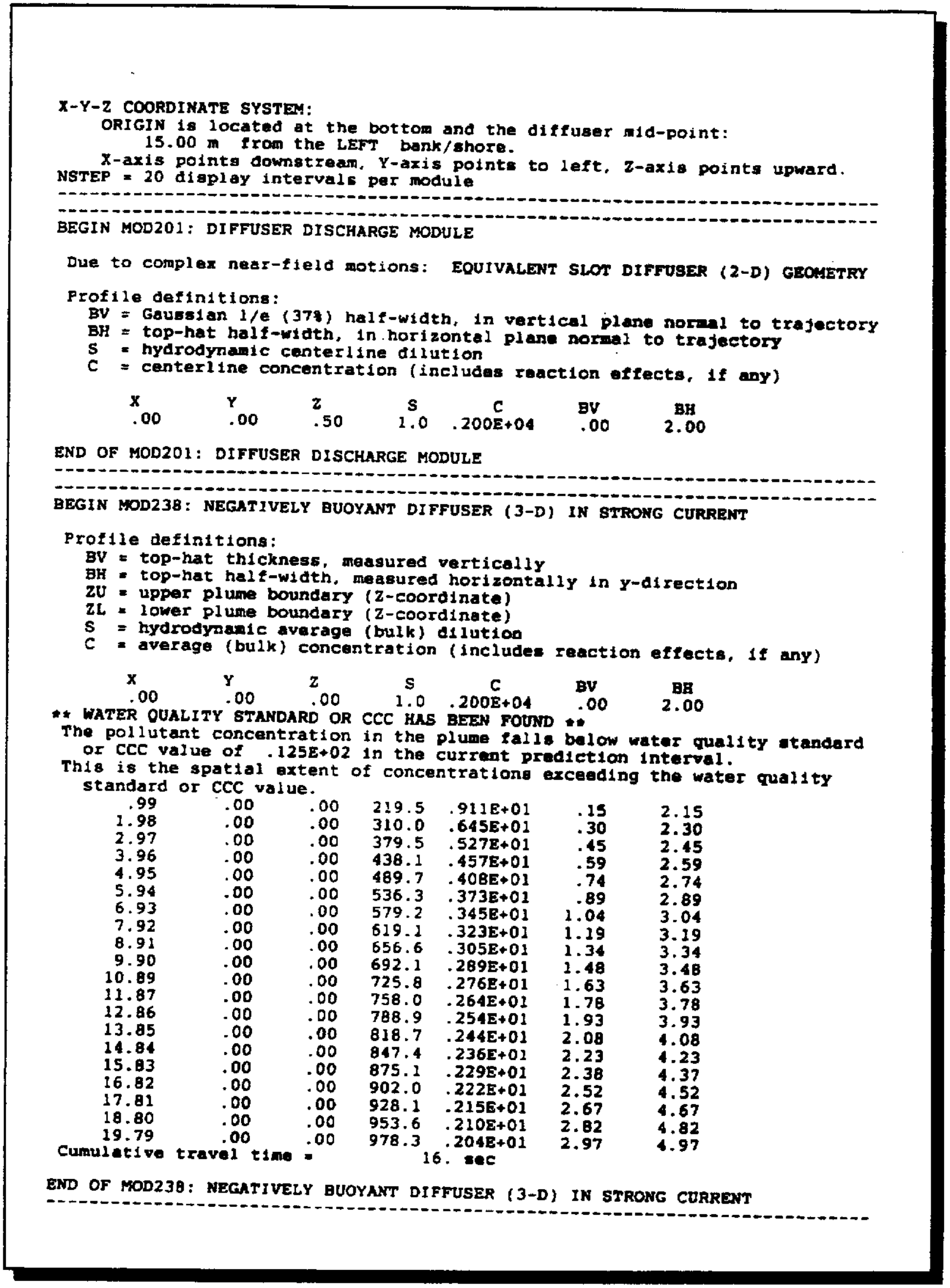


```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                  CORMIX: CORNELL MIXING ZONE EXPERT SYSTEM

SITE NAME/LABEL:                  40mile
  DESIGN CASE:                    3port.05|height.5|69deg|2000mg
  FILE NAME:                      2000MG@69
Using subsystem CORMIX2:          Submerged Multiport Diffuser Discharges
  Start of session:               02/08/96--21:41:52
****************************************************************************
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------------
AMBIENT PARAMETERS:
  Cross-section                             = bounded
  Width                           BS        =          71 m
  Channel regularity              ICHREG    = 1
  Ambient flowrate                QA        =         178 m^3/s
  Average depth                   HA        =           2 m
  Depth at discharge              HD        =         2.5 m
  Ambient velocity                UA        =      1.2535 m/s
  Darcy-Weisbach friction factor  F         =      0.2242
    Calculated from Manning's n             =         .06
  Wind velocity                   UW        =           0 m/s
Stratification Type               STRCND    = U
  Surface density                 RHOAS     =    999.7862 kg/m^3
  Bottom density                  RHOAB     =    999.7862 kg/m^3
----------------------------------------------------------------------------
DISCHARGE PARAMETERS:             Submerged Multiport Diffuser Discharge
  Diffuser type                   DITYPE    = unidirectional perpendicular
  Diffuser length                 LD        = 4 m
  Nearest bank                              = left
  Diffuser endpoints              YB1       =        13 m;   YB2 =      17 m
  Number of openings              NOPEN     =           3
  Spacing between risers/openings SPAC      =           2 m
  Port/Nozzle diameter            D0        =         .05 m
  Equivalent slot width           B0        =      0.0014 m
  Total area of openings          A0        =      0.0019 m^2
  Discharge velocity              U0        =        6.41 m/s
  Total discharge flowrate        Q0        =       .0378 m^3/s
  Discharge port height           H0        =          .5 m
  Nozzle arrangement              BETYPE    = unidirectional without fanning
  Diffuser alignment angle        GAMMA     =          90 deg
  Vertical discharge angle        THETA     =          69 deg
  Horizontal discharge angle      SIGMA     =           0 deg
  Relative orientation angle      BETA      =          90 deg
  Discharge density               RHO0      =   1001.6071 kg/m^3
  Density difference              DRHO      =     -1.8209 kg/m^3
  Buoyant acceleration            GP0       =      -.0179 m/s^2
  Discharge concentration         C0        =            2000 mg-per-litre
  Surface heat exchange coeff.    KS        =           0 m/s
  Coefficient of decay            KD        =           0 /s
----------------------------------------------------------------------------
FLUX VARIABLES PER UNIT DIFFUSER LENGTH:
  Discharge (volume flux)         q0        =    0.009450 m^2/s
  Momentum flux                   m0        =    0.060626 m^3/s^2
  Buoyancy flux                   j0        =   -0.000169 m^3/s^3
----------------------------------------------------------------------------
DISCHARGE/ENVIRONMENT LENGTH SCALES :
  lq  =       0.00 m        lm  =       0.03 m        lM  =      19.79 m
  lm' =    99999.0 m        lb' =    99999.0 m        la  =    99999.0 m
  (These refer to the actual discharge/environment length scales.)
----------------------------------------------------------------------------
NON-DIMENSIONAL PARAMETERS:
  Slot Froude number              FR0       =     1250.76
```

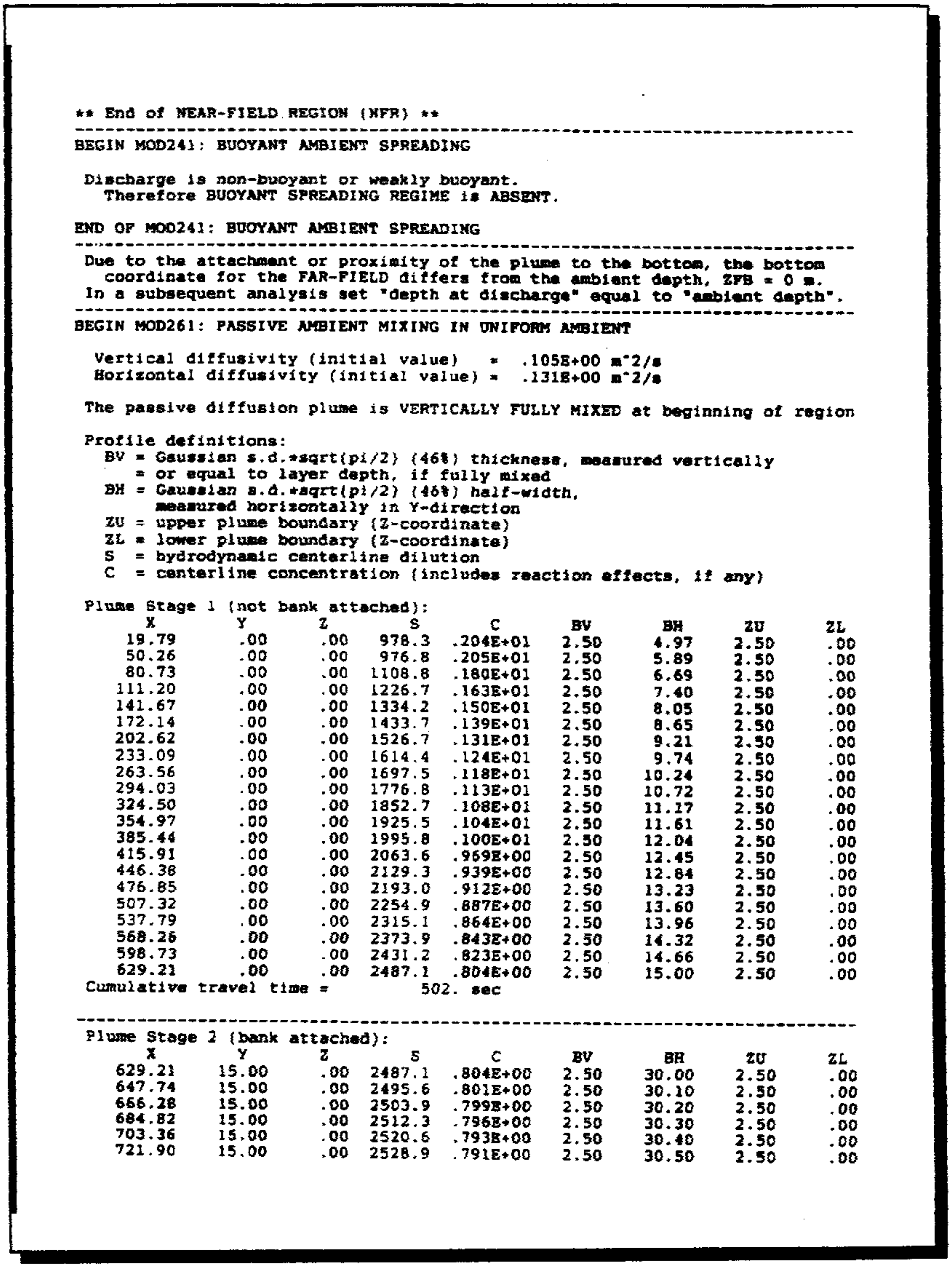
```
  Port/nozzle Froude number        FRD0    =       214.67
  Velocity ratio                   R       =         5.11
-------------------------------------------------------------------------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                          = no
  Water quality standard specified         = yes
  Water quality standard           CSTD    =                12.5 mg-per-litre
  Regulatory mixing zone                   = no
  Region of interest                       =       1000.00 m downstream
*************************************************************************
HYDRODYNAMIC CLASSIFICATION:
  *------------------------*
  | FLOW CLASS   =    MNU4 |
  *------------------------*
  This flow configuration applies to a layer corresponding to the full water
  depth at the discharge site.
  Applicable layer depth = water depth =         2.5 m
*************************************************************************
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):
-------------------------------------------------------------------------
X-Y-Z Coordinate system:
  Origin is located at the bottom below the port center:
            15 m from the left bank/shore.
  Number of display steps NSTEP = 20 per module.
-------------------------------------------------------------------------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no regulatory
  implication.  However, this information may be useful for the discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at edge of NFR =          2.0444 mg-per-litre
  Dilution at edge of NFR                =        978.3
  NFR Location:                        x =        19.79 m
    (centerline coordinates)           y =          .00 m
                                       z =          .00 m
  NFR plume dimensions:       half-width =         4.96 m
                               thickness =         2.96 m
-------------------------------------------------------------------------
Buoyancy assessment:
  The effluent density is greater than the surrounding ambient water
  density at the discharge level.
  Therefore, the effluent is NEGATIVELY BUOYANT and will tend to sink towards
  the bottom.
-------------------------------------------------------------------------
FAR-FIELD MIXING SUMMARY:
  Plume becomes vertically fully mixed ALREADY IN NEAR-FIELD at       19.79 m
  downstream and continues as vertically mixed into the far-field.
************************ TOXIC DILUTION ZONE SUMMARY ************************
No TDZ was specified for this simulation.
********************** REGULATORY MIXING ZONE SUMMARY **********************
No RMZ has been specified.
However:
The ambient water quality standard was encountered at the following
  plume position:
  Water quality standard                 =                12.5 mg-per-litre
  Corresponding dilution                 =          160
  Plume location:                      x =          .98 m
    (centerline coordinates)           y =          .00 m
                                       z =          .00 m
  Plume dimensions:           half-width =         2.14 m
                               thickness =          .14 m
********************* FINAL DESIGN ADVICE AND COMMENTS *********************
CORMIX2 uses the TWO-DIMENSIONAL SLOT DIFFUSER CONCEPT to represent
  the actual three-dimensional diffuser geometry.  Thus, it approximates
```

```
  the details of the merging process of the individual jets from each
  port/nozzle.
In the present design, the spacing between adjacent ports/nozzles
  (or riser assemblies) is of the order of, or less than, the local
  water depth so that the slot diffuser approximation holds well.
Nevertheless, if this is a final design, the user is advised to use a
  final CORMIX1 (single port discharge) analysis, with discharge data
  for an individual diffuser jet/plume, in order to compare to
  the present near-field prediction.
------------------------------------------------------------------------------
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any known
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it judges
  the design configuration as highly complex and uncertain for prediction.
******************************************************************************
DESIGN CASE:                   3port.05|height.5|69deg|2000mg
FILE NAME:                     2000MG@69
Subsystem CORMIX2:             Submerged Multiport Diffuser Discharges
END OF SESSION/ITERATION:      02/12/96--09:12:37
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

```
CORMIX2 PREDICTION FILE:
22222222222222222222222222222222222222222222222222222222222222222222222222222
                      CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX2:                                           Subsystem version:
 Submerged Multiport Diffuser Discharges    CORMIX v.3.10            June 1995
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:         40mile
 Design case:             3port.05|height.5|69deg|2000mg
 FILE NAME:               cormix\sim\2000MG@6.cx2
 Time of Fortran run:     02/08/96--21:46:16

ENVIRONMENT PARAMETERS (metric units)
 Bounded section
 BS     =      71.00 AS     =     142.00 QA     =     178.00 ICHREG= 1
 HA     =       2.00 HD     =       2.50
 UA     =      1.254 F      =       .224 USTAR = .2099E+00
 UW     =       .000 UWSTAR= .0000E+00
 Uniform density environment
 STRCND=  U          RHOAM =  999.7862

DIFFUSER DISCHARGE PARAMETERS (metric units)
 Diffuser type:      DITYPE= unidirectional perpendicular
 BANK   =  LEFT      DISTB =      15.00 YB1    =      13.00 YB2    =      17.00
 LD     =       4.00 NOPEN =    3       SPAC   =       2.00
 D0     =       .050 A0     =       .002 H0     =        .50
 Nozzle/port arrangement:  unidirectional without fanning
 GAMMA =       90.00 THETA =      69.00 SIGMA =         .00 BETA   =      90.00
 U0     =      6.415 Q0     =       .038        = .3780E-01
 RHO0   = 1001.6070  DRHO0 =-.1821E+01  GP0    =-.1786E-01
 C0     = .2000E+04  CUNITS=  mg-per-litre
 IFOLL =  1          KS     = .0000E+00  KD     = .0000E+00

FLUX VARIABLES - PER UNIT DIFFUSER LENGTH (metric units)
 q0     = .9450E-02  m0     = .6063E-01  j0     =-.1688E-03 SIGNJ0=       -1.0
 Associated 2-d length scales (meters)
 lQ=B   =       .001 lM     =      19.79 lm     =        .04
 lmp    =   99999.00 lbp    =   99999.00 la     =   99999.00

FLUX VARIABLES - ENTIRE DIFFUSER (metric units)
 Q0     = .3780E-01  M0     = .2425E+00  J0     =-.6751E-03
 Associated 3-d length scales (meters)
 LQ     =        .08 LM     =      13.30 Lm     =        .39 Lb     =        .00
                                         Lmp    =   99999.00 Lbp    =   99999.00

NON-DIMENSIONAL PARAMETERS
 FR0    =    1250.76 FRD0   =     214.67 R      =       5.11
 (slot)              (port/nozzle)

FLOW CLASSIFICATION
 222222222222222222222222222222222222222222
 2  Flow class (CORMIX2)      =    MNU4   2
 2  Applicable layer depth HS =     2.50  2
 222222222222222222222222222222222222222222

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0     = .2000E+04  CUNITS=  mg-per-litre
 NTOX   =  0
 NSTD   =  1         CSTD   = .1250E+02
 REGMZ  =  0
 XINT   =    1000.00 XMAX   =    1000.00
```

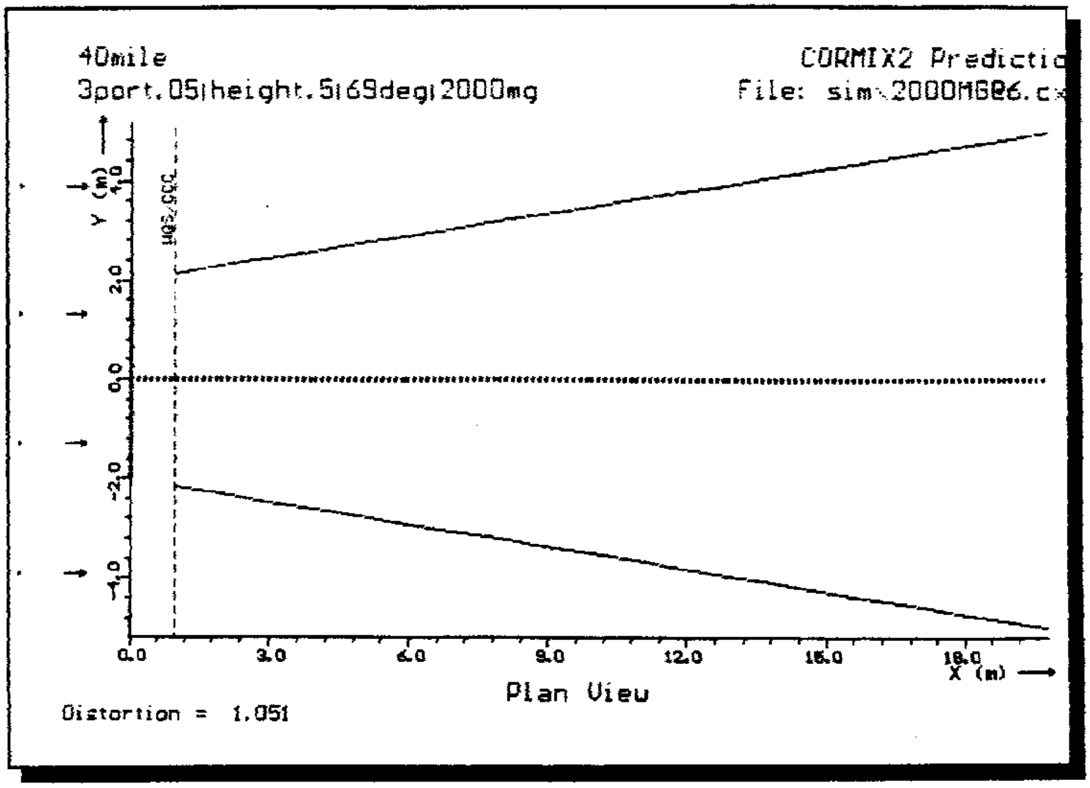


```
X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the bottom and the diffuser mid-point:
        15.00 m  from the LEFT  bank/shore.
    X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP = 20 display intervals per module
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD201: DIFFUSER DISCHARGE MODULE

 Due to complex near-field motions:  EQUIVALENT SLOT DIFFUSER (2-D) GEOMETRY

 Profile definitions:
   BV = Gaussian 1/e (37%) half-width, in vertical plane normal to trajectory
   BH = top-hat half-width, in horizontal plane normal to trajectory
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

       X         Y         Z         S        C         BV        BH
      .00       .00       .50       1.0   .200E+04     .00      2.00

END OF MOD201: DIFFUSER DISCHARGE MODULE
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD238: NEGATIVELY BUOYANT DIFFUSER (3-D) IN STRONG CURRENT

 Profile definitions:
   BV = top-hat thickness, measured vertically
   BH = top-hat half-width, measured horizontally in y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

       X         Y         Z         S        C         BV        BH
      .00       .00       .00       1.0   .200E+04     .00      2.00
** WATER QUALITY STANDARD OR CCC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below water quality standard
   or CCC value of   .125E+02 in the current prediction interval.
 This is the spatial extent of concentrations exceeding the water quality
   standard or CCC value.
      .99       .00       .00     219.5   .911E+01     .15      2.15
     1.98       .00       .00     310.0   .645E+01     .30      2.30
     2.97       .00       .00     379.5   .527E+01     .45      2.45
     3.96       .00       .00     438.1   .457E+01     .59      2.59
     4.95       .00       .00     489.7   .408E+01     .74      2.74
     5.94       .00       .00     536.3   .373E+01     .89      2.89
     6.93       .00       .00     579.2   .345E+01    1.04      3.04
     7.92       .00       .00     619.1   .323E+01    1.19      3.19
     8.91       .00       .00     656.6   .305E+01    1.34      3.34
     9.90       .00       .00     692.1   .289E+01    1.48      3.48
    10.89       .00       .00     725.8   .276E+01    1.63      3.63
    11.87       .00       .00     758.0   .264E+01    1.78      3.78
    12.86       .00       .00     788.9   .254E+01    1.93      3.93
    13.85       .00       .00     818.7   .244E+01    2.08      4.08
    14.84       .00       .00     847.4   .236E+01    2.23      4.23
    15.83       .00       .00     875.1   .229E+01    2.38      4.37
    16.82       .00       .00     902.0   .222E+01    2.52      4.52
    17.81       .00       .00     928.1   .215E+01    2.67      4.67
    18.80       .00       .00     953.6   .210E+01    2.82      4.82
    19.79       .00       .00     978.3   .204E+01    2.97      4.97
Cumulative travel time =          16. sec

END OF MOD238: NEGATIVELY BUOYANT DIFFUSER (3-D) IN STRONG CURRENT
-----------------------------------------------------------------------------
```

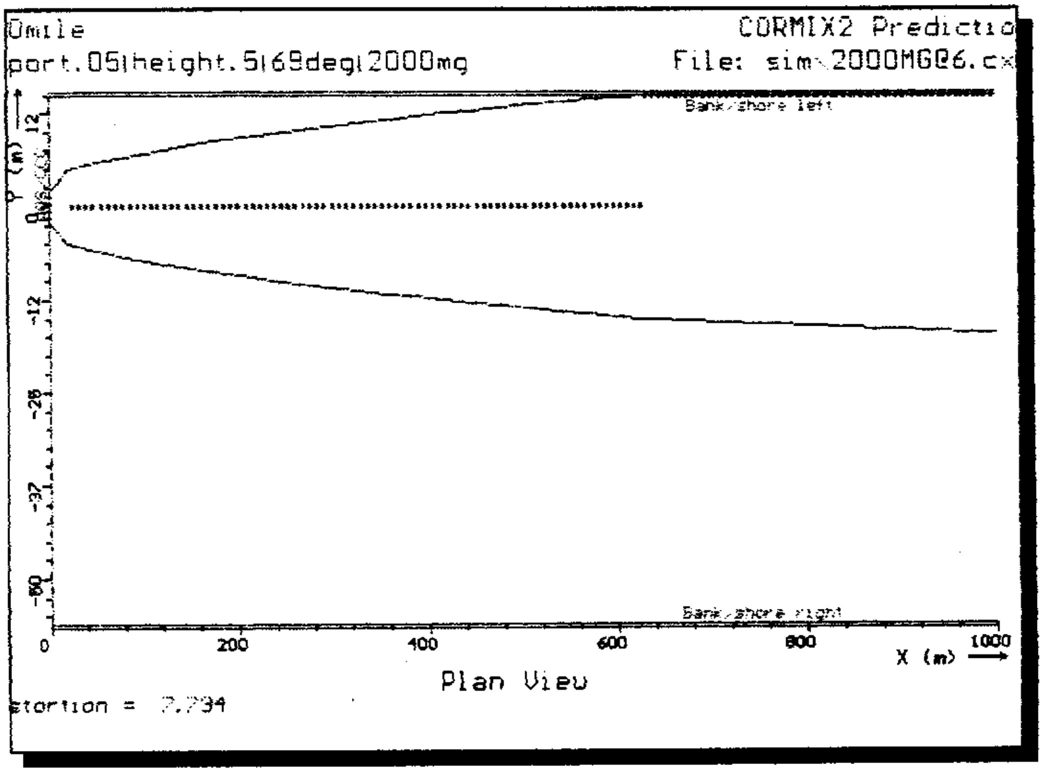


```
** End of NEAR-FIELD REGION (NFR) **
-----------------------------------------------------------------------------
BEGIN MOD241: BUOYANT AMBIENT SPREADING

 Discharge is non-buoyant or weakly buoyant.
   Therefore BUOYANT SPREADING REGIME is ABSENT.

END OF MOD241: BUOYANT AMBIENT SPREADING
-----------------------------------------------------------------------------
 Due to the attachment or proximity of the plume to the bottom, the bottom
   coordinate for the FAR-FIELD differs from the ambient depth, ZFB = 0 m.
 In a subsequent analysis set "depth at discharge" equal to "ambient depth".
-----------------------------------------------------------------------------
BEGIN MOD261: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT

  Vertical diffusivity (initial value)   =  .105E+00 m^2/s
  Horizontal diffusivity (initial value) =  .131E+00 m^2/s

 The passive diffusion plume is VERTICALLY FULLY MIXED at beginning of region

 Profile definitions:
   BV = Gaussian s.d.*sqrt(pi/2) (46%) thickness, measured vertically
      = or equal to layer depth, if fully mixed
   BH = Gaussian s.d.*sqrt(pi/2) (46%) half-width,
        measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

 Plume Stage 1 (not bank attached):
       X          Y         Z        S        C        BV        BH        ZU        ZL
     19.79       .00       .00     978.3  .204E+01    2.50      4.97      2.50       .00
     50.26       .00       .00     976.8  .205E+01    2.50      5.89      2.50       .00
     80.73       .00       .00    1108.8  .180E+01    2.50      6.69      2.50       .00
    111.20       .00       .00    1226.7  .163E+01    2.50      7.40      2.50       .00
    141.67       .00       .00    1334.2  .150E+01    2.50      8.05      2.50       .00
    172.14       .00       .00    1433.7  .139E+01    2.50      8.65      2.50       .00
    202.62       .00       .00    1526.7  .131E+01    2.50      9.21      2.50       .00
    233.09       .00       .00    1614.4  .124E+01    2.50      9.74      2.50       .00
    263.56       .00       .00    1697.5  .118E+01    2.50     10.24      2.50       .00
    294.03       .00       .00    1776.8  .113E+01    2.50     10.72      2.50       .00
    324.50       .00       .00    1852.7  .108E+01    2.50     11.17      2.50       .00
    354.97       .00       .00    1925.5  .104E+01    2.50     11.61      2.50       .00
    385.44       .00       .00    1995.8  .100E+01    2.50     12.04      2.50       .00
    415.91       .00       .00    2063.6  .969E+00    2.50     12.45      2.50       .00
    446.38       .00       .00    2129.3  .939E+00    2.50     12.84      2.50       .00
    476.85       .00       .00    2193.0  .912E+00    2.50     13.23      2.50       .00
    507.32       .00       .00    2254.9  .887E+00    2.50     13.60      2.50       .00
    537.79       .00       .00    2315.1  .864E+00    2.50     13.96      2.50       .00
    568.26       .00       .00    2373.9  .843E+00    2.50     14.32      2.50       .00
    598.73       .00       .00    2431.2  .823E+00    2.50     14.66      2.50       .00
    629.21       .00       .00    2487.1  .804E+00    2.50     15.00      2.50       .00
 Cumulative travel time =          502. sec

-----------------------------------------------------------------------------
 Plume Stage 2 (bank attached):
       X          Y         Z        S        C        BV        BH        ZU        ZL
    629.21     15.00       .00    2487.1  .804E+00    2.50     30.00      2.50       .00
    647.74     15.00       .00    2495.6  .801E+00    2.50     30.10      2.50       .00
    666.28     15.00       .00    2503.9  .799E+00    2.50     30.20      2.50       .00
    684.82     15.00       .00    2512.3  .796E+00    2.50     30.30      2.50       .00
    703.36     15.00       .00    2520.6  .793E+00    2.50     30.40      2.50       .00
    721.90     15.00       .00    2528.9  .791E+00    2.50     30.50      2.50       .00
```

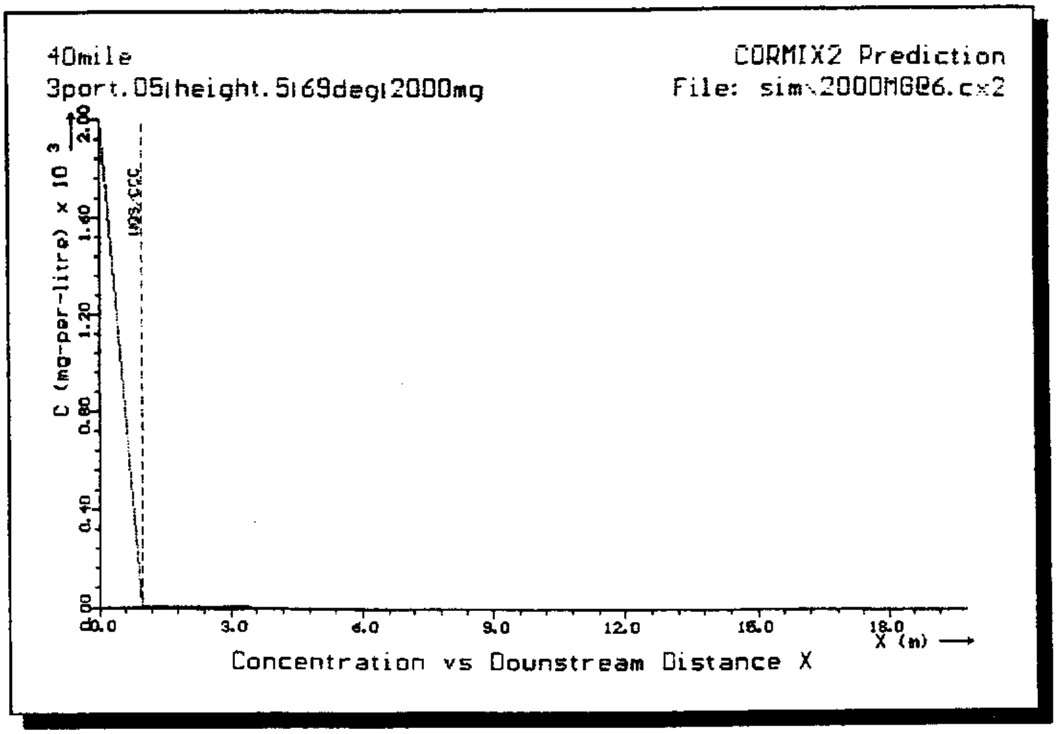
```
      740.44      15.00      .00   2537.2   .788E+00    2.50     30.60     2.50      .00
      758.98      15.00      .00   2545.4   .786E+00    2.50     30.70     2.50      .00
      777.52      15.00      .00   2553.6   .783E+00    2.50     30.80     2.50      .00
      796.06      15.00      .00   2561.8   .781E+00    2.50     30.90     2.50      .00
      814.60      15.00      .00   2570.0   .778E+00    2.50     31.00     2.50      .00
      833.14      15.00      .00   2578.1   .776E+00    2.50     31.10     2.50      .00
      851.68      15.00      .00   2586.2   .773E+00    2.50     31.19     2.50      .00
      870.22      15.00      .00   2594.3   .771E+00    2.50     31.29     2.50      .00
      888.76      15.00      .00   2602.4   .769E+00    2.50     31.39     2.50      .00
      907.30      15.00      .00   2610.4   .766E+00    2.50     31.49     2.50      .00
      925.84      15.00      .00   2618.4   .764E+00    2.50     31.58     2.50      .00
      944.38      15.00      .00   2626.4   .761E+00    2.50     31.68     2.50      .00
      925.84      15.00      .00   2618.4   .764E+00    2.50     31.58     2.50      .00
      944.38      15.00      .00   2626.4   .761E+00    2.50     31.68     2.50      .00
      962.92      15.00      .00   2634.4   .759E+00    2.50     31.78     2.50      .00
      981.46      15.00      .00   2642.3   .757E+00    2.50     31.87     2.50      .00
     1000.00      15.00      .00   2650.2   .755E+00    2.50     31.97     2.50      .00
   Cumulative travel time =          798. sec

   Simulation limit based on maximum specified distance =    1000.00 m.
     This is the REGION OF INTEREST limitation.

  END OF MOD261: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT
  -----------------------------------------------------------------------------
  -----------------------------------------------------------------------------
  CORMIX2: Submerged Multiport Diffuser Discharges        End of Prediction File
  22222222222222222222222222222222222222222222222222222222222222222222222222222
```



Near field Plume Predicition - Plan View



Far field Plume Prediction - Plan View



Near field Dispersion Rate

DIFFUSER LOCATION FOR CORMIX PREDICTION REPORT
Fortymile River NTS Map 116C-7
scale: 1 cm. = 1,000 m. (approx.)

APPENDIX C

DIFFUSION OF SETTLING POND SUSPENDED SEDIMENT IN YUKON RIVERS

by
MICHAEL A. CARSON, Ph.D.

for
FORTYMILE PLACERS

DIFFUSION OF SETTLING-POND SUSPENDED SEDIMENT IN YUKON RIVERS

Report to Fortymile Placers, Dawson City, Yukon

by

M.A. Carson, Ph.D.
Victoria, B.C.

PROJECT APPROACH

To predict the impacts on a water course of suspended sediment introduced through a diffuser, the physical characteristics of the river must be known. The more detailed the information that is available, the more accurate the predictions will be; general examinations using hypothetical data have limited value. The Fortymile was used as an example in this discussion because the necessary information was available. Information was gathered from WSC and from Fortymile Placers, who are familiar with the proposed diffuser site. This report illustrates the information required to examine the impact of suspended sediment introduced through a diffuser and provides an approach for examining the subject.

This brief examination of the possible impacts of suspended sediment being introduced from placer mine settling ponds into the Fortymile River and other Yukon rivers through a diffuser is organized into the following sections:

1. Background suspended sediment levels in Yukon rivers
2. Theoretical aspects of the settling of suspended sediment in the Fortymile River
    - 2.1 Settleable solids versus total suspended sediment
    - 2.2 Ease of maintaining sediment in suspension
3. Results from investigations of sediment settling in flumes
4. Results from similar field investigations
5. Consideration of worst-case scenario
6. Conclusions
7. References
8. Appendix

7 February, 1996

1. BACKGROUND SUSPENDED SEDIMENT LEVELS IN YUKON RIVERS.

I have come across very few data regarding average annual suspended sediment loads on Yukon rivers. Most of the data available come from streams that may not be directly comparable with the Fortymile River.

Perhaps the most reliable data for catchments which, at first sight, appear to be roughly comparable to the Fortymile River are from the westbank tributaries of the Mackenzie River in the NWT (Carson, 1993). Data for the Root, Redstone, Carcajou, Mountain and Ramparts rivers, based on fieldwork by the Water Survey of Canada, indicate amounts of suspended sediment per sq. km. of basin in the range from 115 to 441 tonnes in the average year. These values are high, however, because of relatively large amounts of easily entrained fine-grained Quaternary sediments in the lower parts of the basin.

Probably the best analogue of the Fortymile River in the Mackenzie Basin, for which sediment load data are available, is the upper Liard River. BC Hydro (1985) provided specific sediment yield data for the period 1973-79 for two stations on the upper river: at the Lower Crossing (29 t/sq.km/yr) and above the Beaver River (80 t/sq.km/yr). The former basin is the smaller of the two with an area of 104,000 sq. km.

Based upon the preceding data, a rough estimate for the sediment yield of the Fortymile River would be 50 t/sq.km./yr. Assuming this value, and multiplying by 16,600 sq.km (the area of the Fortymile basin near its mouth, based on WSC information), yields an estimate of the mean annual suspended load of about 830 thousand tonnes.

The vast majority of this sediment would be expected to be transported in May and June (and perhaps early July) based on the hydrograph data for the river (App. p.1). Assuming that it all moved in May and June (mean flow 293 m^3/s), the weighted mean sediment concentration in the river at that time would be about 545 mg/L.

For comparison, isolated May-July suspended sediment concentrations on other rivers in the Yukon (taken from WSC data as of 1990) range from 100 to 700 mg/L on the Stewart River at its mouth and 40 to 650mg/L for the Pelly River at Pelly Crossing; data for the Klondike River (1990 only) for May and June ranged from 230 to 380 mg/L.

These data indicate that the rough estimate of the mean annual load for the Fortymile River of 830,000 tonnes is at least consistent with sediment concentrations on some of the larger Yukon rivers.

Based on the information provided, i.e. a diffuser operating for 90 days, with a flow rate of 0.0378 cubic metres per second and a sediment concentration of 1,000 mg/L (See #2.1 below), the sediment added to the river would be 294 tonnes, assuming operation for 24 hours per day. This amounts to about 0.035% of the estimated mean annual suspended sediment load. Operation for only 12 hours per day would reduce the load to 147 tonnes, or less than 0.02% of the estimated mean annual load.

2. THEORETICAL ASPECTS OF THE SETTLING OF SUSPENDED SEDIMENT IN THE FORTYMILE RIVER

2.1 Settleable solids versus total suspended sediment

It was estimated that the diffuser pipe into the Fortymile River would transmit sediment with concentrations of up to 1 mL/L of settleable solids. Any discussion using this parameter is difficult, however, because, notwithstanding the rationale for the measurement of settleable solids, analysis of the dilution of settleable solids in river water is difficult.

It is preferable to work in terms of total suspended sediment (or non-filterable residue (NFR)) expressed in terms of mg/L, than in terms of settleable solids (mL/L). The conversion from mL/L to mg/L is not straightforward, and varies from stream to stream, and from one mine to another, depending on the type of sediment and the degree to which it flocculates. The data on App. p.2, taken from Environcon (1986) show how variable the relationship is, even for one river. Assuming that Fortymile River is similar in terms of placer mining effluent to Sixty Mile River, a figure of 1 ml/L would be roughly comparable, on average, to 500 mg/L of suspended sediment.

Data for Yukon basins were analyzed by Miles (1993) based on samples collected in 1990-92. All but three of the samples for the Sixty Mile watershed had less than 0.8 mL/L with corresponding concentrations ranging up to 2,400 mg/L. The difference between this data set and that shown in App. p.2 is quite marked, further emphasizing the variability in the relationship.

For the purposes of this investigation, a settleable solids value of 1 mL/L is taken as being equivalent to a suspended sediment value of 1,000 mg/L, as advised in the terms of reference. This value is intermediate between those indicated in the two data sets just noted.

2.2. Ease of maintaining sediment in suspension.

2.2.1 The propensity of suspended sediment to settle to the river bed depends, in the first instance, upon two parameters: the settling velocity of the sediment in still water (w) and the intensity of upward mixing of the water. The latter is usually represented by the shear velocity of the flow (V^*). The ratio of V^* to w is dimensionless. It can be considered an index of the ease of sediment suspension by the flow. The higher is the value, the easier it is for the river to keep sediment in suspension.

There appears to be no standard approved value of V^*/w that is universally accepted as the minimum value to keep sediment in suspension, but various workers have suggested that settling begins when actual values are less than 1.0, whereas sediment stays in suspension when the value is greater than 1.0. Moir (1989, p. 31-32), in developing a computer model for sediment transport in Yukon rivers, adopted this value.

2.2.2 The shear velocity of the flow, V^*, can be calculated from the expression

$$V^* = \sqrt{(Tg/G)}$$

where: T is the tangential force of the flowing water on the channel bed per unit area of the bed (and is usually called bed shear stress);

g is the acceleration due to gravity; and

G is the specific weight of water (about 10,000 Newtons per cubic metre).

In wide channels of uniform depth over the cross-section, where the flow is steady (velocity not changing over time) and uniform (velocity not changing downstream in the channel reach), the value of T over most of the channel width (but not near the bank margins) can be taken as (units of Pascals, i.e. Newtons per sq. metre):

$$T = GDS$$

where: G is the specific weight of water;

D is channel depth (metres); and

S is the dimensionless value of the downstream channel slope.

Thus shear velocity V* can be determined as $\sqrt{(gDS)}$, multiplied by 100 for cm/s.

For the Fortymile River, using the values provided of S = 1.2 m per km (0.0012) and D equal to 2 metres for late summer flow, the expected values for T and V* are:

T = 24 Newtons per sq metre and V* = 15 cm/s.

2.2.3 An independent estimate of V* can be made from the information on mean velocity (Vm) and bed material diameter (d).

Empirical curves exist which relate (Vm/V*) to (D/d_{84}), where D is depth of flow and d_{84} is the particle diameter for which 84% of the bed material is finer (e.g. Leopold, 1984, p. 262).

The information provided for the Fortymile River site indicates that d (away from the deep water line) is about 12-15 cm, and, at lower summer flow, D is about 2 m and Vm is about 1.25 m/s. Using these values D/d_{84} would be about 13 and Vm/V* would be about 9 Thus V* would be about 14 cm/s. Actually a larger value may be more appropriate for d_{84} (for the channel average); using a value of d_{84} equal to 30 cm would lower D/d_{84} to about 7, and change Vm/V* to 7.5, yielding a V* value of 17 cm/s. These two values straddle the value computed in 2.2.2 above.

2.2.4 The settling velocity of suspended grains depends upon many factors, but, values are commonly reported in the literature for spherical particles of specific gravity of 2.65 settling in clear water at different temperatures.

Data are provided in App. p.3. in cm/s, the graph referring to a water temperature of 20° C. Temperature is important because at lower temperatures, the viscosity of the fluid increases, thereby increasing the resistance of the fluid to settling. Adjustments to the fall velocity because of temperature can be made by dividing the value given in the graph by the viscosity correction factor shown in the table. In the calculations in this report a temperature of 10° Celcius is adopted.

2.2.5 For grains at the silt/sand boundary (0.062mm) settling in water at 20° C. would be about 0.34 cm/s, and at 10° C., the settling velocity would be about 0.26 cm/s. The V*/w value for the Fortymile River under the conditions given, at 10° C., would be about 60, well above the critical value for keeping material in suspension.

2.2.6 Thus, under the conditions assumed above, that is flat bed, and restricting attention to the mid-channel area, it appears that little if any sediment should settle out in the Fortymile River from the proposed diffuser.

2.2.7 The conclusion just reached should be tempered by the fact that in real channels, the shear stress and shear velocity usually decrease towards the channel banks because of bank resistance and the shallowing of the depth of flow. App. p.4 shows an example of this. The graph refers to the Athabasca River at Hinton (discussed in some detail below) under different levels of flow, and is taken from the report by Trillium Engineering and Hydrographics Inc. (1995) as part of the Northern River Basin Study. For any given flow, there is marked variability in the magnitude of bed shear stress across the channel, with peak values in the centre decreasing towards the banks. In the Athabasca example, settling would only be expected, at least during open-water conditions, in the right-hand edge of the channel.

The importance of the information above to the Fortymile River study is twofold:

a. sediment should not be introduced to the stream in the shallow parts of the channel near the banks because it is much more likely to settle out in this location;

b. even with diffuser sediment introduced in the main part of the flow, there is, because of dispersion of the sediment plume, likely to be movement of sediment downstream into areas where bed shear stress (and thus V*/w) is below the level for maintaining sediment in suspension.

The probability of settling in the latter case, however, is reduced by the strong dilution of the sediment concentration. This will encourage breakup of any sediment flocs and lower the settling velocity of grains in these areas of weaker sediment concentration. Discussion of worst-case scenarios is provided in Section 5.

2.2.8 Values of the V*/w ratio for other stream conditions (D and S) are given in the matrix in App. p. 5, based on the 20° C. settling velocity for 0.062 mm grains. It is a simple matter to adjust the values for other grain sizes and temperatures by referring to App. p. 3, selecting the new value of w and modifying the ratio accordingly. As an example, for grains with half the diameter (30 microns) at 5° C., the settling velocity is only 0.053 cm/s. The values in App. p. 5 would then be increased by a factor of 6.4x (0.34/0.053).

Note that the chart in App. p. 3 applies only to grains in the clay-silt range. Stokes' Law, upon which the graph is based, does not apply to sands. However, settling velocities for sands of different diameter are given below the table in App. p.5 and the correction factor for reducing the table values is noted. Thus as diameter exceeds 0.2 mm, values of V*/w in the table for the smallest depth-slope combination begin to fall below unity. Particles of this size are unlikely to be found in the diffuser sediment, however, if the suspension is drawn from a settling pond with adequate time for settling (see App. p.3: time to fall 10 cm for different grain sizes).

Note the importance of both grain size and temperature. For the flow intensity at Fortymile River (V^* equal to 15 cm/s), the index of the ease of keeping sediment in suspension would be in excess of 250 for grains of 30 microns at 5° C.

3. RESULTS FROM INVESTIGATIONS OF SEDIMENT SETTLING IN FLUMES

Recent laboratory studies have shown that the settling of sediment in channel flows is somewhat more complex than indicated in Section 2.2.1 above. Work undertaken by Krishnappan and Stephens (1995) at the National Water Research Institute in Burlington, Ontario examined the settling of natural sediment in natural river water.

In that study, sediment suspensions from the Athabasca River were introduced to a closed-system rotating flume at a concentration of 200 mg/L and allowed to settle under different velocities with bed shear stress levels ranging from 0.12 to 0.3 Newtons per sq.metre (N/m^2). These correspond to V^* values of about 1.0 cm/s to 1.7 cm/s, that is about 10% of the value estimated for the Fortymile River.

Unfortunately no data were given for settling velocity and therefore calculation of V^*/w is subject to uncertainty. The report gives the initial grain size of the sediment prior to settling as a mixture with two modes (0.002 mm and either 0.03 mm or 0.06 mm, depending upon the test conditions. Most of the settled sediment seemed to be from the larger of the two modes. Thus, making the standard assumptions of spherical particles, specific gravity of 2.65 and temperature of 20° C., the settling velocity should have been about 0.3 cm/s for the larger grain size. (The issue is complicated by the fact that some of these "grains" were actually flocs of grains so that specific gravity would have been less than 2.65).

Under the above assumptions, the estimate of V^*/w for the coarsest fraction is in the range 3 to 6 depending upon flow conditions. These values are thus much lower than the ratio determined for the Fortymile River (about 60). This is consistent with the fact that the bed shear stress (T) values in the flume were much lower than the 24 N/m^2 determined for late summer flow on the Fortymile River, though near-bank areas would be much lower.

The flume V^*/w values, then, were marginally greater than the "theoretical" value of unity needed to maintain sediment in suspension. App. p.6 shows the decrease in sediment concentration in the tests, as sediment settled out over time, the amount of settling, after almost 6 hours, being about 80% at the lowest bed shear stress to about 25% at the highest bed shear stress.

By chance, a period of 6 hours is about the length of time for water to travel the 27 km from the diffuser site to the mouth of Fortymile River at a speed of 1.25 metres per second. Thus, even under these very low bed shear stresses (and V^*/w values of less than 10% of those in the Fortymile River at low flow), less than 25% of the diffuser sediment would have been expected to settle out on the bed of the Fortymile River downstream.

In terms of applying these results to the Fortymile River case, two points should thus be noted:

a. At the head of the plume, where concentrations would be comparable with those in these tests (200 mg/L), the V*/w value in the Fortymile River would be 10x to 20x greater than in the flume tests. On the basis of this, no significant settling would be expected near the diffuser.

b. Further downstream, as the plume spreads to encompass low-flow areas near the banks, where V*/w values may have dropped towards the lower values of the flume tests, sediment concentrations would, because of dilution, be much lower than the 200 mg/L used in the flume. In fact, with thorough mixing, based on a diffuser input of 0.037 m^3/s, a streamflow of 178 m^3/s and a diffuser sediment concentration of 1,000 mg/L, the fully dispersed sediment concentration in the river from the diffuser would be about 0.2 mg/L.

Both of these observations suggest that, under these conditions, settling of the diffuser sediment should be minimal on the Fortymile River, provided that the diffuser is itself not located in an area of low shear velocity.

One qualification to the above conclusion is that it assumes that the diffuser sediment does not flocculate into larger "grains" with higher settling velocities once it is in the river. Research into the flocculation of suspended sediment in freshwater is in its infancy. In my opinion such flocculation is unlikely in the present case, but it could happen. Unusual conditions would be required for it. The work by Krishnappan and Stephens (1995), for example, indicated that addition of pulp mill effluent into the NWRI recirculatin-flume led to some flocculation and increased settling of the Athabasca sediment. This was attributed to the large quantities of very fine pulp fibre, and associated bacteria, in the effluent, and is probably inapplicable to the Yukon case being investigated.

4. RESULTS FROM SIMILAR FIELD INVESTIGATIONS.

I know of no prior detailed field investigations of the settling of diffuser sediment in natural streams. If none has been done, this is a further strong argument for undertaking a field study because it would produce valuable information applicable to many rivers, and to other situations where assessment of the impact of diffuser effluent on fish habitat is required.

There is, however, an investigation of a similar situation that has just been completed for the Athabasca River, Alberta, just downstream of the Hinton pulp and paper mill. The work was also done by NWRI as part of the Northern River Basin Study and was reported by Krishnappan et al. (1995).

The study is particularly relevant here because the river reach on the Athabasca appears to be very similar to that of the Fortymile, at least in terms of its basic hydraulic parameters. The channel slope is 1.1 to 1.4 m/km, the early autumn flow is about 150 m^3/s with associated flow depths of 2m to 4m depending upon channel width. The width varies from about 75m just downstream of the mill to nearer 150m at the downstream end of the study reach (See App. p.7). Bed material is reported as gravel with median particle diameter about 43 mm, somewhat finer than the data provided for the Fortymile River. The mean bed shear stress in the channel centre under early autumn conditions would be computed at about 20 N/m^2, but, as noted in App. p.4, conditions vary appreciably over the cross-section.

At the time of the autumn survey (App. p.7) the sediment input from the settling lagoon of the pulp mill was 3.6 tonnes per day. This compares with a diffuser input on the Fortymile River (with given flow and estimated concentration of 1,000 mg/L) of 3.2 tonnes per day, were the diffuser to be operated for 24 hours per day.

The top diagram shows, in schematic form, the downstream change in suspended sediment concentration with bank-to-bank samples. The Hinton section (36 mg/L effluent input) is misleading in that the outflow from the lagoon is at the right bank (not channel centre) and this is reflected in the higher concentrations by the right bank in the Haulbridge section just downstream. The diagram indicates the typical kind of bank-to-bank variation in sediment concentration in rivers, with lower concentrations near the banks (see Windfall section) reflecting settling of sediment away from the main current.

The bottom diagram shows the sediment balance (transport rates through different cross-sections) with the inferred amount of sediment settling to the bed based on the decrease in loads as the flow moved downstream. The inferred settling rates amount to 1.84 t/day per km of river length in the 19km reach between Haulbridge and Obed, and 0.61 t/day per km in the next (155 km) reach downstream.

The case study is reported here for two reasons:

i. It indicates the kind of detail needed in any field test to examine the settling process, if this is going to be done by suspended sediment sampling.

ii. It represents hydraulic conditions which, in some ways, are similar to the Fortymile River case.

In the latter context, the study does indicate that settling of some sediment on the channel bed is a possibility. In the Athabasca example, about 50% of the river sediment had settled out over a reach of 175 km. It would be possible to convert this into expected thickness of deposition per month, but the calculations would be meaningless given that deposition would only occur in the shallower parts of the river for which the area is unknown.

Notwithstanding the comments in the previous paragraph, there are certain factors that need to be emphasized which suggest that the application of the Athabasca data would lead to large overestimates of any settling that might occur in the Fortymile River:

a. The average sediment concentration in the river downstream of the Hinton mill is 100x the value of the fully dispersed sediment concentration in the Fortymile River, assuming little sediment in suspension in the latter river above the diffuser site.

b. The settled sediment in the 19km reach of the Athabasca River downstream of the pulp mill was about 10x the sediment load introduced from the mill effluent (i.e. most of it was natural sediment from upstream of the mill) because of the unusual circumstances associated with the mill effluent. The warm, fibre-rich sediment effluent is reported by

Krishnappan et al. (1995) to have acted to flocculate existing sediment in the stream thus precipitating this sediment at rates well in excess of what might be predicted based on upstream conditions. This specific condition is unlikely to be encountered on the Fortymile River.

c. In the reach upstream of the mill (Entrance to Hinton), though no data were reported in the NWRI study, the authors of that report made no comment regarding any settling of sediment. On the contrary, examination of the transport rate at Haulbridge (261 t/d) indicates that it exceeds the combined inputs at Entrance (207 t/d) and Hinton mill (3.6 t/d): thus the reach upstream (Entrance to Hinton) would have been one of net bed scour rather than net deposition.

In summary, although the Athabasca River observations warn us that prediction of settling behaviour and amounts, in the absence of observations on sediment flocculation or dispersion, must be made with caution, the conditions on the Fortymile River are not directly comparable with those on the Athabasca at Hinton, notwithstanding the similarity in hydraulic parameters.

5. CONSIDERATION OF WORST-CASE SCENARIO

It is worthwhile to put all of the above in perspective by considering a possible worst-case scenario, to the extent that this can be done with existing knowledge.

The following is based on the assumptions that, in the high-flow months: (a) the fully-dispersed diffuser sediment is a miniscule fraction of the background sediment concentration; (b) that, as a result, it will be incorporated into the background load without any more settling than would be evident from the natural load; and (c) the introduction of the placer effluent would not flocculate the background sediment to precipitate deposition of the load from upstream.

From the discussion of background levels in Section 1, assumption (a) is valid, and assumption (b) follows from this; from Section 4, assumption (c) is probably valid, but, given the state of research on this topic, there must be an element of uncertainty.

Under the assumed conditions, any settling of sediment would only be at the lower flows. Assuming that these represent about 60 days of the mining season, operation of the diffuser for 10 hours per day (sediment load of 1.3 tonnes per day) would amount to about 80 tonnes.

On the further assumptions of (a) sediment settling at a bulk density of 1 tonne per cubic metre; (b) settling restricted to 1 km length of the river; and (c) suspended sediment deposition being uniform over the full 71 m width of channel, then the worst-case scenario of complete settlement of the sediment would amount to less than 1.2 mm for 10 hour per day effluent discharge.

In reality there should be little if any sediment deposition in the deeper, more rapid flows, so that this part of the bed should stay clean. The sediment not deposited there would, however, be expected to diffuse to the near-bank regions further downsteam, thus extending the length of the downstream near-bank deposition.

This is an extreme worst-case scenario. The example of the Athabasca at Hinton (which could be considered a more likely worst-case scenario) shows that deposition of suspended sediment is a long and drawn-out process. Only 50% of the sediment load had settled out in a distance of 175 km downstream of the mill effluent supply under comparable hydraulic conditions to those on the Fortymile River.

On the Athabasca, rates of deposition in the 19-km reach downstream of the Hinton mill (Haulbridge to Obed) averaged 0.7% of the upstream load per km of river. In the case of the 27-km reach of the Fortymile River between the diffuser site and the river mouth, application of the same rate of settling to the Fortymile River would imply about 19% of the load would settle out in the downstream reach. This amounts to 15 tonnes (out of 80 tonnes) over a distance of 27 km based on operation of the diffuser 10 hours per day. Assuming all of this sediment deposition occurred on a strip of near-bank bed 20 metres wide, this amounts to about 15 cubic metres over an area of 540,000 sq. metres. This is equivalent to an average depth of deposition of 0.03 mm for 10-hour per day operation. This miniscule amount would be expected to be flushed from the bed during the following spring freshet.

6. CONCLUSIONS

6.1. It is difficult to be definitive regarding whether or not some placer effluent will settle onto the bed of the Fortymile River, and if so, in what quantities, given the present state of hydraulic and sedimentological knowledge. The main uncertainties are as follows:

a. Departures of the bed from a uniformly level surface, such as pool-bar bedforms, may produce distortions in the flow pattern in the form of convergence and divergence, altering the distribution of shear stress and shear velocity. In riffle-pool systems, the possibility of sedimentation within pools at low flow (in contrast to the bed scour there at high flows) should be considered (Richards, 1982, p.185-6). The discharge at which this possible changeover (between scour of the pool bed and settling of suspended sediment in the pool) might occur would need to be determined if the bed configuration is of this type.

b. The grain size of the placer effluent suspended sediment is known only in a general sense. The analysis above has assumed that essentially all this sediment settles with velocities typical of coarse silt. Sediment that is coarser than this should have settled out in the settling pond prior to entry into the diffuser system.

c. The behavior of the placer effluent as it reacts with background sediment and natural river water does not appear to be known. In particular, under what conditions dispersal of preexisting sediment flocs from the placer effluent will occur in the river (thus decreasing the propensity for settling), and under what conditions the placer effluent might act to induce flocculation in the background suspended sediment of the river (thus increasing the propensity for settling) is not known. The only case known to me of the latter scenario is for effluent conditions quite different from those in the placer mining industry.

d. The discharge data provided, and used in this report, refer to an average condition. Flows in any given year may be higher or lower than adopted above.

6.2 With these caveats, theoretical considerations, coupled with data from recent flume and field studies, suggest that minimal sedimentation should occur under the stipulated flow conditions.

6.3 A possible worst-case scenario has been provided based on the recent NWRI field study of mill effluent on the Athabasca River, a river of comparable hydraulics, where excessive deposition was triggered by the flocculating effects of the mill effluent. Application of the rate of settling from that study to sixty days of low flow on the Fortymile River indicates, as a worst case, an average amount of deposition of about 0.03 mm over on a strip of near-bank bed of 20 metres width over the full length of the river downstream, assuming diffuser operation for 10 hours per day.

6.4 In short, this analysis suggests that, because of the minimal risk involved, there are strong grounds for implementing a short-term field study to examine the feasibility of the diffuser approach to sediment removal. The justification for such a field study is reinforced by the apparent lack of any previous investigation.

7. REFERENCES

B.C. Hydro, 1985. Liard River Development: Downstream Hydrology. Unpublished interim report, Hydroelectric Generation projects Division, Report No. H 1794., BC Hydro, Vancouver.

Carson, M.A., 1993. Suspended sediment data analysis for westbank tributaries of the Mackenzie River, NWT. Report to Environment Canada, Yellowknife.

Environcon Ltd, 1986. Investigation of the magnitude and extent of sedimentation from Yukon placer mining operations. Report for Indian and Northern Affairs Canada, Ottawa.

Krishnappan, B.G. and R. Stephens, 1995. Critical shear stresses for erosion and deposition of fine suspended sediment from the Athabasca River. Draft report, National Water Research Institute, for the Northern River Basin Study.

Krishnappan, B.G., Stephens, R., Kraft, J.A. and B.H. Moore, 1995. Size distribution and transport of suspended particles in the Athabasca River near Hinton. Draft report, National Water Research Institute, for the Northern River Basin Study.

Leopold, L.B., 1994. A View Of The River. Harvard University Press. 298 pp.

Miles, M., 1993. Report to Yukon placer mining industry. Report not seen. Data provided by L. Chapman.

Moir, J., 1989. Numerical modelling of selected Yukon rivers. Report by Sable Dynamics Research Ltd for Indian and Northern Affairs Canada, Ottawa.

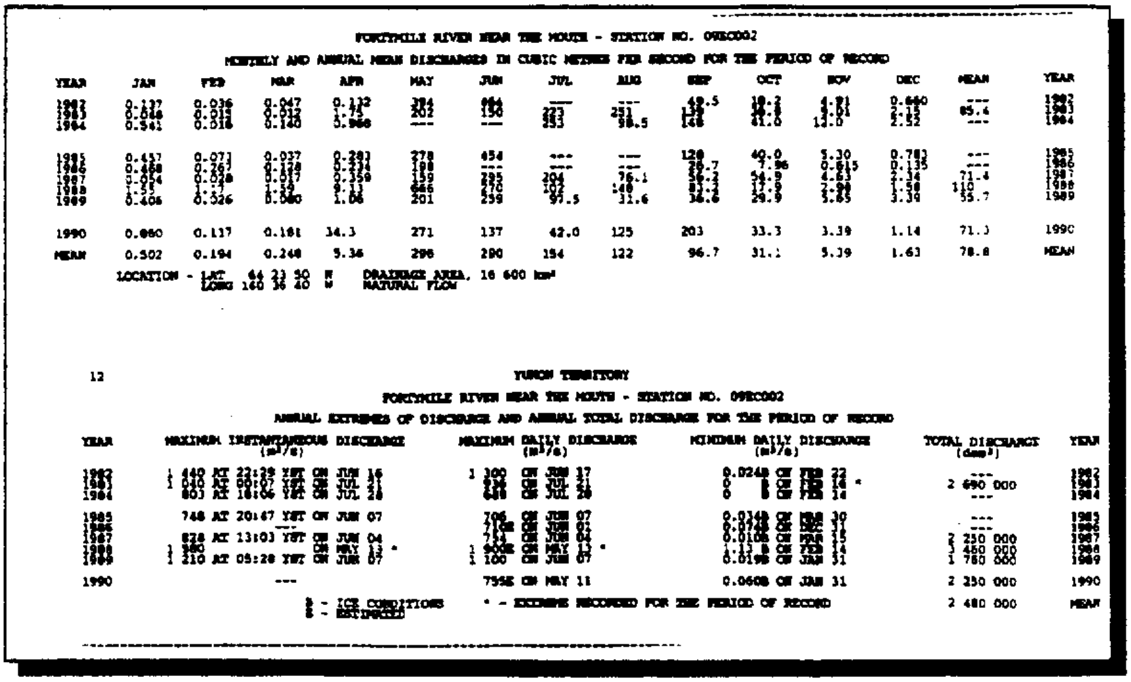
Richards, K., 1982. Rivers: Form and Process in Alluvial Channels. Methuen. 358 pp.

TVA, 1941. A study of the methods used in the measurement and analysis of sediment loads in streams. Inter-Agency report by Tennessee Valley Authority and other agencies. Report No. 4: Methods of analyzing sediment samples. Iowa City, Iowa.

Trillium Engineering and Hydrographics Inc., 1995. Deposition and re-suspension of fine-grained sediments. Report to Environment Canada, Prairie and Northern Region, Winnipeg.

8. APPENDIX

1. Discharge data for the Fortymile River near its mouth
2. Data for settleable solids and total suspended sediment for the Sixty Mile River basin
3. Fall velocity and settling rate for grains of different sizes in the silt-clay fraction
4. Cross-sectional distribution of bed shear stress in the Athabasca River near Hinton
5. Ratios of V^*/w for rivers of varying slope and depth of flow for 0.062 mm diameter quartz spheres in water at 20 degC.
6. Amounts of sedimentation in flume tests at different bed shear stresses: Athabasca River sediment
7. Suspended-sediment budget for the reach of Athabasca River in the vicinity of the Hinton pulp mill effluent supply



FORTYMILE RIVER NEAR THE MOUTH - STATION NO. 09EC002

MONTHLY AND ANNUAL MEAN DISCHARGES IN CUBIC METRES PER SECOND FOR THE PERIOD OF RECORD

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN	YEAR
1982	0.137	0.036	0.047	0.132	[illegible]	[illegible]	---	---	49.5	10.2	4.81	0.660	---	1982
1983	[illegible]	[illegible]	0.012	1.75	202	150	223	251	[illegible]	[illegible]	[illegible]	2.15	85.4	1983
1984	0.541	0.018	0.140	[illegible]	---	---	[illegible]	98.5	148	41.0	13.0	2.52	---	1984
1985	0.437	0.071	0.037	0.281	278	454	---	---	120	40.0	5.30	0.783	---	1985
1986	0.468	0.267	0.128	0.234	198	---	---	---	20.7	7.96	0.615	0.135	---	1986
1987	[illegible]	0.028	0.017	0.359	159	295	204	76.1	56.2	54.9	4.63	2.34	71.4	1987
1988	1.55	[illegible]	1.59	9.11	646	270	102	140	83.2	17.9	2.98	1.58	110	1988
1989	0.406	0.326	0.080	1.06	201	259	97.5	31.6	36.6	29.9	3.65	3.39	55.7	1989
1990	0.060	0.137	0.181	34.3	271	137	42.0	125	203	33.3	3.39	1.14	71.3	1990
MEAN	0.502	0.194	0.248	5.36	298	290	154	122	96.7	31.1	5.39	1.63	78.8	MEAN

LOCATION - LAT 64 23 50 N DRAINAGE AREA, 16 600 km²
LONG 140 36 40 W NATURAL FLOW

12

YUKON TERRITORY

FORTYMILE RIVER NEAR THE MOUTH - STATION NO. 09EC002

ANNUAL EXTREMES OF DISCHARGE AND ANNUAL TOTAL DISCHARGE FOR THE PERIOD OF RECORD

YEAR	MAXIMUM INSTANTANEOUS DISCHARGE (m³/s)	MAXIMUM DAILY DISCHARGE (m³/s)	MINIMUM DAILY DISCHARGE (m³/s)	TOTAL DISCHARGE (dam³)	YEAR
1982	1 440 AT 22:29 YST ON JUN 16	1 300 ON JUN 17	0.024B ON FEB 22	---	1982
1983	1 010 AT 00:07 YST ON JUL 21	[illegible] ON JUL 21	0 B ON FEB 14 *	2 690 000	1983
1984	803 AT 18:06 YST ON JUL 28	[illegible] ON JUL 28	0 B ON FEB 14	---	1984
1985	748 AT 20:47 YST ON JUN 07	706 ON JUN 07	0.034B ON MAR 30	---	1985
1986	---	710E ON JUN 01	0.074B ON DEC 31	---	1986
1987	828 AT 13:03 YST ON JUN 04	754 ON JUN 04	0.010B ON MAR 15	2 250 000	1987
1988	1 980 ON MAY 13 *	1 900E ON MAY 13 *	1.13 B ON FEB 14	3 460 000	1988
1989	1 210 AT 05:28 YST ON JUN 07	1 100 ON JUN 07	0.019B ON JAN 31	1 780 000	1989
1990	---	755E ON MAY 11	0.060B ON JAN 31	2 230 000	1990
				2 480 000	MEAN

B - ICE CONDITIONS
E - ESTIMATED

* - EXTREMES RECORDED FOR THE PERIOD OF RECORD

Appendix Figure 1

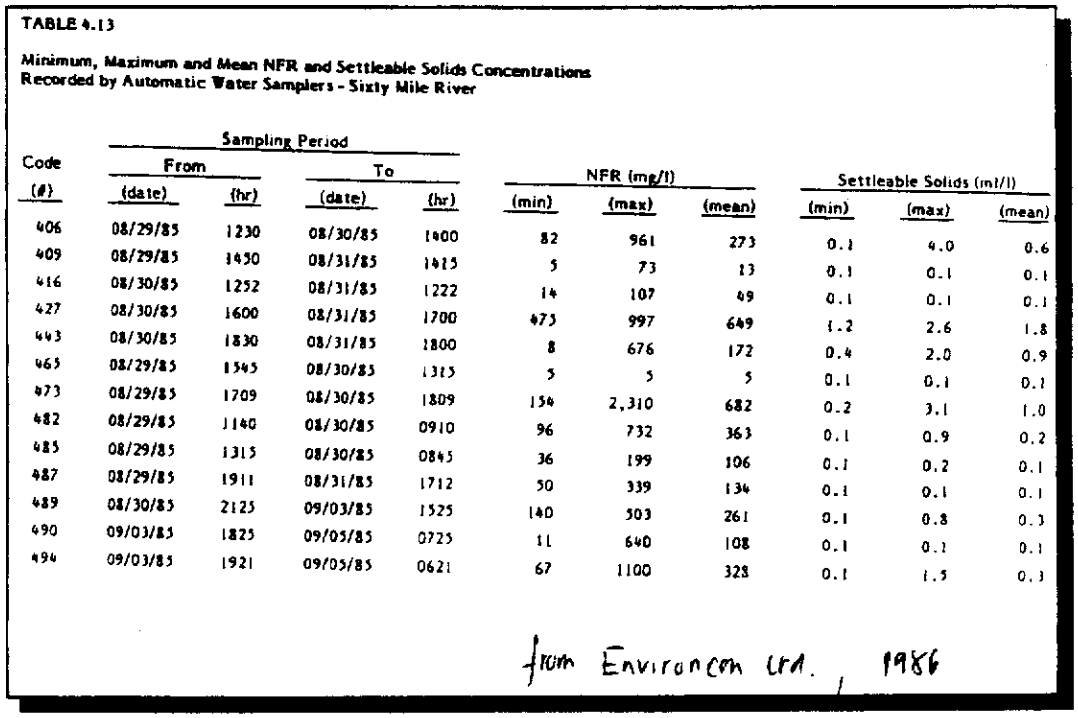


TABLE 4.13

Minimum, Maximum and Mean NFR and Settleable Solids Concentrations
Recorded by Automatic Water Samplers - Sixty Mile River

Code	Sampling Period				NFR (mg/l)			Settleable Solids (ml/l)		
	From		To							
(#)	(date)	(hr)	(date)	(hr)	(min)	(max)	(mean)	(min)	(max)	(mean)
406	08/29/85	1230	08/30/85	1400	82	961	273	0.1	4.0	0.6
409	08/29/85	1450	08/31/85	1415	5	73	13	0.1	0.1	0.1
416	08/30/85	1252	08/31/85	1222	14	107	49	0.1	0.1	0.1
427	08/30/85	1600	08/31/85	1700	475	997	649	1.2	2.6	1.8
443	08/30/85	1830	08/31/85	1800	8	676	172	0.4	2.0	0.9
465	08/29/85	1545	08/30/85	1315	5	5	5	0.1	0.1	0.1
473	08/29/85	1709	08/30/85	1809	154	2,310	682	0.2	3.1	1.0
482	08/29/85	1140	08/30/85	0910	96	732	363	0.1	0.9	0.2
485	08/29/85	1315	08/30/85	0845	36	199	106	0.1	0.2	0.1
487	08/29/85	1911	08/31/85	1712	50	339	134	0.1	0.1	0.1
489	08/30/85	2125	09/03/85	1525	140	503	261	0.1	0.8	0.3
490	09/03/85	1825	09/05/85	0725	11	640	108	0.1	0.1	0.1
494	09/03/85	1921	09/05/85	0621	67	1100	328	0.1	1.5	0.3

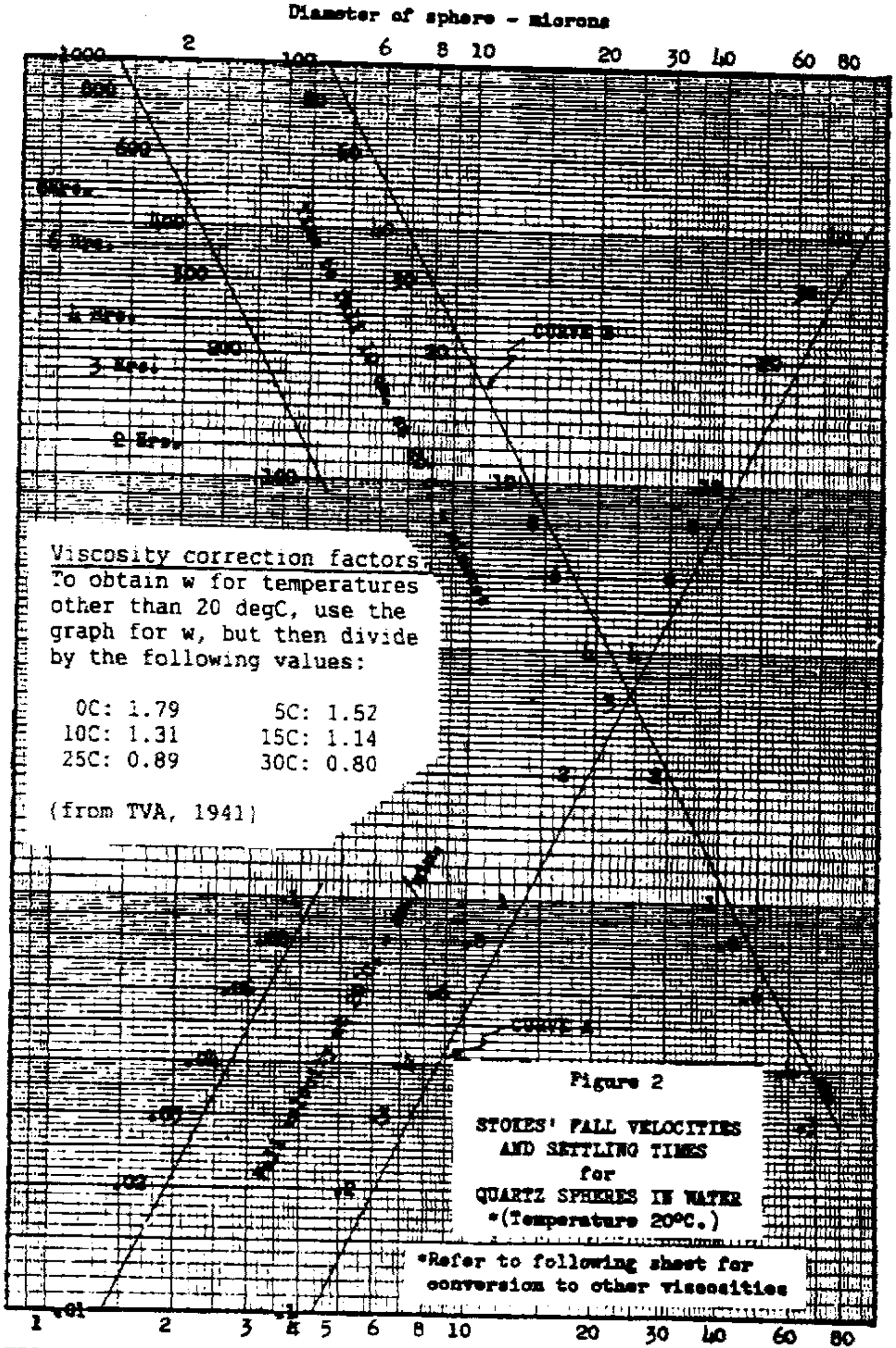
from Environcon Ltd., 1986

Appendix Figure 2

w denotes fall velocity

A 3

31 (cm/min in graph below) Section 12



Viscosity correction factors:
To obtain w for temperatures other than 20 degC, use the graph for w, but then divide by the following values:

0C: 1.79	5C: 1.52
10C: 1.31	15C: 1.14
25C: 0.89	30C: 0.80

(from TVA, 1941)

Figure 2

STOKES' FALL VELOCITIES
AND SETTLING TIMES
for
QUARTZ SPHERES IN WATER
*(Temperature 20°C.)

*Refer to following sheet for conversion to other viscosities

FIG. 2

Appendix Figure 3

Slope m/km	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2
Depth (m)										
0.2	6	8	10	12	13	14	15	16	17	18
0.4	8	12	14	16	18	20	22	23	25	26
0.6	10	14	17	20	23	25	27	29	30	32
0.9	12	17	21	24	27	30	32	35	37	39
1.0	13	18	23	26	29	32	34	37	39	41
1.2	14	20	25	29	32	35	38	40	43	45
1.4	15	22	27	31	34	38	41	44	46	49
1.6	16	23	29	33	37	40	44	47	49	52
1.8	17	25	30	35	39	43	46	49	52	55
2.0	18	26	32	37	41	45	49	52	55	58
2.2	19	27	33	39	43	47	51	55	58	61
2.4	20	29	35	40	45	49	53	57	61	64
2.6	21	30	36	42	47	51	56	59	63	66
2.8	22	31	38	44	49	53	58	62	65	69
3.0	23	32	39	45	50	55	60	64	68	71

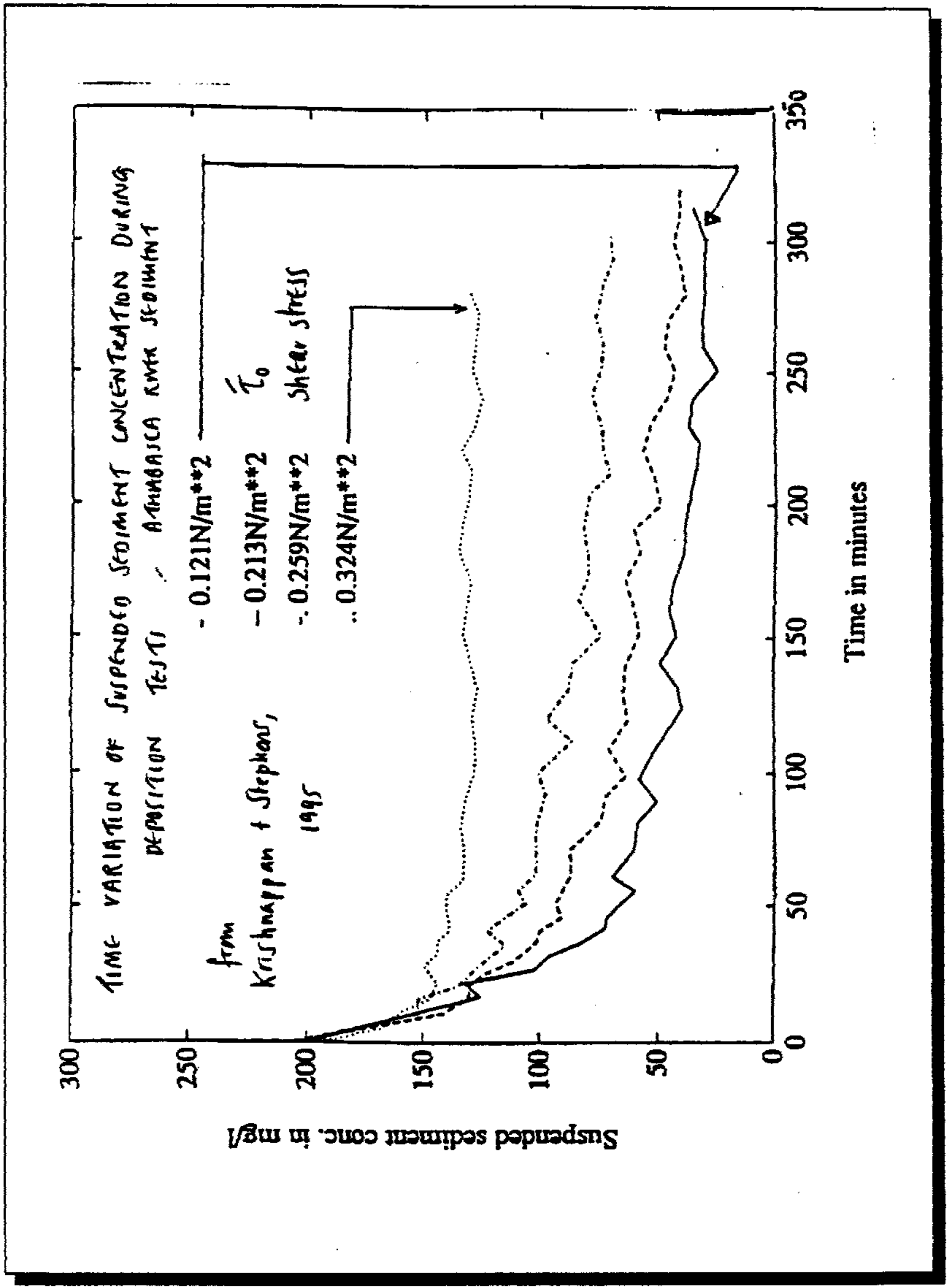
Above values are ratio of shear velocity to fall velocity
for case of quartz spheres of diameter 0.062 mm in 20 degC water
at which temperature fall velocity is 0.34 cm/s

For water at 10C, w=0.26 cm/s; multiply above values by 1.31

For 0.1mm at 10C, w = 0.7 cm/s; multiply above values by 0.48
For 0.1mm at 20C, w = 0.8 cm/s; multiply above values by 0.43
For 0.2mm at 10C, w = 2.0 cm/s; multiply above values by 0.17
For 0.2mm at 20C, w = 2.5 cm/s; multiply above values by 0.14
For 0.4mm at 10C, w = 5.1 cm/s; multiply above values by 0.06
For 0.4mm at 20C, w = 5.8 cm/s; multiply above values by 0.05

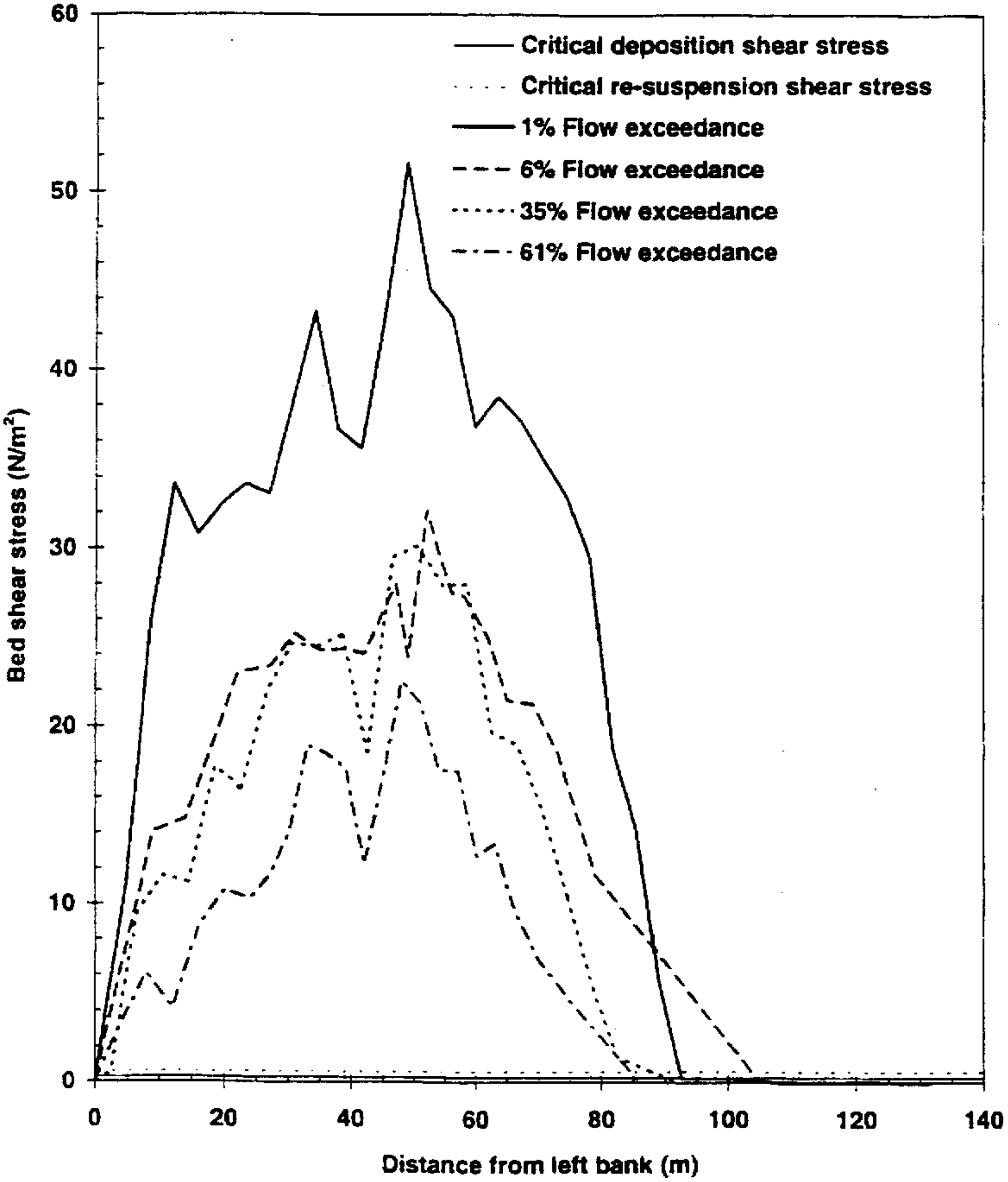
APPROXIMATE VALUES OF V*/w
FOR RIVERS OF DIFFERENT SLOPE AND DEPTH

Appendix Figure 4



Appendix Figure 5

Figure 3 Athabasca River at Hinton - open water



from Trillium, 1995

Appendix Figure 6

A+

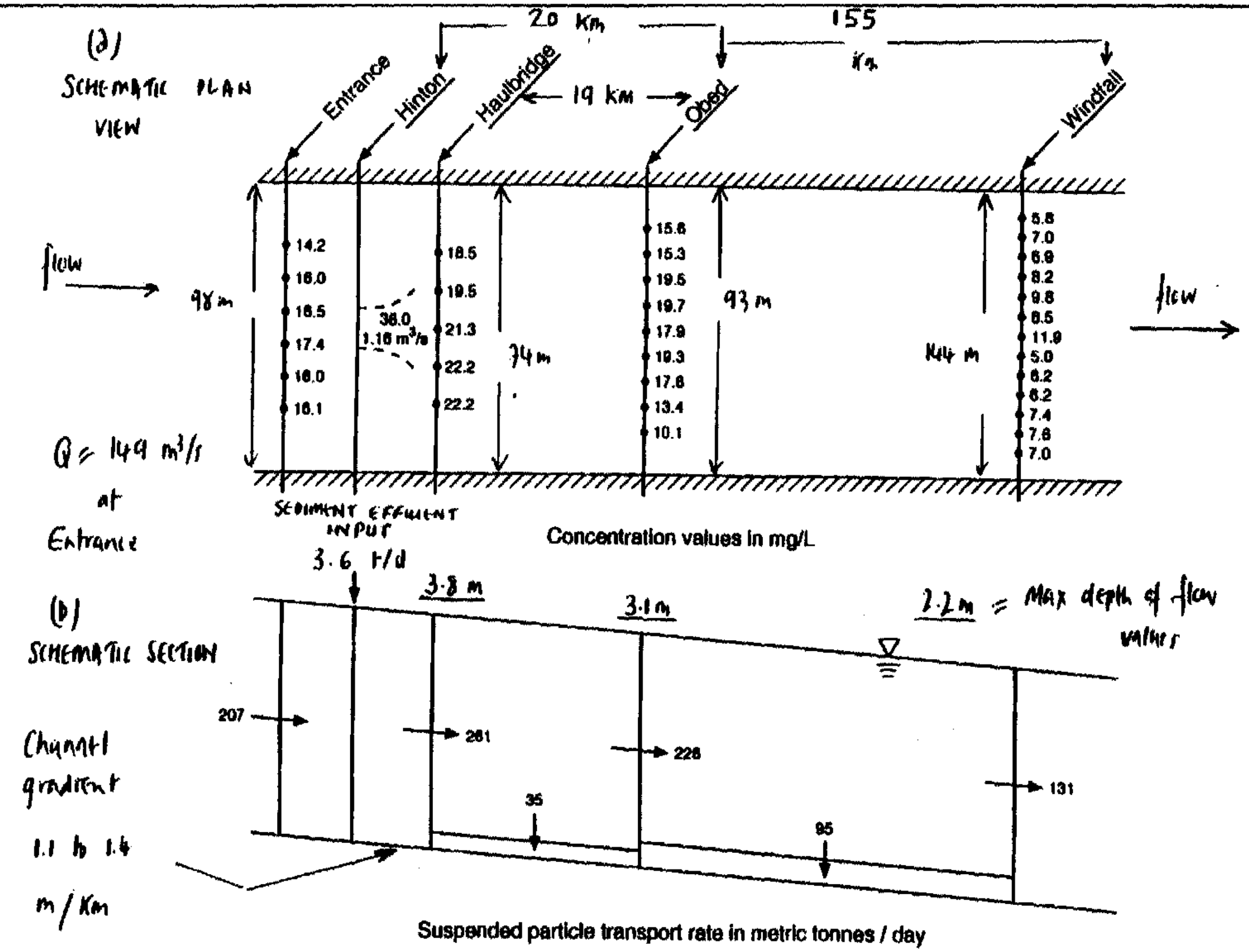


Figure 10. Concentration distribution and suspendend particle mass balance from the fall survey.
Athabasca River (from Krishnappan et al., 1995)

Appendix Figure 7

APPENDIX D

EXCERT FROM REPORT TO YUKON PLACER COMMITTEE ON RELATIONSHIP OF SUSPENDED TO SETTLEABLE SOLIDS

BY
M. MILES AND ASSOCIATES LTD.
1993

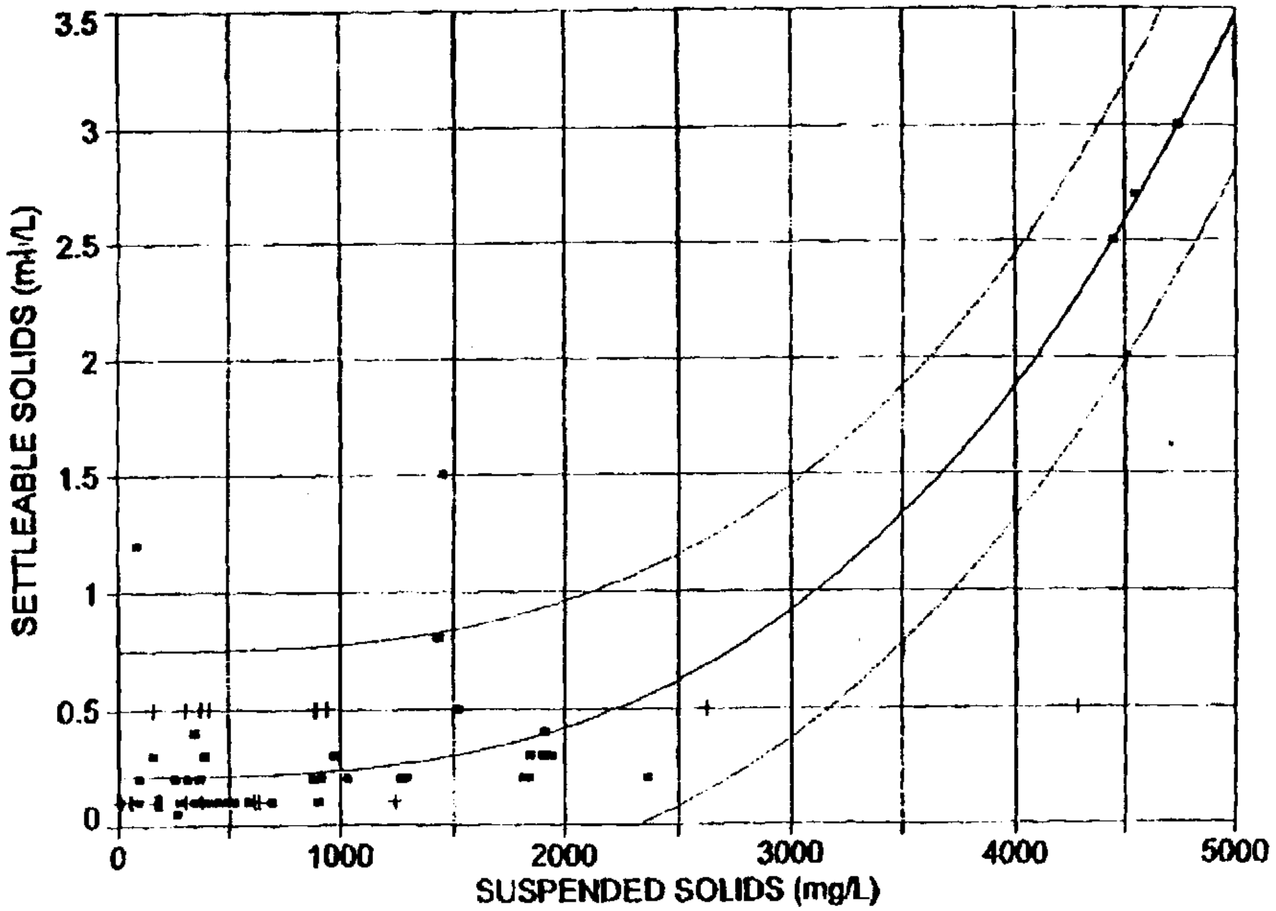
SIXTY MILE WATERSHED, 1990 - 1992

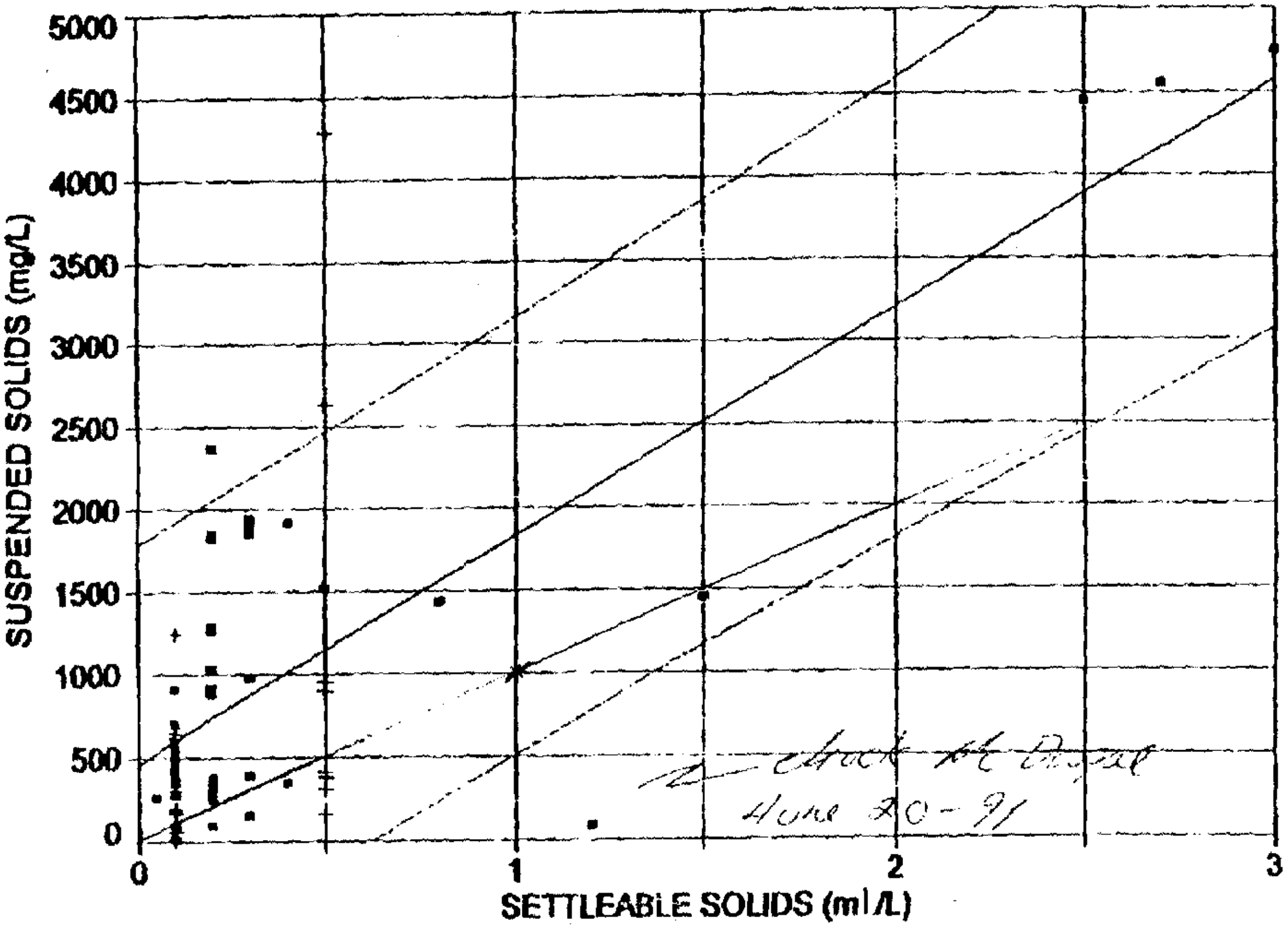
Rank 2 Eqn 7 $y=a+bx^3$

r^2=0.842816843 DF Adj r^2=0.835982584 FitStdErr=0.264268297 Fstat=252.013845

a=0.20796683

b=2.6058965e-11





Rank 8 Eqn 1 y=a+bx

r^2=0.66606349 DF Adj r^2=0.651544512 FitStdErr=646.916327 Fstat=93.7453172

a=458.75467

b=1370.6677

Chuck [illegible]
June 20-91