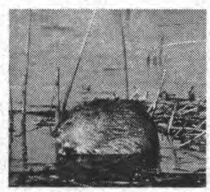
Canada Alberta Northwest Territories

Northern River Basins Study







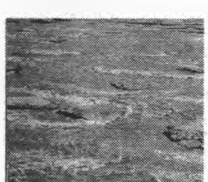


NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 51

SIZE DISTRIBUTION AND TRANSPORT OF SUSPENDED PARTICLES

ATHABASCA RIVER

FEBRUARY AND SEPTEMBER, 1993



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by

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NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 51

SIZE DISTRIBUTION AND TRANSPORT OF SUSPENDED PARTICLES

ATHABASCA RIVER
FEBRUARY AND SEPTEMBER, 1993

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PREFACE:

The Northern River Basins Study was initiated through the "Canada-Alberta-Northwest Territories Agreement Respecting the Peace-Athabasca-Slave River Basin Study, Phase II - Technical Studies" which was signed September 27, 1991. The purpose of the Study is to understand and characterize the cumulative effects of development on the water and aquatic environment of the Study Area by coordinating with existing programs and undertaking appropriate new technical studies.

This publication reports the method and findings of particular work conducted as part of the Northern River Basins Study. As such, the work was governed by a specific terms of reference and is expected to contribute information about the Study Area within the context of the overall study as described by the Study Final Report. This report has been reviewed by the Study Science Advisory Committee in regards to scientific content and has been approved by the Study Board of Directors for public release.

It is explicit in the objectives of the Study to report the results of technical work regularly to the public. This objective is served by distributing project reports to an extensive network of libraries, agencies, organizations and interested individuals and by granting universal permission to reproduce the material.

This report contains referenced data obtained from sources external to the Northern River Basins Study. Individuals interested in using external data must obtain permission to do so from the donor agency.

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Whereas the above publication is the result of a project conducted under the Northern River Basins Study and the terms of reference for that project are deemed to be fulfilled,
IT IS THEREFORE REQUESTED BY THE STUDY OFFICE THAT;
this publication be subjected to proper and responsible review and be considered for release to the public.

(Dr. F. J. Wrona, Ph.D., Science Director) — 7 June 95 (Date)

Whereas it is an explicit term of reference of the Science Advisory Committee "to review, for scientific content, material for publication by the Board",
IT IS HERE ADVISED BY THE SCIENCE ADVISORY COMMITTEE THAT;
this publication has been reviewed for scientific content and that the scientific practices represented in the report are acceptable given the specific purposes of the project and subject to the field conditions encountered.
SUPPLEMENTAL COMMENTARY HAS BEEN ADDED TO THIS PUBLICATION: [ ] Yes [ ] No

(Dr. P. A. Larkin, Ph.D., Chair) — 7 June 95 (Date)

Whereas the Study Board is satisfied that this publication has been reviewed for scientific content and for immediate health implications,
IT IS HERE APPROVED BY THE BOARD OF DIRECTORS THAT;
this publication be released to the public, and that this publication be designated for: **[ ] STANDARD AVAILABILITY [ ] EXPANDED AVAILABILITY**

Lucille Partington
(Lucille Partington, Co-chair) — June 8/95 (Date)

Robert McLeod
(Robert McLeod, Co-chair) — June 12/95 (Date)

SIZE DISTRIBUTION AND TRANSPORT OF SUSPENDED PARTICLES, ATHABASCA RIVER, FEBRUARY AND SEPTEMBER, 1993

STUDY PERSPECTIVE

Suspended particles are an important component of the water column; besides modifying water quality characteristics they are sites for contaminant compounds to become lodged and transported. Consequently, to model the aquatic ecosystem and the transport of contaminants, it is necessary to understand how suspended particles, particularly sediment, interact within a flowing channel. This study on suspended particles characterizes the size distribution and transport processes of suspended particles in the Athabasca River below the Weldwood Pulp Mill/Municipal outfall at Hinton, Alberta.

Related Study Questions

5. Are the substances added to the rivers by natural and man made discharges likely to cause deterioration of the water quality?

14. What long term monitoring programs and predictive models are required to provide an ongoing assessment of the state of the aquatic ecosystems. These programs must ensure that all stakeholders have the opportunity for input.

This Northern River Basins Study project has succeeded in showing for the first time that pulp mill effluent affects the physical transport characteristics of suspended river sediment. The Hinton combined pulp mill/municipal effluent promoted the interaction of effluent solids with suspended river sediment, and accelerated the speed of deposition from the water column. The substance(s) causing the increased deposition were not identified and further study is required to classify them. The findings identified the need to improve existing sediment transport models to explain the observed deposition rates and patterns.

As a consequence of this project's findings another project, "Critical Shear Stress and Deposition of Fine Suspended Sediment From the Athabasca River," will examine these changes to suspended sediment transport characteristics and attempt to quantify them. Knowledge gained from these studies will be used to refine existing water quality / contaminant models.

REPORT SUMMARY

This project was carried out for the Northern River Basins Study (NRBS) to characterize the size distribution and the transport processes of suspended particles in the Athabasca River below the Weldwood Pulp Mill outfall at Hinton. The project consisted of two field surveys: one, during the winter of 1993 and the other during the fall of the same year. The reach sampled is between Entrance, which is eight kilometers upstream from Hinton, and Windfall, which is at a distance of 175 km downstream. The measurements consisted of flow field, size distribution of in-situ and dispersed particles and concentration of particles in the water column.

The data from the two surveys show that the pulp mill effluent has affected the physical transport characteristics of the ambient sediment. It promoted the flocculation of the incoming sediment particles and increased their deposition rates. During low river flow periods, when the ratio between the effluent discharge to flow discharge is the highest (about 4%), 74% of the incoming sediment deposited within 20 km from the outfall. During moderate flows (i.e., flows in the order of five times the winter flow) the deposition continued at a slower rate further downstream from the outfall.

The results point to a need for an improved sediment transport model that considers the flocculation mechanism of the incoming sediment in the presence of pulp mill effluent. Existing models such as the one in WASP-4 will not predict sediment deposition downstream from the Weldwood Pulp Mill outfall and therefore are not suitable for making realistic predictions of pulp mill impacts in the Athabasca River.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the useful discussions that they had with Dr. Bob Crosley of Environment Canada, Western and Northern Region for the selection of transects for both the surveys. The assistance of Mr. Greg MacCulloch of Water Survey of Canada at Calgary in providing equipment and guidance for flow metering is greatly appreciated. The authors also thank Mr. Steve Smith of Technical Operations Section at NWRI for providing technical assistance during the winter survey, Mr. Jim Choles of Alberta Environment for acting as the scientific authority for this contract, Dr. Terry Prowse, the leader of the Hydrology/Hydraulics and Sediment Transport Study Group of NRBS for recommending the study and for the critical review of the manuscript, and NRBS for funding the study.

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SIZE DISTRIBUTION AND TRANSPORT OF SUSPENDED PARTICLES IN THE ATHABASCA RIVER NEAR HINTON

by

B. G. Krishnappan, R. Stephens, J.A. Kraft and B. H. Moore

Introduction:

This project was undertaken for the Northern River Basins Study (NRBS) to characterize the size distribution of the suspended load in the upper reaches of the Athabasca river and to examine the possible impacts of the pulp mill effluent on the transport characteristics of the ambient sediments of the Athabasca river downstream from the Weldwood Pulp Mill at Hinton, Alberta. The results of this project will be useful to answer some of NRBS's fundamental questions, such as whether the substances added to the rivers by natural and manmade discharges are likely to cause deterioration of the water quality and what long term monitoring programs and predictive models are required to provide an ongoing assessment of the state of the aquatic ecosystems. The Hydrology/Hydraulics and Sediment Transport Study Group of NRBS identified this project and recommended it to the study board.

The project consisted of two field surveys: one, during the winter of 1993 when the flow was low and ice-covered and the other, during the fall of the same year under open-water condition. In both surveys, the river reach covered was between Entrance and Windfall on the Athabasca river (see Fig. 1 for sampling locations) and the measurements consisted of flow field, size distribution of in-situ and primary particles, and concentration of suspended particles. In this report, descriptions of the river reach, instrumentation, measurement techniques and the results of the two surveys are described.

River Reach:

The profile of the upper reaches of the Athabasca river is shown in Fig. 2. This figure was reproduced from Kellerhals et al (1972). It shows the reach between Entrance and Windfall as a uniformly sloped reach with an average bed slope of 0.00123. The sampling locations are also marked on this profile. The transect at Entrance is about eight kilometres upstream from the effluent discharge location and it is immediately downstream from a Water Survey of Canada gauging station. The transect at Obed coal mines bridge is 20 kilometres downstream from Hinton. Other transects sampled include the Emerson bridge, the Berland bridge and the Windfall bridge located at 70 km, 105 km and 175 km, respectively from Hinton. There are two other Water Survey of Canada gauging stations within the sampled reach: one at Obed and the other at Windfall. The profile in Fig. 2 shows a break in the bed slope at Solomon Creek upstream from the Entrance transect. The slope changes from a milder slope to a steeper slope at this location. This implies that the flow velocity and the stream power to transport sediment are higher at the downstream reach (i.e. the reach containing the sampling transects) than the upstream reach. In other words, the sediment delivered to the downstream reach from upstream is not likely to be deposited in the sampled reach. Limited information on the bed characteristics shows that the river bed in the study reach consists of shale and bedrock (Kellerhals et al (1972)).

The 1993 flow data for the Hinton Station (near Entrance transect) were obtained from the Water Survey of Canada along with the historical flow records for the same station covering a period of 32 years starting from 1962. A comparison of 1993 flows with the historical flows as expressed in first, second and third quartiles is shown in Fig. 2a. From this figure, it can be seen that the 1993 flows are generally lower than the median flows (second quartile) and on the average closer to first quartile flows. The peak flow has occurred earlier than usual; but, the recession has coincided with the historical data.

Instrumentation:

The size distribution of suspended particles was measured using a new submersible laser particle size analyser developed at the National Water Research Institute, Burlington, Ontario, Canada. This instrument can measure the size distribution of sediment flocs directly in the flow and overcomes the problem of floc breakage that is normally encountered in the traditional method of size measurement involving collection of sediment samples and analysis using laboratory instruments. Complete details of the instrument are given in Krishnappan et al (1992). Here, a brief description is given for the sake of completeness.

The instrument operates on the principle of laser diffraction and it consists of a 2mW laser, a receiving lens, a detector plate, an electronic interface and a microcomputer. The laser, the detector plate and the electronic circuitry are attached to an aluminum chassis mounted inside a watertight canister. The laser beam emerges out through a glass window and passes through a laser path tube, which is attached to a dow prism that deflects the laser beam through 180 degrees. The deflected beam passes through the sensing volume and enters the canister through a second glass window. The receiving lens focuses the diffracted light on the detector plate. From the measured distribution of the diffracted light, the size distribution of the particles in the sensing volume is calculated using the Fraunhofer diffraction theory (Wiener, 1984). A photograph of the instrument is given in Fig. 3 and the deployment of the instrument from a boat is shown in Fig.4. The computer and a generator are placed on the boat and the instrument is lowered into the flow. A Colombus type sounding weight is attached to the lifting cage of the instrument to align the sensing volume to the direction of flow.

Concentration of suspended particles was measured by collecting samples using a P-72 suspended sediment sampler (Guy and Norman, 1970) and analyzing the samples using the filtration method in the laboratory. The size distribution of the primary particles that constitute the flocs was measured using a laboratory version of the laser particle size analyzer. This was done by breaking the flocs using an ultrasonic device and introducing the dispersed sample into the sample cell of the laser particle size analyzer. The operational details of the laboratory version of the particle size analyzer can be found in Krishnappan et al 1992. By comparing the in-situ particle size distribution and the primary particle size distribution, conclusions can be drawn regarding the extent of flocculation of the suspended particles. The flow velocity was measured using a Price current metre according to the Water Survey of Canada procedures. Structure of the sediment flocs was examined by collecting a very dilute sample of the suspended particles in a shallow chamber that fitted on a Wild Leitz inverted microscope.

Measurement Procedure:

1. Winter survey:

The winter survey was carried out in February 1993. The study reach was predominantly ice-covered except in a few locations near the Weldwood Pulp Mill outfall. The effluent entered the river at approximately 20 degrees Celsius and melted the ice cover in the immediate vicinity. The ice-cover reestablishes within a short distance downstream. All the selected transects were ice- covered. At each transect, holes were drilled through the ice using an ice-auger at 10 metre intervals from bank to bank. Ice cover thickness and the water depth in each hole were measured. Velocity measurements were carried out in each hole at 10 cm intervals throughout the depth.

Four to five slush-free holes in the middle section of the river were selected for particle size measurements. These holes had to be enlarged to about 60 cm square for the particle size instrument to fit. This was done by drilling several holes side by side and cutting out a square section using an ice-saw. A photograph showing the blocks of ice removed from the holes is shown in Fig. 5. A tent was built to house the computer and protect it from the wind and cold. Two small, ceramic heaters were used to heat the tent. The temperature inside the tent was around 5 degrees Celsius when the outside temperature was about -30 degrees Celsius. The particle size analyser was lowered into the hole using a tripod with a small rope block and tackle. A photograph of this deployment is shown in Fig. 6. The size distributions of the suspended particles were measured over the vertical in 20 cm intervals. Two 1-litre water samples were collected using the P-72 sampler to measure the suspended sediment concentration and the size distribution of the primary particles. Another sample consisting of two to three drops of water in a shallow glass chamber filled with distilled water was collected for the microscopic analysis of floc structure in the laboratory. The glass chamber was closed with a glass plate by sliding the plate across the meniscus. Care was taken to prevent trapping of any air bubbles inside the chamber during this operation.

Samples of effluent from the Weldwood Pulp Mill discharge were collected for particle concentration measurements. The data on effluent discharge and temperatures were obtained from the Mill authorities.

2. Fall survey:

The fall survey was carried out in September 1993. The sampling reach and transects were the same as in the winter survey (Fig. 1). During this survey, the river was ice-free and sampling was conducted from a boat and from bridges. The transect at Haulbridge was a new one and the transects at Emersion and Berland were omitted because of poor access. The transects at Entrance and Haulbridge were sampled from a boat. The transects at Obed and Windfall were sampled from bridges. The procedure used for the boat survey was as follows:

1. A tag line was strung across the river and measurement locations were marked at every 10- metre interval.
2. Current meter measurements were made from the boat, which was held in place by running the engines to counteract the current speed at measurement locations. Three point velocities were measured at each vertical. These were at 0.2h, 0.6h and 0.8h from the water surface where h is the local flow depth. The average velocity over the vertical was then computed as the average of 0.2h and 0.8h values and was compared with that measured at 0.6h. The average velocity will be close to 0.6h value if the flow is nearly two-dimensional.
3. Measurement of particle sizes was made using the particle size analyser at selected verticals in the middle section of the river. The point of measurement was around the mid-depth.
4. The suspended sediment samples were collected using the P-72 sampler at the same locations where the current meter measurements were made for subsequent laboratory analysis of concentration and primary particle size distribution.
5. Samples for the microscope analysis were collected in the same way as during the winter survey.

The sampling from bridges was similar to boat sampling. In this operation, the sampling locations were marked on the bridge and a cart carrying the particle sizer, the computer and the generator was moved along the bridge to sampling locations. The instruments were lowered into the flow from the bridge on the upstream side of the bridge to reduce the influence of the bridge piers on the measurement.

Results and Discussion:

1. Winter survey:

1a. Flow distribution:

From the vertical distribution of velocity, a depth average velocity was computed for each vertical in a transect. Knowing the depth of water under the ice, the flow rate was calculated assuming linear variation for depth-average velocity and water depth between measurement verticals. The flow rate so calculated for the Entrance transect was 29.3 m^3/s. This value compares well with the data (27.7 m^3/s) supplied by the Water Survey of Canada (see Fig. 2a). For Obed and Emerson, such a calculation of flow rate was not possible because some measurement holes contained slush ice that prevented the velocity measurements. The flow for these transects was, therefore, assumed to be the same as the Entrance transect because there was no significant tributary inflow for this reach and the flow was fairly steady. For Berland and Windfall transects, the flow data were not available because the Berland River flow was not measured during this survey. The other data, such as the lateral distribution of ice-cover thickness, depth of water under ice-cover and depth average velocities for slush-ice-free holes are listed in tabular form for all the transects and are presented in Appendix 1.

1b. Concentration distribution:

As indicated earlier, the concentration of the suspended particles (in mg/L) was measured using the filtration technique in the laboratory. Three samples were analyzed for each vertical and a depth-average value was calculated. The depth-average values for all the transects are listed in the tables given in Appendix 1. These values are of similar magnitude to those presented in Noton and Shaw (1989).

1c. Suspended particle transport rate:

Knowing the depth-average values of flow velocity and concentration of the suspended particles, the transport rate can be calculated as a product of the two and can be integrated across the transect to obtain the total suspended particle transport rate in metric tonnes per day (T/d). Such a calculation was carried out for the Entrance transect and transport rate was computed as 63.7-T/d. For Obed and Emerson transects, the transport rates were calculated as a product of the cross-sectional average concentration and the total flow rate of 29.3m^3/s as the depth-average flow velocity was not available for all the verticals. The values calculated for these two transects are 20-T/d and 14-T/d respectively. Such low values in comparison to that at Entrance imply that the reach below Entrance is a depositional reach. The depth-average concentration values and the suspended-particle mass balance including the effluent mass (shown as an expanding jet in dotted line) are presented schematically in Fig. 7. The ratio between the effluent discharge (1.16m^3/s) and the flow discharge (29.3m^3/s) is about 0.04 and the same between the effluent solids discharge (3.6 T/d) and the ambient sediment discharge (63.7 T/d) is about 0.06. From

Fig. 7, it can be seen that 74% of the incoming sediment has deposited in the reach between the outfall and Obed. The deposition continues in the reach between Obed and Emerson also, but at a slower rate. In this reach, 30% of the material entering the Obed transect has deposited. Since Berland River input of flow and suspended particles were not measured, it is not possible to extend the mass balance analysis downstream from Emerson transect. Only 20% of the material entering the reach at Entrance is leaving the Emerson transect.

1d. Particle Size Distribution:

The size distribution of the suspended particles measured using the submersible size analyzer in one of the verticals of the Entrance transect is shown in Fig. 8. In the same figure, the size distribution of the primary particles measured using the laboratory size analyzer is shown for comparison. From this figure, it can be seen that the suspended particles are transported in a flocculated form at this transect. The in-situ distribution contains particles in size classes as large as 204 and 383 microns whereas the primary particles are finer and do not contain any particles in these size classes.

A similar comparison was made for the Obed transect and the distributions of in-situ and dispersed particles are shown in Fig. 9. The differences in relative size distributions of suspended particles in this figure also provides evidence of flocculated particles in suspension. In addition, it shows that the concentration of particles in every size class has diminished during their transport from Entrance to Obed. This implies that the particles have settled to the river bed and the settlement has been promoted by flocculation, i.e. the smaller particles attaching themselves to larger particles and settling.

From the consideration of flow hydrodynamics and sediment transport alone it is not possible to explain the deposition of suspended particles in this reach. The sediment transporting capacity of the flow at Obed is about the same as that at Entrance and if there is no change in the sediment properties (size and density and consequently settling velocity), then the transport rate at Obed should be equal to that at Entrance. The fact that we observe sediment deposition is an indication that the sediment properties have been altered. The presence of pulp mill effluent in the reach is the most likely explanation for this. Pulp mill effluent contains organic fibres and bacteria that have affinity for ambient inorganic sediment. Sediment particles of different sizes can attach themselves to the organic material and settle as larger units and resist the hydrodynamic drag and lift forces. Evidence of inorganic particles attaching to organic fibres and bacteria was found in relation to marine aggregate formation by Muschenheim et al. (1989). (Particle size data for the remaining three transects were not shown because of their unreliability due to very low concentrations of suspended particles in these transects).

The deposition of the incoming sediment and the solid fraction of the pulp mill effluent is likely to continue during low-flow periods. At freshet, it is possible that the bed-shear stress will exceed the critical shear stress for erosion and the resuspension of the deposited material will occur, resulting in transport of the material further downstream. When the flow rate decreases, the deposition cycle will repeat. The purpose of the fall survey was to examine if the deposition cycle had begun.

2. Fall survey:

2a. Flow Distribution:

The depth-average velocity at a vertical was calculated as the average value of velocities at 0.2 and 0.8 depths from the free surface. The variations of flow depth and depth-average velocities across the measured transects are listed in Tables in Appendix 2. Knowing the depth and the depth-average velocity, the flow rate across the transect was computed assuming linear variations for both depth and depth-average velocity between the measured verticals. The flow rates calculated for the transects are also listed below the tables in Appendix 2. The flow rate measured for the transect at Entrance was 149 m^3/s, which agrees with the data supplied by the Water Survey of Canada (see Fig. 2a). This flow is almost five times the flow measured during the Winter survey at this transect. Note from Fig. 2a that this flow is already in the receding stage of the annual hydrograph.

2b. Suspended Sediment Concentration:

Suspended-sediment samples collected during the fall survey were analysed in the same way as for those collected during the winter survey and the depth-average concentration for each vertical was determined. These values are listed in the Tables in Appendix 2.

2c. Suspended Sediment Transport rate:

Knowing the flow distribution and the suspended-particle concentration distribution, the transport rates of suspended particles were calculated according to the method outlined for the winter survey and the values are listed below the Tables in Appendix 2. These values are used to construct the mass balance diagram as shown in Fig. 10. The ratio of the effluent discharge to the flow discharge during the fall survey is about 0.008 while that of the effluent solids and ambient sediment is around 0.02. From Fig.10, it can be seen that there is evidence of sediment deposition even during this period. But, the rate of deposition is comparatively slower. Between Haulbridge and Obed, there is a small drop in sediment transport rate(about 13%). Between Obed and Windfall the drop is as high as 42%. In the mass balance shown in Fig. 10, the sediment load coming from the Berland River was not considered. If it were included, then the deposition would be even larger.

2d. Size distribution:

The data on the in-situ size distribution of the suspended particles for the fall survey were not available because of a calibration problem with the submersible particle size analyser. The size distributions of the dispersed particles were measured and the median size of these distributions are listed in the tables in Appendix 2. These values show that the size distributions measured during the fall survey were finer than those measured during the Winter survey. This may be due to the finer sediment entering the flow from bank erosion that occurs normally under open-water flow conditions. In ice-covered flows, the source of sediment is mainly from upstream reaches.

Conclusions and Recommendation for further work:

The data from the two surveys show that the pulp mill effluents have affected the physical transport characteristics of the ambient sediment in the Athabasca River downstream from the Weldwood Pulp Mill at Hinton. The effluents appear to have promoted the flocculation of the incoming sediment and increased their deposition rate. The effects are most pronounced during low-flow periods when the ratio of the effluent discharge to the flow discharge is the highest (about 4%, during this study). During low flow periods, 74% of the incoming sediment deposited within 20 km from the effluent discharge location. Deposition can continue up to 100 km, but at a slower rate. In-situ measurement of size distribution of suspended particles during the winter survey shows that the suspended particles are transported in the reach in a flocculated form.

During moderate flows (e.g., flows in the order of five times the base flow), there is still evidence of enhanced sediment deposition; but, the deposition rate is slower and the deposition zone is shifted further downstream.

From the results of the two surveys, one may be tempted to speculate that the deposition of the effluent solids and the ambient sediment could persist over a period of almost eight months in a year when the flow rate is lower than the fall survey value and affect the quality of the aquatic habitat near the river bed in the surveyed reach. The deposited sediment could become resuspended during the high flows that normally start in June in the Athabasca River. Of course, the resuspension potential of the deposited sediment needs to be confirmed. This could be accomplished in a rotating circular flume such as the one at NWRI by measuring the critical shear stress for erosion for different consolidation conditions.

It is also possible to conclude from this study that there is a need for an improved formulation for the transport characteristics of fine sediment, which would consider the process of flocculation caused by the presence of pulp mill effluents in the Athabasca River below Hinton. Existing formulations such as the one in the WASP model (Ambrose et al. 1986) do not treat the flocculation of the fine sediment in an explicit manner and may not predict the observed sediment deposition in the Athabasca river reach below the Weldwood Pulp Mill outfall.

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List of figures:

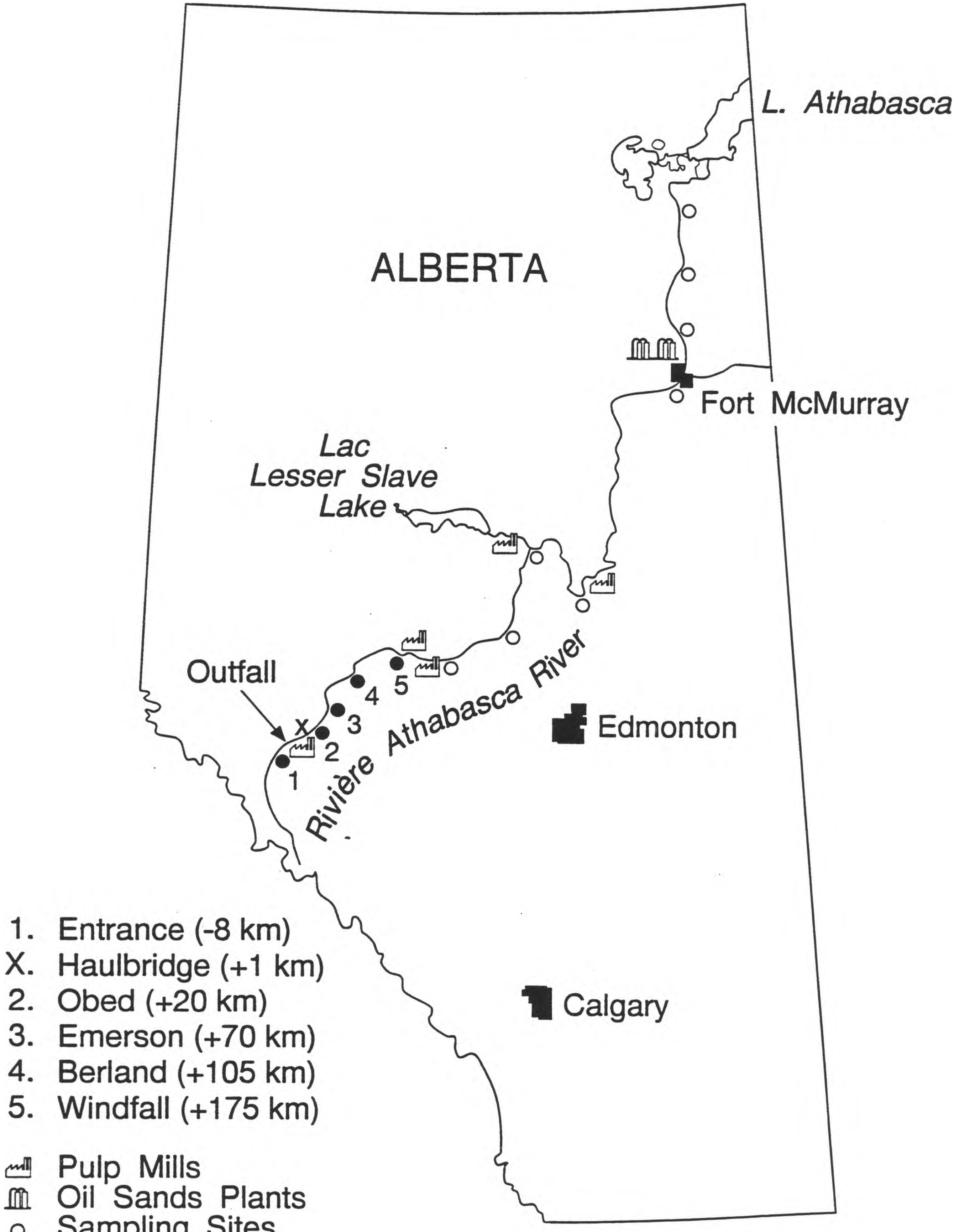
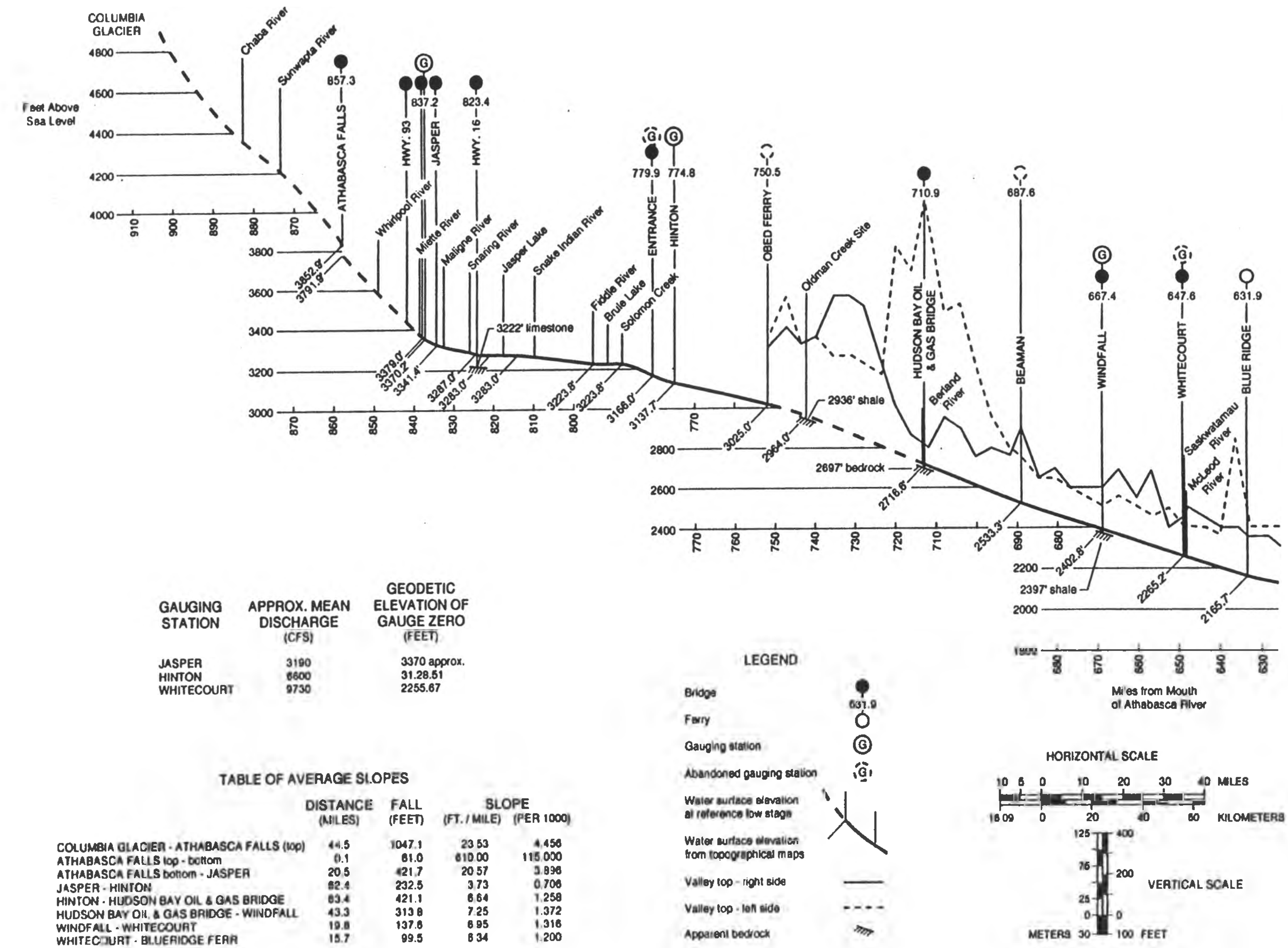


Figure 1. Map of sampling locations



GAUGING STATION	APPROX. MEAN DISCHARGE (CFS)	GEODETIC ELEVATION OF GAUGE ZERO (FEET)
JASPER	3190	3370 approx.
HINTON	6600	31.28.51
WHITECOURT	9730	2255.67

TABLE OF AVERAGE SLOPES

	DISTANCE (MILES)	FALL (FEET)	SLOPE (FT./MILE)	SLOPE (PER 1000)
COLUMBIA GLACIER - ATHABASCA FALLS (top)	44.5	1047.1	23.53	4.456
ATHABASCA FALLS top - bottom	0.1	61.0	610.00	115.000
ATHABASCA FALLS bottom - JASPER	20.5	421.7	20.57	3.896
JASPER - HINTON	62.4	232.5	3.73	0.706
HINTON - HUDSON BAY OIL & GAS BRIDGE	63.4	421.1	6.64	1.258
HUDSON BAY OIL & GAS BRIDGE - WINDFALL	43.3	313.8	7.25	1.372
WINDFALL - WHITECOURT	19.8	137.6	6.95	1.316
WHITECOURT - BLUERIDGE FERR	15.7	99.5	6.34	1.200

Fig. 2. Profile of the Athabasca River near Hinton, Alberta.

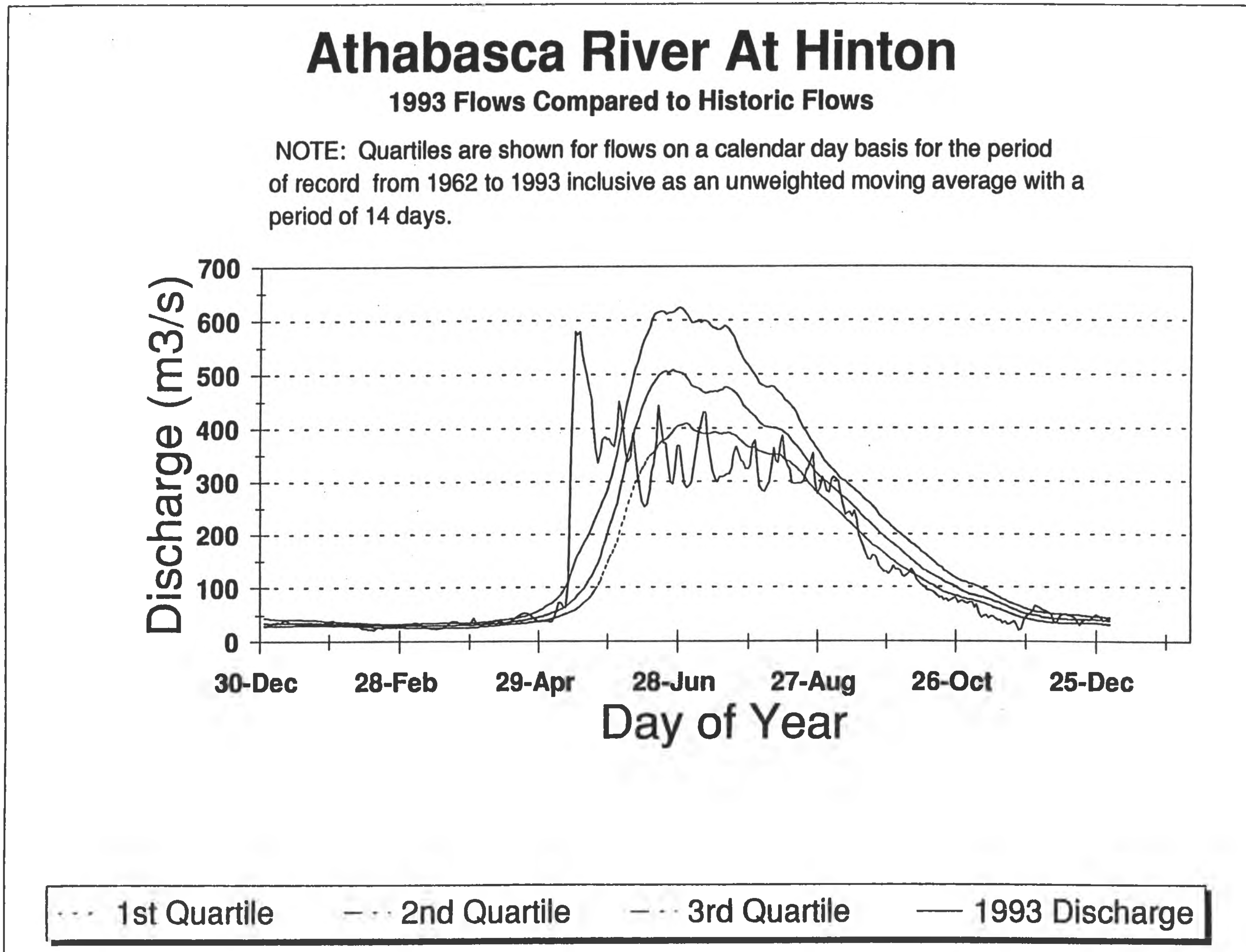


Fig. 2a. 1993 flow hydrograph compared with the historical data for Hinton Station.

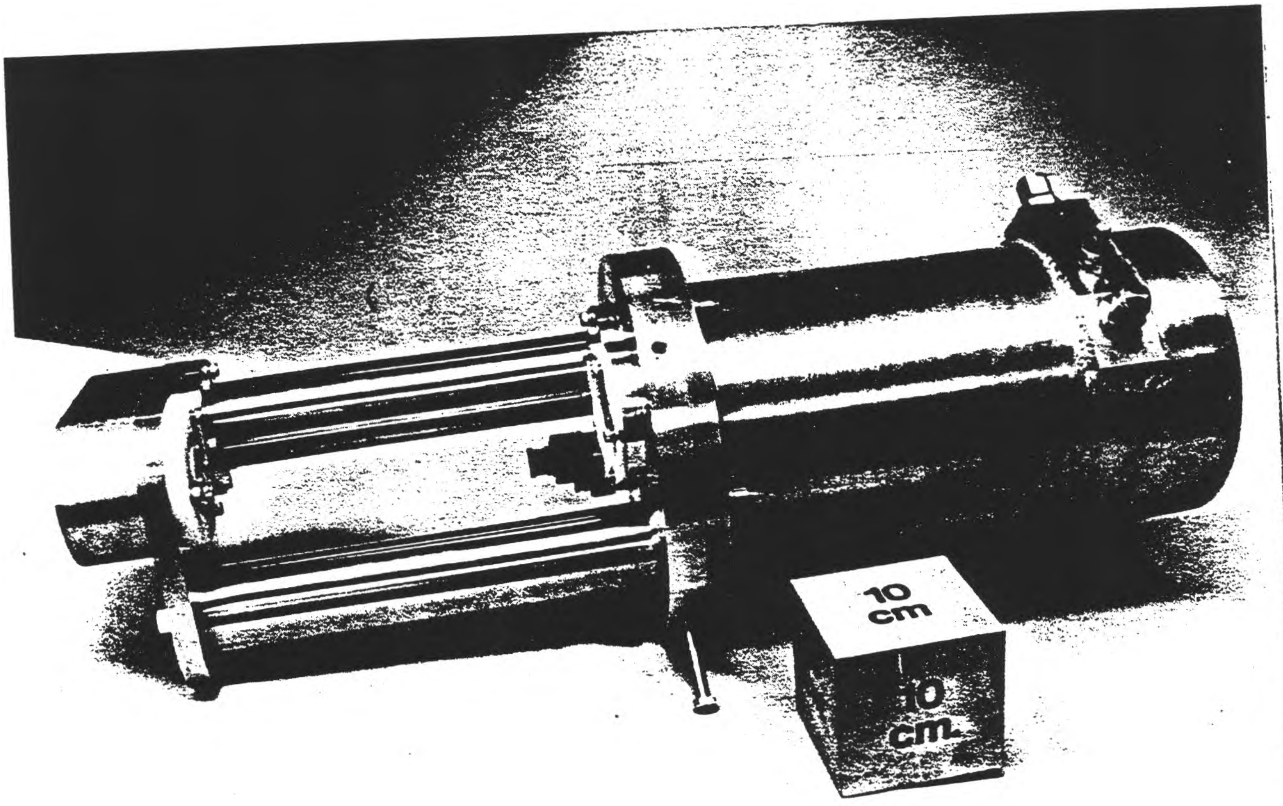


Figure 3. Photograph of NWRI's submersible laser particle size analyser

Figure 4. Photograph showing the deployment of the size analyser from a boat

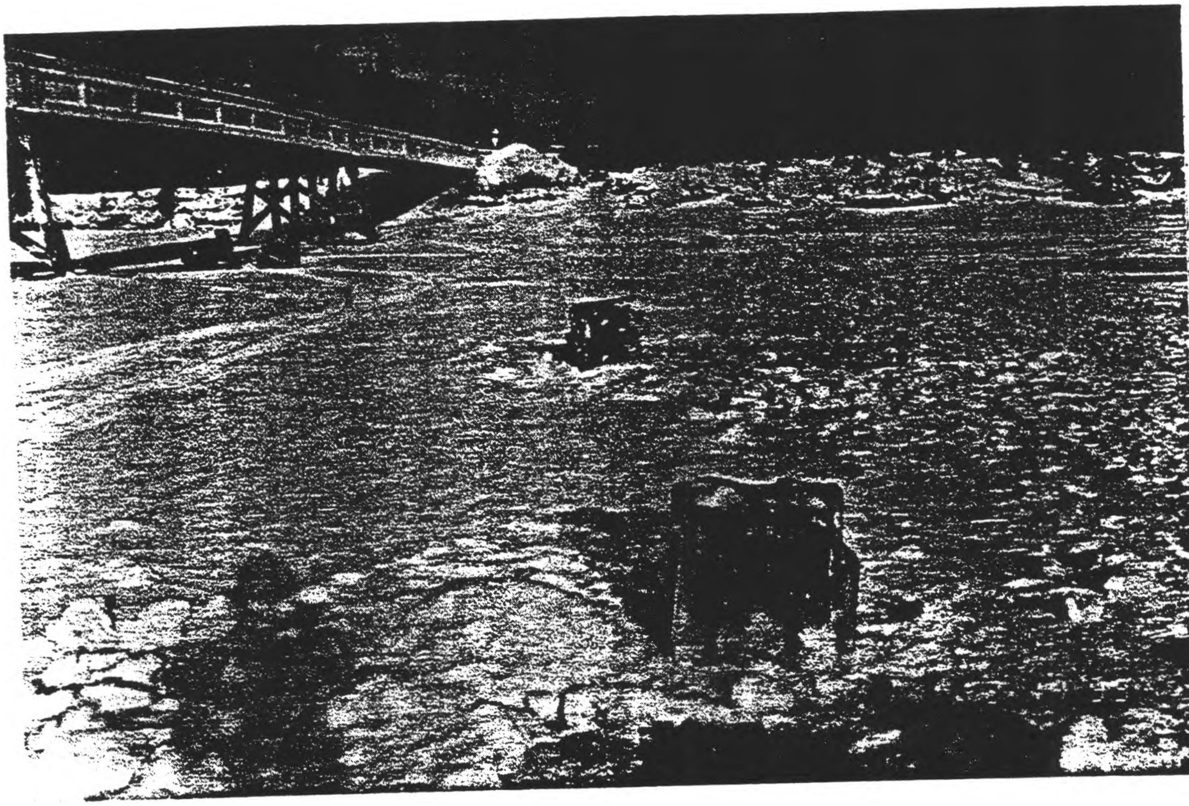


Figure 5. Photograph of blocks of ice cut out from the ice cover in a typical transect

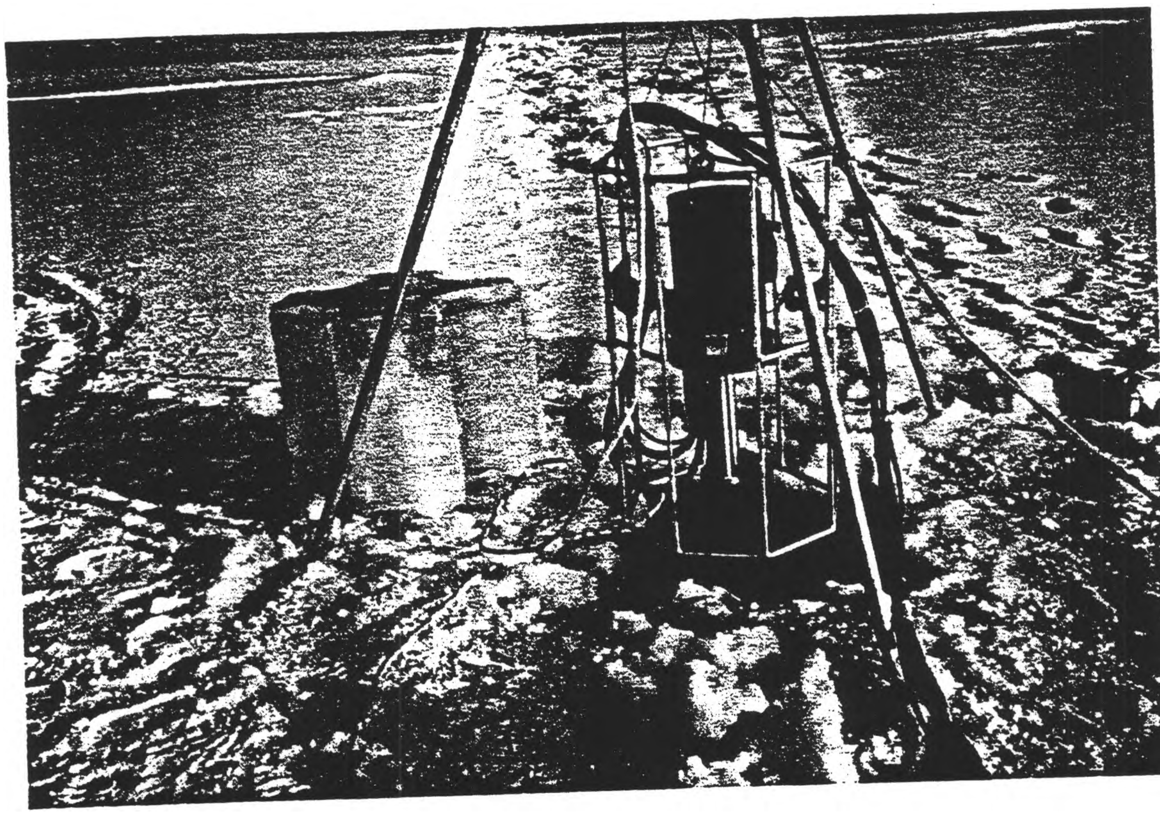
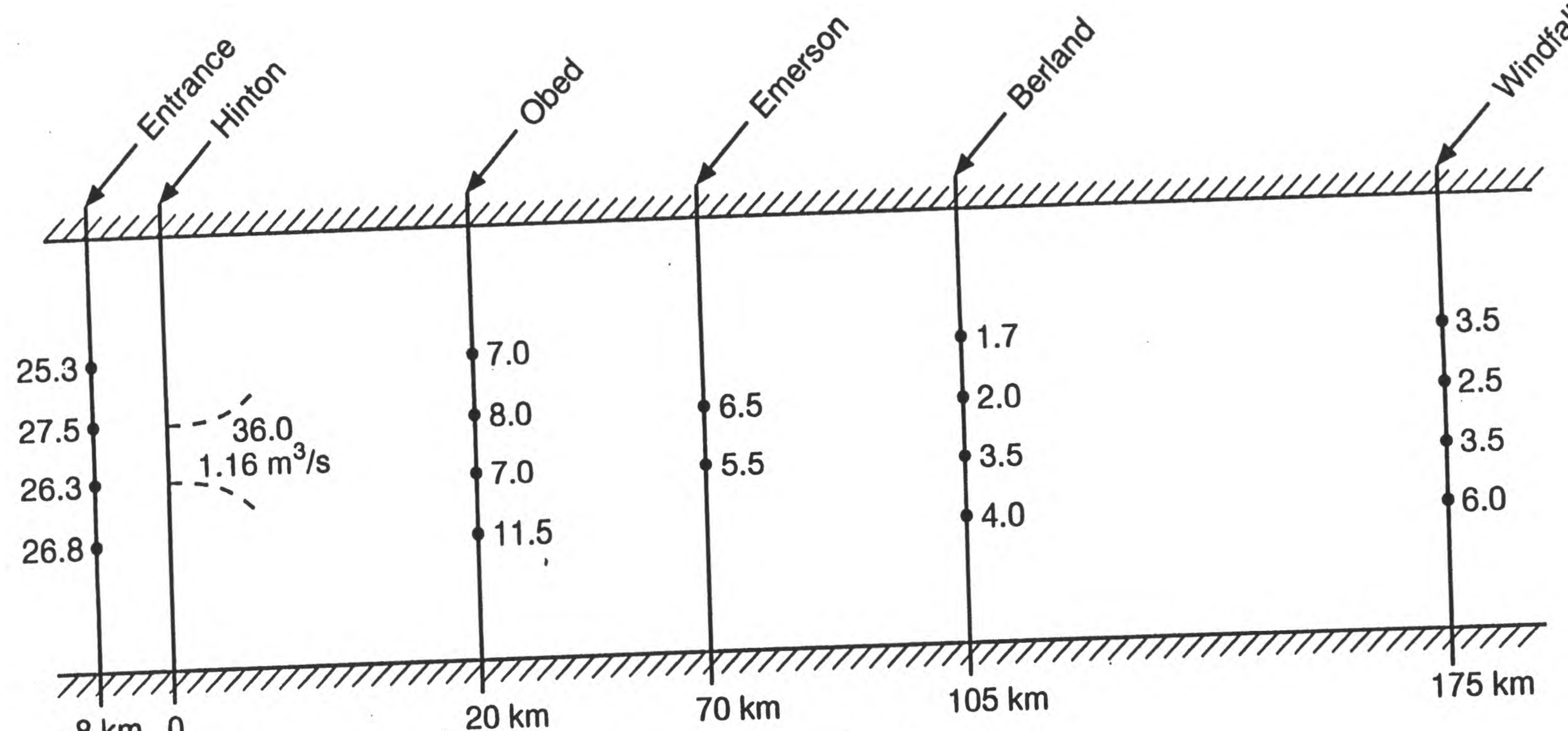
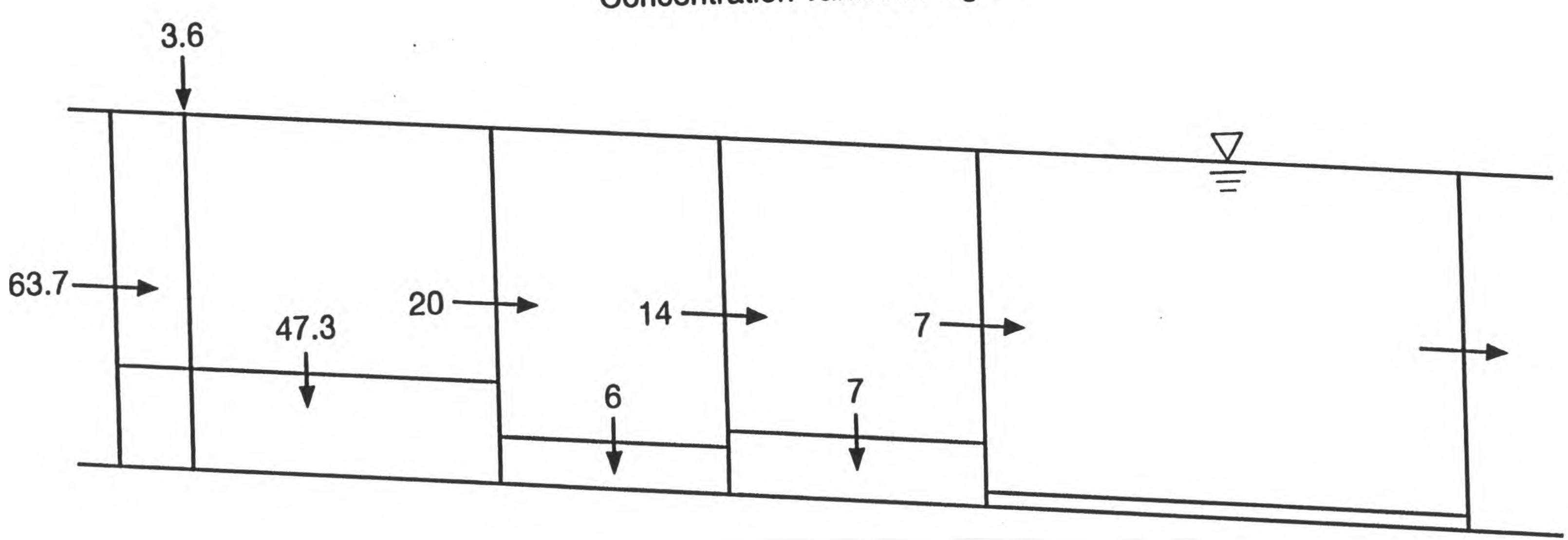


Figure 6. Deployment of the analyser during the winter survey



Concentration values in mg/L



Transport and deposition rates in metric tonnes / day

... balance from the winter survey.

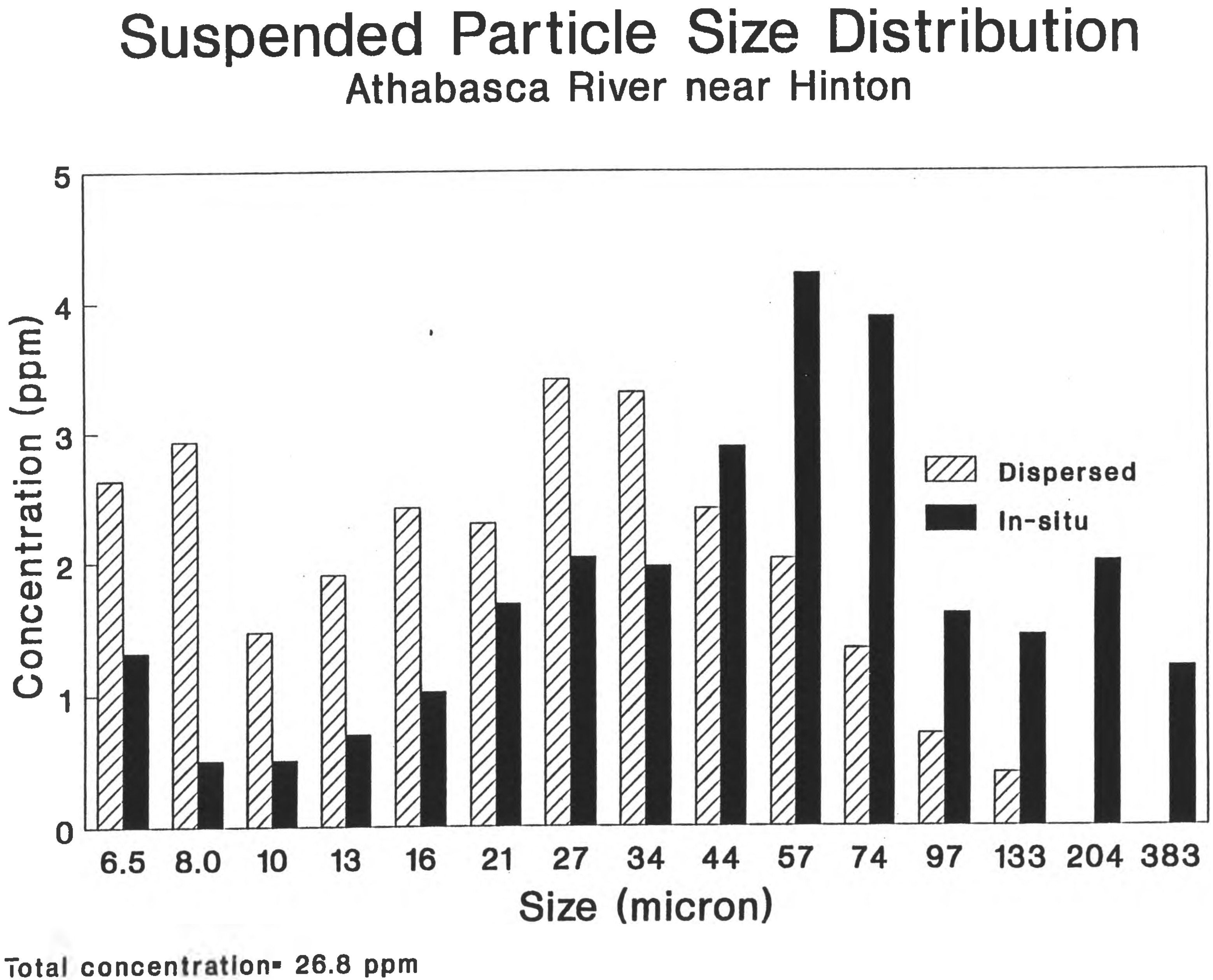


Fig. 8 Size distribution of in-situ and dispersed particles at the Entrance transect.

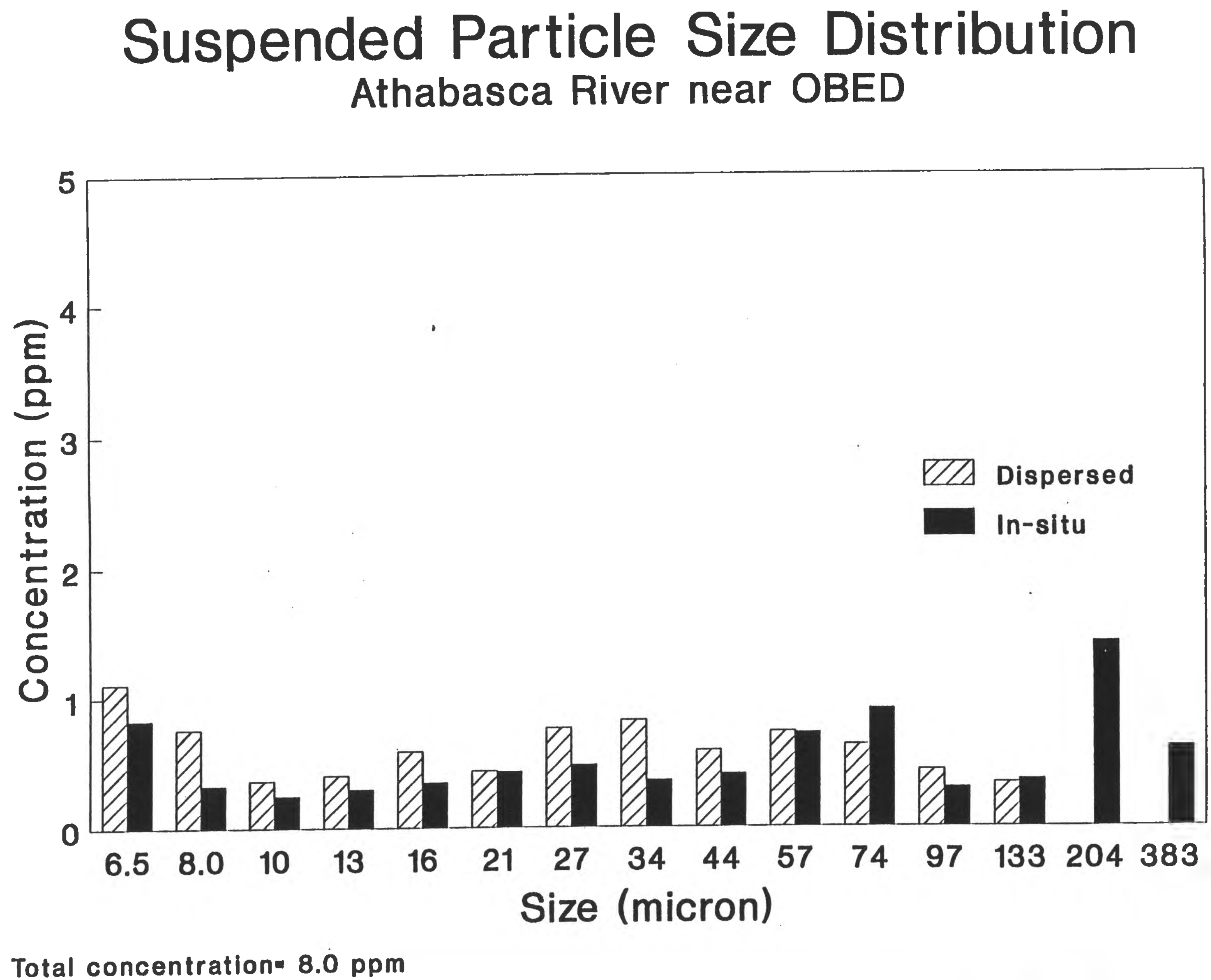


Fig. 9. Size distribution of in-situ and dispersed particles at the Obed transect.

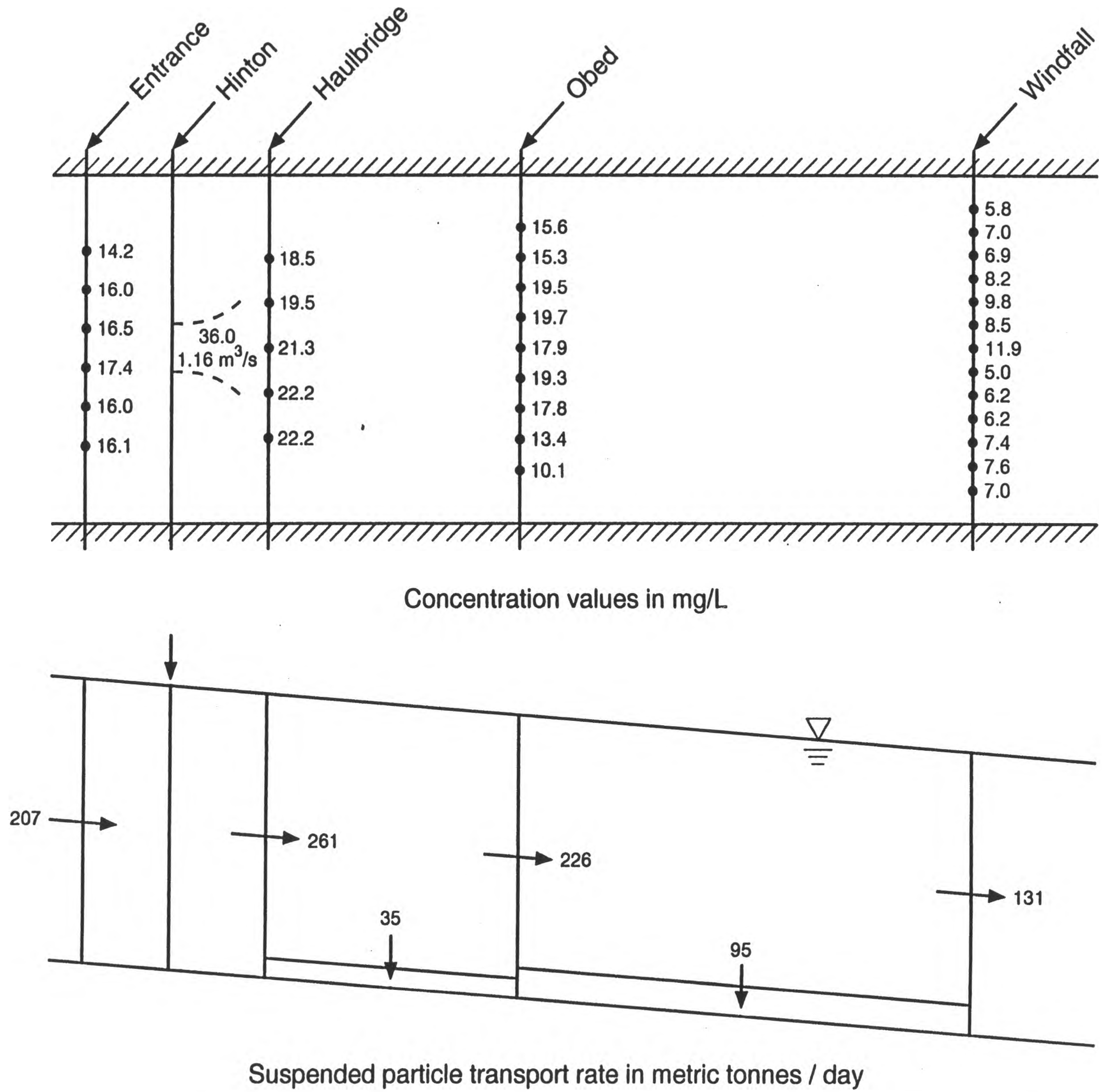


Figure 10. Concentration distribution and suspendend particle mass balance from the fall survey.

APPENDIX-1 WINTER SURVEY TRANSECTS

Winter Survey: Transect- Entrance

Distance from RB (m)	Total depth (cm)	Ice thickness (cm)	Depth under ice (cm)	Depth average velocity (cm/s)	Depth average sed.conc. (mg/L)	Particle size, D_{50} in-situ (µm)	Particle size, D_{50} dispersed (µm)
0	0			0			
10	88	54	34	20.4			
20	190	45	145	62.8	26.8	50	23
30	220	40	180	59.9	26.5	53	32
40	150	50	100	41.7	27.5	51	28
50	148	54	94	32.6	25.5	50	28
60	142	68	74	19.8			
70	130	68	62	26.3			
80	92	46	46	6.8			
87	0			0			

Winter Survey: Transect- Obed

Distance from RB (m)	Total depth (cm)	Ice thickness (cm)	Depth under ice (cm)	Depth average velocity (cm/s)	Depth average sed.conc. (mg/L)	Partice size, D_{50} in-situ (μm)	Particle size, D_{50} dispersed (μm)
0							
10							
20	30	30					
30	104	60	44	21.9			
40	146	60	86	22.5	11.5	66	34
50	176	56	120	39.3	7.0	47.2	35
60	182	44	138	35.8	8.0	49.1	28
70	196	50	146	36.0	7.0	47.0	35
80*	216	40	176				
90*	214	40	174				
100							

* Verticals with slush-ice.

Winter Survey: Transect- Emerson

Distance from RB (m)	Total depth (cm)	Ice thickness (cm)	Depth under ice (cm)	Depth average velocity (cm/s)	Depth average sed.conc. (mg/L)	Particle size,D_{50} in-situ (µm)	Particle size,D_{50} dispersed (µm)
0	0						
10	210	46	164	36.1	5.5		
20*	232	40	192				
30*	192	40	152				
40*	134	52	82				
50*	152	54	98				
60*	170	60	110				
70	146	50	96	70.0	6.5		
80	140	56	84	60.4			
90	120	70	50	60.4			
100	0						

* Verticals with slush ice

Winter Survey: Transect- Berland

Distance from RB (m)	Total depth (cm)	Ice thickness (cm)	Depth under ice (cm)	Depth average velocity (cm/s)	Depth average sed.conc. (mg/L)	Particle size,D_{50} in-situ (µm)	Particle size,D_{50} dispersed (µm)
0	0						
10*	166	72	94				
20*	204	30	174				
30	182	44	138	75.0	4.0		
40	178	44	134	100.7	3.5		
50*	196	48	148				
60	160	46	114	75.8	2.0		
70	122	66	56	45.2	1.7		
80	60	32	28	40.0			

* Verticals with slush ice

Winter Survey: Transect- Windfall

Distance from RB (m)	Total depth (cm)	Ice thickness (cm)	Depth under ice (cm)	Depth average velocity (cm/s)	Depth average sed.conc. (mg/L)	Particle size, D_{50} in-situ (µm)	Particle size, D_{50} dispersed (µm)
0							
10	76	76	0				
20	120	80	40	27.0			
30	132	64	68	47.0			
40	160	52	108	60.0	3.5		
50	176	42	134	70.0	2.5		
60	164	44	120	124.0	3.5		
70*	152	48	104				
80*	130	56	74				
90	106	100	6	35.0			
100	104	64	40	40.0			
110*	96	46	50				
120*	96	46	50				
130	60	60	0	0			
140	60	60	0	0			

* Verticals with slush ice

APPENDIX-2 FALL SURVEY TRANSECTS

Fall Survey: Transect- Entrance

Distance from RB (m)	Flow depth (cm)	Depth average velocity (cm/s)	Depth average sed.conc. (mg/L)	Partice size, D_{50} in-situ (µm)	Particle size, D_{50} dispersed (µm)
0	0	0			
10	120	91.0			
30	200	111.0	16.1		9.2
40	190	120.0	16.0		8.1
50	220	106.0	17.4		10.9
60	200	103.0	16.5		10.1
70	210	98.0	16.0		10.4
80	210	65.0	14.2		8.4
90	210	13.0			
98	0	0			

Total flow rate: 149m^3/s

Suspended particle transport rate: 207 metric tonnes per day.

Fall Survey: Transect- Haulbridge

Distance from RB (m)	Flow depth (cm)	Depth average velocity (cm/s)	Depth average sed.conc. (mg/L)	Particle size, D_{50} in-situ (µm)	Particle size, D_{50} dispersed (µm)
0	0	0			
14	240	81.0	22.2		
24	340	103.0	22.2		8.0
34	380	102.0	21.3		7.9
44	300	88.0	19.5		9.8
54	280	83.0	18.5		
64	190	56.0			
74	0	0			

Total flow rate: 147 m^3/s

Suspended particle transport rate: 261 metric tonnes per day.

Fall Survey: Transect- Obed

Distance from RB (m)	Total depth (cm)	Depth average velocity (cm/s)	Depth average sed.conc. (mg/L)	Particle size,D_{50} in-situ (µm)	Particle size,D_{50} dispersed (µm)
0	0	0			
5	70	22.0	10.1		
20	150	49.0	13.4		5.6
30	200	77.0	17.8		5.8
40	210	93.0	19.3		
53	240	100.0	17.9		
63	310	106.0	19.7		5.9
73	300	107.0	19.5		
78	210	103.0	15.3		5.8
83	100	81.0	15.6		
93	0	0			

Total flow rate: 146 m^3/s

Suspended particle transport rate: 226 metric tonnes per day.

Fall Survey: Transect- Windfall

Distance from RB (m)	Flow depth (cm)	Depth average velocity (cm/s)	Depth average sed.conc. (mg/L)	Particle size, D_{50} in-situ (µm)	Particle size, D_{50} dispersed (µm)
0	0	0			
9.5	130	91.0	5.8		7.3
28.5	220	121.0	7.0		
38	210	122.0	6.9		
47.5	180	130.0	8.2		
57	150	134.0	9.8		
66.5	140	120.0	8.5		
77.9	170	82.5	11.9		7.6
85.5	110	95.6	5.0		
95	100	106.5	6.2		
104.5	80	92.4	6.2		
114	90	93.3	7.4		
123.5	120	85.7	7.6		7.6
133	170	45.5	7.0		
144.4	0	0			

Total flow rate: 199 m^3/s

Suspended particle transport rate: 131 metric tonnes per day.

APPENDIX - 3 TERMS OF REFERENCE

NORTHERN RIVER BASINS STUDY

SCHEDULE A - TERMS OF REFERENCE

Project 1331-B1/C1 Flocculation of Suspended Sediment

Objective

To gather physical data such as size distribution, settling velocity distribution and the extent of flocculation of the suspended sediment in the Peace and Athabasca river systems for the purpose of modelling sediment bound contaminant transport in these rivers (relevant to Scientific Questions #5 and #14 and related to Flow Hydrology/Hydraulics and Sediment Transport and Contaminant study groups).

Description

Sediment transport component of contaminant transport models such as WASP-4, TABS-2, FETRA etc. require input data on sediment characteristics such as size distribution and settling velocity distributions. The sediment fraction that is chemically active is usually fine and tends to form flocs as they are subjected to the turbulence in the river system. The measurement of size distribution of the flocs require non-intrusive instruments as the traditional sampling techniques are known to disrupt the flocs and alter the size distributions.

The Field Malvern Particle Size Analyzer that was developed at the National Water Research Institute (NWRI) in Burlington and which operates on the principle of Laser diffraction (see Krishnappan et al 1992) will be used to measure size distribution of suspended sediment in the upstream reaches of Athabasca and Peace Rivers near the pulp mills (see page 3). Size distribution measurements using the traditional sampling methods will also be carried out to draw conclusions regarding the extent of flocculation. A computer model called FLOCSETL developed at NWRI (Krishnappan 1992) will be used to estimate the settling velocity of the sediment flocs.

References

Krishnappan, B.G., Madsen, N., Stephens, R., and Ongley, E.D. 1992. Field Instrument for Size Distribution of Flocculated Sediment. NWRI Contribution No. 92-117, CCIW, Burlington, Ontario, Canada.

Krishnappan, B.G., 1992. FLOCSETL: A Computer Model to Predict Settling and Flocculation of Fine-grained Sediment in Water Columns: User Manual. NWRI Contribution No. 92-101, CCIW, Burlington, Ontario, Canada.

SCHEDULE A

Reporting Requirements

The contractor will provide the Northern River Basins Study Office with a draft report by December 31, 1993 outlining the results of work performed.

Three weeks after the receipt of review comments the contractor will submit two unbound, camera ready copies of the final report to the Northern River Basins Study Office. An electronic copy of the report, in Word Perfect 5.1 format, is to be submitted along with the final report. Data presented in tables, figures, appendices, etc. in the final letter report are also to be submitted in electronic form (dBase IV format preferred) along with the final report.