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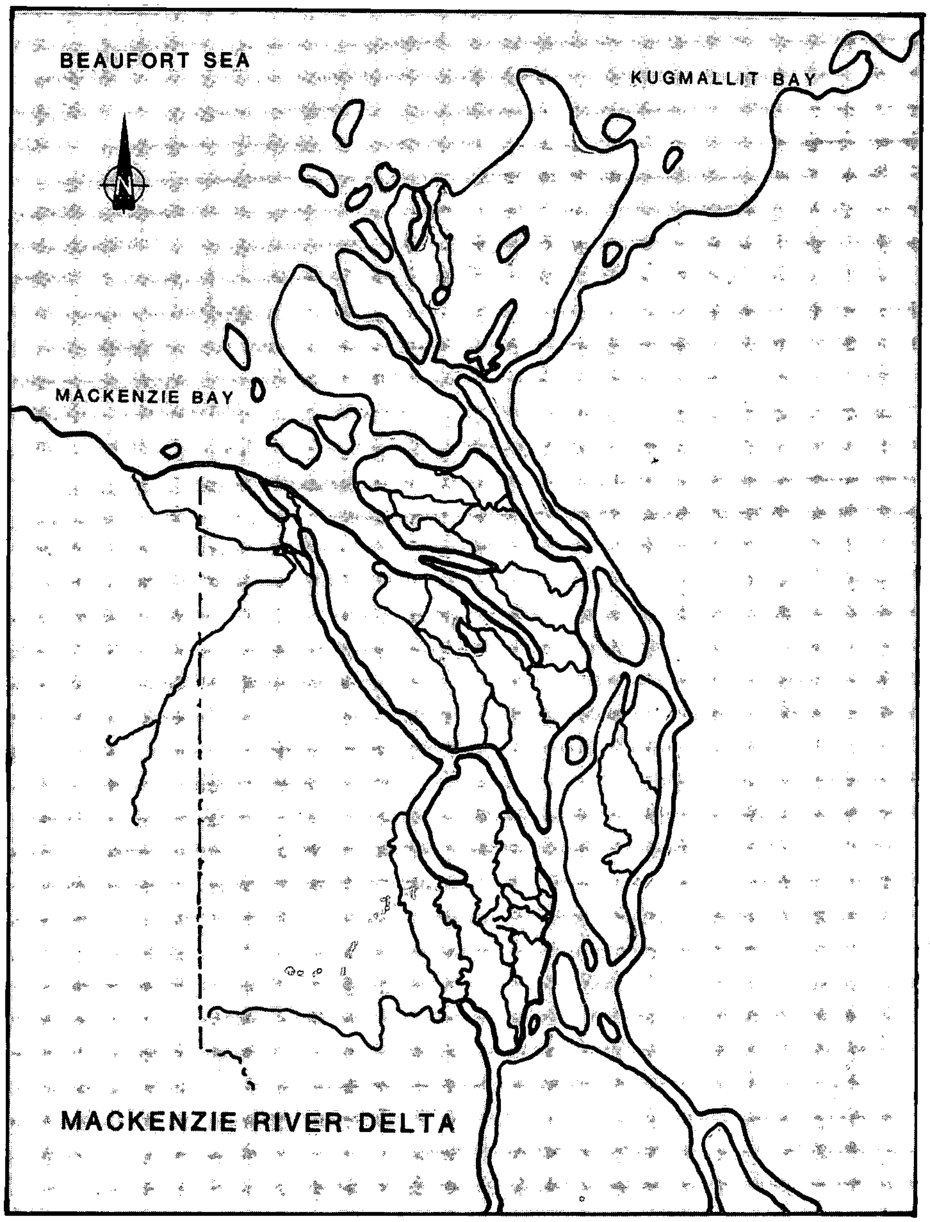

NORTHERN OIL and GAS ACTION PROGRAM

SUSPENDED SEDIMENT DATA ANALYSIS:
• MACKENZIE DELTA, NWT: 1992-93 UPDATE
• WESTBANK TRIBUTARIES, MACKENZIE RIVER, NWT

CANADA'S GREEN PLAN
LE PLAN VERT DU CANADA

Canada

SUSPENDED SEDIMENT DATA ANALYSIS:
• MACKENZIE DELTA, NWT: 1992-93 UPDATE
• WESTBANK TRIBUTARIES, MACKENZIE RIVER, NWT

IWD-NWT NOGAP Project (C11.4)
Mackenzie Delta Sedimentation

for

Inland Waters Directorate
Environment Canada
Yellowknife, NWT

by

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under contract
KE521-2-0265/01-XSG
Supply & Services Canada, Edmonton

March, 1993

CANADA'S GREEN PLAN
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FOREWORD

Evaluation of sediment related issues in the Mackenzie Delta requires improved knowledge and understanding of the source, sediment transport and fate of within and upstream of the delta. Reports included in this document update analyses of sediment measurements done in the Mackenzie Delta during 1991 by IWD, and provide a synthesis of Mackenzie River tributary sources.

Analysis of the entire 1991 NOGAP suspended sediment dataset for Mackenzie Delta inflow and delta stations reveals continuing problems with the conventional river discharge/sediment concentration rating curve approach. Rating curves for the Mackenzie River at Arctic Red and, especially, the Peel River above Fort McPherson show considerable scatter at high flows, and are not entirely satisfactory for computing total sediment loads to the Mackenzie Delta. The presence of relationships between sediment concentrations at IWD's Mackenzie East Channel near Inuvik station and delta inflow, mid-, and outer-delta stations provides one possible option for calculation of sediment loads throughout the delta. This relationship will require further investigation to verify it's use.

Dr. Carson's analysis of miscellaneous sediment samples for west bank Mackenzie River tributaries provide an early indication of the importance of source areas for sediment entering the Mackenzie Delta. Clearly, a more systematic effort is required to progress beyond the current SV-based program. Such improvements will be relevant to current climate change studies based in the Mackenzie River Basin (ie GEWEX, Mackenzie Basin Impact studies etc.).

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SUSPENDED SEDIMENT SAMPLING IN THE MACKENZIE DELTA, NORTHWEST TERRITORIES 1992-93 UPDATE

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Executive Summary

This report updates a prior report, prepared last year, dealing with the suspended sediment sampling program of Inland Waters Directorate, Yellowknife (Environment Canada) in the Mackenzie Delta, Northwest Territories.

The update provides a full analysis and review of sediment data collected by IWD in 1991, the first year of a three-year program, partially funded by NOGAP.

The 1991 data discussed in the update were collected at two delta-head stations (Mackenzie River at Arctic Red River and Peel River upstream of Fort McPherson), three mid-delta stations (Peel Channel upstream of Aklavik Channel, Middle Channel below Raymond Channel and East Channel near Inuvik) and three outer-delta stations (Reindeer Channel below Lewis Channel, Middle Channel near Langley Island, and East Channel below Tununuk Point).

The primary purpose of this sediment program is to obtain mathematical relationships that will allow predictions of sediment concentration at delta stations in the absence of actual sampling. This task is a prerequisite to the development of a sediment adjunct to the one-dimensional hydraulic model being developed for the delta.

The preliminary analysis is encouraging in indicating strong correlations between sediment concentrations at different stations in the delta. It is tentatively proposed that sediment concentrations at all east-central stations in the delta could be predicted from sampled concentrations at Inuvik, and, hopefully, concentrations on the west side might be predictable from Peel River station.

A sampling strategy for Year III of the NOGAP program is provided in order to test these relationships more fully.

Acknowledgements

This report was prepared as part of a contract from Inland Waters Directorate, Yellowknife, Northwest Territories entitled "Mackenzie Delta Channel Stability Assessment / Mackenzie River Basin Sediment Station Analysis" with F.M. Conly as Scientific Authority. The contract was administered by Supply and Services Canada (Alberta/NWT region) under contract number KE521-2-0265/01-XSG. The assistance of Malcolm Conly and Jesse Jasper in the management of this contract is duly acknowledged.

The author is indebted to Paul Squires, Inland Waters Directorate, Yellowknife, and the staff of the Inuvik and Fort Simpson district offices, for provision of much of the data used in this report.

Section 1: Suspended Sediment Sampling in the Mackenzie Delta, Northwest Territories: 1992 - 93 Update

1. INTRODUCTION

1.1 Purpose of report

As part of the first year of IWD Yellowknife's 3-year NOGAP-funded program dealing with sediment-related aspects of northern hydrocarbon development, a complete review was undertaken of IWD's sediment sampling program in the Mackenzie Delta (Carson, 1992a).

This review covered sampling undertaken in the mid-1970s and late 1980s as well as the initial data collected during the first year of the NOGAP program.

The purpose of this document is to update the previous report by the addition of data collected during the rest of 1991 and to provide reassessment of the database in the light of this additional information.

1.2 Purpose of delta sediment program

The purpose of the delta sediment sampling program is threefold:

- ***sampling at mid-delta stations to determine the pathways of suspended sediment (and related contaminants) through the delta complex and, in turn, to assist in interpretation of regional patterns of overbank sedimentation in the delta;***
- ***sampling at outer-delta stations to determine the sediment flux from the delta to the Beaufort Sea;***
- ***comparison of sediment outflows to the Beaufort Sea with sediment inputs from the Mackenzie, Arctic Red and Peel rivers to assess the net overall sedimentation rate in the Mackenzie Delta itself.***

1.3 Summary of 1991 program

Sampling in the first year of the three-year NOGAP program was undertaken at two delta-inflow stations (Mackenzie River at Arctic Red River and Peel River above Fort McPherson), at three mid-delta stations (Peel Channel above Aklavik Ch., Middle Channel below Raymond Ch. and East Channel near Inuvik), and at three outer-delta sites (Reindeer Ch. below Lewis Ch., Middle Ch. near Langley Island and East Channel below Tununuk Point).

Only the mid-delta (Chapter 2) and outer-delta (Chapter 3) stations are considered in detail in this report. In-depth analysis of delta-head stations has been provided previously as part of the overall program for the Mackenzie River Basin (Carson, 1992b). In view of the importance of the delta-head stations to the delta program, however, some linkage in interpretation and planning is obviously needed. This is undertaken in Chapter 4.

The time-consuming nature of the June-through-September 1991 program, together with the numerous problems encountered, have been documented separately by C. Brumwell (1991).

The 1991 program involved three multiple-vertical (MV) suspended sediment measurements at all sites (except 5 for East Ch. at Inuvik) and 11 single-vertical (SV) suspended sediment samples at the three mid-delta stations and 10 SV samples at the three outer-delta sites. The second of the MV sampling was particularly useful in most cases in coinciding with relatively high sediment concentrations. Two separate sessions of bed material sampling (across the measurement section) were undertaken at all six stations.

1.4 Reassessment of sediment rating diagrams

The construction of sediment rating diagrams for these sites has been hampered by the lack of discharge data on most of the days when SV samples have been taken. Hydrometric measurements were made during the late

1980s and 1990s at times of MV sampling, but derivation of discharges for days of SV sampling awaits development of the 1-dimensional flow model for the delta and its hind casting to past years. For this reason, no sediment rating diagram was presented for the three outer-delta stations in the previous report (Carson, 1992a). Reliable estimates of discharge at the delta stations for dates corresponding to SV sampling in the 1980s and 1990s are not expected to be available until the beginning of Year III (Kerr, 1993, pers. comm.) and thus no further development of any sediment ratings for the delta stations is undertaken in this report.

Some additional comment, however, is warranted in connection with mid-delta sites where most of the data were obtained in 1974 and 1975. Discharge data are available for these stations in the mid-1970s: these were taken from the report by Davies (1975), derived as part of a special IWD hydrometric study in those two years.

It was noted previously (Carson, 1992a, p. 9-11) that the sediment rating diagrams for the mid-delta stations are inferior to that for Mackenzie River at Arctic Red River and show considerable scatter. In particular, it was noted that June samples showed concentrations lower than expected on the basis of the rating, while July and August were correspondingly higher than expected. Possible reasons for this, focusing on differences in sediment production between June and the rest of the open-water season, were put forward.

Further investigation of the matter, however, now leads to the belief that some of the scatter may be due to systematic error in the discharge data. It has been determined in recent years that estimates of early June discharges at the delta-head (Mackenzie River at Arctic Red River) have usually been too high (sometimes far too high) because of backwater effects arising from ice in the delta. This has led to downward revision of many of the May and June discharge values at that station (Carson, 1992b, p. 9).

In the delta itself, it is clear that water levels are strongly controlled not only by ice jams during breakup in early June, but also by water level fluctuations in the Beaufort Sea (Carson, 1992c, p. 6) throughout the open-water season.

In this context, the accuracy of the 1974 and 1975 data for daily mean discharges seems uncertain, given that flow measurements were made no more frequently than once a month and that discharges were estimated from stage-flow ratings based on four or five points (Fig. 1.1). On the other hand, it must be recognized that the scatter in the sediment rating diagrams was not restricted to SV data: it also applies to MV data collected at times of actual measurement of discharge.

1.5 Sediment concentration values: methodology

In the 1970s and early 1980s almost all depth-integrated sediment sampling in the Mackenzie Basin used D-49 samplers integrating through the full water column, even though the depth limit for the D-49 sampler is theoretically 5 metres. In the mid-1980s, changes were made in sampling protocol, and deeper water columns were generally sampled with point-integrating instruments that allow split-sampling of the column in increments of up to 5 metres. This is the procedure generally used in the NOGAP delta program. On some occasions and at some sites, split-sample intervals of more than 5m (up to 10m at Peel Ch. in 1991) have been used. In at least some of these cases, this was due to malfunction of the sampler (Brumwell, 1991).

The procedure of split-sampling introduces certain problems in determination of the mean sediment concentration for the full vertical. This arises from the fact that near-surface water (usually less turbid) is generally moving more quickly than near-bed water (usually more turbid). Thus, in computing the mean of two or more split-samples in a vertical, the simple mean (weighting the splits equally) will tend to overestimate the true mean.

Ideally, the concentrations of the different split-samples in a vertical would be weighted by the local velocity at the depth of the split sample. This is comparable, for example, with the established IWD procedure in pooling concentration values for different verticals in a MV sampling to get the mean for the cross-section: in that case the concentration in each vertical is weighted by local panel discharge. In the case of split-sampling at the SV site, however, current-metering usually does not accompany the sediment sampling program.

One possible approach in circumventing this problem would be to ensure that the duration of sampling in a given vertical is the same for each split: in this way, smaller volumes of suspension would be sampled in the slower-moving water nearer to the bed. Then, if the splits were combined in a single suspension prior to analysis, the composite sample would automatically have produced a weighting of concentration in the different splits according to local velocity.

In the absence of the above-procedure, an alternative is to estimate the local velocity for each split in a given vertical by the quantity of suspension sampled (determined in the laboratory) relative to the nozzle intake time during the sampling (recorded on the sampling field sheets). This procedure requires that the same nozzle is used at all depths in a given vertical. Then, the concentration of each split-sample in a vertical could be weighted by local intake velocity, in precisely the same way that individual concentrations for different verticals in a sediment measurement are weighted by local discharge.

None of the data received in the preparation of the present report has been adjusted in any of these ways. Thus the sediment concentrations given in the following chapters for the 1991 sampling refer as follows:

- ***any SV concentration which is derived from split sampling is the simple mean of the splits in that vertical;***
- ***any MV concentration is the simple mean of the concentration for different verticals; except that,***
- ***any MV concentration which involved split-sampling of one or more verticals is the simple mean of all the splits in the cross-section.***

The last procedure, while not as accurate as the IWD's normal MV procedure using weighting by local discharge, is generally satisfactory because deeper verticals are at least weighted more than shallow verticals, arising from the larger number of splits at deeper points.

It is recommended that IWD develop a suitable standard for consistent calculations using split-sample data. The need for this becomes especially important in the context of expressing grain size data for the suspended sediment, these data invariably indicating coarser sediment in the lower parts of the water column.

2. MID-DELTA STATIONS

This chapter updates information provided in the Year I report: locations of all stations are given in that report and are not repeated here.

2.1 Peel Channel below Aklavik Channel

The 1991 bathymetry at this section is consistent with that shown in the 1970s hydrographic chart: a straight channel with a left side thalweg and right side shoal. The 1991 SV sampling was done at the Coast Guard buoy, on the measurement section, at 195m from the right bank.

2.1.1 Cross-sectional distribution of sediment

The 1991 bed material sampling show much the same pattern as those in 1975 (July 17): silt-clay in the thalweg zone but more than 50% sand (fine and very fine) on the right bank shoal. It is presumed that, while the sand represents modern in-channel alluvium, the silt-clay is older floodplain sediment that is currently being scoured.

The locus of peak current speed shows some variation: mean velocity in the vertical peaked over the thalweg at 0.63 m/s on June 12 1991 (1060 m3/s), but occurred to the right of the thalweg at about 170m RB (almost at channel centre) on July 25 1992 (710 m3/s) averaging 0.51 m/s.

The suspended sediment distribution found in the above-average concentrations of August 29, 1991 (but with discharge of only 749 m3/s) is shown in Fig. 2.1. The systematic increase in concentrations from right bank to thalweg matches the pattern shown at lower sediment levels on June 12, 1991 (Year I report: Fig. 2.4) and found in the 1970s (Year I report: Fig. 2.3).

The k-value for the August 29, 1991 flow was 1.00, and that for the weaker and less turbid Sept. 11, 1991 flow was 0.97. All the data collected to date indicate that the SV location used is representative of this section. It is suggested that Year III sampling at this site can be restricted to the SV location, subject to a MV check if a high flow occurs.

2.1.2 Additions to the sediment rating file

The updated sediment rating file is given in Table 2.1. The additional samples collected in 1991 provide no really high concentrations which are needed for the development of a good sediment rating. Yet the 496 mg/L level for August 29 (with Q only 749 m3/s) plots well above the main swarm of points in the sediment rating diagram (Year I report).

It is not clear whether the lack of high concentrations in the data set reflects genuinely lower sediment levels in Peel Channel (compared to Peel River upstream) or whether it is simply the result of sampling on these particular dates. On the Peel River near Fort McPherson, sediment levels were quite high in August 1991 (especially between 5th and 24th), frequently being over 1000 mg/L, and at 10,000 mg/L on August 5. Only two samples were taken on Peel Channel during this time, both being close to 400 mg/L, much lower than upstream, but this may reflect the flashiness of the sediment pulse.

The low sediment concentration on June 12, at a time of high discharge, is consistent with previous observations regarding the temporal pattern of sediment concentrations during the open-water season in the delta.

2.1.3 Suspended sediment grain size

Suspended sediment grain size, usually measured only in samples with more than 300 mg/L, was available for four sampling dates in 1991.

Sand made up only a small percentage (<5%) in all the samples. The balance between silt and clay was, however, quite variable, the silt content ranging from 37 to 61 percent in the fully depth-integrated samples.

2.2 Middle Channel below Raymond Channel

The measurement section occurs downstream of the abrupt right-hand turn below Horseshoe Bend, almost at the downstream limit of the right inner-bank bar. In the Year I report, the SV location was given as 300m from left bank on the measurement section. The location was changed, however, after July 4, 1991, with the introduction of a sediment buoy at 650m LB and 320m upstream of the section.

2.2.1 Cross-sectional sediment distribution

The bed material samples collected in 1991 indicate the section to be essentially sand throughout the full width. In the deeper left half of the channel this is mostly fine sand, while very fine sand increases towards the right bank.

The MV sampling of August 28 (10,500 m3/s) and September 12, 1991 (12,000 m3/s) were consistent with that of June 12 (16,600 m3/s) (Year I report: Fig. 2.11) in showing a weak increase in concentrations from the thalweg to the inner right bank. The k-value on both dates was 0.98 compared to 1.06 in June. This difference is consistent with the shift in the SV location. The cross-sectional pattern for August 28 is shown in Fig. 2.2.

The 1991 k-values are all quite acceptable and suggest that the two SV locations are representative of the section. However, no data are available at really high flows and at concentrations above a few hundred mg/L. Given the time-consuming nature of MV sampling at this site, and given the consistency shown, it is suggested that any MV sampling in Year III be restricted to times when either flows are very high (above 20,000 m3/s) or the water is very turbid.

2.2.2 Additions to sediment rating file

The updated sediment file is given in Table 2.2. The 1991 open-water season provided three additional sampling at concentrations close to or above 1000 mg/L. All three sampling for which discharge data are available (the MV sampling) plot within the existing sediment rating swarm.

2.2.3 Suspended sediment grain size

The sand fraction on the four sampling days with concentrations above 300 mg/L ranged from 2 to 21 percent. The ranges shown, for each day in Table 2.2, reflect the increase in sand content from the near-surface split sample to the near-bed split.

The sand fraction of the suspended load in 1991 was relatively small given that very fine and fine sand dominate the bed material in this reach.

The silt fraction ranged widely from 37% to 63%, mostly in the 40-50% range, with no obvious pattern in the ratio of silt-to-clay in the database.

2.3 East Channel near Inuvik

The measurement section at this station is located in a straight, roughly symmetrical reach with a generally flat bed. The sediment buoy for SV samples was located at 100-110m from the right bank, on the measurement section in 1991.

2.3.1 Cross-sectional distribution of sediment

The bathymetry shows a slight preferential shoaling towards the left bank. This appears to be reflected in the bed material distribution which, while mostly clayey silt in the right half, is dominantly fine sand to the left of mid-channel (Fig. 2.3), on the basis of the 1991 sampling.

Sampling of suspended sediment on multiple verticals was done on four dates in 1991 after the June 6 sampling discussed in the Year I report. These were July 26 (374 m3/s), August 27 (226 m3/s), September 17 (145 m3/s) and October 4 (148 m3/s). The last three were all are very low concentrations (< 60 mg/L).

The July sampling is particularly important because it corresponds to quite high concentrations. The cross-sectional distribution on that date is given in Fig. 2.3. There is a slight increase in concentration from the right bank towards the area of the left-of-centre sandy shoal, a pattern also found in the August sampling. The k-value was 0.99. The values for the following three ranged from 0.96 to 1.06.

The data collected to date therefore indicate that the SV location is representative of the cross-section at this station. It is suggested that all Year III sediment sampling be restricted to the SV location, except for an occasional MV sampling if a high, turbid flow occurs.

2.3.2 Additions to sediment rating file

The sediment rating file for the East Channel near Inuvik is much bigger than for the other mid-delta stations (Year I report Table 2.8) reflecting the proximity to the IWD office.

The extra data from the 1991 season (Table 2.3) were especially useful in adding three days of relatively high concentrations (>750 mg/L), and in providing more MV sampling days with measured water discharge. All of the latter plot within the existing sediment rating swarm. However, the much lower sediment concentration on May 27 than on July 26, with almost twice the discharge, indicates, as at other delta stations, the problems that will be encountered in attempting to develop a good sediment rating relationship.

2.3.3 Suspended sediment grain size

Suspended sediment in East Channel is finer-grained than in Middle Channel and more comparable with Peel Channel, as might be expected from the reduced intensity of flow.

Sand concentrations were less than 5%, except for the sample taken on August 7 with very high sediment levels (1271 mg/L of which 19% was sand). Silt contents ranged between 33% and 63%. As in Peel Channel, these variations in depth-integrated values reflect day-to-day changes, unlike in Middle Channel where they were, in part, controlled by changes in depth through the water column.

2.4 Conclusions

It was argued in the Year I report that maintenance of sediment sampling at the mid-delta stations could not be regarded as high-priority in comparison with monitoring sediment at the delta-head and outer-delta stations. In addition, attention was directed to the real problems in developing sediment rating relationships for these stations.

One possible strategy for estimating sediment concentrations more accurately at these stations is through correlation with their upstream sources: the Mackenzie at Arctic Red River (for Middle Channel and East Channel) and Peel River above Fort McPherson (for Peel Channel). A second strategy - at least for the stations with dominantly Mackenzie River water - is to predict mid-delta sediment concentrations from just one (frequently sampled station), as suggested in the Year I report (p. 11-12).

2.4.1 Predicting mid-delta concentrations from upstream sources

In the case of both Peel and East Channels, sediment concentrations at mid-delta would be expected to be lower than at the upstream source. This statement is based on the assumption that deposition en route exceeds bank scour; in addition, both side channels receive near-surface water as they branch off from the main stems, and this water is generally less turbid than the water at depth. In contrast, Middle Channel would be expected to have higher concentrations, using the reverse arguments.

The task of developing a correlation between upstream and mid-delta stations is complicated, however, by the variable time-lag between the stations, probably 3 to 4 days on average. The task is beyond the scope of the present update, but it is certainly worth investigating when all the NOGAP data are available. Preliminary results seem to sustain the expectations above: Peel Channel concentrations in June-July 1991, for example, averaged 181 mg/L compared to 233 mg/L on Peel River.

It is not yet clear, however, whether the data are sufficiently consistent to enable reliable predictions of mid-delta concentrations from upstream. This must await a larger database.

2.4.2 Predicting mid-delta concentrations from Inuvik

In the case of East and Middle channels, the question logically arises as to whether concentrations in Middle Channel could adequately be predicted from the Inuvik station itself. If this were the case, it would provide a large saving in resources.

Preliminary data for 1991 show that, on average, concentrations in Middle Channel were about twice those at Inuvik (Table 2.4). There are, however, three major departures from this value, with the adjustment factor of 2.14x markedly under predicting on two occasions (at low concentrations) and seriously over predicting twice (at high concentration). The standard deviation in the percentage error (54%) is high. Examination of the 1970s data for the two stations showed a similar pattern with the adjustment factor, again, much higher at low flows than at high flows.

This systematic change in the adjustment factor according to the level of concentration suggests that a direct log-log regression of the sediment concentration in Middle Channel on that at Inuvik would be more effective than the use of a constant adjustment factor. Analysis bears this out. The regression of log (c) at Middle Channel on that at East Channel for 1974-75 (15 points) produced a prediction percentage (coefficient of determination) of 89%. This is much higher than the actual sediment rating [log(c) against log(Q)] for Middle Channel using the same data set, where the percentage prediction was only 56 percent (Year I report: Table 2.6). The standard error of estimate was similarly improved to only 0.14 log units in the regression between the two stations, compared to 0.29 for the Middle Channel sediment rating.

Application of the same approach to the entire dataset (including 1991 for which no discharge data are available) produced essentially the same regression and standard error, the correlation diagram being shown in Fig. 2.4.

The success of this approach suggested that it be extended to other mid-delta stations derived from Mackenzie River water: Aklavik and N. Kalinek, where 1974-75 data are available (Year I report). The same dramatic improvement in prediction of log concentration was found. On Aklavik Channel (Fig. 2.5), percentage prediction using log(c) at Inuvik as a predictor increased to 90% (compared with 52% in the Aklavik log(c)-log(Q) sediment rating), and SEE decreased to 0.14 log units (from 0.30 units). On the North Kalinek (Fig. 2.6), percentage prediction improved from 62% to 95% and SEE decreased from 0.30 to 0.11 log units. In both cases the sample size is small.

Similar successes were not found, as would be expected, for stations with water largely derived from Peel River. On Peel Channel the use of Inuvik log(c) values as a predictor (rather than Peel log(Q) values) decreased the prediction, although on West Channel (which receives Mackenzie-derived water via Aklavik Channel) a slight improvement in prediction did occur.

The results described above provide an important breakthrough in the modelling of sediment concentrations at mid-delta stations and suggest that this is the logical approach to be taken in the development of the sediment flux model. The possibility of similarly "hind casting" concentrations on Mackenzie River at Arctic Red River from lag-adjusted readings at Inuvik is a question that also should be explored. Indeed it may be central to the development of a satisfactory sediment flux model for the delta (see Section 4.1).

3. OUTER-DELTA STATIONS

This chapter updates information provided in the Year I report: locations of all stations are given in that report and are not repeated here.

3.1 Reindeer Channel below Lewis Channel

The 1990s sampling station in this reach is located about 1600m downstream of a sharp right hand bend in Reindeer Channel. In this location the inner right-bank shoal has almost disappeared and the channel is only slightly asymmetrical.

The collection of SV samples was usually done at mid-channel, except June 28-July 12 when done at 100m RB. After July 12, the buoy was reinstalled at 270m RB (320m LB) where it was used (until destroyed) until August 21. The remaining SV samples were taken at mid-channel with anchor support.

3.1.1 Cross-sectional distribution of sediment

Bed sediment is largely very fine sand, especially in the deeper part of the channel (Fig. 3.1), though the margins may contain up to 50% silt as well. The channel bed is noticeably finer grained than Middle Channel at mid-delta (Fig. 2.2).

The Year I report noted a systematic increase in sediment concentrations towards the right bank in this reach which was still evident at the 1990s section, though not to the extent of further upstream, closer to the bend. The two additional MV sampling in 1990 confirm this asymmetry, peak concentrations occurring in both cases to the right of channel centre. The suspended sediment distribution for July 30, 1991 is shown in Fig. 3.1. A similar pattern was found on September 20, 1991, when concentrations were only about 100 mg/L.

The k-values for 1991 were as follows: 0.97 (June 20), 0.90 (July 30) and 0.95 (Sept. 20) using single vertical sampling at 250m from the right bank. It should be noted that the actual SV samples on September 20 were, according to field notes, taken at 400m from the left bank (approximately 200m RB), in the region of higher concentrations. This SV site would have produced a k-value of 0.84. It is not clear why the September 20 SV sample was taken at a different location, but, clearly, the usual SV site provides a much better estimate of the mean section concentration.

The k-values are relatively consistent, but it may be significant that the biggest departure from unity (0.90) occurred in the MV sampling with the largest concentrations. In other words, this suggests that sampling errors at the section may increase at times of high loads. For this reason it is recommended that additional MV sampling be undertaken in Year III at times when the water is especially turbid or when flows are high. At lower flows, there appears to be no reason for taking MV sampling in 1993.

It is recognized that full sediment measurements combined with hydrometric measurements are very time-consuming. Yet there is no compelling reason why hydrometric measurements have to be done in all cases of MV sampling. The actual MV sampling at this site takes only 45 minutes. At times of turbid flow, the extra half-hour of sampling for MV data provides invaluable data. Section 1.5 provides comments on the weighting of sediment data in the absence of current meter data.

A final point to note at this section is the marked difference between concentrations in the upper and lower parts of the vertical, especially in the right half of the channel, a feature noted in the Year I report.

3.1.2 Additions to the sediment rating file

The updated sediment rating file is given in Table 3.1. The additional samples collected in July-August 1991 provided data for high-concentration flows. The much higher concentrations on July 30 compared to June 20, with very similar measured discharges, are consistent with previous observations at stations in the Mackenzie Delta (Year I report: p. 10).

Building on the approach developed in connection with the mid-delta stations, the rating of Reindeer concentrations on those of the East Channel at Inuvik has been explored. While it is unlikely that any Inuvik water actually passes down Reindeer Channel, both stations receive water that is derived largely from the Mackenzie River.

The analysis was restricted to 1991 data because no sampling was done at Inuvik at the time of the late 1980s sampling program in the Outer Delta. As far as possible, the concentrations used for Inuvik are those occurring about two (2) days prior to those at Reindeer.

The scatter diagram is shown in Fig. 3.2. Although only 9 points are available, the relationship is very encouraging, with a percentage prediction of log (c) in Reindeer Channel of 93% and a standard error of estimate (SEE) of only 0.11 log units. The prediction is much better than would be expected from a rating using discharge at Reindeer Channel as predictor.

3.1.3 Suspended sediment grain size

Silt typically constitutes 50-60% of the suspended sediment, and most of the remainder is generally clay. Sand concentrations are, however, quite variable (Table 3.1) amounting to 20-30% of the sample in several cases.

As indicated in Fig.3.1, sand concentrations are greater (as expected) in the bottom half of the sampling column. The 24% sand indicated in Table 3.1 for July 30 was the bottom half of the single-vertical.

It is interesting to note that sand generally forms a very low fraction of the suspended sediment even though the bed material is largely very fine sand.

3.2 Middle Channel near Langley Island

The measurement section in this reach is downstream of the confluence of East and West Twin Channels of Middle Channel, following a left-hand bend in the latter. There is a slight asymmetry in the section with the thalweg being close to the right bank.

The Year I report gave the SV location as being 175m RB on the measurement section. However, all subsequent 1991 sampling were done at 100m RB. Little difference is expected between the two verticals based on data from the Year I report, and the fact that both verticals are located in the thalweg.

3.2.1 Cross-sectional sediment distribution

The bed material on the section, to the left of the thalweg (Fig. 3.3), is almost entirely sand (fine and very fine); the bed is somewhat coarser than in Reindeer Channel. To the right of the thalweg, the bed sample is largely silt, and presumably represents older floodplain alluvium that is currently being undercut by the river.

The sediment distribution for July 30, 1991 (Fig. 3.3) shows conditions at relatively high sediment concentrations. There is, as expected, a weak increase in concentration from the right bank thalweg towards the left margin. The same pattern was noted for the June 13 flow (Year I report) and September 20 (when concentrations were only 60-80 mg/L).

The k-values for 1991 were: 1.05 (June 13), 1.01 (July 30), and 1.11 (Sept. 20). These are reasonably satisfactory, the biggest departure from unity occurring during the lowest sediment levels. As at other stations, it is suggested that no MV sampling be done in Year III except at high or turbid flows.

3.2.2 Additions to sediment rating file

The updated sediment file is given in Table 3.2. As in Reindeer Channel, the late July and early August data provide useful high-concentration data. Again, the increase in concentration, compared to June 6, is much greater than would be expected on the basis of the increase in discharge.

The "cross-delta" sediment relationship using measured concentration in East Channel at Inuvik as a predictor is shown in Fig. 3.4.

Again, while recognizing the limited database, the relationship is very encouraging. The percentage prediction is 96% and the SEE is only 0.09 log units.

3.2.3 Suspended sediment grain size

Suspended sediment grain size is generally comparable with that noted for Reindeer Channel below Lewis Channel. Silt generally made up 50-60% of the sample in the 1991 data, the balance being mostly clay. Sand was generally less than 8%, except for isolated samples from the lower part of the sampling column.

The make-up of suspended sediment contrasts markedly with that of the bed which, over most of the channel, is 90% fine and very fine sand.

3.3 East Channel below Tununuk Point

The measurement section at this station is located in a wide, shallow straight reach about 2 km downstream of Tununuk Point. Though the section is essentially symmetrical, most of the flow originates from Neklek Channel which swings around Tununuk Point in a sharp left hand bend before merging with upper East Channel, the flow of which is confined to the right side of the section.

The SV sampling in 1991 was done at the Coast Guard buoy, 600m above the measurement section and 375m from the right bank.

3.3.1 Cross-sectional distribution of sediment

The bed material throughout the full width of the section is dominantly (80%) gravel, though two sampling just to the right of mid-channel did show 30-50% finer than 2mm (Fig. 3.5). The actual stone-size distribution of the gravel is more difficult to determine because of the limited size of many of the samples (mostly less than 350 g), but the data indicate that more than 50% of the sediment is generally coarser than 8mm.

It seems likely, therefore, that the bed is quite stable at this section. In addition, little contribution to the samples of suspended load is expected.

The Year I report noted that the first MV sampling (June 13, 1991) showed a systematic increase in concentration towards midstream from both banks, the right bank flow being much clearer than the left. On the other hand, the SV sampling (near mid-channel but upstream) showed a concentration near to the average for the section, with a k-value of 1.08. However, the overall sediment level (at about 130 mg/L) was low.

The later two MV sampling produced k-values that were much lower: 0.89 in the sediment-rich July 31 flow, and 0.86 in the much clearer September 19 flow. In other words, in contrast to the June 13 sampling, the SV site overestimated the mean section concentration.

This inconsistency in the k-value is perhaps not surprising given that the SV site appears to be directly on the mixing front between the flow from Neklek Channel (usually more turbid) and the flow from upper East Channel. As remarked in the Year I report, it may be difficult to find a SV site with consistent k-values until further downstream when mixing will be more complete.

Additional MV sampling are clearly needed in this reach in Year III, especially when flows are turbid.

3.3.2 Additions to sediment rating file

The updated sediment rating file is given in Table 3.3. The 1991 concentration data are similar to those at the other two outer-delta stations with the same build-up to about 1000 mg/L at the end of July. Again, the much higher concentration on July 31, compared to June 13, at essentially the same discharge, should be noted.

The relationship between sediment concentrations in Lower East Channel with those at Inuvik is shown in Fig. 3.6. The percentage prediction of log(c) below Tununuk Point is 90% with a SEE of only 0.13 log units.

3.3.3 Suspended sediment grain size

Suspended sediment grain size seems to be slightly more variable in East Channel, based on the 1991 data, than in Reindeer and Middle channels. Silt content ranged from 42% to 66%, though the statistical significance of the difference with the other two channels is very weak.

Sand concentrations, on the other hand, were generally more constant, at no time exceeding 10%. The lower sand concentrations in East Channel are consistent with the bed material which is largely gravel and a poor source of sediment for the suspended load. In addition, because of the abrupt "step-up" in level of the bed in moving from Neklek to East Channel, no large movement of sandy bed load from Middle Channel into East Channel would be expected.

The aberrantly high sand concentrations in isolated near-bed samples on Reindeer and Middle Channel near Langley Island are presumably the result of pulses of bed load temporarily in suspension in these two sand-bedded channels. Such pulses should be much less evident on Lower East Channel.

3.4 Conclusions

3.4.1 Sampling strategy

The Outer Delta sampling program is a time-consuming and expensive operation, but is essential if data are to be obtained to compute sediment fluxes to the Beaufort Sea. Delta-head inputs on the Arctic Red River, Mackenzie at Arctic Red River and Peel River cannot be assumed to be representative of outflow volumes because of deposition within the delta area, and because of bank erosion on delta channels.

A major source of concern at the present time with the delta sediment program (both outer delta and mid-delta) is the large amount of scatter in the sediment rating diagrams. At present there is no simple strategy available for dealing with the large errors that would be introduced in applying these sediment rating relationships to the delta stations.

On the other hand, preliminary examination of the sparse data supply so far available suggests that fairly systematic differences exist between the sediment levels in the three outlets. In addition, and perhaps more importantly, sediment concentrations at the outlet stations appear to be readily predictable, with good accuracy, from measured concentrations in East Channel at Inuvik.

The data currently available are insufficient to provide reliable sediment regressions for the outer station using Inuvik data, but with additional information gained from the 1992 and 1993 field seasons, this should become possible. Once that has been achieved, it seems likely that a single regular sampling program at Inuvik, with frequent sampling (once a week at low flows, daily at high flows) would be sufficient to generate data in the years ahead for virtually the entire Mackenzie Delta.

To this end, it is important that, as far as possible, sediment sampling at the outer-delta stations in 1993 be done on the same day at all three stations, and preceded (by the appropriate time lag) by sampling at Inuvik.

3.4.2 Comparison of sediment levels in the Outer Delta

The data provided in Table 3.4 show that, on average, 1991 concentrations at the Reindeer station are 1.41x those at the Middle Channel station; those on East Channel are, on average, 0.87x those of Middle Channel.

In the case of East Channel, the lower concentrations are presumably mainly the result of dilution of the sediment-rich Middle Channel (Neklek) flow with clearer water from the middle reach of East Channel upstream of Tununuk. Variations in the percentage of the East Channel flow that originates from Neklek (as well as variation in the turbidity contrast between the two channels) would be expected to produce variation in the ratio.

In the case of Reindeer Channel, the average 41% increase in concentration compared to Middle Channel is presumably related to extra bank scour in the former reach. Again, the error term seems to vary systematically during the summer being consistently negative in June and mid-July.

It should be noted that application of the same approach to the 1988 data set did not produce the same ratios: that for Reindeer was only 1.12x Middle Channel; and East Channel averaged essentially the same concentrations as Middle Channel. The errors in the above approach clearly need to be borne in mind, and their magnitude should be reappraised with the additional data from 1992 and 1993.

A preliminary comparison along East Channel between Inuvik and Tununuk Point is given for 1991 in Table 3.5. This shows, that, on average, concentrations at Tununuk are 50% greater than at Inuvik. As in the comparison between Middle Channel and Inuvik (Table 2.4), however, this mean is affected by a number of aberrant values, notably for July 16 and August 21, the same dates as in the comparison with Middle Channel. These are the sampling days immediately before and after the turbid flows of late July and early August. No attempt has been made to ascertain the reasons for these anomalies. The implications of this downstream increase in sediment concentration is considered in the next subsection.

3.4.3 Delta sediment budget

An important goal of the delta sampling program is comparison of incoming sediment loads with those delivered to the Beaufort Sea. Ultimately this requires comparison of loadings at the different stations. Such loadings are not yet developed for the mid- and outer-delta stations because of lack of discharge data, but a preliminary insight into this balance can be gained by comparison of sampled concentrations, provided that they are done at comparable times.

The preliminary data for 1991, which do not involve sampling of the same "parcel" of water at the delta head and in the Outer Delta, indicate that concentrations in Reindeer Channel, especially, but also in Middle Channel, seemed to be substantially higher than in the incoming Mackenzie River. The 1991 time trend of concentrations in East Channel below Tununuk Point (the outer station with the lowest sediment levels) is compared with spot sampling on the Mackenzie River at Arctic Red River in Fig. 3.7. The concentrations on lower East Channel seem to be comparable with, if not higher than, those on the Mackenzie at the delta-head.

The implication appears to be that, in 1991 at least, the delta was an area of net erosion (bank erosion exceeding overbank and lake deposition) rather than a zone of net deposition. On lower East Channel, concentrations are still comparable with those on the incoming Mackenzie, presumably representing a balance between the effects of loss of sediment along the upper and middle East Ch. and acquisition of sediment along Middle Channel. Similar comparisons using the 1988 data are much more difficult because of the timing of outer-delta sampling.

In addition to same-day sampling at the Outer Delta stations, therefore, it would be useful if Year III sampling on Mackenzie River at Arctic Red River could also be arranged in such a way that it meshed with sampling in the Outer Delta, allowing for the travel time of the water.

The rudimentary first attempt at a semi-quantitative input-output analysis for the delta, described above, with all its limitations, does suggest that the delta sampling program may yield data that are somewhat at variance with popular ideas regarding the role of the delta as a sink for sediment. This may prove to be an important finding of the NOGAP program if verified by analysis of the 1992 and 1993 data.

4. DELTA-HEAD STATIONS

Analysis of the delta-head stations is, strictly speaking, beyond the terms of reference of this report. However, given the importance attached to "cross-delta" sediment relationships in the two previous sections, it seems essential to include such analysis here.

No sampling was planned for Arctic Red River in the NOGAP program, but sampling was done on both the Mackenzie River at (upstream of) Arctic Red River and Peel River above Fort McPherson.

4.1 Mackenzie River at Arctic Red River

4.1.1 Accuracy of SV data

Sampling in this reach has always posed a problem because of the cross-sectional gradient in sediment concentration, increasing from the rockwall right bank towards the left bank shoal (the downstream end of the left bank point bar). Typical patterns were given by Carson (1988, Fig. 7) for the 1980s. The traditional SV location was about 200m from the left bank, close to Arctic Red River village, and about 3 km downstream of the 1980's measurement section. In this position, notwithstanding its location towards the left bank, it was generally representative of the wash load (finer than 0.125 mm); in part, this seems to have been due to its location well downstream from the left bank bar.

During the course of the 1980s, however, it was clear that elongation of the left-bank bar towards the SV site was taking place. This was accentuated during the major floods of 1988 with massive buildup and extension of the bar. In the belief that the SV site would no longer be representative of the reach, it was therefore recommended in the 1988 report that SV sampling at this station be abandoned and replaced by limited MV sampling until an alternative section and SV station could be established.

These recommendations were summarized in the Year I report on sediment sampling in the delta (Carson, 1992a, p.20). Subsequent sampling in 1991 confirmed these concerns, though interpretation of the data is complicated by a shift in SV sampling to a near-right bank location (125m RB) on the measurement section. The unweighted k-values for the three 1991 sampling were:

June 4 mean mg/L = 319 k=1.46 Q=17600 m3/s

June 28 mean mg/L = 314 k=1.52 Q=19700 m3/s

July 25 mean mg/L = 1080 k=1.24 Q=24600 m3/s.

The lower concentrations in the right side of the channel are indicated in Fig. 4.1 for the high-flow event. The pattern is fully consistent with the observations noted in the 1980's.

In view of these data it is clear that spot SV sampling at 125m RB cannot be relied upon to provide accurate estimates of the mean concentration in the section. Inspection of the cross-river pattern suggests that a SV location at about 370m RB to 410m RB would be much better, though the location of the vertical that corresponds to mean concentration in the section appears to shift from flood to flood. Brumwell (1991) notes that "the 1992 SV site may be moved to mid-channel where we hope a buoy might survive. The 1991 site was subject to heavy debris." The 1992 SV data may, therefore, be more representative of the cross-section.

In view of the importance of this station it is recommended that as many as half of the Year III sampling here be MV sampling and that the rest be SV sampling at 390m RB. The MV sampling need not be unduly time-consuming if they are not preceded by hydrometric measurements. As noted in Chapter 1, an appropriate procedure could be developed simply using the existing five verticals, sounding them for depth prior to split sampling, and using local nozzle velocity x depth as an appropriate weighting factor for each split.

4.1.2 Sediment rating data

No additions have been made to the sediment rating data file, given the difficulty of assessing the appropriate k-value to use in adjusting SV values. However, a large sediment rating file exists. The purpose of the 1991 program was primarily to assess the cross-sectional pattern rather than to add new data to the sediment rating file.

4.2 Peel River above Fort McPherson

Previous assessment of sediment data on Peel River was undertaken in the Mackenzie Basin Sediment Station Analysis (Carson, 1992b) but was incomplete. This subsection represents an update of that evaluation. Almost all analysis at this site is based on data from the new (1988) SV site at the ferry crossing, because of uncertainty regarding the reliability of most of the 1970s SV data (Carson, 1989).

The purpose of the 1980s-1990s sediment program (including the NOGAP program) at this site is threefold:

- ***development of a procedure to ensure that the new SV location is representative of the cross-section;***

- ***development of a mathematical model that will predict daily sediment concentrations with acceptable accuracy;***

- ***development of a relationship between sediment concentration on Peel River and sediment concentration at the Peel Channel station.***

4.2.1 Representativeness of SV site

The new SV location at the Peel River ferry crossing has the major advantage that it allows convenient sampling from the in-channel end of the ferry by reliable non-WRB observers. There is, however, one definite problem with the site: this is that the SV location is near the outer bank immediately downstream of a meander bend, and SV concentrations usually need adjustment because they are generally less than elsewhere in the cross-section. The k-value data from this site are summarized in Table 4.1. They range between 1.08 and 1.33.

In 1988, the two k-values were used by WRB to produce a k-value curve for the sampling season, adjusting each day's concentration by a value given by this curve. A similar curve was used by Carson (1992b, Fig. 3.5 top) for 1989, based on three k-values, and for 1990, based on no k-value data. No k-adjustment has yet been made to the 1989 and 1990 data by WRB. The 1989 WRB Sediment Station Analysis sheet for this station includes the comment:

> *"Because single vertical samples were collected on the top 2.5 metres only, the relationship between single verticals and the sediment measurements ("k") is not clearly defined."*

This remark could be misleading. It is true that regular SV sampling by the observer in 1989 was restricted to the top 2.5m, but this was not the case at the time of k-factor sampling by WRB staff. The 1989 field sheets indicate that the May 25 SV sampling was done through the top 5 metres (SV depth was 10.2m), the June 3 SV sampling was done through the top 4 metres (SV depth was 4.5m) and the October 3 SV sampling was done through the top 6m (SV depth was 7m). There are therefore no grounds for believing that the k-value data are inaccurate, though it is unfortunate that the May 25 sampling was not done by split sampling through the full depth.

The actual k-curves, based on such few k-value data, may or may not be accurate. It may be more reliable, as well as more objective, in developing such curves to search for a relationship between the k-factor and discharge (Fig. 4.2: top). The impression gained from data so far available is that there is an abrupt increase in k-value at about 2000 m3/s from about 1.13 to about 1.33. The reason for this is presumably the change in cross-section with discharge: as water level rises and helical flow from the previous bend increases, more of the turbid flow moves over the left bank shoal and away from the right bank (Fig. 4.3). However, stage is not uniquely controlled by discharge, but also by backwater effects from ice and high water levels in the delta. The three high k-values all relate to late May or early June. It may be that the best predictor of the k-value is stage (Fig. 4.2: bottom). Additional k-value data are needed at stages in the range 7.0 to 8.0 metres.

As far as the future is concerned, such k-curves might not be needed if a satisfactory mathematical model for sediment concentration could be developed. The reason is that the model would use k-adjusted data to develop the relationship, so that any subsequent output of predicted concentrations would automatically be k-adjusted.

4.2.2 Modelling daily sediment concentrations

The sediment rating diagram for Peel River is still not fully established, the problem being the uncertainty of predicting sediment concentrations in post-snowmelt summer floods when concentrations can be much higher than expected on the basis of the sediment rating (Carson, 1992b, p. 24-5). The sediment rating developed in the 1992 report (having been adjusted for bias on detransformation from logarithmic values) was:

$$c = 2.252 \times 10^{-3} \times Q^{1.666}$$

the regression having been derived from 1970s MV data, 1988 data (daily mean concentration) and 1989-90 data (instantaneous concentration), k-factor adjustments having been made to all the SV data. All discharge values were daily means. The total number of data pairs was 187. The percentage prediction of log(c) from log(Q) was only 61% with a SEE of 0.34 log units.

Most of the scatter appeared to be due to above-average concentrations during summer floods from rainstorms. A preliminary model was developed in the 1992 report to include the variable effect of summer rainstorms on sediment levels at this station (Carson, 1992, p. 24-25). The model decreases all predicted concentrations on days before June 14 (based on these flows being largely snowmelt) and increases them on and after this date (assuming all floods to be rainstorm-induced). The actual correction factor used depends on the number of days that have elapsed since the start of the flood that contains the day in question. These factors were based on comparison of predicted concentrations with actual concentrations in the 1988-90 database.

The comparison of actual versus predicted concentrations (using this flood adjustment factor) showed a definite improvement in the regression compared to the ordinary discharge-concentration sediment rating. Though the percentage prediction increased only marginally (from 61% to 67% and the SEE decreased only from 0.34 to 0.32 log units, the reduction at scatter at high flows was nonetheless significant.

One of the problems with the data set is the use of instantaneous concentration data for 1989 and 1990. In both years, summer storms produced sharp peaks in sediment (up to 19000 mg/L in late June 1989 and up to 9700 mg/L in June 1990) with these sampled instantaneous values being many times higher than the instantaneous values of adjacent days. It was believed that replacement of instantaneous concentration data with daily mean values (not available for the 1992 report) would further reduce the standard error of both the sediment rating and the more complex model.

Unfortunately it is still not possible to use daily mean concentration values for 1989 and 1990 as IWD Inuvik believes that data are inadequate for digitizing. The reason appears to be the fact that SV sampling by the observer in 1989 and 1990 was restricted to the top 2.5 metres of flow, whereas actual river depth at the SV site varied between 4.5 m and 10 m.

The reluctance of WRB staff to process these data further is understandable. Certainly a program of comparative sampling of 0-2.5m depth integration versus full-depth integration is needed at the SV site in order that the 1989 and 1990 SV data can be adjusted to make them representative of the full vertical. This program was recommended earlier (Carson, 1992, p. 15). However, preliminary analysis of these data indicates that the underestimation of concentration by these shallow-depth samples may be only about 15 percent (Carson, 1992, p. 15). Such adjustment, while important, amounts to "fine-tuning" of the data. This is in marked contrast to the development of a sediment rating curve where the "errors" at this site in predicting concentration from discharge range from more than 50% underprediction to more than 4x overprediction (Carson, 1992, p. 25).

These 1989 and 1990 concentration data, even without "fine-tuning", are still important in the development of the sediment rating relationship for this station because of the many high flows that occurred in these two years, with frequent concentrations above 1000 mg/L.

The only other way of possibly resolving this issue is to replace the daily mean discharge data from 1989 and 1990 that were used in the sediment rating with instantaneous values. Thus a new composite set of sediment rating data has been developed based on 1970s MV daily means, 1988 daily means and 1989-91 instantaneous data. The 1991 data were not k-adjusted. At least individual Q,c data pairs are now consistent: no pairs are in mixed-mode format with a daily mean value associated with an instantaneous value. However, the error in using daily mean discharge (rather than instantaneous discharge) was generally very small.

The new data set gives the following sediment rating (Fig. 4.4) after adjustment for bias:

$$c = 3.04 \times 10^{-3} \times Q^{1.626}$$

with a percentage prediction of 55% and a SEE of 0.36 log units. The overall scatter is worse than in the dataset of the Year I report.

The simple sediment rating itself (Fig. 4.4) indicates severe problems as is apparent from the instantaneous 1991 August data summarized below:

Date	m3/s	mg/L
2	913	82
4	1320	191
5	1640	10038
6	1330	1616
7	1480	1605
8	1400	738
15	1130	667
18	1390	1211
19	1630	2167
20	1720	1549
23	1560	259
24	1630	2077
25	1510	823
31	1020	153

The sediment peaks at 10038, 2167 and 2077 mg/L do correspond to flood pulses, but the magnitude of the first sediment peak is quite remarkable. In addition, the peak at 2077 mg/L is an order of magnitude higher than on the previous day, while discharge was only marginally higher.

Unless there were major sampling problems (none being indicated on the field sheets) it can only be concluded that the sediment regime is much flashier than the hydrological component during summer floods.

It had been hoped to use the new 1989-91 data to update the "flood adjustment factors" of the more complex model, but it was felt that it was now inappropriate to do this given the lack of daily mean concentrations for the three years.

It had also been hoped to test both the sediment rating and the more complex model by comparing predicted monthly loads with actual WRB-computed loads. This had been done for 1988, but that year was not representative given the lack of significant summer floods. Unfortunately the lack of daily mean concentrations for 1989, 1990 and 1991 means that this assessment is also impossible.

The general conclusion to emerge from this reanalysis of the data therefore is one of considerable uncertainty regarding any model for the prediction of daily mean concentrations at this site. It is clear that the sediment regime is far too flashy to be modelled with a sediment rating approach alone. And, until depth- and k-adjustments have been made, followed by interpolation to give daily mean values, (or until additional years of data have been acquired to compensate for 1989 and 1990) no proper assessment of the complex predictive model can be undertaken.

4.2.3 Relationship with Peel Channel data

In the absence of regular sampling at Peel Channel in the years ahead, it seems that the best approach for prediction of sediment concentrations there will be by correlation with those at Peel River, for the same reasons as in the case of the stations with Mackenzie River water.

Unfortunately most of the sediment rating file for Peel Channel dates from 1974 and 1975, during which years sediment concentration data from Peel River are suspect (Carson, 1989). This comparative approach will therefore have to be based on the three years of NOGAP data only, the first year of which (Table 4.2) allows little comparison at high sediment levels.

As in the case of the other delta stations, therefore, it is suggested that the Year III program involve weekly (at least) SV sampling at the upstream station (Peel River) and, using an appropriate time lag, at the downstream station (Peel Channel).

5. CONCLUSIONS

5.1 Introduction

As noted by Brumwell (1991), the NOGAP Mackenzie Delta sediment sampling program (including the two delta-head stations) is an expensive and time-consuming operation.

It is clear that a longterm (10 years or more) program of sediment sampling at 8 or more delta stations, undertaken frequently enough (at least once a week in the open water season), is far beyond IWD's resources. Yet such data are needed if the fundamental issues related to sediment transport to the Beaufort Sea are to be adequately addressed. The solution to this dilemma is the prediction (rather than measurement) of sediment concentrations at delta stations, using established mathematical relationships.

The problem is that no simple mathematical relationship appears to be adequate for this purpose in the delta area. The use of the ONE-D-SED model (Morse, 1991; Wisner, 1991), previously being contemplated (Kerr, 1991, pers. comm.), is entirely inappropriate because of its inability to deal with wash load, which constitutes essentially all the delta suspended sediment (Carson, 1992a, p.3).

The obvious alternative is the use of sediment rating curves. However, the preliminary results to date, including the data gathered in the 1970s and 1980s, indicate that prediction of suspended sediment concentrations from discharge at these stations, using rating curves, is far from satisfactory. A more definitive assessment must await generation of discharges using the 1-d model and the additional sediment data for 1992 and 1993.

One of the major problems with these sediment rating curves in the delta is that, for given discharge, there can be a wide range of concentrations, depending only in part on the month of sampling. On the other hand, anomalous concentrations at a given station on a given date tend to be repeated at other stations at the same time (allowing for lags in travel time). It is for this reason that more accurate predictions of sediment concentrations, at most delta stations, occur through "cross-delta" correlations, i.e. correlation with measured concentrations at another station, as noted in Chapters 2 and 3.

5.2 Use of East Channel at Inuvik as a base station

The possibility of using Inuvik data for this purpose, not only for predicting concentrations at eastern mid-delta stations, but also at the three outer delta stations, seems extremely promising, and warrants further investigation. It offers the option of a regular sediment program at a single convenient location being used to generate the sediment data at many delta stations with limited cost.

It is hoped that, ultimately, a good sediment rating can be developed at Inuvik between log(c) and log(Q), after which time, little additional sampling would be needed at Inuvik. Sediment concentrations at Inuvik in the future might then be predicted from discharge at

Inuvik; and sediment concentrations in the rest of the delta could be predicted from Inuvik concentrations.

Yet, from examination of the Inuvik (and other delta) sediment ratings to date, it is doubtful if such prediction of the Inuvik concentratons can ever be done with a great deal of accuracy. In other words, any sediment flux model for the Mackenzie Delta is likely to require full-program sediment sampling at Inuvik, in the future, for any year in which the model is to be applied.

This should not be regarded as a serious problem. Sampling at Inuvik is relatively easy and convenient because of its proximity to the WSC district office. It is generally recognized that some "bench mark" sediment stations are required across Canada for longterm monitoring of sediment transport. In the Mackenzie Basin, East Channel at Inuvik is a logical site as the bench mark station, provided that no systematic alteration in morphology of the distributary entrance from Mackenzie River takes place.

The only real drawback with this approach is that an Inuvik-based sediment flux model cannot be applied to past years in which sediment data have not been collected at the Inuvik station. This applies to all years prior to 1991 except for 1974 and 1975. There is, however, one possible solution to this problem: provided that a good correlation is determined between concentrations at Inuvik and those for the Mackenzie at Arctic Red River, it should be possible to predict Inuvik concentrations from measured Mackenzie concentrations. Inspection of data from the Mackenzie station indicates that sufficient data exist for the period 1980-1988, at least, for this purpose, provided that a satisfactory between-station relationship can be established.

Unfortunately only limited data are currently available for such a comparison between the two stations (Fig. 5.1) because of the sparse 1975 sediment data and complete lack of 1977 data on the Mackenzie, two of the three years of pre-1991 data at Inuvik. On the other hand, the preliminary data are very encouraging. The percentage prediction of log(c) on the Mackenzie from log(c) at Inuvik is 90% with a standard error of estimate of only 0.15 log units. This is far superior to the actual sediment rating for the Mackenzie River station in which the percentage prediction is 68 % and SEE is 0.22 log units (Carson, 1992b, p. 22). The regression would, of course, need to be inverted for prediction of concentrations at Inuvik from the Mackenzie River station in the period 1974-92.

It should be borne in mind that the 1970s data are daily mean values and the 1991 data are instantaneous. The 1970s data for Mackenzie River were taken as exactly three days prior to the sampling date at Inuvik. In the case of the 1991 data, the chosen lag was forced by data availability and it ranged from 1 to 4 days. It should also be noted that Inuvik data for 1974 August 12, 14 and 16 were not used. Only one Mackenzie sample was available during this period (12th) with a daily mean of 9640 mg/L, the highest on record by far. The value has previously been regarded as suspect (Carson, 1988, p. 28).

Notwithstanding the limited database for Fig. 5.1, the relationship is encouraging. More comparative data, especially for concentrations above 500 mg/L, are needed, and this should be a major goal of the Year III program.

5.3 Year III program: stations that are dominantly Mackenzie River water

With the above perspective, it is therefore important to design the Year III sampling program in a way that permits unambiguous comparisons in concentrations between sites.

Sampling at Mackenzie at Arctic Red River should precede sampling at Inuvik by the time of water travel between the two points; and sampling at the Outer Delta sites should lag that at Inuvik by the appropriate travel time. In addition, given the limited expense of sampling at Inuvik compared to other sites, it would be useful to sample on the day before and the day after the scheduled sampling day at Inuvik in order to allow for errors in estimating the travel time through the delta.

The acquisition of appropriately time-lagged sediment data at Inuvik and Mackenzie at Arctic Red River constitutes the most crucial part of the Year III sediment program for reasons given at the end of the previous section. In addition it is clear that concentration data for the Mackenzie must be fully representative of the cross-section. For this reason, much of the sampling on the Mackenzie at Arctic Red River should be MV sampling as noted in Section 4.1.

Sampling on Middle Channel should as far as possible be done on the same day as the scheduled sampling at Inuvik. Ideally, if sufficient resources are available, it would be useful to sample on Aklavik and North Kalinek Channels (SV sampling at the 1970s sites) to increase confidence in the relationships established with Inuvik data in Chapter 2. Again, sampling would need to be done on the same day at all mid-delta sites.

Sampling at the three Outer Delta stations would ideally also be done on the same day, lagged appropriately after Inuvik. This strategy has generally been followed in the NOGAP program.

The MV data collected to date are generally sufficient to indicate the representativeness of the SV sites. In view of the limited resources available, it is recommended that (with the exceptions noted below) no MV sampling be undertaken at these stations in 1993, and the savings be used to increase SV sampling (at the regular SV site in each case) to once a week. In the event of a major flood, it would be useful to have more than one day's sampling at each site, but always lagged in such a way that the sampling program attempts to follow the water downstream.

The exceptions regarding MV sampling are as follows. In the event that a very high flow and/or turbid water coincides with a regular visit to <u>any</u> of the stations, it is highly desirable that MV sampling be done during that visit. In addition, on East Channel below Tununuk Point and the Mackenzie River at Arctic Red River, additional MV sampling is still needed under normal summer flow conditions. Much of this MV sampling could use the "abbreviated" sediment measurement approach (without current metering) discussed in Section 1.5.

No more bed material sampling would seem to be needed at any of these sites in the near future.

Acquisition of 1993 data in the above manner, together with existing data (and 1992 data not yet examined), should allow a proper evaluation at the end of Year III of the most appropriate statistical procedure for predicting sediment concentrations at these delta stations.

5.4 Year III program: Peel River and Peel Channel

The problems with these two sites are much more serious than at the Mackenzie River stations.

Peel Channel sediment concentrations will be largely controlled by Peel River sediment inputs, with concentrations at the downstream station tending to be lower than upstream for reasons given in Chapter 2. Unfortunately sampling at Peel Channel in August 1991 seemed to miss the two sediment pulses on Peel River, thus making it difficult to develop a good cross-delta relationship between the two stations.

The sediment rating diagram for <u>**Peel River**</u> is mediocre at best. Some (small) part of the scatter may be related to uncertainty in the appropriate k-adjustment of SV data, and the use of near-surface sampling rather than full depth integration during 1989 and 1990. The major problem, however, is the flashiness of the sediment regime, with small summer storms being capable of producing large (but variable) short-lived pulses in sediment concentration.

Inspection of the catchment upstream might identify the cause of these pulses (e.g. sites of major bank instability or mudflows), but will not solve the problem of load computation.

No progress has been made on further development of the complex sediment model for the station because of lack of daily values for sediment concentration for 1989-91. There is no guarantee that the model developed in the Year I report will solve the problems of sediment prediction at this site, but at the moment this approach appears to be the only one that offers hope, unless a longterm full-time seasonal program of sampling is envisaged at this site over the next five years or so.

The sediment rating diagram for Peel Channel is still incompletely developed but shows considerable scatter with several points (two of which are MV values) being an order of magnitude away from the value predicted by the sediment rating. This presumably results from the same factors at work as at the Peel River site. In the case of Peel River, the modelling approach developed utilizes the full hydrograph of each flood for predicting sediment levels at any point in a flood. This approach can not yet be extended to Peel Channel because of the lack of reliable hydrometric data at present.

As noted in Chapter 4, it seems likely, therefore, that the best approach for prediction of sediment concentrations at Peel Channel will be by correlation with those at Peel River. As in the case of the other delta stations, therefore, it is suggested that the Year III program involve weekly (at least) SV sampling at the upstream station (Peel River) and, using an appropriate time lag, at the downstream station (Peel Channel).

The program suggested above for Peel River and Peel Channel is, however, confronted with two serious hurdles.

The first is the much more "flashy" sediment regime on the Peel than on the Mackenzie, with sediment pulses being short-lived in many cases. This is evident in the data for early August 1991 (Table 4.2). In such a situation, comparison of isolated daily mean concentrations between Peel River and Peel Channel is difficult: comparison of instantaneous values is even more so, given the marked changes in a day. The instantaneous 463 mg/L at Peel Channel on August 7 presumably represents a parcel of water that flowed through the Peel River station at some time on August 4 (191 mg/L inst.) or August 5 (10038 mg/L inst.).

A meaningful Year III program of comparison between Peel River and Peel Channel would therefore require a frequent SV program at Peel River, with at least one SV per day at times of turbid flow corresponding to summer storms, and at least one SV per week during between-flood periods. This could, however, be done largely by the regular observer.

The second problem is the uncertain representativeness of the SV site (off the ferry) at the Peel River station. The program is therefore likely to need MV sampling at all times of heavy flows or turbid water, and this requires the presence of Inuvik technical staff. This does not necessarily require current-meter work as well. It could be done with the "abbreviated" approach using nozzle velocity described in Section 1.5.

5.5 Additional sediment stations ?

The preliminary success of the cross-delta sediment relationships raises the question of whether additional stations should be sampled to develop similar relationships for new sites in the delta. While this may seem to conflict with the limited resources currently available for sediment work, and the difficulties of delta work previously noted, the question should at least be raised because much of the expense of the delta program is in travel. Additional stations en route between existing stations may not involve enormous extra expense.

In fact it has already been recommended that two of the 1970s stations be reactivated in Year III: Aklavik Channel above Schooner Channel and North Kalinek Channel above Oniak Channel. These two sites constitute distinct gaps in the mid-delta transect (Year I report, p. 12). No other important gaps exist on the mid-delta transect, except possibly for Raymond Channel and Kalinek Channel (after the branch-off of North Kalinek Ch. and before it joins Middle Ch. just downstream of Horseshoe Bend).

The amount of sediment transported in these two channels is assumed to be insignificant compared to Middle Channel below Raymond Channel. However, given the proximity of both sites to Station 10MC8, any SV sampling at these two sites would involve minimal extra work. Raymond Channel could be sampled downstream of the branch-off before the first bend; Kalinek Channel could be sampled in the straight reach just before it joins Middle Channel.

It should be recognised that the mid-delta and outer-delta sampling programs probably do not allow satisfactory computation of sediment loads to Shallow Bay, but this is not a stated goal of the NOGAP program. In theory it might seem that the sediment contributed by branch-offs from Middle Channel to Shallow Bay between Raymond Channel and Reindeer Channel could be determined as the difference in sediment load at 10MC8 (Middle Ch. below Raymond Ch.) and the combined total of the three outer delta stations. However, as previously noted (Section 3.4.3), it appears that there is an increase in sediment load along Middle Channel because of bank scour which would mask any loss in sediment through the channel branch offs.

A program to monitor the sediment flux to Shallow Bay would therefore require sampling on West Channel (reactivating the 1970s station), Jamieson and Schooner channels (all sampled while in the Aklavik area), together with Raymond, Napoiak, Pederson, Crooked and Amagokvik channels (which branch off Middle Channel). The latter five channels could be sampled at their branch-offs from Middle Channel while en route from 10LC008 to the Outer Delta stations. It may be useful to attempt this comprehensive Shallow Bay sampling program once during Year III in order to assess its practicability. However, it is likely to complicate the already complex Year III sampling program, and could not be justified on a regular basis, unless it is shown that a specific important goal warrants it.

It is therefore suggested that additional sediment stations in Year III be restricted to Aklavik and North Kalinek channels, and possibly Raymond and Kalinek channels.

5.6 Endnote

The review of suspended sediment data in the delta is now beginning to indicate one method of predicting sediment concentrations to be more preferable than others. The ONE-D-SED model has severe theoretical limitations and sediment rating approaches contain too much statistical error. The cross-delta relationships, developed in this report, however, look to be extremely promising.

Further development of the appropriate databases in Year III requires careful timing of sampling to ensure that, as far as possible, a given "parcel" of water is sampled as it moves downstream from the delta-head, through mid-delta stations to the outer-delta sites.

This will require prior determination of times of travel between stations as a function of discharge. In addition, frequent sampling is needed at the base stations (East Channel near Inuvik; Peel River above Fort McPherson) to allow for variability in the time of travel.

Finally, at the two main delta-head stations, great care is needed to ensure that samples taken are representative of the cross-section, given the marked cross-sectional variability in these reaches.

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List of Tables

Year	Month	Day	Type	m3/s	mg/L	% sand
74	6	12	M	1883	222	
74	7	12	S	952	536	
74	7	18	M	833	71	
74	8	1	M	1116	349	
74	8	8	S	1000	107	
74	8	15	S	1289	749	
74	8	29	S	1065	193	
74	9	9	S	765	99	
74	9	18	S	549	33	
75	6	17	S	1500	597	
75	6	23	S	1210	317	
75	7	17	M	864	153	
75	8	13	M	733	71	
75	8	20	M	742	82	
75	9	11	M	575	39	
91	6	12	M	1060	126	
91	6	18	S		255	
91	6	26	S		211	
91	7	4	S		121	
91	7	13	S		80	
91	7	16	S		110	
91	7	28	S		296	3
91	7	30	S		255	
91	8	7	S		463	2
91	8	21	S		420	2
91	8	29	M	749	496	1-5
91	9	4	S		145	
91	9	11	M	490	50	
91	9	30	S		66	

M denotes multiple vertical; S single vertical

All 1974 data are daily mean values.
1975 sediment concentrations are instantaneous values;
1975 discharge data are daily means.

TABLE 2.1

PEEL CHANNEL UPSTREAM OF AKLAVIK CHANNEL (10MC003):

SEDIMENT RATING DATA

Middle Channel 10MC6 and 10MC8

Year	Month	Day	Type	m3/s	mg/L	
74	7	11	*	18000	638	
74	7	19	*	15800	249	
74	7	31	M	19000	2320	
74	8	8	*	16800	1100	
74	8	14	S	21700	1390	
74	8	29	S	16700	387	
74	9	9	*	15700	192	
74	9	19	*	12600	81	
75	6	13	*	24800	904	
75	6	17	*	21800	741	
75	6	23	S	16500	365	
75	7	18	M	13900	492	
75	8	12	M	13200	164	
75	8	20	S	12700	617	
75	9	5	M	11000	204	
75	9	11	M	10000	91	
91	6	12	M	16600	214	
91	6	18	S		272	
91	6	26	S		294	
91	7	4	S		325	10-14
91	7	13	S		213	
91	7	16	S		285	
91	7	28	S		1350	2-18
91	7	30	S		930	8-21
91	8	7	S		1080	10-21
91	8	21	S		238	
91	8	28	M	10500	119	
91	9	4	S		86	
91	9	12	M	12000	82	
91	9	30	S		79	

All 1974 values are daily means.
1975 sediment concentrations instantaneous;
1975 discharges are daily means.

* denotes verticals not known

TABLE 2.2

MIDDLE CHANNEL DOWNSTREAM OF HORSESHOE BEND:

SEDIMENT RATING DATA

Year	Month	Day	Type	m3/s	mg/L	% sand
91	5	27	S	692	266	
91	6	6	M	392	135	
91	6	11	S		113	
91	6	19	S		145	
91	6	26	S		180	
91	7	4	S		217	5
91	7	13	S		111	
91	7	16	S		91	
91	7	26	M	374	816	2-3
91	7	30	S		799	2
91	8	7	S		1271	19
91	8	21	S		43	
91	8	27	M	226	55	
91	9	4	S		35	
91	9	17	M	145	27	
91	10	4	M	148	20	

TABLE 2.3

EAST CHANNEL NEAR INUVIK (10LC002):

1991 SEDIMENT RATING DATA

Year	Month	Day	10MC8 actual mg/L	10LC2 actual mg/L	ratio Middle/ East	10MC8 predicted mg/L	10MC8 (p-a) /p
91	6	12	214	113	1.89	242	0.12
91	6	18	272	145	1.88	310	0.12
91	6	26	294	180	1.63	385	0.24
91	7	4	325	217	1.50	464	0.30
91	7	13	213	111	1.92	238	0.10
91	7	16	285	91	3.13	195	-0.46
91	7	28	1350	816	1.65	1746	0.23
91	7	30	930	799	1.16	1710	0.46
91	8	7	1080	1271	0.85	2720	0.60
91	8	21	238	43	5.53	92	-1.59
91	8	28	119	55	2.16	118	-0.01
91	9	4	86	35	2.46	75	-0.15
91	9	12	82				
91	9	30	79				
				Mean	2.14	Stan.devn	0.54

predicted 10MC8 concentration equals 2.14x 10LC2

TABLE 2.4

COMPARISON OF SEDIMENT CONCENTRATIONS FOR
MIDDLE AND EAST CHANNELS
ON MID-DELTA TRANSECT

Year	Month	Day	Type	m3/s	mg/L	% sand
87	8	25	M		378	
88	6	14	D		769	
88	6	27	S		416	
88	7	26	S		860	
88	7	29	S		1223	
88	7	30	S		1022	
88	7	31	S		690	
88	8	1	S		651	
88	8	5	S		678	
88	9	16	S		410	
91	6	14	S		248	
91	6	20	M	6700	370	
91	6	28	S		597	29
91	7	3	S		630	9-14
91	7	12	S		393	1
91	7	16	S		267	
91	7	26	S		1449	6-18
91	7	30	M	7070	1170	2-24
91	8	7	S		1875	6-9
91	8	21	S		177	
91	8	31	S		120	
91	9	20	M	4260	95	
91	9	25	S		115	

D denotes dip sample
M denotes multiple vertical sampling
S denotes single vertical sample

All concentrations are instantaneous

TABLE 3.1

REINDEER CHANNEL BELOW LEWIS CHANNEL: 10MC902

SEDIMENT RATING DATA

Year	Month	Day	Type	m3/s	mg/L	
87	8	25	M		313	
88	6	14	D		716	
88	6	27	S		422	
88	7	26	S		989	
88	7	29	S		957	
88	7	30	S		840	
88	7	31	S		813	
88	8	1	S		515	
88	8	5	S		484	
88	8	13	S		273	
91	6	13	M	5370	171	
91	6	20	S		218	
91	6	28	S		256	
91	7	3	S		383	6-15
91	7	13	S		207	
91	7	16	S		159	
91	7	26	S		1034	5-8
91	7	30	M	6420	1037	2-8
91	8	7	S		1491	2,4,42
91	8	21	S		131	
91	8	31	S		84	
91	9	20	M	4120	69	
91	9	26	S		76	

M denotes multiple vertical sampling
S denotes single vertical sampling
D denotes dip sample

All concentrations are instantaneous

TABLE 3.2

MIDDLE CHANNEL NEAR LANGLEY ISLAND (10MC901):

SEDIMENT RATING DATA

Year	Month	Day	Type	m3/s	mg/L	% sand
87	9	1	M		82	
88	6	14	D		617	
88	6	27	S		715	
88	7	26	S		700	
88	7	29	S		625	
88	7	30	S		686	
88	7	31	S		717	
88	8	1	S		687	
88	8	5	S		718	
88	9	13	S		566	
91	6	13	M	3950	144	
91	6	20	S		184	
91	6	28	S		187	
91	7	2	S		224	10
91	7	13	S		145	
91	7	16	S		214	
91	7	26	S		938	6-8
91	7	31	M	4040	834	3-6
91	8	7	S		1369	2-4
91	8	21	S		144	
91	8	31	S		94	
91	9	19	M	2780	69	
91	9	25	S		85	

D denotes dip sample
M denotes multiple vertical sampling
S denotes single vertical sample

All concentrations are instantaneous

TABLE 3.3

EAST CHANNEL BELOW TUNUNUK POINT (10LC901):

SEDIMENT RATING DATA

Date	Reindeer mg/L actual	Reindeer mg/L predicted	(p-a)/a	Middle mg/L actual	East mg/L actual	East mg/L predicted	(p-a)/a
Jun 13	248	241	-0.03	171	144	149	0.03
Jun 20	370	307	-0.20	218	184	190	0.03
Jun 28	597	361	-0.65	256	187	223	0.16
Jul 2	630	540	-0.17	383	224	333	0.33
Jul 12	393	292	-0.35	207	145	180	0.19
Jul 16	267	224	-0.19	159	214	138	-0.55
Jul 26	1449	1458	0.01	1034	938	900	-0.04
Jul 30	1170	1462	0.20	1037	834	902	0.08
Aug 7	1875	2102	0.11	1491	1369	1297	-0.06
Aug 21	177	185	0.04	131	144	114	-0.26
Aug 31	120	118	-0.01	84	94	73	-0.29
Sep 20	95	97	0.02	69	69	60	-0.15
Sep 25	115	107	-0.07	76	85	66	-0.29
Mean	577		-0.10	409	356		-0.06
	Standard deviation		0.21		Standard deviation		0.23

predicted Reindeer concentration equals 1.41x Middle Channel
predicted East Ch. concentration equals 0.87x Middle Channel

TABLE 3.4

COMPARISON OF SEDIMENT CONCENTRATIONS AT THREE OUTER-DELTA STATIONS

Year	Month	Day	Inuvik mg/L	Tununuk mg/L	Tununuk/ Inuvik
91	5	27	266		
91	6	6	135		
91	6	11	113	144	1.27
91	6	19	145	184	1.27
91	6	26	180	187	1.04
91	7	4	217	224	1.03
91	7	13	111	145	1.31
91	7	16	91	214	2.35
91	7	26	816	938	1.15
91	7	30	799	834	1.04
91	8	7	1271	1369	1.08
91	8	21	43	144	3.35
91	8	27	55	94	1.71
91	9	4	35		
91	9	17	27		
91	10	4	20		
				Mean	1.51

TABLE 3.5

COMPARISON OF EAST CHANNEL SEDIMENT CONCENTRATIONS

NEAR INUVIK AND BELOW TUNUNUK POINT

	k	m3/s	mg/L	stage metres
1988 June 2	1.33	3130	543	8.268
1988 Sept 9	1.08	1870	1246	6.920
1989 May 25	1.31	2070	523	8.522
1989 June 3	1.33	2740	1023	7.870
1989 October 3	1.13	527	34	4.594
1991 July 10	1.15	855	176	5.520
1991 Sept 10	1.10	662	63	4.940
1991 June 4		2240	347	7.438

All 1991 m3/s data and all 1989-1991 mg/L data are instantaneous values

All other data are daily mean values

No SV data have been found for the June 1991 MV sampling.

TABLE 4.1

PEEL RIVER ABOVE FORT MCPHERSON (10MC002):

K-VALUE DATA FOR NEW SINGLE-VERTICAL SITE

		mg/L at Peel	
Day	Date	River	Channel
1	June 1		
2	2		
3	3		
4	4	347	
5	5	239	
6	6		
7	7		
8	8		
9	9		
10	10		
11	11		
12	12	371	126
13	13		
14	14	430	
15	15		
16	16		
17	17		
18	18	224	255
19	19		
20	20		
21	21		
22	22		
23	23	244	
24	24		
25	25	262	
26	26		211
27	27		
28	28	133	
29	29		
30	30		
31	July 1		
32	2		
33	3		
34	4		121
35	5		
36	6		
37	7		
38	8		
39	9	82	
40	10	172	
41	11	165	
42	12		
43	13		80
44	14		
45	15		
46	16		110
47	17	161	
48	18	349	
49	19		
50	20		
51	July 21		
52	22		
53	23	277	
54	24	125	
55	25		
56	26		
57	27		
58	28	73	296
59	29		
60	30		255
61	31		
62	August 1		
63	2	82	
64	3		
65	4	191	
66	5	10038	
67	6	1616	
68	7	1605	463
69	8	738	
70	9		
71	10		
72	11		
73	12		
74	13		
75	14		
76	15	667	
77	16		
78	17		
79	18	1211	
80	19	2167	
81	20	1549	
82	21		420
83	22		
84	23	259	
85	24	2077	
86	25	823	
87	26		
88	27		
89	28		
90	29		496
91	30		
92	31	153	
93	Sept 1		
94	2		
95	3		
96	4		145
97	5	110	

TABLE 4.2
PEEL RIVER AND CHANNEL DATA, 1991
JUNE 1 - SEPTEMBER 5, 1991

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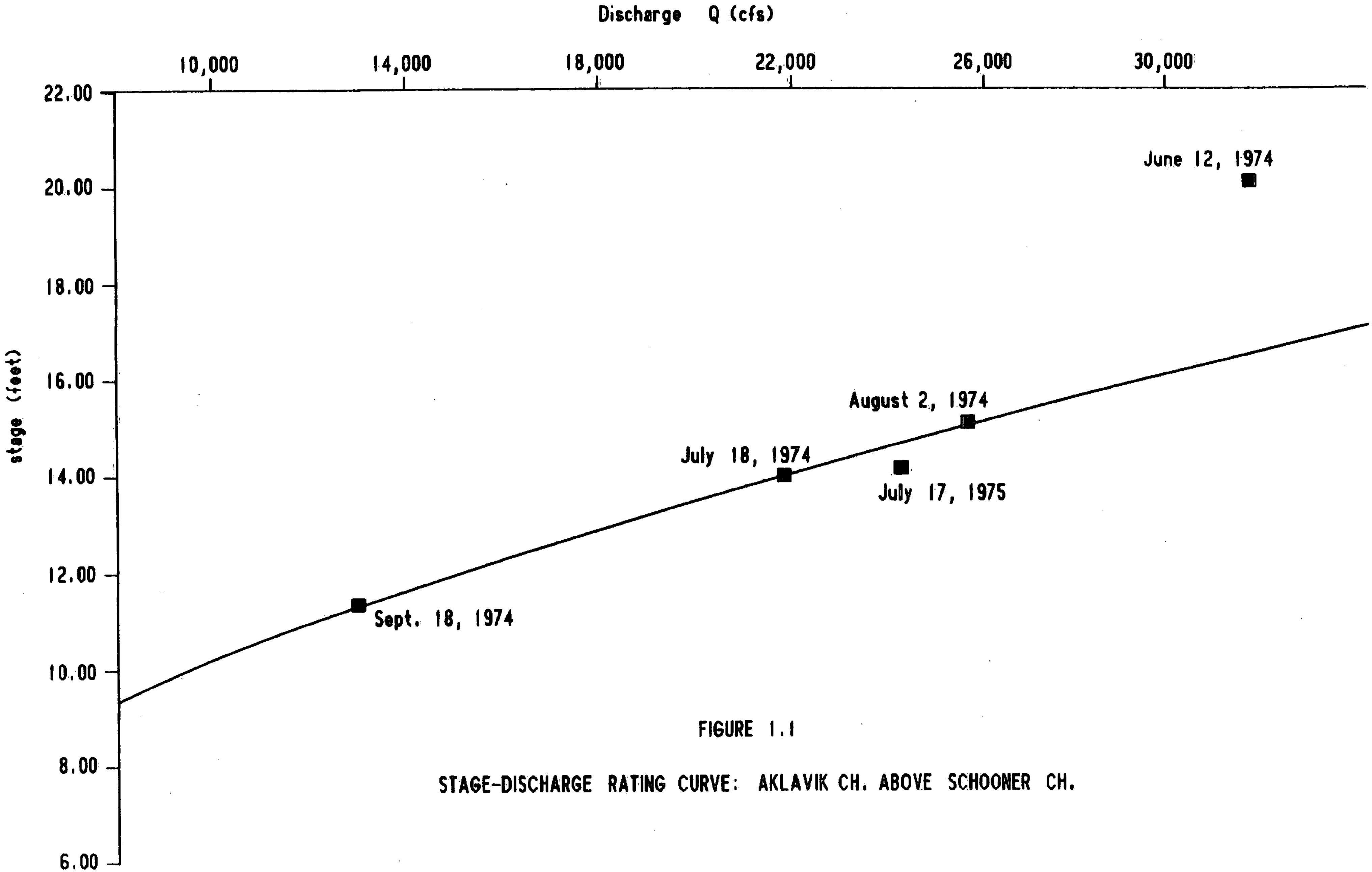


FIGURE 1.1

STAGE-DISCHARGE RATING CURVE: AKLAVIK CH. ABOVE SCHOONER CH.

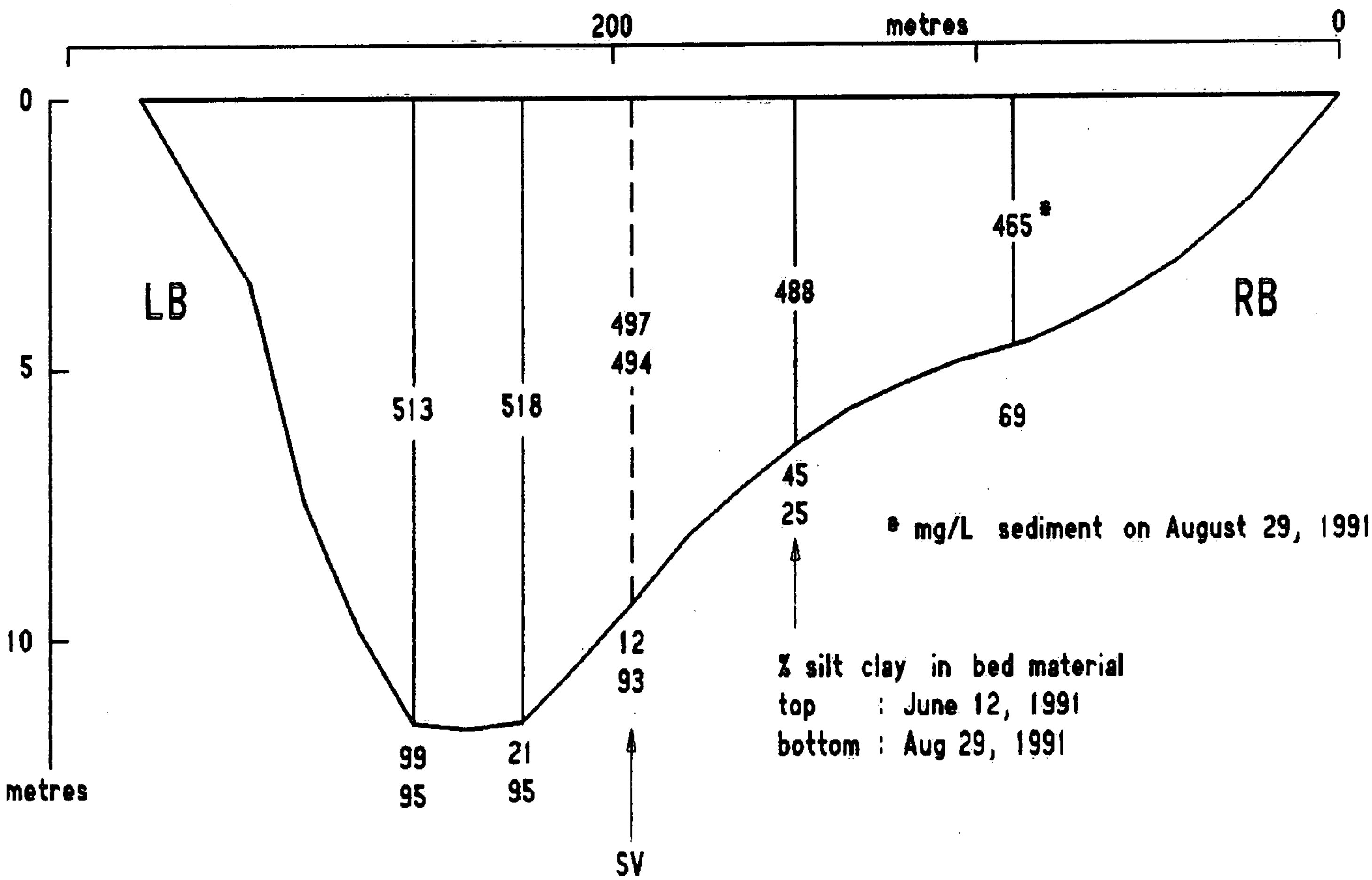


FIGURE 2.1 PEEL CHANNEL ABOVE AKLAVIK CHANNEL: 10MC003
CROSS-SECTIONAL SEDIMENT DISTRIBUTION
(water level and bed geometry as on June 12, 1991)

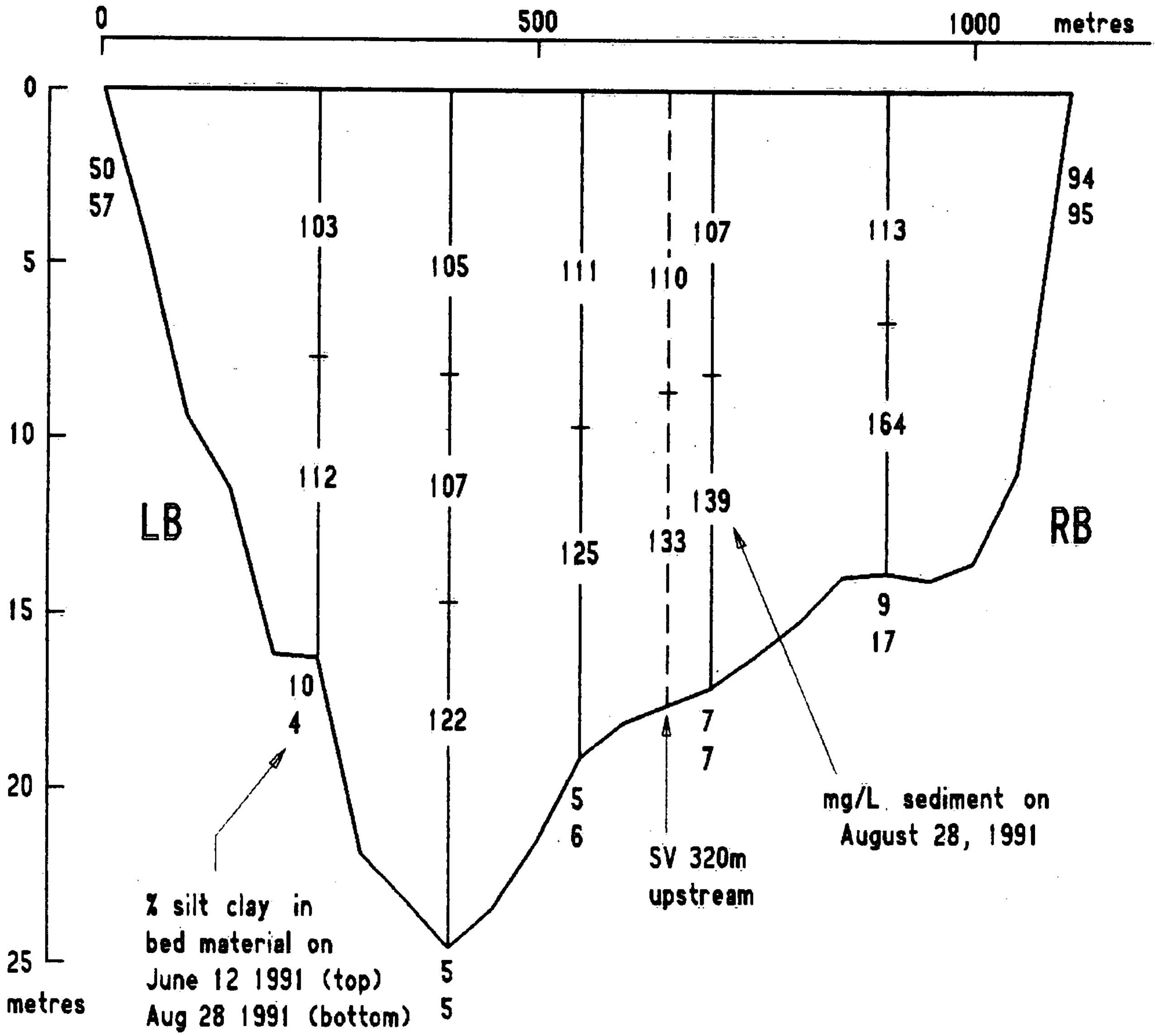


FIGURE 2.2 MIDDLE CHANNEL BELOW RAYMOND CHANNEL: 10MC008
CROSS-SECTIONAL DISTRIBUTION OF SEDIMENT
(water level and bed geometry as on June 12, 1991)

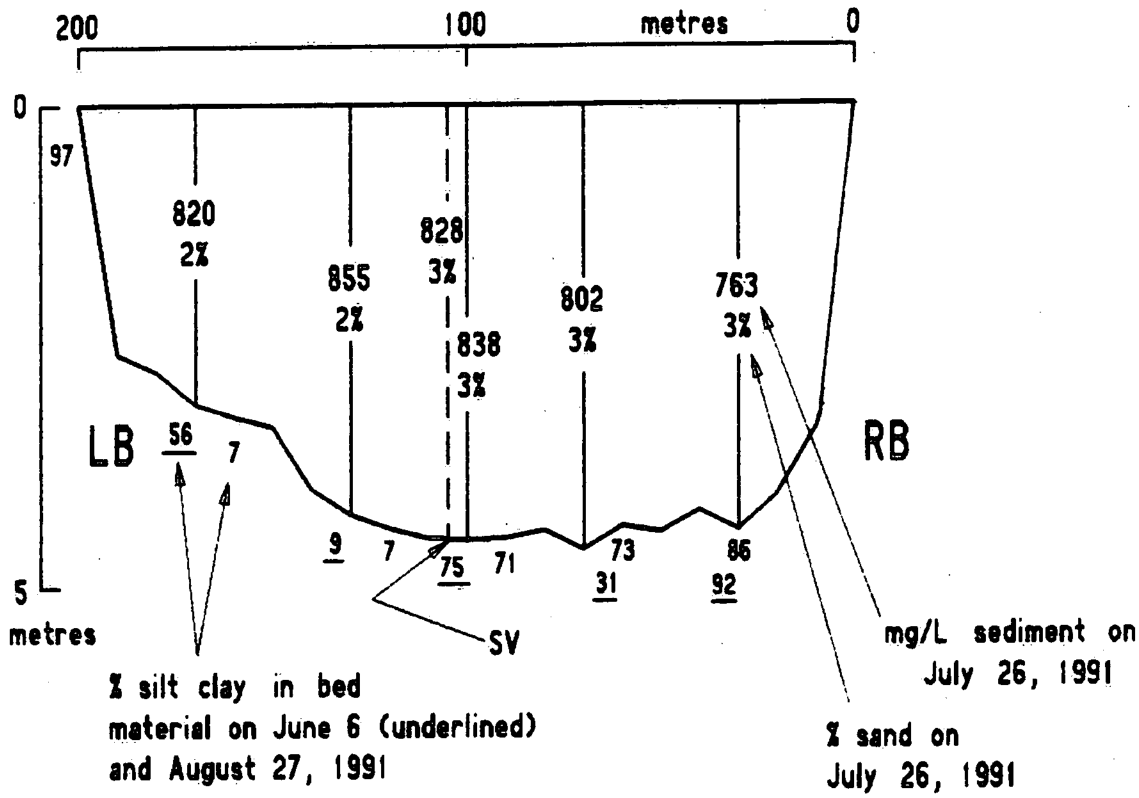


FIGURE 2.3 EAST CHANNEL NEAR INUVIK: 10LC002
CROSS-SECTIONAL SEDIMENT DISTRIBUTION
(water level and bed geometry as on June 6, 1991)

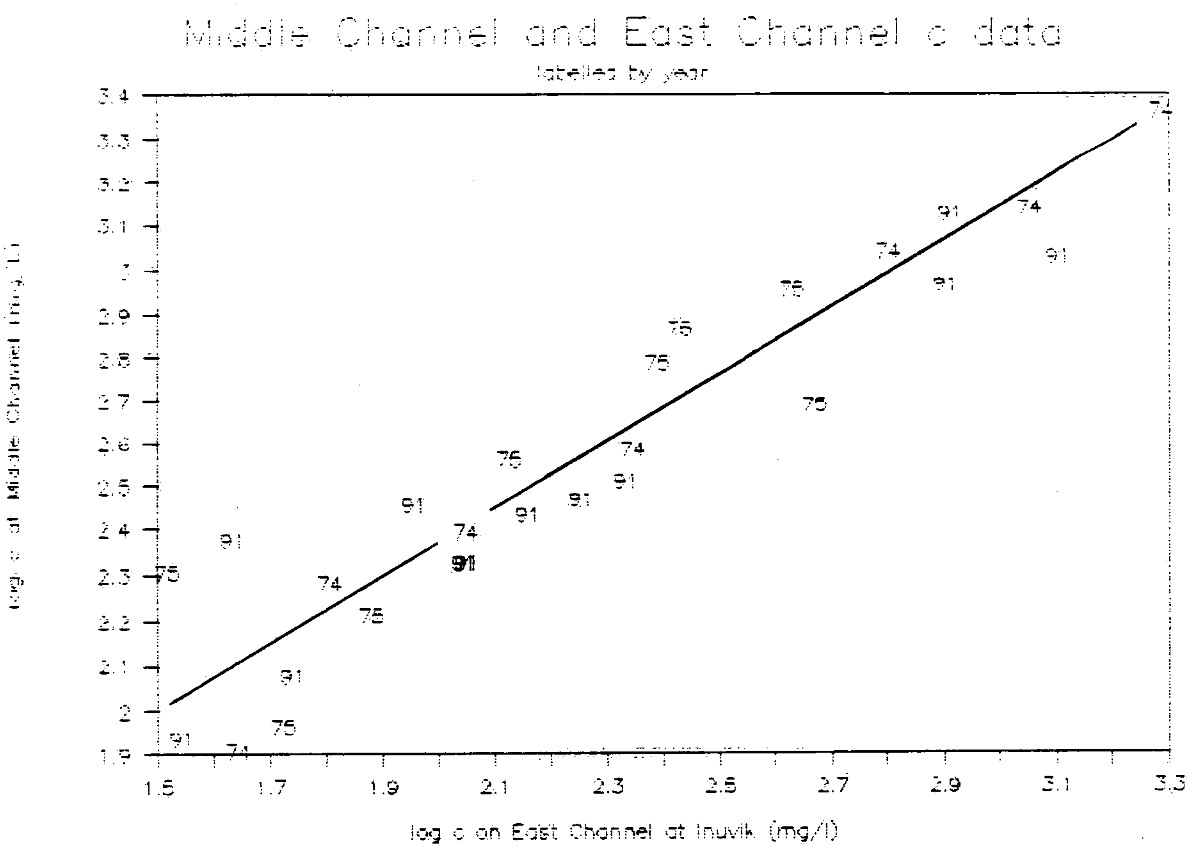


FIGURE 2.4

SEDIMENT RELATIONSHIP FOR MIDDLE CHANNEL (BELOW RAYMOND CH.) AND EAST CHANNEL NEAR INUVIK

Aklavik and Inuvik c data: 1974-75

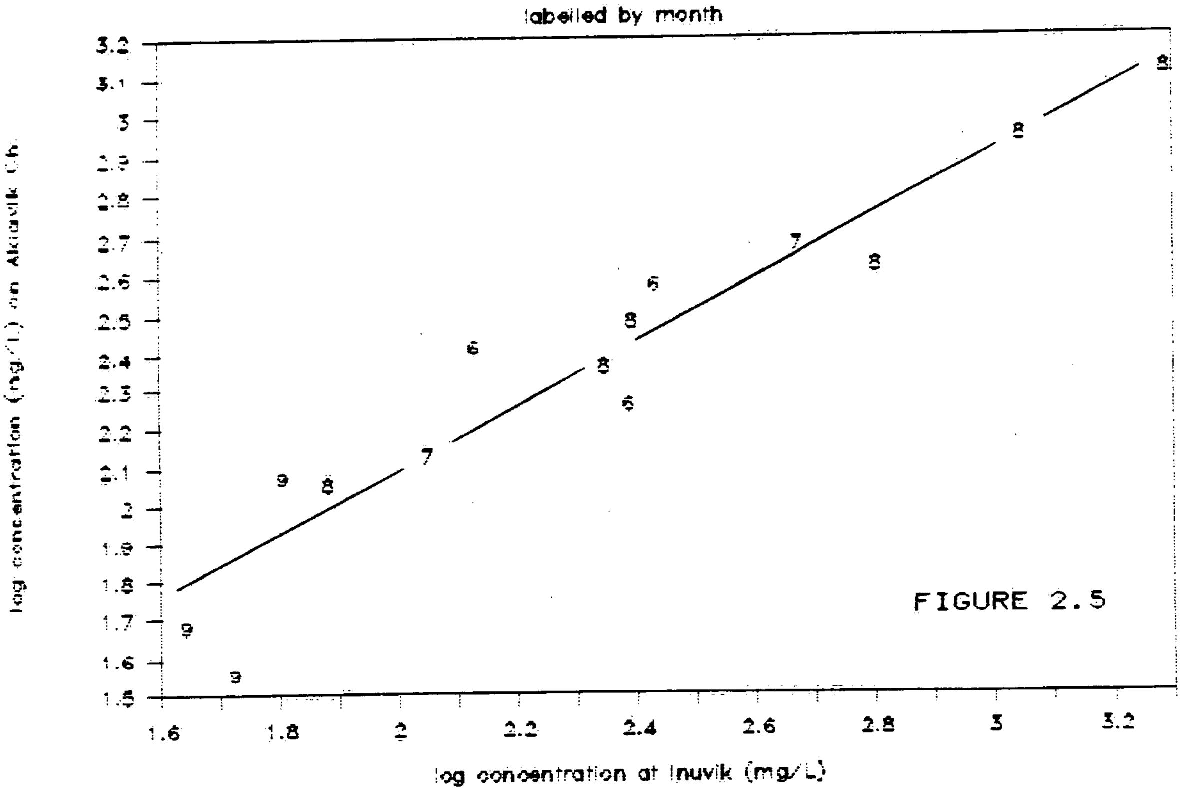


FIGURE 2.5

N. Kalinek and Inuvik data: 1974-75

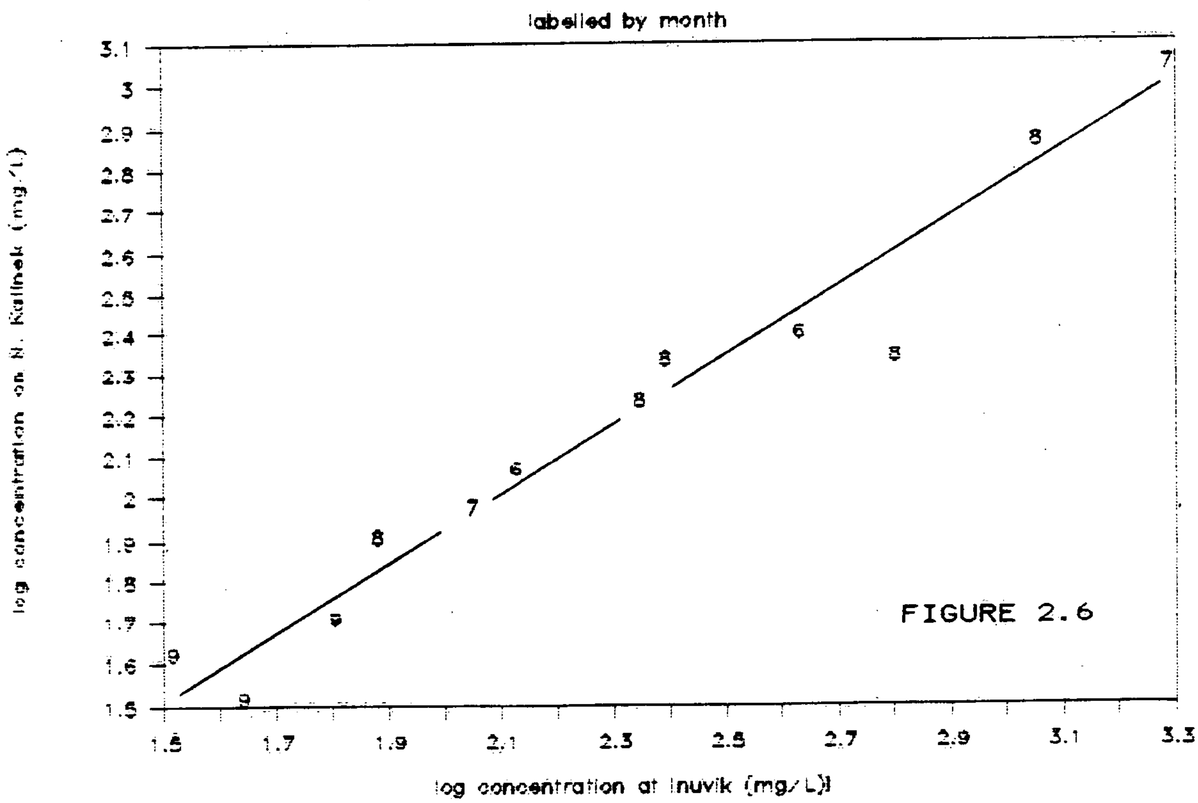


FIGURE 2.6

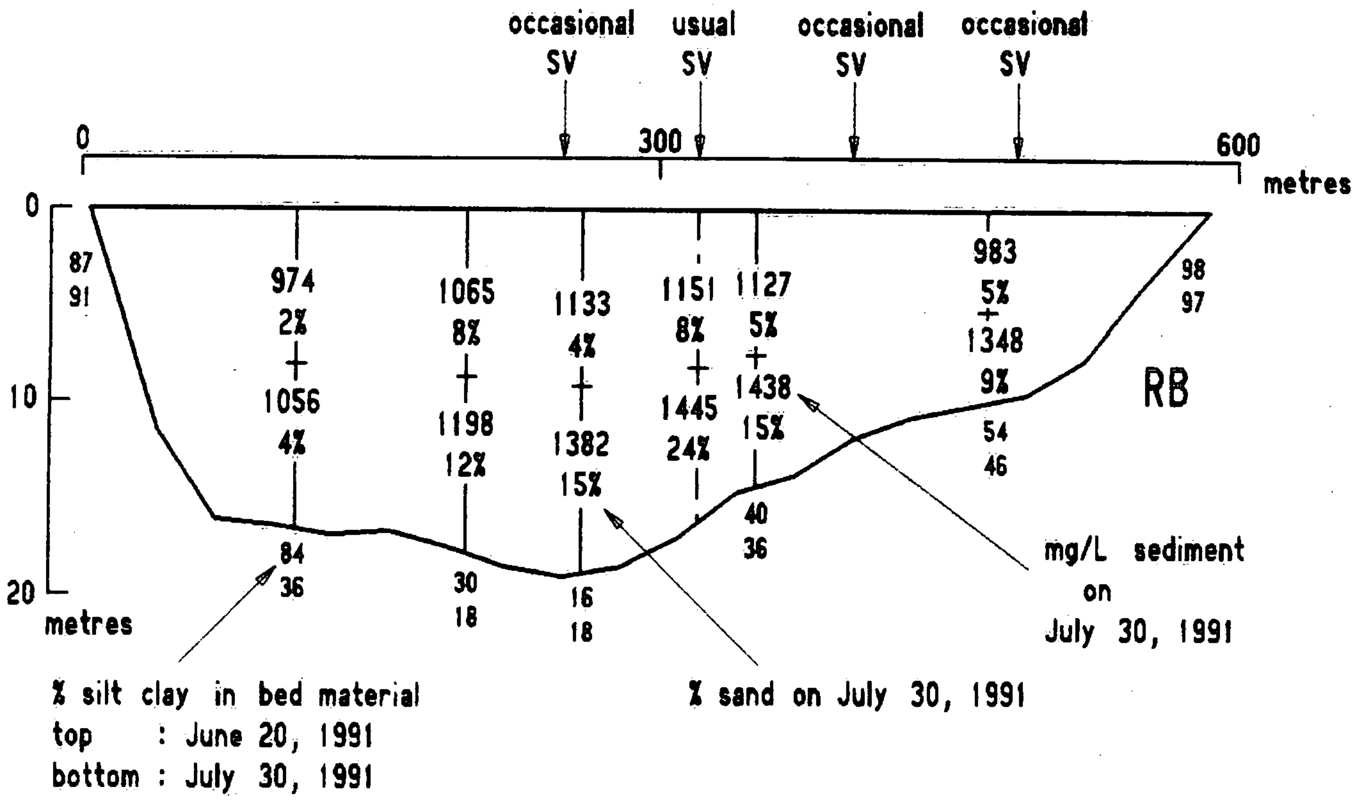


FIGURE 3.1 REINDEER CHANNEL BELOW LEWIS CHANNEL: 10MC902
CROSS-SECTIONAL SEDIMENT DISTRIBUTION
(water level and bed geometry as on June 20, 1991)

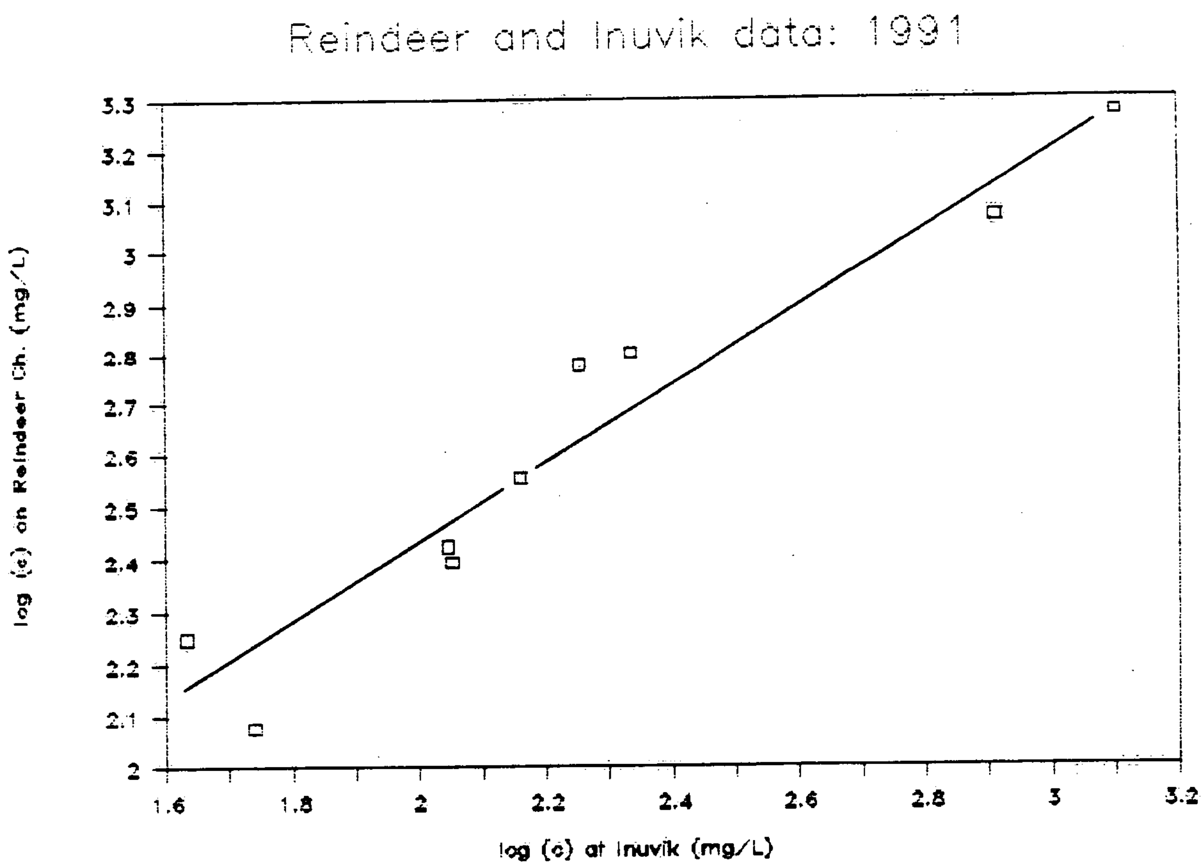


FIGURE 3.2

SEDIMENT RELATIONSHIP FOR REINDEER CHANNEL (BELOW LEWIS CH.) AND EAST CHANNEL NEAR INUVIK

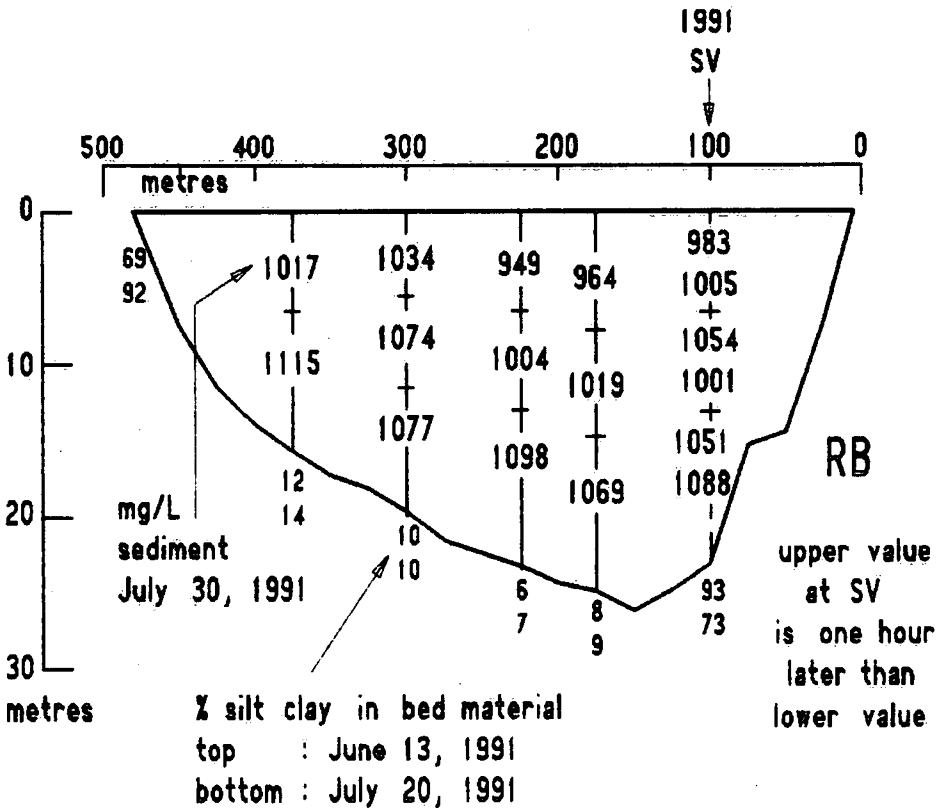


FIGURE 3.3 MIDDLE CHANNEL NEAR LANGLEY ISLAND : 10MC901
CROSS-SECTIONAL SEDIMENT DISTRIBUTION
(water level and bed geometry as on June 13, 1991)

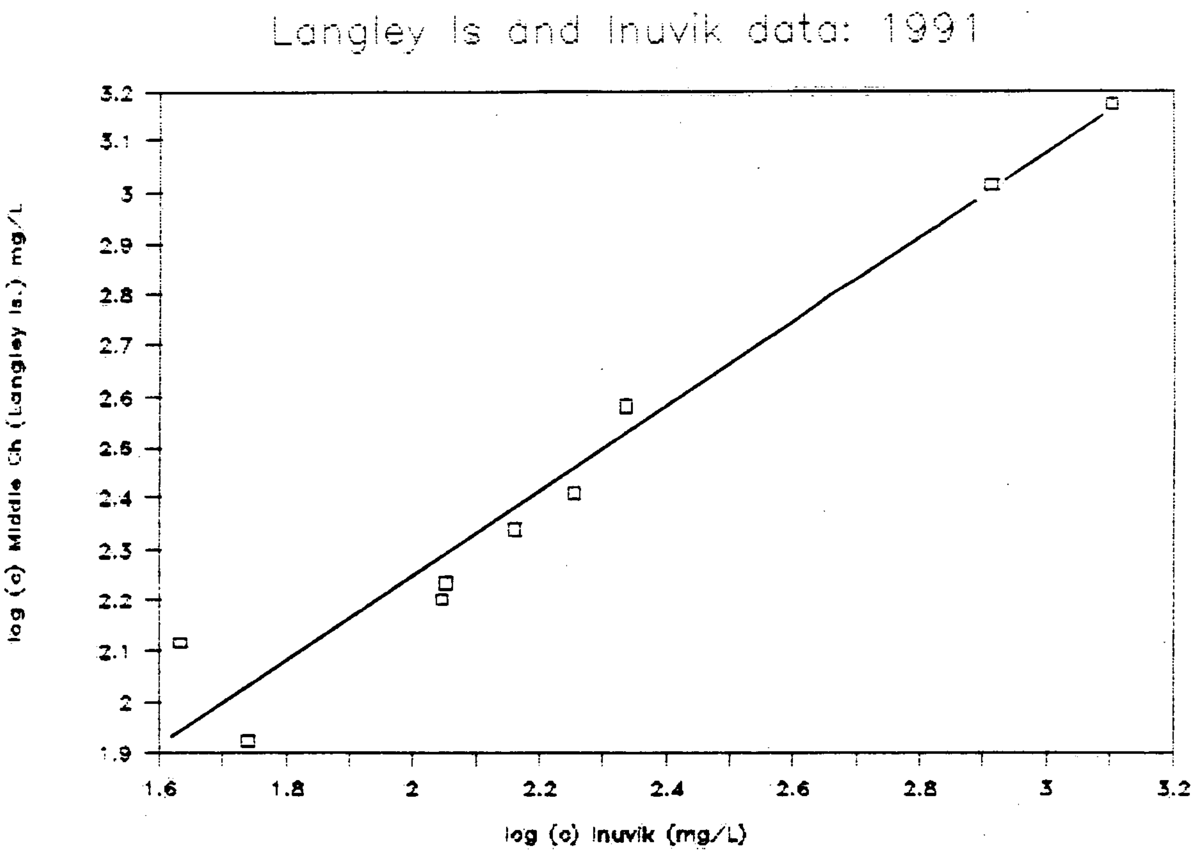


FIGURE 3.4

SEDIMENT RELATIONSHIP FOR MIDDLE CHANNEL (NEAR LANGLEY IS.) AND EAST CHANNEL NEAR INUVIK

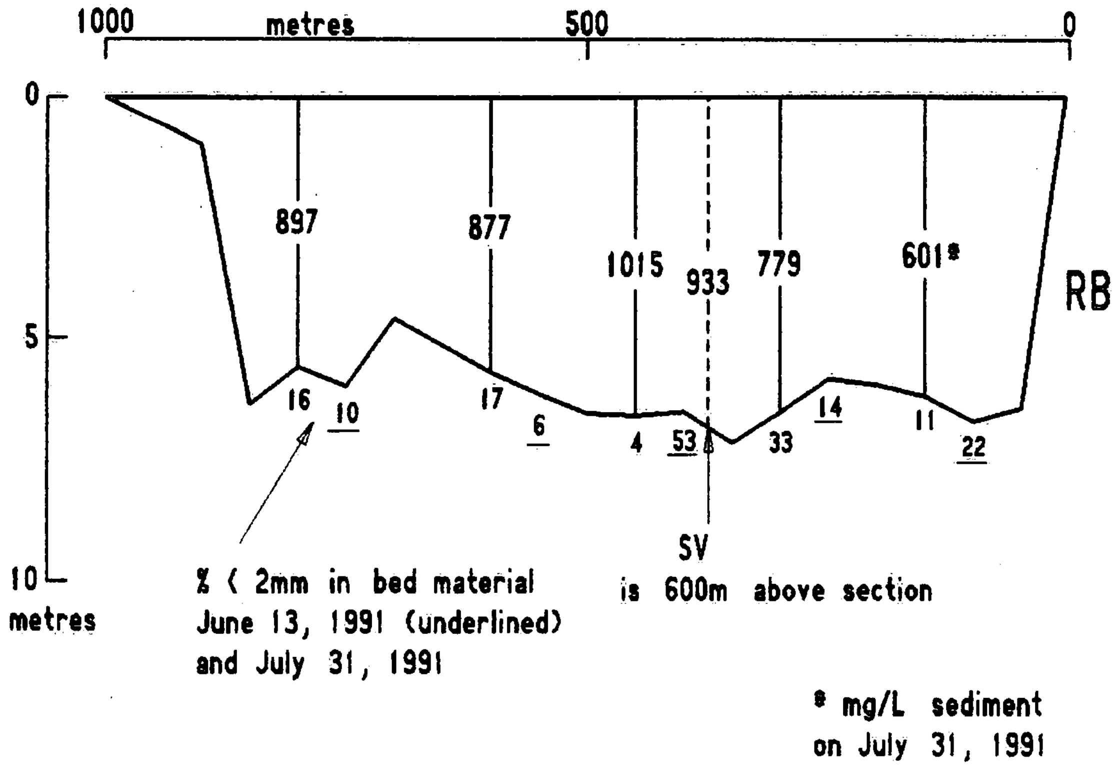


FIGURE 3.5 EAST CHANNEL BELOW TUNUNUK POINT: 10LC901
CROSS-SECTIONAL SEDIMENT DISTRIBUTION
(water level and bed geometry as on June 13, 1991)

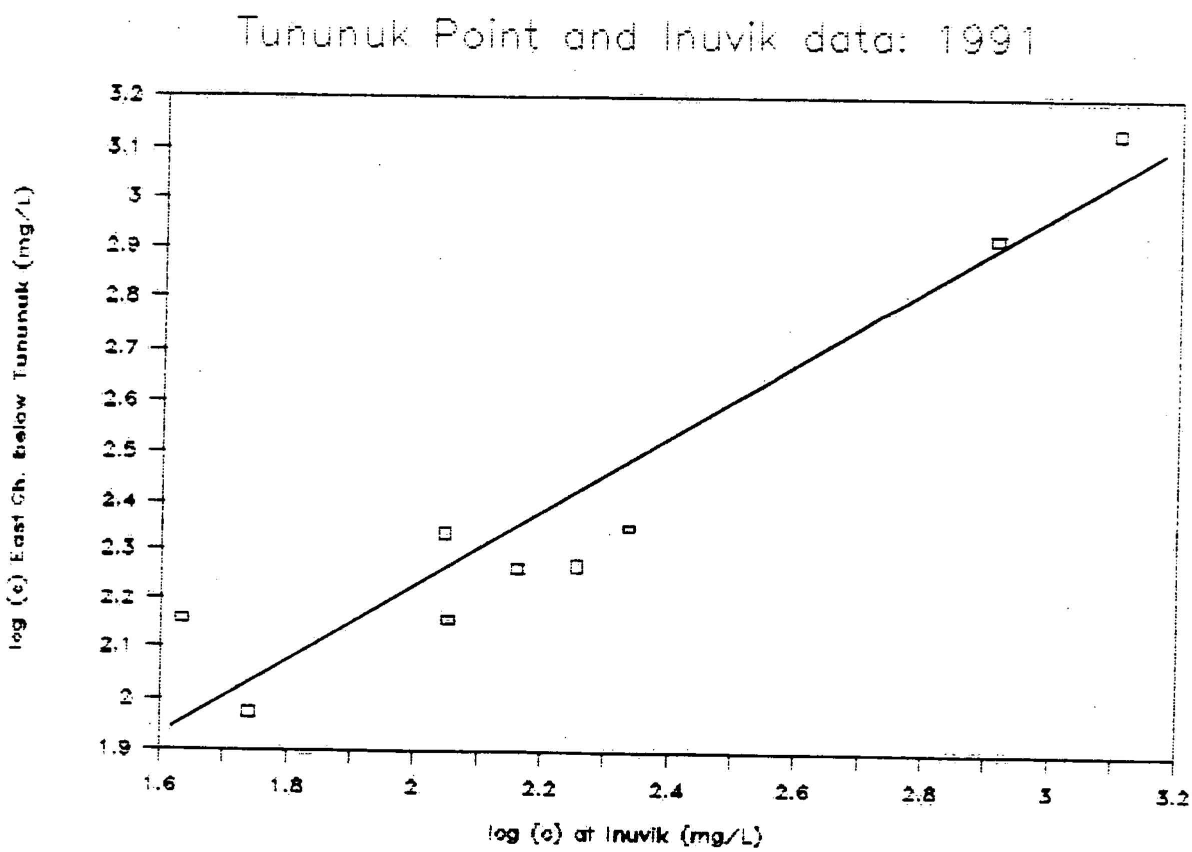


FIGURE 3.6

SEDIMENT RELATIONSHIP FOR EAST CHANNEL (BELOW TUNUNUK POINT) AND EAST CHANNEL NEAR INUVIK

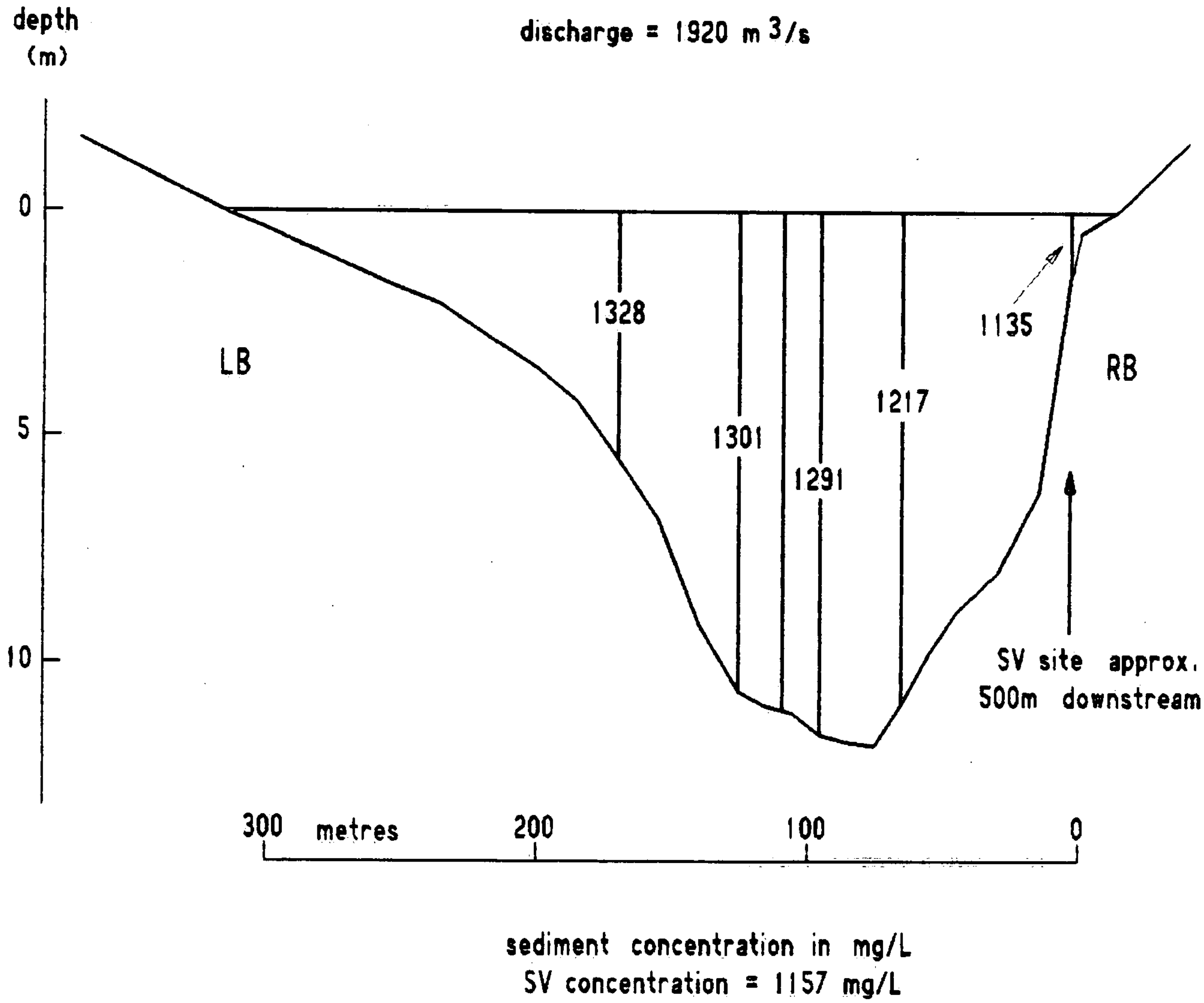


FIGURE 4.3
PEEL RIVER AT NEW MEASUREMENT SECTION:
SEPTEMBER 9, 1988

Peel River k-value data, 1988–1991

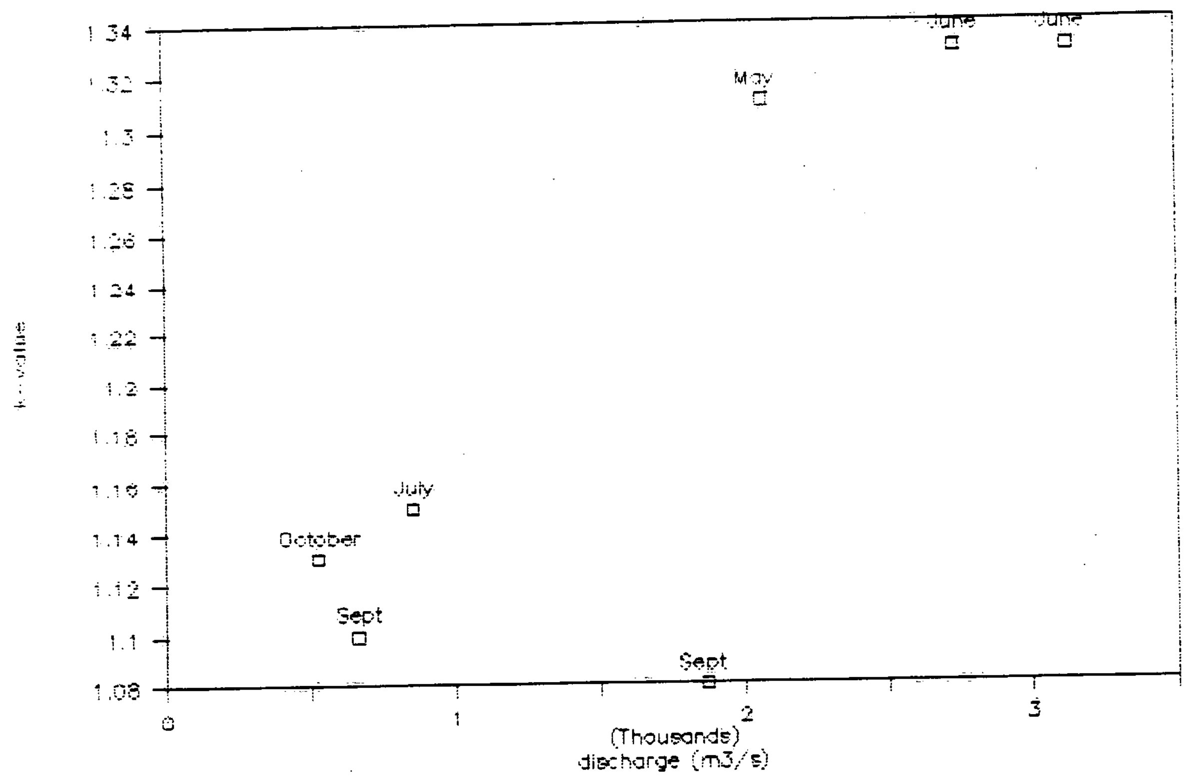
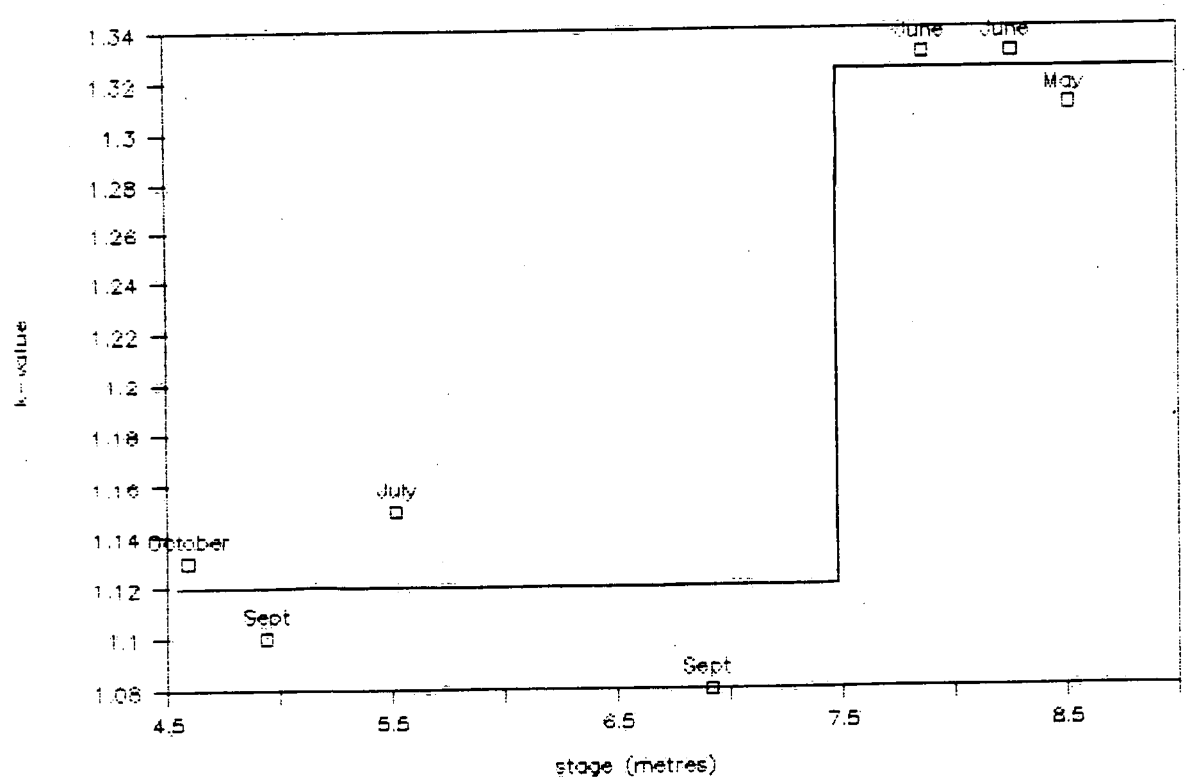


FIGURE 4.2

Peel River k-value data, 1988–1991



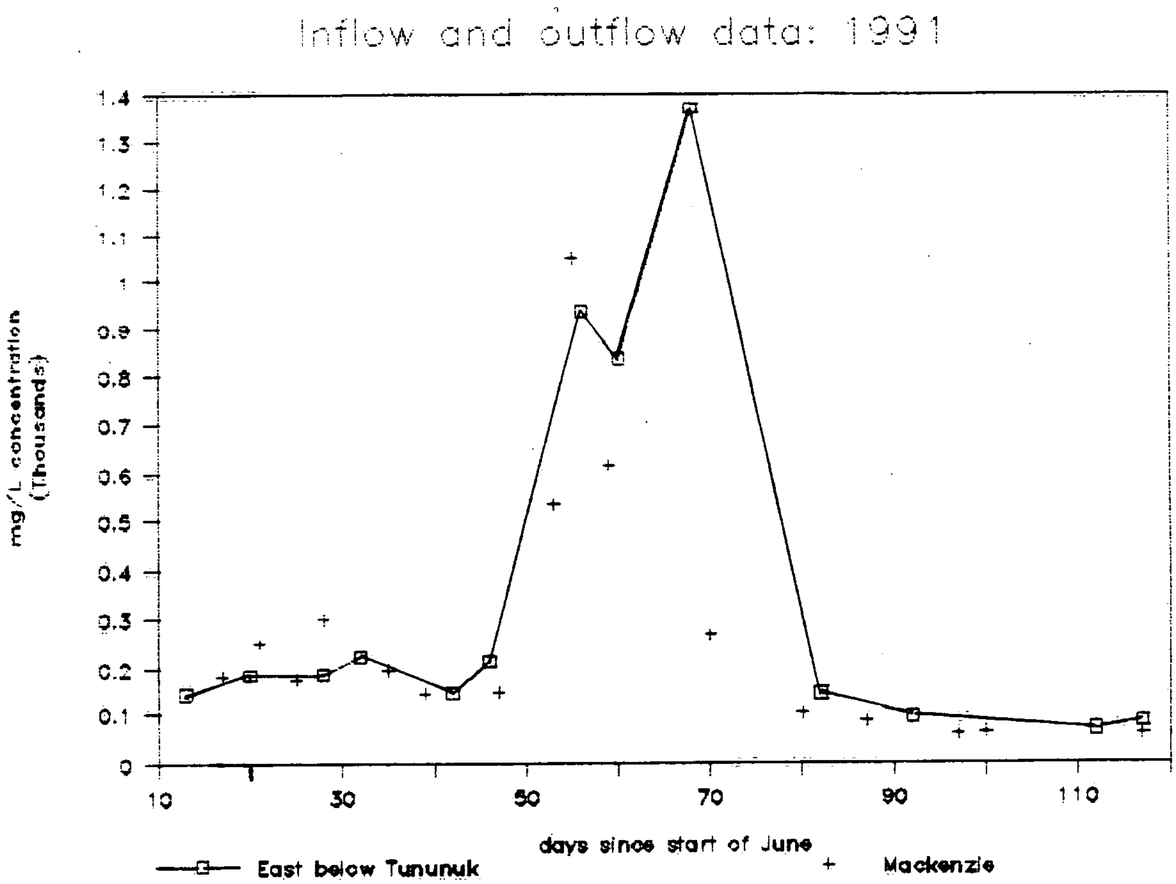


FIGURE 3.7

COMPARISON OF 1991 RECORD OF SEDIMENT CONCENTRATIONS ON EAST CHANNEL (BELOW TUNUNUK) AND MACKENZIE RIVER AT ARCTIC RED RIVER

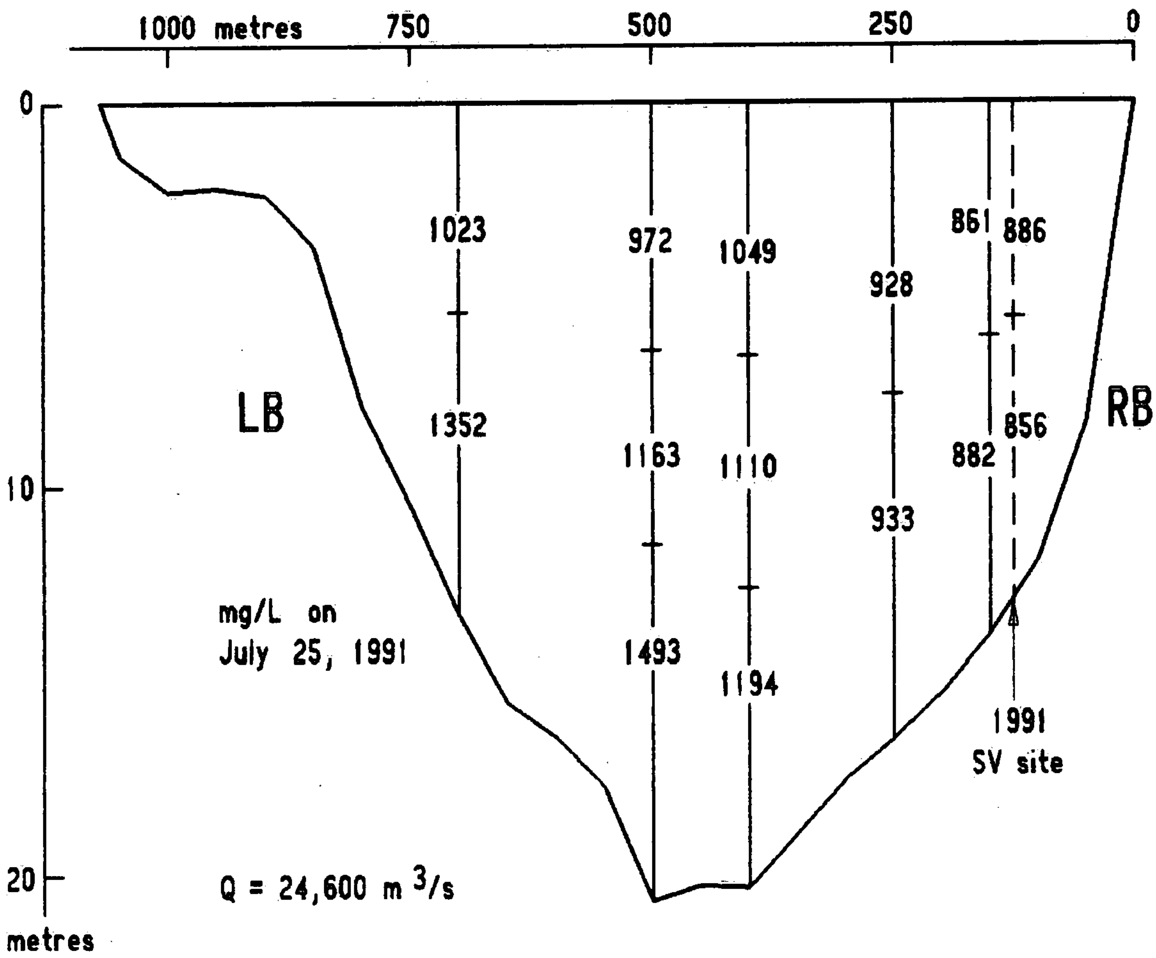


FIGURE 4.1 MACKENZIE RIVER AT ARCTIC RED RIVER: 10LC014
CROSS-SECTIONAL SEDIMENT DISTRIBUTION

Peel River k-value data, 1988–1991

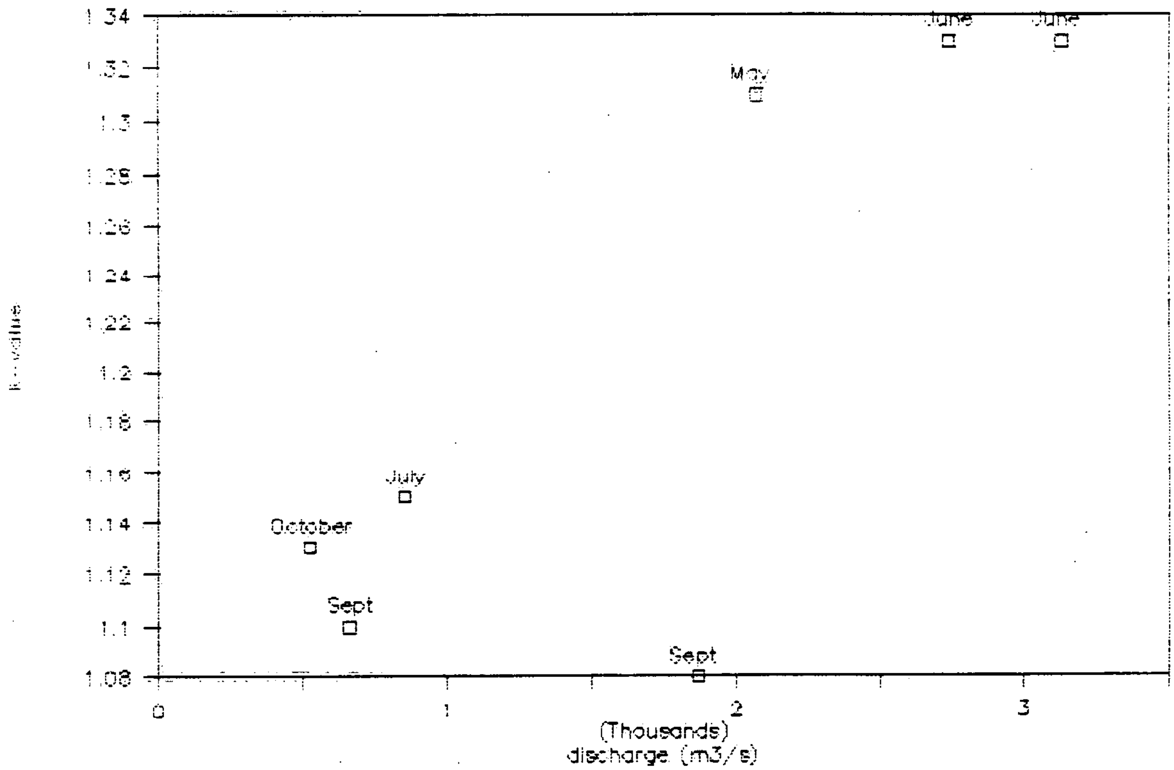
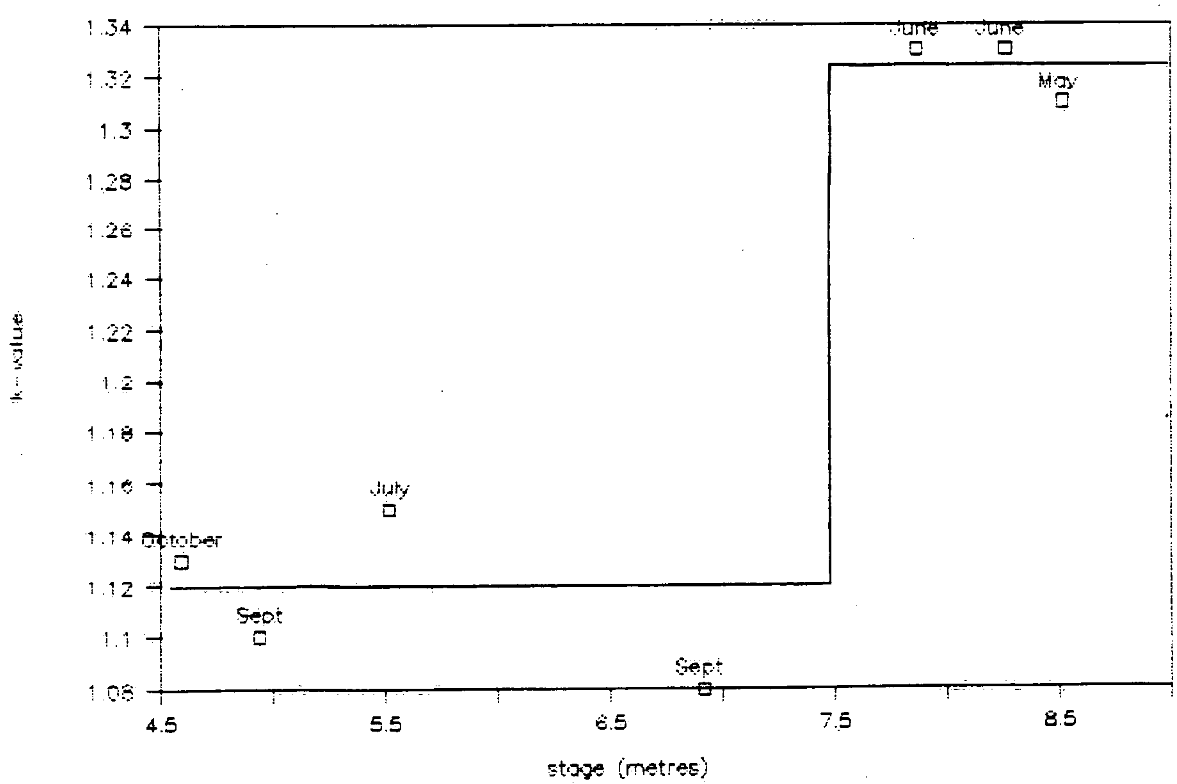
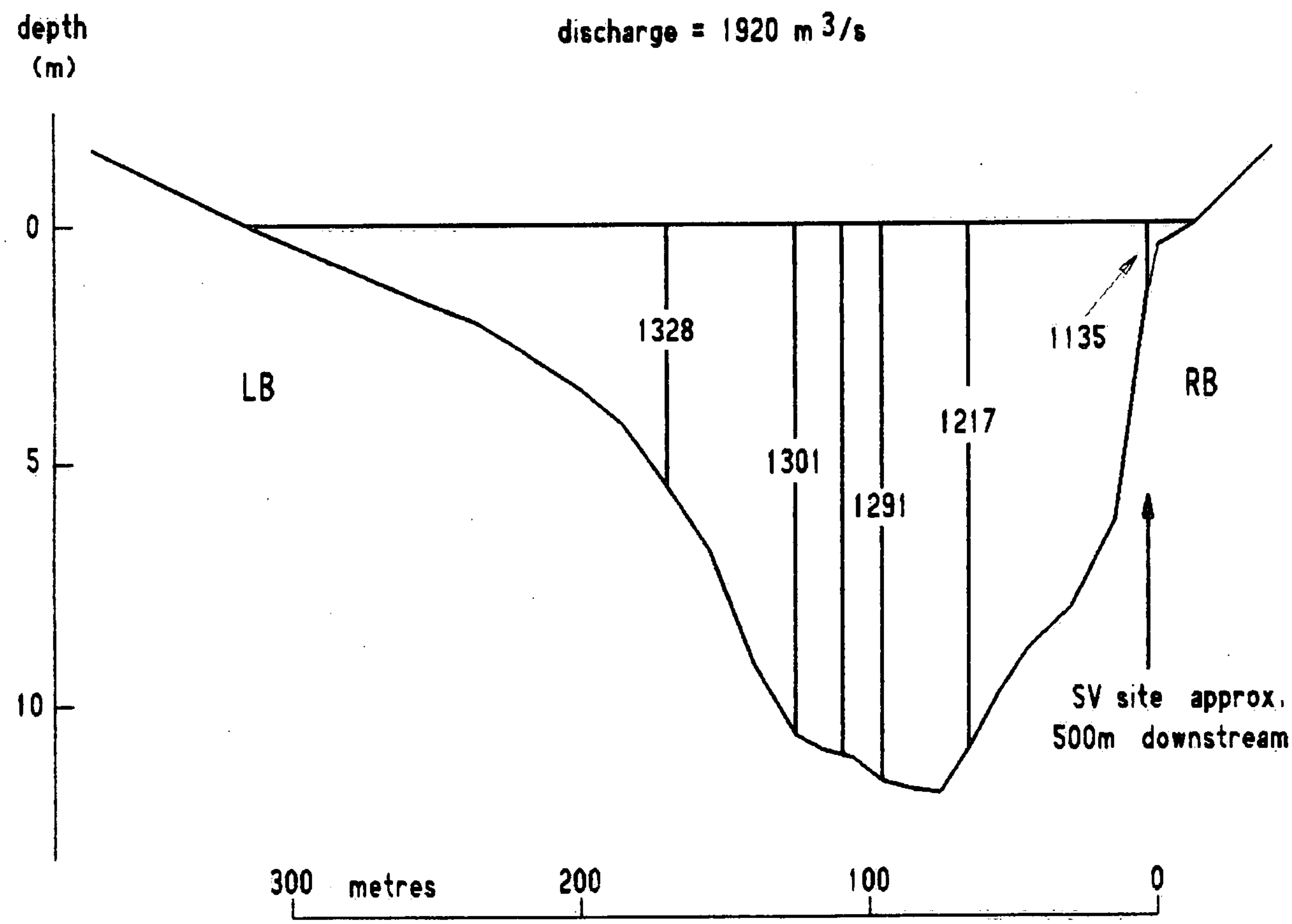


FIGURE 4.2

Peel River k-value data, 1988–1991





sediment concentration in mg/L
SV concentration = 1157 mg/L

FIGURE 4.3
PEEL RIVER AT NEW MEASUREMENT SECTION:
SEPTEMBER 9, 1988

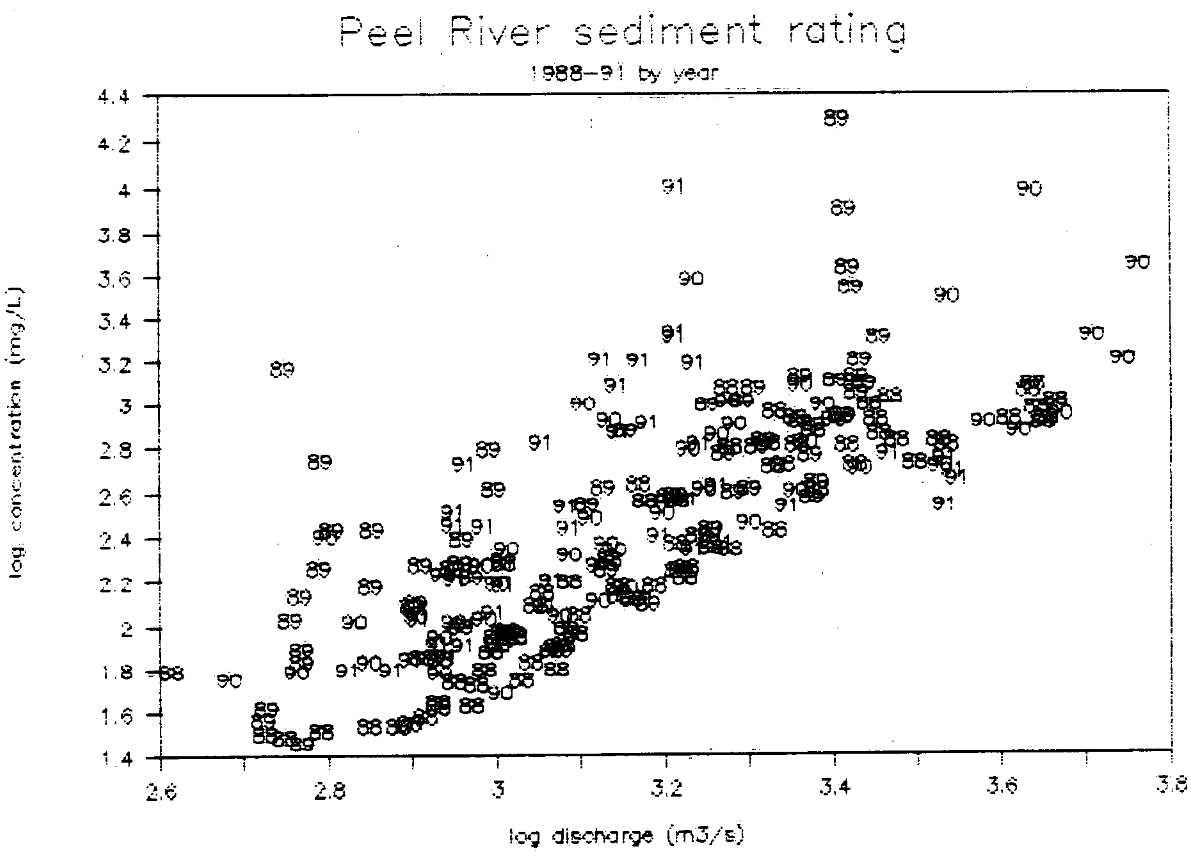
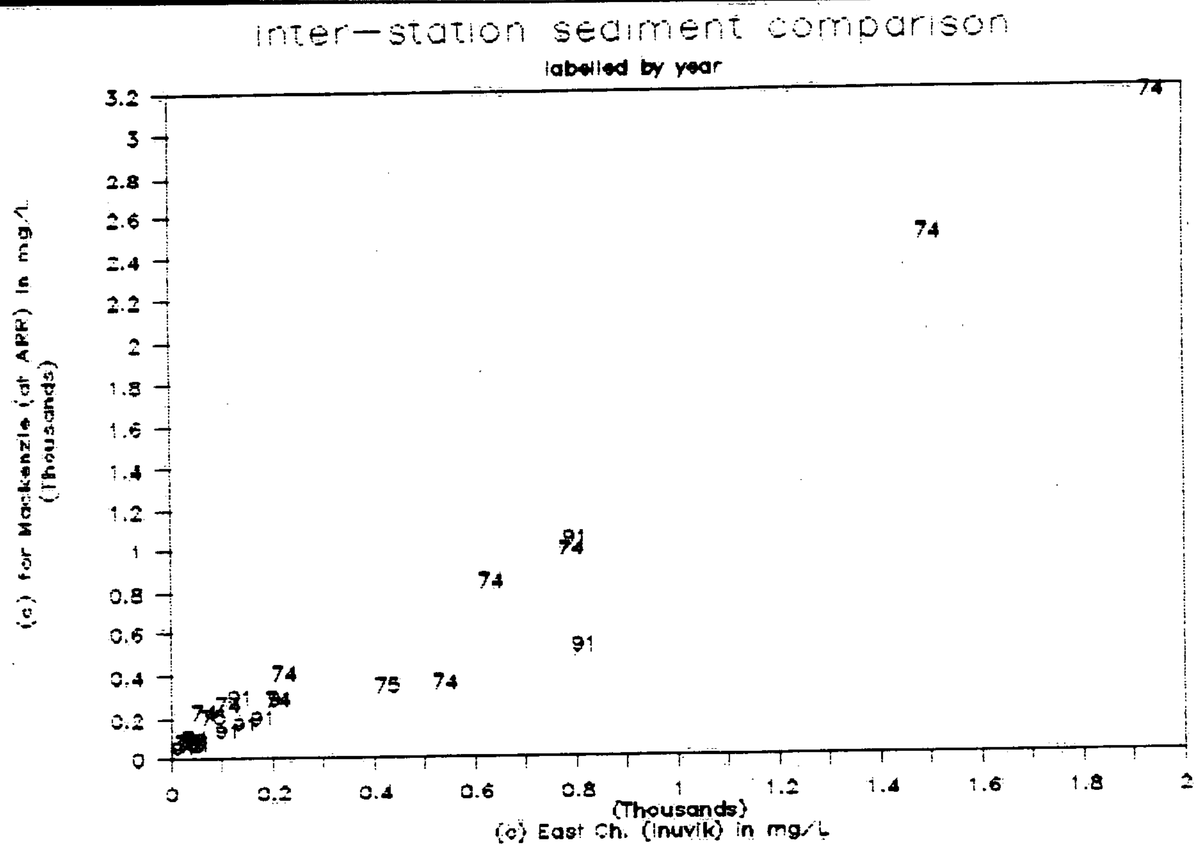


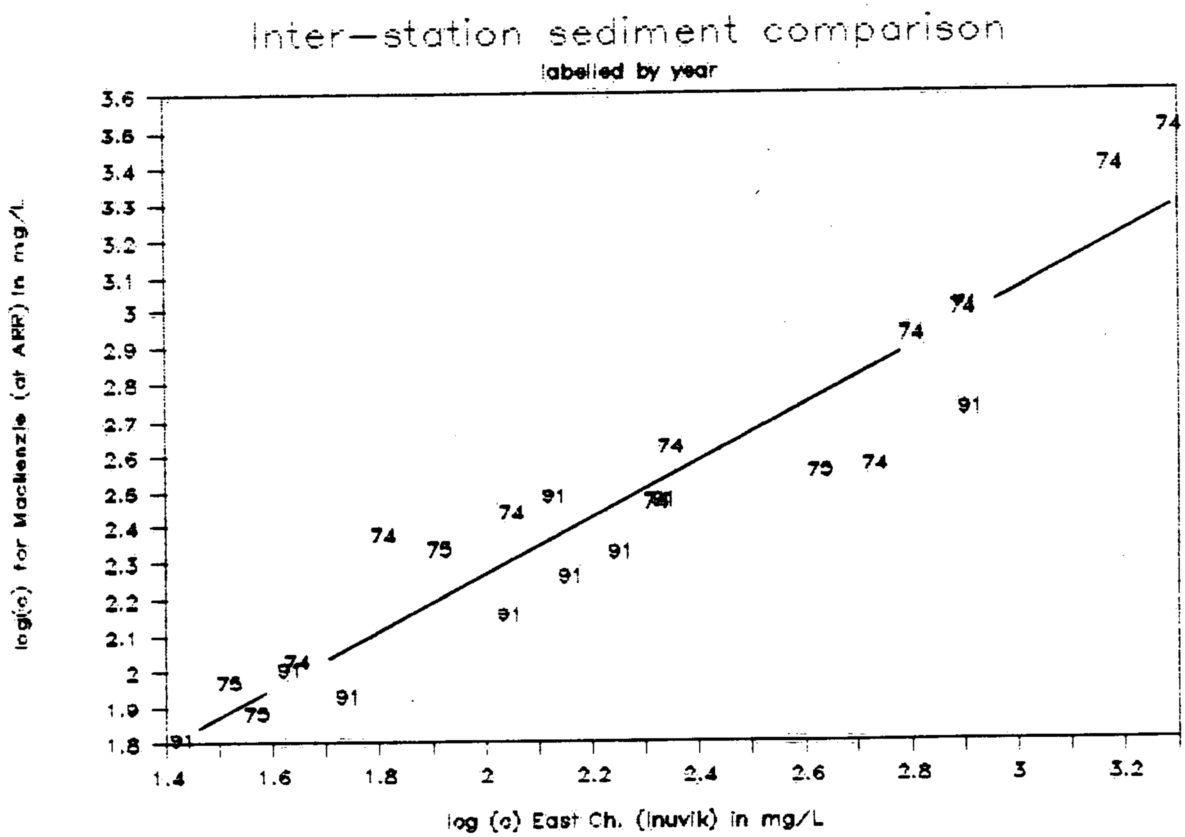
FIGURE 4.4

PEEL RIVER SEDIMENT RATING, 1988–1991



inter—station sediment comparison
labelled by year
(c) for Mackenzie (at ARR) in mg/L
(Thousands)
(Thousands)
(c) East Ch. (Inuvik) in mg/L

FIGURE 5.1



Inter—station sediment comparison
labelled by year
log(c) for Mackenzie (at ARR) in mg/L
log (c) East Ch. (Inuvik) in mg/L

SUSPENDED SEDIMENT DATA ANALYSIS FOR WESTBANK TRIBUTARIES OF THE MACKENZIE RIVER, NORTHWEST TERRITORIES

for

Inland Waters Directorate
Environment Canada
Yellowknife, NWT

by

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under contract
KE521-2-0265/01-XSG
Supply & Services Canada, Edmonton

February, 1993

Executive Summary

This report provides a review of sediment data collected by Inland Waters Directorate of Environment Canada on rivers draining to the Mackenzie River from the high country in the western part of the basin.

These rivers are the Flat River (tributary to the South Nahanni River and then to the Liard River), the Harris, Martin and Root rivers (between Fort Simpson and Camsell Bend), and, further south, the Redstone, Carcajou, Mountain and Ramparts rivers. The latter four stations are serviced by Water Resources Branch staff in Inuvik, while the first four are managed by WRB staff from Fort Simpson.

For each station, a sediment rating curve is developed to predict sediment concentrations from water discharge, usually daily mean values in both cases. This sediment rating is then applied to daily discharge data for the period of record at each station to estimate annual loads up to and including 1990. The full period of record analyzed here begins in 1974, but in the case of the newer Inuvik-based stations load estimates for early years have had to be made by comparison with data from the Root station.

The preliminary analysis, when extrapolated to the full suite of tributaries between Fort Simpson and Arctic Red River, indicates that about 70% of the 49 Mt increase in load of the Mackenzie River between these two mainstem stations originates from tributary sediment inputs. These initial conclusions are regarded as suspect because of both uncertainty in some of the sediment ratings (some of which are based on only 10 data points) and uncertainty in extrapolating sediment yields from these stations to unsampled parts of the Mackenzie Basin.

The sediment loads of the Redstone, Carcajou and Mountain rivers, in particular, are probably too low as estimates of inputs to the Mackenzie River because of their location up to 100 km upstream from the main stem. It is therefore recommended that the sampling sites on these three rivers be relocated close to their mouths.

The development of more reliable sediment ratings as more data are gathered in the years ahead, together with new data that are more representative of conditions at the mouths of these basins, should provide a much more realistic assessment of the spatial pattern of sediment production in the Mackenzie basin.

Acknowledgements

This report was prepared as part of a contract from Inland Waters Directorate, Yellowknife, Northwest Territories entitled "Mackenzie Delta Channel Stability Assessment / Mackenzie River Basin Sediment Station Analysis" with F.M. Conly as Scientific Authority. The contract was administered by Supply and Services Canada (Alberta/NWT region) under contract number KE521-2-0265/01-XSG. The assistance of Malcolm Conly and Jesse Jasper in the management of this contract is duly acknowledged.

The author is indebted to Paul Squires, Inland Waters Directorate, Yellowknife, and the staff of the Inuvik and Fort Simpson district offices, for provision of much of the data used in this report.

The review comments by Malcolm Conly and Henry Hudson (IWD, Winnipeg) on an earlier draft of the report are also gratefully acknowledged.

Section 2: Suspended Sediment Data Analysis for Westbank Tributaries of the Mackenzie River, Northwest Territories

1. INTRODUCTION

1.1 Purpose of report

An earlier analysis of 1974-1990 sediment loads for stations in the Mackenzie River basin (Carson, 1992) noted the absence of analytical sediment data for westbank tributaries of the mainstem Mackenzie River between the Liard and Arctic Red rivers (Fig. 1.1). Sampling has, however, been undertaken on many of these rivers, albeit on an intermittent and miscellaneous basis, and it is timely to undertake a review of the currently available data.

The stations involved, listed in order of downstream entry to the Mackenzie River, are:

10GC002	Harris River near the mouth	1972-76
10GC003	Martin River at Highway No. 1	1973-76
10GA001	Root River near the mouth	1987-
10HB005	Redstone River, 63 km above mouth	1987-
10KB001	Carcajou River below Imperial River	1987-
10KC001	Mountain River below Cambrian Creek	1987-
10KD004	Ramparts River near Fort Good Hope	1987-

The first two rivers drain small basins just downstream of Fort Simpson. These basins are part of the relatively subdued terrain of the interior plains upstream of Camsell Bend (Fig. 1.2). The remaining five rivers, in contrast, have their headwaters in the Mackenzie Mountains and drain much more precipitous terrain before entering the Mackenzie Valley lowlands.

The sediment station on the Flat River near the mouth (10EA003) is also included in the report. The Flat River is a tributary of the South Nahanni River which drains the corridor between the Selwyn and Mackenzie Mountains (Fig. 1.2) and is, in turn, a left-bank tributary of the Liard River. Miscellaneous data are available for the Flat River from 1978 to 1991.

In almost all cases only miscellaneous data are available. This means that estimation of annual sediment loads requires derivation of a sediment rating relationship to allow prediction of daily mean sediment concentration from daily mean discharge at the station.

Application of the sediment rating to the long-term hydrometric record at each station then permits hind casting of past sediment loads on a daily basis. Such longterm hind casting is needed in order to extrapolate the short term sediment record to a longer period that is more representative of average conditions. Short-term data are highly influenced by the presence (or absence) of high-magnitude floods which are generally responsible for most of the sediment movement in these basins. In the present case, the sediment record is extrapolated to the period 1974-1990. The purpose of standardizing the sediment load data to this period is to allow meaningful comparison with the sediment data analyzed previously on the mainstem stations (Carson, 1992).

The information derived in this analysis should prove useful in assessing the sources of sediment in the Mackenzie Basin, and, in particular, the contribution of westbank tributaries to the increment in load between Fort Simpson and Arctic Red River. These tributaries seem to supply a considerable quantity of sediment to the Mackenzie River, as would be expected from their steep gradients on the east flank of the Mackenzie Mountains.

The reasons for attempting to document sediment loads from these basins were outlined previously in a report dealing with sediment issues in the Mackenzie Basin (Carson, 1988, Chap. 5). Issues such as the impact of global warming on increased sediment production from the Mackenzie Basin, and the impact of hydrocarbon development in the basin on delivery of sediment-bound contaminants to the delta, require a proper understanding of present sources of sediment production in the basin if they are to be addressed adequately.

1.2 Nature of report

The following chapters deal separately with the above stations with the goal of producing annual sediment load data for each year for the 1974-90 period. However, in some cases, there are gaps in the discharge record, and in others the hydrometric program was begun only in the mid-1980s.

The final chapter attempts to interpolate data for missing years by comparisons between stations. In addition, by expressing data in the form of specific sediment yield (tonnes per sq.km. per year), some generalization for unsampled westbank tributary basins is also attempted.

The report does not provide full sediment station analysis for these stations. Only brief description of basin conditions is given. The Terrain Sciences Division of Geological Survey of Canada has apparently undertaken mapping of surficial deposits in some of these basins in recent years (Dallimore, 1992, pers. comm.). This work will be useful in the assessment of sediment sources at a later date.

2. FLAT RIVER NEAR THE MOUTH

The location of the Flat River station is shown in Fig. 2.1, just upstream of its confluence with the South Nahanni River, about 90km upstream of the Liard River at Nahanni Butte.

2.1 Description of basin and sampling reach

Topographic and hydrologic data for the Flat and South Nahanni basins upstream of their confluence were summarized by Thakur and Lindeijer (1973). The basin area of the Flat River is 8614 sq. km. (compared to 14641 sq. km. for S. Nahanni above Virginia Falls). The mean elevation of the Flat basin is also substantially lower at 810m compared to 1570m for the South Nahanni. Forest covers 70% of the Flat basin, but only 31% of the higher South Nahanni basin. Lakes and swamps constitute a minimal portion of the landscape in both basins.

A map of the sampling reach is given in Fig. 2.2. No information is at hand on bed conditions, but rock outcrops are common in the lower valley sides. Channel width usually ranges from 100m to 120m in the open water season, and during snowmelt mean velocities can exceed 2 metres per second.

The sampling section is located in a straight reach about 2 km downstream of a sharp incised meander bend, by which time most of the bend induced variability in sediment concentration is likely to have been eliminated.

The single vertical (SV) sampling site is about 3m from the left water's edge. Sampling is done with a depth integrating DH48 sampled by wading into the channel. No data have been found for multiple-vertical (MV) samples which would provide information on the representativeness of the SV site.

2.2 Sediment rating relationship

The sediment data collected on the Flat River are given in Table 2.1 along with the associated discharge data. The sediment rating diagrams are given in Figure 2.3. Some of the scatter is presumably due to the fact that concentrations are instantaneous values while discharge data are daily mean values. No instantaneous discharge values have been found for times of sediment sampling.

One anomalous point exists on the diagrams (1984 April 12) and has not been used in the analysis. The resultant best fit regression (ordinary least squares: OLS) is:

$$\log c = -2.597 + 1.981 \log Q \qquad (2.1)$$

with a percentage prediction (coefficient of determination) of 78% and a standard error of estimate (SEE) of 0.27 log units, based on 62 data points. This level of precision is quite satisfactory for the purposes of predicting mean annual load. No monthly loads have been computed by IWD at this station to allow an independent assessment of precision.

In order to avoid detransformation bias on converting Eqn 2.1 to non-logarithmic values, the conventional adjustment factor (Ferguson, 1986) of exp (2.65*SEE*SEE) was used to increase all predictions of concentration. The resultant sediment rating is:

$$c = 3.085 \times 10^{-3} \times Q^{1.981} \qquad (2.2)$$

This is the equation used to predict daily concentrations and (when multiplied by [m3/s]*0.-0864) to produce daily sediment load in tonnes.

2.3 Sediment loads

The mean monthly and annual loads for the period 1974-1990 are given in Table 2.2.

The mean annual load for the period is computed as 505 thousand tonnes (kt). The largest predicted annual load in the period is 1988 with more than twice the mean for the period, almost all of this occurring in June and July.

The mean annual specific sediment yield for the basin is 59 t/sq.km./yr based on a basin area of 8560 sq. km. This yield is substantially less than the mean yield for the Liard basin at its mouth for the same period (170 t/sq.km./yr) and confirms the view put forward in the Year I report (Carson, 1992) that most of the sediment in that basin is derived from lowland areas rather than the upland zones.

3. HARRIS RIVER NEAR THE MOUTH

3.1 Description of basin and sampling reach

The Harris River station is located near the mouth of a small leftbank tributary to the Mackenzie River a few kilometres downstream of Fort Simpson. No data for the basin are reported by Thakur and Lindeijer (1973). The basin area is reported by IWD (1989) as 701 sq.km.

No information appears to exist on bed conditions and no map of the sampling reach has been found. No MV samples appear to have been taken to assess the representativeness of the SV site.

3.2 Sediment rating relationship

The sediment data collected on the Harris River are given in Table 3.1 along with the associated discharge data. The sediment rating diagrams are given in Figure 3.1.

The resultant best fit regression is:

$$\log c = 0.887 + 0.364 \log Q \qquad (3.1)$$

with a percentage prediction (coefficient of determination) of only 31% and a standard error of estimate (SEE) of 0.41 log units, based on 102 data points.

This level of precision is barely satisfactory for the purposes of predicting mean annual load, though much of the scatter is at relatively low flows which should not result in too much error. Such scatter at low flows is not uncommon in small streams. The important point is not to let the scatter exert an undue influence on the rating as it fits the data for larger flows. There is some indication that the rating for Harris River may underestimate concentration at very high flows, but the rating is accepted for the present purposes. The predicted 1974 load of 1094 tonnes compares favourably with that computed by IWD (1100 tonnes) for that year. No other annual loads have been computed by IWD for the 1974-90 period.

In order to avoid detransformation bias on converting Eqn 2.1 to non-logarithmic values, the conventional adjustment factor (Ferguson, 1986) of exp (2.65*SEE*SEE) was again used to increase all predictions of concentration.

The resultant sediment rating is:

$$c = 11.944 \times Q^{0.364} \qquad (3.2)$$

This is the equation used to predict daily concentrations and (when multiplied by [m3/s]*0.0864) to produce daily sediment load in tonnes.

3.3 Sediment loads

The mean monthly and annual loads for the period 1974-1990 are given in Table 3.2.
The mean annual load for the period is computed as 1356 tonnes. Unlike at the Flat River station, the largest predicted annual load in the period is not 1988, though this is the second largest. The highest predicted load was for 1982 based on high flows in May of that year.

The mean annual specific sediment yield for the basin is only 2 t/sq.km./yr based on a basin area of 701 sq. km. This yield is slightly higher than that given for the early 1970s in the Year I report.

4. MARTIN RIVER AT HIGHWAY NO. 1

4.1 Description of basin and sampling reach

The Martin River station is located near the mouth of a leftbank tributary to the Mackenzie River, about 20 km downstream of Fort Simpson. No data for the basin are reported by Thakur and Lindeijer (1973). The lower part of the river cuts through glaciolacustrine sediments. The basin area is reported by IWD (1989) as 2050 sq.km.

No map of the sampling reach has been found. No MV samples appear to have been taken to assess the representativeness of the SV site. No bed material data have been found.

4.2 Sediment rating relationship

The sediment data collected on the Martin River are given in Table 4.1 along with the associated discharge data. The sediment rating diagrams are given in Figure 4.1.

The resultant best fit regression is:

$$\log c = -0.806 + 0.652 \log Q \qquad (4.1)$$

with a percentage prediction (coefficient of determination) of only 52% and a standard error of estimate (SEE) of 0.31 log units, based on 107 data points. This level of precision is, again, barely satisfactory for the purposes of predicting mean annual load.

The greater concern, however, is the obvious poor fit at higher flows (Fig. 4.1: dashed line). This is produced by strong positive residuals at lower flows which induce a gentler slope to the least-squares line. To reduce this problem, the regression was redone for only those data points with discharge greater than 2.5 m3/s (logQ=0.4). This discharge appears to correspond to a "kink" in the sediment rating diagram. The new ordinary least squares regression, based on 90 data points, is:

$$\log c = 0.470 + 0.918 \log Q \qquad (4.2)$$

and, as seen in Fig. 4.1 (solid line), provides a better fit at higher discharges. The percentage prediction is 65% and the SEE is 0.265 log units.

In order to avoid detransformation bias on converting Eqn 2.1 to non-logarithmic values, the conventional adjustment factor was again used to increase all predictions of concentration. The resultant sediment rating is:

$$c = 3.541 \times Q^{.918} \qquad (4.3)$$

This is the equation used to predict daily concentrations and (when multiplied by [m3/s]*0.0864) to produce daily sediment load in tonnes.

The predicted load for 1974 for the May to September period (18kt) compares favourably with that computed by IWD (21 kt) for that year. The predicted load for June to September 1976 of 6.0 kt is higher than IWD's computation (3.7 kt) for the same period. No other seasonal or annual loads have been computed by IWD for the 1974-90 period.

4.3 Sediment loads

The mean monthly and annual loads for the period 1974-1990 are given in Table 4.2.

The mean annual load for the period is computed as 46 thousand tonnes (kt). The largest predicted annual load in the period is 1988 at more than 8x the mean for the period, almost all of this occurring in July of that year. This one month, in fact, accounts for 45% of the total predicted load for the period 1974-1990, with an estimated 355 kt, of which 304 kt is predicted to have occurred in the three days of extreme flood on July 2 to July 4. The peak daily concentration in that flood was not excessive, however, being predicted at 1820 mg/L. As a result of this single flood, July ranks first in mean monthly sediment load for 1974-90, higher than May, and markedly higher than June. The longterm representativeness of this pattern must be viewed as uncertain.

The mean annual specific sediment yield for the basin is 23 t/sq.km./yr based on a basin area of 2050 sq. km. This yield, while about 3x higher than computed for the early 1970s, and an order of magnitude higher than the Harris basin, is still substantially less than the mean yield for the Liard basin at its mouth for the same period (170 t/sq.km./yr). This, along with the yield for the Flat River station, is consistent with the general pattern of increasing yields with increasing basin area noted in the Year I report.

5. ROOT RIVER NEAR THE MOUTH

The Root River drains a 9933 sq.km. basin on the west bank of the Mackenzie River entering the main stem just downstream of Camsell Bend (Fig. 1.1, 1.2). In size it is comparable with the ungauged North Nahanni River basin which joins the Mackenzie on the same bank, just upstream of Camsell Bend (Fig. 1.1).

5.1 Description of basin and sampling reach

Thakur and Lindeijer (1973) give the mean elevation of the basin to be 844m, and indicate 63% of the area to be forest-covered. Lakes and swamps constitute an insignificant (1%) fraction of the basin area. The GSC surficial geology map (Mackenzie Valley Transportation Corridor: southern part) shows that the valley is incised through a veneer of rolling ground moraine composed of till, though there is a large fluvioglacial deposit at the confluence with the Mackenzie River.

The locations of the gauge and sampling section are shown in Fig. 5.1 in a straight reach about 3 km downstream of a sharp right hand bend and about 12 km upstream of the confluence with the Mackenzie River.

The largest daily flow on record (1975-90) is 5730 m3/s (in 1988). Channel width at the measurement section ranges from more than 150m at high flows (> 1000 m3/s) to less than 100m at flows less than 100 m3/s.

No information has been found regarding bed material. No data have been found for MV sampling.

5.2 Sediment rating relationship

The sediment data for Root River are given in Table 5.1. The sediment rating for the station is shown in Fig. 5.2 based on 33 data points. The relationship seems reasonably good with a percentage prediction of log(c) by log (Q) of 78% and a standard error of estimate of only 0.30 log units. The OLS regression is

$$\log (c) = -2.460 + 2.075 \log (Q)$$

which after adjustment with the bias correction factor (1.27) transforms to

$$c = 4.394 \times 10^{-3} \times Q^{2.0754}$$

It should be noted, however, that the maximum discharge sampled was only 673 m3/s (1988), whereas maximum daily discharge was greater than 1000 m3/s in seven years in the period 1974 to 1990, and reached 5730 m3/s in 1988. It is unfortunate that the only sampling done in the major storm of that year was one occasion on the falling limb of the hydrograph.

5.3 Sediment loads

The lack of sampling at very high flows appears to have produced a bias in the sediment rating equation, with a slope that is probably too steep. Application of the rating to the period of hydrometric records produced unrealistically high sediment concentrations at such flows, with peak concentrations of more than 30,000 mg/L in both 1982 and 1986, and more than 275,000 mg/L in 1988 at the peak flow of 5730 m3/s. This is a substantial contrast with the actual concentration of 1668 mg/L measured at an instantaneous flow of 673 m3/s four days after the peak. The predicted peak day figure corresponds to a one-day sediment load of 137 Mt, which is only slightly less than the 1988 load of the Mackenzie River at Arctic Red River.

In an attempt to produce more realistic estimates at these very high flows, the arbitrary decision was made to impose a maximum value on predicted concentrations at 15,000 mg/L. This should be regarded as an interim measure until the sediment rating becomes better defined at very high flows.

The predicted loads for 1975-1990 are given in Table 10.1, together with an estimate for 1974. The derivation of the 1974 load is described in Chapter 10.

The mean annual load for 1974-1990 is 4.3 million tonnes (Mt), the record being dominated by 1982 (14.4 Mt) and 1988 (18.2 Mt). The mean annual load is equivalent to a specific sediment yield of 441 t/sq.km. per year, based on an area of 9820 sq.km. This is the highest specific sediment yield determined in the Mackenzie Basin, those for the Arctic Red and Peel rivers for the same period being slightly greater than 300 t/sq.km/yr (Carson, 1992, Table 4.10).

6. REDSTONE RIVER 63 KM ABOVE THE MOUTH

The Redstone River catchment, at its confluence with the Mackenzie River, is much larger than the Root River basin, with an area of 16,400 sq. km (IWD, 1989), though Thakur and Lindeijer (1973) use 15,747 sq.km. The length of the main channel is given by Thakur and Lindeijer (1973) as about 315 km. The gauging station 63 km above the mouth is reported as having a basin area of 15,400 sq. km (IWD, 1989), only slightly less than the full basin area.

Information on sediment delivery from the Redstone basin should also be relevant in the context of the ungauged Keele River basin which flanks the west bank of the Mackenzie downstream of the Redstone River.

6.1 Description of basin and sampling reach

The mean elevation of the full basin is given by Thakur and Lindeijer (1973) as 1296m (substantially higher than the Root basin) with only 48% of the basin being forest-covered. Though there is little difference in basin maximum elevation compared with the Root, a much larger proportion of the Redstone basin extends into the Mackenzie Mountains. As in the previous basins, land occupied by swamp and lakes forms a minimal portion (1%) of the basin. Though no detailed reports of the surficial geology have been seen, it seems likely that sediment sources are more numerous downstream of the station than upstream, based on the glacial history of the area.

No detailed map of the site has been found. The sediment station description is given in Fig. 6.1

The lower Redstone River is a sinuous wandering-to-braided coarse-grained channel which appears to deliver huge quantities of sand and gravel to the Mackenzie. The sediment station is located upstream of this reach and where the channel, though sinuous, is narrower and largely single-thread. The gauge is located about 1 km downstream of a sharp right hand bend. Shifting bed forms affect the stage-discharge rating. The maximum daily flow on record (1980-88) of 3390 m3/s occurred in 1988.

The measurement section is about 500m downstream of the gauge. The SV sampling site is indicated as being 150m above the gauge: sampling is done with a DH48 sampler wading in from the left bank into about one metre of flow. No MV data have been found: collection of such data in high flows would be difficult in such a steep river.

6.2 Sediment rating relationship

The limited sediment database for the Redstone River is given in Table 6.1. The rating diagram for the station is shown in Fig. 6.2 based on only 9 data points. The relationship is not as strong as that for the Root River with a percentage prediction of log(c) by log (Q) of 59% and a standard error of estimate of 0.40 log units. The OLS regression is:

$$\log(c) = -2.538 + 1.953 \log(Q)$$

which after adjustment with the bias correction factor (1.53) transforms to:

$$c = 4.432 \times 10^{-3} \times Q^{1.953}$$

which is not radically different from that for the Root River.

There is a similar problem with lack of data points at very high flows, although not to the same degree as at the Root River station. The maximum discharge sampled so far is only 808 m3/s (1989), whereas maximum daily discharge in the 1980-90 period was 3390 m3/s in 1988.

6.3 Sediment loads

The lack of sampling at very high flows may have produced a similar bias in the sediment rating equation, with a slope that is too steep. Application of the rating to the period of hydrometric records produced very high sediment concentrations at such flows, but lower than at the Root River station. Peak predicted daily sediment concentration exceeded 10,000 mg/L in only three years, the highest being 35,000 mg/L at the height of the 1988 flood. (These high predicted concentrations are partly the result of the 53% increase associated with the detransformation bias correction.) As in the case of the Root River, a maximum allowable value of 15,000 mg/L was imposed upon the sediment rating predictions.

The predicted loads for 1980-1990 are given in Table 10.2, together with estimates for 1974-79. The derivation of the 1974-79 loads is described in Chapter 10.

The mean annual load for 1974-1990 is 5.0 Mt, the record being dominated by 1982 (11.3 Mt) and 1988 (11.2 Mt), as in the case of the Root River. The mean annual load is equivalent to a specific sediment yield of 327 t/sq.km. per year, based on an area of 15,400 sq.km. This is less than that determined for the Root River, but still greater than computed for the Peel and Arctic Red rivers.

7. CARCAJOU RIVER BELOW IMPERIAL RIVER

The Carcajou River basin has a drainage area of about 9135 sq. km. at its confluence with Mackenzie River, and the main channel has a length of about 320km (Thakur and Lindeijer, 1973). The station "below Imperial River" is located roughly 75 km upstream of the mouth, at which site the drainage area is given as 7400 sq. km. (IWD, 1989)

7.1 Description of basin and sampling reach

The character of much of the Carcajou basin upstream of the station is not appreciably different from that of the Root and Redstone basins. Mean elevation for the full basin is only slightly less than in the Root basin at 778m. The river itself is quite different, however, with a down-channel steepness that is an order of magnitude less (based on data from Thakur and Lindeijer, 1973).

The locations of the gauge and measurement section are shown in the station description (Fig. 7.1). The measurement section is a short distance downstream from a sharp right hand bend. The stream bed is indicated as being sand and gravel.

The maximum daily flow on record (1978-90) is 1930 m3/s (in 1990). At flows of about 650 m3/s, channel width is about 125m, and mean velocity is about 2 m/s.

The collection of SV samples is done on the measurement section, with a DH-48 sampler, wading in from the right bank to a depth of about one metre. No MV samples appear to have been taken at this station.

7.2 Sediment rating relationship

The limited sediment database for the Carcajou River is given in Table 7.1 The sediment rating for the station is shown in Fig. 7.2 based on only 12 data points. The relationship is very strong, however, with a percentage prediction of log(c) by log (Q) of 87%, though the standard error of estimate of 0.31 log units is no better than that of the Root River. The high percentage prediction, relative to the mediocre SEE, seems to reflect the wide distribution of points throughout the full diagram, in contrast to the Root station for which most of the data points clustered about medium-level values. The OLS regression is:

$$\log (c) = -1.643 + 1.791 \log (Q)$$

with a slope that is somewhat gentler than for the two previous stations. After adjustment with the bias correction factor (1.29) this transforms to:

$$c = 0.0293 \times Q^{1.791}$$

The problem with lack of data points at very high flows, found at the two previous stations, is not as evident here. The maximum discharge sampled was 1530 m3/s (1990), which exceeds the maximum daily discharge in all years in the 1978-90 period except for 1990 in which the peak was 1930 m3/s.

7.3 Sediment loads

Application of the rating to the period of hydrometric records produced reasonable sediment concentrations at very high flows, with levels of near to 10,000 mg/L at peak flows in 1982, 1983, 1984, 1988 and 1990.

The predicted loads for 1978-1990 are given in Table 10.2, together with estimates for 1974-77. The derivation of the 1974-77 loads is described in Chapter 10.

The mean annual load for 1974-1990 is 2.1 Mt, the peak year being 1990 (6.8 Mt). Significantly, the load in 1988, an extreme year on the Root and Redstone rivers, was slightly less than average on the Carcajou River. The mean annual load is equivalent to a specific sediment yield of 282 t/sq.km. per year, based on an area of 7,400 sq.km. This is less than that determined for the Redstone, but still only slightly less than computed for the Peel and Arctic Red rivers.

8. MOUNTAIN RIVER BELOW CAMBRIAN CREEK

The Mountain River basin, where it meets the Mackenzie River, has an area of 14980 sq.km. and a length of about 335 km.(Thakur and Lindiejer, 1973). Station 10KC001 "below Cambrian Creek" is located well upstream from the confluence (about 90 km) with a drainage area given by IWD (1989) as 11,100 sq.km. Thus the station represents about 75% of the full basin area and the full river length.

8.1 Description of basin and sampling reach

The full basin is reported as having a mean elevation of 1372m, comparable with that of the Redstone basin, but the forest cover is much less at only 27 percent.

The location of the station is at the edge of the Carcajou Range of the Mackenzie Mountains where it fronts the more subdued terrain of the Mackenzie Valley trough. The site is shown on Fig. 8.1 in relation to a map of late glacial deposits and drainage. Much of the lower basin, downstream of the station, is part of an old preglacial lake bed into which the present Mountain River has incised.

The locations of the gauge and measurement section are given in the station description of Fig. 8.2. The site occurs in a narrow rock canyon, upstream of rapids and just prior to a major change in the morphology of Mountain River into a broad, braided channel where it debouches onto the lowland plain. The stage record is reported as being affected by shifting control associated with buildup of gravel bars.

The peak daily flow on record (1978-90) is given as 1320 m3/s (in 1982 and 1990).

The collection of SV samples is done, using a DH-48 sampler, on the measurement section, wading in from the left bank to a depth of about one metre. No MV sampling data have been found.

8.2 Sediment rating relationship

The few sediment data for Mountain River so far available are given in Table 8.1. The sediment rating diagram for the station is shown in Fig. 8.2 based on only 5 data points. This is clearly not enough for predictions to be made with confidence. The relationship is again very strong, with a percentage prediction of log(c) by log (Q) of 98% and a standard error of estimate of only 0.14 log units. The OLS regression is

$$\log (c) = -5.757 + 3.113 \log (Q)$$

with a slope that is much greater than at the previous stations. After adjustment with the bias correction factor (1.05) this transforms to

$$c = 1.845 \times 10^{-6} \times Q^{3.113}$$

As at some of the other stations, the scatter diagram is presently deficient at very high flows, with only one point at discharges greater than 400 m3/s. In contrast, peak daily flow exceeded 1000 m3/s in four of the years during 1978-90, with a peak of 1320 m3/s in both 1982 and 1990. Considerable uncertainty therefore exists regarding the extrapolation of rating to very high flows. Peak predicted concentrations were not unreasonable, however, being just less than 10,000 mg/L.

8.3 Sediment loads

The predicted loads for 1978-1990 are given in Table 10.2, together with estimates for 1974-77. The derivation of the 1974-77 loads is described in Chapter 10.

The mean annual load for 1974-1990 is 1.3 Mt, the peak years being 1986 (3.3 Mt) and 1990 (3.1 Mt). As in the case of the Carcajou River, the load in 1988, an extreme year on the Root and Redstone rivers, was less than average on the Mountain River. The mean annual load is equivalent to a specific sediment yield of 115 t/sq.km. per year, based on an area of 11,100 sq.km. This is the lowest value deter mined for the west bank stations downstream of Camsell Bend, and only 26% of that determined for the Root River.

It seems probable that this value reflects the location of the station, being sited upstream of the main infill of glacial and related drift in the lower basin.

9. RAMPARTS RIVER NEAR FORT GOOD HOPE

The station on the Ramparts River is located 18km upstream of its confluence with Mackenzie River. The basin area at the station is given by IWD (1989) as 7410 sq.km.

9.1 Description of basin and sampling reach

The Ramparts River at its confluence with Mackenzie River was not included in the morphometric database of Thakur and Lindeijer (1973). However, the Hydrology Information Series Map for Fort Good Hope cites a later database (Thakur and Lindeijer, 1974) in which the drainage area is given as 7530 sq.km and the channel length as 418 km.

As shown in Fig. 8.1, however, the basin is located at the northern end of the Mackenzie Mountains, and much more of the basin corresponds to Mackenzie Valley lowlands than in the case of upstream west bank tributaries of Mackenzie River.

Much more of the length of the Ramparts River (than in the case of Mountain River) flows on the late-glacial lacustrine sediments that are found in the Mackenzie lowlands upstream of Fort Good Hope. However, downcutting into this deposit appears to be restricted to the lower part of the river. As noted in the text accompanying the Hydrology Information Series Map for Fort Good Hope, the Ramparts River is radically different from the west bank tributaries draining the main part of the Mackenzie Mountains. In the lower 180 km it is a sand-bed river, with an extremely tortuous meander pattern in a large muskeg area on the plain corresponding to the lacustrine deposits. In the lower 39 km, the river appears to be incising into these deposits and flows over a much less sinous course.

The site of the station is shown in Fig. 9.1. It is located in the incised, generally straight, lower reach of the river, just upstream of the 180° change in direction to the northeast.

The peak daily flow on record (1985-90) was 660 m3/s (1987).

The collection of SV samples is undertaken on the measurement section with a DH-48 sampler, wading into the river from the right bank to a depth of about one metre. Again, no MV sampling data have been found.

9.2 Sediment rating relationship

The small sediment database is given in Table 9.1. The sediment rating diagram for the station is shown in Fig. 9.2 based on only 10 data points. The relationship is rather weak, with a percentage prediction of log(c) by log (Q) of 68%, but more importantly with a standard error of estimate of 0.51 log units. The OLS regression is

$$\log(c) = -1.805 + 2.034 \log(Q)$$

with a slope that is comparable with the Root and Redstone rivers. The high SEE error produces a large bias correction factor (1.99). The final detransformed equation is

$$c = 0.0312 \times Q^{2.034}$$

As at some of the other stations, the present scatter diagram is not well represented at very high flows, with only one point at discharges greater than 250 m3/s. This compares with peak daily discharge values of 309 m3/s to 660 m3/s for the 1985-90 period, the shortest hydrometric period of all the west bank tributary stations.

Predicted peak sediment concentrations seemed reasonable at this site ranging from 3620 mg/L in 1989 to 16950 mg/L in 1987, but must still be regarded as uncertain given the limited database presently available.

9.3 Sediment loads

The predicted loads for 1985-1990 are given in Table 10.2, together with estimates for 1974-84. The derivation of the 1974-84 loads is described in Chapter 10.

The mean annual load for 1974-1990 is 2.7 Mt, the peak year being 1990 (9.2 Mt), as in the case of the Carcajou River. As in that case also, the load in 1988, a record year on the Root and Redstone rivers, was less than average on the Ramparts River. The mean annual load is equivalent to a specific sediment yield of 365 t/sq.km. per year, based on an area of 7410 sq.km. This is, somewhat surprisingly, comparable with the value for the Redstone River.

10. SYNTHESIS OF SEDIMENT DATA

10.1 Estimation of loads in years with missing hydrometric data

Only three of the eight stations examined above have complete discharge data (and hence predicted sediment loads) for 1974-1990, though Root River is missing only 1974 data. At all three stations, the 1974 load accounted for only about 5% of the 1974-1990 load, and this percentage was used to estimate the 1974 load for Root River.

The Carcajou and Mountain rivers have complete hydrometric records from 1978 on, the Redstone River (at km 63) from 1980 on, while the Ramparts River has discharge data beginning in 1985. This poses definite problems in extrapolation of data because, as already noted, years of high sediment load in the Camsell Bend area basins do not always coincide with those further south. In particular, the 1988 load was an extreme occurrence in the Root River basin, but not in the basins further south. Notwithstanding this problem, the only approach available for extrapolating the loads of the Redstone, Carcajou and Mountain rivers to 1974-77 seems to be by comparison with the Root basin. Table 10.1 displays the annual loads of the northern tributaries as a percentage of the 1980-90 mean load. The percentage figure for the Root (e.g. 71% in 1974) was then used to estimate the 1974-77 loads of these three rivers (and 1978-79 for the Redstone) based on their 1980-90 means.

In the case of the Ramparts River, the 1974-84 loads were estimated in a similar way, using the Mountain River as a reference station (Table 10.2). However, since the Mountain loads for 1974-77 are based on the Root station as a reference, the same holds true for the Ramparts River.

The comparison between the Mountain River and the Ramparts River seems reasonably valid, given their geographic proximity: both basins should be affected by the same storms. The use of the Root River station for the 1974-77 extrapolations is not as justifiable, but these 18 station-years of extrapolated data represent a relatively small portion (20%) of the total database for the west bank rivers of the Root, Redstone, Carcajou, Mountain and Ramparts

The final summary of estimated loads and specific sediment yields for these five basins for 1974-90, using these estimations for ungauged years, is given in Table 10.2.

10.2 Estimation of loads in unsampled basins

One approach to estimation of loads in unsampled basins is through application of representative specific sediment yields determined at the gauged stations.

The problem with this approach is that specific yield varies appreciably among the sampled basins, as previously noted. In addition, some of the basins were sampled well above the mouth, and specific yield at the mouth is likely to be higher for reasons discussed previously. The estimates of specific yields for all basins at their confluence with the Mackenzie River, listed in Table 10.3, were made on the basis of comparison with the values derived from Table 10.2 for those basins actually sampled and already noted.

The full suite of basins considered in Table 10.3 has a combined basin area of only about 140,000 sq.km. out of the 390,000 sq.km. of extra Mackenzie basin between Fort Simpson and the 10LC014 sediment station above Arctic Red River. It is believed, however, that the list covers all major tributary sources of sediment. A large part of the 150,000 sq.km. not included is the Great Bear River catchment which has an area of 145,000 sq.km. at the outlet of the lake (IWD, 1989).

The sum of the predicted loads from the basins of Table 10.3 is 33.3 Mt (million tonnes). This compares with the increment in measured load for the same period between the Liard station near its mouth (47.2 Mt) and Mackenzie at Arctic Red River (97.8 Mt) of 50.6 Mt. Only a few megatons of this increment is from the upper Mackenzie River upstream of the Liard River (Carson, 1992, p.38). The main component (about 49 Mt) is the result of bank erosion along the mainstem Mackenzie River between Fort Simpson and Arctic Red River and inputs by tributaries, almost entirely on the west side. The difference between this 49 Mt figure and the 34 Mt estimated for the tributaries is therefore a measure of mainstem erosion plus errors in the estimation of the westbank loads.

An alternative approach was attempted previously (Carson, 1988), in the absence of these data, by comparison of a stream power index for these stations (using the product of maximum elevation*basin area*stream slope, with values for these three variables taken from the Thakur-Lindeijer database) with the index value for Arctic Red River. The Arctic Red River load (for 1974-83) was then scaled up or down according to the ratio of the stream power index in each case. The results of that approach are given as estimate (1) in Table 10.3. These estimates are probably too low for the period 1974-90, the loads for the Mackenzie River above Arctic Red River being estimated at 98 Mt for 1974-90 compared to 89 Mt for 1974-83. Thus the total load of 40.8 Mt should be increased by 10% to 45 Mt (Table 10.3 estimate (2)).

Ironically, the crude statistical method used in the 1988 report accounts for about 92% of the 49 Mt of Mackenzie load downstream of Fort Simpson, while the rating analysis undertaken in this report accounts for only 70 percent. This does not mean, however, that the 1988 estimates are necessarily more reliable, because the amount acquired by the Mackenzie mainstem itself may well be more than the 8% implied by the 1988 method.

It does seem highly likely, however, that the sediment yields derived in Table 10.2 and used in the derivation of loads in Table 10.3, are, in some cases, too low. It seems significant, for instance, that the yields in Table 10.2 decrease as the station location shifts further from the Mackenzie confluence upstream into the basin. The largest yield is that of the Root for which the station is located almost at the river mouth. The smallest yield is that of the Mountain River, where the station is located even further upstream than Redstone River at 63 km above the mouth.

There are two points here. One is that sediment yields in Canada usually increase downstream because most of the suspended sediment originates through bank erosion processes, and this becomes more important in the lower parts of basins where stream discharge is greater, and streams are often incised into the floors of their valleys. The second point is that, in the Mackenzie Basin, easily erodible deposits laid down in Pleistocene and early Holocene times are located primarily in the lower parts of the west-bank basins.

With the exception of the Root River, the yields of the sampled west-bank basins are probably too low, especially in the case of the Redstone and Mountain rivers. It may be statistical coincidence, but it should perhaps be noted that if the sediment yield of the Root basin is applied to the entire area of west bank basins, the resultant load is 47 Mt, only a few million tonnes short of the full load delivered from downstream of Fort Simpson.

10.3 Appraisal of data

The analysis above, while providing a logical framework for the assessment of the contribution of westbank tributaries to the sediment load of the Mackenzie River downstream of Fort Simpson, nonetheless highlights several pitfalls in the data.

One problem is clearly the meagre database used for the sediment ratings at most of the stations, and, perhaps even more importantly, the scarcity of sampling at high flows.

Another problem, especially relevant in the case of the Redstone, Carcajou and Mountain rivers, is the location of the sampling stations so far upstream that they may in fact be missing much of the sediment delivered from the basins. These comments are made on the basis of the known surficial geology of the basins, and the comparison in sediment yields with the Root River. It is true that the yield of the Root basin may be inflated compared to those south of the Redstone River because of the extreme 1988 flood. However, if the 1988 load is removed from the record of the Root and Redstone rivers, the specific yields at those two stations would still be 352 and 300 t/sq. km./yr respectively, substantially higher than the 115 t/sq.km./yr for the Mountain River.

It seems unclear, therefore, as to what use can be made of the sediment data from these three stations given their location so far from the mainstem Mackenzie. The advantages of the upstream locations from the point of view of reliable hydrometric records are acknowledged, given the shifting character of the channels closer to the mainstem, and given the relatively small increase in basin area downstream of the stations. However, while retaining the hydrometric stations at these sites, it would seem to be more appropriate to undertake the sediment sampling immediately upstream of the confluence with the Mackenzie River. Discharge data from the upstream stations could be combined with the sediment data from near the mouth.

A precedent for the suggestion above was made in the 1970s in the case of Arctic Red River, for which sediment sampling was undertaken close to the mouth, approximately 75 km downstream from the hydrometric station near Martin House.

The proposal, if implemented, would, of course, require careful choice of sampling vertical, and choice of sampling section close by so that the representativeness of the single vertical could be assessed. In addition, it would be sensible to continue SV sampling at the upstream hydrometric stations concurrently with downstream sampling: in this way, a statistical relationship could be developed between concentrations at the upstream and downstream sites, thus allowing eventual conversion of existing data to equivalent downstream values.

As a preliminary measure, it is recommended that IWD identify a suitable SV site near the mouth of each of these three rivers (Redstone, Carcajou and Mountain) and undertake a program of comparative sampling at the existing station and near-mouth sites whenever visits are made to these stations.

11. SUMMARY AND CONCLUSIONS

This report provides preliminary estimates of sediment loads for west-bank tributaries of the mainstem Mackenzie River for the period 1974-1990. When expressed in terms of load per unit basin area (specific yield), the data allow some interpretation of the spatial pattern of sediment production in the western part of the Mackenzie basin. In principle, they also permit an estimate to be made of the contribution of these west-bank tributaries to the 49 million tonnes of suspended sediment acquired by the Mackenzie River between Fort Simpson and Arctic Red River in the average year.

The Flat River station, which leads to the South Nahanni River and Liard River, and is not a direct tributary of the Mackenzie River, is also included here because it provides useful data on sediment yield in the high-country part of the western basin. A reasonably satisfactory sediment rating exists for the Flat River station, and it might be improved by use of instantaneous discharge data (rather than daily mean values) as a predictor of instantaneous concentration. (Hudson (1993, pers. comm.) is currently investigating the effects of using mixed-mode data on the sediment ratings of Alberta stations, but no conclusions are yet available.) The rating seems acceptable for the prediction of mean annual load. It is not known whether other reasons exist which warrant continued operation of the sediment program at this site.

The sediment programs on the Harris and Martin rivers were undertaken in the early 1970s. The sediment ratings are poor, as is not uncommon in small basins. However, the data, when extrapolated to the full 1974-90 discharge record, are still useful in confirming the low sediment yields found in these small basins.

The sediment database for the Root River is the largest for the five large basins south of Camsell Bend, reflecting miscellaneous sampling 5 to 10 times per year beginning in 1987. Unfortunately, as is often the case with miscellaneous sampling that accompanies routine hydrometric visits to stations, the data are biased to average flows. As a consequence, extrapolation of the sediment rating to very high flows, as occurred in the record 1988 flood, is highly uncertain. Special effort is needed to obtain more sampling at high flows (above 1000 m3/s) at this station. As a general comment, this also applies to the stations further north discussed next.

The four stations north of the Root River (Redstone, Carcajou, Mountain and Ramparts) have only limited sediment data, and thus all four sediment ratings must be viewed with uncertainty, and treated as preliminary only. Continued sampling on an intermittent basis will eventually provide more reliable ratings, provided that effort is made to sample at high flows.

The projected 1974-1990 sediment yields for the Carcajou and Ramparts rivers are higher than expected, and this may reflect bias in the sediment ratings. The specific yield for the Mountain River station (at about twice that of the Flat River, but only a third of that of the Ramparts River) is clearly too low as an estimate for the Mountain River basin as a whole. It seems likely that, with the exception of the Ramparts River, this set of stations is located too far inland to be representative of sediment loads at the confluence with the Mackenzie River.

It is therefore recommended that, on the Redstone, Carcajou and Mountain rivers, sediment sampling be undertaken at the mouths of these rivers (as well as at the stations) at times of all visits to the hydrometric site.

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List of Tables

TABLE 2.1

FLAT RIVER NEAR THE MOUTH (10EA003):
SUMMARY OF SEDIMENT DATA
(2 pages)

	m3/s	mg/L	% clay	% silt	% sand
78 JUN 26	162	52			
78 JUL 20	196	82			
78 AUG 21	170	32			
78 OCT 4	72	8			
79 JUN 2	302	265	35	54	11
79 JUL 10	212	75			
79 AUG 16	135	25			
79 SEP 14	126	23			
80 MAY 15	223	241			
80 AUG 30	84	29			
80 OCT 8	141	48			
81 JUN 17	268	101			
81 JUL 6	134	20			
81 SEP 21	78	8			
82 JUN 7	219	128			
82 JUL 22	99	24			
82 SEP 3	76	10			
82 SEP 23	56	5			
83 MAY 13	151	152			
83 JUN 30	164	55			
83 JUL 12	97	22			
83 AUG 18	137	46			
83 SEP 29	51	10			
84 APR 12	18	113			
84 APR 14	162	201			
84 JUN 11	398	308			
84 JUL 5	322	77			
84 AUG 15	131	30			
84 SEP 28	57	7			
85 MAY 24	202	395	42	54	4
85 JUN 27	168	42			
85 AUG 1	140	24			
85 AUG 1	140	40			
85 OCT 3	59	6			
86 MAY 30	699	865	27	60	13
86 JUN 25	184	52			
86 AUG 28	103	13			
87 MAY 21	214	525			
87 JUN 10	287	202			
87 JUL 22	105	40			
87 AUG 19	157	44			
87 OCT 23	42	5			
88 MAY 27	251	116			

88	JUL 7	421	227	25	68	7
88	JUL 15	442	225	33	58	9
88	AUG 29	120	38			
89	MAY 18	233	138			
89	MAY 25	155	48			
89	MAY 27	139	37			
89	MAY 31	267	397			
89	JUN 8	261	97			
89	JUN 19	205	81			
89	AUG 7	121	32			
89	SEP 3	82	12			
89	SEP 18	63	5			
89	OCT 3	56	4			
90	MAY 4	135	225			
90	MAY 14	172	211			
90	JUN 11	223	76			
90	JUL 23	146	42			
90	SEP 4	105	20			
90	OCT 15	55	26			
91	MAY 08	306	596	19	65	16
91	JUN 10	211	114			
91	JUL 22	208	54			
91	SEP 6	159	52			

All samples are depth-integrated except 1987 (dip)

All discharge data are daily mean values
All concentrations are instantaneous values

TABLE 2.1

FLAT RIVER NEAR THE MOUTH (10EA003):

SUMMARY OF SEDIMENT DATA

1974	654		
1975	748		
1976	528		
1977	383	JAN	0
1978	665	FEB	0
1979	595	MAR	0
1980	244	APR	0
1981	337	MAY	110
1982	459	JUN	214
1983	149	JUL	130
1984	310	AUG	38
1985	295	SEP	10
1986	713	OCT	2
1987	368	NOV	0
1988	1244	DEC	0
1989	337		
1990	553	Total	504
Mean	505		

All loads in kilotonnes

TABLE 2.2.

FLAT RIVER NEAR THE MOUTH (10EA003):

SUMMARY OF PREDICTED MONTHLY AND ANNUAL SUSPENDED SEDIMENT LOADS

	m3/s	cfs	mg/L
72 JUL 5	0.55		2
72 JUL 20	0.02		1
72 AUG 10	0.04		1
73 APR 30	1.42	50	22
73 MAY 4	5.38	190	26
73 MAY 7	8.44	298	28
73 MAY 11	6.68	236	17
73 MAY 14	4.56	161	15
73 MAY 18	3.00	106	10
73 MAY 22	2.53	90	10
73 MAY 25	1.99	70	8
73 MAY 28	1.59	56	9
73 MAY 30	1.25	44	5
73 JUN 1	1.14	40	1
73 JUN 2	1.08	38	1
73 JUN 5	0.93	33	1
73 JUN 8	0.77	27	2
73 JUN 12	0.68	24	3
73 JUN 18	0.79	28	5
73 JUN 20	1.06	37	4
73 JUN 21	0.97	34	3
73 JUN 22	0.83	29	3
73 JUN 27	1.70	60	27
73 JUN 29	3.46	122	21
73 JUL 3	2.03	72	14
73 JUL 6	1.74	61	9
73 JUL 9	1.10	39	10
73 JUL 13	0.75	27	10
73 JUL 16	0.47	17	8
73 JUL 20	0.25	9	15
73 JUL 23	0.15	5	11
73 JUL 27	0.11	4	11
73 JUL 30	0.06	2	10
73 AUG 3	0.03	1	5
73 AUG 7	0.03	1	5
73 AUG 10	0.03	1	3
73 AUG 13	0.02	1	1
73 AUG 17	0.03	1	3
73 AUG 20	0.32	11	16
73 AUG 24	0.23	8	3
73 AUG 27	0.22	8	2
73 SEP 4	0.18	6	1
73 SEP 10	0.14	5	1
73 SEP 17	0.18	6	1
73 SEP 24	0.15	5	1
73 OCT 2	0.13	5	1
73 OCT 10	0.11	4	1
73 OCT 17	0.10	4	1
73 OCT 24	0.07	3	1
74 APR 30	0.40	14	15
74 MAY 9	2.27	80	14
74 MAY 13	12.38	437	62
74 MAY 15	22.80	805	65

TABLE 3.1

(2 pages)

74	MAY	17	24.78	875	44
74	MAY	21	14.53	513	17
74	MAY	24	11.05	390	24
74	MAY	27	9.15	323	17
74	MAY	29	7.59	268	15
74	MAY	31	6.34	224	13
74	JUN	3	5.30	187	15
74	JUN	5	4.81	170	12
74	JUN	7	4.16	147	11
74	JUN	10	4.05	143	12
74	JUN	12	3.77	133	14
74	JUN	14	3.40	120	17
74	JUN	17	3.00	106	4
74	JUN	19	3.14	111	2
74	JUN	21	2.95	104	1
74	JUN	24	2.80	99	7
74	JUN	26	4.56	161	21
74	JUN	28	3.99	141	23
74	JUL	3	2.32	82	14
74	JUL	5	2.06	73	17
74	JUL	16	0.81	29	19
74	JUL	19	0.54	19	16
74	JUL	22	0.27	10	14
74	JUL	24	0.17	6	17
74	JUL	26	0.14	5	29
74	JUL	29	0.15	5	13
74	AUG	2	0.12	4	2
74	AUG	7	0.52	18	4
74	AUG	9	1.08	38	6
74	AUG	12	0.83	29	2
74	AUG	19	0.44	16	4
74	AUG	29	0.50	18	5
74	SEP	4	0.35	12	6
74	SEP	16	0.57	20	9
74	SEP	23	0.55	20	11
74	OCT	1	0.68	24	14
74	OCT	2	0.68	24	14
74	OCT	3	0.67	24	14
74	OCT	4	0.67	24	14
74	OCT	5	0.67	24	14
75	MAY	13	13.10		21
75	JUL	10	0.16		72
75	JUL	14	0.11		8
75	JUL	23	0.04		5
75	AUG	5	0.05		3
75	AUG	11	0.31		4
75	AUG	18	0.08		3
75	SEP	17	0.12		3
75	SEP	23	0.20		4

All 1973-74 data are daily mean values
1972 and 1975 sediment data are instantaneous

HARRIS RIVER NEAR THE MOUTH (10GC002):
SUMMARY OF SEDIMENT DATA

1974	1094
1975	1667
1976	1511
1977	466
1978	437
1979	737
1980	5
1981	1045
1982	3360
1983	2072
1984	591
1985	2163
1986	1517
1987	356
1988	2822
1989	1868
1990	1348
Mean	1356

JAN	0
FEB	0
MAR	0
APR	61
MAY	877
JUN	161
JUL	120
AUG	44
SEP	34
OCT	50
NOV	8
DEC	1
Sum	1356

All loads in tonnes

TABLE 3.2

HARRIS RIVER NEAR THE MOUTH (10GC002)

SUMMARY OF PREDICTED ANNUAL AND MONTHLY SUSPENDED SEDIMENT LOADS

TABLE 4.1

MARTIN RIVER
AT HIGHWAY
NO. 1

(10GC003)

(2 pages)

			m3/s	cfs	mg/L
73	MAY	3	21.2	750	76
73	MAY	4	39.9	1410	185
73	MAY	11	41.9	1480	138
73	MAY	14	27.9	986	61
73	MAY	19	15.2	537	30
73	MAY	22	15.1	532	26
73	MAY	25	13.2	465	29
73	JUN	1	11.1	393	20
73	JUN	2	11.5	407	17
73	JUN	5	8.8	311	20
73	JUN	8	6.7	235	19
73	JUN	12	5.7	203	29
73	JUN	18	23.2	820	155
73	JUN	20	30.9	1090	70
73	JUN	22	21.8	771	30
73	JUN	23	18.2	643	27
73	JUL	3	27.2	962	53
73	JUL	9	11.4	402	19
73	JUL	16	4.9	173	21
73	JUL	19	3.8	135	15
73	JUL	23	2.5	89	13
73	JUL	30	1.5	52	10
73	AUG	3	1.2	42	9
73	AUG	7	1.0	37	8
73	AUG	13	1.3	47	7
73	AUG	20	8.3	293	24
73	AUG	29	5.2	183	8
73	SEP	4	3.0	107	14
73	SEP	13	1.8	62	18
73	SEP	17	1.5	52	10
73	SEP	23	1.2	41	11
73	SEP	28	1.0	34	5
73	OCT	12	0.6	22	4
74	MAY	1	0.5	17	13
74	MAY	6	3.5	123	10
74	MAY	10	15.5	548	49
74	MAY	13	57.8	2040	203
74	MAY	15	75.9	2680	302
74	MAY	17	79.9	2820	301
74	MAY	21	57.2	2020	131
74	MAY	27	40.5	1430	68
74	MAY	29	31.2	1100	50
74	MAY	31	23.6	834	42
74	JUN	3	17.4	614	40
74	JUN	5	16.6	587	39
74	JUN	7	14.9	526	36
74	JUN	10	13.6	480	45
74	JUN	12	12.3	434	32
74	JUN	14	12.4	438	35
74	JUN	17	15.1	532	67
74	JUN	19	21.4	757	56
74	JUN	21	23.4	827	42
74	JUN	24	23.4	827	43
74	JUN	26	32.9	1160	65

74	JUN	28	29.5	1040	45
74	JUL	3	13.6	480	19
74	JUL	5	10.5	371	15
74	JUL	16	3.2	112	12
74	JUL	19	2.7	94	13
74	JUL	24	2.0	69	27
74	JUL	26	2.0	72	60
74	JUL	29	2.1	73	39
74	AUG	2	1.9	68	158
74	AUG	7	6.1	214	173
74	AUG	9	17.6	620	92
74	AUG	12	13.6	480	39
74	AUG	15	8.4	297	15
74	AUG	19	7.7	272	70
74	AUG	22	9.5	335	22
74	AUG	29	9.0	318	11
74	SEP	4	5.5	195	10
74	SEP	16	3.6	126	9
74	SEP	20	2.9	104	4
75	MAY	4	101.0		279
75	MAY	9	75.0		156
75	MAY	13	55.0		91
75	JUN	16	18.0		18
75	JUL	10	2.0		157
75	AUG	5	5.0		40
75	AUG	11	22.0		34
75	AUG	18	7.0		83
75	SEP	24	3.0		6
76	MAY	25	13.9	490	39
76	MAY	31	18.4	650	40
76	JUN	3	16.1	570	33
76	JUN	8	11.9	420	22
76	JUN	11	9.5	334	17
76	JUN	14	7.1	250	13
76	JUN	18	6.0	212	17
76	JUN	23	4.0	140	16
76	JUN	30	2.4	84	13
76	JUL	8	6.9	245	12
76	JUL	12	4.1	146	8
76	JUL	20	7.8	275	19
76	JUL	26	5.0	175	8
76	AUG	5	2.7	97	10
76	AUG	11	1.7	59	8
76	AUG	18	5.7	200	16
76	AUG	24	58.6	2070	90
76	AUG	27	32.0	1130	39
76	AUG	31	19.9	703	21
76	SEP	9	13.3	471	9
76	SEP	17	8.7	307	6
76	SEP	20	7.3	257	5
76	SEP	30	5.2	184	5
76	OCT	5	4.0	141	5
76	OCT	12	3.7	129	6

TABLE 4.1

MARTIN RIVER
AT HIGHWAY
NO. 1

(10GC003)

(2 pages)

All data are daily mean values except 1975 sediment (instant.)

1974	18.2			
1975	26.4			
1976	26.2			
1977	20.5		JAN	0.0
1978	8.2		FEB	0.0
1979	24.5		MAR	0.0
1980	0.9		APR	0.2
1981	19.7		MAY	19.3
1982	111.0		JUN	3.0
1983	43.9		JUL	22.0
1984	7.4		AUG	1.0
1985	21.0		SEP	0.6
1986	37.0		OCT	0.2
1987	2.6		NOV	0.0
1988	386.2		DEC	0.0
1989	27.9			
1990	7.2		Sum	46.3
Mean	46.4			

All loads in kilotonnes

TABLE 4.2

MARTIN RIVER AT HIGHWAY NO. 1 (10GC003):

SUMMARY OF PREDICTED MONTHLY AND ANNUAL SUSPENDED SEDIMENT LOADS

Date			m3/s	mg/L	% clay	% silt	% sand
87	MAY	25	162	564			
87	JUN	23	54	26			
87	AUG	6	84	22			
87	SEP	24	58	8			
88	MAY	4*	163	210			
88	MAY	12	145	114			
88	JUN	16	165	79			
88	JUL	5*	673	1668	46	43	11
88	JUL	12	248	221			
88	AUG	3	146	63			
88	AUG	12	163	115			
88	SEP	2	109	71			
89	APR	29*	400	1190			
89	MAY	2*	333	640			
89	MAY	4*	289	502			
89	MAY	19	322	493			
89	JUN	23	199	150			
89	JUL	5	252	214			
89	AUG	11	85	36			
89	OCT	7	59	10			
89	OCT	10	54	6			
90	MAY	2*	96	324			
90	MAY	3	123	274			
90	MAY	23	175	345			
90	JUN	15	129	50			
90	JUL	27	77	21			
90	SEP	11	179	67			
91	APR	30*	271	1049			
91	MAY	9	284	393	43	54	3
91	MAY	28	212	110			
91	JUN	13	219	220			
91	JUL	26	188	167			
91	SEP	3	222	214			

All data are instantaneous values except where asterisked (daily mean discharge)
All samples were depth-integrated except 1987 (dip)

TABLE 5.1

ROOT RIVER NEAR THE MOUTH (10GA001):

SUMMARY OF SEDIMENT DATA

Date			m3/s	mg/L	% clay	% silt	% sand
1987	JUN	19	198	65			
	JUL	20	369	240			
	SEP	25	166	21			
1988	MAY	11	172	373	22	58	20
	MAY	25	365	758	29	57	14
	AUG	10	385	200			
	SEP	23	233	87			
1989	JUN	6	E808	1955	25	57	18
1991	AUG	6	*485	288	29	60	11

All data are instantaneous values except where asterisked (daily mean discharge)

E denotes estimate

TABLE 6.1

REDSTONE RIVER AT 63 KM ABOVE THE MOUTH (10HB005): SUMMARY OF SEDIMENT DATA

	Date		m3/s	mg/L	% clay	% silt	% sand
1987	JUN	18	105	132			
	JUL	21	70	19			
	SEP	22	61	13			
1988	MAY	12	75	128			
	MAY	25	285	1439	23	45	32
	JUL	6	434	2069	17	50	33
1989	JUN	7	189	459	25	50	25
	JUN	20	303	731	22	44	34
1990	JUN	26	1530	4834	20	59	21
	SEP	27	138	110			
1991	MAY	8	640	2016	16	53	31
	AUG	8	*115	104			

All data are instantaneous values except where asterisked (daily mean discharge)

TABLE 7.1

CARCAJOU RIVER BELOW IMPERIAL RIVER (10KB001):

SUMMARY OF SEDIMENT DATA

	Date		m3/s	mg/L	% clay	% silt	% sand
1987	JUL	21	197	23			
	SEP	22	129	8			
1988	JUL	6	720	1327	18	58	24
1989	JUN	7	396	290	27	49	24
1991	AUG	8	*239	29			

All data are instantaneous values except where asterisked (daily mean discharge)

TABLE 8.1

MOUNTAIN RIVER BELOW CAMBRIAN CREEK (10KC001):

SUMMARY OF SEDIMENT DATA

	Date		m3/s	mg/L	% clay	% silt	% sand
1987	JUN	17	101	53			
	JUL	21	22	3			
	AUG	18	51	89			
	SEP	24	49	24			
1988	MAY	9	115	446	7	17	76
	MAY	26	167	131			
1989	JUN	9	169	726	3	40	57
	JUN	20	269	979	3	35	62
1991	MAY	9*	120	2012	17	22	61
	AUG	8*	34	57			

All data are instantaneous values except where asterisked (daily mean discharge)

TABLE 9.1

RAMPARTS RIVER NEAR FORT GOOD HOPE (10KD004):

SUMMARY OF SEDIMENT DATA

	annual sediment load				annual load as % of 1980-90			
	Flat	Harris	Martin	Root	Flat	Harris	Martin	Root
1974	654	1094	18.2	3700	144	70	30	71
1975	748	1667	26.4	2900	164	107	44	55
1976	528	1511	26.2	4696	116	97	44	90
1977	383	466	20.5	376	84	30	34	7
1978	665	437	8.2	2774	146	28	14	53
1979	595	737	24.5	1473	131	47	41	28
1980	244	5	0.9	422	54	0	1	8
1981	337	1045	19.7	248	74	67	33	5
1982	459	3360	111.0	14483	101	216	185	276
1983	149	2072	43.9	2285	33	133	73	44
1984	310	591	7.4	2130	68	38	12	41
1985	295	2163	21.0	5442	65	139	35	104
1986	713	1517	37.0	8782	157	97	62	167
1987	368	356	2.6	218	81	23	4	4
1988	1244	2822	386.2	18225	273	181	644	348
1989	337	1868	27.9	1223	74	120	47	23
1990	553	1348	7.2	4211	122	86	12	80
Total	8582	23058	789	73588	1980-90 mean loads			
Mean	505	1356	46.4	4329	455	1559	60	5243
1974-90	kt	t	kt	kt	kt	t	kt	kt

TABLE 10.1

ANNUAL LOADS AS PERCENTAGE OF 1980-90 LOAD
FOR
FLAT, HARRIS, MARTIN AND ROOT RIVERS

	Root	Redstone	Carcajou	Mountain	Ramparts	yr/ (85-90)
1974	3700	4323	1759	1074	2287	0.60
1975	2900	3349	1362	832	1754	0.46
1976	4696	5480	2229	1361	2897	0.76
1977	376	426	173	106	229	0.06
1978	2774	3227	1344	721	1525	0.40
1979	1473	1705	1387	990	2097	0.55
1980	422	2622	1815	888	1868	0.49
1981	248	606	449	579	1220	0.32
1982	14483	11270	3467	2852	6061	1.59
1983	2285	4999	2366	528	1105	0.29
1984	2130	6208	3235	990	2097	0.55
1985	5442	7686	1988	836	3174	
1986	8782	8748	3272	3313	2171	
1987	218	1257	642	827	5842	
1988	18225	11181	1898	782	1235	
1989	1223	4967	1289	1901	1226	
1990	4211	7440	6823	3132	9221	
Mean	4329	5029	2088	1277	2706	
80-90 mean		6089	2477	1512		
85-90 mean				1798	3812	
Basin area km2	9820	15400	7400	11100	7410	
Sediment yield t/km2/yr	441	327	282	115	365	

yr/(85-90) is Mountain load as fraction of 1985-90 mean load and is used to estimate 1974-84 loads for Ramparts

TABLE 10.2

SUMMARY OF PREDICTED SEDIMENT LOADS
FOR SEDIMENT STATIONS BETWEEN CAMSELL BEND
AND ARCTIC RED RIVER STATION

		area sq.km.	yield t/sq.km./yr	predicted load Mt (1)	estimated load Mt (2)	Mt (3)	(1)-(3)
	Harris	701	2	0.0			
	Martin	2050	23	0.0			
	N. Nahanni	7125	441	3.1	5.2	5.7	-2.6
	Root	9933	441	4.4	6.8	7.5	-3.1
E	Willowlake	21184	23	0.5	0.3	0.3	0.2
	Wrigley	1300	441	0.6	0.6	0.7	-0.1
	Johnson	2214	441	1.0	1.6	1.8	-0.8
	Dahadinni	2709	441	1.2	1.0	1.1	0.1
	Redstone	15747	327	5.1	8.9	9.8	-4.6
	Keele	27110	327	8.9	9.2	10.1	-1.3
	Carcajou	9135	282	2.6	0.5	0.6	2.0
	Mountain	14983	115	1.7	6.6	7.3	-5.5
	Ramparts	7530	365	2.7			
E	Hare Indian	11352	115	1.3	0.1	0.1	1.2
	Ontaratue	6853	23	0.2	0.0	0.0	0.2
	Total	139926		33.3	40.8	44.9	
	Flat	8560	59	0.5			
	Liard	277000	170	47.2			
	Arctic Red	21000	305	6.5			
	Peel	71000	315	22.3			

"estimated load" refers to estimate made by Carson (1988) based on comparison with 1974-83 load of Arctic Red River (2) and adjusted to 1974-90 (3)

E denotes east-bank tributary

TABLE 10.3

SUMMARY OF SEDIMENT LOADS AND YIELDS PREDICTED FOR TRIBUTARIES OF MACKENZIE RIVER BETWEEN FORT SIMPSON AND ARCTIC RED RIVER

List of Figures

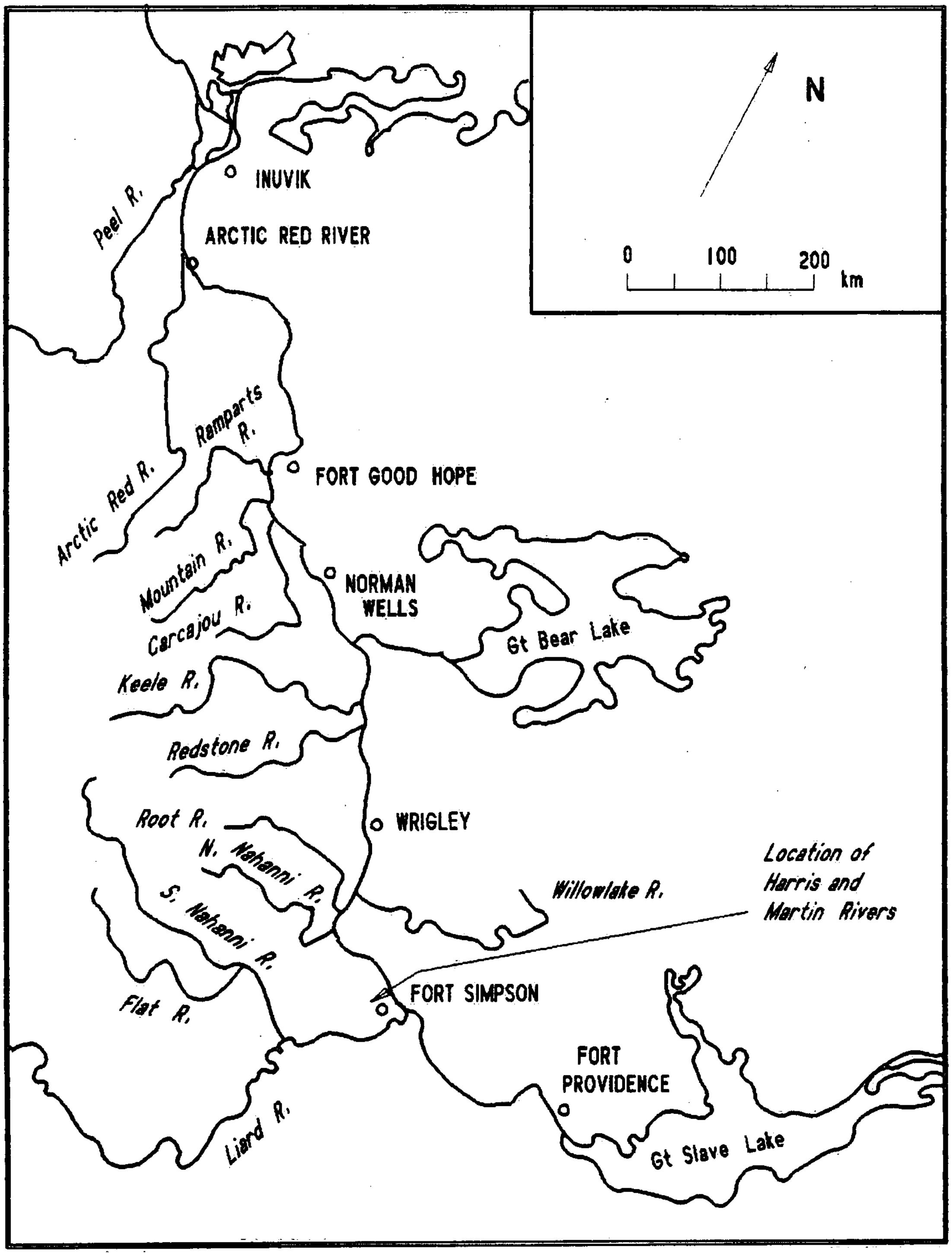
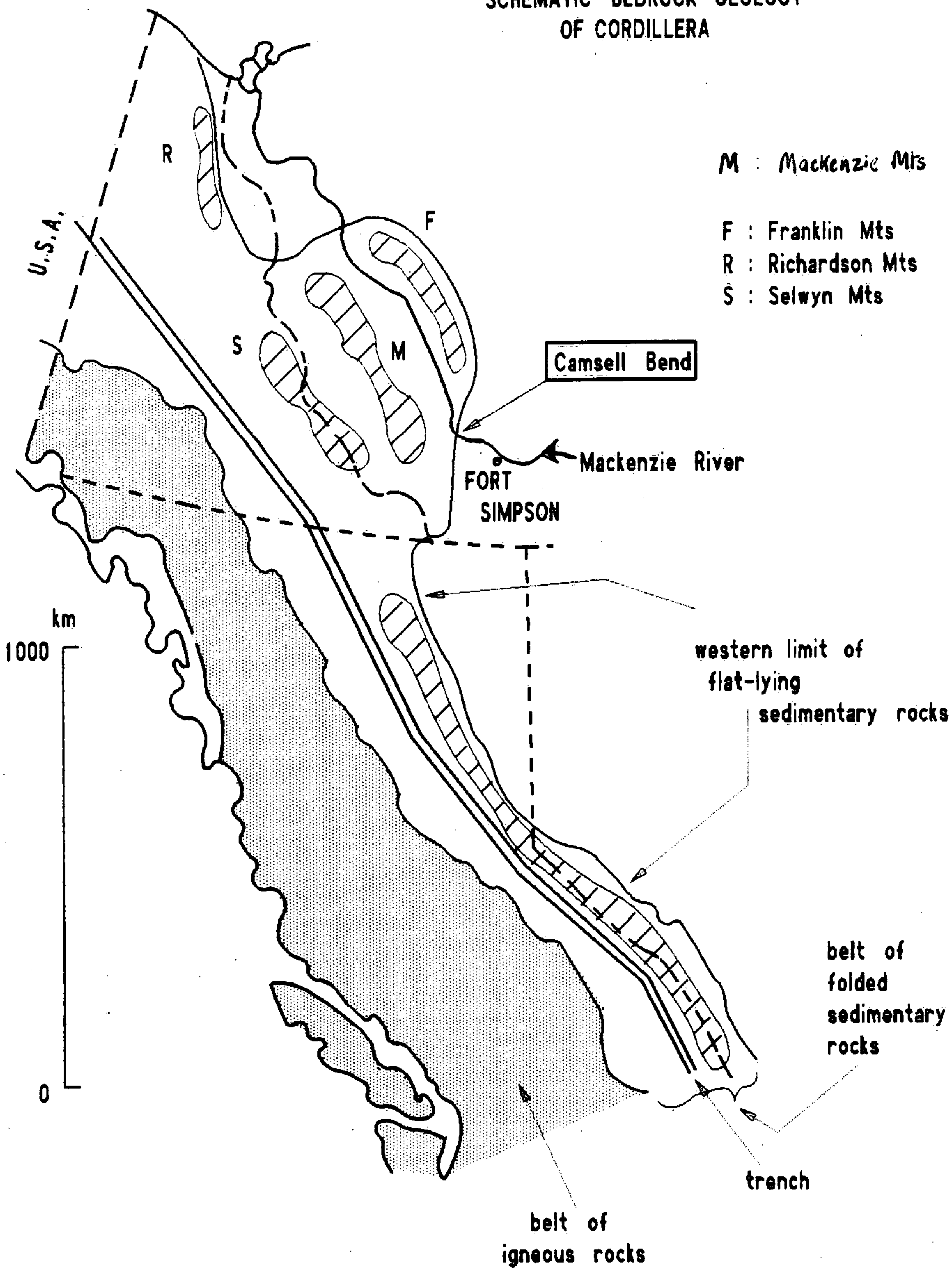


FIGURE 1.1

THE MACKENZIE RIVER DRAINAGE NETWORK

FIGURE 1.2

SCHEMATIC BEDROCK GEOLOGY
OF CORDILLERA



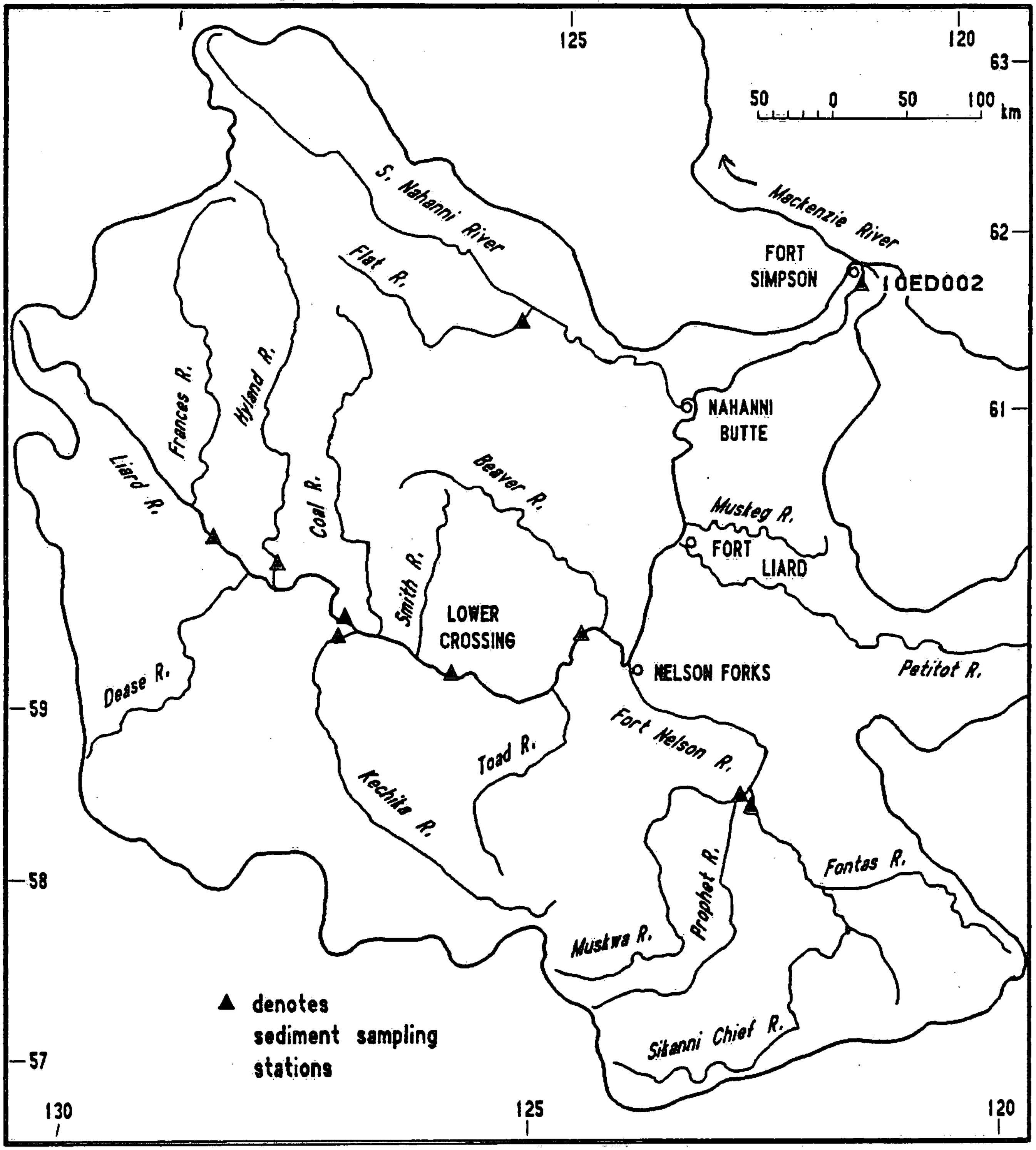


FIGURE 2.1

THE LIARD RIVER DRAINAGE NETWORK

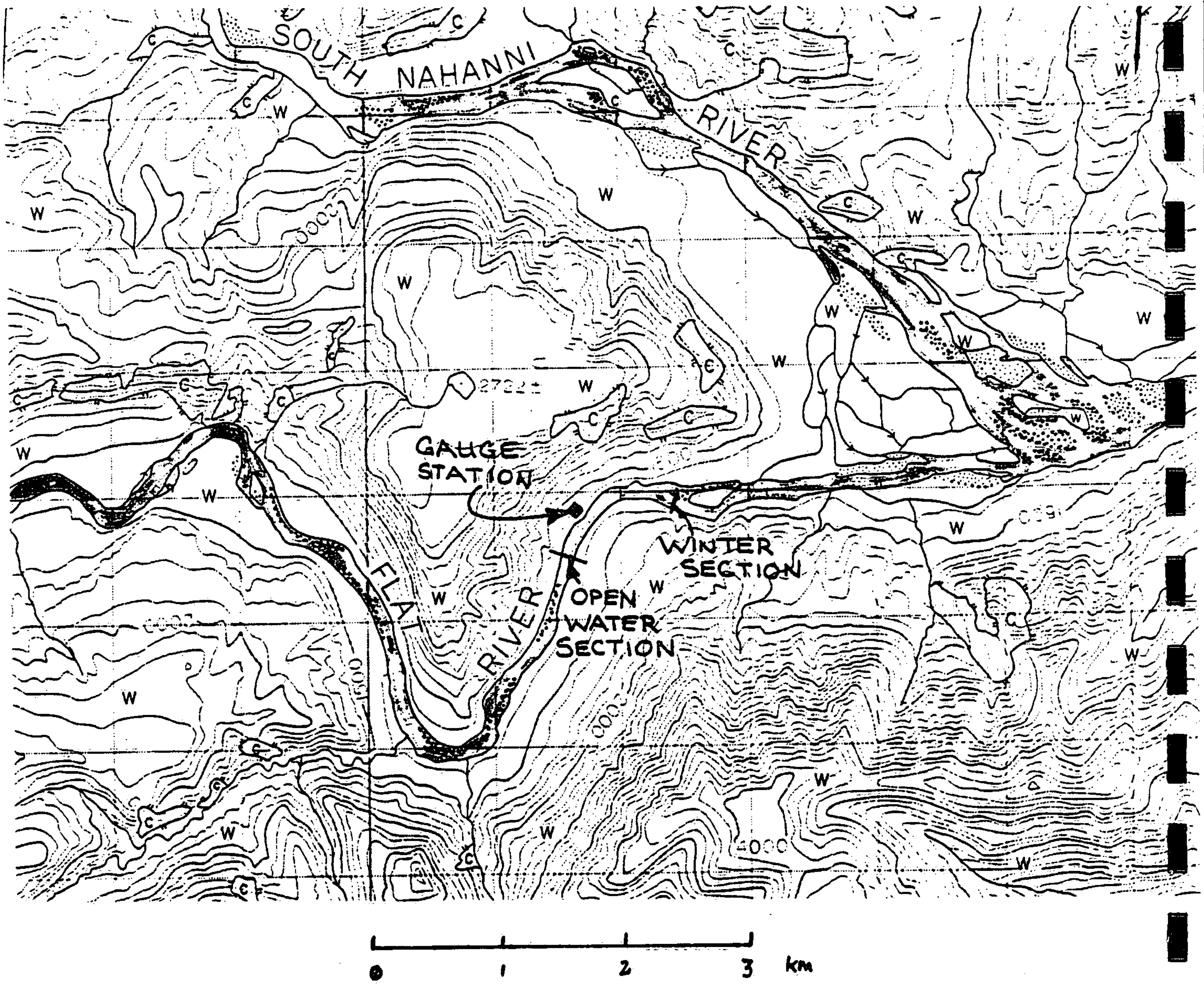


FIGURE 2.2

TOPOGRAPHIC SETTING OF THE FLAT RIVER STATION

FIGURE 2.3A

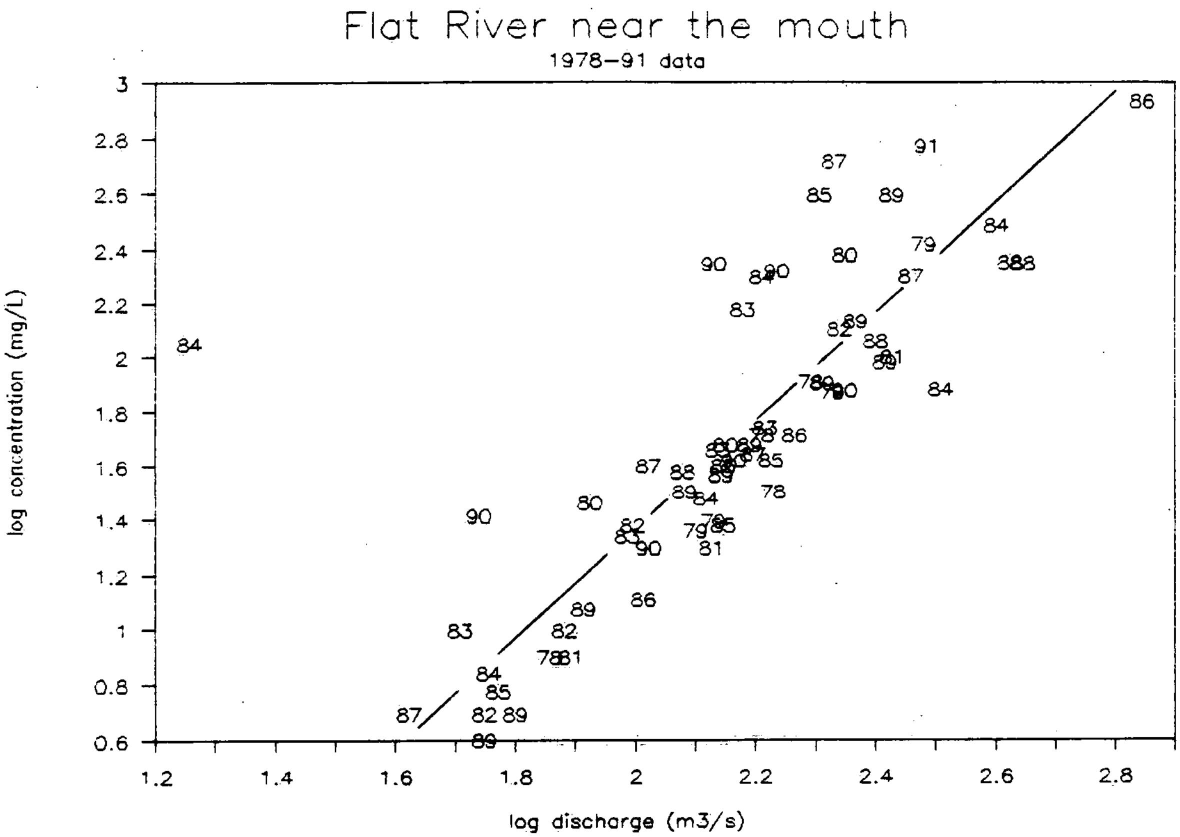


FIGURE 2.3B

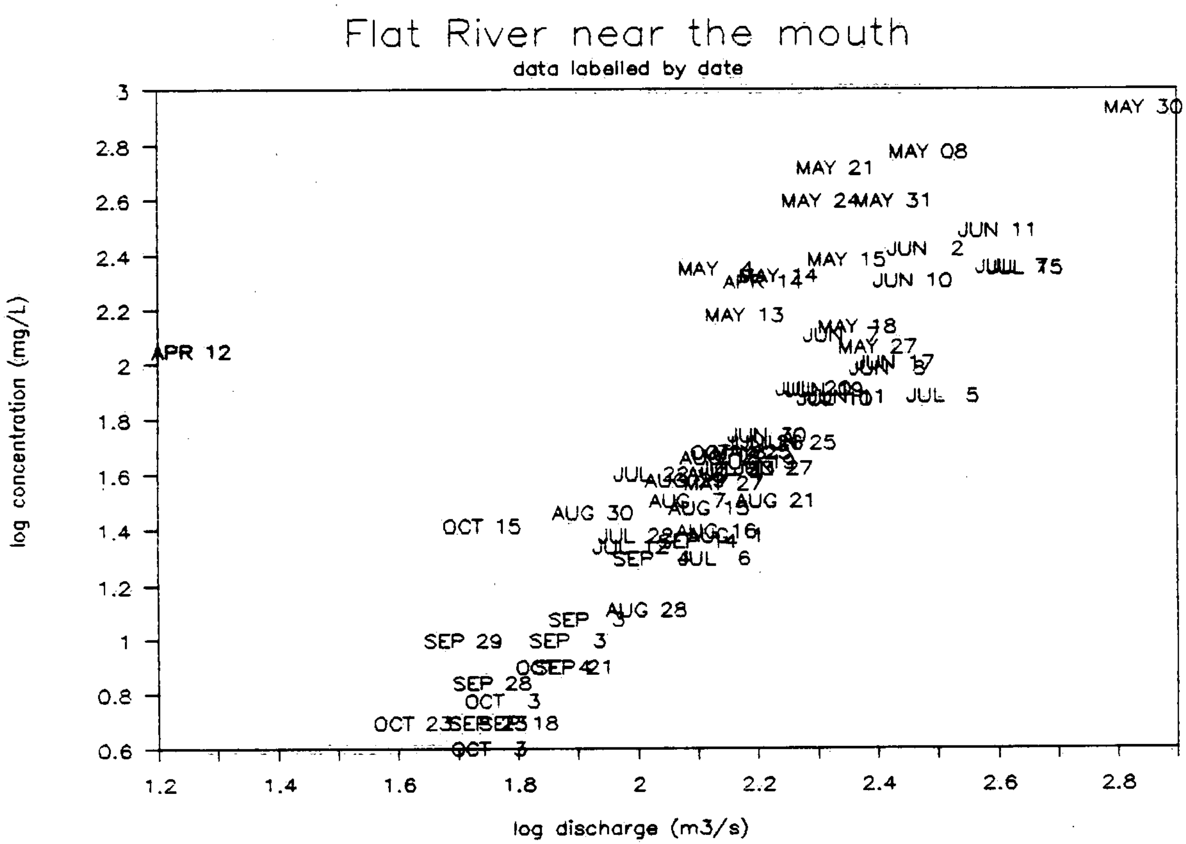


FIGURE 3.1A

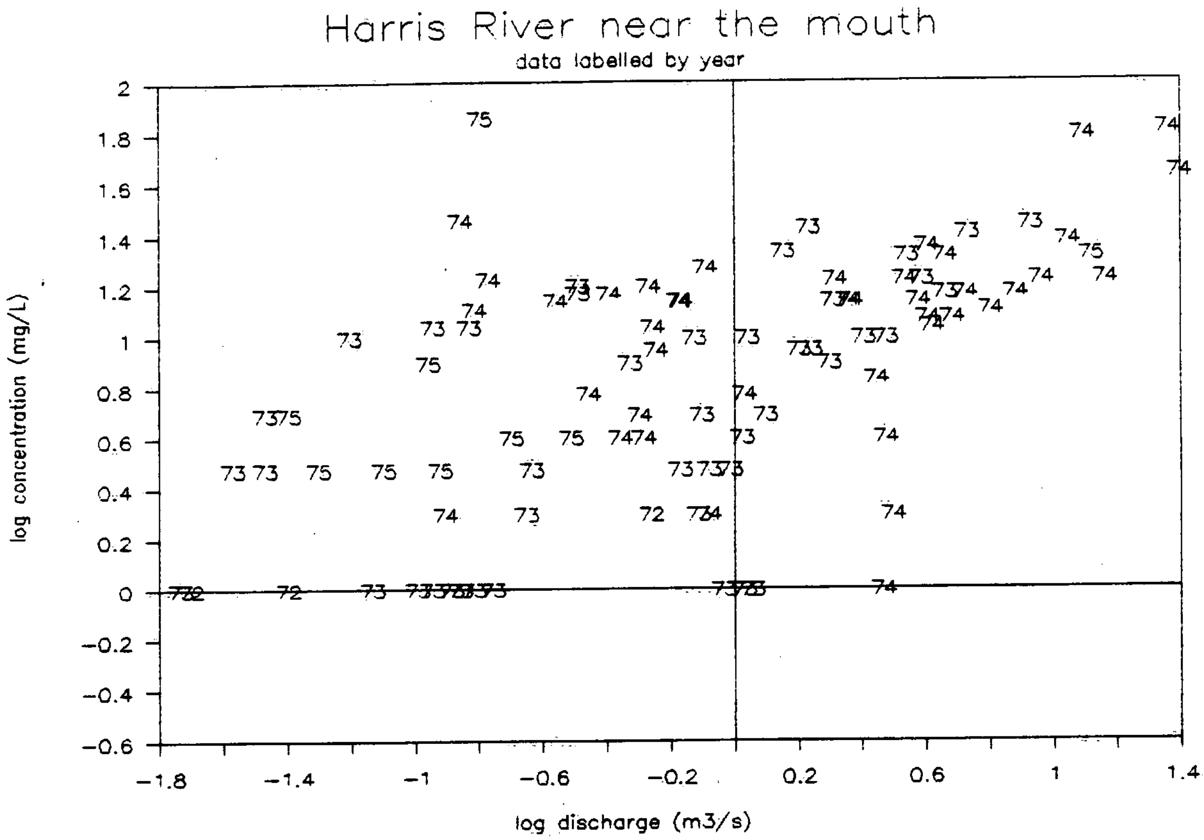


FIGURE 3.1B

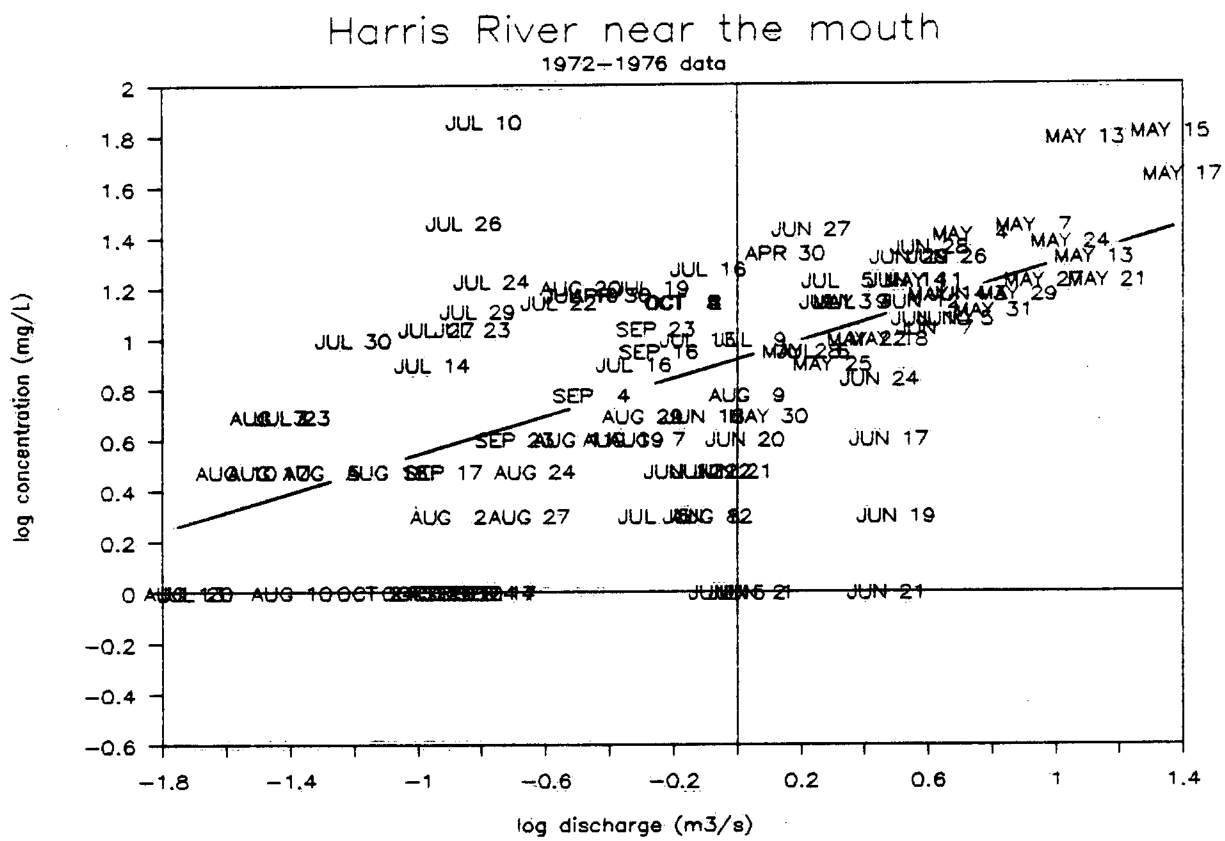


FIGURE 4.1A

Martin River near the mouth

data labelled by date

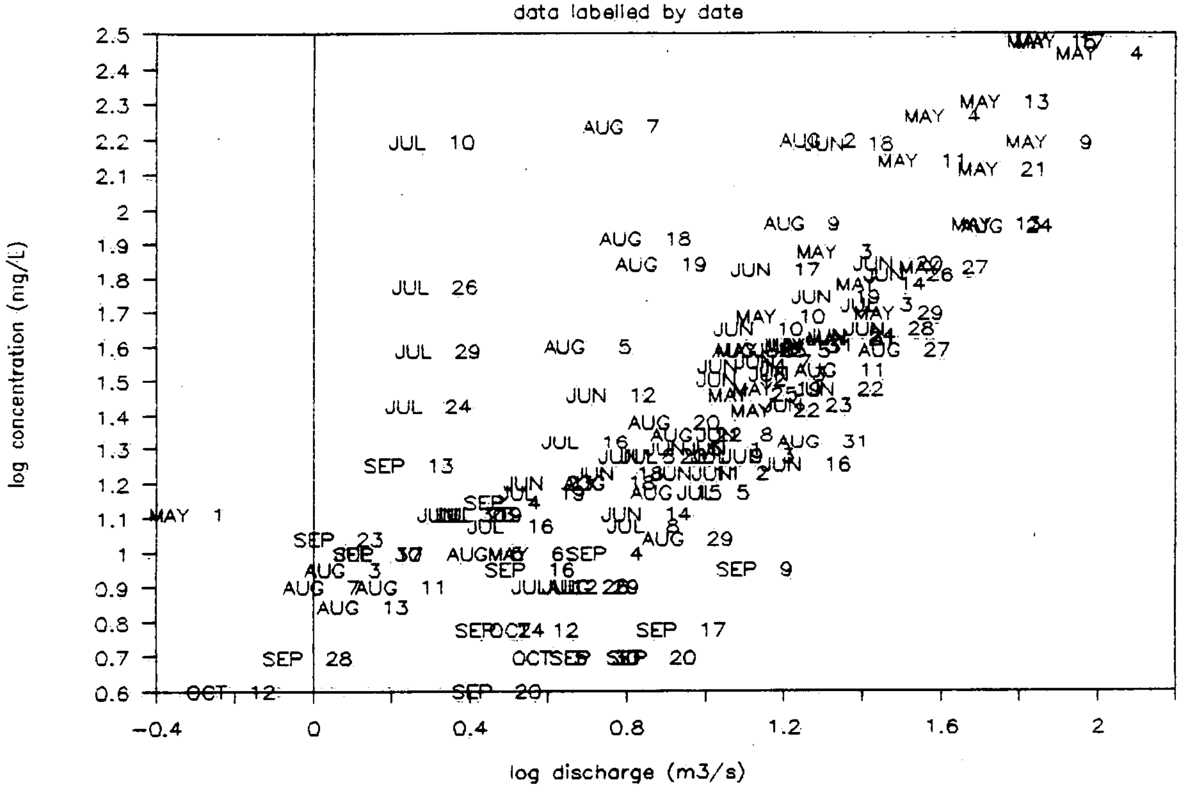
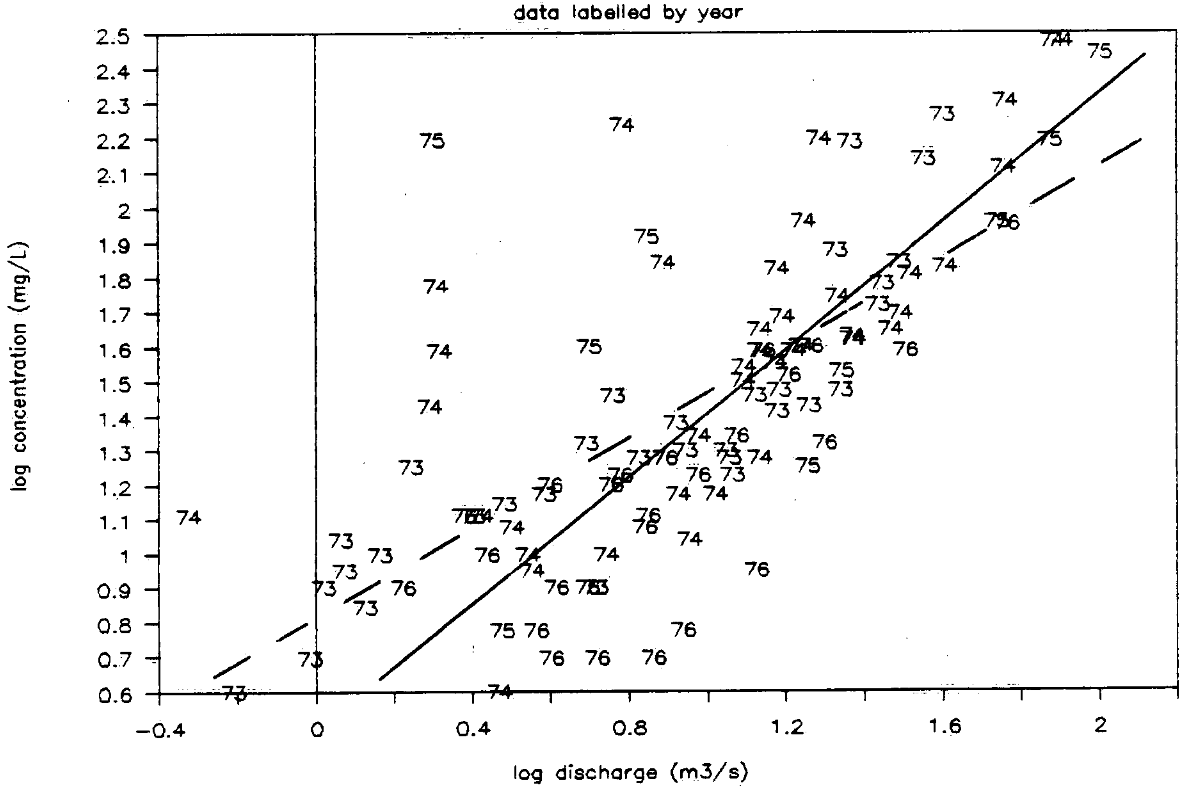


FIGURE 4.1B

Martin River near the mouth

data labelled by year



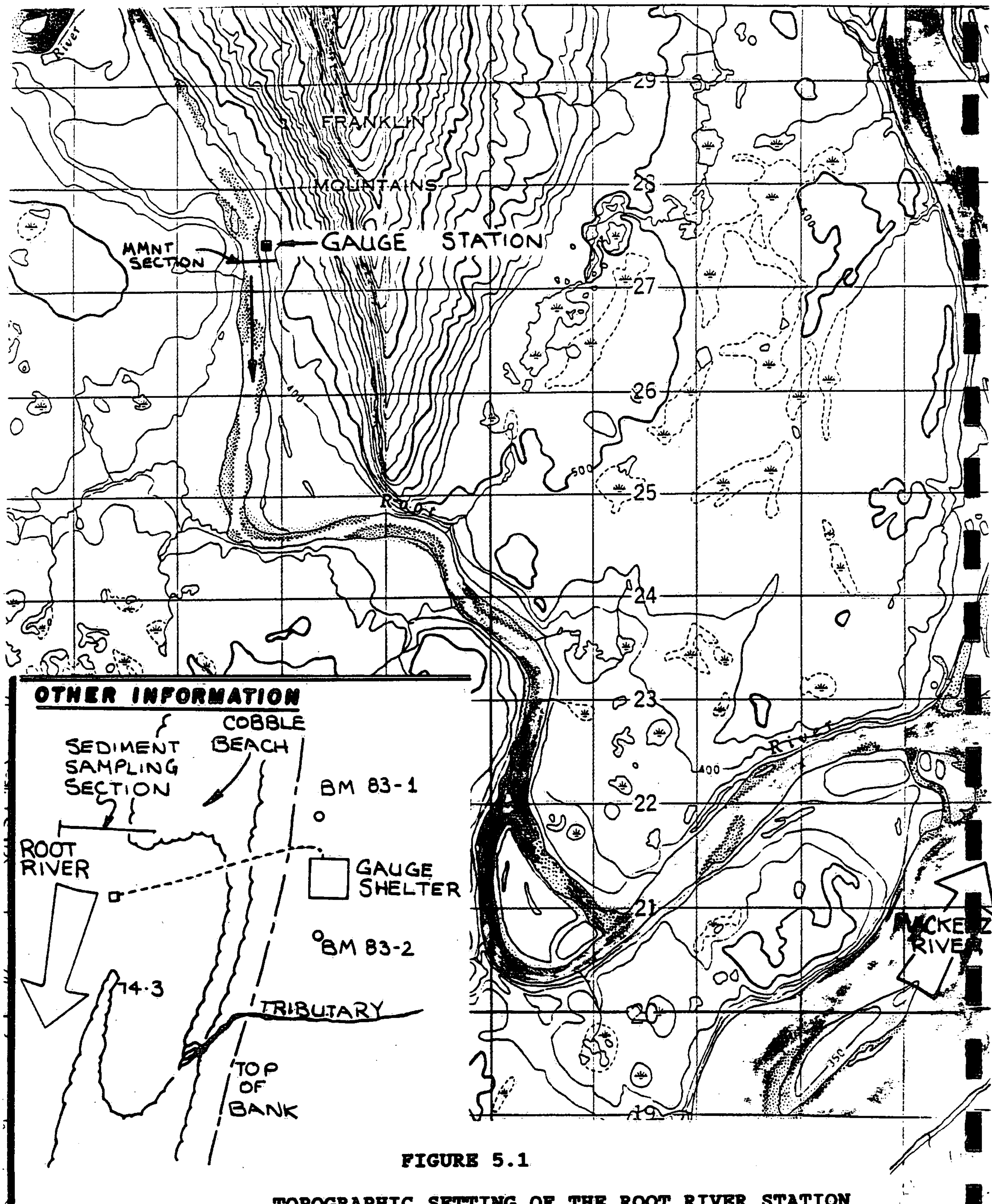
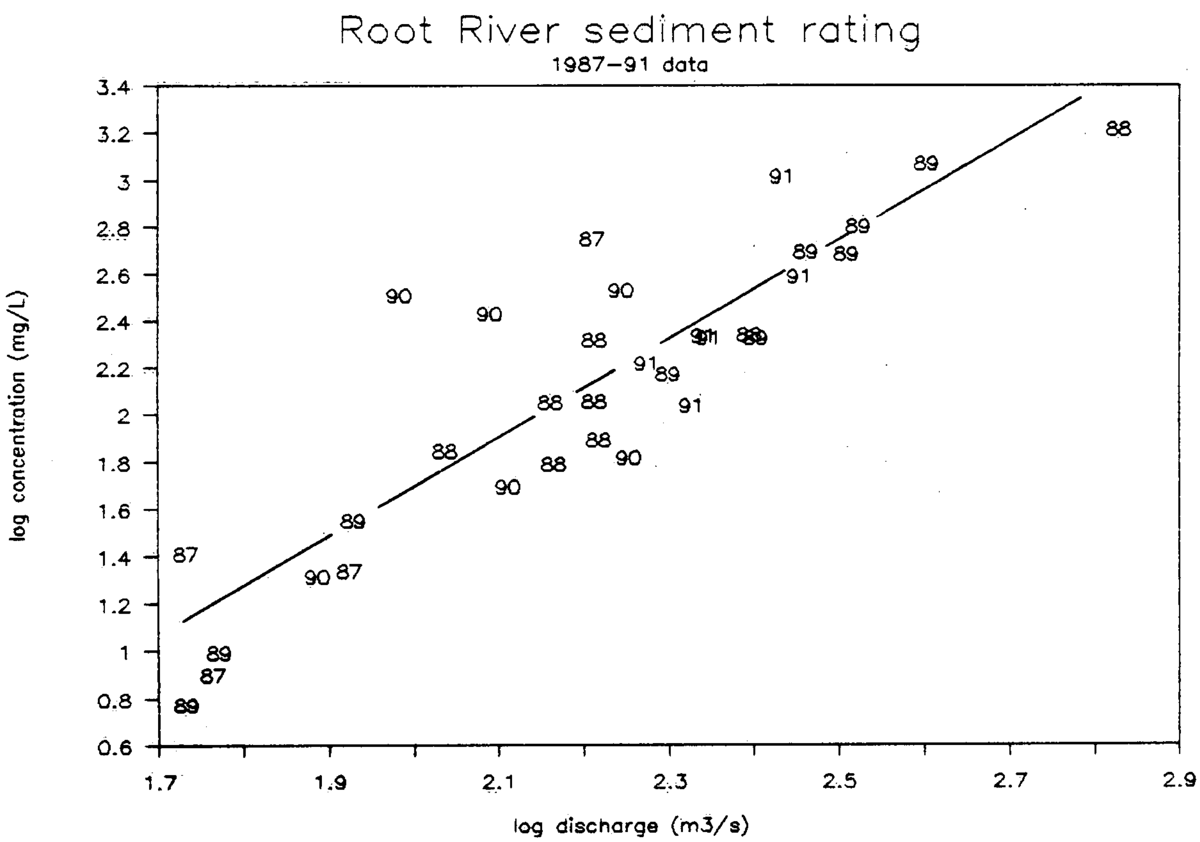


FIGURE 5.1

TOPOGRAPHIC SETTING OF THE ROOT RIVER STATION

FIGURE 5.2



Root River sediment rating
1987–91 data
log concentration (mg/L)
log discharge (m3/s)
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
1.7
1.9
2.1
2.3
2.5
2.7
2.9

SKETCH SHOWING LOCATION OF BENCH MARKS AND GAUGING EQUIPMENT. INDICATE DOCKING AND LANDING AREAS.

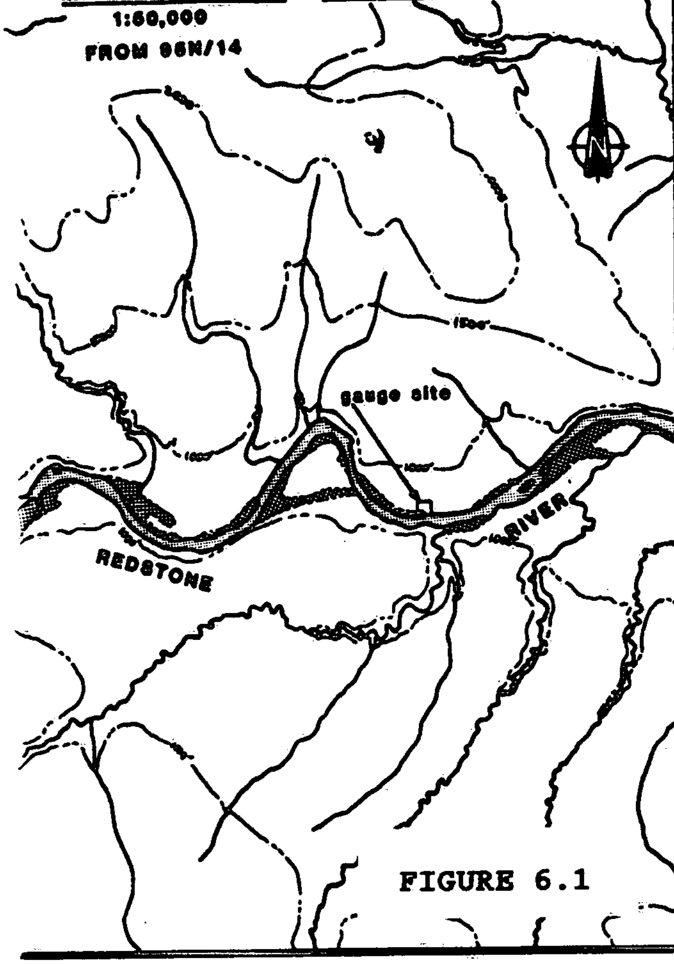
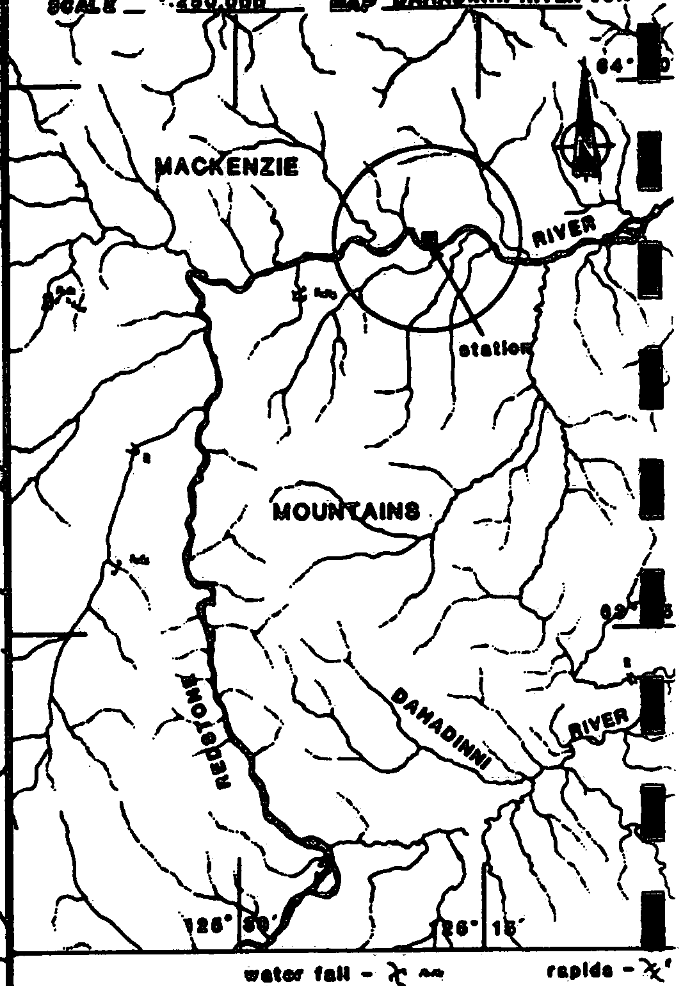


FIGURE 6.1

SCALE 1:250,000 MAP DAHADINNI RIVER 96N



ENVIRONMENT CANADA
WATER SURVEY OF CANADA

DESCRIPTION OF STATION

Station No. 10HB005 Drainage Area 15 400 km²

Station Name Redstone River 63 km above mouth

District N.W.T.

Latitude 63° 55' 30" Longitude 125° 18' 03"

Established 1978 08 05 By W.D. Hyde

Description of Gauging Equipment and Location

Instrument Shelter contains a servo-manometer, recorder and data collection platform. A boat, metering frame, 50C and 75C sounding weight are stored on-site.

Located on left bank 166 air km bearing S 27° E of Norman Wells. Access by helicopter.

Description of Control & Measuring Sections

Braided gravel channel control with backwater from ice in winter. Open water metering section as shown; winter section 800 m to 1 000m downstream of shelter.

Prepared by PSq Date Revised Sept 28,89

ELEVATION OF GAUGE DATUM AND DESCRIPTION OF BENCH MARKS

Elevation of Gauge Datum 0.000 m, assumed

Conversion Equation to convert to

DCP ID# 480C01EA, 01:43, 14W, 19°/174°

BM #78-1	Paint on rock ledge 25m toward river and 10m upstream of gauge	3.612 m
BM #78-2	Head of spike in S.E. corner of shelter base (tree stump)	8.214 m
BM #78-3	Head of spike in top of tree stump 2 m downstream of BM #78-2	8.208 m
Note:	All of above referenced to BM #74-3	
BM #74-3	Paint on rock ledge on right bank directly across from shelter	4.221 m

OTHER INFORMATION

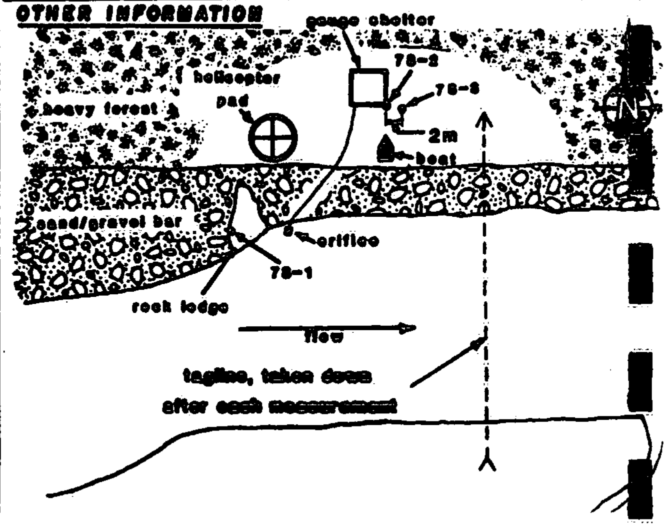
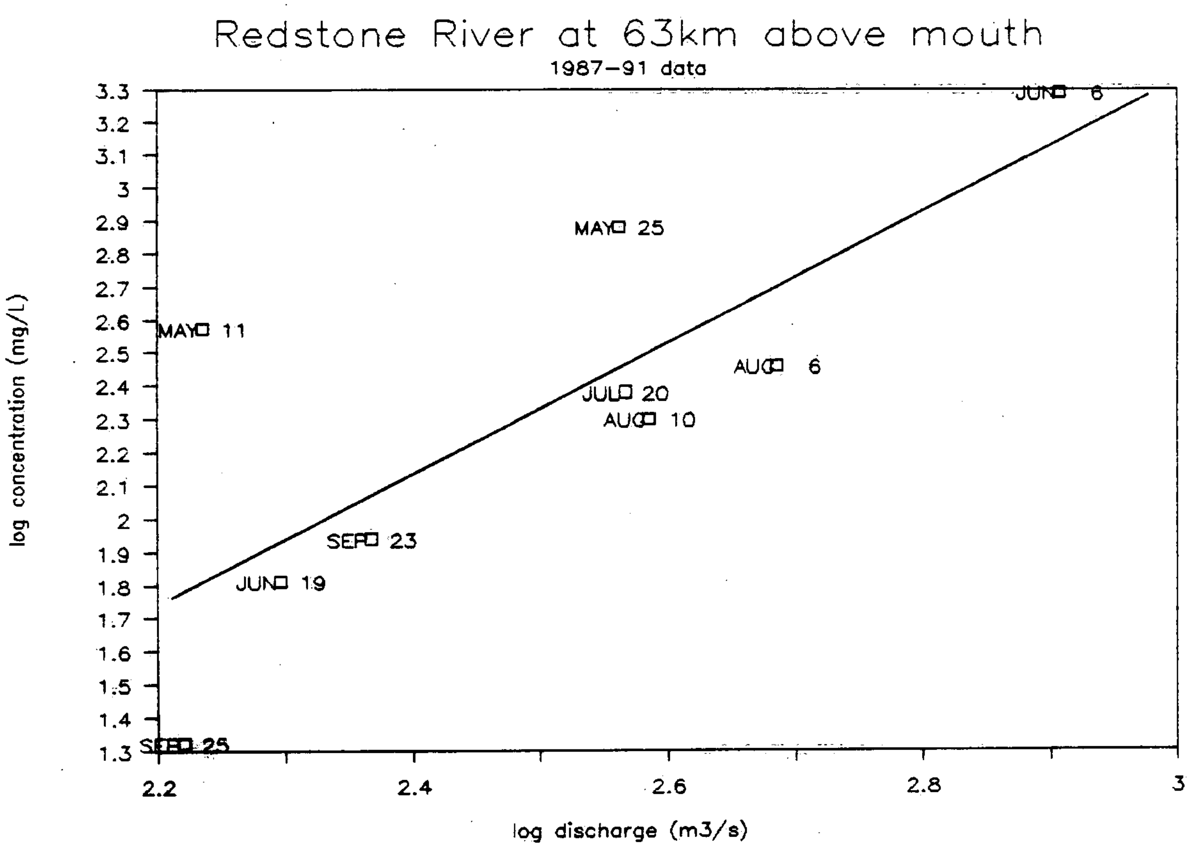


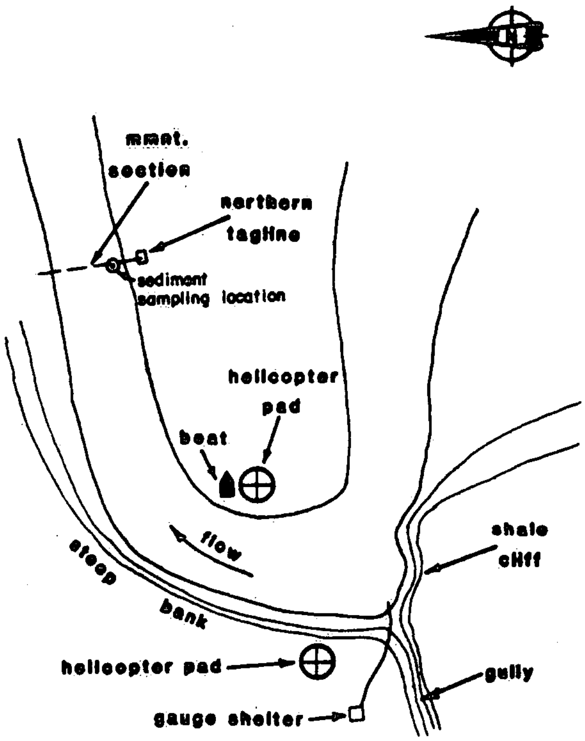
FIGURE 6.2



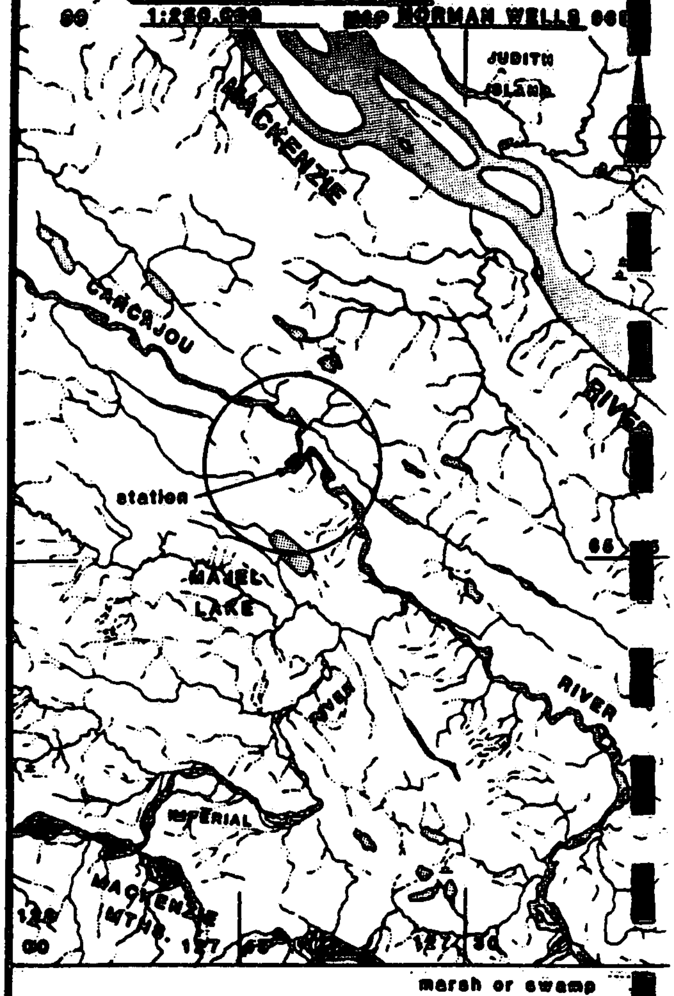
Redstone River at 63km above mouth
1987–91 data
log concentration (mg/L)
log discharge (m3/s)
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
2.2
2.4
2.6
2.8
3
JUN 6
MAY 25
MAY 11
AUG 6
JUL 20
AUG 10
SEP 23
JUN 19
SEP 25

SKETCH SHOWING LOCATION OF BENCH MARKS AND GAUGING [EQUI]PMENT. INDICATE DOCK AND LANDING AREAS.

FIGURE 7.1



SKETCH OF STATION LOCATION



ENVIRONMENT CANADA
WATER SURVEY OF CANADA

DESCRIPTION OF STATION

Station No. 10KB001 Drainage Area 7 400 km^2

Station Name Carcajou River below Imperial River

District NWT

Latitude 65° 17' 47" N Longitude 127° 40' 49"W

Established July 1976 By H.L. Wood

Description of Gauging Equipment and Location

Instrument shelter contains a servo-manometer, recorder and data collection platform. A boat, 50C sounding weight and boat frame are stored on-site.

Station is located on left bank 41 air km bearing N 87° W of Norman Wells. Access is by helicopter.
Sampling done during open water conditions at each visit.
Sediment sampling equipment includes a DH48 sampler, nozzle and waders.

Description of Control & Measuring Sections

Channel control; streambed is sand and gravel

All measurements are made from a boat or ice surface 500 m below shelter.
Single vertical depth integrating sediment sample taken by wading at site marked on map.

Prepared by W. Hanna Date 19 Mar 1992

ELEVATION OF GAUGE DATUM AND DESCRIPTION OF BENCH MARKS

Elevation of Gauge Datum 0.000 m, assumed

Conversion Equation to convert to

DCP # 480BE02C, 01:41, 14W, 17°/172°

BM # 84-1	Iron pin located at entrance to gully on opposite side to gauge	7.772 m
90-1	Paint on bedrock 23m SE of 84-1	5.365 m
91-1	Head of pin in bedrock 2.1m SW of 90-1	7.625 m
91-2	Head of bolt in bedrock 3.7m E of 91-1	7.472 m
91-3	Head of bolt in bedrock 4.4m E of 91-2	7.063 m

OTHER INFORMATION

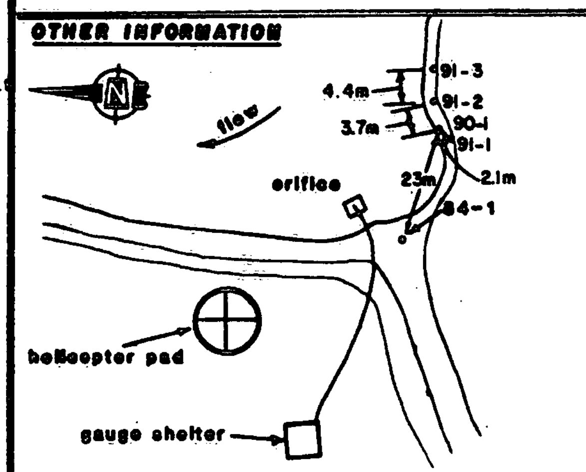
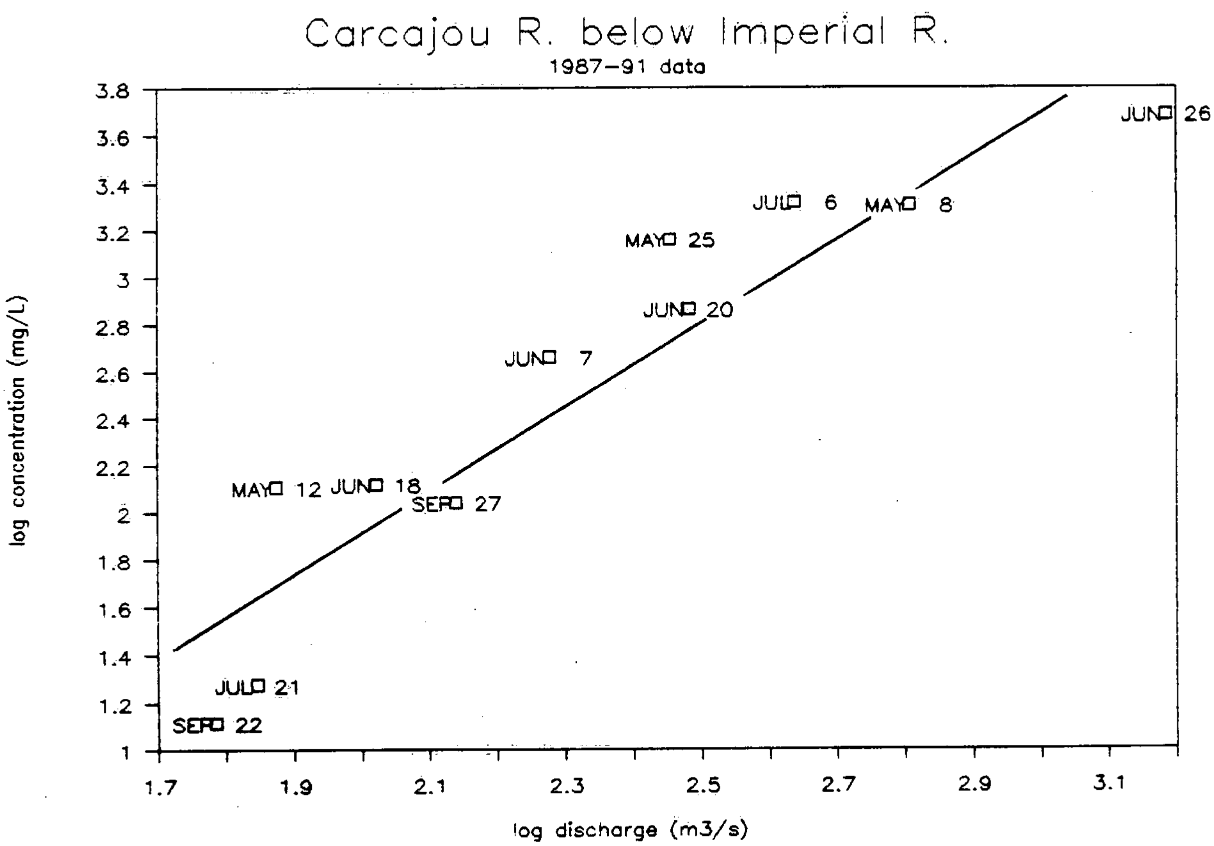


FIGURE 7.2



Carcajou R. below Imperial R.
1987–91 data
log concentration (mg/L)
log discharge (m3/s)
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
1.7
1.9
2.1
2.3
2.5
2.7
2.9
3.1
JUN 26
JUL 6
MAY 8
MAY 25
JUN 20
JUN 7
MAY 12
JUN 18
SEP 27
JUL 21
SEP 22

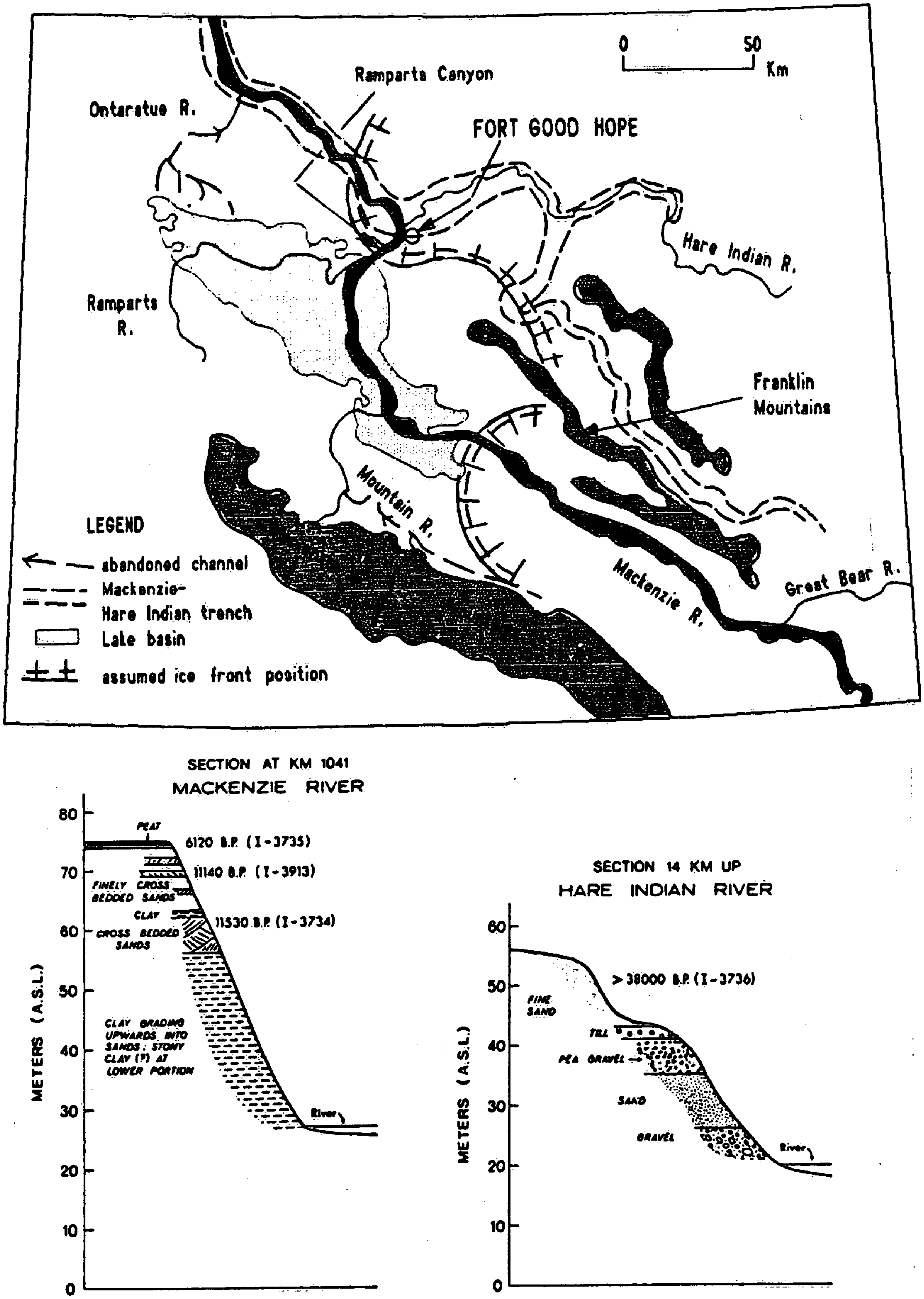


FIGURE 8.1

LATE GLACIAL DRAINAGE CONDITIONS AND
VALLEY FILL STRATIGRAPHY, MACKENZIE RIVER NEAR NORMAN WELLS

(from MacKay and Mathews, 1973)

SKETCH SHOWING LOCATION OF BENCH MARKS AND GAUGING EQUIPMENT. INDICATE DOCKING LANDING AREAS.

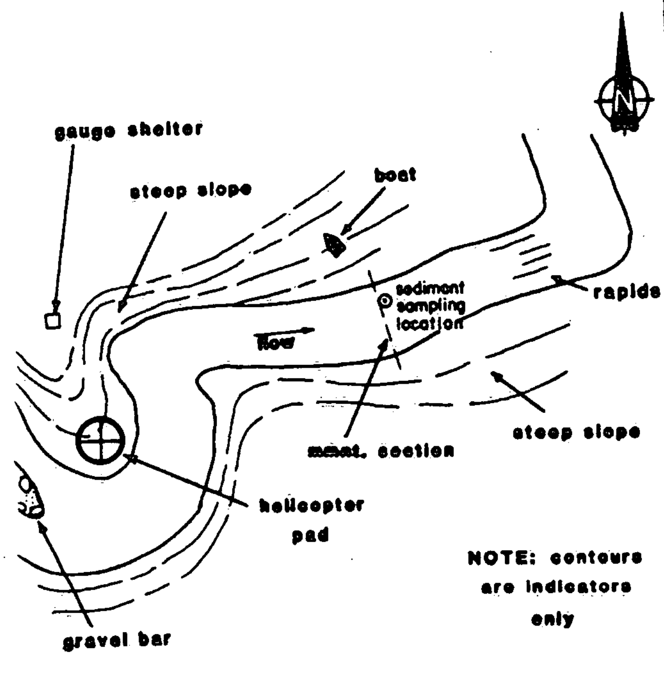
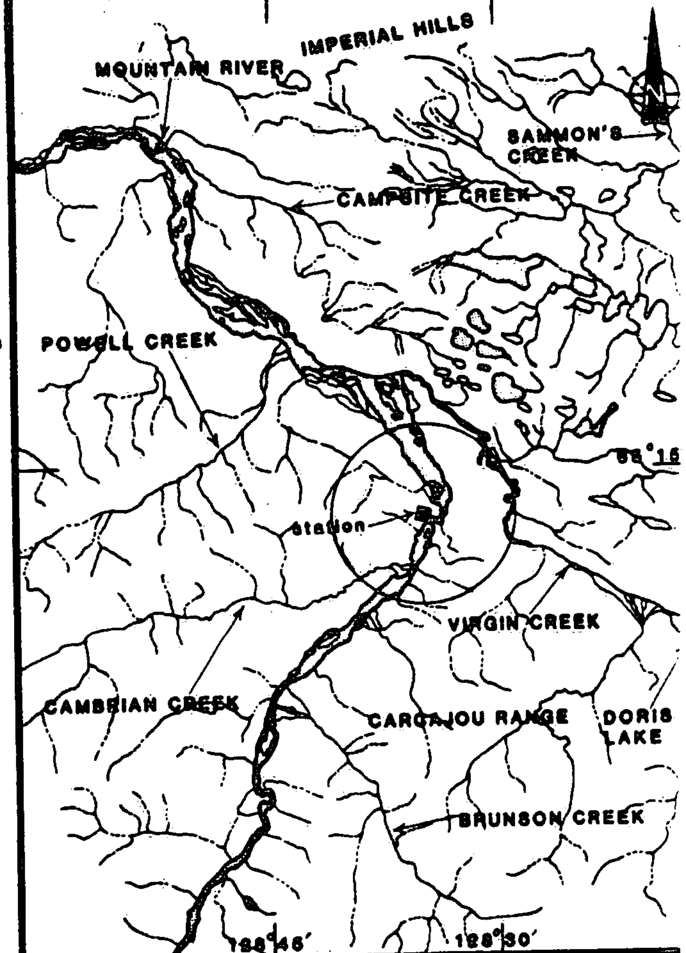


FIGURE 8.2

SKETCH OF STATION LOCATION

SCALE 1:250,000 MAP SAN SAULT RAPIDS 106 H



ENVIRONMENT CANADA
WATER SURVEY OF CANADA

DESCRIPTION OF STATION

Station No. 10KC001 Drainage Area 11 100 km^2

Station Name Mountain River below Cambrian Creek

District NWT

Latitude 65° 13' 46" N Longitude 128° 33' 48" W

Established September 1974 By D.E. Bohnet

Description of Gauging Equipment and Location

Instrument shelter contains a servo-manometer, recorder and data collection platform

Station is located on the left bank 82 km west of Norman Wells. A boat, #50C and #75C sounding weights are secured on the left bank 500 m below the gauge. Access is by helicopter

Sediment sampling equipment required is DH48 sampler, nozzle and waders.

Description of Control & Measuring Sections

Complex channel control consisting of canyon, and braided channel rapids below the gauge.

Sediment sampling done during open water conditions.

Measurements are made by boat at storage site and from ice 100 m below open water section.

Single vertical depth integrating sediment sample taken by wading at site marked on map.

Prepared by M. Hansen Date 19 March 1992

ELEVATION OF GAUGE DATUM AND DESCRIPTION OF BENCH MARKS

Elevation of Gauge Datum 0.000 m, assumed

Conversion Equation to convert to

DCP # 480BF35A, 01:42, 14W, 17°/172°

BM #74-2	Paint mark on rock below gauge	12.664 m
BM #78-1	Paint mark on rock across from BM #74-2 at foot of gauge pool	8.108 m
BM#88-1	Paint mark on rock 8 m east of BM#78-1	6.220 m
BM#88-2	Paint mark on rock 2 m east of BM#88-1	6.751 m

OTHER INFORMATION

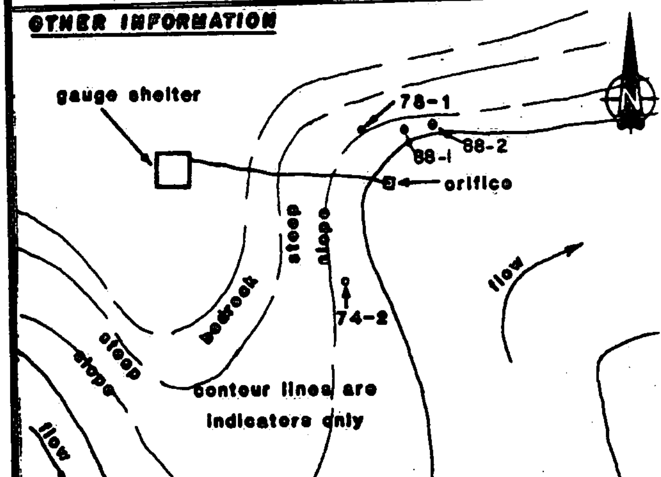
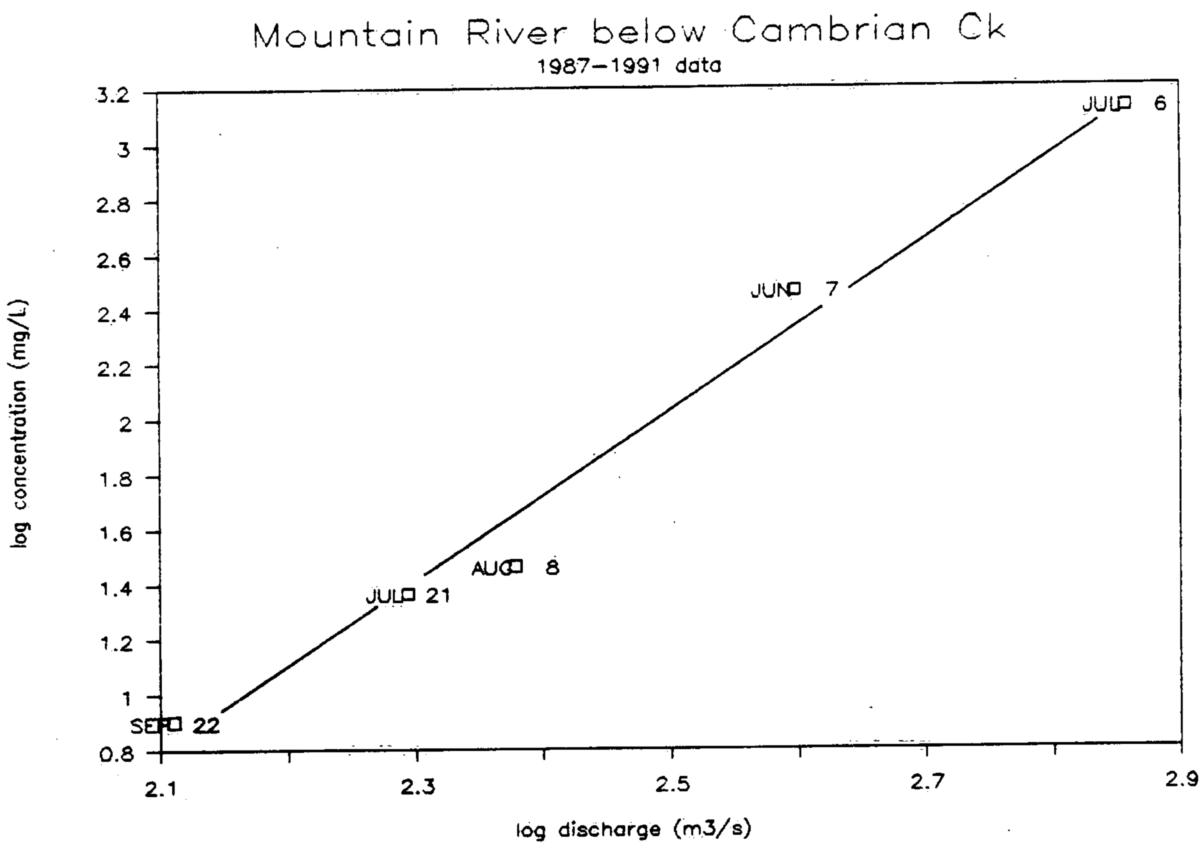


FIGURE 8.3



Mountain River below Cambrian Ck
1987–1991 data
log concentration (mg/L)
log discharge (m3/s)
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
2.1
2.3
2.5
2.7
2.9
JUL 6
JUN 7
AUG 8
JUL 21
SEP 22

SKETCH SHOWING LOCATION OF BENCH MARKS AND GAUGING PLANT. INDICATE DOCKS AND LANDING AREAS.

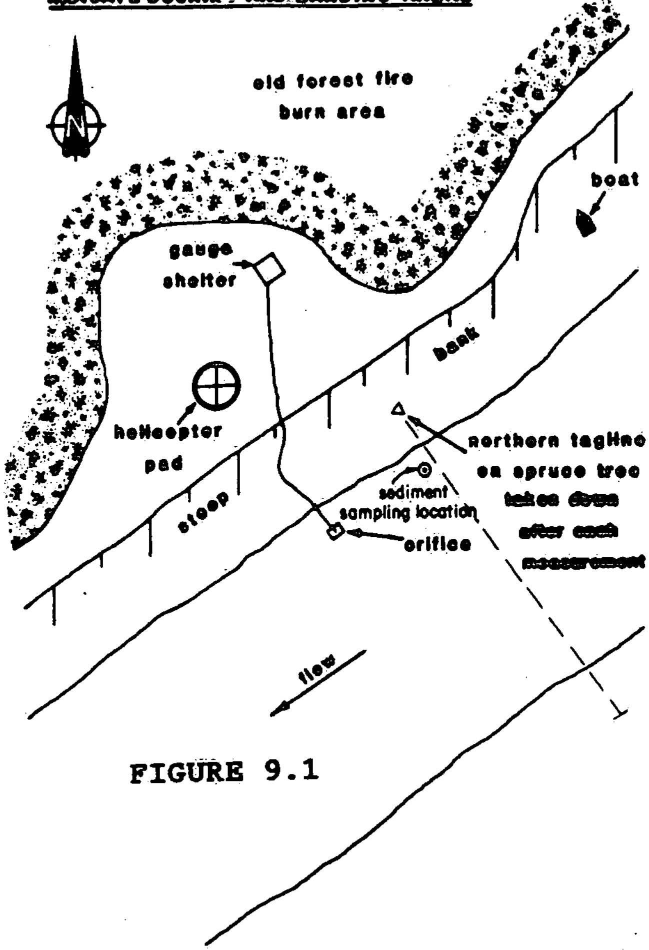
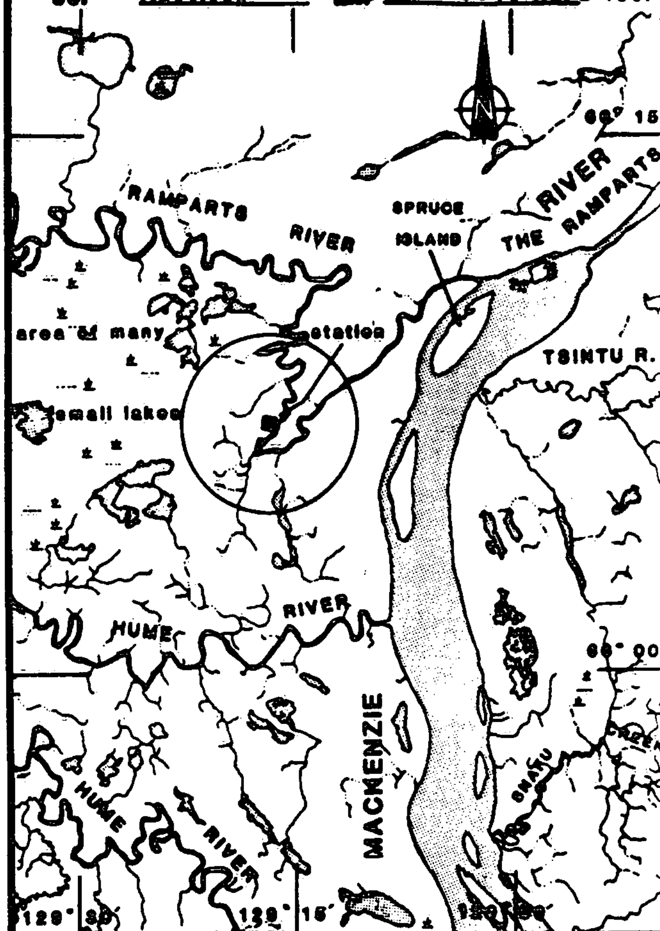


FIGURE 9.1

SKETCH OF STATION LOCATION
SCALE 1:250,000 MAP FORT GOOD HOPE 106I



marsh or swamp -

ENVIRONMENT CANADA
WATER SURVEY OF CANADA

DESCRIPTION OF STATION

Station No. 10KD004 Drainage Area 7 410 km^2

Station Name Ramparts River near Fort Good Hope

District NWT

Latitude 66° 06' 44" Longitude 129° 16' 31"

Established May 1984 By M.A. Hansen

Description of Gauging Equipment and Location

Instrument shelter contains a servo-manometer, recorder and data collection platform.

Station is located on the right bank 33 air km bearing S 59° W of Fort Good Hope and 18 km upstream from the mouth. Access is by helicopter.
Sediment sampling equipment used includes a DH48sampler, nozzle and waders.

Description of Control & Measuring Sections

Channel control with sand/gravel stream bed. All open water measurements are made by boat at section 40 m upstream of gauge. Boat and #50C sounding weight are located 250 m upstream from gauge.
Single vertical depth integrating sediment sample taken by wading at site marked on the map.
Sampling done during open water conditions.

Prepared by M. Hansen Date 19 March 1992

ELEVATION OF GAUGE DATUM AND DESCRIPTION OF BENCH MARKS

Elevation of Gauge Datum 0.000 m, assumed

Conversion Equation to convert to

DCP # 4802236E, 01:52, 22W, 15°/172°

BM #84-1	Iron pin located directly down steep bank by orifice line.	5.485 m
BM #84-2	Iron pin located in southeast of shelter.	12.781 m
BM #84-3	Iron pin located 15 m west of shelter.	12.621 m

OTHER INFORMATION

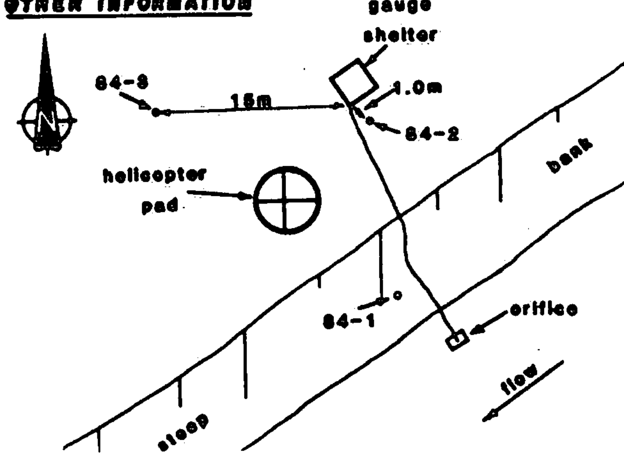
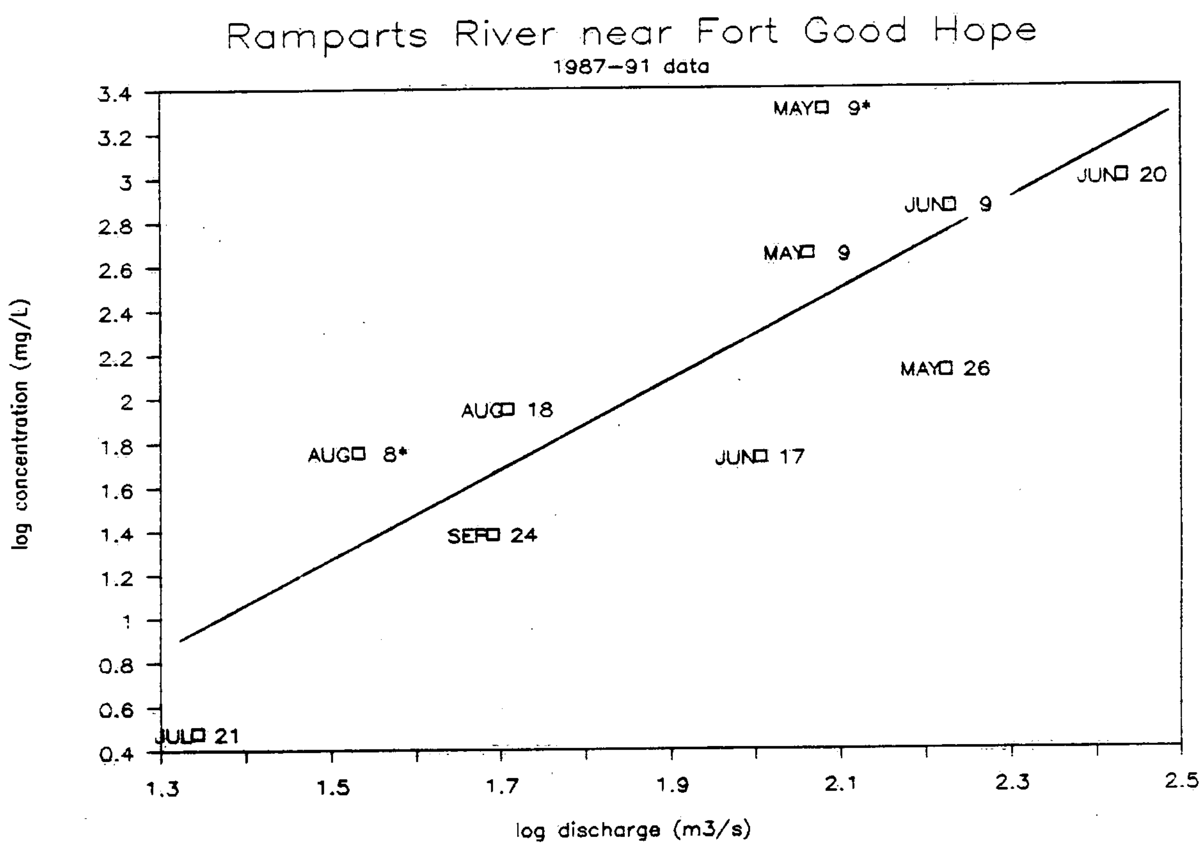


FIGURE 9.2



Ramparts River near Fort Good Hope
1987–91 data
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
log concentration (mg/L)
MAY 9*
JUN 20
JUN 9
MAY 9
MAY 26
AUG 18
AUG 8*
JUN 17
SEP 24
JUL 21
1.3
1.5
1.7
1.9
2.1
2.3
2.5
log discharge (m3/s)