# TOTAL DISSOLVED SOLIDS TRENDS
# IN THE
# SASKATCHEWAN RIVER BASIN

PRODUCED FOR

WATER QUALITY BRANCH

&

WATER RESOURCES BRANCH

ENVIRONMENT CANADA

BY

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## SUMMARY

The Water Resources and Water Quality Branches of Environment Canada have, over the past three decades collected total dissolved solids (TDS) data from surface waters throughout the Saskatchewan River Basin. The Water Resources Branch (WRB) collects TDS as an adjunct to their sediment monitoring program, for the purpose of calculating geochemical yield. Water Quality Branch (WQB) collects TDS samples at their fixed river monitoring stations, and at special project sites, for definition of baseline conditions and assessment of trend in concentrations.

The total database consists of 33,585 samples, which includes 9,771 samples collected by WQB and 23,814 by WRB. Data have been collected at 223 locations. Water Quality Branch has data for 180 sites, WRB for 85 sites and there are 42 sites which overlap. The database is extensive, i.e. greater than 100 samples over at least 5 years, for 64 of the 223 total sites. Thirty-one of these long-term sites are actively sampled by one or other agency. Out of a total of 57 active stations, only 5 sites are currently sampled by both agencies.

The historical database generally covers the entire basin adequately, with a few minor exceptions including the northern tributaries of the mainstem Saskatchewan River and the South Saskatchewan River downstream of the Alberta border. A large proportion of the total sites sampled, 106 of 223, are located along the east slopes of the Rocky Mountains.

The daily TDS concentration of rivers in the Saskatchewan basin can be adequately characterized by one depth integrated sample collected at mid-channel. There is no need for a multiple-vertical sampling strategy, as is required for suspended solids. This means that despite differences in sampling strategy between WRB and WQB, this factor does not need to be accounted for when combining data from both sources. However, WQB data should be multiplied by 1.055 to compensate for analytical differences. WQB estimates TDS by sum of ions, whereas WRB used a direct gravimetric technique.

The TDS record at many points in the basin is substantial, and permits powerful time series analyses. WQB data, which follows a fixed monthly schedule, is more useful in this respect than WRB data which emphasizes high flows and open-water months. The principal long-term trends in TDS concentrations across the basin relate to flow regulation on the North and South Saskatchewan Rivers, which depresses the natural winter TDS maximum, and reduces the annual variance in concentration. More subtle effects from altered land use or increased effluent loadings are not apparent on the South Saskatchewan at Highway 41, or the Red Deer River at Bindloss, but a trend of slowly increasing TDS concentration is detectable on the lower Bow River. Municipal wastes or irrigation return flow are probably responsible for this increase. Dams recently completed or under construction on the Red Deer and Oldman Rivers are expected to disrupt the annual TDS pattern in a manner similar to that experienced by the other regulated rivers in the basin.

In both the ice-cover and open-water seasons, there is a general increase in tributary TDS concentrations from west to east, with concentrations being low in the western sub-basins, intermediate for the North Saskatchewan and Battle sub-basins and high in the eastern sub-basins draining Saskatchewan and Manitoba. The first TDS means >500 mg/L are found in prairie streams at least 100 km east of the mountains. At the opposite end of the basin, in eastern Saskatchewan, concentrations are seldom <500 mg/L and values >1000 mg/L are commonplace.

Main-stem rivers had a nearly constant mean TDS concentration across the basin, ranging between 200 and 300 mg/L, with only a subtle increase from west to east. This trend indicates that dilute mountain runoff dominates main-stem river water concentrations throughout the basin, despite the influx of ion-rich water from the tributaries. The higher main-stem concentrations in the Battle River arise because this sub-basin, and no other, is free of the influence of mountain runoff.

Geochemical loads calculated from WQB data, WRB data or all data combined usually differ by 10% or less, except in winter when under-sampling by Water Resources Branch causes inflated loading estimates. For all other seasons, or annual estimates, data from either Branch will produce reliable results. At most locations, sampling for 10 years will produce estimates of mean TDS loads with a standard error of 10-15%. Sampling beyond this limit will not improve precision of the loading estimate; unless information on changes in load through time is required.

Most of the annual TDS load is carried during the open-water season; the small proprotion carried during ice-cover increases with increasing regulation of stream flow. Rates of geochemical yield are greatest for the mountain and foothill areas relative to the prairies.

## ACKNOWLEDGEMENTS

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## INTRODUCTION

### Background

Total dissolved solids (TDS) is a measure of the concentration of all dissolved substances, primarily salts, contained in water; TDS is the equivalent of suspended sediments (SS) for material in solution. In fresh water TDS is nearly equivalent to salinity, the total mass of inorganic ions in solution. Almost invariably, salinity of fresh water is completely dominated by four major cations, calcium, magnesium, sodium and potassium, and four major anions, bicarbonate, carbonate, sulphate and chloride (Wetzel, 1975). Total dissolved solids includes these ions plus dissolved organic matter and noncharged inorganic molecules such as silica ($SiO_2$).

The gravimetric method for measuring TDS is synonymous with filterable residue and is measured by passing water through a 0.45 um filter and evaporating the filtrate to dryness. This method tends to overestimate salinity because of the inclusion of colloidal material or dissolved organic matter. Alternatively TDS can be estimated as the sum of ions measured independently.

The Water Resources and Water Quality Branches of Environment Canada have, over the past three decades, collected TDS samples from surface water throughout the Saskatchewan River Basin, and have established extensive data bases. The Water Resources Branch (WRB) collects TDS as an adjunct to their sediment monitoring program, for the purpose of calculating geochemical yield (the mass of inorganic ions entering the river over a given period, per unit of land area). Water Quality Branch (WQB) collects TDS samples at all their fixed river-monitoring stations, and at special project sites, for definition of baseline conditions and assessment of trend in concentrations. The primary objective of this project was to analyze the historical TDS data collected by both agencies from the Saskatchewan River Basin, from its headwaters in the Eastern Slopes of the Rocky Mountains to its point of discharge into Cedar

Lake, Manitoba. The full data set consisted of 9,771 samples from WQB and 23,814 from WRB, for a total of 33,585 samples.

Specific objectives were:

- To determine compatibility of data collected by the two Branches, taking into account differences in sampling and analytical methods.
- To summarize the temporal and geographical distribution of the sampling sites, and to compare the two Branches with respect to distribution of sampling sites and overlap between them.
- To summarize the TDS record for each site and for each basin, identify geographic trends in mean TDS concentrations and relate these trends to basin hydrology and geology.
- To assess the utility of the data for analyzing trends in TDS concentration due to interventions such as dam construction, changes in land use and point-source loadings.
- To assess the suitability of the data for calculation of geochemical load.

## The Saskatchewan River

The Saskatchewan River is a tributary of the Nelson River, and drains one of the largest basins (365,000 $km^2$) in the Hudson Bay Drainage. The river's two long branches, the North and South Saskatchewan Rivers, arise from a network of meltwater-fed streams in the Eastern Slopes of the Rocky Mountains. The South Saskatchewan River is formed from the confluence of the Bow and Oldman Rivers in southern Alberta; its only other large tributary is the Red Deer River, which enters just east of the Alberta-Saskatchewan border. Major tributaries of the North Saskatchewan River include the Brazeau, Clearwater and Battle Rivers. About 175 km northeast of Saskatoon, the north and south branches join to form the Saskatchewan River, which continues east and eventually empties into Cedar Lake, Manitoba.

The great divide of the Rocky Mountains defines the western boundary of the Saskatchewan River basin. The basin encompasses essentially all of southern Alberta, much of south and central Saskatchewan and a small part of Manitoba.

The Saskatchewan River system is a typical dendritic drainage, with numerous small tributaries coalescing relatively quickly to form a few large channels. Most of the smaller mountain rivers and streams converge less than 200 km from the mountains. The prairie region is dominated by a few large rivers; major tributaries, such as the Battle River, are rare. There are several internal stream systems in the arid regions (Gap Creek, Eyehill Creek) which end at saline lakes and have no surface connection with the surrounding drainage. Tributary density increases again in the Precambrian Shield region, which the Saskatchewan River flows through below the confluence of the North and South branches, reflecting the higher rainfall and differing geomorphology of the region.

Climate of the basin is continental, with long, cold winters and short, cool summers. Warm, dry adiabatic (chinook) winds moderate temperatures in southern Alberta. Annual precipitation may be as high as 800 mm in the mountains, but over most of the basin it is 400-500 mm, and in the short-grass prairie region of southwest Alberta and south Saskatchewan, it may be as low as 300 mm (Fisheries & Environment Canada, 1978).

Except for the mountain tributaries and the extreme downstream portion of the Saskatchewan River main stem, the entire basin lies within the Interior Plain physiographic region (Fisheries & Environment Canada, 1978). A narrow band of montane forest occupies the mountainous area. Most of the South Saskatchewan River flows through prairie grassland, while the North Saskatchewan sub-basin contains prairie or aspen parkland. At the eastern end of the basin is a small area of boreal forest.

Intense agricultural development extends throughout the basin. Rivers are heavily used for irrigation, especially in the South Saskatchewan sub-basin, and there are many reservoirs, the largest being Lake Diefenbaker in south-central Saskatchewan. Major cities in the basin are Edmonton, Red Deer, Calgary, Lethbridge and Medicine Hat, (Alberta) and Saskatoon, Saskatchewan. Industrial development is centered in these urban areas.

## METHODS

This project used a staged approach in which results from one phase determined the specific analysis procedure to be used in subsequent phases. Each phase corresponds to one section of this report. First, the distribution of sampling sites was examined with respect to geographic and temporal coverage of the basin and the various rivers which compose the drainage network. The two sampling networks were compared for uniformity of distribution and degree of redundancy. Next, the data from the two sources were compared for sampling and analytical compatibility, and the suitability of the data for statistical analysis was determined. This analysis included a comparison of field collection methods and laboratory techniques, with the intent of producing a simple conversion (based on regression analysis) to reconcile the two data bases. Variation in TDS over short (hourly) periods, and across the width of river channels was also investigated. Finally, the data were checked for outliers, and tested for normality.

Regional patterns in TDS concentration were described using simple summary statistics (means and variances) for tributaries and mainstems, in summer and winter. The more difficult problem of identifying temporal patterns was approached with time series analysis. Finally, geochemical loads were calculated by interpolation as used in NAQUADAT (Alberta Environment, 1981).

Much of the computer analysis used a CYBER 730 computer at the Computer Science Centre of Energy and Natural Resources, Ottawa. Water Quality Branch Data was compiled from the national NAQUADAT data base, and combined with Water Resources Branch data on tape. Most analyses used the SPSS statistical package (Nie et al. 1975). Subsets of pertinent data were transferred to microcomputers for analysis using SYSTAT (Wilkinson 1985). Details of statistical methods are given in the relevant sections.

## DISTRIBUTION OF SAMPLING EFFORT

Combining both data bases, there are 265 TDS sampling sites in the Saskatchewan River Basin, 180 from Water Quality Branch (WQB) and 85 from Water Resources Branch (WRB). Of that total, 42 sites overlap, leaving 223 'unique' stations, counting locations sampled by both WRB and WQB as one 'unique' station (Table 1).

Neither WRB nor WQB originally designed their network around TDS. Water Resources Branch obtains TDS as a by-product of laboratory analysis for suspended sediments. This data is of special significance when samples contain a significant proportion of fine particles, and also when bottom withdrawals for particle-size analysis are performed. The primary use of TDS data by WRB is for calculation of total geochemical load (dissolved and particulate). WQB samples TDS for a number of reasons: to accumulate baseline data; to monitor long-term changes in TDS concentration; to compare against water quality objectives; and to double check measured ion concentrations, since they estimate TDS as the sum of ionic constituents.

Bearing these origins in mind, and considering all sites from both sources, geographic coverage of the basin is generally good. Most regions of the basin are represented, and numbers of stations are proportionate with the size of the catchment and the density of the drainage network. Table 2 lists the nine sub-basins which compose the Saskatchewan River Basin, along with the code letters used in classifying Water Survey of Canada hydrometric stations.

Sub-basins A and B, which cover the headwaters in the Rocky Mountains are very well represented, with 53 and 63 unique sampling locations, respectively (Map 1). Both WRB and WQB have taken far more samples from these two sub-basins than from anywhere else in the basin (Fig. 1).

TABLE 1 Summary of sampling sites in the Saskatchewan River Basin
Totals in brackets count shared sites as one.

| | TOTAL | WRB | WQB | SHARED |
|---|---|---|---|---|
| NUMBER OF SITES | 265 (223) | 85 | 180 | 42 |
| NUMBER OF ACTIVE SITES | 57 (52) | 34 | 23 | 5 |
| NUMBER OF: | | | | |
| CLASS I SITES | 64 | 30 | 34 | |
| CLASS II SITES | 96 | 23 | 73 | |
| CLASS III SITES | 105 | 32 | 73 | |

CLASS I >100 samples taken over >5 years

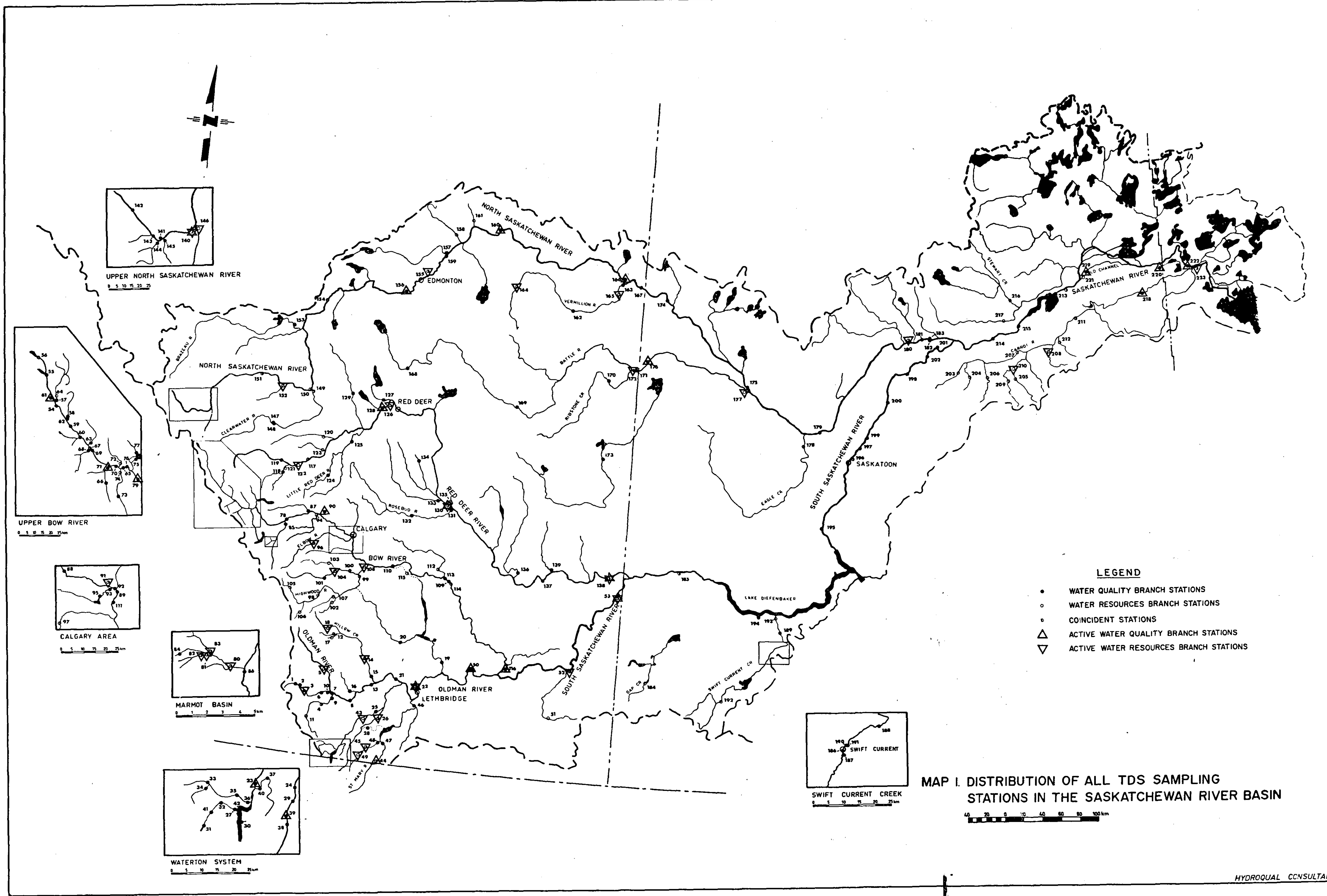
CLASS II 20-100 samples taken over 2-5 years

CLASS III <20 samples or only 1 year of sampling

TABLE 2 Sub-basins of the Saskatchewan River Basin.

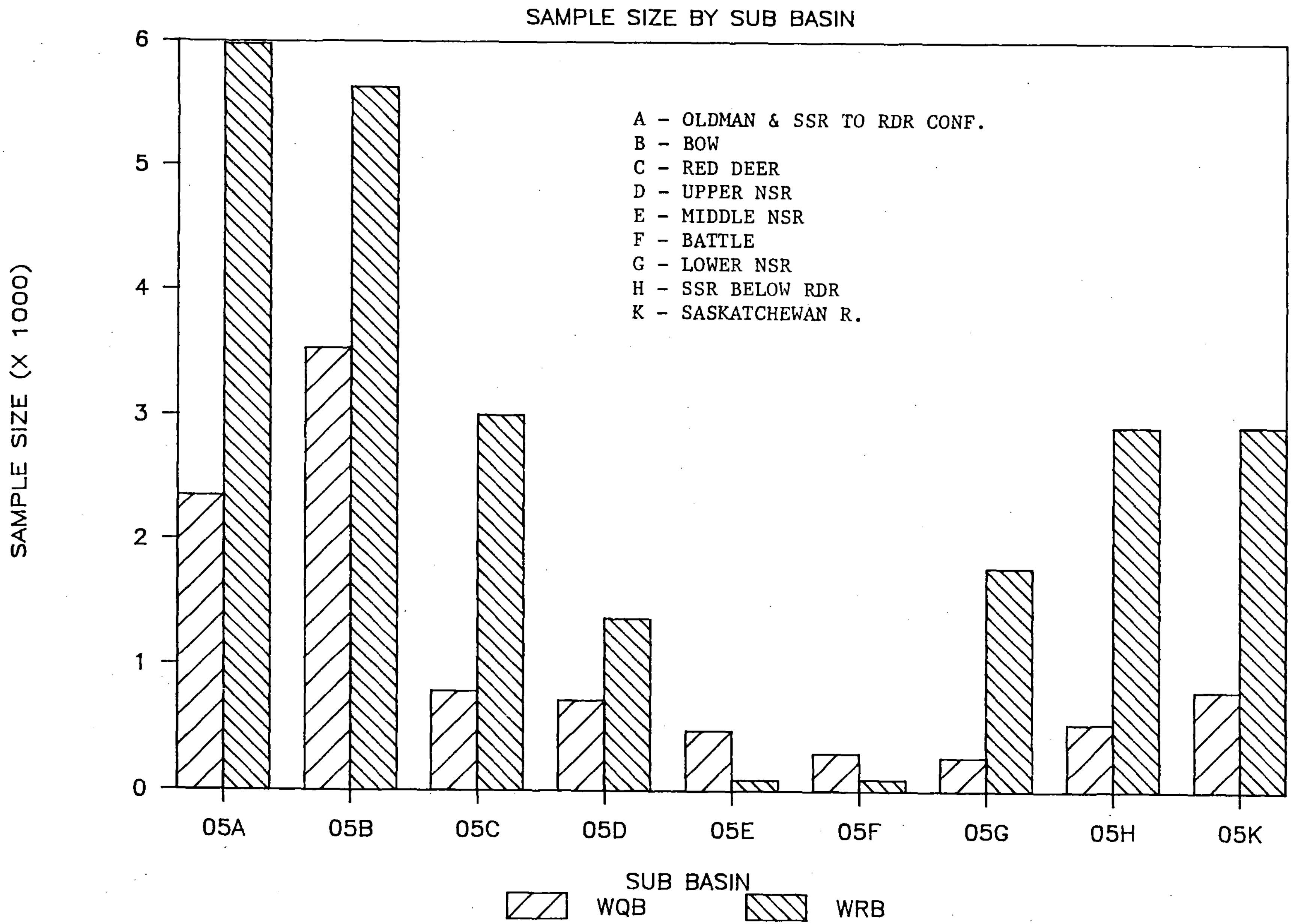
| LETTER* CODE | SUB-BASIN |
|---|---|
| A | OLDMAN AND SOUTH SASKATCHEWAN RIVERS TO CONFLUENCE WITH RED DEER RIVER |
| B | BOW RIVER |
| C | RED DEER RIVER |
| D | UPPER NORTH SASKATCHEWAN RIVER |
| E | MIDDLE NORTH SASKATCHEWAN RIVER |
| F | BATTLE RIVER |
| G | LOWER NORTH SASKATCHEWAN RIVER |
| H | SOUTH SASKATCHEWAN RIVER BELOW RED DEER RIVER |
| K | SASKATCHEWAN RIVER |

*from hydrometric surveys, Water Survey of Canada




MAP I. DISTRIBUTION OF ALL TDS SAMPLING STATIONS IN THE SASKATCHEWAN RIVER BASIN

FIGURE 1 Numbers of TDS samples collected by WQB and WRB in sub-basins of the Saskatchewan River basin.



Distribution of sampling stations is particularly dense in the southern Rockies: Oldman River headwaters area has 11 unique stations, and the headwaters of the Waterton and Belly Rivers have 23 (Map 1). Extensive sampling of streams in Waterton Lakes National Park in 1973-1976 accounts for many of the stations in the latter catchment. Similarly, extensive sampling of the upper Bow River and its tributaries in the mid-70's accounts for the density of locations in that area (Map 1). Coverage of the Bow River in the foothills is weak, with only two stations, and none on the Kananaskis River, an important tributary. Farther north, the Brazeau River, which empties into the North Saskatchewan River, has only one sampling station, and that drew only three samples.

In the prairie grasslands, where watercourses are fewer in number and change character slowly, TDS sampling has been less intense (sub-basins E-H, Fig. 1). However, there are stations at approximately regular intervals along the North and South Saskatchewan Rivers and their major tributaries, the Oldman, Bow, Red Deer and Battle Rivers (Map 1). Virtually all of the smaller rivers, such as Little Red Deer and Rosebud Rivers, Eagle and Swiftcurrent Creeks have been sampled at one or more stations, but in many cases the sample size is small. For instance, only two samples have ever been taken from Ribstone Creek, only six (at two locations) on the Little Red Deer, and only four on the Rosebud River. Even though both WRB and WQB sampled Eagle Creek (which flows into the North Saskatchewan River northwest of Saskatoon) only 11 samples have been taken there.

Sampling in sub-basins E and F (North Saskatchewan River downstream of Edmonton and Battle River, respectively) has been relatively less intensive (Fig. 1). Only 954 samples (considering all WRB samples taken on the same day as one sample) have been collected from both sub-basins, and the Battle River alone accounts for over half (504) (Appendix A). No doubt part of this low sampling frequency is due to a relatively small number of tributary watercourses.

The boreal forest zone, downstream of the North and South Saskatchewan Rivers' confluence has not been thoroughly covered in terms of sample site distribution (Fig. 1). The Carrot River, which for most of its length parallels the Saskatchewan River, has been sampled at 11 locations (including tributaries), three of which are still active (Map 1). But on the north side of the mainstem river only two of the predominantly muskeg tributary catchments, Torch Creek and Whitefox River, have been sampled. No samples have been taken from several small tributaries of the North Saskatchewan River near Prince Albert, (The Garden, Spruce and Sturgeon Rivers and Shell Brook) even though the main river itself has been thoroughly sampled in that area (sites 180-183, Map 1).

For the swampy streams entering the Saskatchewan River below Tobin Lake, a rigorous sampling program is probably not necessary. Drainage of the area is deranged and flow is often sluggish or intermittent, especially in smaller channels; access may be difficult; and muskeg streams are anticipated to have generally similar ionic composition. Nevertheless, sampling of at least the larger channels, such as the Moss, Grassberry and Sturgeon-Weir Rivers would round out baseline coverage for the basin.

Active sampling stations (as of 1983) include 35 for WRB and 23 for WQB; five sites are sampled by both agencies (Table 2) for a total of 53 'unique' active locations. In addition to the five identical locations sampled by WRB and WQB, several other stations are so close in proximity that maintenance of both is likely redundant (Table 3). Historical data from sites sampled by both WRB and WQB have proved useful in comparing sampling and analytical methods. However, if a limited number of sites is to be maintained, efficiency could be improved by eliminating redundant sites.

Water Quality Branch active stations, although few in number, are generally well distributed, in that they sample a cross-section of major rivers throughout the basin. However, WQB has no stations on either the North or South Saskatchewan Rivers downstream of Alberta, although there are three on the Saskatchewan River main stem (Map 1). WRB sampling sites are less

TABLE 3 Coincident and redundant active TDS stations. Coincident stations are those sampled at identical locations by WRB and WQB. Redundant stations are those situated so near to each other that the second provides no new information.

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## COINCIDENT STATIONS

| REFERENCE[1] NUMBER | STATION CODE | | LOCATION |
|---|---|---|---|
| | WRB | WQB | |
| 22 | 05AD007 | 05AD002 | OLDMAN RIVER NEAR LETHBRIDGE |
| 53 | 05AK001 | 05AK0001 | S. SASKATCHEWAN R. AT HWY #41 |
| 130 | 05CE001 | 05CE0001 | RED DEER RIVER AT DRUMHELLER |
| 138 | 05CK004 | 05CK0001 | RED DEER RIVER AT BINDLOSS |
| 140 | 05DA009 | 05DA0001 | N. SASKATCHEWAN R. AT WHIRLPOOL PT. |

## REDUNDANT STATIONS

| | | | |
|---|---|---|---|
| 126 | 05CC002 | | RED DEER RIVER AT RED DEER |
| 128 | | 05CC0004 | RED DEER RIVER AT HWY #2 |
| 172 | 05FE004 | | BATTLE R. NEAR SASKATCHEWAN BOUNDARY |
| 176 | | 05FE0001 | BATTLE RIVER NEAR UNWIN |
| 222 | | 05KH0001 | SASKATCHEWAN R. ABOVE CARROT R. |
| 223 | 05KJ001 | | SASKATCHEWAN R. AT THE PAS |

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1 REFERS TO STATION LIST IN APPENDIX A

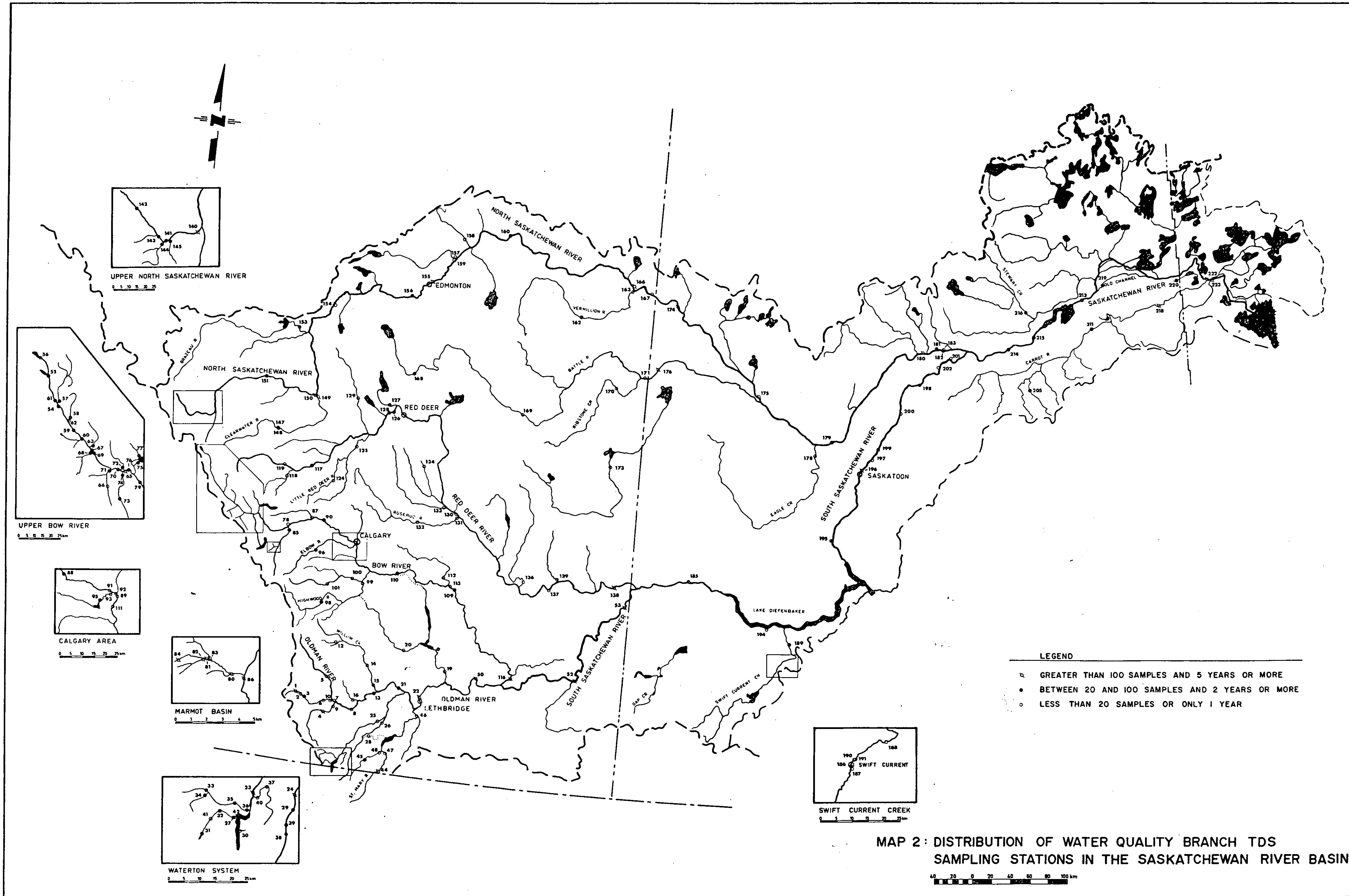
evenly spread, with a strong bias toward foothill rivers, especially in southern Alberta. Coincidentally, the biases of the two agencies tend to complement one another, so that general coverage of the whole basin by the combined sampling sites is adequate, with a few exceptions.

First, sites are concentrated in the Oldman River sub-basin inconsistently with sampling density in the rest of the system. A total of 14 stations are extant above the Bow-Oldman confluence, most of these maintained by WRB. Some of these, such as those on the St. Mary River (Map 1), are on transboundary rivers, but many are on relatively small foothills tributaries (Map 1).

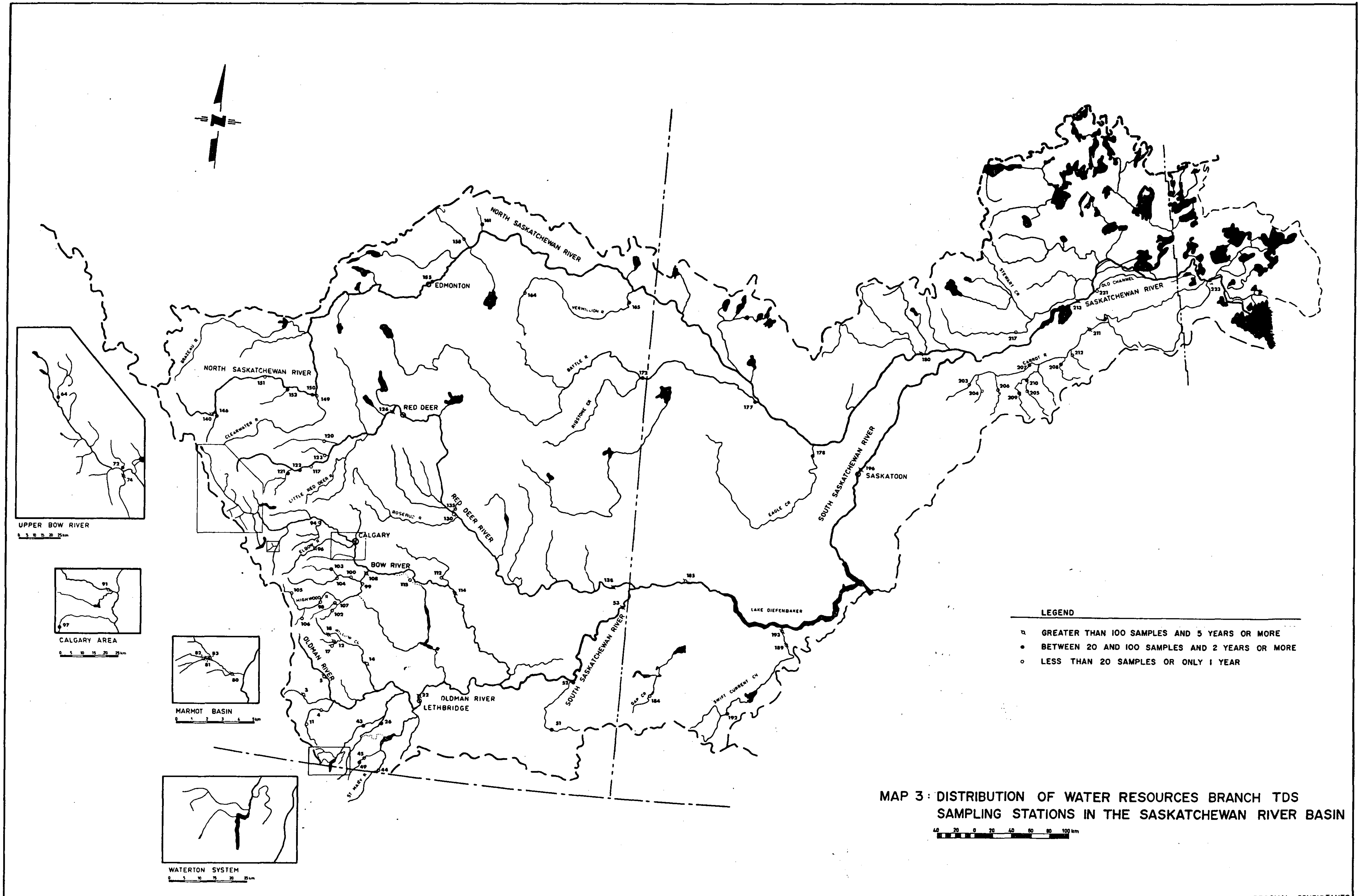
The second apparent deficiency in the active sampling network is the paucity of sites on the South Saskatchewan River. Despite the central importance of this river as the major watercourse in southern Saskatchewan, there are no active TDS sites on the South Saskatchewan River from the Alberta border to its confluence with the North Saskatchewan River. On the other hand, there are three active sites on the Carrot River or its tributaries.

Maps 2 and 3 illustrate the location of all sampling sites, active and inactive for WQB and WRB, respectively. Sites have been classified according to how useful the collected data are, based on the number of samples and the time span over which they were collected. Sites with <20 samples, or only 1 year of sampling permit only a rough approximation of TDS concentrations or loads, and are placed in Class III. Sites with 20-100 samples taken over 2-5 years, (Class II) allow a fair approximation of TDS levels, but data are insufficient to analyze for long-term trends or interventions. The third class, Class I, contains those sites with >100 samples, taken over >5 years; as it turns out all of these sites have been sampled for more than a decade.

About 30 sites from each agency are in Class I (Table 2). A relatively large number of sites (96) are in Class II, and more than one third (105 out of 265; Table 2) fall into Class III, and contain very few data. Not surprisingly, most active sites are in Class I: of 23 WQB active sites, 12




MAP 2: DISTRIBUTION OF WATER QUALITY BRANCH TDS SAMPLING STATIONS IN THE SASKATCHEWAN RIVER BASIN




MAP 3: DISTRIBUTION OF WATER RESOURCES BRANCH TDS SAMPLING STATIONS IN THE SASKATCHEWAN RIVER BASIN

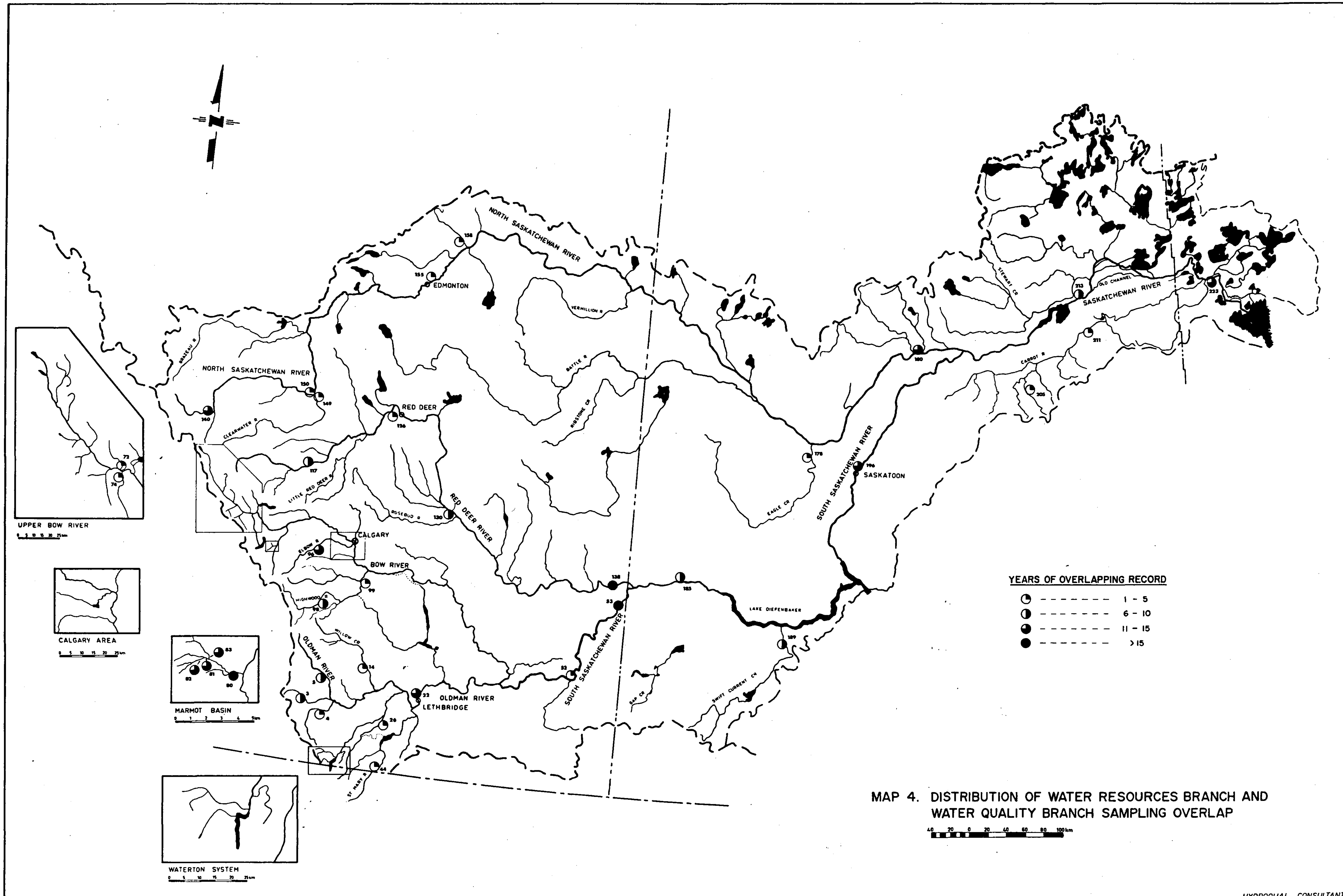
are in Class I, 10 are in Class II, and only one, (site 131) is in Class III (as of 1983). For the 35 active WRB sites, 19, 13 and 3 are in Class I, II and III respectively.

Of the 42 sites sampled by both WRB and WQB, 35 sites were sampled contemporaneously for some period by both agencies (Map 4). At most (21) of these sites, the sampling overlap persisted for more than 5 years. Although redundant sampling is not efficient in terms of allocation of effort, the existence of these shared stations has made possible comparisons of sampling and analytical methods (see following sections).

The WQB and WRB sampling strategies are very different. WQB takes one sample every month on a fixed schedule throughout the year. WRB sampling is flow-dependent, and emphasizes higher flows (when most suspended sediment is transported); sampling during winter or periods of base flow is sparse. Sampling intensity by WQB and WRB is compared with discharge regime for two representative sites, in Table 4. At both sites the WQB sampling regime matches the distribution of real flow fairly closely, but WRB sampling distribution is significantly different from the distribution of flow (Kolmogorov - Smirnov Goodness of Fit test, $p<0.01$). The analysis indicates that WRB does not adequately sample the low flow condition.

## DATA COMPARABILITY AND CONCILIATION

Our ability to calculate geochemical loads, monitor pollution, or assess changes in TDS concentrations caused by changing land-use changes would be improved by combining the WRB and WQB data sets. This is possible if a) TDS concentrations measured by WQB are equivalent to those measured by WRB, or b) a simple conversion factor is found. When formulating such a conversion, a number of differences in sampling methods and analytical techniques, which could lead to systematic differences in TDS estimates, must be taken into account.




MAP 4. DISTRIBUTION OF WATER RESOURCES BRANCH AND WATER QUALITY BRANCH SAMPLING OVERLAP

Table 4 Frequency of TDS sampling by WRB and WQB at two sites in the Saskatchewan River Basin compared to frequency of discharge classes.

| DISCHARGE ($M^3/S$) | % OF TOTAL TIME EQUALLED OR EXCEEDED | % OF TOTAL SAMPLES | |
|---|---|---|---|
| | | WQB | WRB |
| **SOUTH SASKATCHEWAN RIVER AT HIGHWAY #41** | | | |
| 0-100 | 51 | 44 | 25 |
| 100-200 | 25 | 23 | 27 |
| 200-300 | 9 | 10 | 13 |
| 300-400 | 5 | 5 | 9 |
| 400-500 | 2 | 3 | 9 |
| 500-600 | 1 | 5 | 5 |
| 600-700 | 1 | 2 | 4 |
| 700-800 | 1 | 2 | 2 |
| 800-900 | <1 | 1 | 2 |
| 900-1000 | <1 | <1 | 1 |
| >1000 | 1 | 3 | 4 |
| **RED DEER RIVER AT BINDLOSS** | | | |
| 0-25 | 41 | 35 | 10 |
| 25-50 | 22 | 24 | 20 |
| 50-75 | 12 | 14 | 18 |
| 75-100 | 14 | 8 | 12 |
| 100-125 | 8 | 6 | 12 |
| 125-150 | 5 | 4 | 7 |
| 150-175 | 3 | 2 | 5 |
| 175-200 | 2 | 1 | 4 |
| 200-225 | 2 | <1 | 2 |
| 225-250 | 1 | 1 | 2 |
| >250 | 2 | 6 | 8 |

Sampling Error

WQB results are all based on single depth-integrated samples taken by lowering a weighted, open bottle into the water column. Ideally, the bottle is lowered to just above the bed, then raised at a fixed rate such that the bottle fills just as it reaches the surface. In practice the filling rate is hard to estimate so the bottle may be raised and lowered several times. Samples are usually taken about mid-day from a bridge or other projection over the central channel (H. Block, WQB, pers. comm.).

Sampling by WRB is more complex and exacting, and is intended to accurately measure suspended-solids concentrations. At most sites and times, TDS measures are based on depth-integrated samples taken at mid-channel, or at a location judged to be representative of the average suspended sediment concentration, in a manner similar to that described for WQB. However, the sampling bottle is raised and lowered only once. Two replicates are taken at the same point, and the instantaneous TDS concentration is taken as the mean from these two samples.

On selected occasions a more complicated and precise sampling method is employed by WRB to test cross-sectional variability. Water velocity and discharge are measured at points across the river, and based on these measurements the channel is divided into five vertical panels, each representing one-fifth of total discharge. A depth-integrated sample, consisting of two replicates, is then taken at the mid-point of each panel, by the methods described above. The mean TDS concentration for the channel is taken as the mean of the five instantaneous measures. In other instances, the river channel is divided into a variable number of panels of equal width, and samples are taken as in equal-discharge panels. These data are used to calculate correction factors applicable to the data obtained from single mid-channel samples.

To integrate TDS data from the two branches, a decision must be made as to which data from the WRB data set are to be compared against the WQB data. The alternatives are, compressing the WRB data into one mean value for each day, or choosing one datum which corresponds most closely to the WQB datum with respect to time of sampling. If variation in TDS concentrations within one day or across the width of the channel is small, then a single mean value for the day may be used. Therefore, a detailed analysis of temporal and cross-channel variation in WRB data was carried out.

Variation in TDS concentrations across the channel was examined at 20 WRB sites, chosen to represent the range of sub-basins and river types to be found across the Saskatchewan River drainage. Data were selected from 1959 to 1983, i.e. spanning the whole period over which TDS samples have been collected. Samples at some stations were compared over several years to see if improvements in analytical or sampling techniques had caused a change in apparent cross-channel variation. In general, cross-channel variation was low (Table 5). Of the 30 sites/times examined, 16 (53%) had a coefficient of variation (C.V.) less than 3%, 23 (77%) had a C.V. <5%, and none had a C.V. >10%. There were no obvious trends in variability of TDS measurements across channels with mean TDS concentration (range of means: 86-317 mg/L), nor were there any patterns with respect to type of river (prairie river or mountain stream), geographic position in the basin or time of sampling (Table 5).

A more detailed examination of TDS variation across channels was made with data from three sites (Red Deer R. at Red Deer, Red Deer R. at Bindloss, and North Saskatchewan River at Prince Albert), where multiple vertical sampling was repeated regularly, over a period of three or four months. Again, although the range of means was quite broad (175.4-322.0 mg/L), and varied substantially from week to week, at every station cross-channel variation in TDS concentration was respectably small (Table 6). Fourteen out of nineteen cases (74%) displayed C.V.s less than 5%, and in every case but one C.V. was <10%. As before, no trends in cross-channel variation with time, site, or mean TDS concentration appear (Table 6).

For the above three sites, plus two others (North Saskatchewan River at Prince Albert and Saskatchewan main stem at The Pas) analysis of variance

TABLE 5 Cross-channel variation in TDS concentrations at selected sites in the Saskatchewan River basin. (% C.V. = Coefficient of Variation as % of mean; SD = Standard Deviation)

| STATION | DATE | N | MEAN | SD | %C.V. |
|---|---|---|---|---|---|
| AA008 (CROWSNEST R. AT FRANK) | 1980-08-11 | 2 | 258.0* | 0 | 0 |
| AB021 (WILLOW CR; CLARESHOLM) | 1973-05-29 | 6 | 227.2 | 9.5 | 4.2 |
| AD007 (OLDMAN R.; LETHBRIDGE) | 1983-05-31 | 7 | 128.6 | 3.2 | 2.5 |
| AK001 (S. SASKATCHEWAN R.) | 1966-06-08 | 6 | 206.5 | 7.3 | 3.5 |
| | 1978-10-03 | 6 | 180.2 | 3.2 | 1.8 |
| BF019 (CABIN CR; SEEBE) | 1975-10-08 | 2 | 149.5 | 0.7 | 0.5 |
| BH004 (BOW R.; CALGARY) | 1975-07-16 | 3 | 248.3 | 7.1 | 2.9 |
| BJ004 (ELBOW R.; BRAGG CREEK) | 1969-06-06 | 9 | 192.3 | 16.4 | 8.5 |
| | 1983-05-28 | 12 | 182.9 | 4.6 | 2.5 |
| BL021 (HIGHWOOD; PICKLEJAR) | 1976-08-04 | 3 | 138.7 | 11.1 | 8.0 |
| BL024 (HIGHWOOD; MOUTH) | 1972-07-12 | 4 | 177.0 | 4.4 | 2.5 |
| CC002 (RED DEER; RED DEER) | 1981-06-17 | 5 | 222.2 | 3.1 | 1.4 |
| CE001 (RED DEER; DRUMHELLER) | 1982-07-15 | 5 | 230.6 | 1.3 | 0.6 |
| CK004 (RED DEER; BINDLOSS) | 1967-05-03 | 7 | 317.1 | 10.3 | 3.3 |
| | 1983-07-01 | 2 | 281.0 | 2.8 | 1.0 |
| DA009 (S. SASKATCHEWAN R.) | 1981-08-25 | 5 | 86.4 | 3.0 | 3.4 |
| DF001 (N. SASKATCHEWAN R.) | 1975-08-19 | 5 | 199.2 | 4.2 | 2.1 |
| KJ001 (SASKATCHEWAN; THE PAS) | 1959-05-27 | 6 | 234.0 | 21.9 | 9.4 |
| | 1982-10-16 | 5 | 258.2 | 20.2 | 7.8 |
| | 1983-07-19 | 6 | 227.5 | 8.3 | 3.7 |
| | 1983-10-05 | 6 | 219.0 | 9.6 | 4.4 |
| GG001 (N. SASKATCHEWAN R.) | 1964-06-24 | 7 | 198.3 | 15.1 | 7.6 |
| | 1971-04-26 | 29 | 214.0 | 6.0 | 2.8 |
| | 1971-06-15 | 19 | 215.7 | 12.2 | 5.6 |
| | 1982-07-12 | 6 | 206.5 | 5.1 | 2.5 |
| HB001 (S. SASKATCHEWAN R.) | 1965-08-13 | 6 | 219.5 | 11.5 | 5.2 |
| | 1970-05-26 | 6 | 204.2 | 4.3 | 2.1 |
| HG001 (S. SASKATCHEWAN R.) | 1968-10-17 | 6 | 251.2 | 2.1 | 0.8 |
| KB005 (BURNTOUT BROOK) | 1983-04-21 | 6 | 224.3 | 3.0 | 1.3 |
| KC001 (CARROT R.) | 1978-04-19 | 9 | 185.1 | 6.8 | 3.7 |

*BOTH READINGS IDENTICAL

TABLE 6 Cross-channel variation in TDS concentrations at sites sampled regularly by multiple vertical sampling. (SD = Standard deviation; C.V. = Coefficient of Variation as % of mean).

| STATION | DATE | N | MEAN (mg/L) | SD (mg/L) | C.V. (%) |
|---|---|---|---|---|---|
| CC002 | 1981-05-07 | 5 | 258.2 | 13.6 | 5.3 |
| (RED DEER RIVER | 1981-05-12 | 5 | 205.2 | 38.2 | 18.6 |
| AT RED DEER) | 1981-05-23 | 5 | 175.4 | 1.5 | 0.9 |
| | 1981-05-24 | 5 | 180.4 | 2.6 | 1.4 |
| | 1981-06-01 | 5 | 193.2 | 3.0 | 1.6 |
| | 1981-06-17 | 5 | 222.2 | 3.1 | 1.4 |
| | 1981-07-31 | 5 | 180.4 | 11.5 | 6.4 |
| CK004 | 1981-03-25 | 5 | 322.0 | 2.3 | 0.7 |
| (RED DEER RIVER | 1981-05-27 | 5 | 221.6 | 3.5 | 1.6 |
| AT BINDLOSS) | 1981-06-03 | 5 | 205.8 | 7.2 | 3.5 |
| | 1981-06-25 | 5 | 258.0 | 5.0 | 1.9 |
| | 1981-07-22 | 6 | 214.0 | 7.5 | 3.5 |
| | 1981-08-03 | 5 | 216.4 | 4.3 | 2.0 |
| | 1981-08-17 | 5 | 247.0 | 11.8 | 4.8 |
| GG001 | 1978-05-10 | 9 | 246.4 | 6.3 | 2.6 |
| (N. SASKATCHEWAN | 1978-06-15 | 7 | 223.7 | 9.6 | 4.3 |
| R. AT PRINCE | 1978-07-17 | 7 | 195.4 | 14.6 | 7.5 |
| ALBERT) | 1978-07-19 | 7 | 187.4 | 5.6 | 3.0 |
| | 1978-10-17 | 8 | 235.5 | 23.3 | 9.9 |

was used to statistically compare differences in TDS concentration across the channel. Relative channel position was used as the treatment, and sampling dates were treated as replicates. The sampling dates are far enough apart that data remain independent. At four of the five sites, TDS concentrations did not vary significantly across the width of the channel. However, a significant difference ($p<0.05$) did appear at the fifth site, Saskatchewan River at The Pas (Table 7). According to Tukey's Test (Zar 1974), only one position (720 feet from the north shore), had significantly greater TDS concentrations than all other positions but one. This difference appears to be due to water from the Carrot River, which has much higher TDS concentrations than the Saskatchewan River (means 790 and 230 mg/L, respectively) and which enters the Saskatchewan River approximately 3 km upstream of this sampling site. Evidently complete mixing across the wide channel of the Saskatchewan had not yet taken place by the time water reached the sampling site.

Summarily, variation in TDS concentration across the width of river channels is usually small enough that sampling of multiple verticals is not required. This also means the error from combining the multiple vertical WRB data with the single vertical WQB data is justified. Considering the number of sites tested, the effect of mixing zones created by tributary or point-source effluents is not a significant factor with regard to the WRB data. It is improbable that the situation is any different for most WQB sites. In most instances mixing of upstream tributaries and effluents are considered in WQB site selection. These results also mean it is possible to average data from the five WRB verticals to obtain a single TDS estimate.

Using the WRB data it was also feasible to test diurnal variability in river TDS. The WRB data includes some replicate samples taken at intervals throughout a day.

Diurnal variability was examined at four sites (Table 8) where samples had been taken at intervals of an hour or less. The sites include a large river and two small streams, and both prairie and mountain regimes.

TABLE 7 Summary of Anova on cross-channel variation in TDS concentrations for selected sites in the Saskatchewan River basin. (SD = Standard Deviation; NS = Not Significant).

RED DEER R. AT RED DEER (CC002): MAY - JULY 1981

| DISTANCE (FT) | 25 | 38 | 50 | 70 | 90 |
|---|---|---|---|---|---|
| MEAN (mg/L) | 205.0 | 213.5 | 222.5 | 225.0 | 223.3 |
| SD (mg/L) | 53.0 | 27.5 | 33.9 | 27.1 | 35.6 |
| n | 4 | 4 | 4 | 4 | 4 |

ANOVA F = 0.6 (NS) df = 4, 12

RED DEER R. AT RED DEER (CC002): MAY - JUNE 1981

| DISTANCE (FT) | 32 | 50 | 63 | 81 | 101 |
|---|---|---|---|---|---|
| MEAN (mg/L) | 182.7 | 181.3 | 182.0 | 183.3 | 182.3 |
| SD (mg/L) | 8.1 | 6.8 | 10.1 | 10.2 | 6.4 |
| n | 3 | 3 | 3 | 3 | 3 |

ANOVA F = 0.2 (NS) df = 4, 8

RED DEER R. AT BINDLOSS (CK004): MARCH - AUGUST 1981

| DISTANCE (FT) | 112 | 136 | 152 | 164 | 172 |
|---|---|---|---|---|---|
| MEAN (mg/L) | 241.9 | 242.6 | 241.7 | 237.4 | 244.7 |
| SD (mg/L) | 41.0 | 42.0 | 38.6 | 42.1 | 39.7 |
| n | 7 | 7 | 7 | 7 | 7 |

ANOVA F = 1.9 (NS) df = 4, 24

N. SASKATCHEWAN RIVER AT PRINCE ALBERT (GG001): JUNE - OCTOBER 1981

| DISTANCE (FT) | 210 | 375 | 510 | 620 | 655 | 800 |
|---|---|---|---|---|---|---|
| MEAN (mg/L) | 213.8 | 211.8 | 209.3 | 208.3 | 207.5 | 212.0 |
| SD (mg/L) | 25.7 | 26.2 | 28.5 | 31.8 | 29.1 | 21.7 |
| n | 4 | 4 | 4 | 4 | 4 | 4 |

ANOVA F = 0.7 (NS) df = 5, 15

SASKATCHEWAN RIVER AT THE PAS (KJ001): JANUARY - NOVEMBER 1972

| DISTANCE (FT) | 720 | 600 | 580 | 500 | 400 | 230 |
|---|---|---|---|---|---|---|
| MEAN (mg/L) | 273.6 | 254.7 | 248.0 | 247.8 | 250.8 | 242.0 |
| SD (mg/L) | 35.2 | 24.9 | 29.3 | 28.9 | 29.0 | 34.1 |
| n | 9 | 9 | 9 | 9 | 9 | 9 |

ANOVA F = 5.1** df = 5, 40

TUKEY'S METHOD OF MULTIPLE MEANS COMPARISONS: (MEANS OF DISTANCES NOT UNDERLINED BELOW ARE SIGNIFICANTLY DIFFERENT, p<0.05).

| 720 | 600 | 580 | 500 | 400 | 230 |
|---|---|---|---|---|---|
| ------- | ------- | | | | |
| | ------- | ------- | ------- | ------- | ------- |

TABLE 8 Variation in TDS concentrations within one day at four sites in the Saskatchewan River basin. (SD = standard deviation; C.V. = Coefficient of Variation as % of mean).

| STATION | DATE | N | MEAN (mg/L) | SD (mg/L) | C.V. (%) |
|---|---|---|---|---|---|
| AB028 (WILLOW CREEK) | 1970-07-17 | 14 | 193.3 | 9.0 | 4.7 |
| BL024 | 1983-06-03 | 35 | 168.7 | 5.5 | 3.2 |
| | 1983-06-17 | 29 | 192.4 | 8.9 | 4.6 |
| (HIGHWOOD RIVER) | | | | | |
| HB001 (S. SASKATCHEWAN R.) | 1965-04-20 | 11 | 203.1 | 3.8 | 1.8 |
| HD037 (SWIFTCURRENT CR.) | 1971-04-08 | 16 | 248.1 | 18.1 | 7.3 |

Short-term variation in TDS concentrations was always small; the coefficient of variation was <5% in four out of five cases and always <10% (Table 8). Hence, temporal variation is not a problem, and creates no impediment to collapsing multiple daily samples to a single mean value with minimal error. It also implies that one sample per day provides a reliable approximation of the daily average condition. Although these results are based upon WRB data, there is no reason to believe they do not apply equally well to WQB data.

## Analytical Error

A second problem confounding comparisons of WQB and WRB data is the difference in analytical methods used to estimate TDS concentrations. WRB measures TDS directly using an evaporative gravimetric method. The procedure is as follows (R. Yungwirth, Regina Sediment Laboratory, Water Survey of Canada, personal communication): from routine stations, the laboratory receives duplicate 0.5 l samples for each sampling day. Water is not filtered; rather, bottles are allowed to stand for at least 1 week (usually longer) to allow suspended solids to settle out. Then approximately 50 ml from each duplicate is carefully decanted, transferred to a pre-weighed Pyrex evaporating dish, and dried overnight at 105°C. TDS content of the sample is taken as weight gain of the evaporating dish.

WQB calculates TDS concentration as the combined mass of separately measured inorganic ions in solution. Formulae for TDS estimation are (Environment Canada 1985):

$$TDS = Na + K + 0.393(Ca) + 0.234(TH) + Si + SO_4 + Cl + 0.6(TA)$$

where TA = total alkalinity

TH = total hardness

If total hardness is not measured, then

$$TDS = Na + K + Ca + Mg + Si + SO_4 + Cl + 0.6(TA)$$

These equations provide a simple sum of the major ions in solution, with hardness and alkalinity added as empirical factors which allow for any minor ions. This calculation renders a result more closely corresponding to salinity in the strict sense (Wetzel 1975) rather than the broader term of dissolved solids or filterable residue.

Direct measurement is potentially the more accurate of the two methods, but because WRB does not filter the samples, interference from suspended matter is possible. Error from that source is probably small because of the long time samples are allowed to settle before decanting. Overestimation of TDS due to colloidal particles and dissolved organic matter is still a potential source of error. However, some colloidal material would not be removed by filtration in any case (assuming a filter of nominal pore size 0.45 um, as is usual), and organic matter concentrations are usually low in the Saskatchewan River Basin.

The TDS calculation methods used by WQB is free from interference from suspended or colloidal material, but requires that eight or nine other parameters be measured before TDS may be calculated. The large number of contributing error sources increases the error margin of calculated TDS; compensating this, the accuracy of ion determinations by spectrophotometry is very good, so even the combined error expressed in TDS calculations should be low. The TDS formulae are strictly empirical, but solidly based, and since the relative concentrations of ions in surface hard waters are reasonably constant (Wetzel 1975) the accuracy of the formulae is much the same throughout the basin. Further, unaccounted minor ions are unlikely to influence the level of dissolved solids in most samples.

A systematic difference between measured and calculated TDS estimates is possible due to variable measurement of dissolved organics and minor ions. Calculated TDS ($TDS_c$), depending only on concentrations of major ions, is likely to be slightly less than TDS estimated by evaporation ($TDS_m$). Unfortunately, a complete comparison of WRB and WQB is not feasible because so few sites have simultaneous data.

A check did prove possible using data from the WQB data base alone. At a number of sites throughout the basin, simultaneous measures of TDS and filterable residue are available. Filterable residue is the mass of solutes in a volume of water which has passed through a 0.45 um filter, and is therefore equivalent to TDS measured by decanting (the WRB method) assuming error from suspended sediments is negligible.

We calculated a simple regression of filterable residue (FR) on $TDS_c$ (Fig. 2). As expected, there was a small systematic difference, with calculated TDS being slightly lower:

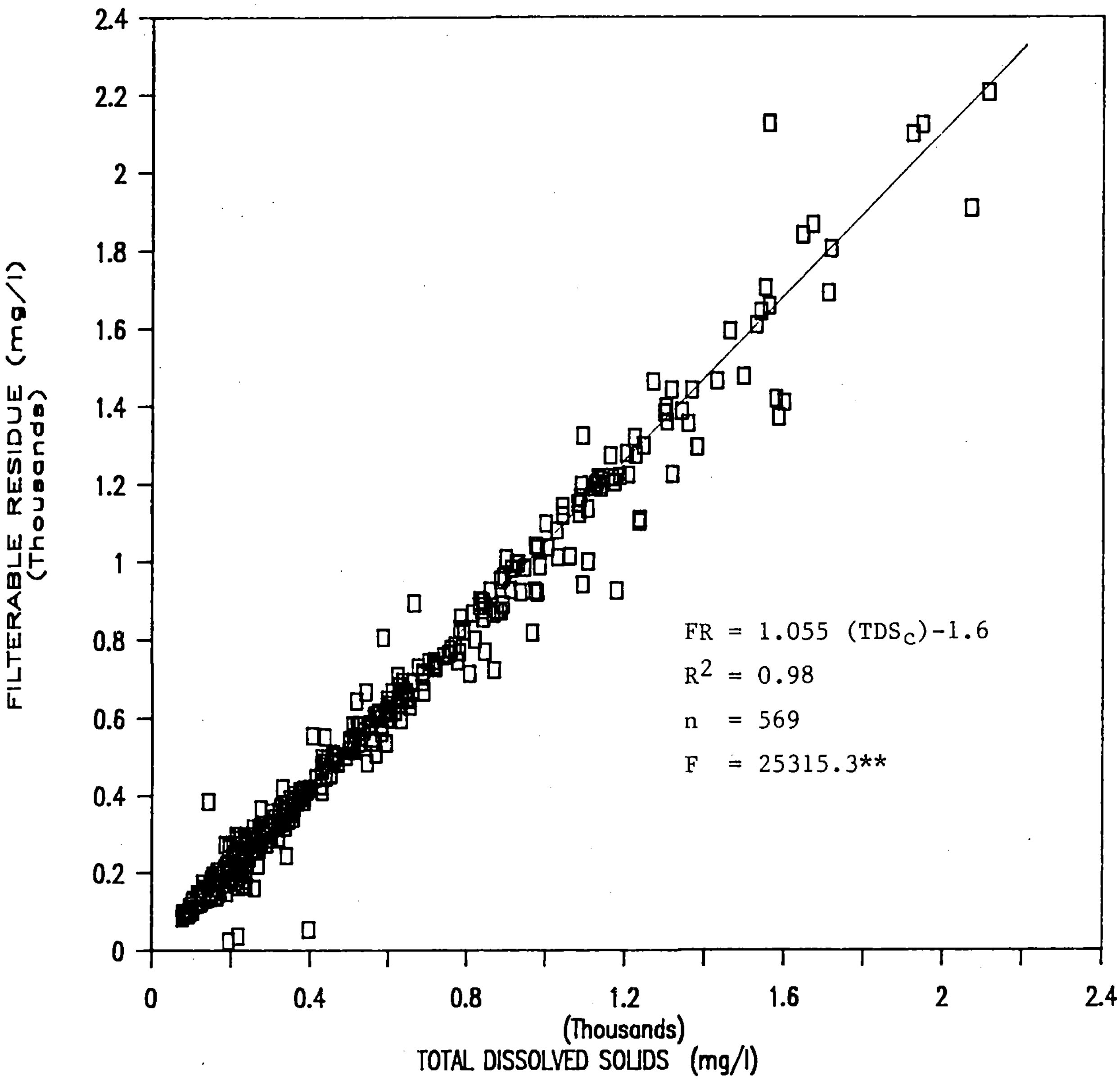
$$FR = 1.055\,(TDS_c) - 1.6$$
$$R^2 = 0.98$$
$$p<0.001$$
$$n = 569$$

The data set had three aberrant values removed. The regression slope is significantly greater than 1 ($t = 8.73$, $p<0.01$, $df = 567$), but the intercept does not significantly differ from zero ($t = 0.41$, $p<0.10$). Examination of residuals plots revealed no problems of non-normality or unequal variances. The 95% confidence interval about the regression slope is small (1.043-1.067), indicating the FR-$TDS_c$ relationship is stable across the basin. Hence, a simple conversion factor (1.055) may be used to convert FR values to $TDS_c$ values, and presumably to convert $TDS_m$ to $TDS_c$ as well. The small value of the conversion factor indicates that, while a systematic difference in TDS measures exists between WQB and WRB, this difference is slight. For instance, a typical TDS value of 250 mg/L from WQB is equivalent to 265 mg/L from WRB. We recommend that this conversion factor be applied whenever data from both Branches is being used.

## Normality

Standard parametric statistical methods require, among other things, that the data display a normal distribution (Zar, 1974). If the distribution

FIGURE 2 Regression of filterable residue concentrations on concentrations of TDS calculated as the sum of ions, for sites in the Saskatchewan River basin.



is badly non-normal, the data must be transformed to achieve normality, or subjected to less robust nonparametric methods (e.g. Lehmann, 1975).

It would be impractical to attempt to test for normality at every site in data sets of the size dealt with here. Instead we chose a subset of 9 WQB sites and 10 WRB sites, selected to span the Saskatchewan River basin from east to west, and to contain representatives of large rivers and small streams, and mountains and plains. The sites were also chosen to contain data sets of varying sizes from very small (<30) to very large (>900), and to span a range of mean TDS levels, from <100 to >1000 mg/L. WQB and WRB stations are considered separately because the different sampling strategies employed by the two Branches could bias the data in different directions. Normality was tested with the Kolmogorov-Smirnov Goodness-of-Fit test (Ostle and Mensing, 1975) at a 95% confidence level.

Data distributions were normal at all nine of the WQB sites (Table 9), but at only five of the WRB sites (Table 10). The critical factor determining whether data from any given site would be normal appeared to be sample size. All the sites from WQB had fewer than 220 data. Sites from WRB were also normal up to a sample size of 122 (Table 10), but larger samples became increasingly skewed. There is no other discernable pattern with respect to type of river, geographic location, or TDS concentration.

Three kinds of data distributions were encountered, illustrated in Fig. 3. WQB data from the Saskatchewan River at The Pas (Fig. 3a) displays an exemplary normal distribution, which has neither skewness, kurtosis (flattening) nor a long tail. Such distributions are typical of smaller data sets. The data distributions of Streeter Creek at Nanton (Fig. 3b) and Red Deer River near Drumheller (Fig. 3c) illustrate the two sorts of non-normal distributions encountered (Streeter Creek at Nanton is marginally normal at the 95% level). Both are strongly skewed toward lower or higher values, with a long tail on one side. The Red Deer River distribution, i.e. biased toward low values, was the more common distribution among non-normal data sets.

TABLE 9 Summary of Kolmogorov-Smirnov test for normality on TDS data from nine sites sampled by Water Quality Branch.

| SITE | N | MEAN (mg/L) | TEST OF NORMALITY D[1] | PROB.[2] | RESULT |
|---|---|---|---|---|---|
| CRANDELL CR. NEAR CRANDELL L. (AD0052) | 24 | 82.4 | 0.165 | 0.53 | NORMAL |
| SWIFT CURRNT CR, STEWART VALLEY (HD0004) | 36 | 736.0 | 0.199 | 0.12 | NORMAL |
| N. SASKATCHEWAN AT BORDEN (GD0001) | 45 | 224.4 | 0.089 | 0.87 | NORMAL |
| RED DEER R. AT RED DEER (CC0004) | 68 | 228.3 | 0.128 | 0.22 | NORMAL |
| KANANASKIS R. AT KANANASKIS (BF0006) | 83 | 173.0 | 0.071 | 0.79 | NORMAL |
| BELLY R. AT WATERTON (AD0060) | 92 | 102.7 | 0.095 | 0.38 | NORMAL |
| SASKATCHWAN R. AT THE PAS (KJ0001) | 113 | 240.4 | 0.064 | 0.75 | NORMAL |
| BOW R. NEAR MOUTH (BN0001) | 147 | 200.1 | 0.066 | 0.54 | NORMAL |
| BATTLE R. AT UNWIN (FE0001) | 216 | 563.6 | 0.049 | 0.69 | NORMAL |

1. Value of Kolmogorov-Smirnov statistic indicating maximum deviation from the normal distribution.

2. Significance level of observed D.

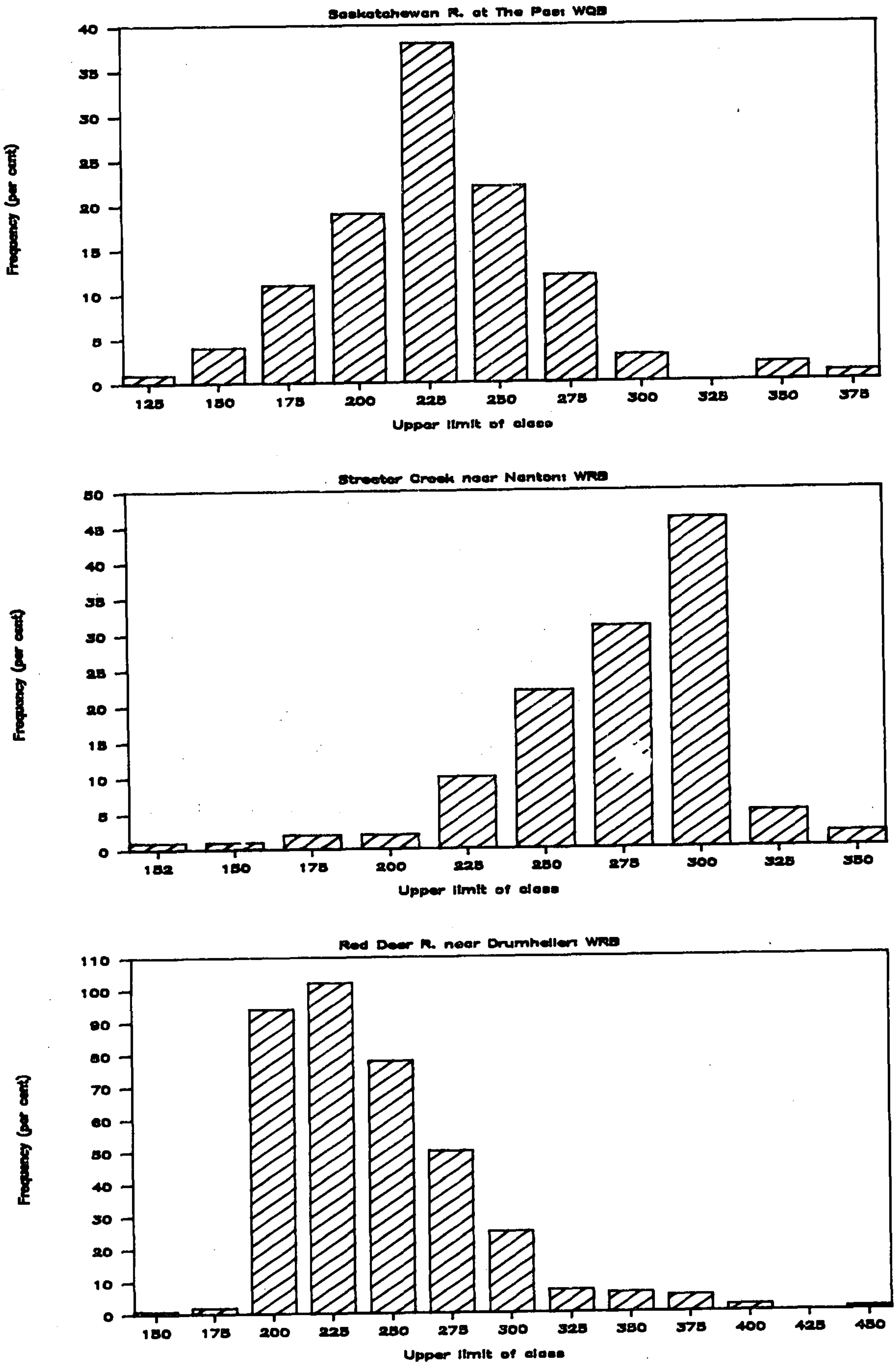
TABLE 10 Summary of Kolmogorov-Smirnov test for normality on TDS data from ten sites sampled by Water Resources Branch.

| SITE | N | MEAN (mg/L) | TEST OF NORMALITY D[1] | PROB.[2] | RESULT |
|---|---|---|---|---|---|
| LEATHER R. AT STAR CITY (KB006) | 22 | 265.5 | 0.187 | 0.43 | NORMAL |
| EAGLE CR. AT ENVIRON (GC006) | 30 | 1348.0 | 0.106 | 0.89 | NORMAL |
| WESKATENAU CREEK (EC002) | 40 | 379.2 | 0.090 | 0.91 | NORMAL |
| PIPESTONE CR. AT L.LOUISE (BA002) | 78 | 90.5 | 0.070 | 0.83 | NORMAL |
| STREETER CR. AT NANTON (AB030) | 122 | 262.8 | 0.118 | 0.07 | NORMAL |
| SASKATCHWAN R., TOBIN L. (KD003) | 161 | 234.7 | 0.106 | 0.05 | NON-NORMAL |
| OLDMAN R. AT WALDRON'S CNR. (AA023) | 263 | 177.9 | 0.090 | 0.03 | NON-NORMAL |
| RED DEER R., DRUMHELLER (CE001) | 371 | 230.8 | 0.096 | 0.00 | NON-NORMAL |
| ELBOW R. AT BRAGG CR. (BJ004) | 622 | 206.3 | 0.063 | 0.02 | NON-NORMAL |
| S. SASKATCHWAN AT SASKATOON (HG001) | 981 | 228.3 | 0.052 | 0.01 | NON-NORMAL |

1. Value of Kolmogorov-Smirnov statistic indicating maximum deviation from the normal distribution.

2. Significance level of observed D.

FIGURE 3 Typical frequency distributions of TDS data.



To further investigate this pattern, at five sites with overlapping data the distributions of the combined dataset were compared with those of the WQB and WRB defined separately. WRB data were non-normal at every site (Table 11), and the sample sizes were all large (413-1861). WQB data were distributed normally at three sites with <110 samples (Table 11), but non-normal at the remaining two sites with over 200 samples. Combining data from WQB and WRB produced no improvement in normality. These findings tend to confirm that something inherent to sample size, not sampling regime, is primarily responsible for these apparent differences in normality.

Log-transformations of the data (Table 11) usually reduced the skewness of data distributions slightly, but was never sufficient to render a distribution normal, as judged by the Kolmogorov-Smirnov test. Further, two of three normally distributed WQB data sets were rendered non-normal by log-transformation. The square root arcsine transformation:

$$(x' = \arcsin (x)^{1/2})$$

was applied to data from several sites but also produced no improvement (data not shown).

We conclude then that any data set from WRB or WQB should be assumed to be non-normally distributed if sample size exceeds 150. Unlike other water quality parameters such as suspended sediments, which are almost invariably log-normally distributed, TDS data do not appear amenable to this transformation. If normality of the data must be considered in data analysis procedures no alternatives remain except searching for other, less common and more complex transformations, or proceeding with non-parametric statistical methods.

Analysis of Outliers

Outliers were detected by comparing data to the mean and standard deviation (SD) for that site. In normally distributed data, 99.74% of all

TABLE 11 Summary of Kolmogorov-Smirnov test for normality on untransformed and log-transformed TDS data from selected sites in the Saskatchewan River basin where WRB and WQB sampling periods are coincident.

| SITE | N | UNTRANSFORMED D[1] | UNTRANSFORMED PROB.[2] | UNTRANSFORMED RESULT | LOG-TRANSFORMED D[1] | LOG-TRANSFORMED PROB.[2] | LOG-TRANSFORMED RESULT |
|---|---|---|---|---|---|---|---|
| N. SASKATCHEWAN R. AT PRINCE ALBERT: | | | | | | | |
| COMBINED | 1235 | 0.100 | 0.0 | NON-NORMAL | 0.050 | 0.004 | NON-NORMAL |
| WQB | 107 | 0.123 | 0.080 | NORMAL | 0.141 | 0.029 | NON-NORMAL |
| WRB | 1128 | 0.109 | 0.0 | NON-NORMAL | 0.051 | 0.005 | NON-NORMAL |
| S. SASKATCHEAN R. AT SASKATOON: | | | | | | | |
| COMBINED | 893 | 0.051 | 0.019 | NON-NORMAL | 0.083 | 0.0 | NON-NORMAL |
| WQB | 82 | 0.126 | 0.149 | NORMAL | 0.121 | 0.179 | NORMAL |
| WRB | 811 | 0.060 | 0.005 | NON-NORMAL | 0.085 | 0.0 | NON-NORMAL |
| OLDMAN RIVER AT LETHBIRDGE: | | | | | | | |
| COMBINED | 413 | 0.109 | 0.0 | NON-NORMAL | 0.082 | 0.007 | NON-NORMAL |
| WQB | 68 | 0.141 | 0.131 | NORMAL | 0.184 | 0.020 | NON-NORMAL |
| WRB | 345 | 0.140 | 0.0 | NON-NORMAL | 0.114 | 0.0 | NON-NORMAL |
| RED DEER RIVER AT BINDLOSS: | | | | | | | |
| COMBINED | 1786 | 0.111 | 0.0 | NON-NORMAL | 0.074 | 0.0 | NON-NORMAL |
| WQB | 203 | 0.157 | 0.0 | NON-NORMAL | 0.105 | 0.022 | NON-NORMAL |
| WRB | 1583 | 0.096 | 0.0 | NON-NORMAL | 0.074 | 0.0 | NON-NORMAL |
| TWIN CREEK: | | | | | | | |
| COMBINED | 747 | 0.082 | 0.0 | NON-NORMAL | 0.080 | 0.0 | NON-NORMAL |
| WQB | 224 | 0.116 | 0.005 | NON-NORMAL | 0.135 | 0.001 | NON-NORMAL |
| WRB | 523 | 0.095 | 0.0 | NON-NORMAL | 0.070 | 0.013 | NON-NORMAL |

1. Value of Kolmogorov Statistic indicating maximum deviation from the normal distribution.
2. Significance level of observed D.

observations will be within three SD of the mean (Snedecor and Cochran, 1980), so any datum lying beyond 3 SD of the mean is possibly aberrant. In data sets of this size, it is impractical to scan data from every site, therefore a simpler computer based procedure was utilized. For each site, the maximum value was subtracted from the mean plus 3 SD, and the minimum was subtracted from the mean minus 3 SD. Results <0 represent the difference between the extreme value and normal limit, and indicate the value is a potential outlier.

While this test flags extreme points, it does not conclusively determine whether they are true outliers; even a dataset with a theoretically perfect normal distribution would still have a few points (0.26% of the total) that were >3 SD from the mean, and the proportion increases as the distribution becomes less perfectly normal. Hence, outliers should be removed only with caution.

To double check that extreme values were indeed aberrant, and not just tails of the distribution, an outlier statistic was calculated according to the formula (Davies and Goldsmith, 1972):

$$R = \frac{(\text{mean} - \text{observed})}{SD}$$

where 'observed' refers to the datum being checked. Results were compared to tables in Davies and Goldsmith (1972) for n<30, and in Beyer (1971) for n>30, at a 5% significance level.

A total of 61 extreme values were deviant out of a possible 530. WQB sites had 30 outliers, and WRB had 31. Of these totals, 24 and 26 respectively were high outliers, and the remainder (6 and 5) were low. Given the size of the total data sets (9,800 and 24,000 data) this number of outliers is proportionately very low, and indicates there are few errors in the data.

Outliers are of two sorts 1) bad data, that is, errors of analysis, sample collection, or transcription; 2) true outliers: correctly sampled observations which belong to a different sample distribution than the rest of the data. Outliers of the first kind are usually obvious upon inspection. Of the 61 outliers detected, none are conspicuously wrong, implying that these are true statistical outliers, not errors.

These results imply the datasets do not contain a significant proportion of the "bad data points", which would tend to produce misleading results upon analysis. The data checking and handling procedures employed by both agencies to ensure data quality appear to be working well.

## TEMPORAL PATTERNS IN TDS

Long-term trends in TDS concentrations may result from land-use changes, altered effluent loadings or from changes in the hydrologic regime caused by interventions like dam construction. Subtle changes in concentration may be difficult to detect by plotting raw data against time because of naturally occurring seasonal or annual fluctuations. Time series analysis is a body of methods used to separate long-term trends or cyclic patterns from short-term variation. The strength of time series analysis often suffers from lack of data. The extraordinarily large TDS database available for many locations in the Saskatchewan River Basin (15-25 years) is ideally suited for time trend analysis. At selected locations long-term trends were evaluated using moving average, sine curve and regression analysis techniques.

### Moving Average & Sine Curve Analysis

Moving averages were calculated by averaging each point in the time series with a set number of adjacent points on each side. The resulting smoothed curve has had day to day variation suppressed so that long-term trends are more apparent. Trends over longer or shorter periods may be emphasized by including more or fewer terms in the moving average; the best results usually arise from repeated smoothing using a different number of terms each time. After considerable experimentation, a two-stage "filter", achieved by smoothing once with a 4-term moving average, and then again with a 24-term moving average was found to work well for most TDS data. Fig. 4 illustrates the effect of this filter on TDS data from the North Saskatchewan River at Prince Albert. The numerous spikes in the top graph, which result from short-term variation in TDS load, have been removed in the filtered series (bottom), making the annual cycle more apparent.

Sine curve analysis, following the method of Steele (1982), allows removal of annual average patterns. The general form of the equation is:

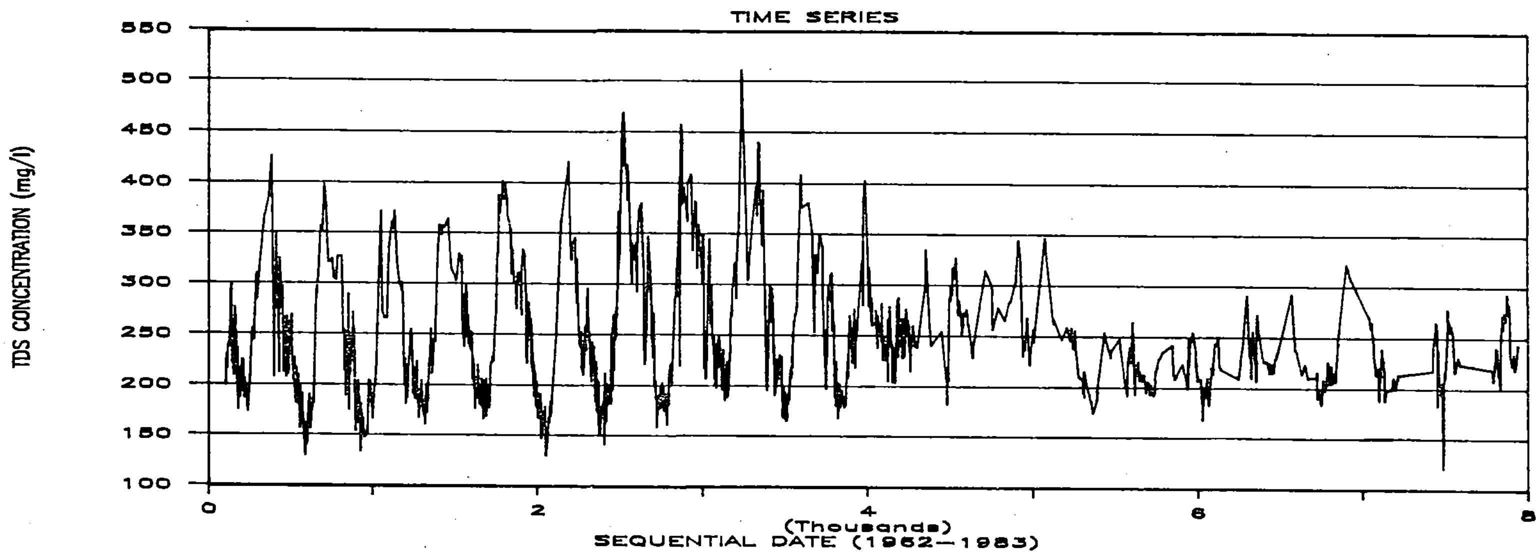
$$TDS\ (x) = A\ [\sin\ (bx + C)\ ] + B$$

where TDS (x) = TDS concentration (mg/L) on day x of the year,
A = amplitude of the harmonic (mg/L),
b = a constant, 0.0172 radians/day which converts day of the year to arc of a circle,
x = day of the year (Julian day),
C = phase angle of the harmonic in radians, and
B = mean of the harmonic (mg/L).

An iterative method of curve-fitting was used; a value for C, the phase angle of the harmonic, was supplied as a constant for each iteration. The phrase [sin(bx+c)] then contained no variables except x, and the model equation could be simplified to a simple straight line (y=a+bx), which was fit to the data using ordinary least squares regression. The best fit sine wave, as judged from $R^2$-values, was found by repeated iterations with different values of C. Fig. 5 shows the best fit regression for the North Saskatchewan River at Prince Albert.

The sine curve, by modelling the seasonal increases and decreases in TDS concentration, removes this source of variation from the time series. Consequently the residuals largely reflect long-term trends, with the seasonal cycle removed, plus the variance left unaccounted by sine curve regression. Short-term noise from random variation was removed from the residuals series by calculating 4,24-term moving averages, as described above. Figure 6

FIGURE 4 Time series of TDS data (top) and smoothed data (bottom) from the North Saskatchewan River at Prince Albert



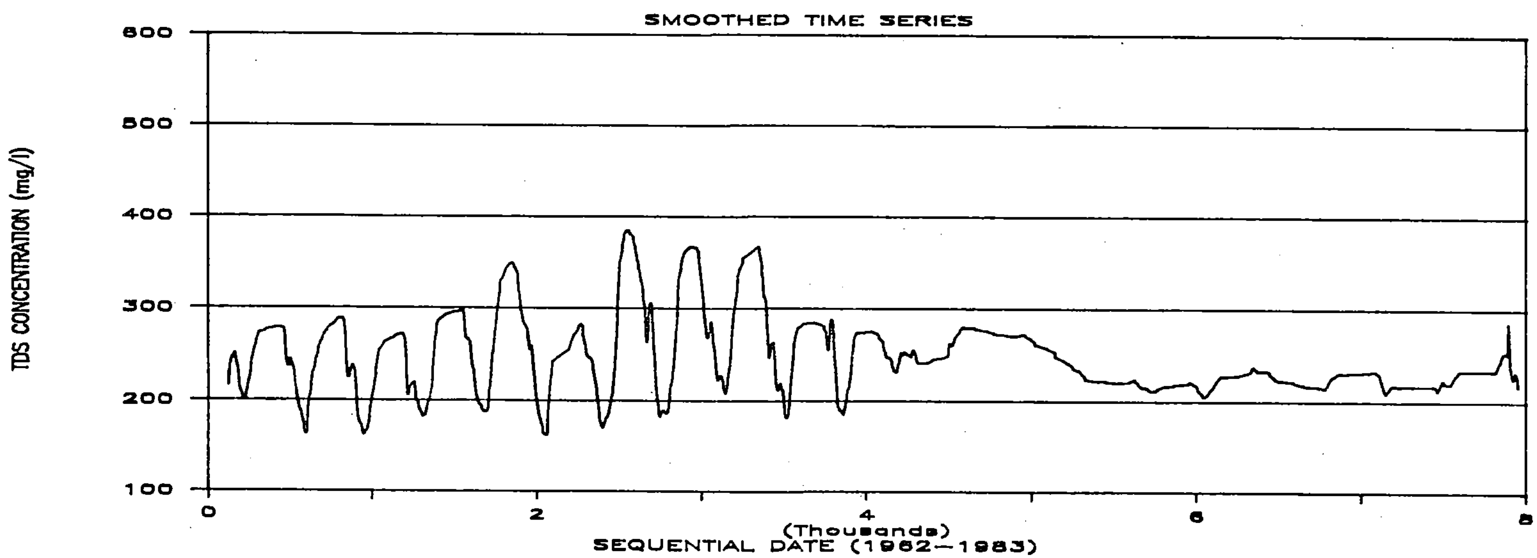



FIGURE 5 Annual pattern of TDS concentrations from the North Saskatchewan River at Prince Albert, and the best fit sine wave regression.

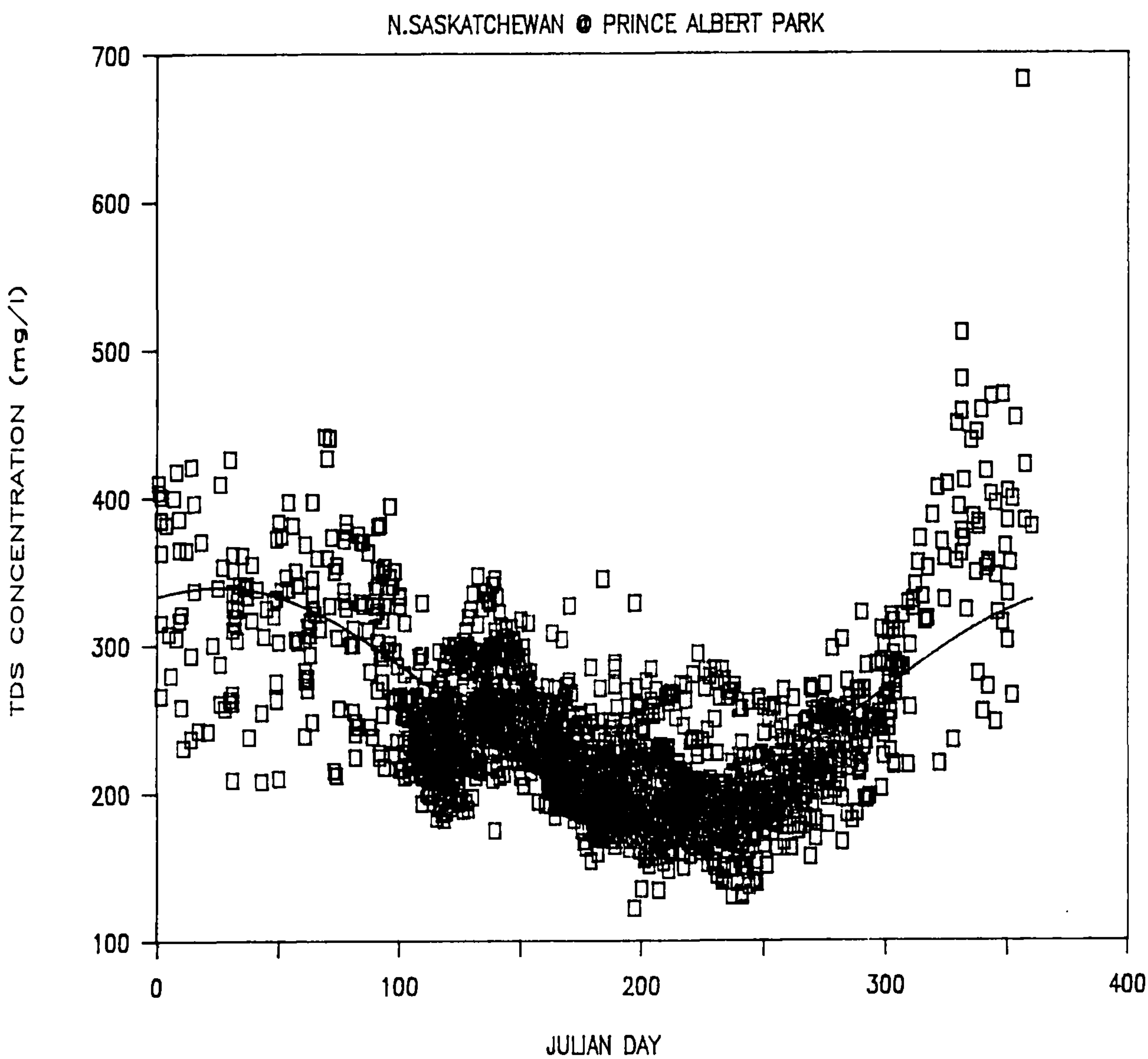
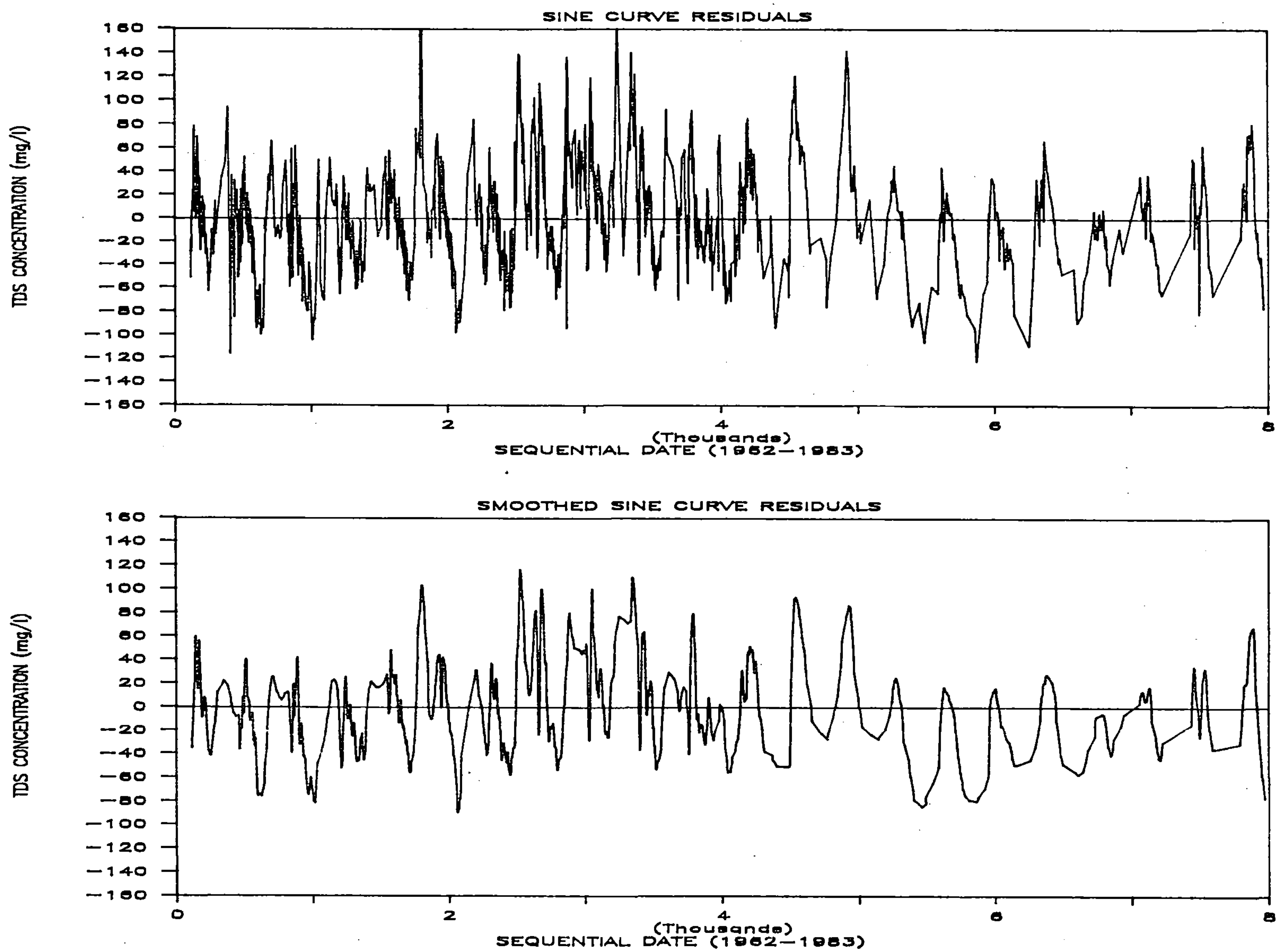


FIGURE 6 Annual pattern of TDS concentrations from the North Saskatchewan River at Prince Albert and the best fit sine wave regression



illustrates the pattern of residuals before and after smoothing for the North Saskatchewan River at Prince Albert.

Sites for moving average and sine curve analysis were chosen on the basis of a long, preferably continuous record of TDS, known or suspected interventions that might be expected to alter TDS loads, and to represent different regions throughout the basin. Combined data from WQB and WRB were used.

Table 12 summarizes results of sine curve analysis for nine sites in the Saskatchewan River basin. The raw data and best-fit sine curves are plotted in Appendix B. At only three sites did $R^2$ values exceed 0.5, and the best regression, Bow River at the mouth, had an $R^2$ of only 0.536 (Table 12). (An $R^2$ of 0.629 was possible for North Saskatchewan River at Prince Albert if only data prior to 1972 were used). Much poorer fits, with $R^2$ values as low as 0.146 were achieved for other sites.

The values of C, the phase angle (which determines wave-length), were all very similar, near 4.5. Values of B, the mean of the harmonic, varied widely, reflecting the different average TDS concentrations in the various rivers. The amplitude of the sine wave (A), also varied considerably (25.65 - 568.14 mg/L), and corresponded closely with mean (B) values (Table 12).

Figures 7 to 14 present smoothed time series of TDS and smoothed residuals from sine wave regressions for a number of sites. The very long and complete series at Bindloss on the Red Deer River exhibits no trend of increasing or decreasing TDS concentration, however, it does show a small decline in the range of annual TDS variation from about 1977 onward. These methods are not sensitive enough to reflect subtle changes in TDS concentration that might be expected at this site due to increasing urbanization or irrigation in the basin. The South Saskatchewan River at Highway 41 displays a similar stable pattern over the period 1955 to 1984 (Fig. 8).

TABLE 12 Summary of sine curve regressions of TDS concentration against time for sites in the Saskatchewan River Basin. General form of equation is:
TDS = A x (sin((0.0172 x Julian day) + C)) + B

| SITE | $R^2$ | A | B | C | PERIOD |
|---|---|---|---|---|---|
| Bow River at mouth | 0.536 | -29.64 | 202.11 | 4.5 | 1967-1983 |
| Carrot R. at Turnberry | 0.518 | -568.14 | 815.09 | 4.2 | 1973-1984 |
| N. Saskatchewan R. at Prince Albert | 0.507 | -71.29 | 268.46 | 4.3 | 1962-1983 |
| S. Saskatchewan R. at Highway #41 | 0.440 | -50.33 | 242.33 | 4.6 | 1966-1984 |
| Red Deer R. at Bindloss | 0.427 | -64.95 | 302.47 | 4.5 | 1966-1984 |
| Oldman R. at Highway #36 | 0.421 | -49.07 | 224.27 | 4.6 | 1967-1983 |
| Battle R. at Unwin | 0.333 | -143.53 | 565.79 | 5.0 | 1966-1984 |
| Saskatchewan R. at The Pas | 0.237 | -34.53 | 242.37 | 4.3 | 1956-1983 |
| S. Saskatchewan R. at Saskatoon | 0.146 | -25.65 | 239.75 | 4.5 | 1960-1975 |

FIGURE 7 Smoothed time series of TDS data (top) and smoothed sine curve residuals (bottom) for Red Deer River at Bindloss

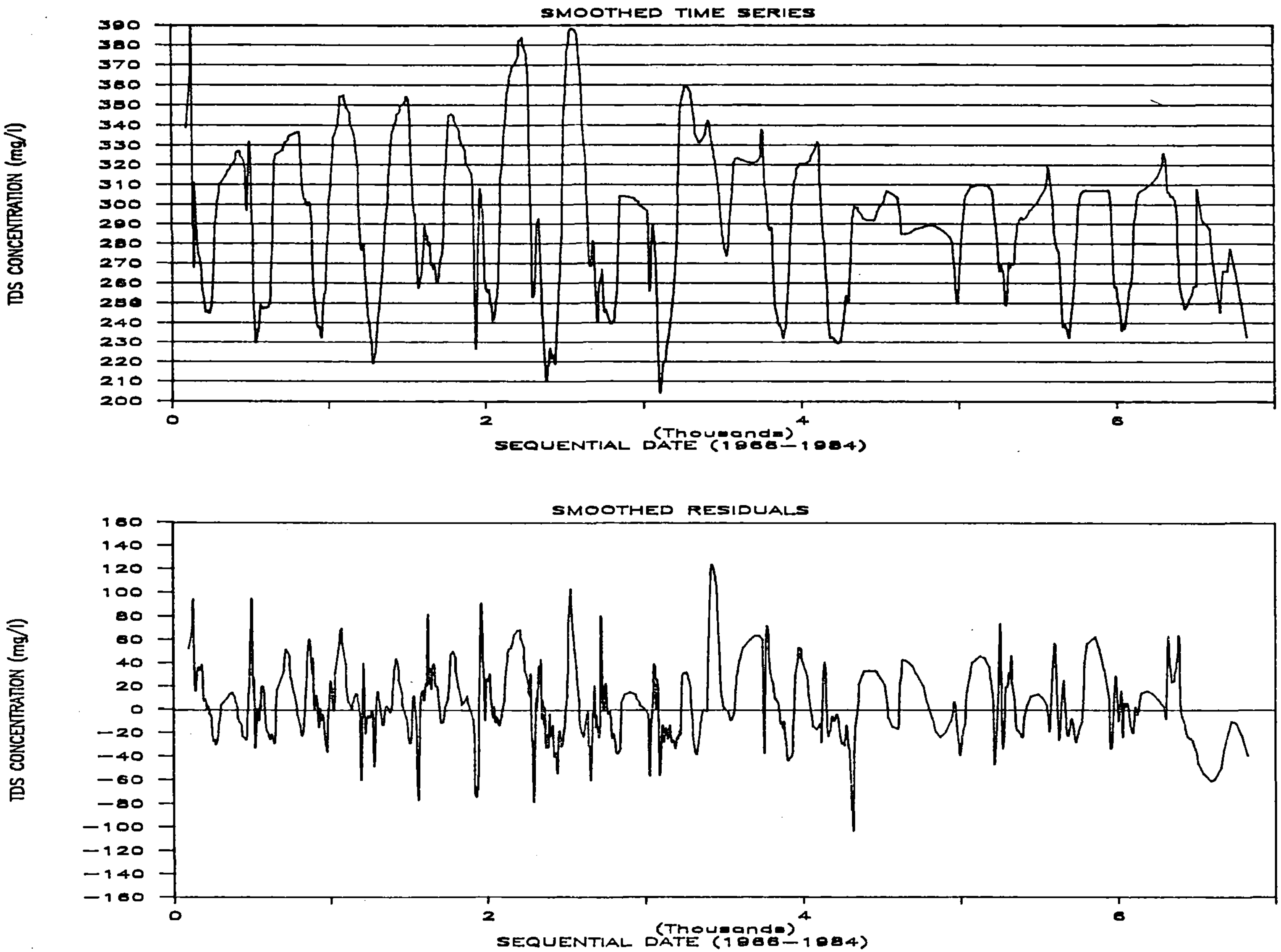
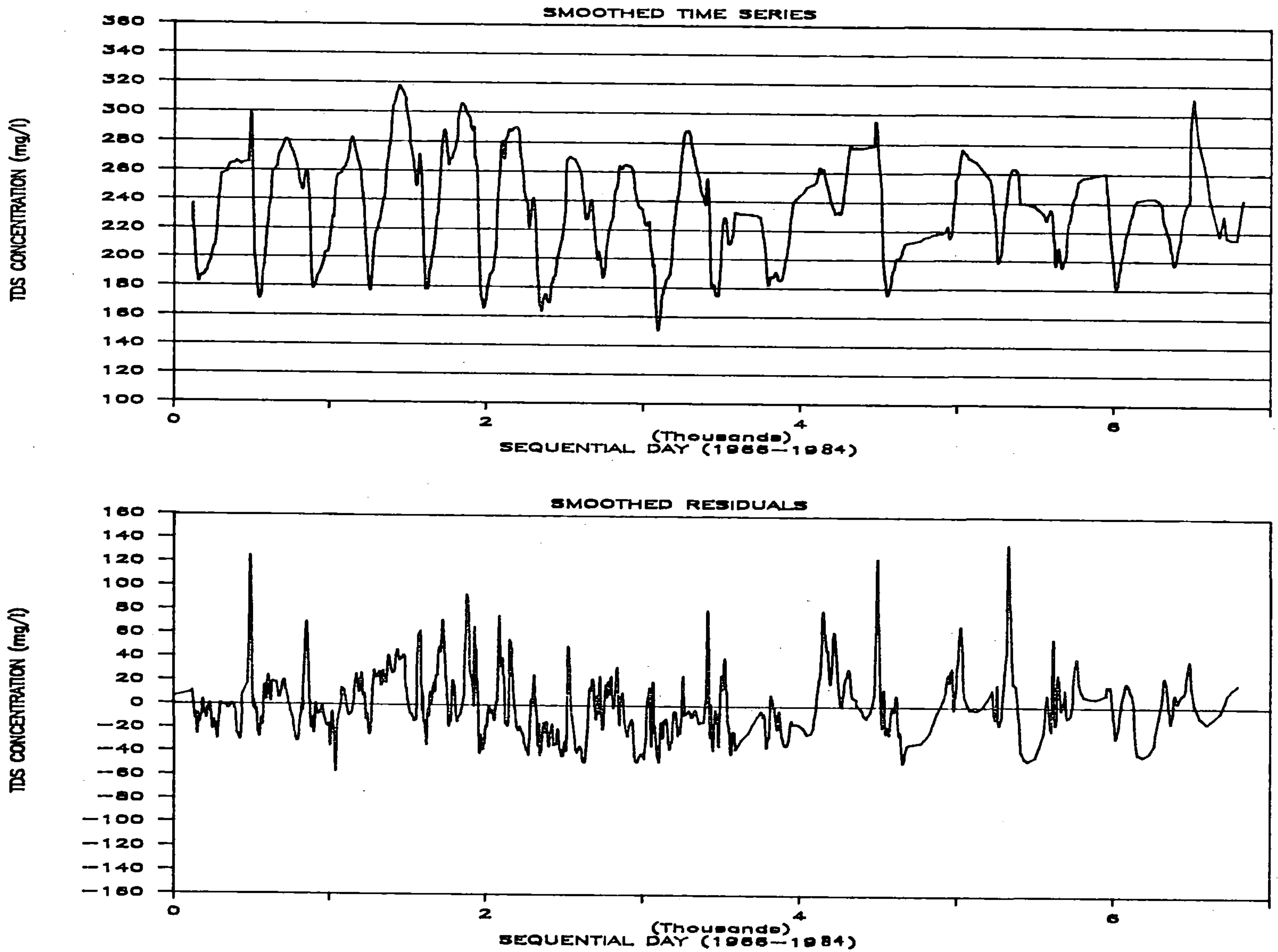


FIGURE 8 Smoothed time series of TDS data (top) and smoothed sine curve residuals (bottom) for South Saskatchewan River at Highway #41




*HydroQual*

FIGURE 9 Smoothed time series of TDS data (top) and smoothed sine curve residuals (bottom) for South Saskatchewan River at Saskatoon

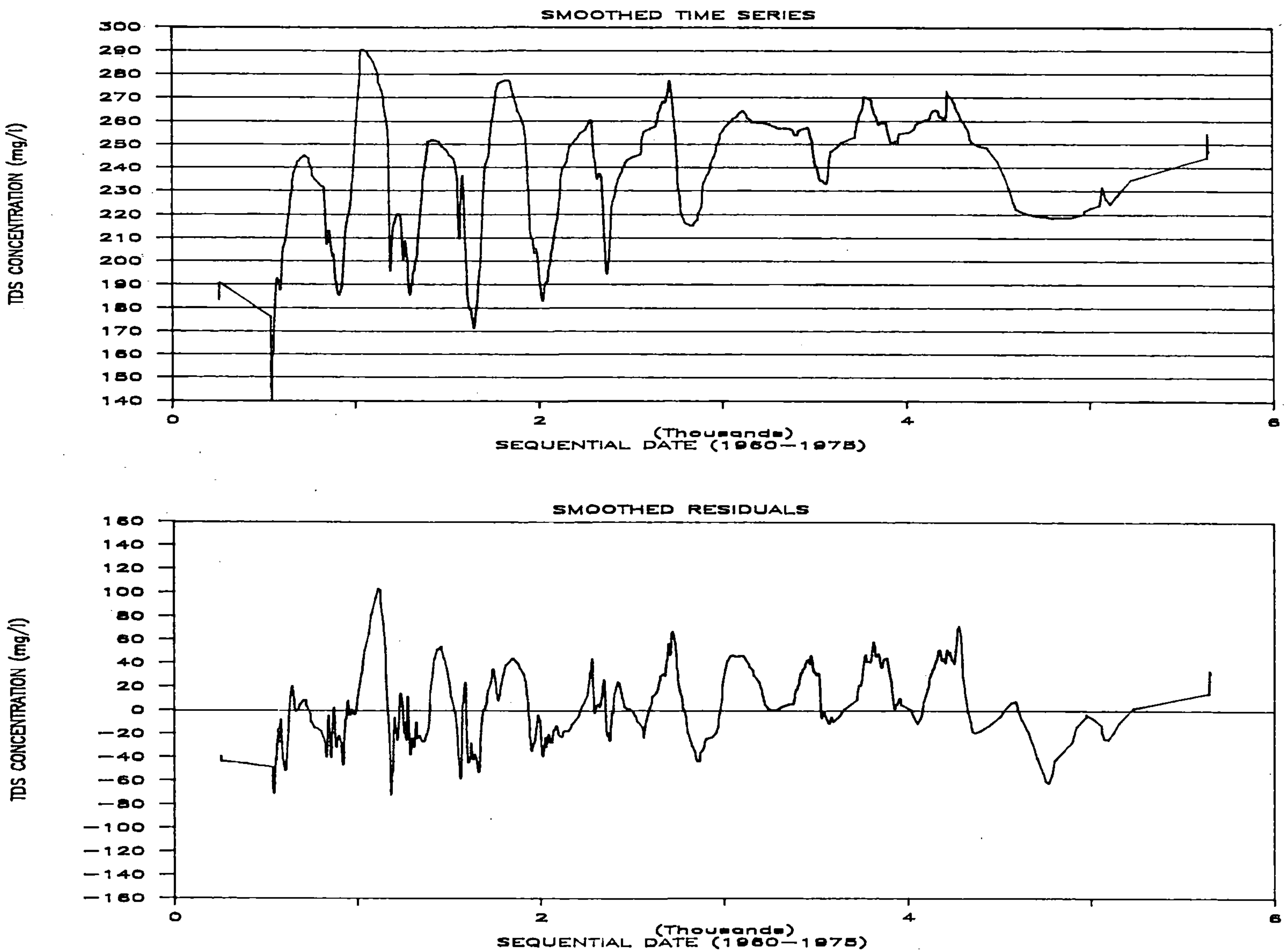


FIGURE 10 Smoothed time series of TDS data (top) and smoothed sine curve residuals (bottom) for Saskatchewan River at The Pas

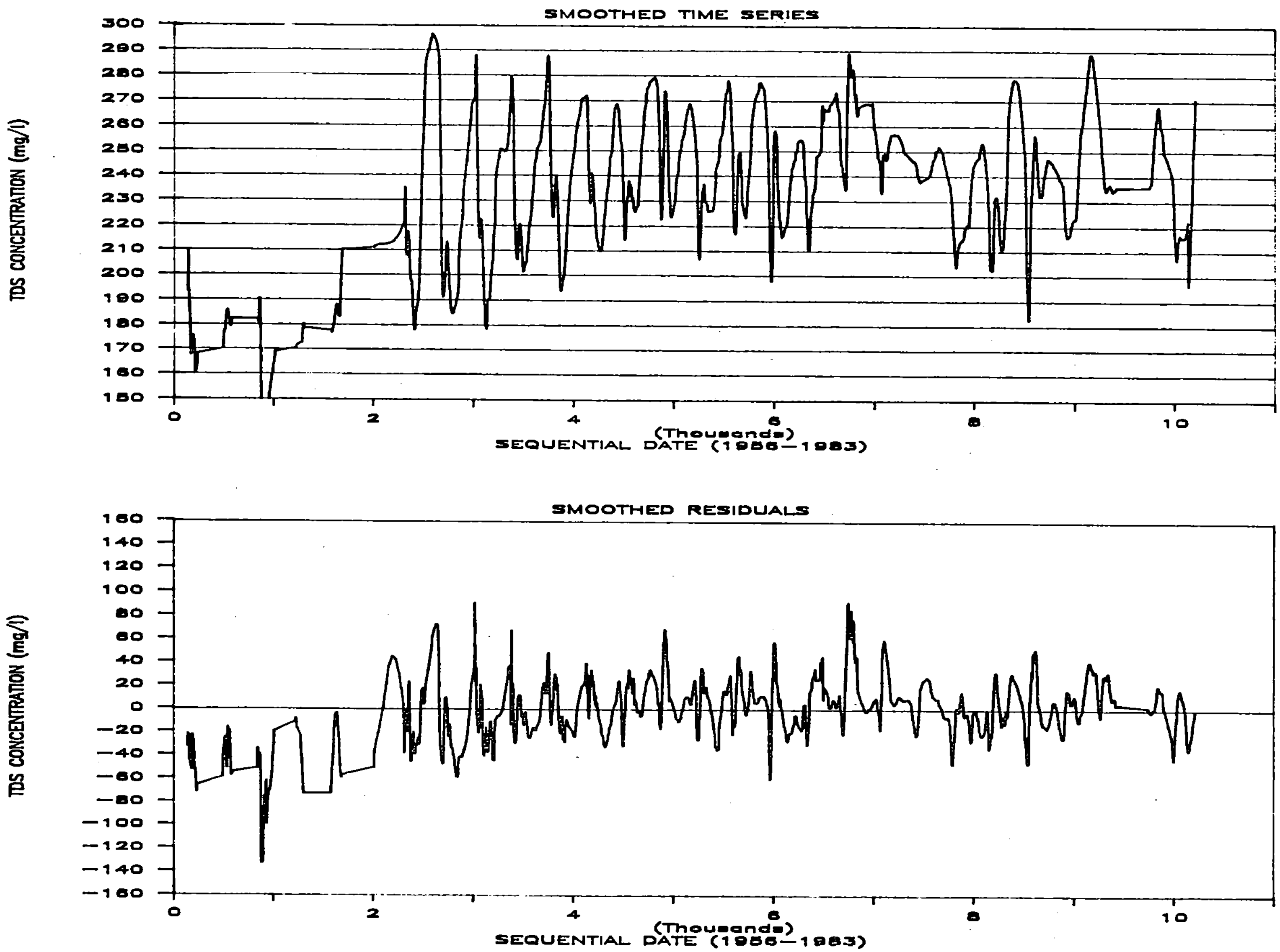


FIGURE 11 Smoothed time series of TDS data (top) and smoothed sine curve residuals (bottom) for Battle River at Unwin

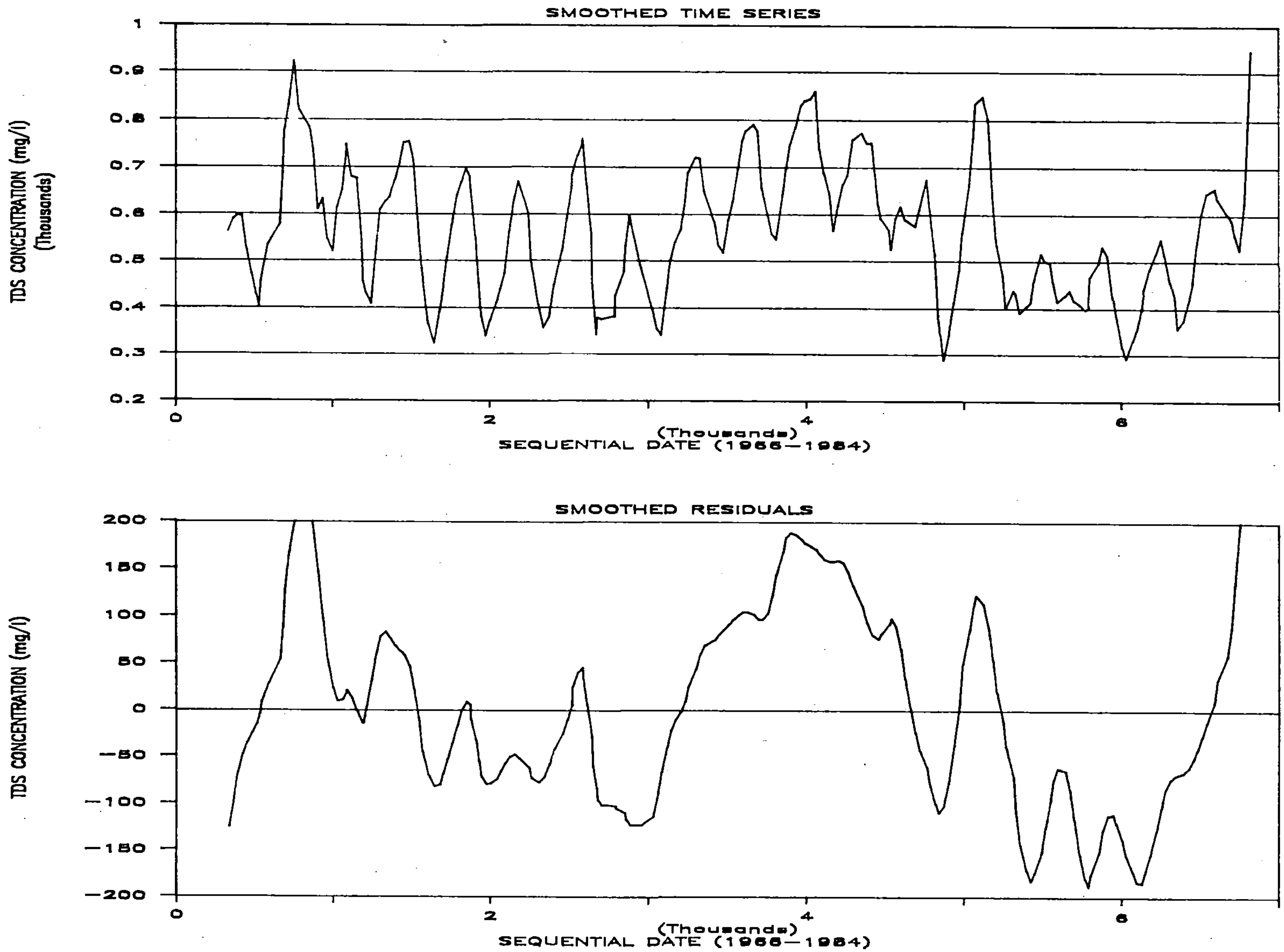


FIGURE 12 Smoothed time series of TDS data (top) and smoothed sine curve residuals (bottom) for Carrot River at Turnberry

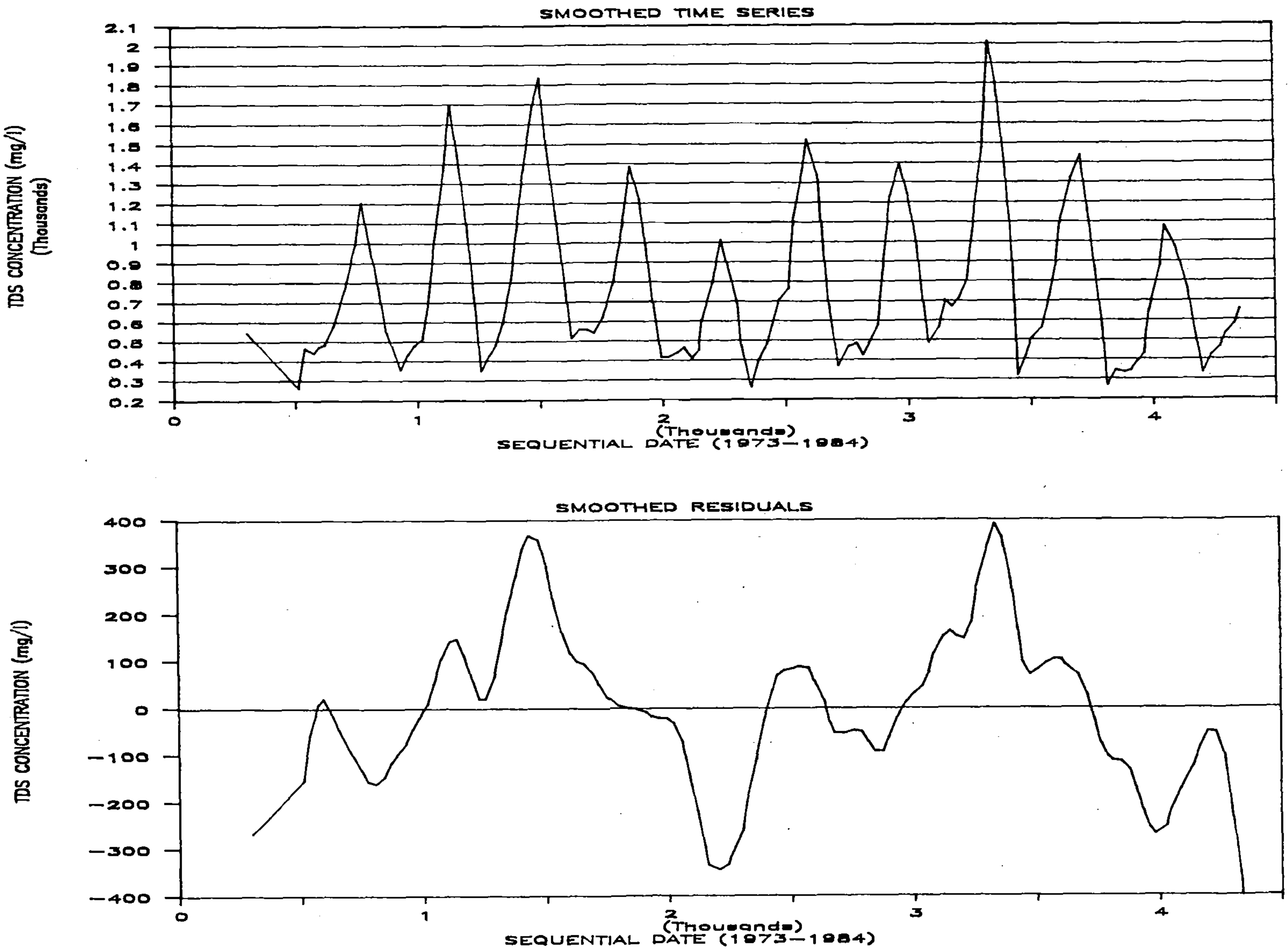


FIGURE 13  Smoothed time series of TDS data (top) and smoothed sine curve residuals (bottom) for Bow River at the Mouth.

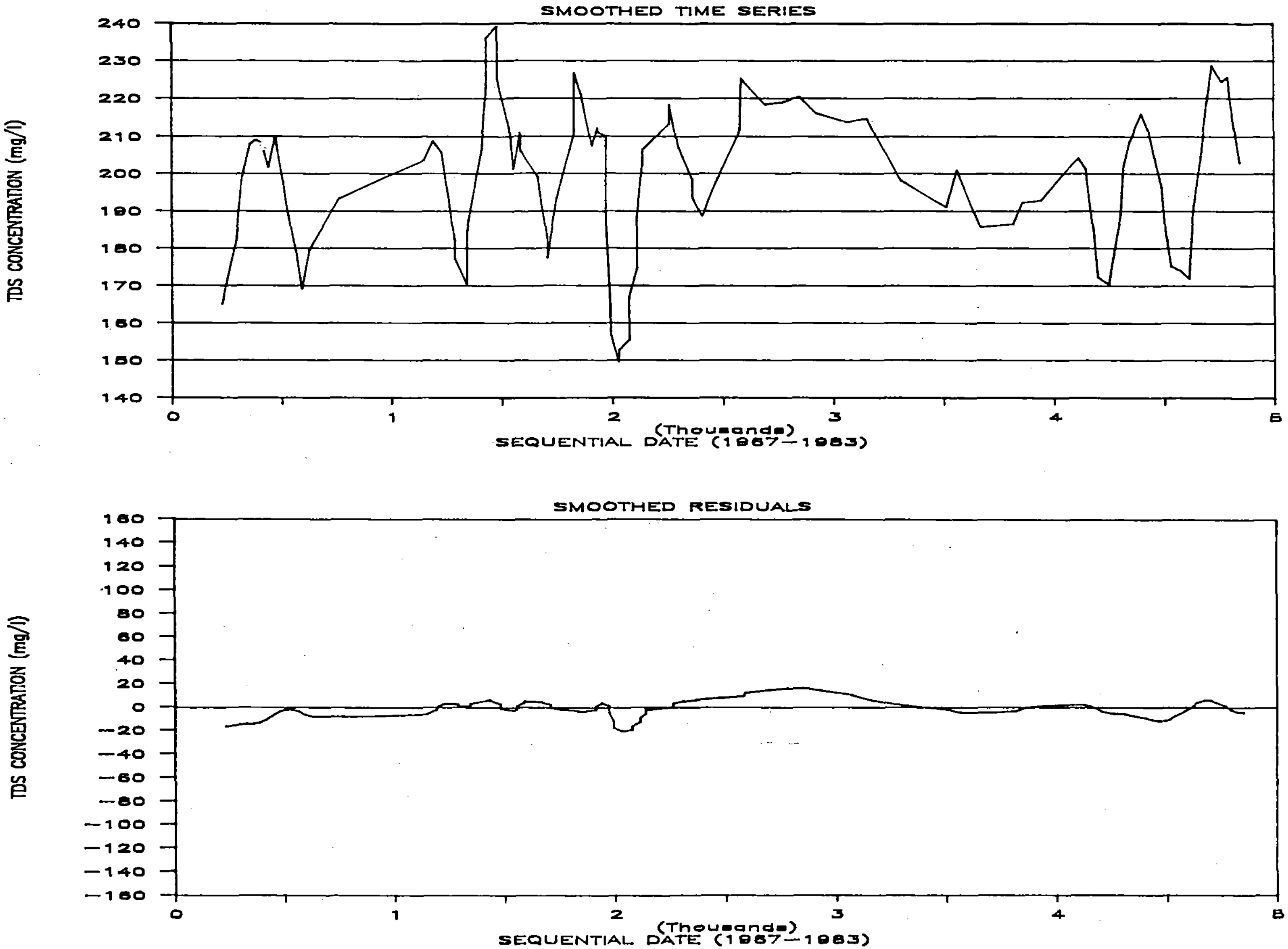
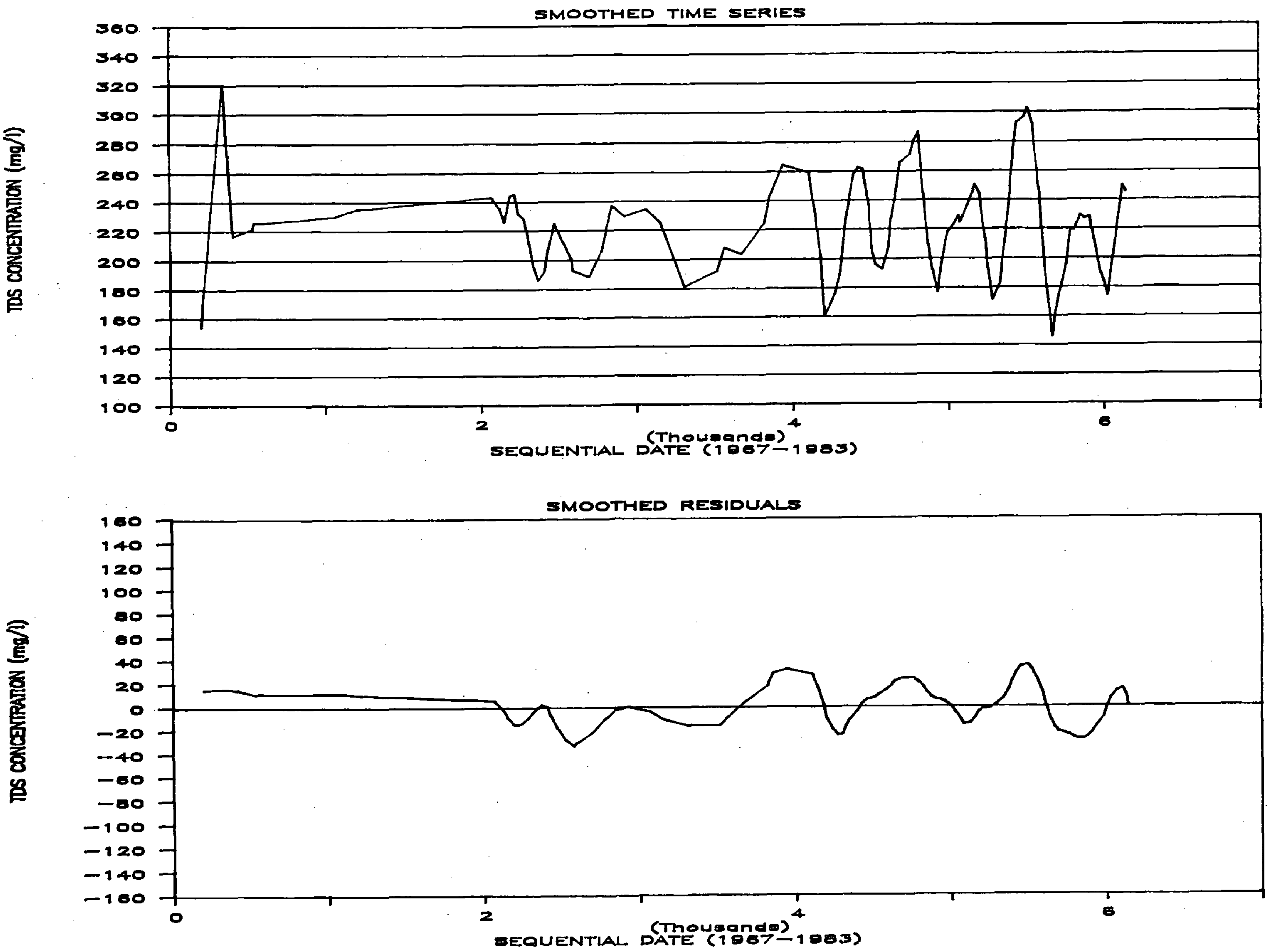


FIGURE 14 Smoothed time series of TDS data (top) and smoothed sine curve residuals (bottom) for the Oldman River at Highway #36.



On the other hand, a definite change in the TDS pattern is evident for the South Saskatchewan River at Saskatoon (Fig. 9). From 1960 to about 1967 a pronounced seasonal cycle is evident in both the smoothed TDS data and the sine curve residuals. An increase in summer low TDS concentrations (smaller negative residuals) and a decrease in winter high TDS concentrations (smaller positive residuals) is also apparent during this period. After 1967, the seasonal cycle abruptly vanishes to be replaced by a higher, less cyclic pattern of TDS concentrations, which varied erratically over multi-year periods. The residuals during much of the post-1967 period show unchanged winter values but much higher summer concentrations. This change in TDS pattern coincides with the closing of Lake Diefenbaker.

The North Saskatchewan River at Prince Albert exhibits a similar in pattern to that of the South Saskatchewan at Saskatoon. The conspicuous feature of both the residuals and the raw data at this site is the abrupt decline in annual variation of TDS concentration after 1972 (4000 days) (Figures 4 & 6). This change in the TDS regime corresponds to the closing of Lake Abraham on the mountain headwaters of the North Saskatchewan River. There are no other changes in this drainage likely to produce so sudden a change in TDS patterns. Lake Abraham is over 600 km upstream of this sampling site (site 180, Map 1), but Allison (1978) has shown that, by retaining and mixing water from different times of the year, reservoirs alter the dissolved solids load far downstream.

The effect of reservoirs on annual variation in TDS concentrations explains the surprisingly poor fit of the sine wave function to Saskatchewan River at The Pas (Table 12). The pattern of water chemistry experienced at this site is an integration of events on all upstream tributaries. At least eight reservoirs were built on the river system during the 1956-1983 period of record. A sudden increase in concentration and a change in annual pattern about 1963 (Fig. 10) does correspond to the completion of Tobin Lake, the nearest upstream reservoir. However, since the annual pattern of TDS concentration is more pronounced after that point, it is possible that the pre-1963 trend is an artefact of infrequent sampling in the early years of the program or different analytical techniques.

The Battle River at Unwin and Carrot River at Turnberry, two unregulated rivers at opposite ends of the basin, demonstrate another type of long-term trend. There is evidence here of a second cyclic pattern of increasing and decreasing TDS concentrations, with a period of about ten years on the Battle River and six years on the Carrot River. The cycle is particularly evident in the sine curve residuals (Fig. 11,12). This pattern is probably a reflection of long-term patterns of precipitation and runoff, rather than any human influence.

The smoothed time series for the Bow and Oldman Rivers (Figures 13 and 14) do not indicate a regular annual pattern as is apparent for the other locations. This is primarily a function of the irregular database collected at both sites. A more reliable trend indicator is the plot of sine curve residuals, which imply no long-term for either site.

Regression Analysis

Another approach to detecting long-term trends in TDS concentrations is to suppress short-term variation by computing means for each season, and regressing the means against year of record. This method was applied to the nine sites that were used for sine curve analysis, using two operationally-defined seasons: autumn (August to onset of ice-cover) and the ice-cover period. River discharge is generally low and stable during these two seasons, so trends in TDS are more likely to be apparent, considering that impacts due to point source loading increases should be greatest at low flows. Dates of freeze-up and spring thaw for various regions within the basin were estimated from the data in Robin and Cudbird (1970) and Environment Canada (1970-1984).

Significant regressions were obtained at four sites for the ice-cover season, but only once for the autumn season (Table 13). This may result from similar winter flows from year to year and hence regressions less

TABLE 13 Summary of regressions of seasonal mean TDS concentrations against year of record for sites in the Saskatchewan River Basin.

ICE-COVER SEASON

| SITE | SLOPE | INTERCEPT | N | $R^2$ |
|---|---|---|---|---|
| S. Saskatchewan River at Highway #41 | -3.12 | 498 | 19 | 0.420** |
| S. Saskatchewan River at Saskatoon | -5.14 | 603 | 13 | 0.532** |
| N. Saskatchewan at Prince Albert | -5.13 | 670 | 20 | 0.405** |
| Saskatchewan River at The Pas | -1.22 | 357 | 22 | 0.313** |
| AUTUMN (AUGUST TO ICE-COVER) | | | | |
| Bow River at the mouth | 1.89 | 52 | 12 | 0.536** |

** significant at $p<0.01$

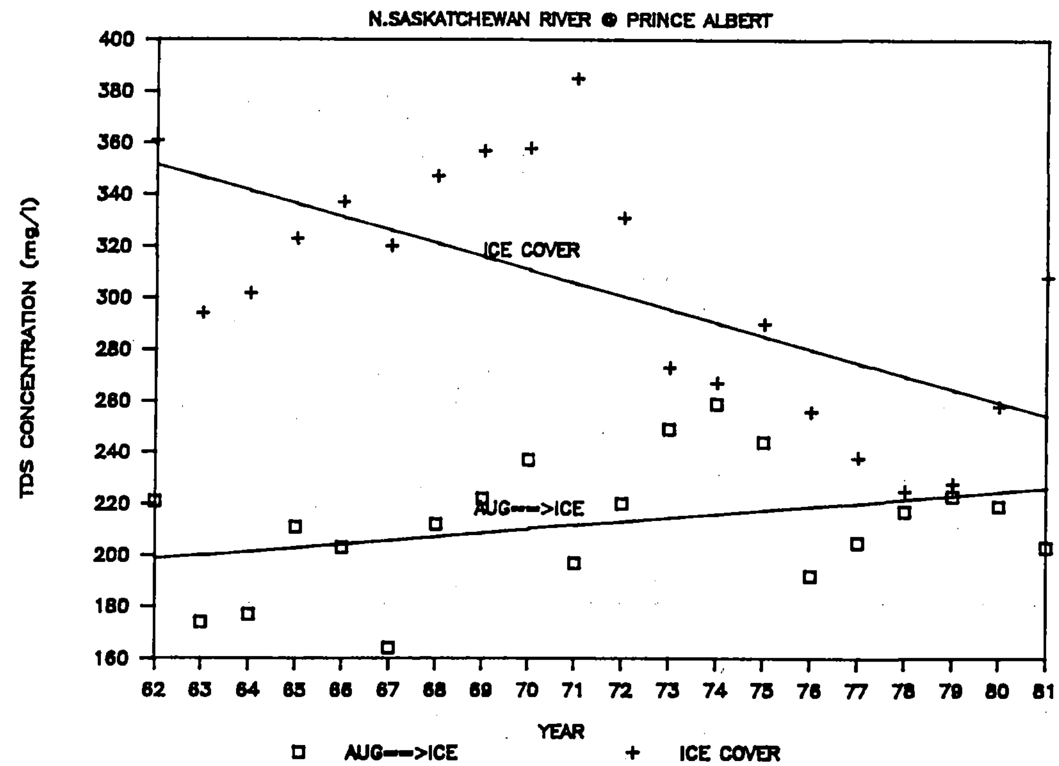
contaminated with seasonal variation. The four sites that did produce significant regressions for the ice-cover season are all on the Saskatchewan River or its North and South branches. The other five sites are all on smaller tributary rivers, many of which (e.g. Carrot and Battle Rivers) are essentially free of gross human disturbance.

Regression slopes for the winter interval were all negative and similar in absolute value, ranging roughly 1-5 mg/L per year. Hence, winter TDS concentrations in these rivers have been slowly declining; quite the reverse of expectations based on increased anthropogenic salt loads. Three of the four sites (the exception being South Saskatchewan River at Highway 41) are on rivers which have had reservoirs constructed upstream during the period of record, and it is known that reservoirs tend to reduce winter peaks of TDS concentration. These regressions may reflect a period of high winter TDS concentrations before dam construction, and a period of lower TDS concentrations after dam construction, rather than a continuing trend.

Seasonal means from the North Saskatchewan River at Prince Albert do contain an obvious intervention, with a group of high values before 1972 (the year of completion of Lake Abraham) and a group of abruptly lower values after (Fig. 15). There are no obvious breaks in the data at other sites (Fig. 16-19), although a long-term cyclic trend may be obscuring them.

The only site to produce a significant regression for the autumn season was the Bow River at the mouth (Table 13). The slope of this regression is low and positive, suggesting that TDS concentrations in this river have historically increased by about 2 mg/L per year. Increases in salt-laden irrigation return flow and runoff from the city of Calgary are two probable sources of the increased salt load. A similar trend might be anticipated at the mouth of the Oldman River, which also receives municipal wastes from Lethbridge and substantial irrigation return flow. Unfortunately the data record for the Oldman River at Highway 36 is erratic (Fig. 14), and the sampling site is located upstream of many of the irrigation return flow channels.

FIGURE 15 Seasonal means of TDS concentration for the North Saskatchewan River at Prince Albert (top) and Saskatchewan River at The Pas (bottom)



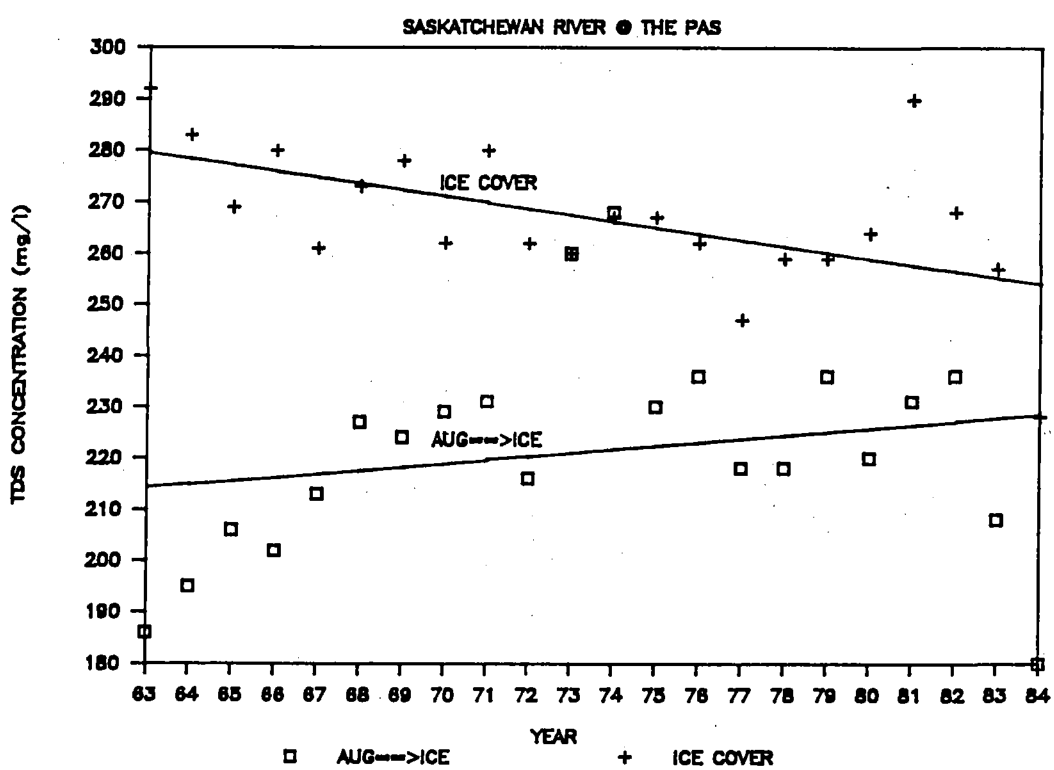
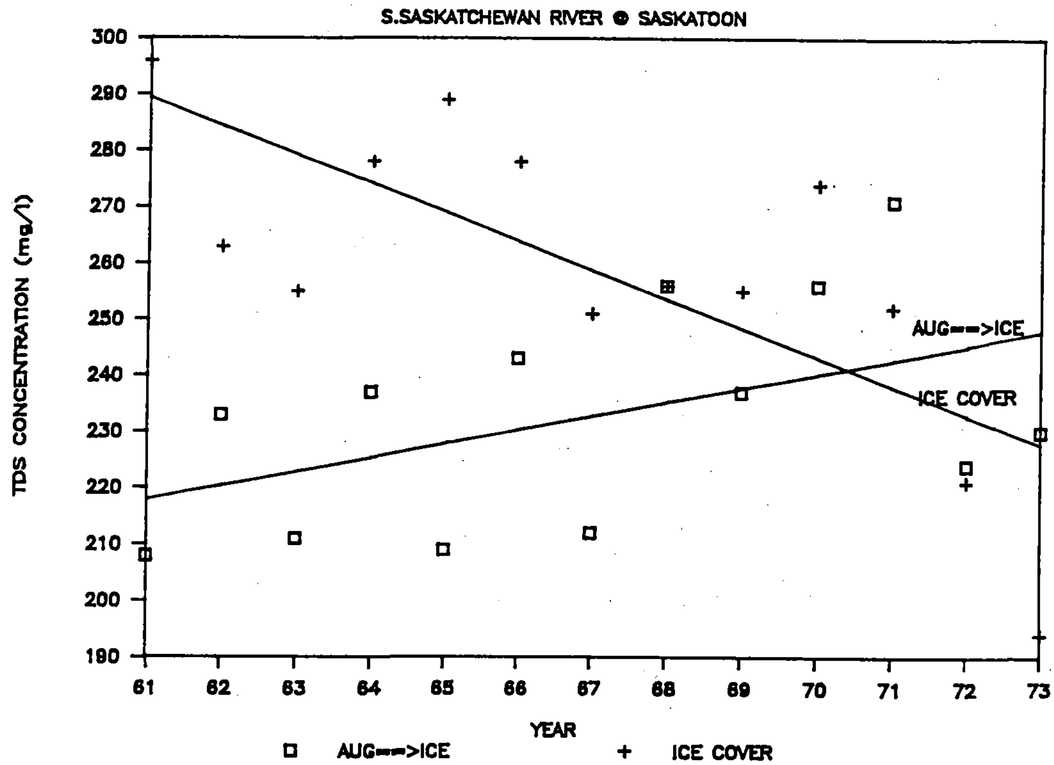



FIGURE 16 Seasonal means of TDS concentration for the South Saskatchewan River at Saskatoon (top) and Oldman River at Highway #36 (bottom)



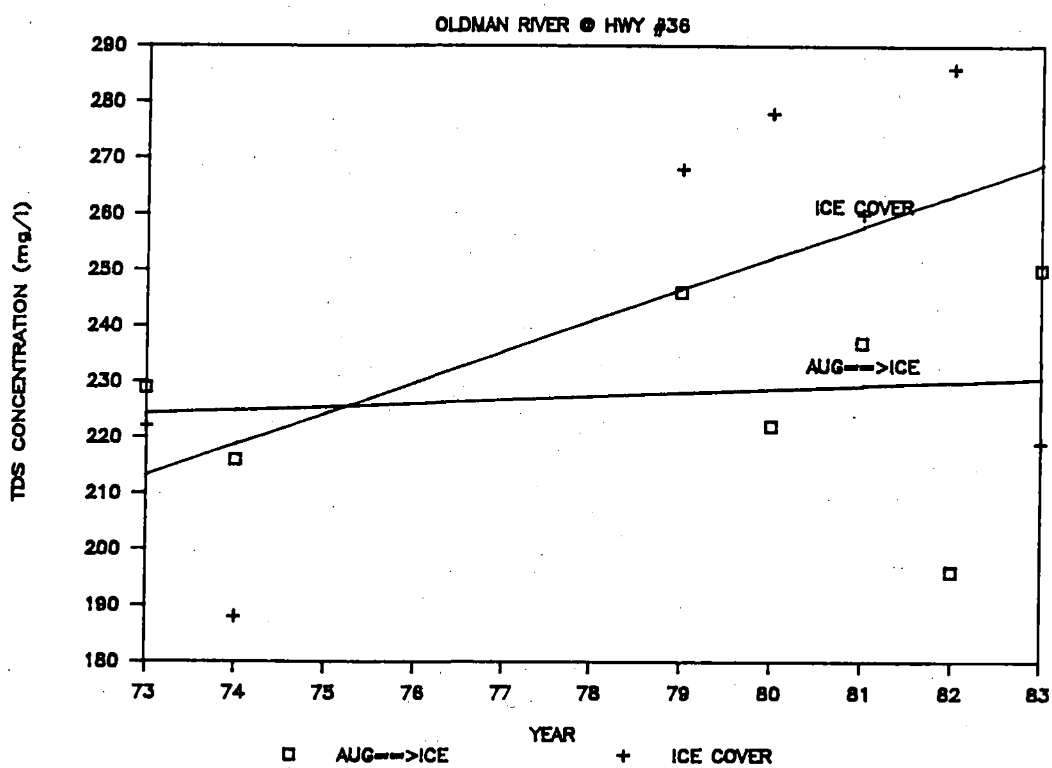
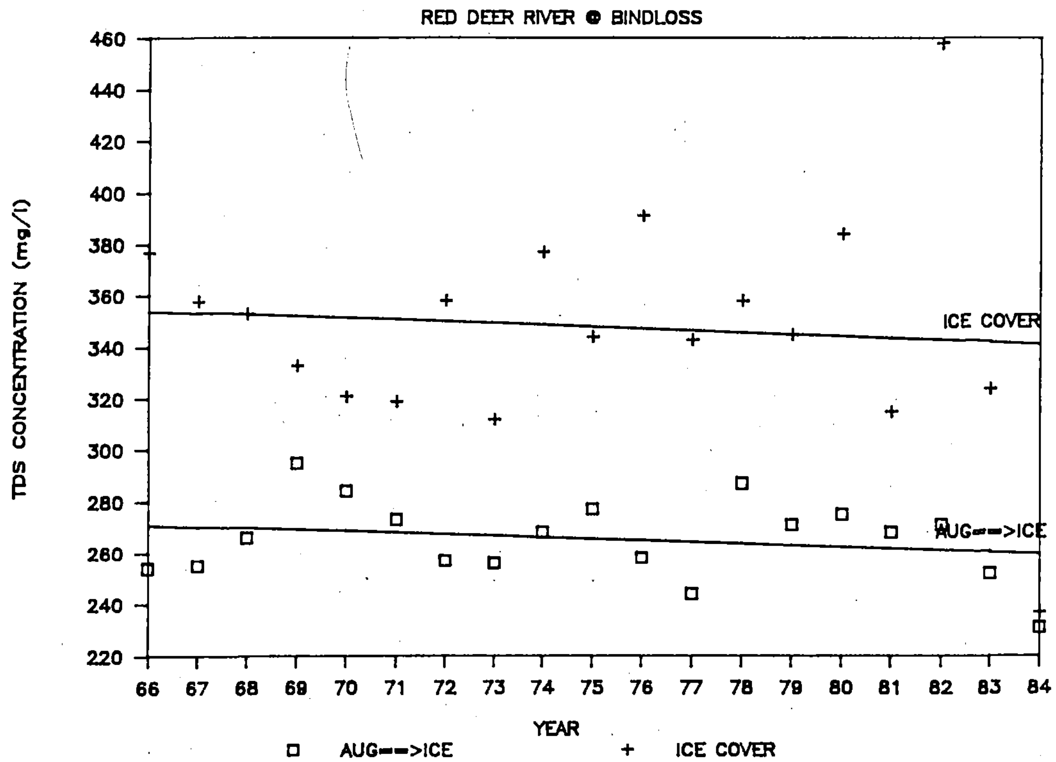



FIGURE 17 Seasonal means of TDS concentration for the Red Deer River at Bindloss (top) and South Saskatchewan River at Highway #41 (bottom)



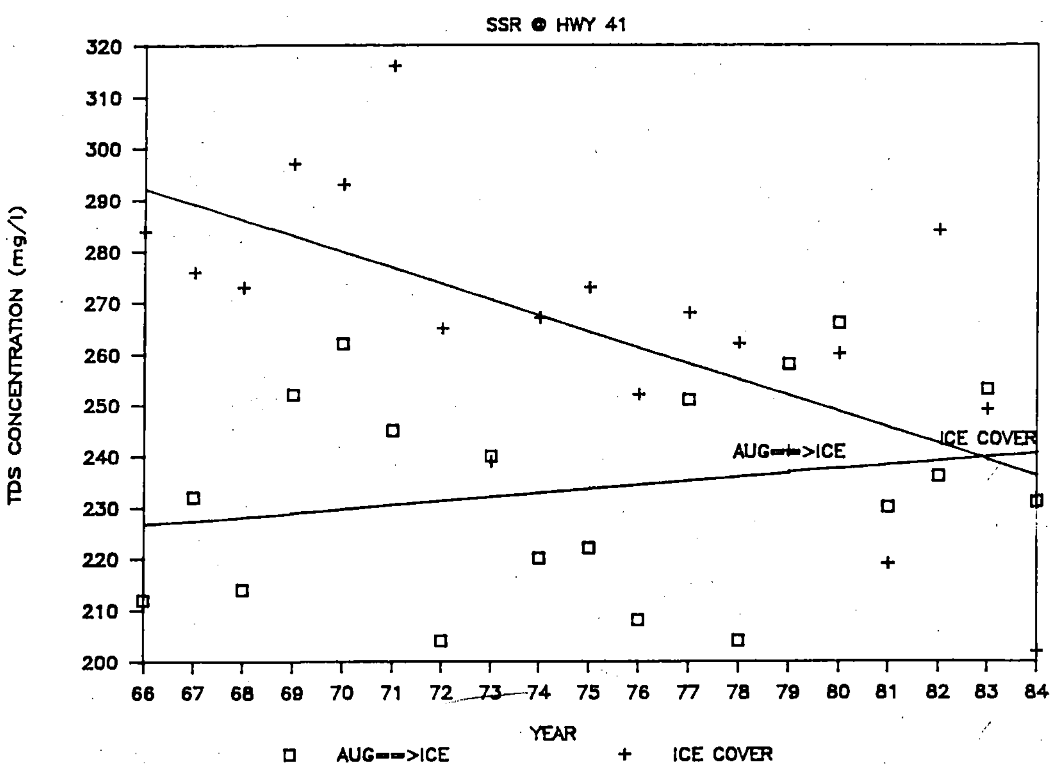
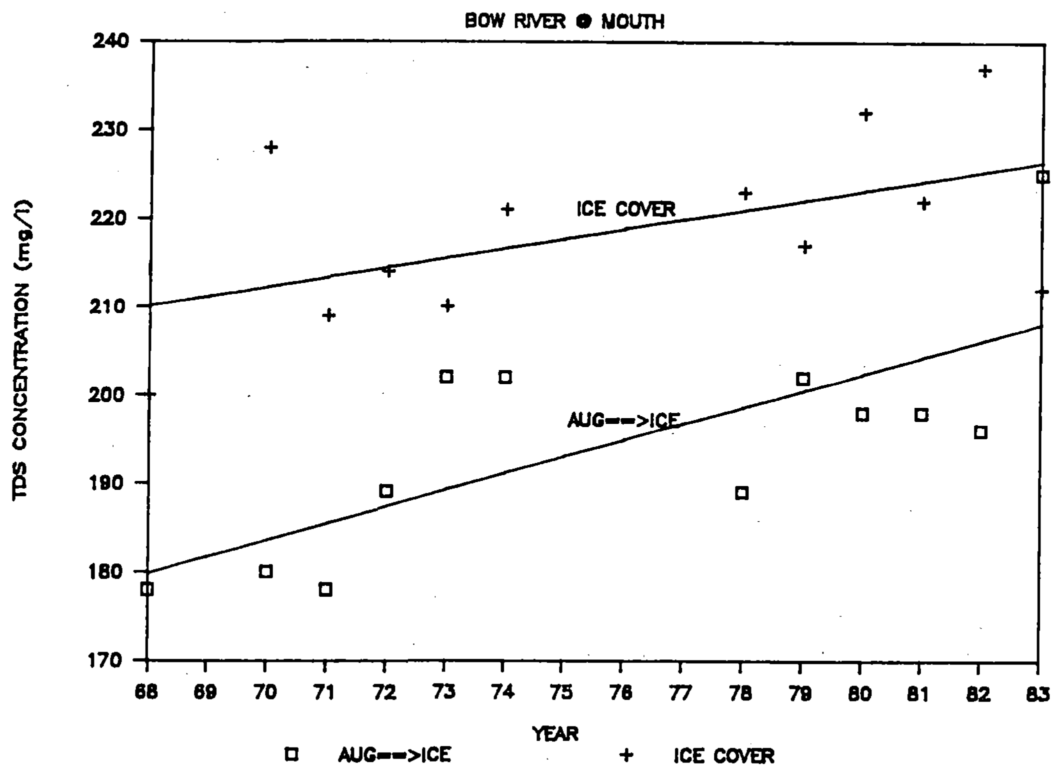



FIGURE 18 Seasonal means of TDS concentration for the Bow River at the Mouth (top), and Battle River at Unwin (bottom)



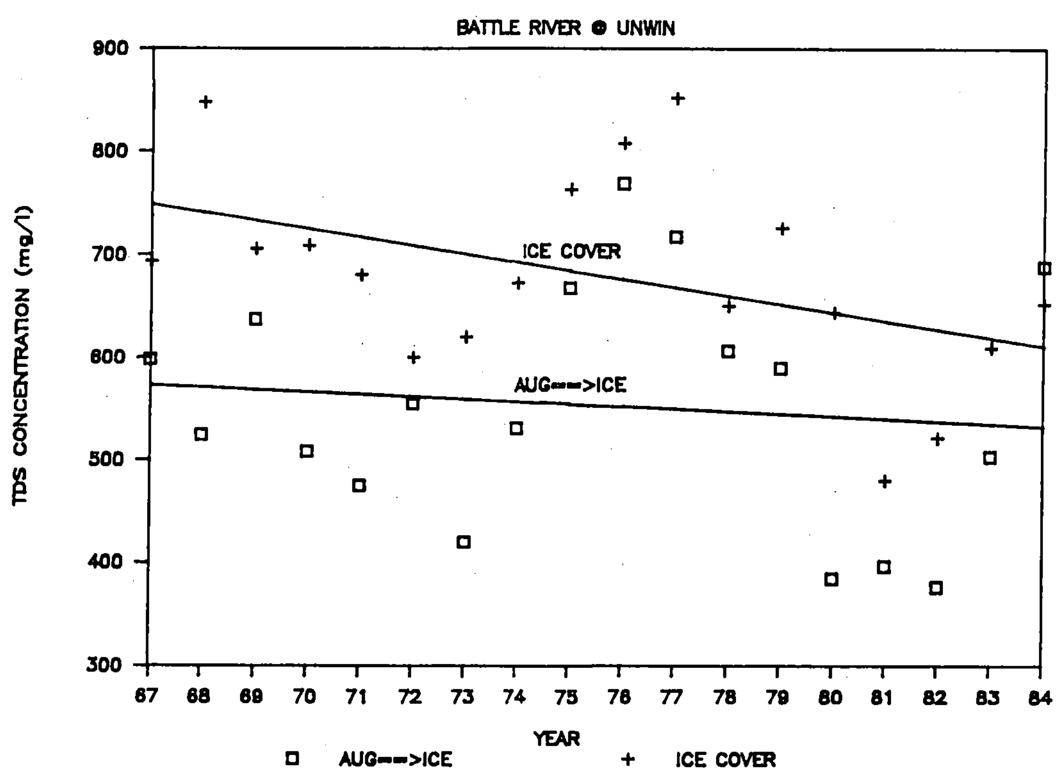
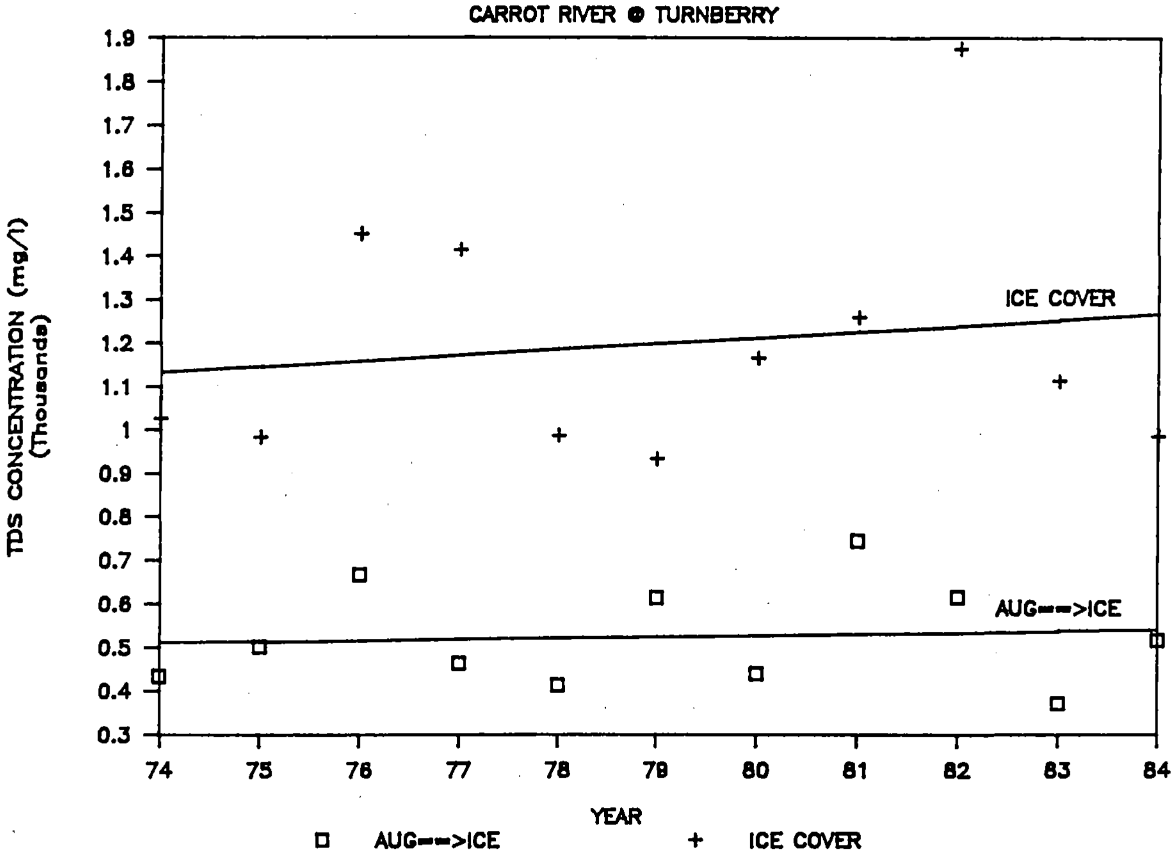



FIGURE 19 Seasonal means of TDS concentration for Carrot River at Turnberry



Summarily, the TDS record at many points in the basin is substantial, and permits powerful time series analyses. WQB data, which follows a fixed monthly schedule, is more useful in this respect than WRB data which emphasizes high flows and open-water months. The principal trends in the basin relate to flow regulation on the North and South Saskatchewan Rivers, which depresses the winter TDS maximum, and weakens the annual cycle of TDS concentrations. More subtle effects from altered land use or increased effluent loadings are not apparent on the South Saskatchewan at Highway 41, or the Red Deer River at Bindloss, but a trend of slowly increasing TDS concentration is detectable on the lower Bow River. Municipal wastes or irrigation return flow are probably responsible for this increase. Dams recently completed or under construction on the Red Deer and Oldman Rivers are expected to disrupt the annual TDS pattern downstream in a manner similar to that on other regulated rivers.

## REGIONAL PATTERNS IN TDS

### Differences Between WRB and WQB

Mean TDS concentrations at sampling sites across the Saskatchewan River basin range from <25 mg/L to >1900 mg/L, but most means were between 100 and 1000 mg/L (Appendix A). Fig. 20 shows the annual mean TDS concentrations for all stations within each of the sub-basins of the Saskatchewan River Basin. Although means of WQB data are different from those of WRB for some basins, overall there is no consistent difference between the two data sets.

When sub-basin means are compared in more detail, separating the ice-cover and open-water seasons, and tributaries from mainstem rivers, there are still few differences between WQB and WRB results for the open-water season despite the difference in sampling emphasis (Fig. 21). WQB means are often slightly less than WRB means in summer, but the difference is slight in most sub-basins, and not consistent across the basin. Large differences between means calculated with the two data sets did occur for five sub-basins during the ice-cover season. In sub-basins C, E, G, H and F, the mean TDS of

FIGURE 20 Annual mean TDS concentrations for sub-basins of the Saskatchewan River basin.

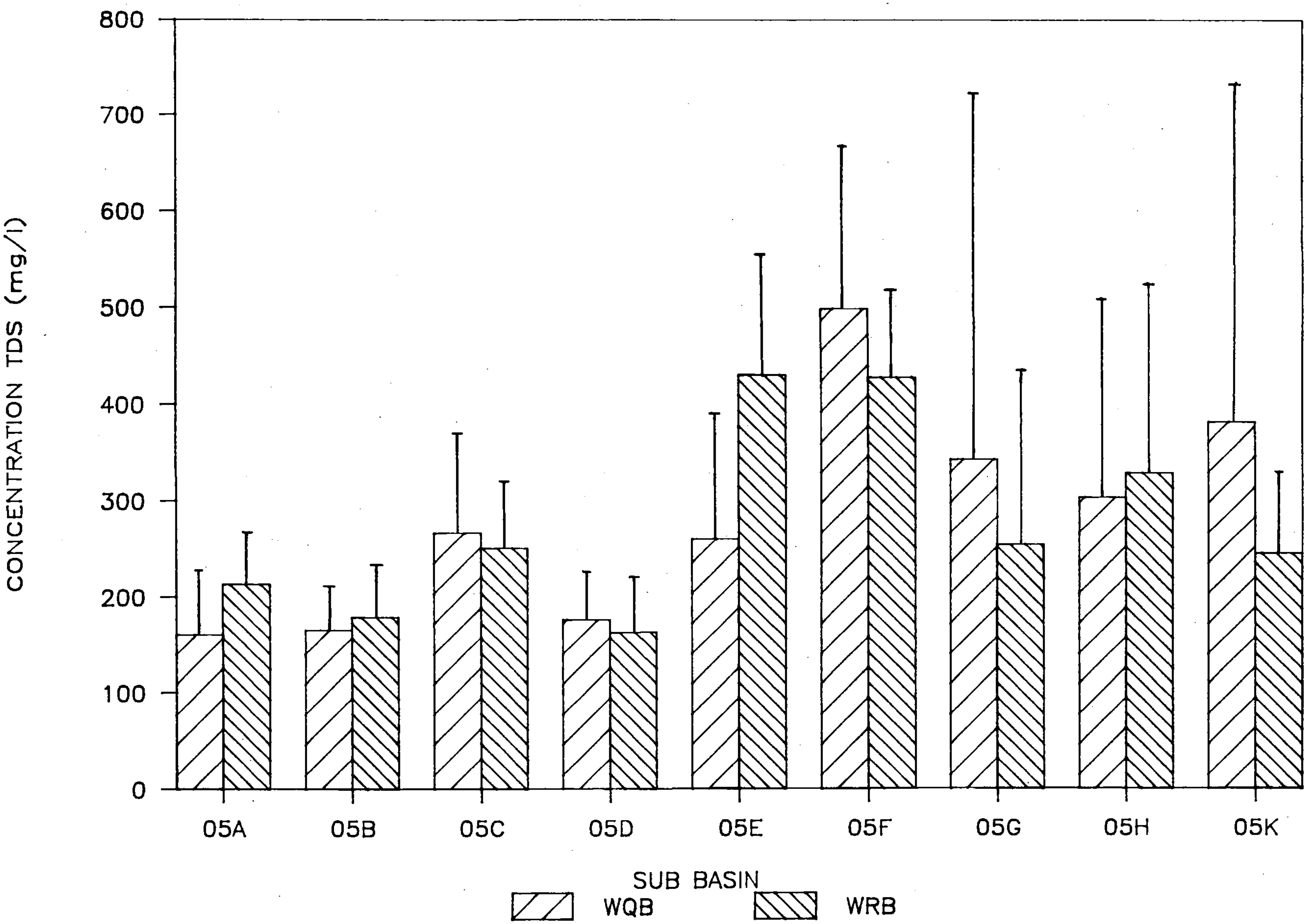
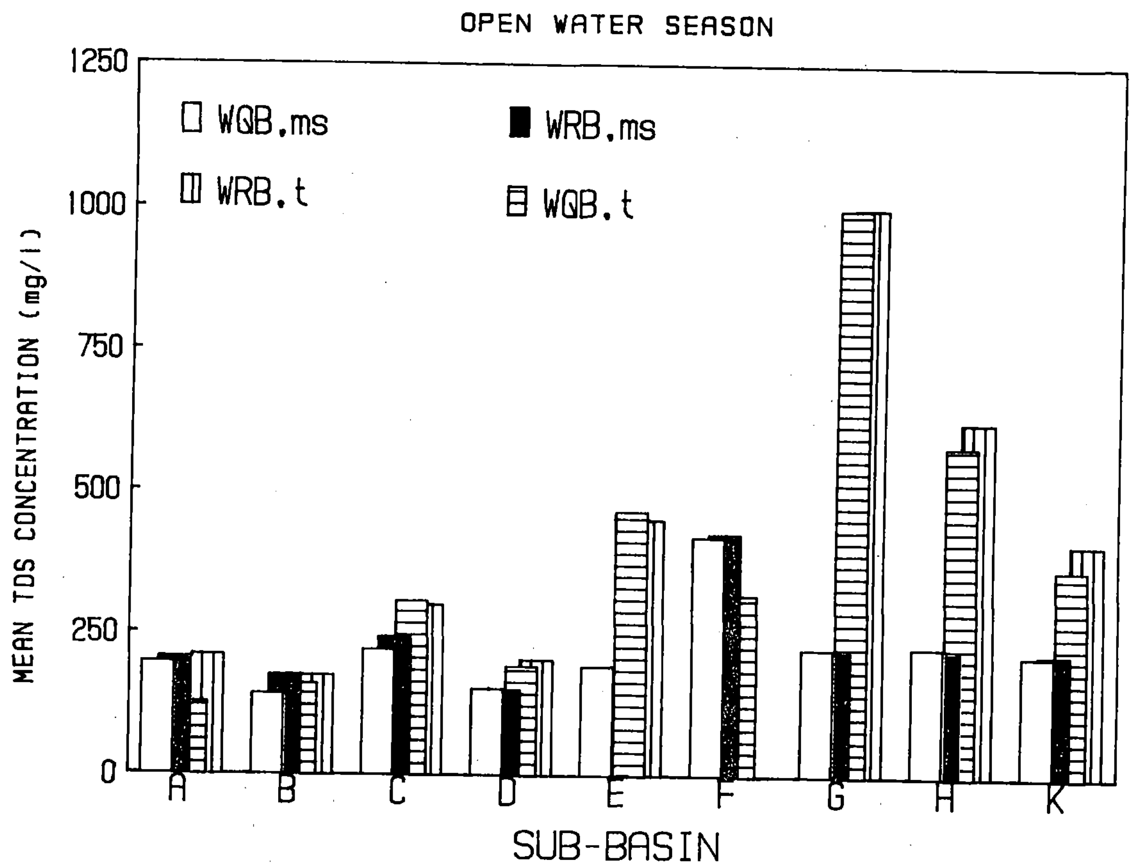
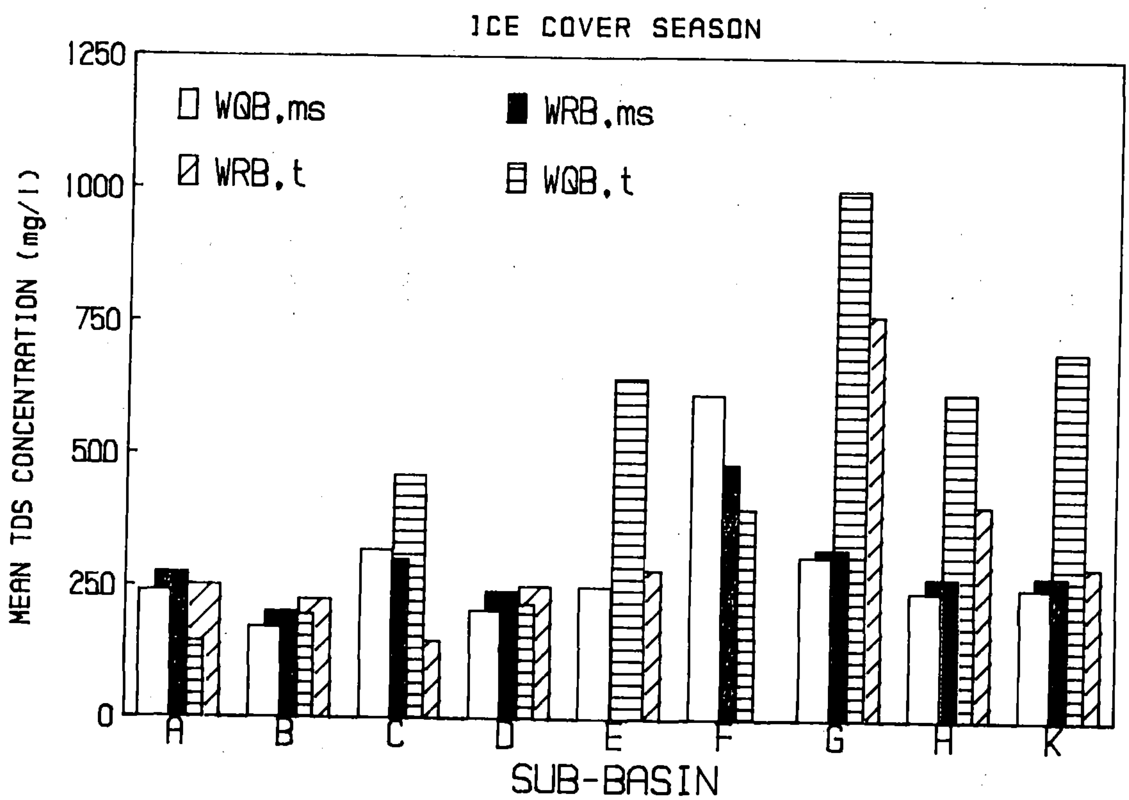


FIGURE 21 Mean TDS concentrations of tributaries and main-stem rivers in the Saskatchewan River basin for the open-water (top) and ice-cover (bottom) seasons.



WRB data are 32% to 76% lower than those for WQB data (Fig. 21); the difference is most pronounced for the tributary systems relative to the mainstem rivers.

Differences in seasonal mean TDS estimates as large as these indicate a problem with estimating the winter TDS content of small watercourses with these data. The discrepancy appears to be a result of undersampling by WRB. That problem, in turn, arose because WRB sampling was intended to monitor suspended sediment transport, which is at a minimum during the period of winter low flow. WRB has no winter samples at all from mainstem rivers in sub-basin E, and none from tributaries in sub-basin F (Fig. 21).

Annual Patterns

The nine sub-basins fall into three categories of annual mean TDS concentrations (Fig. 20): sub-basins A,B,C and D, comprising the mountain foothills and plains of western Alberta, have relatively low TDS levels and minimal variation. Mean annual TDS concentrations in these four sub-basins are all between 150 and 250 mg/L and standard deviations range from 40-70 mg/L. The region is dominated by streams and small rivers, most of them fed initially by mountain snowmelt and surface runoff, which is naturally low in dissolved ions. Sub-basin C, which embraces the entire Red Deer River drainage, and which therefore has a larger prairie influence, exhibits somewhat higher TDS concentrations than the other western sub-basins.

Sub-basins E and F, the North Saskatchewan River and the Battle River drainage in eastern Alberta, define the second group of sub-basins. They are characterized by high annual average TDS concentrations and high variation. Mean TDS concentrations in these sub-basins are >400 mg/L, except for sub-basin E as measured by WQB (Fig. 20). Standard deviations range from 75 to 190 mg/L. Sluggish current, high evaporation rates, and the relatively high contribution of solute-bearing groundwater, which are all typical of prairie regions, contribute to the high ionic content of water in these rivers.

The last three sub-basins, G, H and K, form a third group. Mean TDS concentrations in these basins are intermediate between those of the other groups (range 350-380 mg/L) but variance is extremely high, as exemplified by standard deviations of 200-350 mg/L. These three sub-basins cover the eastern half of the Saskatchewan River basin in Saskatchewan and Manitoba. Sub-basins G and H lie entirely within the central grasslands and therefore, would be expected to have the same high TDS concentrations experienced by sub-basins E and F. However, within each of these sub-basins there is a dramatic difference between the mean TDS of tributaries and main stem rivers, the effect of which is discussed in the following section.

## Seasonal Patterns

TDS concentrations in most rivers are higher during the ice-cover season than at other times of the year (Fig. 21). This is due to lower river discharge, reduced surface runoff and freeze-out during ice formation. Bank storage and relatively concentrated ground water make up a larger proportion of total flow than at other seasons, creating a late winter maximum in TDS levels.

In the open-water season, sub-basins may again be combined into three general groups. Sub-basins A through D have uniformly low TDS concentrations, and main stems, which in these regions are mostly still small rivers, carry TDS at the same concentrations as tributaries (Fig. 21). As before, sub-basin C, the upper Red Deer River, has somewhat higher mean concentrations than the other three western sub-basins.

Sub-basins E and F, North Saskatchewan and Battle Rivers, are marked by the incompleteness of their data. Mean open-water TDS concentrations in both basins are intermediate between the A-D group and G-K group (Fig. 21), but behaviour of main stems and tributaries is not consistent. In sub-basin

E, mean main stem TDS concentration (193 mg/L) was less than half the mean tributary concentration (458 mg/L), but in sub-basin F the main-stem concentrations were greater (425 vs 320 mg/L). The only main stem in sub-basin E is the North Saskatchewan River, whose flow is still largely composed of mountain runoff; hence it has a lower mean TDS concentration than its prairie stream tributaries. The Battle River, which arises on the plains and has no mountain headwaters, is the main stem of sub-basin F; hence it carries slightly higher TDS concentrations than its shorter tributaries.

The last group of sub-basins, G, H and K, covering the eastern half of the Saskatchewan River basin in Saskatchewan and Manitoba, are marked by two common features: tributary TDS concentrations in the open-water season are often greater, than in other sub-basins; and there is a large difference in TDS levels between tributaries and main stems (Fig. 21). The most extreme example is sub-basin G, whose mean tributary TDS concentration (1000 mg/L) is nearly five times greater than the mean for main stems (223 mg/L), and far greater than the mean for any other region. However, this presentation is misleading: the only main stem in sub-basin G is the North Saskatchewan River; the only tributary sampled was saline Eagle Creek (plus one sample from Eyehill Creek which is not a true tributary), which supports TDS concentrations as high as 1800 mg/L. Had sampling included any of the small tributaries entering the North Saskatchewan River from the north (Shell Brook, Sturgeon River, Spruce River, etc.) then mean tributary TDS concentrations would be much lower.

The situation is similar in sub-basin H, the South Saskatchewan River drainage in Saskatchewan. Except for a solitary sample from Gap Creek (actually a closed system and not a tributary) the only tributary in this region is Swiftcurrent Creek which has been intensively sampled (Map 1). It is not unexpected that the main stem South Saskatchewan River, being fed originally by mountain streams in the west, would have a lower mean TDS concentration for the open-water season than Swiftcurrent Creek, a typical prairie river.

The situation is similar in sub-basin H, the South Saskatchewan River drainage in Saskatchewan. Except for a solitary sample from Gap Creek (actually a closed system and not a tributary) the only tributary in this region is Swiftcurrent Creek which has been intensively sampled (Map 1). It is not unexpected that the main stem South Saskatchewan River, being fed originally by mountain streams in the west, would have a lower mean TDS concentration for the open-water season than Swiftcurrent Creek, a typical prairie river.

In sub-basin K the difference in open-water mean TDS concentration between tributaries and main stem (Saskatchewan River) is smaller than in sub-basins G and H, because much of this drainage lies in the forest-prairie transition zone, or in boreal forest overlying Precambrian Shield, so tributary concentrations are lower. Nevertheless, the open-water mean tributary concentration (388 mg/L) is close to twice the mean main-stem concentration (215 mg/L). Most of this difference is due to the high and variable TDS concentrations in the Carrot River system, which has been thoroughly sampled by both WRB and WQB. Numerous other tributaries, many of them draining boreal forest, enter the Saskatchewan River from the north, but with the exception of the Torch and Whitefox rivers, these have not been sampled. The low TDS concentrations (150-200 mg/L) exhibited by the few samples (ten in total from both rivers) taken from these tributaries suggests that, were the whole system more thoroughly and uniformly sampled, both the sub-basin mean TDS concentration, and the difference between tributaries and main stems would be substantially less.

Notwithstanding the overall increase in TDS concentrations in winter, the pattern of differences among sub-basins is identical to that seen in the open-water season (Fig. 21). High winter TDS is the result of lower river discharge, reduced surface runoff and freeze-out during ice formation. Again, there are frequently large differences in mean TDS concentrations of tributaries as estimated by WQB and WRB, attributable to WRB's under-sampling during winter months.

Summary of Seasonal and Annual Patterns

In both the ice-cover and open-water seasons, there is a general increase across the basin in tributary TDS concentrations from east to west, with concentrations being low (relatively) in sub-basins A-D, intermediate in sub-basins E and F, and high in sub-basins G-K. The first TDS means >500 mg/L are found in prairie streams at least 100 km east of the mountains. At the opposite end of the basin, in eastern Saskatchewan, concentrations are seldom <500 mg/L and values >1000 mg/L are commonplace (Appendix A).

Main-stem rivers had a nearly constant mean TDS concentration across the basin, between 200 and 300 mg/L, with only a subtle increase from west to east (Fig. 21). Thus, it is tributaries that are largely responsible for real or apparent cross-basin trends in average TDS concentration. Further, the very small downstream trend of increasing main-stem TDS concentrations, despite the influx of ion-rich water from tributaries, indicates that dilute mountain runoff dominates main-stem river water concentrations across the basin. The higher main-stem concentrations in the Battle River sub-basin arise because this sub-basin and no other, is free of the influence of mountain runoff that feeds tributaries to the North and South Saskatchewan Rivers.

## SOLUTE LOADS AND GEOCHEMICAL YIELD

Background

The central objective of the WRB sampling program is estimation of solute loads and yields for comparison with similar data for suspended solids. These solute loads may be obtained by a number of numerical techniques, broadly classed as interpolation or extrapolation. Interpolation methods include the widely-used interval methods, in which solute load for a given interval is estimated from measures of concentration and discharge at the limits of the interval. Extrapolation methods include the rating curve method, in which load is estimated from discharge data and a site-specific discharge-concentration relationship. Interpolation methods are usually used by WRB; in this section utility and limitations of the TDS data for both methods are assessed.

Evaluation of Interpolation Method

This analysis addressed several specific problems. First, the error incurred in estimating TDS loads by the interval method using WRB data was compared with estimates using WQB data. WRB sampling is weighted toward peak flows in late spring and against low winter flows. WQB samples on a fixed schedule of one sample per month throughout the year. The two sampling strategies may produce different estimates of TDS loads, depending upon how the annual TDS load is distributed among the seasons. Second, we explored the data requirements (number of years of record) for estimating average seasonal or annual TDS load, and the accuracy that could be achieved.

A simple interval loading method was used. Intervals were delimited by the instantaneous TDS and daily mean discharge measures taken at the beginning and end of any period of time. Instantaneous loads at the beginning and end of the interval were calculated as discharge times TDS concentration. The mean of these two load estimates, multiplied by the duration of the interval, rendered the load estimate for that period, which was added together with all other intervals to derive the total load for the season or year of interest.

As well as annual loads, three seasons within the year were considered: open-water, ice-cover and "runoff". The last embraces the period of high flow from ice-off until July 31, and hence is a sub-class within the open-water season. Four sites were chosen for analysis, based on presence of a long data record from both WQB and WRB. The TDS load estimated from combined WQB and WRB data was used as the standard against which loads from the individual data sets were compared.

Results were similar at all four sites analyzed (Table 14). Annual load varied from 0.63 tonnes in Marmot Creek, a tiny mountain stream, to just under 4500 tonnes in the Saskatchewan River at the Pas, but in all cases more than two-thirds of the annual load (66-92%) was delivered during the open-water season. Despite the higher concentrations typical of the winter, only 8-34% of total load was carried during the ice-cover season. Within the open-water season, the period of high runoff appears to be important, since 41 to 70% of the annual load is carried at that time.

This disproportionate distribution of annual TDS load is a consequence of the discharge regime. Flows are higher in summer than in winter, so TDS loads are greater in the open-water season. Also, the ice-cover season is relatively brief (130 of 365 days at Bindloss). Flows are highest during spring runoff, so TDS loads are greatest then. The decrease in concentration experienced during high flows does not offset the corresponding increase in flow.

The proportion of the annual load carried by ice-cover flows is least in Marmot basin (8%) but increases eastward to a high of 34% at The Pas (Table 14). This pattern is another consequence of reservoirs regulating flows in the system. Reservoirs detain water from spring runoff, mix it with water from other seasons, and release water of nearly unvarying TDS concentration at a rate much more constant than the natural condition. Consequently, winter's contribution to the annual load is greater on regulated than on free-flowing rivers, and as the effects of more reservoirs are felt further downstream the contribution of winter flows continually increase.

Both WQB and WRB data produce load estimates which are similar and respectably close to those produced from all data combined (Table 14), which by the nature of the interval method must produce the most accurate estimate because there are more measurements, and hence interpolated intervals are smaller. WQB estimates tend to be a little lower and WRB estimates a little higher than combined-data results, but the differences are not consistent, and usually less than 10% (Table 14). In only three instances was the mean

Table 14 Annual and seasonal TDS loads (tonnes) for four sites in the Saskatchewan River Basin, as calculated from WQB data (monthly sampling)** and WRB data (flow-weighted sampling) compared to the data sets combined.

| PERIOD | COMBINED | | | WQB | | WRB | |
|---|---|---|---|---|---|---|---|
| | LOAD (TONNES X $10^3$) | C.V.[1] (%) | %OF ANNUAL | LOAD | % OF COMBINED[2] | LOAD | % OF COMBINED[2] |
| **RED DEER RIVER AT BINDLOSS (n = 16)** | | | | | | | |
| Annual | 505 | 26.3 | 100 | 511 | 101 | 585 | 115 |
| Open-water | 424 | 25.3 | 84 | 423 | 98 | 450 | 106 |
| Runoff | 292 | 35.0 | 58 | 315 | 107 | 304 | 104 |
| Ice-cover | 81 | 59.2 | 16 | 88 | 108 | 135 | 166* |
| **SASKATCHEWAN RIVER AT THE PAS (n = 18)** | | | | | | | |
| Annual | 4494 | 26.4 | 100 | 4286 | 95 | 4708 | 105 |
| Open-water | 2956 | 35.1 | 66 | 2749 | 93 | 2999 | 101 |
| Runoff | 1848 | 40.1 | 41 | 1705 | 92 | 1863 | 101 |
| Ice-cover | 1538 | 22.2 | 34 | 1538 | 100 | 1716 | 111* |
| **SOUTH SASKATCHEWAN RIVER AT HIGHWAY #41 (n = 12)** | | | | | | | |
| Annual | 1096 | 25.8 | 100 | 1064 | 97 | 1159 | 106 |
| Open-water | 911 | 30.9 | 83 | 871 | 96 | 915 | 100 |
| Runoff | 669 | 36.4 | 61 | 651 | 97 | 666 | 99 |
| Ice-cover | 184 | 15.3 | 17 | 193 | 104 | 244 | 132* |
| **MARMOT CREEK (n = 12)** | | | | | | | |
| Annual | 0.63 | 12.6 | 100 | 0.58 | 93 | 0.65 | 104 |
| Open-water | 0.58 | 13.7 | 92 | 0.53 | 92 | 0.60 | 104 |
| Runoff | 0.44 | 20.5 | 70 | 0.40 | 90 | 0.46 | 103 |
| Ice-cover | 0.05 | 21.2 | 8 | 0.05 | 102 | 0.06 | 110 |

1. Coefficient of variation
2. TDS load as a percentage of load calculated from combined data.

* mean load statistically different from combined-data load, $p < 0.05$.
** except at Marmot Creek, where sampling was flow-weighted by both WRB and WQB.

annual TDS load as calculated by WRB or WQB data significantly different than that calculated from combined data. All three exceptions are WRB estimates for the ice-cover season. It is in the nature of the interval method that fewer data, as from WRB in winter, may sometimes produce higher total load estimates, because TDS loads are calculated across longer intervals, during which the true flow may be less than at the boundaries.

It appears, then, that TDS loading calculations are quite insensitive to sampling regime, since very different programs produced remarkably similar estimates. Under-sampling of rivers in winter by WRB did produce significant overestimation of TDS loads in that season, but the small contribution of ice-cover flows to the annual total ensured that estimates of annual TDS load are not seriously biased.

To evaluate the length of record needed to produce accurate estimates of annual or seasonal TDS loads, mean loads were calculated, for the same sites and seasons as before, incorporating sequentially more years' data into the mean. The standard error (SE) of the mean was then plotted against the number of years' data used to derive it (Fig. 22-25). The curves tend to decline steeply to an asymptote, representing the natural year-to-year variation of TDS transport, and hence the accuracy limit of loading estimates.

For most sites and seasons a uniform result appeared: SE stabilized at 10-15% of the mean in 8-10 years. Marmot Creek data produced a lower stable SE, about 5%, in about the same length of time (Fig. 25). The lower error there is undoubtedly due to the very small size of this headwater stream and hence to greater uniformity of geologic and hydrologic conditions within its basin. Usually there were no important differences among WQB, WRB or combined data with respect to the stable SE or the number of years' data needed to approach it. WQB curves were sometimes higher than the others, especially initially, but approached an asymptote within 2% (SE) of the others in the same period (Fig. 22-25). Seasonal differences show no

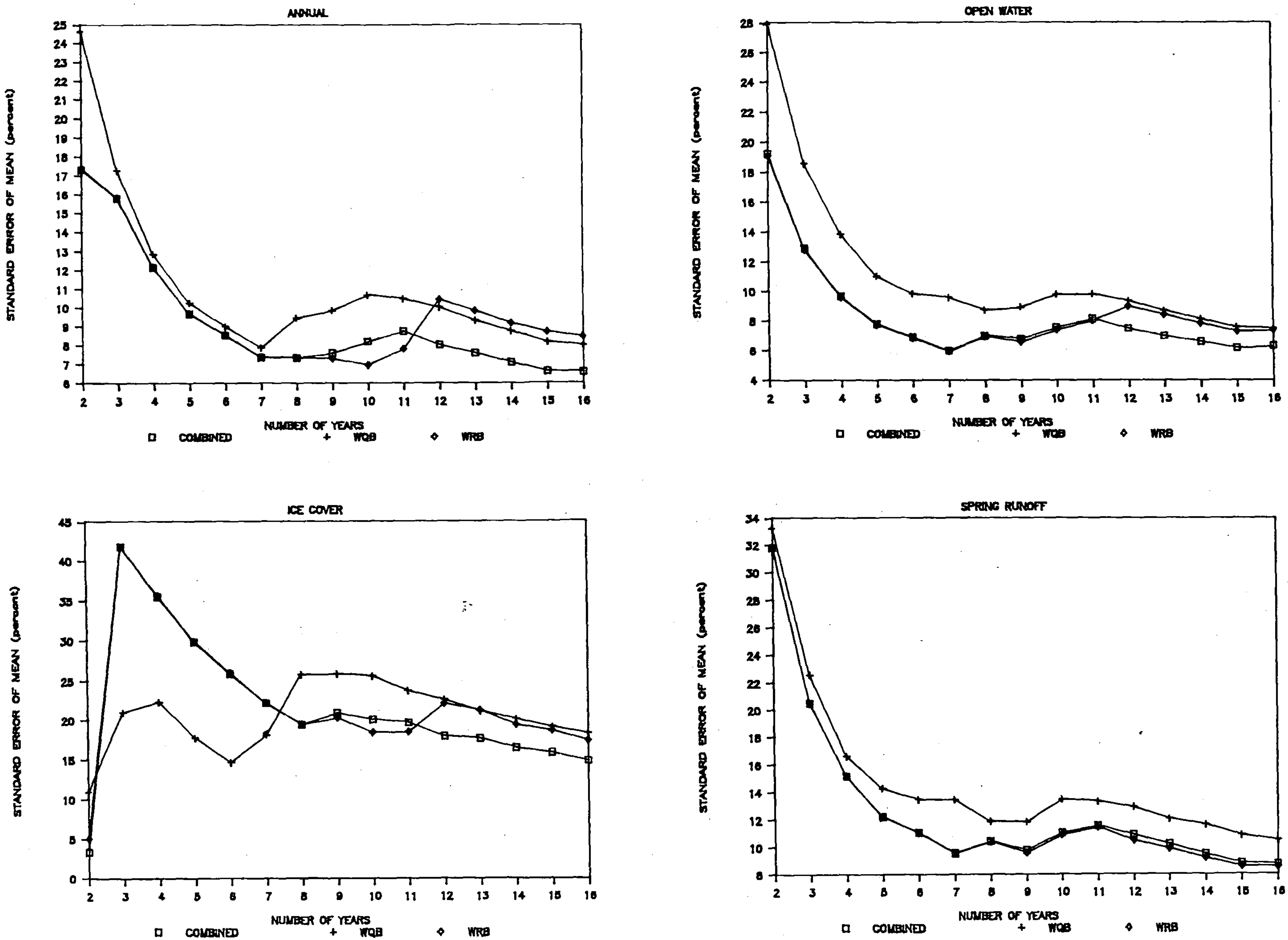



FIGURE 22 Change in Standard Error of the annual mean TDS load with increasing years of record for the Red Deer River at Bindloss.

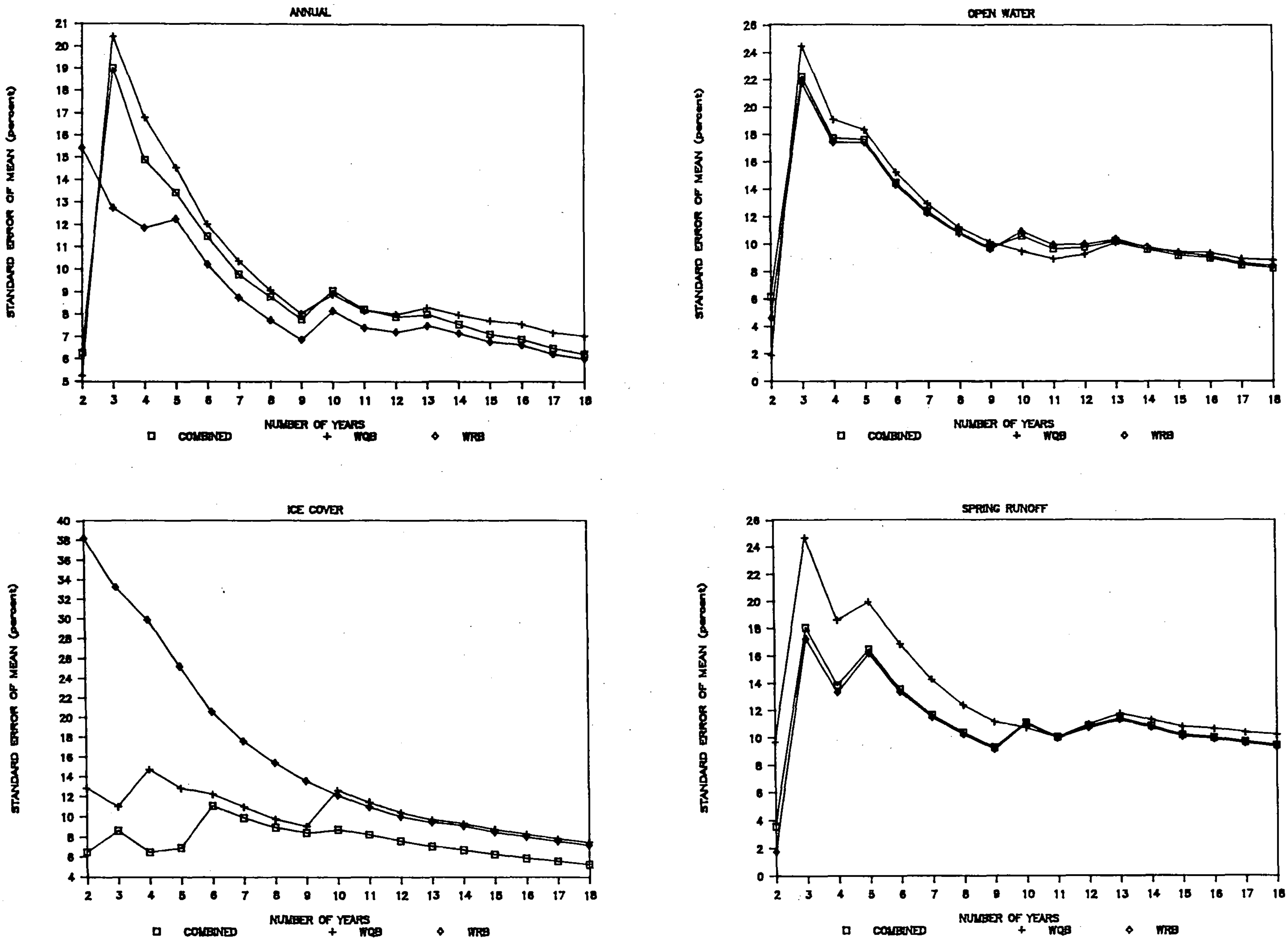



FIGURE 23 Change in Standard Error of the annual mean TDS load with increasing years of record for the Saskatchewan River at The Pas

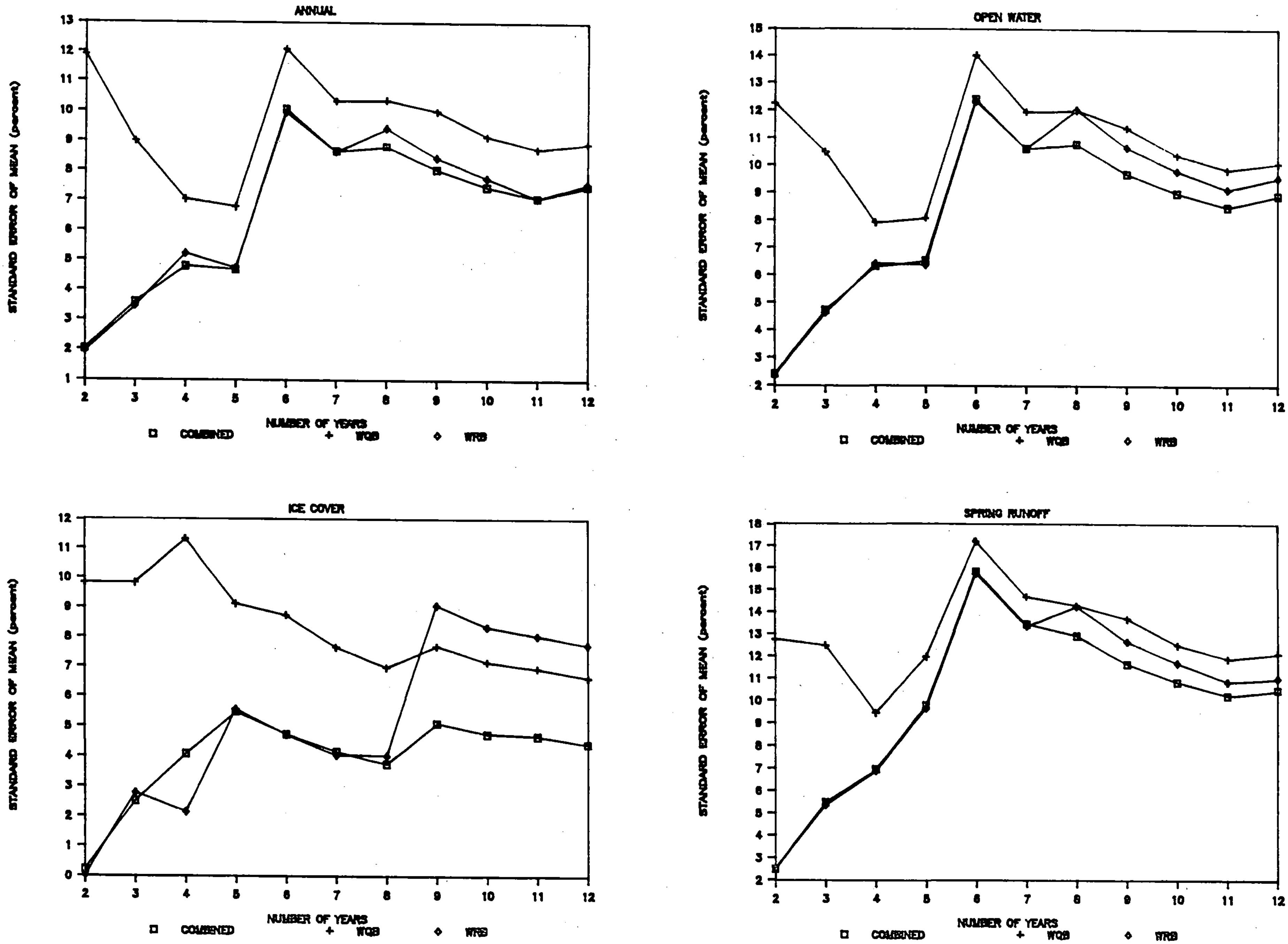



FIGURE 24 Change in Standard Error of the annual mean TDS load with increasing years of record for the South Saskatchewan River at Highway #41

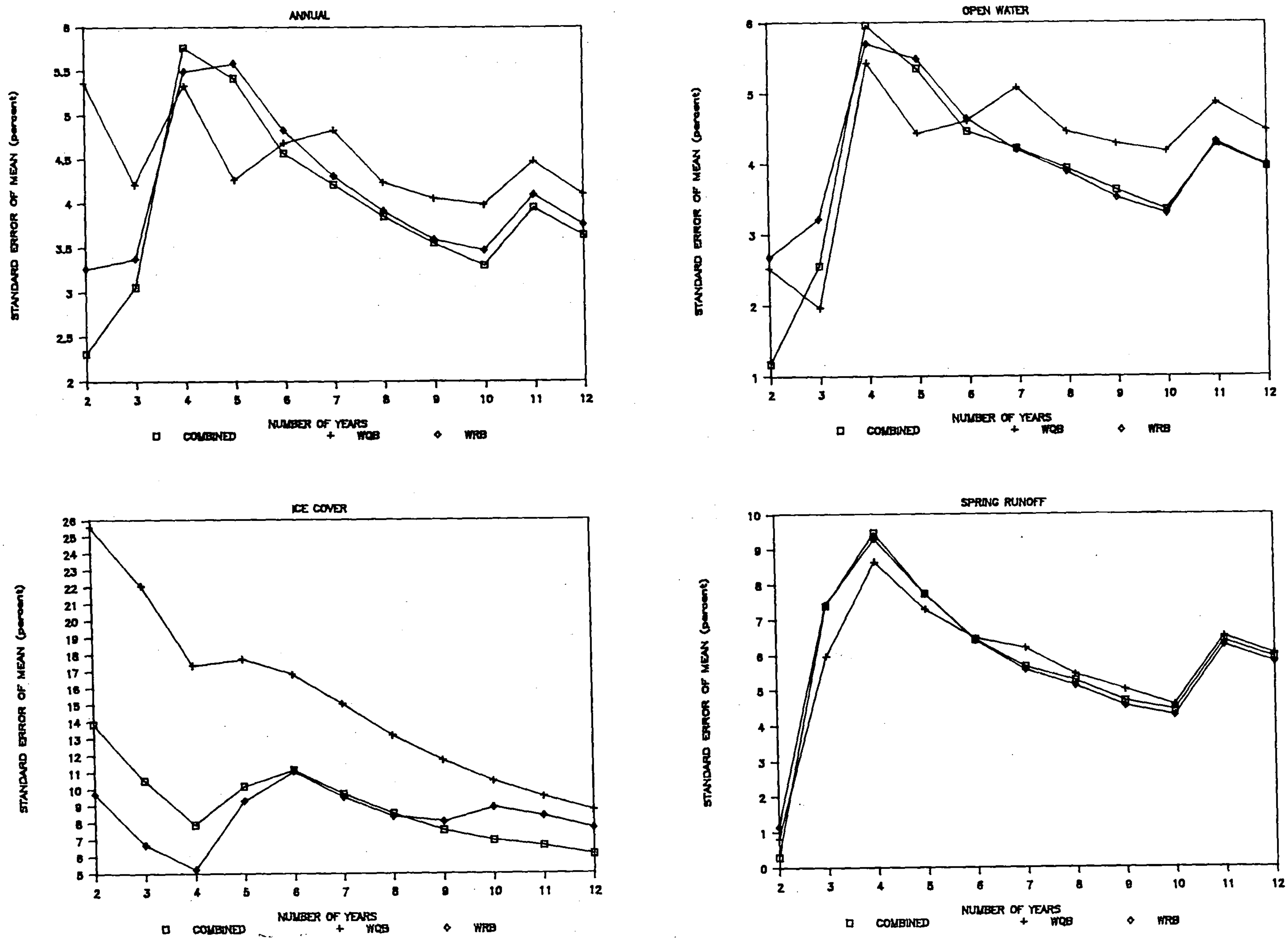



FIGURE 25 Change in Standard Error of the annual mean TDS load with increasing years of record for the Marmot Creek

consistency from site to site, and probably reflect the particular data used.

The constancy of the stable SE (10-15%) among the sites and seasons considered here, and the uniformity of duration (8-10 years) needed to reach it, imply that these results probably apply to TDS data generally. Hence, continued sampling beyond 10 years for the sole purpose of estimating TDS loads more precisely is unwarranted. The stable SE is a reflection of the natural variability of the data from year to year, mostly resulting from annual variation in runoff and discharge. Regressions of TDS on discharge have much lower slopes than between sediments and discharge (see below). Thus relatively large annual variation in discharge (at a given time of the year) produces a relatively small variation in TDS load, reflected in the low SE seen here.

Evaluation of Extrapolation Method

These methods differ from the above because they are based on extrapolation from known data instead of interpolation within it. In the simplest case, sample data are used to develop a regression relationship (rating curve) between TDS concentration and discharge. The regression is then used to predict TDS concentrations from discharge for periods for which no water quality data are available.

TDS load for any given period is the simple sum of all predicted TDS loads (concentration times discharge) for short periods as defined by the rating curve. This approach was tested here using data from the same sites evaluated for the interval method. Combined WQB and WRB data were used, and both TDS concentration and discharge were log-transformed to ensure linearity of the regression (Walling 1984). Only regressions of concentration against discharge were computed. The convenient and often-used method of regressing instantaneous load (concentration X discharge) against discharge was avoided because the load term already contains discharge. The variables are therefore not independent, and a spuriously strong correlation results.

The full year was sub-divided into two climatic seasons, ice-cover and open-water. The latter was sub-divided into two hydrologic seasons: the runoff season extends from ice-out to the end of July; "autumn" extends from August 1 to freeze-up.

Regressions were weak at most sites and times considered (Table 15); only four cases out of 20 produced $R^2$ values > 0.5, and many were <0.1. No formal tests of significance were carried out because the large sample sizes in most instances guarantees a significant result even for regressions whose predictive power is minimal. There were no consistent differences in $R^2$ values among seasons, but of the stations tested, the very low correlations for the Saskatchewan River at The Pas are conspicuous (Table 15). Again, this result probably reflects the influence of upstream impoundments, which retain and mix water from different seasons and thereby weaken the TDS-discharge relationship.

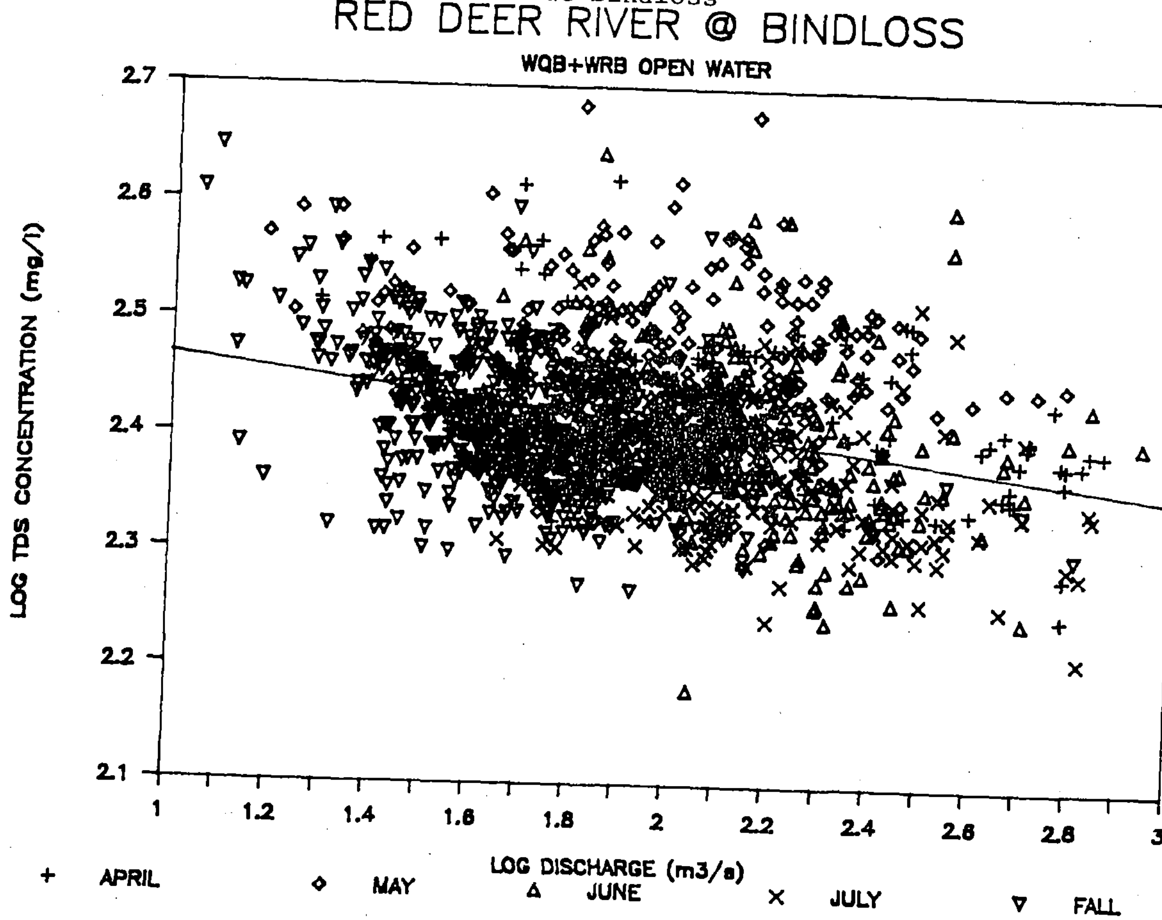
Slopes of regressions were always negative, reflecting the diluting effect of high flows (Walling 1984), and when plotted by month a definite hysteresis pattern is evident (Fig. 26-29). Hysteresis arises because the TDS-discharge relationship varies with time of the year. Hence, a given discharge will tend to produce higher TDS concentrations in spring than the same discharge in fall. TDS data form an ellipse (instead of a straight line) when plotted sequentially against discharge (Fig. 26-29).

More complex procedures, such as separate regressions for different months, may alleviate the hysteresis problem. However, the generally weak relationship between discharge and TDS at the sites examined here suggests that the simple rating curve technique is not a method to be preferred for calculation of TDS loads. Doubtless this conclusion extends to other sampling sites in the basin as well.

Table 15. Correlations between TDS concentration and discharge during different seasons for four sites on the Sskatchewan River Basin.

| | ANNUAL | ICE-COVER | OPEN-WATER | RUNOFF | AUTUMN |
|---|---|---|---|---|---|
| **RED DEER RIVER AT BINDLOSS** | | | | | |
| $R^2$ | 0.332 | 0.522 | 0.080 | 0.134 | 0.226 |
| n | 1795 | 248 | 1547 | 950 | 597 |
| **SASKATCHEWAN RIVER AT THE PAS** | | | | | |
| $R^2$ | 0.104 | 0.048 | 0.029 | 0.051 | 0.015 |
| n | 1328 | 136 | 1192 | 695 | 497 |
| **SOUTH SASKATCHEWAN RIVER AT HIGHWAY #41** | | | | | |
| $R^2$ | 0.392 | 0.261 | 0.343 | 0.253 | 0.386 |
| n | 2452 | 242 | 2210 | 1370 | 840 |
| **MARMOT CREEK** | | | | | |
| $R^2$ | 0.590 | 0.002 | 0.649 | 0.535 | 0.296 |
| n | 1328 | 136 | 1192 | 695 | 497 |

FIGURE 26 Rating curves of TDS concentration against discharge during the open-water (top) and ice-cover (bottom) seasons for the Red Deer River at Bindloss




and ice-cover seasons for the Red Deer River at Bindloss

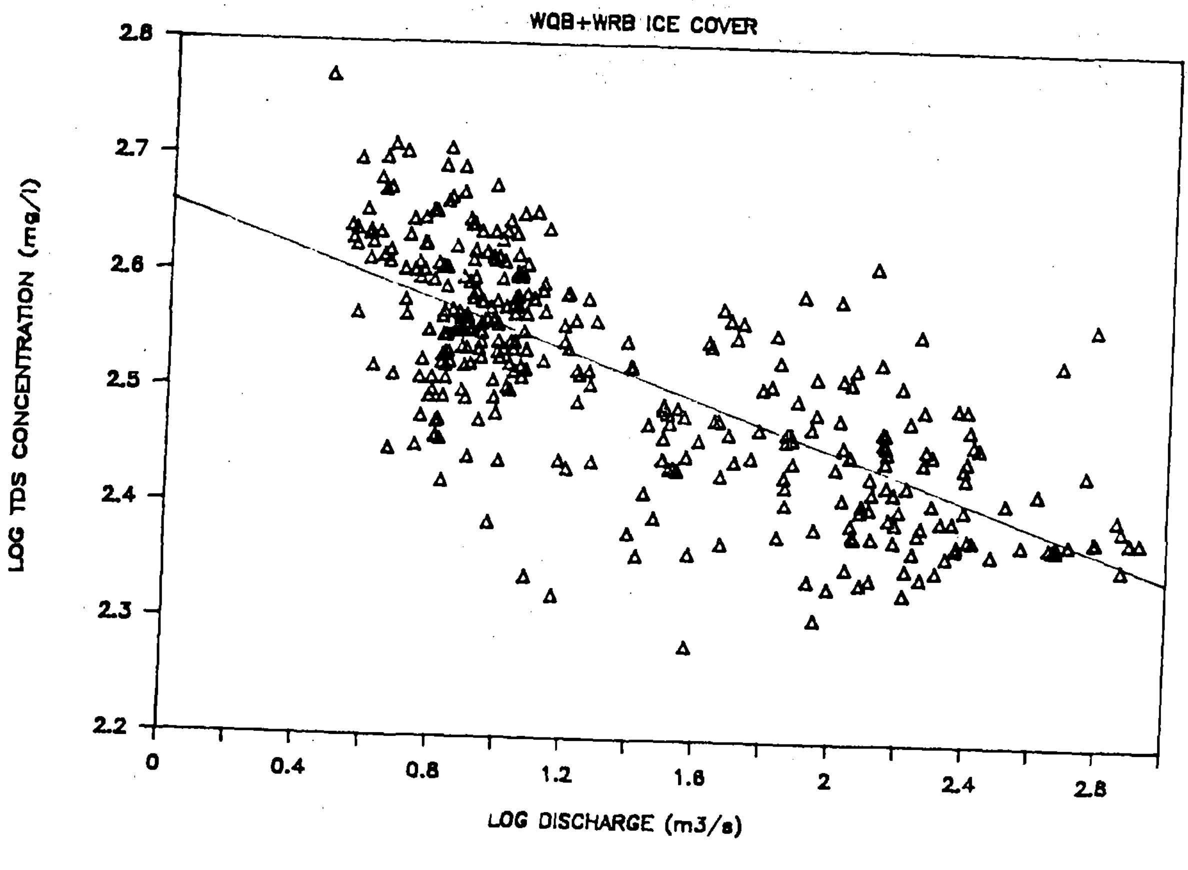
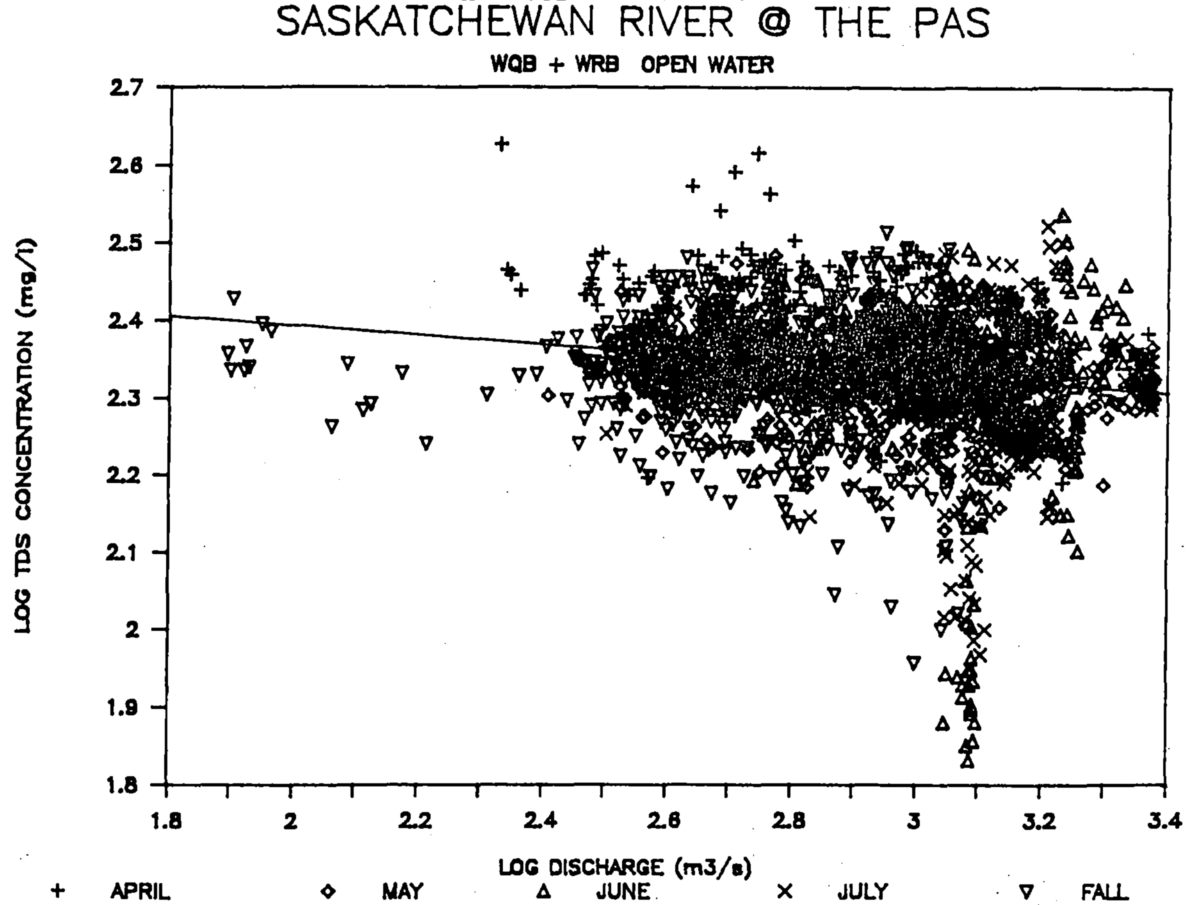


FIGURE 27 Rating curves of TDS concentration against discharge during the open-water (top) and ice-cover (bottom) seasons for the Saskatchewan River at The Pas.



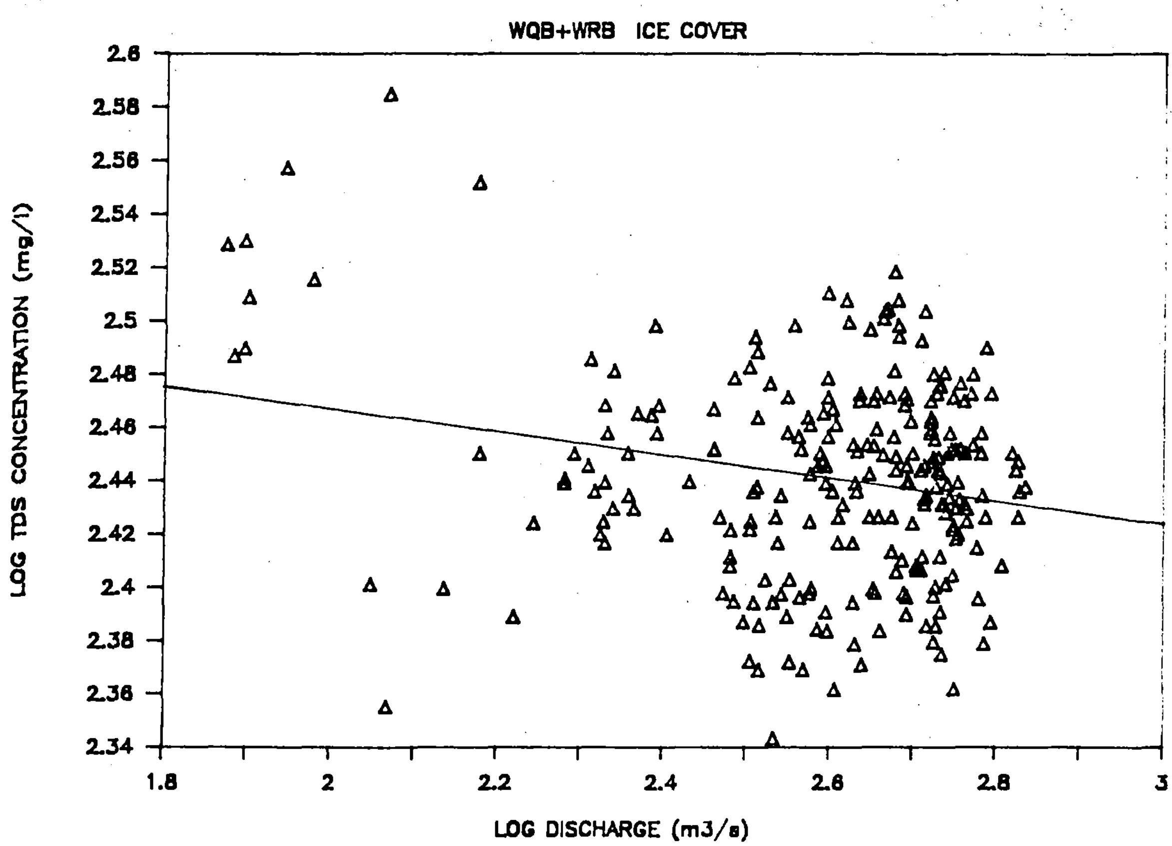
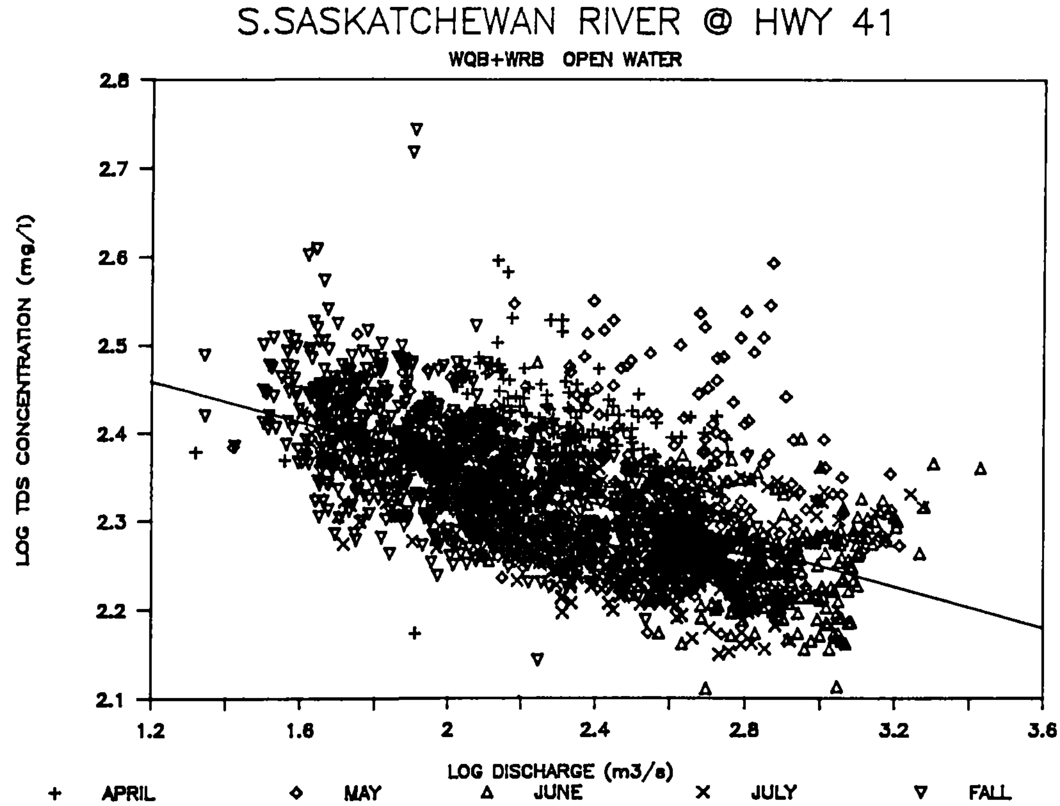



FIGURE 28 Rating curves of TDS concentration against discharge during the open-water (top) and ice-cover (bottom) seasons for the South Saskatchewan River at Highway #41



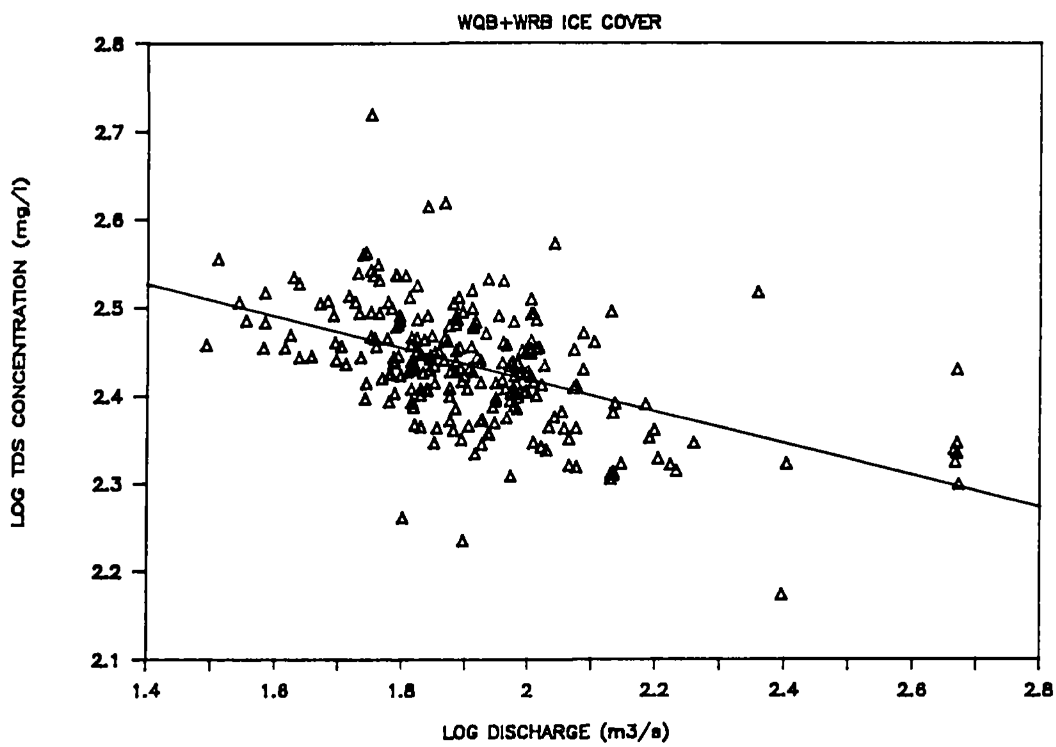
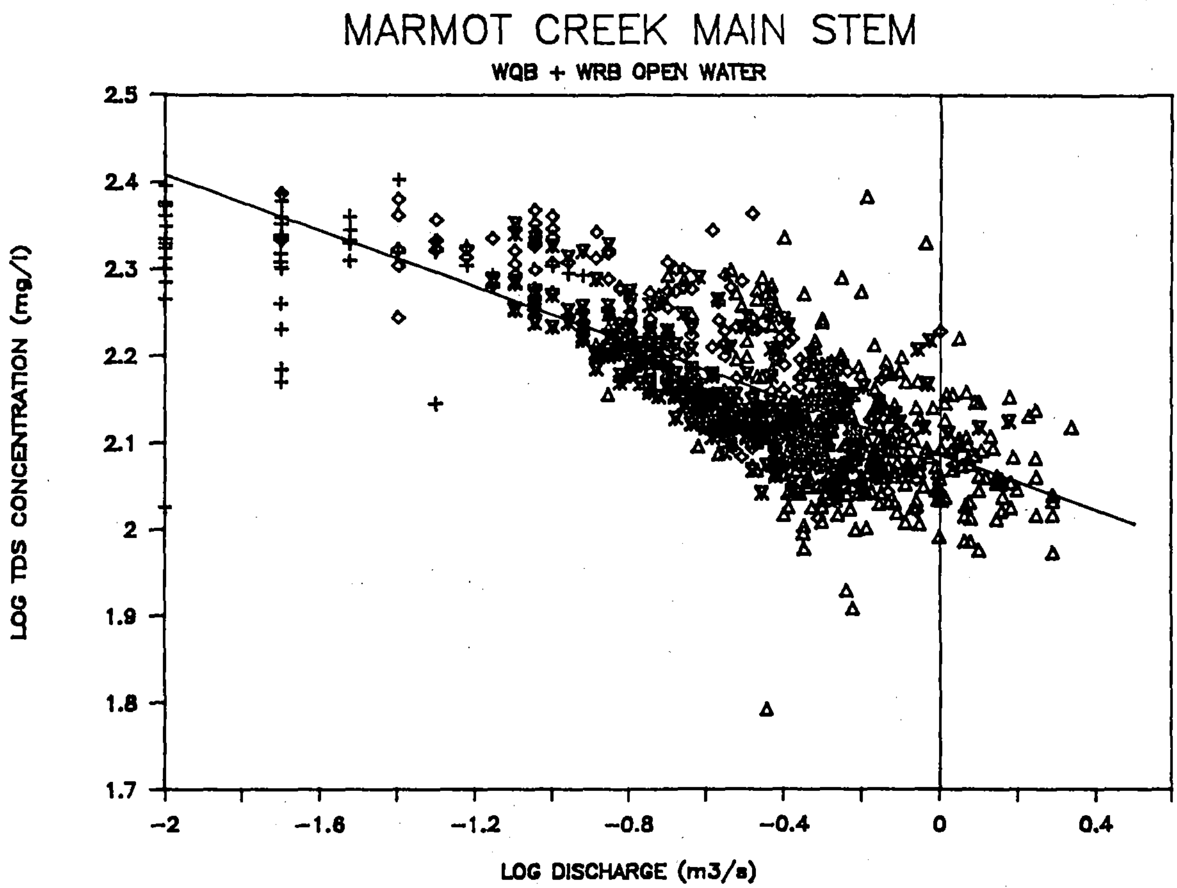
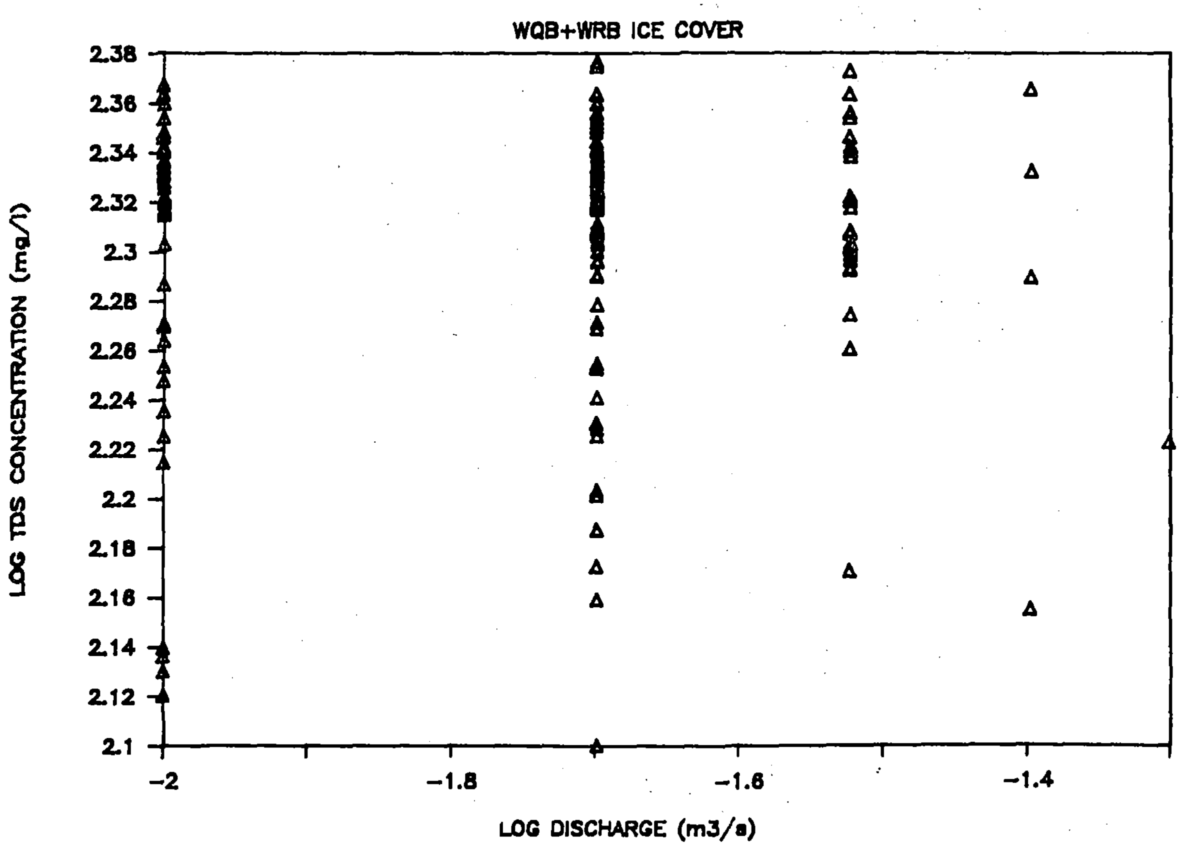



FIGURE 29 Rating curves of TDS concentration against discharge during the open-water (top) and ice-cover (botton) seasons for Marmot Creek



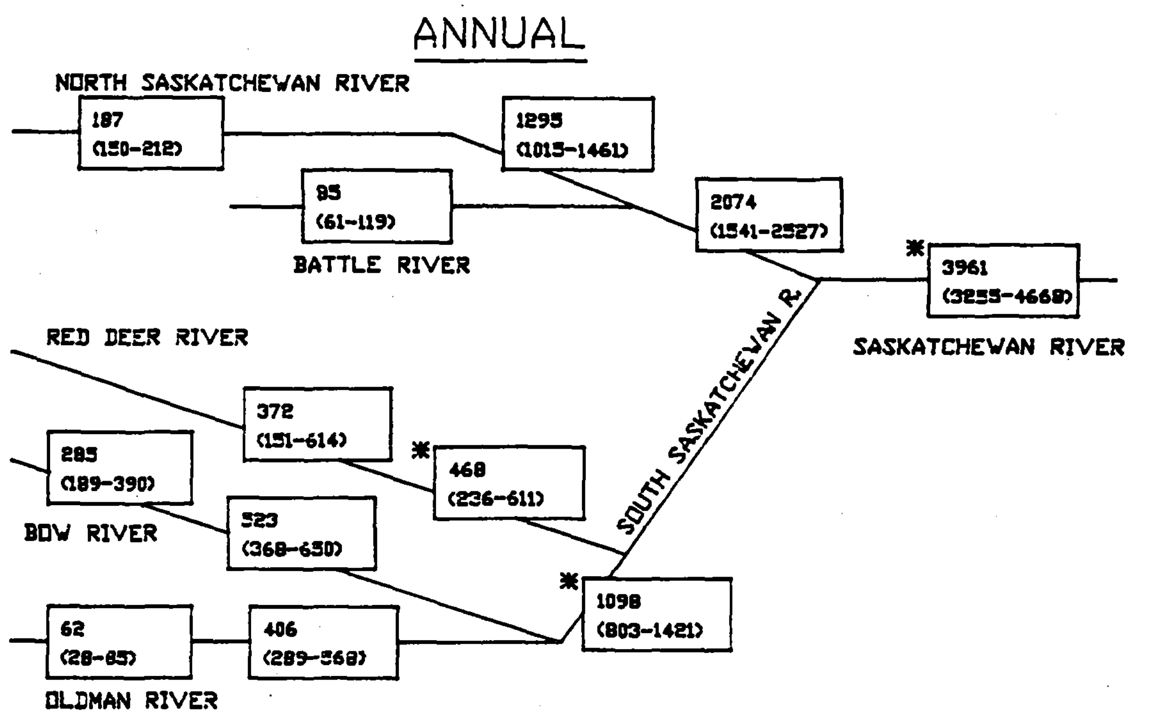



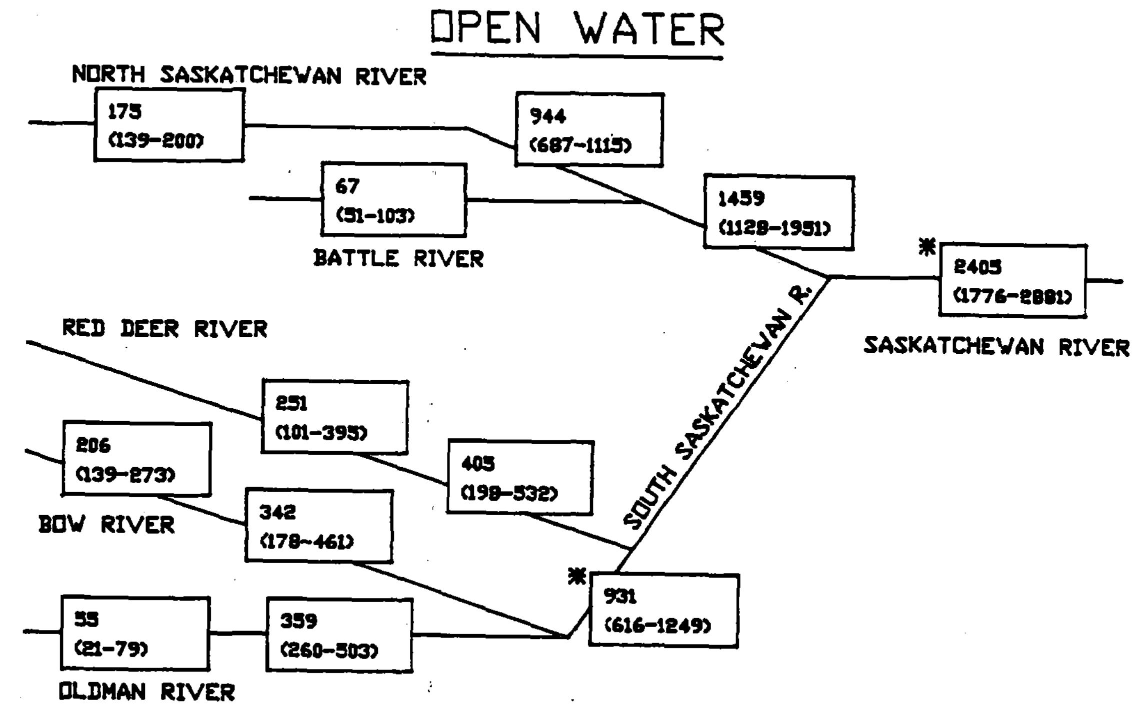
## Geochemical Yield

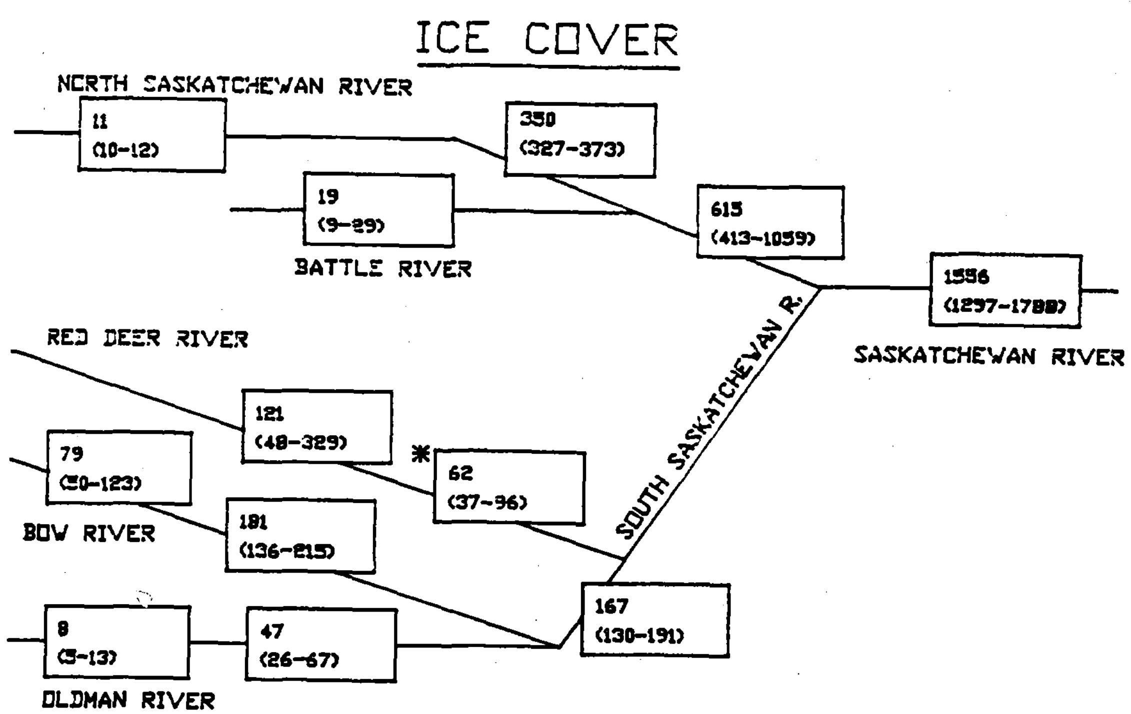
We used the TDS monitoring network to derive actual rates of geochemical hield for the entire Saskatchewan River basin. To do this we selected a set of 12 sites located at key points on the major rivers in the basin. All sites had a complete data record (WQB and WRB combined) for the five-year period 1978-1982. Annual loads, and loads for the open-water, ice-cover and runoff seasons were computed by interpolation for each point. The sites are:

| | | |
|---|---|---|
| NORTH SASKATCHEWAN R. | - | WHIRLPOOL POINT |
| NORTH SASKATCHEWAN R. | - | ALBERTA BORDER (HWY 3) |
| NORTH SASKATCHEWAN R. | - | PRINCE ALBERT |
| BATTLE RIVER | - | UNWIN |
| RED DEER R. | - | CITY OF RED DEER |
| RED DEER R. | - | BINDLOSS |
| BOW RIVER | - | CANMORE |
| BOW RIVER | - | MOUTH |
| OLDMAN RIVER | - | WALDRON'S CORNER |
| OLDMAN RIVER | - | LETHBRIDGE |
| SOUTH SASKATCHEWAN R. | - | HWY. #41 |
| SASKATCHEWAN RIVER | - | THE PAS |

Trellis diagrams (Fig. 30) illustrate the increasing TDS load as water moves downstream. Annual loads varied from 62 X $10^3$ tonnes on the Oldman River in the foothills, to almost 4000 x $10^3$ tonnes on the Saskatchewan River main-stem. On a seasonal basis most of the TDS load is transported during the open-water season, especially during spring runoff. The percentage of open-water versus total loadings were 61%, 65% and 70% for the Saskatchewan River at The Pas, Bow River and North Saskatchewan Rivers respectively, which are all highly regulated. Open-water percentages were higher for the non-regulated systems like the Battle River (78%), Red Deer River (86%) and Oldman River (88%).



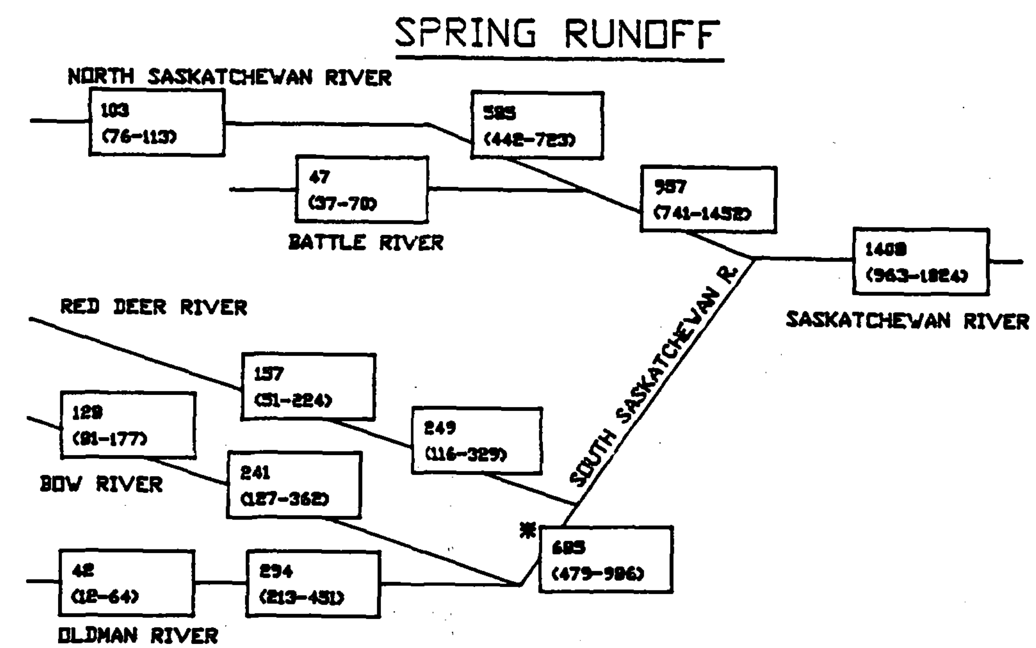




FIGURE 30

SEASONAL LOADINGS 1978-1982

UNITS ARE TONNES*1000

* = NO SIGNIFICANT DIFFERENCE WITH UPSTREAM LOADING (P=<.1)

There are a few locations where average downstream loads are somewhat less than loadings at the reach immediately upstream, or the sum of loadings from upstream tributaries. This includes the Red Deer River at Bindloss and South Saskatchewan River at HWY 41 during winter, and the Saskatchewan River at The Pas during the open-water season. To better confirm whether these patterns are true paired t-tests were used (n = 5) to compare loads at all consecutive downstream points throughout the basin. All non-significant differences are noted on the trellis diagram (Figure 30).

The apparent reduction between Red Deer and Bindloss during winter is not statistically significant, however the decline for the South Saskatchewan at HWY 41 is. However, it is still doubtful that a true salt imbalance below the confluence of Bow and Oldman Rivers does occur, it is most probably an artifact of the winter sampling regime and the precision of the interpolation method. The reduced loading for the Saskatchewan River at The Pas, relative to the sum of loadings from the North Saskatchewan, Red Deer and South Saskatchewan Rivers, is not statistically significant for the entire open-water season, but is for spring-runoff. This pattern could be the result of water storage in Lake Diefenbaker.

Geochemical yield, the load of TDS per unit area of drainage basin, was calculated for the twelve sites by dividing the net load by the area of the drainage basin between that point and the next upstream point. Yields for the year and seasons are presented in Fig. 31. McPherson (1975) computed geochemical yields from a range of foothill streams and rivers based on at least 5 years of data. His estimate for the Oldman River, 39.4 tonnes/km$^2$ is comparable to the 43.1 tonnes/km$^2$ estimated here. For other mountain streams, McPherson (1975) reported solute yields of 53.7 tonnes/km$^2$ (Elbow River) to 96 tonnes/km$^2$ (Crowsnest River), again very similar to the range in this study (43.1-97.4 tonnes/km$^2$). For a set of small prairie streams in central Alberta, McPherson (1975) obtained solute yields of 10.1-30.3 tonnes/km$^2$, which is similar to the 11.1-32.1 tonnes/km$^2$ range reported here for larger drainage areas in the same area.

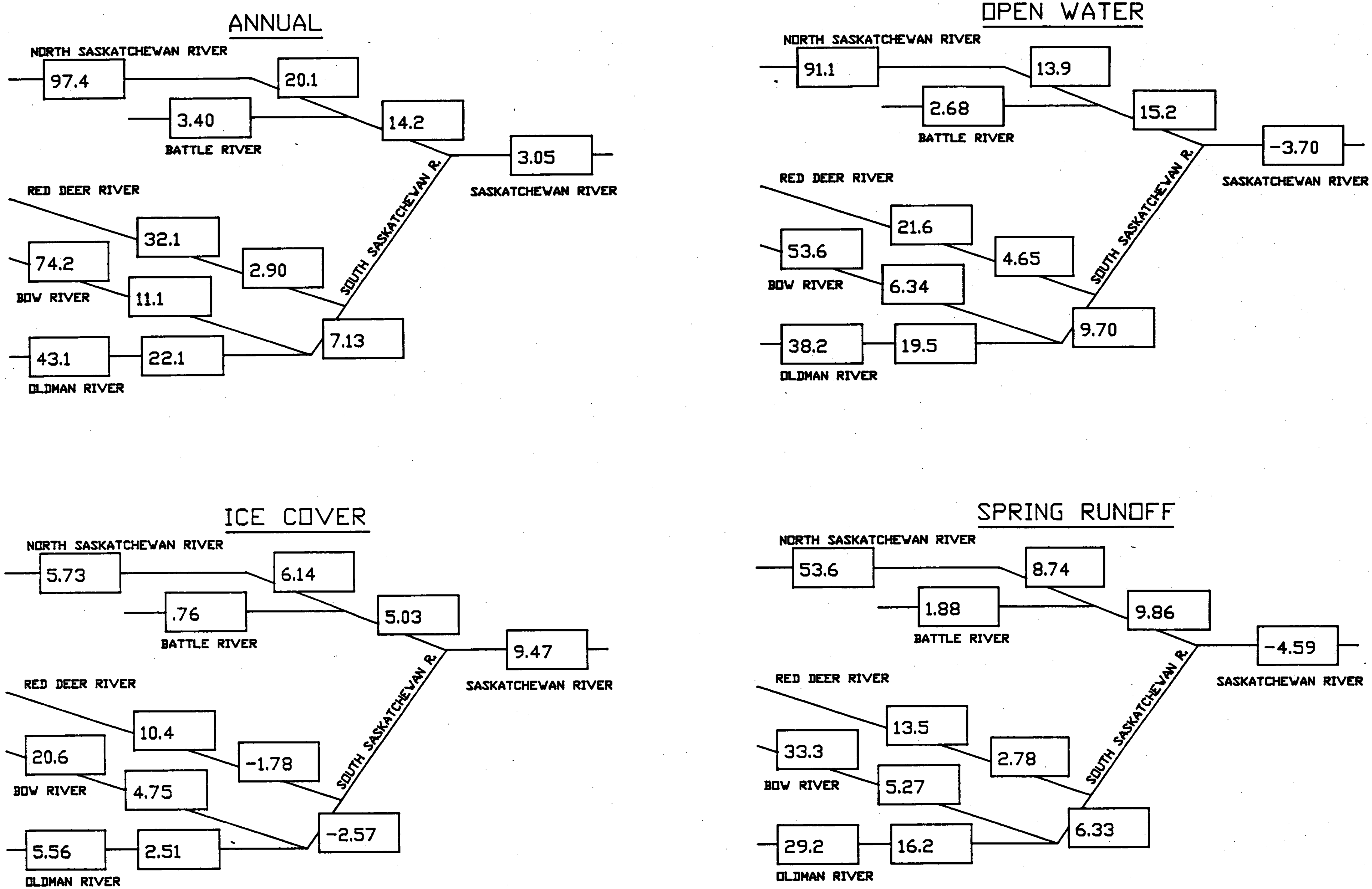



FIGURE 31

YIELD 1978-1982

UNITS ARE TONNES/ KM^2

The mountain and foothills regions dominate TDS yield (Fig. 31). On an annual basis, foothill basins contributed 43-97 tonnes TDS per $km^2$ while rates on the prairies ranged from 3-22 tonnes/$km^2$. Rainfall in the mountains is far more than on the arid central grassland. This causes rapid erosion and a high TDS load, even though concentrations are kept low by dilution. On the prairies, erosion is reduced because of sparse rainfall, high soil porosity and rapid evaporation. Depressional storage is also significant and there are several internal drainage systems of substantial size, which means the actual area contributing salts to the major tributaries is only a small faction of the total drainage area. During the ice-cover season, when ground water influx predominates over surface runoff, the difference in solute loads between mountain and prairie sites is less than at other times, and on the North Saskatchewan River the pattern actually reverses.

## CONCLUSIONS AND RECOMMENDATIONS

### Distribution of Sampling Effort

1. There is a disproportionate number of active sampling sites, especially from WRB, on the Oldman River system in southwest Alberta. Some of these stations should be discontinued.

2. Sampling by WRB and WQB at the same location, or at locations in the same proximity (Table 1) is redundant and inefficient. These stations should be sampled by only one agency.

3. There are three active stations on the Carrot River, inconsistent with sampling intensity for other tributaries of that size. Utility of these three stations should be reviewed, and unnecessary stations should be discontinued.

4. Some of that sampling effort could be advantageously applied to sampling rivers that have been sampled inadequately or not at all:

   a) The Brazeau, Clearwater, and Kananaskis Rivers in Alberta;

   b) Small prairie rivers such as Ribstone Creek, Rosebud River, Eagle Creek;

   c) Tributaries of the North Saskatchewan River near Prince Albert: Garden, Spruce, Sturgeon Rivers, and Shell Brook;

   d) Northern Tributaries of the Saskatchewan River main stem: Torch Creek, and Whitefox, Moss, Grassberry, Sturgeon-Weir Rivers;

   e) The South Saskatchewan River from the Alberta border to the confluence -- not presently being sampled by either WRB or WQB.

5. The efficacy of maintaining three WQB sites on the Saskatchewan River should be reviewed, with a view toward potentially transferring some of

that effort to the North and South Saskatchewan Rivers, neither of which is presently being sampled by this agency.

6. It is logical to maintain a cross-section of sites that already have a long historical record of TDS data, so that continuing trends may be detected. These sites should be strategically located across the basin.

Data Comparability and Conciliation

7. Variation in TDS concentration is so small across even wide channels that multiple vertical sampling is not needed. If WRB continues to collect TDS samples along with SS samples, then only one of the set of cross-channel samples needs to be analyzed for TDS.

8. Temporal variation in TDS concentrations within one day is also minimal; one sample per day is sufficient to characterize a site.

9. Because cross-channel and diurnal variations in TDS concentration are insignificant, data from multiple verticals or repeated sampling within one day by WRB may be compressed to a single mean value for comparison with WQB data, with no loss of accuracy.

10. Analytical methods used by WRB and WQB for TDS lead to very similar results. When comparing or merging data from both Branches, WQB data (calculated as the sum of ions) may be converted to WRB data (calculated gravimetrically) by multiplying by 1.055. This simple conversion applies equally well at most sites and TDS concentrations found throughout the Saskatchewan River Basin.

11. Data from either WRB or WQB or both should be assumed to be non-normal if there are more than 150 observations. Data sets larger than that limit typically have highly skewed distributions, with a mean biased toward lower values. Non-normal TDS data are not always normalized by

the usual logarithmic transformation; hence, nonparametric statistical methods should be considered.

12. The historical database is largely free of outliers confirming that the data collection and handling procedures of both agencies are adequate.

Temporal Patterns in TDS

13. The long history of data at many sites in the Saskatchewan River Basin makes them ideally suited to time series analysis. Moving averages, sine curve regression, and regression of seasonal means are all workable methods of analyzing these data.

14. The long-term TDS records at many locations have been most affected by stream regulation. This is especially apparent for the North Saskatchewan River at Prince Albert, the South Saskatchewan River at Saskatoon and to a lesser extent the Saskatchewan River at The Pas. Regulation dampens the annual fluctuation in TDS by retaining and mixing water from many seasons.

15. There has been no overt long-term increase or decline in annual average TDS concentrations in the major rivers of the Saskatchewan Basin over the period of record.

16. Regressions of mean TDS concentration for the ice-cover season against time had negative slopes (decling winter concentrations) for four sites on the North and South Saskatchewan Rivers, which probably reflects the reduction in winter TDS concentrations imposed by construction of reservoirs. A positive slope for Bow River, late summer and autumn TDS data indicates increasing concentrations probably caused by increasing salt load from Calgary effluents and irrigation return flow. A similar trend may be occurring on the Oldman River at Highway #36, however the data record is incomplete.

17. WQB data, which is collected on a regular monthly schedule, is better suited to time series analysis of river concentration than WRB data, which emphasizes open water and high flows.

## Spatial Patterns in TDS

18. Mountain streams have much lower TDS concentrations than those arising on the prairie. Main-stem rivers have nearly constant mean TDS concentrations, near 200 mg/L in summer and 250 mg/L in winter, although there is a small increase from west to east. Hence, dilute mountain runoff continues to dominate main-stem rivers right across the basin, despite the influx of ion-rich water form prairie tributaries; consequently tributaries are largely responsible for real or apparent cross-basin trends in average TDS concentrations.

19. Regional means estimated from WQB and WRB data are generally similar during the open-water season. Differences in winter values reflect the different sampling strategies employed by each agency.

## Geochemical Yield

20. The interpolation method (interval method) of calculating TDS loads is preferable to the extrapolation method (rating curves). The latter method is limited by the poor correlation between TDS concentration and discharge, and hysteresis in the relationship.

21. Loads calculated from WQB data, WRB data, or all data combined usually differ by 10% or less, except in winter when under-sampling by WRB causes inflated loading estimates. For all other seasons, or annual estimates, data from either Branch will produce reliable results.

22. At most sites, sampling for 10 years will produce estimates of mean annual TDS loads with a standard error of 10-15%. Sampling beyond this

limit will not improve precision of the loading estimate; unless information on changes in load through time is required.

23. Most of the annual TDS load is carried during the open-water season; the small proportion carried during ice-cover increases with increasing regulation of stream flow.

24. Mountains and foothills are the dominant source of TDS in the Saskatchewan River basin. On an areal basis, yield is substantially greater from erodible prairie sub-basins, but low runoff reduces their overall contribution of TDS to the Saskatchewan River system.

Recommendations for Future Work

25. Evaluate whether the present frequency of TDS sampling will reliably detect anticipated trends in TDS in the basin. This could be done through sensitivity analysis, which would evaluate the adequacy of the present sampling regime given probable changes in point or non-point pollution sources.

26. Examine the chemical composition of TDS at several sites for changes in proportions of major ions that will indicate effects of irrigation return flow or altered point-source loadings. TDS appears to be relatively insensitive to subtle changes, that might better be identified by investigation of specific ions.

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# APPENDIX A

Total Dissolved Solids Sampling Sites and data summary for the Saskatchewan River Basin

| CODE | WQB/ WRB | SITE | SITE DESCRIPTION | YR BEGIN | YR END | YRS | N | MEAN | STD DEV | MAX | MIN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Q | AA0001 | Crowsnest W. Coleman | 64 | 77 | 14 | 109 | 180.7 | 23.3 | 246.9 | 134.0 |
| 2 | Q | AA0002 | Crowsnest E. Coleman | 64 | 77 | 14 | 106 | 223.8 | 35.6 | 308.0 | 143.7 |
| 3 | Q | AA0003 | Crowsnest @ Frank | 71 | 77 | 7 | 40 | 229.4 | 37.7 | 298.6 | 150.6 |
| 3 | R | AA008 | Pincher C @ Pincher Creek | 70 | 83 | 12 | 234 | 229.9 | 42.9 | 338.0 | 138.0 |
| 4 | Q | AA0004 | Castle n. Beaver Mines | 64 | 77 | 14 | 116 | 130.2 | 29.6 | 302.8 | 75.9 |
| 4 | R | AA022 | Castle n. Beaver Mines | 70 | 72 | 2 | 12 | 108.5 | 20.1 | 142.5 | 75.3 |
| 5 | Q | AA0005 | Oldman n. Waldron's Cnrs. | 64 | 78 | 15 | 112 | 188.4 | 45.0 | 362.0 | 100.4 |
| 5 | R | AA023 | Oldman n. Waldron's Cnrs. | 70 | 83 | 10 | 263 | 177.9 | 36.1 | 279.0 | 109.0 |
| 6 | Q | AA0010 | Crowsnest n. Lundbreck | 72 | 73 | 2 | 2 | 239.1 | 28.5 | 259.2 | 219.0 |
| 7 | Q | AA0036 | Oldman N. Cowley | 66 | 66 | 1 | 1 | 187.1 | 0.0 | 187.1 | 187.1 |
| 8 | Q | AA0049 | Oldman n. Brocket | 71 | 73 | 3 | 2 | 190.2 | 17.2 | 202.3 | 178.0 |
| 9 | Q | AA0050 | Castle @ Hwy 3 | 72 | 74 | 3 | 2 | 154.3 | 5.6 | 158.2 | 150.3 |
| 10 | Q | AA0051 | Crowsnest n. Cowley | 71 | 73 | 3 | 1 | 143.8 | 0.0 | 143.8 | 143.8 |
| 11 | R | AA028 | Castle @ Ranger Stn. | 70 | 72 | 2 | 12 | 94.1 | 15.1 | 126.3 | 65.5 |
| 12 | Q | AB0001 | Streeter C. n. Nanton | 71 | 74 | 4 | 10 | 261.1 | 39.6 | 324.0 | 185.7 |
| 12 | R | AB030 | Streeter C. n. Nanton | 65 | 69 | 5 | 122 | 262.8 | 37.4 | 331.0 | 101.0 |
| 13 | Q | AB0005 | Oldman n. Ft. Macleod | 60 | 74 | 10 | 72 | 197.0 | 35.2 | 285.3 | 103.3 |
| 14 | Q | AB0010 | Willow C. n. Claresholm | 71 | 74 | 4 | 3 | 268.4 | 19.5 | 289.6 | 251.1 |
| 14 | R | AB021 | Willow C. n. Claresholm | 64 | 83 | 20 | 1051 | 251.2 | 41.5 | 397.0 | 125.0 |
| 15 | Q | AB0019 | Willow c. @ Hwy 2 | 71 | 74 | 4 | 3 | 255.6 | 43.2 | 290.5 | 207.3 |
| 16 | Q | AB0025 | Beaver C. N. Bracket | 71 | 73 | 3 | 2 | 405.8 | 142.2 | 506.4 | 305.3 |
| 17 | R | AB022 | W. Streeter C. n. Nanton | 74 | 74 | 1 | 2 | 151.0 | 9.9 | 158.0 | 144.0 |
| 18 | R | AB028 | Willow C. @ Chain Lakes | 65 | 83 | 18 | 963 | 173.3 | 26.6 | 334.0 | 111.0 |
| 19 | Q | AC0009 | Little Bow @ Hwy 25 | 71 | 77 | 7 | 13 | 297.1 | 64.2 | 469.4 | 243.8 |
| 20 | Q | AC0011 | Little Bow @ Hwy 23 | 71 | 73 | 3 | 2 | 327.5 | 71.9 | 378.3 | 276.7 |
| 21 | Q | AD0001 | Oldman n. Monarch | 66 | 74 | 9 | 98 | 221.3 | 48.3 | 318.8 | 117.6 |
| 22 | Q | AD0002 | Oldman n. Lethbridge | 66 | 84 | 17 | 155 | 207.6 | 47.7 | 347.8 | 108.6 |
| 22 | R | AD007 | Oldman n. Lethbridge | 72 | 83 | 12 | 740 | 191.1 | 46.4 | 383.0 | 107.0 |
| 23 | Q | AD0005 | Waterton @ Hwy 6 | 64 | 84 | 21 | 237 | 92.5 | 25.3 | 268.8 | 60.6 |
| 24 | Q | AD0006 | Belly @ Hwy 5 | 64 | 76 | 12 | 127 | 108.9 | 19.0 | 159.5 | 77.6 |
| 25 | Q | AD0027 | Waterton n. Standoff | 71 | 74 | 4 | 4 | 151.9 | 37.7 | 198.2 | 116.0 |
| 26 | Q | AD0029 | Belly @ Hwy 2 | 71 | 74 | 4 | 3 | 261.5 | 115.0 | 398.6 | 183.7 |
| 26 | R | AD002 | Belly @ Hwy 2 | 70 | 83 | 10 | 73 | 198.8 | 48.3 | 336.0 | 63.0 |
| 27 | Q | AD0040 | Cameron C. below Cameron Falls | 71 | 76 | 6 | 38 | 87.3 | 15.4 | 115.8 | 57.5 |
| 28 | Q | AD0045 | Belly - St. Mary Diversion | 71 | 73 | 3 | 2 | 140.1 | 47.2 | 173.4 | 106.7 |
| 29 | Q | AD0049 | Belly @ N. Boundary | 73 | 76 | 4 | 23 | 102.4 | 16.4 | 124.5 | 75.1 |
| 30 | Q | AD0050 | Hell Roaring c. @ Mouth | 73 | 75 | 3 | 11 | 75.7 | 10.3 | 94.5 | 57.1 |
| 31 | Q | AD0051 | Cameron C. @ Outlet Cameron Lk. | 73 | 76 | 4 | 23 | 44.4 | 3.5 | 51.1 | 32.3 |
| 32 | Q | AD0052 | Cameron C. S.W. Crandell | 73 | 76 | 4 | 24 | 82.4 | 14.9 | 120.3 | 53.9 |
| 33 | Q | AD0053 | Boueman Bk. | 73 | 76 | 4 | 24 | 97.0 | 14.2 | 110.5 | 58.4 |
| 34 | Q | AD0054 | Blakiston Bk. above Boueman Bk. | 73 | 76 | 4 | 23 | 106.4 | 17.9 | 127.0 | 60.3 |
| 35 | Q | AD0055 | Blakiston Bk. above Canyon Church | 73 | 76 | 4 | 25 | 106.6 | 18.2 | 134.6 | 60.1 |
| 36 | Q | AD0056 | Blakiston Bk. @ Hwy 5 | 72 | 76 | 5 | 35 | 120.2 | 18.3 | 141.1 | 68.5 |
| 37 | Q | AD0057 | Crooked C. @ Hwy 5 | 72 | 75 | 4 | 22 | 222.5 | 38.5 | 298.9 | 164.2 |
| 38 | Q | AD0058 | Belly above N. Fork | 74 | 76 | 3 | 17 | 97.6 | 16.3 | 126.8 | 73.7 |

| CODE | WQB/ WRB | SITE | SITE DESCRIPTION | YR BEGIN | YR END | YRS | N | MEAN | STD DEV | MAX | MIN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 39 | Q | AD0060 | Belly @ Hwy 6 | 74 | 84 | 11 | 92 | 102.7 | 17.7 | 141.1 | 73.5 |
| 40 | Q | AD0061 | Galway C. @ Hwy 6 | 74 | 76 | 3 | 15 | 150.8 | 20.0 | 178.5 | 96.0 |
| 41 | Q | AD0062 | Lineham Bk. n. Mouth | 74 | 75 | 2 | 7 | 75.8 | 7.2 | 89.8 | 68.3 |
| 42 | Q | AD0064 | Cameron C. @ Mouth | 74 | 75 | 2 | 17 | 84.0 | 16.0 | 106.4 | 55.4 |
| 43 | R | AD028 | Waterton n. Glenwood | 74 | 83 | 10 | 70 | 160.1 | 40.7 | 271.0 | 104.0 |
| 44 | Q | AE0001 | St. Mary n. Int'l boundary | 60 | 84 | 25 | 264 | 110.1 | 22.2 | 189.5 | 72.7 |
| 44 | R | AE027 | St. Mary n. Int'l boundary | 77 | 78 | 2 | 7 | 102.3 | 14.1 | 129.0 | 87.0 |
| 45 | Q | AE0026 | Lec C. @ Beazer | 74 | 78 | 5 | 48 | 227.6 | 19.3 | 256.5 | 175.8 |
| 45 | R | AE037 | Lec C. @ Beazer | 79 | 83 | 4 | 17 | 166.8 | 30.0 | 243.0 | 120.0 |
| 46 | Q | AE0031 | St. Mary n. Lethbridge | 71 | 74 | 4 | 4 | 224.0 | 75.8 | 332.8 | 169.2 |
| 47 | Q | AE0032 | St. Mary n. Cardston | 71 | 74 | 4 | 4 | 127.1 | 29.9 | 171.0 | 105.6 |
| 48 | Q | AE0033 | Lee C. @ Cardston | 71 | 74 | 4 | 3 | 295.1 | 39.8 | 326.8 | 250.5 |
| 49 | R | AE039 | Touch C. n. Beazer | 79 | 83 | 5 | 25 | 181.0 | 27.5 | 252.0 | 134.0 |
| 50 | Q | AG0001 | Oldman @ Hwy 36 | 67 | 83 | 17 | 103 | 222.0 | 54.0 | 361.5 | 118.3 |
| 51 | R | AH041 | Peigan C. n. Pakowki | 76 | 82 | 6 | 33 | 278.2 | 151.2 | 649.0 | 111.0 |
| 52 | Q | AJ0001 | S. Sask. @ Medicine Hat | 60 | 74 | 15 | 152 | 210.7 | 39.1 | 350.5 | 129.1 |
| 52 | R | AJ001 | S. Sask. @ Medicine Hat | 74 | 83 | 10 | 62 | 222.6 | 41.7 | 346.0 | 156.0 |
| 53 | Q | AK0001 | S. Sask. @ Hwy 41 | 68 | 84 | 16 | 163 | 220.9 | 43.7 | 363.6 | 129.7 |
| 53 | R | AK001 | S. Sask. @ Hwy 41 | 66 | 83 | 18 | 2289 | 221.9 | 44.5 | 554.0 | 129.0 |
| 54 | Q | BA0003 | Bow below Lake Louise | 71 | 76 | 6 | 34 | 103.8 | 19.3 | 129.4 | 66.9 |
| 55 | Q | BA0005 | Bow n. Hector Lake | 72 | 76 | 5 | 22 | 96.3 | 15.6 | 122.1 | 77.4 |
| 56 | Q | BA0006 | Bow @ outlet of Bow Lake | 73 | 76 | 4 | 19 | 86.7 | 8.7 | 106.8 | 66.3 |
| 57 | Q | BA0007 | Pipestone @ Hwy 1 | 72 | 76 | 5 | 35 | 134.1 | 28.3 | 165.9 | 80.2 |
| 58 | Q | BA0008 | Baker C. n. Mouth | 72 | 76 | 5 | 27 | 140.8 | 21.0 | 159.6 | 84.6 |
| 59 | Q | BA0009 | Bow below Eldon | 73 | 76 | 4 | 26 | 109.4 | 21.1 | 150.3 | 79.0 |
| 60 | Q | BA0010 | Bow @ Eisenhower Jct. | 73 | 76 | 4 | 25 | 116.6 | 18.6 | 150.1 | 82.6 |
| 61 | Q | BA0011 | Bow above Lake Louise | 75 | 84 | 10 | 78 | 88.7 | 9.7 | 105.0 | 70.9 |
| 62 | Q | BA0018 | Baker C. @ Mouth | 75 | 76 | 2 | 4 | 126.6 | 29.6 | 160.6 | 97.7 |
| 63 | Q | BA0019 | Johnston C. @ Hwy 1a | 72 | 76 | 5 | 33 | 213.1 | 59.4 | 295.0 | 113.1 |
| 64 | R | BA002 | Pipestone n. Lake Louise | 72 | 73 | 2 | 78 | 90.5 | 8.9 | 115.0 | 74.0 |
| 65 | Q | BB0002 | Bow @ Banff | 64 | 74 | 11 | 108 | 145.5 | 35.4 | 227.6 | 81.9 |
| 66 | Q | BB0003 | Brewster C. above Douglas C. | 72 | 74 | 3 | 12 | 176.9 | 44.4 | 235.7 | 114.3 |
| 67 | Q | BB0005 | Bow below Johnstone C. | 73 | 76 | 4 | 26 | 121.9 | 21.9 | 153.3 | 85.6 |
| 68 | Q | BB0006 | Redearth C. @ Hwy 1 | 72 | 76 | 5 | 34 | 129.5 | 30.0 | 168.5 | 69.9 |
| 69 | Q | BB0007 | Bow @ Massive | 73 | 76 | 4 | 26 | 133.4 | 31.7 | 203.0 | 88.9 |
| 70 | Q | BB0008 | Bow above Banff | 72 | 76 | 5 | 34 | 136.6 | 24.6 | 169.7 | 91.9 |
| 71 | Q | BB0009 | Brewster C. @ Mouth | 73 | 83 | 8 | 68 | 187.6 | 34.9 | 229.9 | 110.1 |
| 72 | Q | BB0010 | Forty Mile C. n. Mouth | 73 | 76 | 4 | 26 | 214.3 | 26.5 | 246.4 | 162.1 |
| 72 | R | BB003 | Forty Mile C. n. Banff | 72 | 73 | 2 | 129 | 187.2 | 30.1 | 284.0 | 140.5 |
| 73 | Q | BC0002 | Spray n. Goat C. | 73 | 76 | 4 | 26 | 207.9 | 27.7 | 254.0 | 148.2 |
| 74 | Q | BC0003 | Spray n. Mouth | 72 | 76 | 5 | 32 | 214.3 | 30.6 | 264.3 | 141.4 |
| 74 | R | BC001 | Spray n. Mouth | 72 | 77 | 6 | 254 | 207.0 | 29.2 | 303.0 | 151.0 |
| 75 | Q | BD0001 | Cascade n. outlet Minnewanka | 71 | 76 | 6 | 33 | 200.3 | 20.7 | 253.6 | 174.3 |
| 76 | Q | BD0002 | Bow below Spray | 72 | 77 | 6 | 41 | 164.3 | 32.3 | 222.7 | 102.9 |
| 77 | Q | BD0003 | Cascade above Minnewanka | 73 | 76 | 4 | 23 | 210.5 | 41.4 | 317.4 | 154.8 |

| CODE | WQB/ WRB | SITE | SITE DESCRIPTION | YR BEGIN | YR END | YRS | N | MEAN | STD DEV | MAX | MIN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 78 | Q | BE0006 | Bow n. Seebe | 71 | 74 | 4 | 2 | 153.7 | 4.7 | 157.1 | 150.4 |
| 79 | Q | BE0013 | Bow above Canmore | 73 | 84 | 11 | 98 | 161.6 | 30.5 | 200.6 | 94.6 |
| 80 | Q | BF0001 | Marmot Ck. main stem | 63 | 79 | 15 | 344 | 169.4 | 36.1 | 230.0 | 94.0 |
| 80 | R | BF016 | Marmot Ck. main stem | 63 | 83 | 21 | 984 | 166.9 | 36.0 | 289.0 | 62.0 |
| 81 | Q | BF0002 | Middle Fork. Marmot basin | 63 | 79 | 17 | 368 | 153.3 | 38.0 | 212.3 | 81.6 |
| 81 | R | BF017 | Middle Fork. Marmot basin | 69 | 83 | 15 | 632 | 145.6 | 33.2 | 237.0 | 88.0 |
| 82 | Q | BF0003 | Twin C. Marmot basin | 64 | 79 | 16 | 383 | 136.9 | 35.0 | 203.7 | 48.2 |
| 82 | R | BF018 | Twin C. Marmot basin | 69 | 83 | 15 | 614 | 131.5 | 31.4 | 219.0 | 74.5 |
| 83 | Q | BF0004 | Cabin C. Marmot basin | 63 | 79 | 17 | 385 | 202.3 | 29.1 | 307.7 | 132.5 |
| 83 | R | BF019 | Cabin C. Marmot basin | 69 | 83 | 14 | 882 | 211.1 | 25.9 | 300.0 | 142.0 |
| 84 | Q | BF0005 | Middle Fork C. Marmot basin | 63 | 78 | 16 | 188 | 142.6 | 49.6 | 257.2 | 47.0 |
| 85 | Q | BF0006 | Kananaskas @ Kananaskas | 64 | 74 | 7 | 83 | 173.0 | 17.0 | 218.9 | 134.1 |
| 86 | Q | BF0007 | Kananaskas above Marmot C. | 63 | 78 | 15 | 231 | 163.0 | 19.9 | 211.6 | 99.3 |
| 87 | Q | BG0001 | Ghost n. Mouth | 71 | 74 | 4 | 2 | 169.6 | 4.5 | 172.8 | 166.4 |
| 88 | Q | BH0001 | Bow @ Bearspaw Dam | 67 | 74 | 8 | 64 | 167.0 | 17.8 | 194.1 | 128.9 |
| 89 | Q | BH0007 | Bow @ Crushing Bridge | 69 | 69 | 1 | 2 | 197.0 | 2.7 | 198.9 | 195.1 |
| 90 | Q | BH0017 | Bow @ Cochrane | 71 | 84 | 12 | 70 | 164.8 | 19.5 | 203.2 | 122.8 |
| 91 | Q | BH0018 | Bow @ Edmonton Tr. Bridge | 66 | 66 | 1 | 1 | 119.7 | 0.0 | 119.7 | 119.7 |
| 91 | R | BH004 | Bow @ Edmonton Tr. Bridge | 69 | 83 | 14 | 457 | 175.2 | 29.9 | 347.0 | 119.0 |
| 92 | Q | BH0019 | Bow E. St. George's Isl | 69 | 69 | 1 | 11 | 174.4 | 12.4 | 185.1 | 142.6 |
| 93 | Q | BH0021 | Elbow @ MacDonald Bridge | 69 | 69 | 1 | 4 | 189.8 | 11.2 | 199.6 | 180.0 |
| 94 | R | BH009 | Jumpingpound C. n. Mouth | 70 | 70 | 1 | 1 | 189.0 | 0.0 | 189.0 | 189.0 |
| 95 | Q | BJ0001 | Elbow below Glenmore Dam | 67 | 74 | 8 | 72 | 217.6 | 28.8 | 267.3 | 168.7 |
| 96 | Q | BJ0003 | Elbow @ Bragg C. | 64 | 77 | 14 | 69 | 204.9 | 25.8 | 243.5 | 132.7 |
| 96 | R | BJ004 | Elbow @ Bragg C. | 59 | 83 | 16 | 622 | 206.3 | 31.3 | 281.0 | 132.0 |
| 97 | R | BK001 | Fish C. n. Priddis | 69 | 77 | 5 | 22 | 198.6 | 45.7 | 273.0 | 123.0 |
| 98 | Q | BL0001 | Highwood @ Diebels Ranch | 64 | 77 | 14 | 82 | 186.7 | 32.3 | 262.6 | 123.3 |
| 98 | R | BL019 | Highwood @ Diebels Ranch | 69 | 77 | 5 | 19 | 160.8 | 27.8 | 216.3 | 126.8 |
| 99 | Q | BL0002 | Highwood @ Hwy 2 | 71 | 74 | 4 | 4 | 216.0 | 22.0 | 243.7 | 190.7 |
| 99 | R | BL009 | Highwood @ Hwy 2 | 70 | 77 | 3 | 6 | 185.5 | 30.8 | 237.0 | 162.7 |
| 100 | Q | BL0003 | Sheep @ Okotoks | 71 | 74 | 4 | 4 | 220.6 | 39.0 | 260.2 | 171.0 |
| 100 | R | BL012 | Sheep @ Okotoks | 76 | 76 | 1 | 1 | 180.3 | 0.0 | 180.3 | 180.3 |
| 101 | Q | BL0008 | Sheep @ Buck Ranch | 67 | 73 | 6 | 14 | 188.4 | 32.9 | 253.7 | 131.9 |
| 102 | R | BL007 | Stimson C. n. Pekisko | 72 | 77 | 3 | 17 | 240.4 | 53.0 | 335.0 | 138.0 |
| 103 | R | BL013 | Threepoint C. n. Millarville | 70 | 77 | 4 | 27 | 186.6 | 49.4 | 283.3 | 130.0 |
| 104 | R | BL014 | Sheep @ Black Diamond | 78 | 83 | 2 | 14 | 184.5 | 27.2 | 227.0 | 150.0 |
| 105 | R | BL021 | Highway below Picklejar C. | 70 | 77 | 4 | 11 | 133.7 | 17.4 | 167.0 | 110.7 |
| 106 | R | BL022 | Cataract C. n. Forestry Rd. | 72 | 77 | 3 | 16 | 106.9 | 18.8 | 150.3 | 82.3 |
| 107 | R | BL023 | Pekisko C. n. Longview | 72 | 77 | 3 | 15 | 193.2 | 41.7 | 244.0 | 134.3 |
| 108 | R | BL024 | Highwood n. Mouth | 71 | 83 | 12 | 505 | 202.6 | 36.1 | 355.0 | 124.0 |
| 109 | Q | BM0001 | Bow above Bassano Dam | 67 | 74 | 8 | 47 | 204.7 | 44.2 | 411.2 | 140.9 |
| 110 | Q | BM0002 | Bow below Carseland Dam | 67 | 74 | 8 | 68 | 179.6 | 31.4 | 235.4 | 64.7 |
| 111 | Q | BM0003 | Bow @ Graves Bridge | 72 | 74 | 3 | 2 | 164.7 | 27.5 | 184.1 | 145.2 |
| 112 | Q | BM0008 | Crowfoot C. n. Cluny | 71 | 73 | 3 | 2 | 351.4 | 94.8 | 418.4 | 284.3 |
| 112 | R | BM008 | Crowfoot C. n. Cluny | 77 | 77 | 1 | 1 | 613.0 | 0.0 | 613.0 | 613.0 |

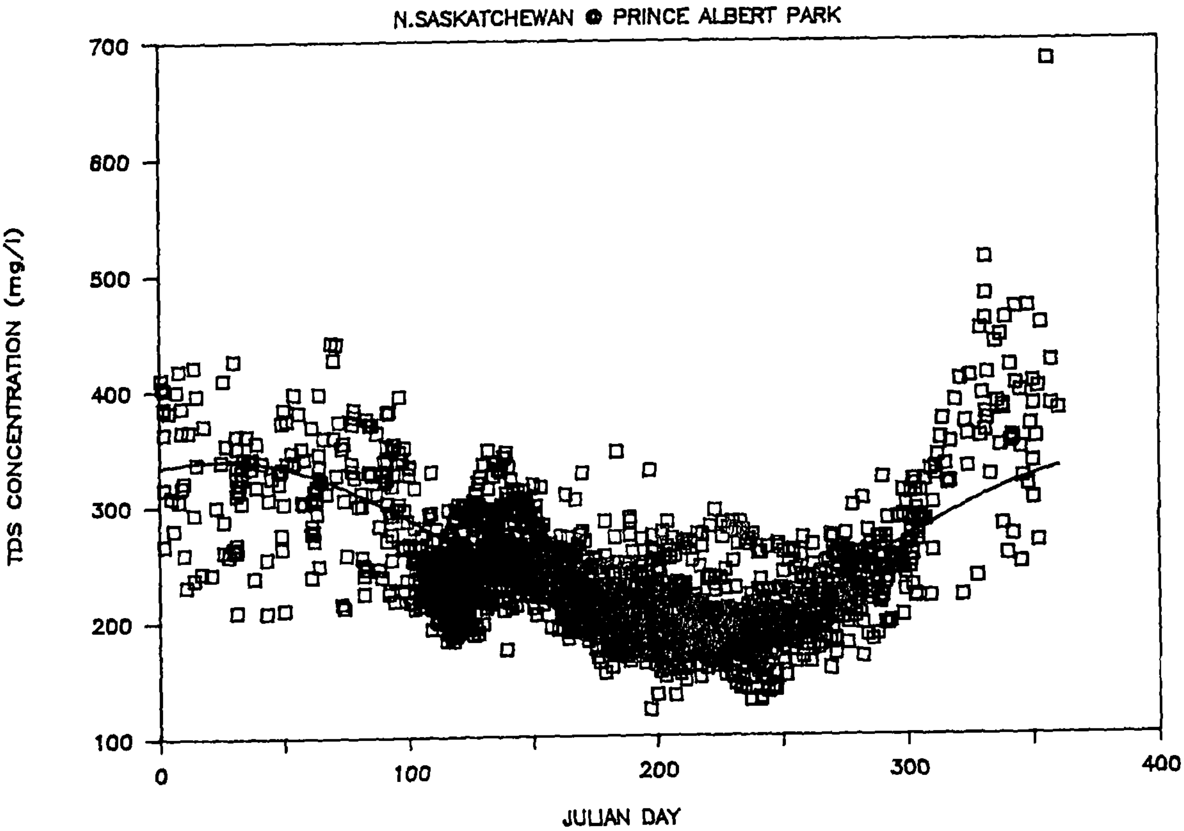
| CODE | WQB/ WRB | SITE | SITE DESCRIPTION | YR BEGIN | YR END | YRS | N | MEAN | STD DEV | MAX | MIN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 113 | Q | BM0009 | Bow @ Crowfoot Ferry | 73 | 74 | 2 | 2 | 161.7 | 9.4 | 168.4 | 155.0 |
| 114 | R | BM004 | Bow below Bassano Dam | 70 | 79 | 10 | 324 | 186.3 | 25.6 | 275.0 | 139.0 |
| 115 | R | BM014 | W. Arrowood C. n. Arrowood | 76 | 77 | 2 | 2 | 1390.3 | 97.2 | 1459.0 | 1321.5 |
| 116 | Q | BN0001 | Bow n. Mouth | 67 | 83 | 17 | 147 | 200.1 | 28.1 | 271.1 | 148.1 |
| 117 | Q | CA0001 | Red Deer n. Sundre | 63 | 78 | 16 | 82 | 199.8 | 34.5 | 263.3 | 127.9 |
| 117 | R | CA010 | Red Deer n. Sundre | 70 | 77 | 3 | 17 | 206.5 | 19.9 | 253.0 | 176.0 |
| 118 | Q | CA0005 | Main Deer C. | 71 | 73 | 3 | 15 | 254.1 | 40.9 | 304.8 | 178.8 |
| 119 | Q | CA0006 | Red Deer n. Forestry Trunk | 72 | 73 | 2 | 2 | 206.2 | 47.7 | 239.9 | 172.4 |
| 120 | R | CA002 | James n. Sundre | 72 | 72 | 1 | 2 | 193.0 | 23.3 | 209.5 | 176.5 |
| 121 | R | CA003 | Main Deer C. n. Sundre | 68 | 70 | 3 | 20 | 267.5 | 27.3 | 312.0 | 223.0 |
| 122 | R | CA009 | Red Deer below Burnt Timber C | 74 | 83 | 10 | 72 | 207.1 | 25.1 | 267.0 | 149.0 |
| 123 | R | CA011 | Bearberry C. n. Sundre | 76 | 77 | 2 | 10 | 170.7 | 26.6 | 224.0 | 131.0 |
| 124 | Q | CB0008 | Little Red Deer n. Cremona | 73 | 74 | 2 | 3 | 245.5 | 24.6 | 269.9 | 220.6 |
| 125 | Q | CB0024 | Little Red Deer n. Red Deer Lodge | 71 | 74 | 4 | 3 | 247.5 | 85.3 | 345.8 | 193.4 |
| 126 | Q | CC0001 | Red Deer @ Red Deer | 60 | 74 | 9 | 79 | 231.3 | 42.7 | 311.7 | 153.6 |
| 126 | R | CC002 | Red Deer @ Red Deer | 70 | 83 | 14 | 930 | 222.2 | 32.4 | 557.0 | 109.0 |
| 127 | Q | CC0002 | Blindman n. Blackfalds | 66 | 74 | 9 | 87 | 325.9 | 140.7 | 772.3 | 127.3 |
| 128 | Q | CC0004 | Red Deer @ Hwy 2 | 77 | 83 | 7 | 68 | 228.3 | 41.6 | 329.6 | 154.1 |
| 129 | Q | CC0007 | Medicine in Eckville | 71 | 74 | 4 | 2 | 248.1 | 108.7 | 324.9 | 171.2 |
| 130 | Q | CE0001 | Red Deer @ Drumheller | 60 | 83 | 24 | 221 | 243.8 | 62.1 | 440.1 | 150.3 |
| 130 | R | CE001 | Red Deer @ Drumheller | 75 | 83 | 9 | 371 | 230.8 | 42.5 | 474.0 | 143.0 |
| 131 | Q | CE0020 | Rosebud @ Rosedale | 74 | 74 | 1 | 1 | 583.7 | 0.0 | 583.7 | 583.7 |
| 132 | Q | CE0021 | Rosebud @ Hwy 21 | 71 | 74 | 4 | 3 | 801.7 | 357.6 | 1211.2 | 550.7 |
| 133 | Q | CE0022 | Kneehills C. n. Drumheller | 71 | 73 | 3 | 2 | 1408.7 | 818.4 | 1987.4 | 830.0 |
| 134 | Q | CE0023 | Ghostpine C. n. Haxley | 71 | 73 | 3 | 2 | 610.7 | 103.6 | 684.0 | 537.4 |
| 135 | R | CE020 | Michichi C. @ Drumheller | 78 | 78 | 1 | 1 | 1851.0 | 0.0 | 1851.0 | 1851.0 |
| 136 | Q | CH0002 | Berry C. n. Mouth | 71 | 74 | 4 | 3 | 346.9 | 239.3 | 604.4 | 131.3 |
| 137 | Q | CJ0001 | Red Deer @ Jenner Ferry | 71 | 73 | 3 | 2 | 259.5 | 27.6 | 279.0 | 240.0 |
| 138 | Q | CK0001 | Red Deer @ Blindloss | 66 | 84 | 19 | 212 | 292.7 | 86.8 | 589.1 | 163.0 |
| 138 | R | CK004 | Red Deer @ Blindloss | 66 | 83 | 18 | 1583 | 273.5 | 49.8 | 515.0 | 152.0 |
| 139 | Q | CK0008 | Blood Indian C. n. Mouth | 71 | 73 | 3 | 1 | 721.1 | 0.0 | 721.1 | 721.1 |
| 140 | Q | DA0001 | N. Sask. @ Whirlpool Pt. | 70 | 84 | 11 | 100 | 133.4 | 33.3 | 183.7 | 69.6 |
| 140 | R | DA009 | N. Sask. @ Whirlpool Pt. | 72 | 83 | 12 | 640 | 117.8 | 26.6 | 216.0 | 68.0 |
| 141 | Q | DA0002 | N. Sask. @ Sask. Crossing | 71 | 77 | 7 | 40 | 129.4 | 35.6 | 186.9 | 72.7 |
| 142 | Q | DA0003 | N. Sask. n. Mt. Sask. | 72 | 76 | 5 | 32 | 145.8 | 42.8 | 202.0 | 66.2 |
| 143 | Q | DA0004 | N. Sask. below Archtomys C. | 73 | 76 | 4 | 24 | 154.6 | 52.9 | 228.2 | 72.4 |
| 144 | Q | DA0005 | Howse n. Mouth | 73 | 76 | 4 | 22 | 102.3 | 19.7 | 149.3 | 69.6 |
| 145 | Q | DA0006 | Mistaya n. Mouth | 72 | 76 | 5 | 33 | 118.5 | 20.5 | 147.5 | 83.2 |
| 146 | R | DA002 | Siffleur n. Mouth | 75 | 83 | 9 | 58 | 165.1 | 45.9 | 299.0 | 110.0 |
| 147 | Q | DB0001 | Clearwater above Limestone | 64 | 72 | 4 | 7 | 222.4 | 40.7 | 290.2 | 176.6 |
| 148 | Q | DB0002 | Clearwater @ Forestry Trunk | 71 | 73 | 3 | 2 | 256.5 | 38.4 | 283.7 | 229.4 |
| 149 | Q | DB0006 | Clearwater @ Rocky Mtn. House | 64 | 77 | 14 | 102 | 246.9 | 35.6 | 321.4 | 162.9 |
| 149 | R | DB001 | Clearwater @ Rocky Mtn. House | 70 | 72 | 2 | 6 | 254.1 | 13.3 | 269.7 | 230.0 |
| 150 | Q | DC0001 | N. Sask. n. Rocky Mtn. House | 66 | 77 | 12 | 109 | 198.2 | 58.2 | 344.0 | 99.7 |
| 150 | R | DC001 | N. Sask. n. Rocky Mtn. House | 70 | 73 | 4 | 557 | 202.1 | 54.5 | 389.0 | 103.0 |

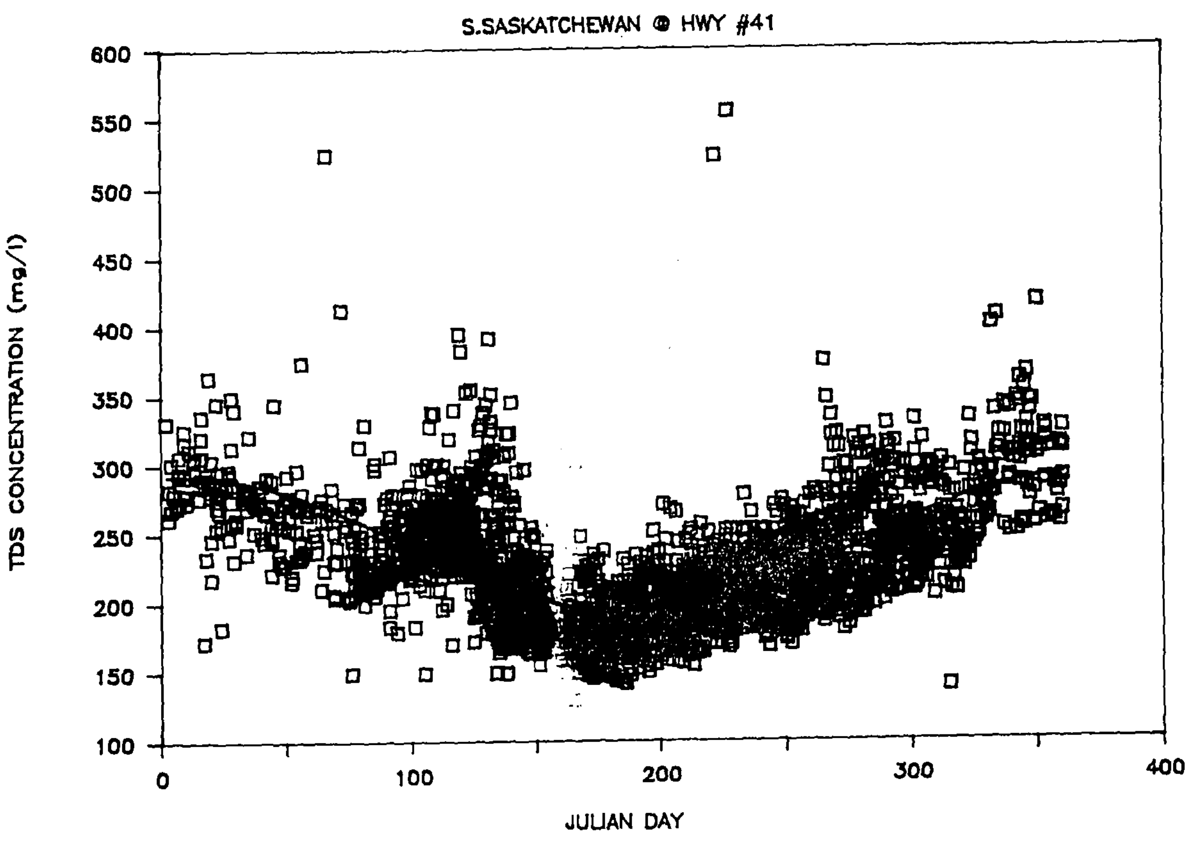
| CODE | WQB/ WRB | SITE | SITE DESCRIPTION | YR BEGIN | YR END | YRS | N | MEAN | STD DEV | MAX | MIN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 151 | Q | DC0002 | N. Sask @ Saunders | 64 | 73 | 10 | 47 | 146.5 | 31.3 | 217.3 | 92.7 |
| 151 | R | DC002 | N. Sask @ Saunders | 75 | 77 | 2 | 10 | 166.9 | 17.3 | 194.0 | 148.0 |
| 152 | R | DC006 | Ram n. Mouth | 76 | 83 | 8 | 45 | 248.7 | 58.5 | 396.0 | 156.0 |
| 153 | Q | DD0006 | Brazeau below Powerhouse | 71 | 74 | 4 | 3 | 173.1 | 15.8 | 191.0 | 161.1 |
| 154 | Q | DE0002 | N. Sask. n. Drayton | 71 | 74 | 4 | 2 | 176.3 | 0.6 | 176.7 | 175.8 |
| 155 | Q | DF0001 | N. Sask. @ Edmonton | 60 | 74 | 15 | 124 | 198.2 | 43.5 | 328.6 | 120.8 |
| 155 | R | DF001 | N. Sask. @ Edmonton | 74 | 88 | 10 | 64 | 192.3 | 18.0 | 232.0 | 134.0 |
| 156 | Q | DF0008 | N. Sask. @ Devon | 77 | 83 | 7 | 66 | 174.2 | 15.3 | 216.5 | 129.6 |
| 157 | Q | EA0003 | Sturgeon n. Mouth | 71 | 74 | 3 | 3 | 411.2 | 115.9 | 541.4 | 319.3 |
| 158 | Q | EC0002 | Redwater E. Redwater | 71 | 74 | 4 | 3 | 300.2 | 27.4 | 329.7 | 275.6 |
| 158 | R | EC003 | Redwater E. Redwater | 74 | 78 | 4 | 11 | 343.2 | 74.2 | 434.0 | 214.0 |
| 159 | Q | EC0004 | N. Sask @ Road 938 | 74 | 77 | 4 | 13 | 186.8 | 16.6 | 206.0 | 149.6 |
| 160 | Q | EC0005 | N. Sask @ Pakan | 77 | 83 | 7 | 66 | 188.5 | 16.5 | 234.7 | 154.9 |
| 161 | R | EC002 | Waskatenau C. n. Waskatenau | 74 | 82 | 9 | 40 | 379.2 | 75.5 | 622.0 | 255.0 |
| 162 | Q | EE0001 | Vermillion n. Mannville | 64 | 74 | 10 | 63 | 520.7 | 213.3 | 1272.1 | 203.9 |
| 163 | Q | EE0010 | Vermillion @ Lea Park | 71 | 74 | 4 | 4 | 514.1 | 141.1 | 717.9 | 412.9 |
| 164 | R | EE003 | Vermillion @ Vegreville | 74 | 83 | 6 | 16 | 375.4 | 109.6 | 552.0 | 207.0 |
| 165 | R | EE007 | Vermillion @ Hazeldine | 79 | 83 | 5 | 22 | 604.3 | 104.6 | 766.0 | 375.0 |
| 166 | Q | EF0001 | N. Sask. @ Lea Park | 66 | 84 | 12 | 101 | 214.9 | 52.9 | 362.7 | 133.4 |
| 167 | Q | EF0002 | N. Sask. @ Lloydminster Ferry | 73 | 73 | 1 | 1 | 263.9 | 0.0 | 263.9 | 263.9 |
| 168 | Q | FA0001 | Battle @ Ponoka | 60 | 74 | 10 | 78 | 327.8 | 101.6 | 624.7 | 113.5 |
| 169 | Q | FC0010 | Battle n. Alliance | 71 | 74 | 4 | 3 | 380.6 | 79.9 | 471.4 | 320.9 |
| 170 | Q | FD0002 | Ribstone C. n. Edgerton | 71 | 73 | 3 | 2 | 358.1 | 54.9 | 396.9 | 319.2 |
| 171 | Q | FE0001 | Battle n. Marsden | 71 | 74 | 4 | 3 | 480.2 | 108.9 | 602.4 | 398.4 |
| 172 | R | FE004 | Battle n. Sask. Boundary | 80 | 83 | 4 | 41 | 426.3 | 67.3 | 639.0 | 325.0 |
| 173 | Q | GA0002 | Sounding C. n. Monitor | 71 | 74 | 4 | 1 | 884.3 | 0.0 | 884.3 | 884.3 |
| 174 | Q | EF0001 | N. Sask. @ Hwy 3 | 71 | 82 | 12 | 105 | 202.5 | 28.4 | 332.4 | 130.8 |
| 175 | Q | EG0001 | Battle @ N. Battleford | 60 | 74 | 13 | 115 | 244.6 | 73.7 | 603.3 | 134.3 |
| 176 | Q | FE0001 | Battle n. Unwin | 66 | 84 | 19 | 213 | 564.7 | 176.8 | 1018.7 | 108.0 |
| 177 | R | FF001 | Battle @ Battleford | 79 | 83 | 5 | 51 | 428.6 | 81.4 | 614.0 | 219.0 |
| 178 | Q | GC0001 | Eagle C. @ Grid Rd. Bridge | 74 | 78 | 5 | 14 | 1822.6 | 410.7 | 2613.4 | 1242.7 |
| 178 | R | GC006 | Eagle C. @ Grid Rd. Bridge | 75 | 80 | 6 | 30 | 1348.0 | 689.2 | 2812.0 | 332.0 |
| 179 | Q | GD0001 | N. Sask. @ Hwy 5 | 68 | 74 | 7 | 45 | 224.4 | 44.2 | 312.5 | 153.4 |
| 180 | Q | GG0001 | N. Sask. @ Prince Albert | 66 | 78 | 13 | 107 | 258.5 | 67.2 | 479.8 | 132.1 |
| 180 | R | GG001 | N. Sask. @ Prince Albert | 62 | 83 | 22 | 1754 | 235.1 | 55.0 | 682.0 | 122.0 |
| 181 | Q | GG0002 | N. Sask. E. Prince Albert | 68 | 74 | 7 | 48 | 269.5 | 68.3 | 444.8 | 156.9 |
| 182 | Q | GG0003 | N. Sask. @ Cecil Ferry | 68 | 79 | 9 | 50 | 273.4 | 76.4 | 472.2 | 166.0 |
| 183 | Q | GG0005 | N. Sask. @ N. Cecil Ferry | 74 | 74 | 1 | 1 | 340.8 | 0.0 | 340.8 | 340.8 |
| 184 | R | HA072 | Gap C. @ Junction Res. | 72 | 72 | 1 | 1 | 747.0 | 0.0 | 747.0 | 747.0 |
| 185 | Q | HB0001 | S. Sask. n. Lemsford | 65 | 74 | 10 | 89 | 227.2 | 47.4 | 366.1 | 111.1 |
| 185 | R | HB001 | S. Sask. n. Lemsford | 61 | 75 | 12 | 1078 | 223.9 | 42.6 | 398.3 | 110.0 |
| 186 | Q | HD0001 | Swift Current C. @ Swift Current | 66 | 74 | 8 | 49 | 463.1 | 127.3 | 831.8 | 185.6 |
| 187 | Q | HD0002 | Swift Current C. above Swift Current | 68 | 74 | 5 | 5 | 517.7 | 163.5 | 771.2 | 329.6 |
| 188 | Q | HD0003 | Swift Current C. @ Waldeck | 68 | 74 | 6 | 13 | 805.7 | 480.5 | 2058.8 | 264.8 |
| 189 | Q | HD0004 | Swift Current C. n. Stewart | 68 | 78 | 11 | 36 | 736.0 | 388.8 | 1920.5 | 231.3 |

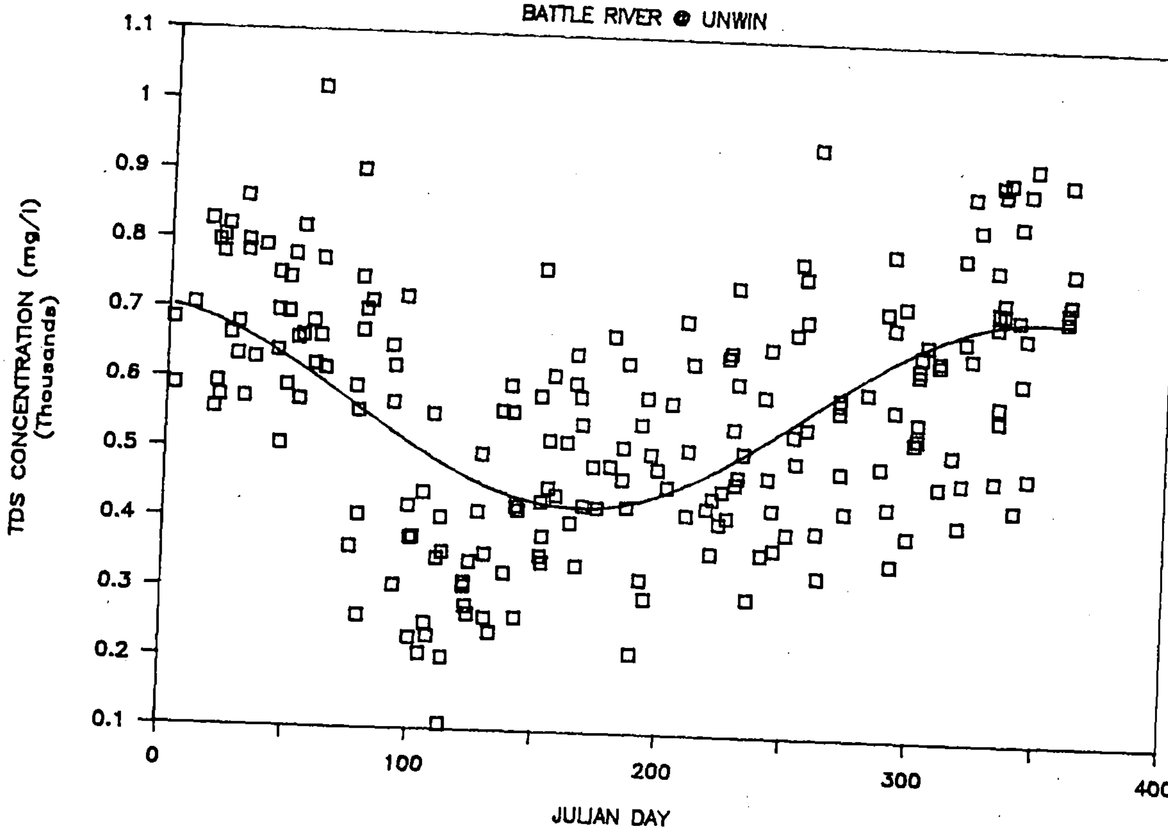
| CODE | WQB/ WRB | SITE | SITE DESCRIPTION | YR BEGIN | YR END | YRS | N | MEAN | STD DEV | MAX | MIN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 189 | R | HD039 | Swift Current C. n. Stewart | 73 | 82 | 10 | 249 | 679.6 | 232.6 | 1368.0 | 171.0 |
| 190 | Q | HD0006 | Watershed A1, Swift Current | 71 | 72 | 2 | 1 | 24.8 | 0.0 | 24.8 | 24.8 |
| 191 | Q | HD0009 | Watershed A4, Swift Current | 71 | 72 | 2 | 1 | 35.8 | 0.0 | 35.8 | 35.8 |
| 192 | R | HD036 | Swift Current C. below Rock C. | 72 | 81 | 8 | 48 | 405.6 | 129.0 | 923.0 | 158.0 |
| 193 | R | HD037 | Swift Current C. below Mouth | 65 | 73 | 9 | 566 | 539.4 | 218.4 | 1776.0 | 168.0 |
| 194 | Q | HE0001 | S. Sask. @ Sask. Landing | 70 | 74 | 2 | 3 | 211.8 | 30.5 | 243.0 | 182.1 |
| 195 | Q | HF0001 | S. Sask. @ Hwy 15 | 68 | 74 | 7 | 51 | 228.5 | 17.6 | 265.5 | 186.9 |
| 196 | Q | HG0001 | S. Sask. @ Saskatoon | 60 | 74 | 15 | 119 | 229.1 | 37.3 | 369.9 | 106.0 |
| 196 | R | HG001 | S. Sask. @ Saskatoon | 61 | 75 | 12 | 981 | 228.3 | 39.9 | 561.0 | 129.0 |
| 197 | Q | HG0007 | S. Sask. above Saskatoon | 72 | 73 | 2 | 2 | 226.1 | 9.8 | 233.0 | 219.2 |
| 198 | Q | HH0001 | S. Sask. @ St. Louis | 66 | 74 | 9 | 91 | 244.1 | 36.6 | 438.0 | 138.7 |
| 199 | Q | HH0002 | S. Sask. @ Clarkboro Ferry | 68 | 78 | 11 | 37 | 232.5 | 18.5 | 269.2 | 160.7 |
| 200 | Q | HH0003 | S. Sask. @ Gabriel Ferry | 68 | 74 | 6 | 15 | 240.0 | 38.3 | 369.5 | 209.1 |
| 201 | Q | HH0004 | S. Sask. @ Birch Hills Ferry | 68 | 78 | 8 | 17 | 235.5 | 13.7 | 263.3 | 216.0 |
| 202 | Q | HH0007 | S. Sask. @ Hwy 3 | 78 | 79 | 2 | 8 | 255.1 | 16.6 | 278.8 | 232.7 |
| 203 | R | KA001 | Carrot n. Kinistino | 72 | 81 | 4 | 5 | 195.7 | 34.7 | 245.0 | 155.0 |
| 204 | R | KA009 | Goosehunting C. n. Beatty | 72 | 72 | 1 | 1 | 194.5 | 0.0 | 194.5 | 194.5 |
| 205 | Q | KB0001 | Doghide C. N. Tisdale | 68 | 74 | 7 | 41 | 996.2 | 519.0 | 2149.2 | 197.0 |
| 205 | R | KB009 | Doghide C. N. Tisdale | 74 | 76 | 3 | 13 | 286.6 | 149.2 | 738.0 | 140.0 |
| 206 | R | KB001 | Melfort C. n. Melfort | 72 | 76 | 4 | 13 | 411.5 | 126.8 | 674.0 | 207.0 |
| 207 | R | KB003 | Carrot n. Armley | 72 | 82 | 9 | 42 | 482.4 | 301.3 | 1105.0 | 159.0 |
| 208 | R | KB005 | Burntout Bk. n. Arbourfield | 72 | 83 | 11 | 64 | 264.0 | 100.6 | 522.0 | 108.0 |
| 209 | R | KB006 | Leather C. n. Star City | 72 | 79 | 7 | 22 | 265.5 | 70.9 | 421.0 | 168.0 |
| 210 | R | KB011 | Doghide n. Runciman | 77 | 83 | 6 | 34 | 357.1 | 246.6 | 1259.0 | 150.0 |
| 211 | Q | KC0001 | Carrot n. Smokey Burn | 66 | 74 | 9 | 87 | 439.5 | 160.1 | 774.6 | 129.8 |
| 211 | R | KC001 | Carrot n. Smokey Burn | 72 | 82 | 9 | 180 | 396.5 | 180.3 | 843.0 | 115.0 |
| 212 | R | KC002 | Connell C. n. Connell Creek | 77 | 81 | 4 | 18 | 240.3 | 100.6 | 388.0 | 69.0 |
| 213 | Q | KD0001 | Sask. below Squaw Rapids | 67 | 74 | 7 | 35 | 224.3 | 28.4 | 274.8 | 175.1 |
| 213 | R | KD003 | Sask. below Squaw Rapids | 65 | 80 | 8 | 161 | 234.7 | 35.2 | 320.0 | 180.0 |
| 214 | Q | KD0002 | Sask. N. Gronlid | 68 | 74 | 7 | 34 | 243.8 | 36.7 | 329.5 | 166.2 |
| 215 | Q | KD0003 | Sask. @ Hwy 35 | 68 | 74 | 7 | 50 | 246.3 | 71.1 | 644.2 | 164.5 |
| 216 | Q | KE0001 | Torch n. Love | 66 | 74 | 9 | 98 | 194.0 | 57.0 | 430.0 | 56.7 |
| 217 | R | KE005 | Whitefox n. Garrick | 72 | 72 | 1 | 1 | 150.0 | 0.0 | 150.0 | 150.0 |
| 218 | Q | KH0002 | Carrot n. Turnberry | 73 | 84 | 12 | 125 | 789.7 | 548.4 | 2769.0 | 147.8 |
| 219 | Q | KH0003 | Dragline Channel n. Squaw Rapids | 79 | 84 | 6 | 54 | 227.2 | 33.0 | 302.5 | 176.0 |
| 220 | Q | KH0004 | Birch below Cumberland Dam | 79 | 84 | 6 | 49 | 324.7 | 77.5 | 611.2 | 245.8 |
| 221 | R | KH009 | Sask. Old Channel | 74 | 76 | 3 | 11 | 250.1 | 50.9 | 326.0 | 142.0 |
| 222 | Q | KH0001 | Sask. above Carrot | 74 | 84 | 11 | 118 | 212.9 | 32.2 | 284.1 | 146.2 |
| 223 | Q | KJ0001 | Sask. @ The Pas | 61 | 74 | 14 | 113 | 240.4 | 39.9 | 384.5 | 119.9 |
| 223 | R | KJ001 | Sask. @ The Pas | 56 | 83 | 27 | 2367 | 227.6 | 41.2 | 424.0 | 68.0 |

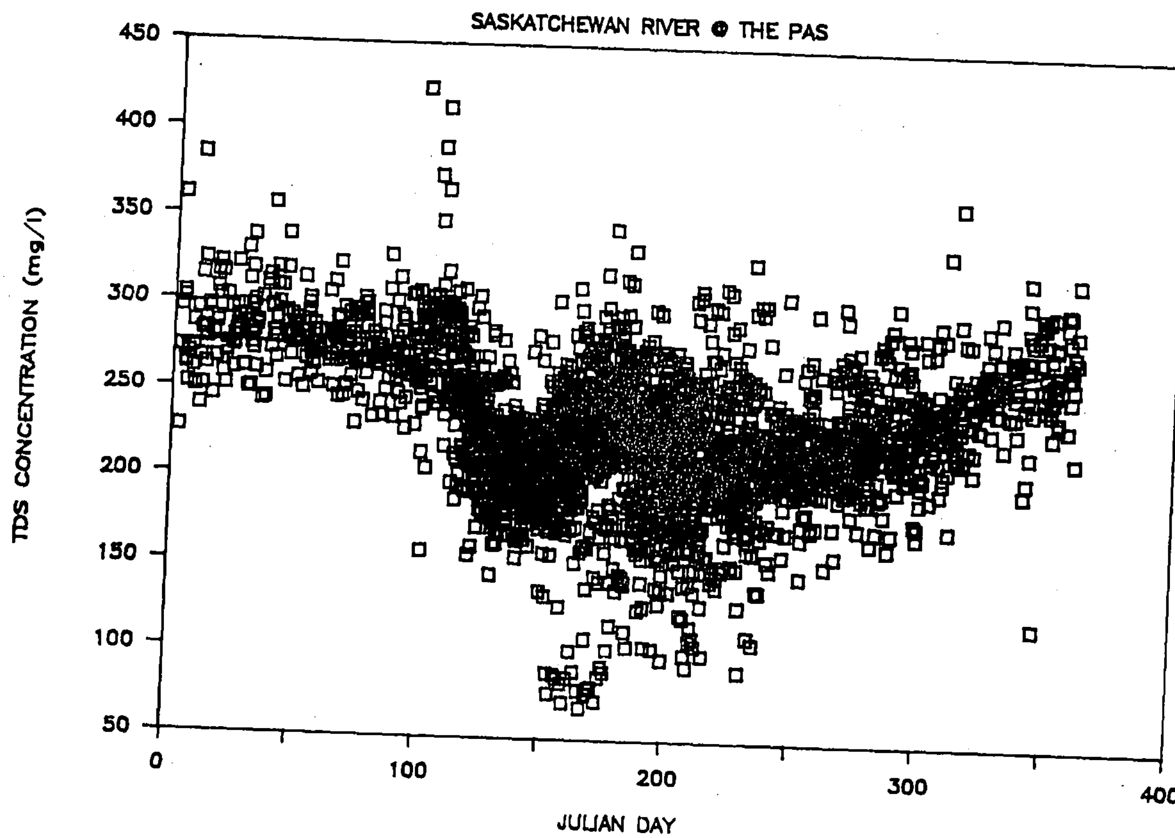
# APPENDIX B

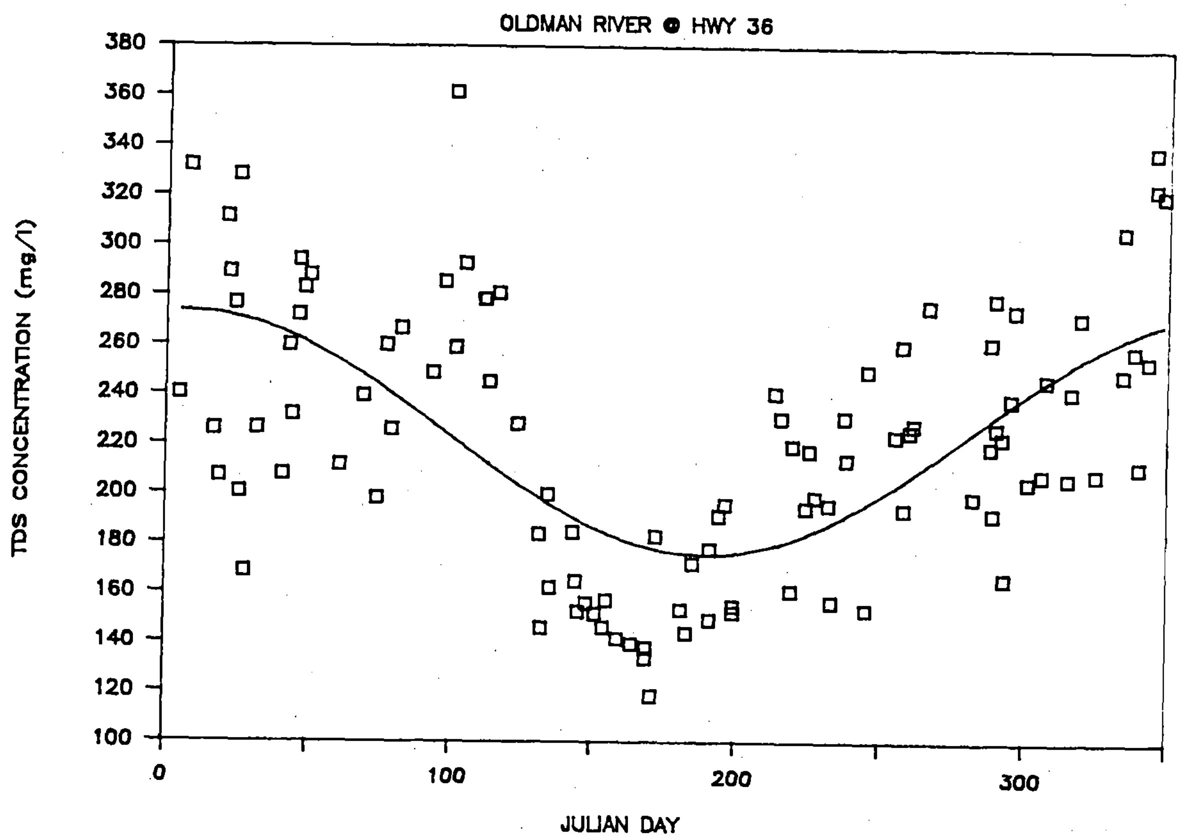
Sine curve regressions for TDS data
from selected sites in the Saskatchewan River Basin

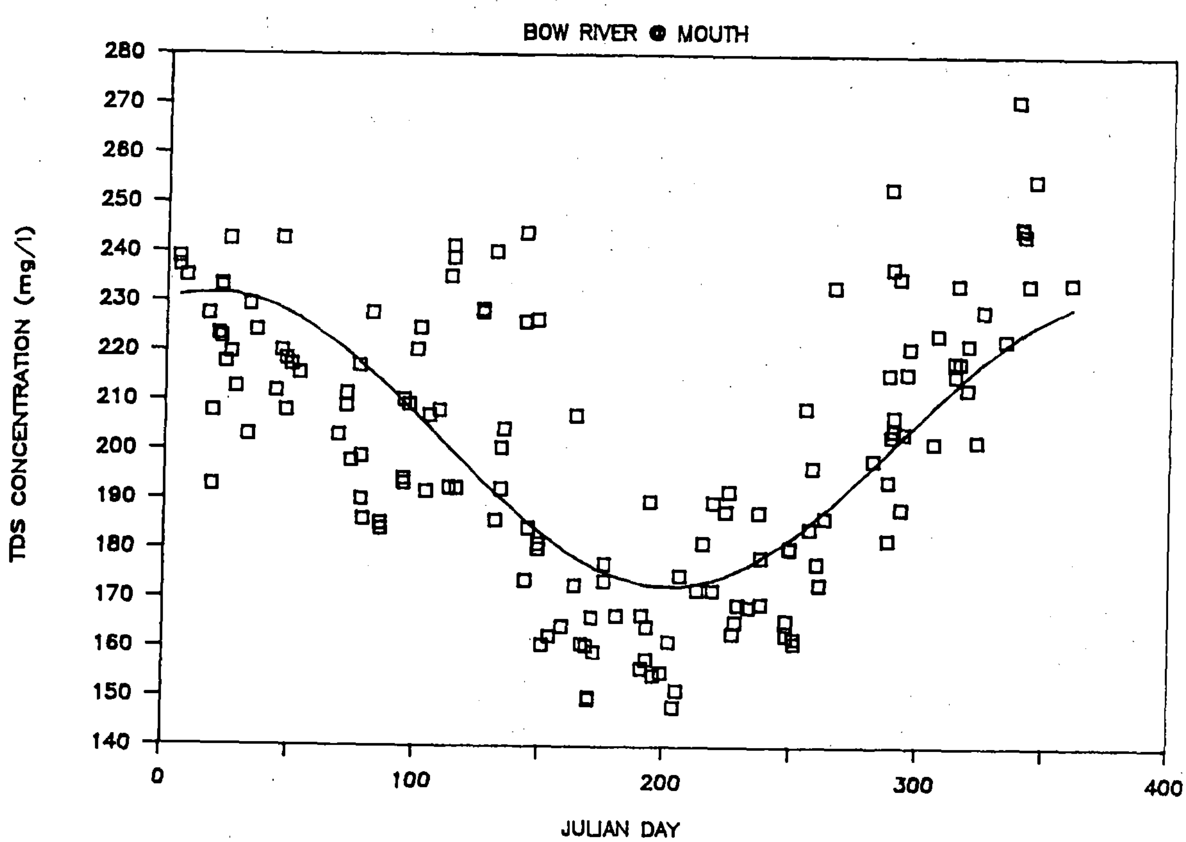

N.SASKATCHEWAN @ PRINCE ALBERT PARK
700
600
500
400
300
200
100
0
100
200
300
400
TDS CONCENTRATION (mg/l)
JULIAN DAY

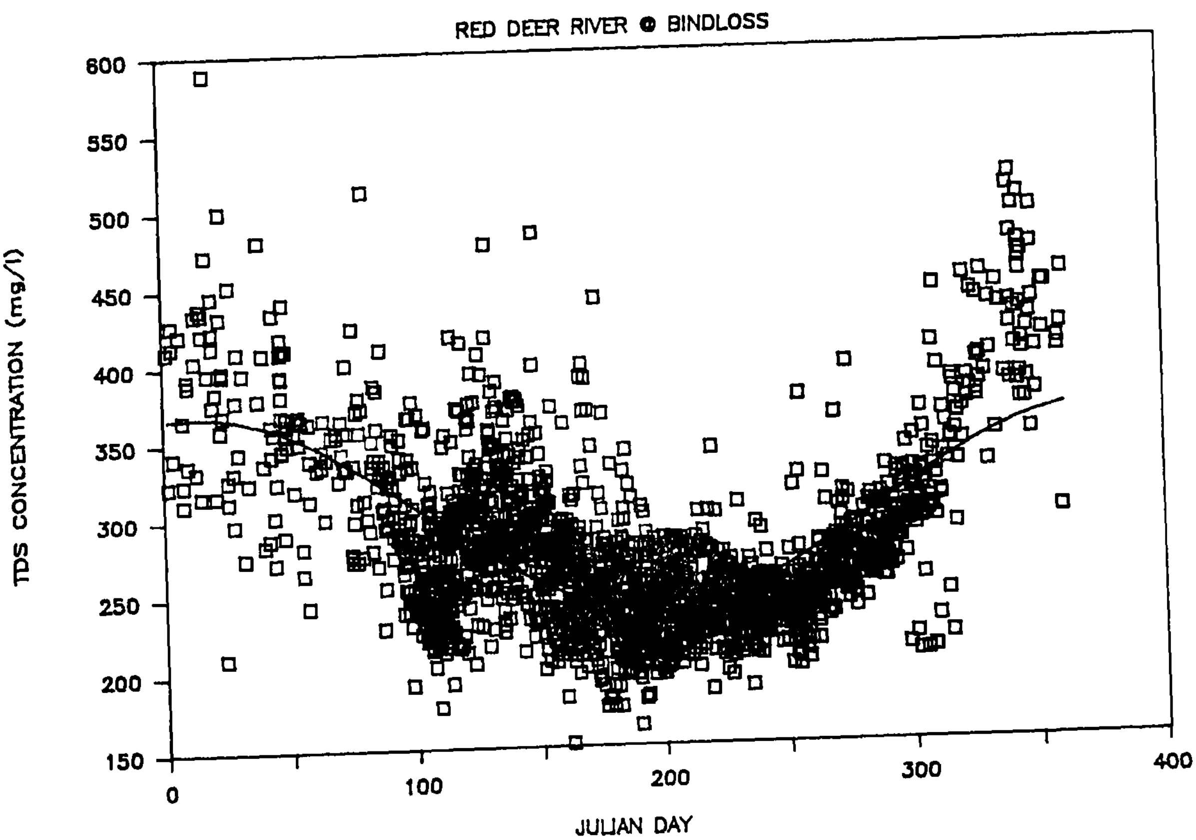

S.SASKATCHEWAN @ HWY #41
600
550
500
450
400
350
300
250
200
150
100
0
100
200
300
400
TDS CONCENTRATION (mg/l)
JULIAN DAY

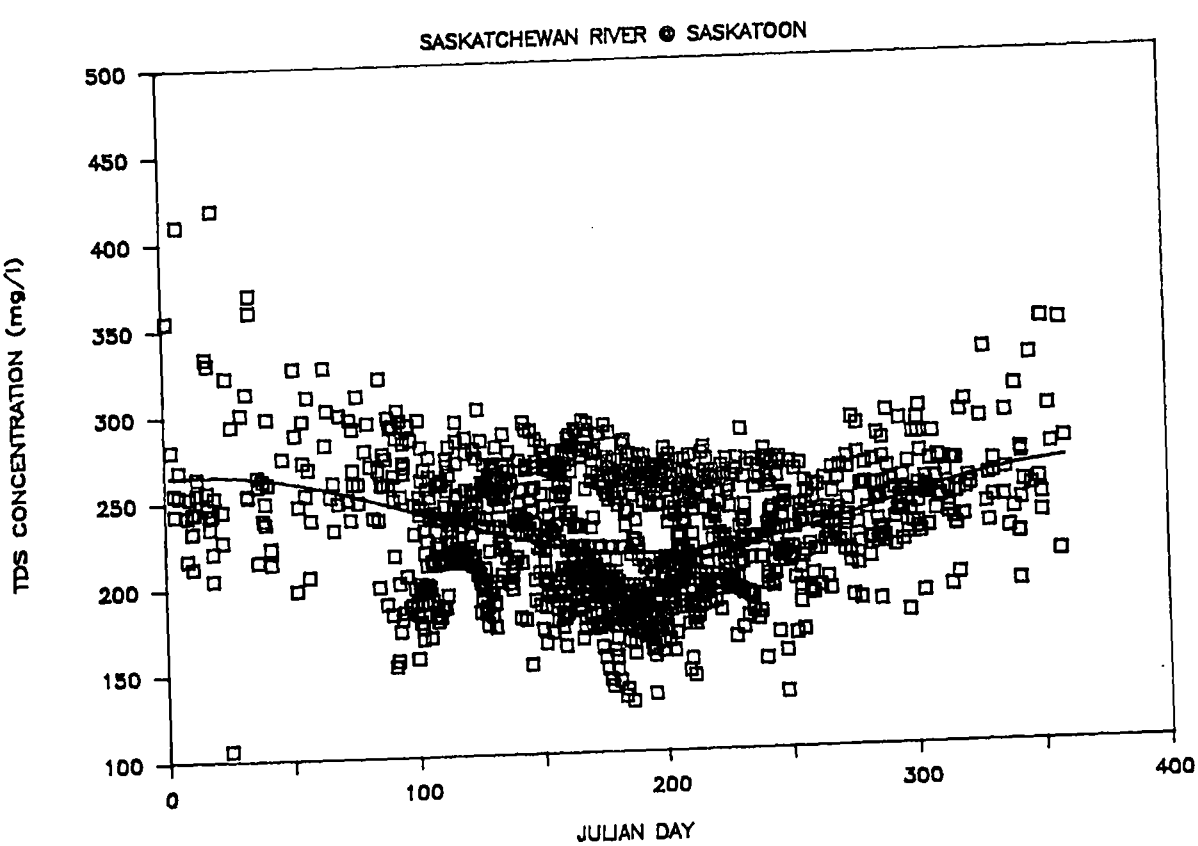

BATTLE RIVER @ UNWIN
TDS CONCENTRATION (mg/l)
(Thousands)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
100
200
300
400
JULIAN DAY

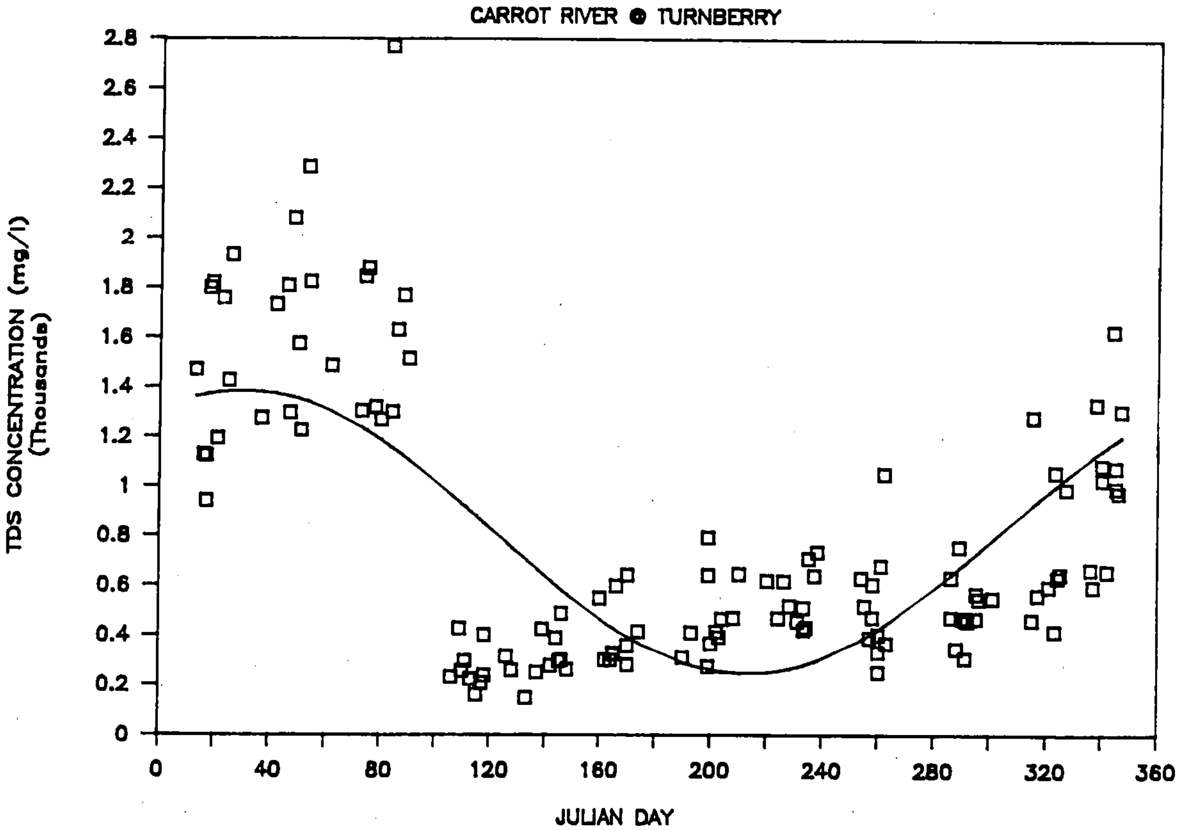

SASKATCHEWAN RIVER @ THE PAS
TDS CONCENTRATION (mg/l)
450
400
350
300
250
200
150
100
50
0
100
200
300
400
JULIAN DAY


OLDMAN RIVER @ HWY 36
TDS CONCENTRATION (mg/l)
JULIAN DAY
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
0
100
200
300


BOW RIVER @ MOUTH
TDS CONCENTRATION (mg/l)
JULIAN DAY
280
270
280
250
240
230
220
210
200
190
180
170
160
150
140
0
100
200
300
400


RED DEER RIVER @ BINDLOSS
TDS CONCENTRATION (mg/l)
600
550
500
450
400
350
300
250
200
150
0
100
200
300
400
JULIAN DAY


SASKATCHEWAN RIVER @ SASKATOON
TDS CONCENTRATION (mg/l)
500
450
400
350
300
250
200
150
100
0
100
200
300
400
JULIAN DAY


CARROT RIVER @ TURNBERRY
TDS CONCENTRATION (mg/l)
(Thousands)
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
40
80
120
160
200
240
280
320
360
JULIAN DAY