AN EVALUATION OF NUTRIENTS AND BIOLOGICAL CONDITIONS IN THE BOW RIVER, 1986 to 1988

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OVERVIEW

This report presents the results of 1986-88 Bow River water quality monitoring programs conducted by Alberta Environment. Plant nutrient, coliform bacteria count and aquatic plant biomass trends and differences between sites were analyzed. Only statistically significant trends and differences are presented in this report. This program was mainly designed to detect changes in river water quality since the installation of phosphorus removal at Calgary sewage treatment plants in 1982-83. It does not address contaminant release from the Calgary Domtar site (Golder Associates Ltd. 1990) or other industrial sites.

Total and dissolved phosphorus levels have been substantially reduced at sites downstream from Calgary, but remain higher at those sites than at upstream sites. In addition, since the installation of phosphorus-removal technology in 1983, there has been a small but statistically significant increase in river phosphorus concentrations at Carseland, perhaps reflecting the general increase in sewage volumes from Calgary. Silica has also declined at some sites in recent years, perhaps due to low rainfall or decreased groundwater flow. Total coliform counts increased gradually over the sampling period at Cochrane, Bowness and Bow City, and fecal coliforms have increased at Bowness. Total and fecal coliform bacteria counts exceeded the Alberta Surface Water Quality Objective for direct contact recreation and the CCREM guideline for irrigation on most occasions at Stier's Ranch, and frequently at Carseland. Furthermore, morning dissolved oxygen measurements at the Stier's Ranch robot monitor site were sometimes below the Alberta Surface Water Quality Objective. These coliform and dissolved oxygen data may reflect a combination of lower than average river flows, effects of aquatic plant respiration on dissolved oxygen, population growth or urban development.

The biomass of epilithic algae has not significantly decreased since 1983 at sites downstream from Calgary, and has remained higher there than at Bowness. In contrast, fall macrophyte biomass has decreased significantly at some, but not all sampling sites.

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ACKNOWLEDGEMENTS

I thank all biologists, technologists and clerical staff who assisted in sampling and the preparation of this report.

1.0 INTRODUCTION

Alberta Environment has monitored aquatic plant biomass and water chemistry at a series of sites on the Bow River, in Calgary and downstream, since early in the 1980's. This program was primarily designed to monitor changes in water quality and nuisance aquatic plant growth after the installation of phosphorus removal at Calgary's two sewage treatment plants. These facilities became fully operational during the winter of 1982-83. Previous reports (Cross et al. 1984, Charlton and Bayne 1986) have discussed results to 1985. These results did not show a consistent reduction in plant biomass, in spite of an 80% reduction in total phosphorus loading to the Bow River from 1982 to 1983.

This report presents and discusses results from 1986 to 1988. It includes an analysis of long-term trends since 1979 and differences between sites in epilithic algal chlorophyll a, plant nutrients, coliforms, and fall (peak) macrophyte biomass. Dissolved oxygen measurements from the robot monitor at Stier's Ranch (site M8 in Figure 1) have also been included because aquatic plants can strongly influence this variable.

2.0 METHODS

2.1 SAMPLING

All sampling sites are illustrated in Figure 1. Standard Alberta Environment sampling methods (Alberta Environment 1988) were generally used throughout these monitoring programs. Monthly grab samples were collected for most chemical and biological constituents. Epilithic algae were sampled monthly from nine to twelve bottom rocks

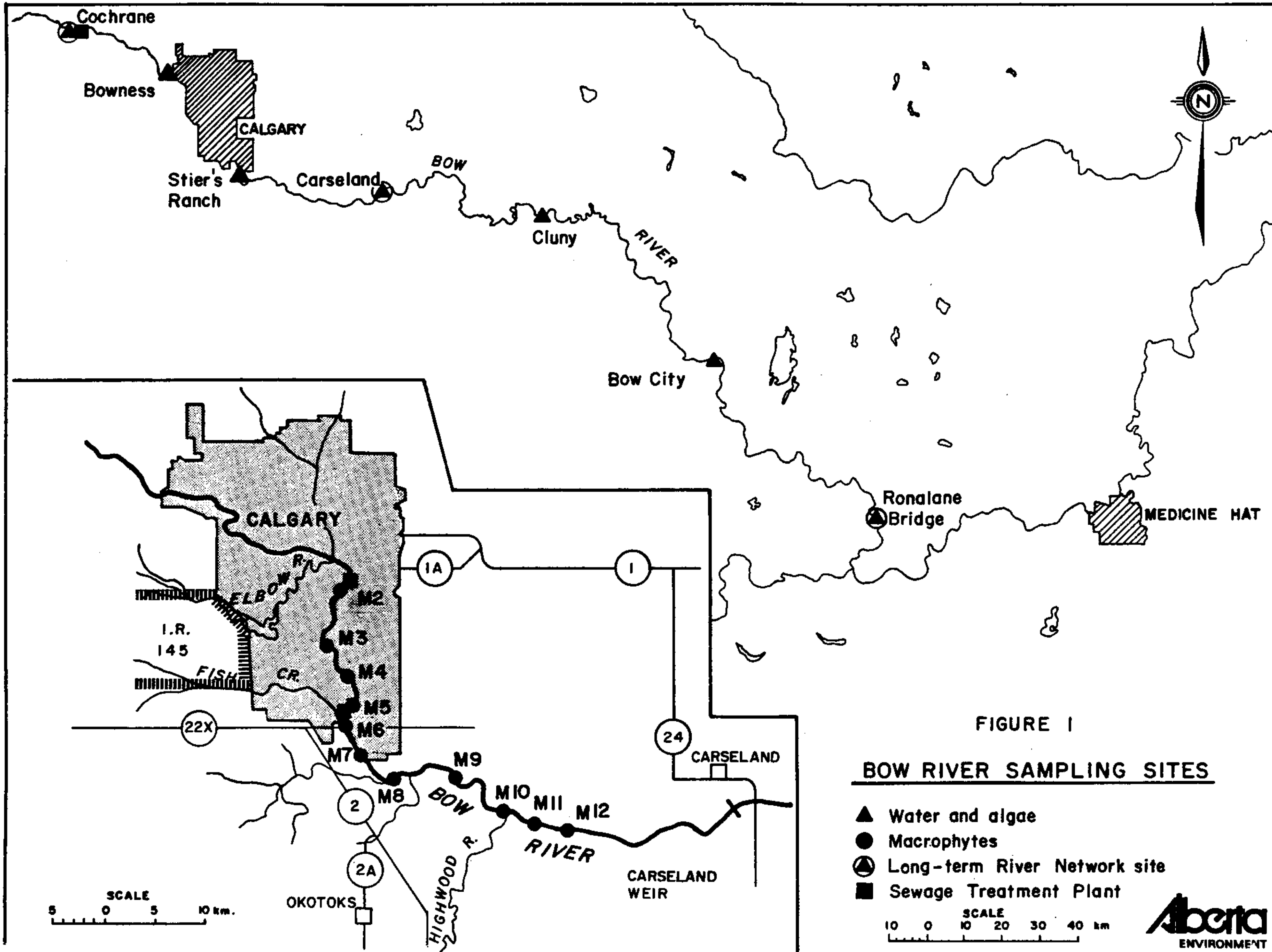


FIGURE 1

BOW RIVER SAMPLING SITES

using a template method. During fall, five macrophyte samples were collected from right and left banks at each site with a collecting net and 0.0929 m^2 frame.

Only half the macrophyte sites were sampled in the fall of 1988, as high flows prevented further sampling. The frequency and duration of sampling for chemical constituents, algae and coliforms varied over the period 1979-88. Some sites were not sampled for the entire time period for all variables. Fewer samples were collected and analyzed at Bowness, Stier's Ranch, Cluny and Bow City after 1987; only coliform bacteria, nutrients and constituents directly related to plant growth were sampled at these sites (monthly from May to October). Long-term river network monitoring sites at Cochrane, Carseland and Ronalane were sampled monthly year-round although epilithic algae were sampled only from May to October at the latter two. Macrophytes were sampled between August 25 and September 6 each year as a measure of "near peak" biomass. Maximum biomass occurred in mid to late September in previous studies (Charlton et al. 1986).

Analytical methods for water chemistry, coliforms and algae are summarized by NAQUADAT codes in Table 1. Missing values are summarized by variables in Table 2. Dissolved oxygen and other variables were monitored hourly with a Schneider RM25 Robot Monitor at Stier's Ranch. The monitor was calibrated bi-weekly. Annual sewage flow, nutrient loading estimates and coliform data were obtained from the City of Calgary, Environment Canada and the Municipal Branch of Alberta Environment.

Table 1. Analytical methods and NAQUADAT codes for variables presented in this report.

Variable	Analytical Method	Year	NAQUADAT Code
total phosphorus	colourimetry on autoanalyzer	1979-88	15406L[a]
dissolved phosphorus	colourimetry on autoanalyzer, 0.45 u membrane filter	1979-83 1984-88	15103F[b] 15103L
reactive silica	colourimetry using heteropoly blue method on autoanalyzer	1979-88	14105L
dissolved nitrite/nitrate	colourimetry on autoanalyzer GFC filter	1979-80	7119F
	as above, 0.45 u membrane filter	1979-83 1984-88	7110F 7110L
total ammonia	ion selective electrode	1979-84	7506L
	colourimetry on autoanalyzer	1985-88	7505L
total nitrogen	calculated, total Kjeldahl nitrogen plus nitrite/nitrate	1979-88	7602
epilithic chlorophyll *a*	spectrophotometry samples collected by brushing	1980-83	6721L
	as above, samples collected by a template method	1984-88	6722L
phytoplankton chlorophyll *a*	colourimetry, GFC filter	1980-86	6717L
	fluorometry, 0.4 u filter	1987-88	6715L
	spectrophotometry, GFC filter	1980-86[c]	6720L
total coliforms	tube fermentation test	1981-83	36002L
	membrane filter count	1984-88	36001L
fecal coliforms	membrane filter count	1984-88	36011L

[a] lab analysis
[b] field filtered
[c] at Bowness, Stier's, Cluny, Bow City

Table 2: Significant ($P < 0.05$) differences between sites and changes in selected water quality variables in the Bow River after the installation of phosphorus removal at Calgary's sewage treatment plants in 1982-83.

VARIABLE	PERIOD OF ANALYSIS	SITES	MISSING VALUES[b] SITES	MISSING VALUES[b] YEARS
MEDIAN DIFFERENCES OVER TIME[c]				
total phosphorus	79-82 vs 83-88	Cochrane (+0.002)[a] Carseland (-0.135) Ronalane (-0.085)	see below	
total nitrogen	79-82 vs 83-88	Carseland (-0.108) Ronalane (-0.053)	Carseland	82
SIGNIFICANTLY DIFFERENT GROUPS OF SITES[d,e]				
total phosphorus	83-88	1. Cochrane (0.007), Bowness (0.008)[f] 2. Stier's Ranch (0.045), Carseland (0.037) 3. Bow City (0.025), Ronalane (0.027)	Bowness Stier's Ranch Carseland Bow City	80-83 82-83 82 82-83
dissolved phosphorus	84-88	1. Cochrane (0.003), Bowness (0.003) 2. Stier's Ranch (0.018), Carseland (0.020) 3. Bow City (0.010), Ronalane (0.011)	Cochrane Bowness Stier's Ranch Carseland Bow City Ronalane	84-86 80-83 82-83 80-83 82-83 81
reactive silica	85-88	1. Bowness (2.87) 2. Stier's Ranch (2.48) 3. Carseland (1.80) > Bow City (0.54), Ronalane (0.54) Cluny (1.10) > Ronalane (0.54) (Cochrane excluded)	Cochrane Bowness Stier's Ranch, Carseland, Bow City Ronalane	84-86 79-84 83-84 84
total nitrogen	83-88	1. Bowness (0.282), Ronalane (0.574) 2. Stier's Ranch (1.420) 3. Carseland (1.270) (Bow City, Cochrane excluded)	Carseland Bow City Cochrane	82 79-85 79-86
epilithic chlorophyll _a_	84-88	1. all sites differed from one another	Cochrane Bowness Carseland Bow City Ronalane	no data 79-83 80-83 79 79-82
fecal coliforms	84-88	1. Bowness (2), Bow City (8), Ronalane (10) 2. Stier's Ranch (520) 3. Carseland (113) (Cochrane excluded)	Cochrane Carseland Bowness, Stier's Ranch, Bow City Ronalane	79-83, 85-86 79-83,87 79-84 79-82,87
total coliforms	84-88	1. Bowness (14), Bow City (160) Ronalane (115) 2. Stier's Ranch (5400) 3. Carseland (700)	same as above	

a seasonal Hodges-Lehman median difference estimate, mg/L
b either no data or a partial record; 1985-88 Cluny data excluded from all analyses except silica
c combined data before September 1982 compared to data after February 1983
d groups of sites different from all sites in other groups, but not different from other sites in the same group, except as noted
e Kruskal-Wallis test
f May - October median, mg/L

2.2 DATA ANALYSIS

Most water quality variables exhibited significant seasonal variation, serial correlation or flow-dependency, factors which can adversely influence parametric statistical testing. Therefore, the nonparametric Kruskal-Wallis test with pairwise comparisons calculated by WQStat II (Loftis et al. 1989) was used to test the significance ($P < 0.05$) of differences between individual sites for nutrients, coliforms and epilithic algae. Values less than the detection limit were set at one half the detection limit, as required by WQStat II. Of the nitrogen compounds, only total nitrogen was tested for differences between sites. Calgary's sewage treatment plants underwent improvements in 1986 which greatly changed the relative loading of the various forms of nitrogen. All data over the entire year from each site from April 1983 to October 1988 were grouped for analysis. Shorter time periods were selected for some variables to provide analysis on more sites.

The Seasonal Hodges-Lehman median estimate was used to test for significant ($P < 0.05$) changes in median total phosphorus and total nitrogen in all data before December 1982, when the phosphorus removal system was installed, and after March 1983. Full treatment efficiency for phosphorus removal was achieved by March 1983. Only these two variables at the long term river network sites had sufficient data for a valid analysis.

Differences in macrophyte biomass between individual years were tested ($P < 0.05$) using one-way analysis of variance (ANOVA) on transformed data (base 10 logarithm + 1), followed by the Student-Newman-Keuls range test where the ANOVA indicated significant differences. Pearson's correlation coefficients between macrophyte biomass after 1982 and sampling years were calculated to determine whether macrophyte biomass has declined since phosphorus removal was initiated.

To detect long-term water quality trends in the chemical and biological data, flow trends were first tested for the Cochrane and Ronalane sites using the Seasonal Kendall test. Since there was no significant long-term flow trend detected at these sites, chemical and biological data were not flow-adjusted. Data were then tested for flow-dependency by regression analysis. Seasonality of the data was assessed using the Kruskal-Wallis test and inspection of seasonal box and whisker plots and correlograms.

Water quality data sets longer than five years duration were then tested year-round using either the Seasonal Kendall test, if seasonality was present, or the Kendall test, if it was not detected. Data sets of five years duration or less were deseasonalized if seasonality was present. This is a more robust procedure for shorter data sets (Hirsch and Slack 1984). They were then also tested year-round with the Kendall test. Where sufficient data were available, the data set was tested for time periods before and after the installation of phosphorus removal at the sewage treatment plants, and for time periods before and after changes in analytical methods. Dissolved oxygen records from the Stier's monitor were analyzed for 1984 to 1987. Dissolved oxygen data from 1988 and May and June 1985 were not available for analysis.

Correlation coefficients and ANOVA were calculated using the software package SPSS-X (Release 2.1 and 3.0) (SPSS Inc. 1988). Flow dependency was tested using a Lotus 1-2-3 program (Shaw et al. 1990). Kruskal-Wallis tests, Seasonal Hodges-Lehman estimates, seasonality, serial correlation and long-term trends were assessed using WQStat II (Loftis et al. 1989).

3.0 RESULTS AND DISCUSSION

Only those constituents for which significant trends were detected by trend analysis are presented in Figures 2 to 22. These graphs were produced using STATGRAPHICS (Version 2.6), which plots any values greater than 1.5 times the interquartile range as an outlier. Only May to October data have been plotted, as this was considered to be the period of greatest macrophyte growth. This was also the sampling period for which the most data were available at most sites. Samples in which most values were less than the detection limit were plotted with a median equal to the 25 percentile, and generally lacked range bars. Horizontal bars without percentile rectangles denote samples where all measurements were at the method detection limit.

Significant differences before and after the 1982-83 installation of phosphorus removal at Calgary's sewage treatment plants and differences between sites are summarized in Table 2. Significant differences caused by changes in analytical methods have been excluded from this table. Significant trends are summarized in Table 3. Data for all analyses (except for the Stier's Ranch monitor) can be obtained from the provincial government data management system, NAQUADAT.

Table 3. Significant ($p < 0.05$) trend analysis results for the Bow River sampling sites, 1979 - 1988.

SITE	VARIABLE	PERIOD OF ANALYSIS	SEASONALITY PRESENT	KENDALL TAU	SEASONAL KENDALL TAU	SLOPE ESTIMATOR UNITS/YR[b]
Cochrane	total phosphorus	1979 - 1988	No	2.429		0.00032
	total dissolved phosphorus	1979 - 1988	No	1.963		<0.00001
	silica	1979 - 1988	No	-5.127		-0.076
	total coliforms[c]	1979 - 1988	Yes		2.053	0.1
Bowness	total phosphorus	1979 - 1988	Yes		2.293	0.00030
	total coliforms	1983 - 1984	Yes		2.383	1.5
	fecal coliforms[c]	1983 - 1984	Yes		2.358	0.3
	epilithic chlorophyll <u>a</u>[d]	1984 - 1988	No	-2.026		-9.1
Carseland	total dissolved phosphorus	1983 - 1988	Yes		1.984	0.00231
	ammonia	1983 - 1988	Yes		-3.172	-0.01130
Bow City	total coliforms	1983 - 1988	Yes		1.977	12.0
Ronalane	silica	1985 - 1988	Yes		-2.397	-0.080
	ammonia	1985 - 1988	Yes	-3.949[a]		-0.00750
		1983 - 1988	Yes		-2.347	-0.00917

[a] using deseasonalized data
[b] mg/L except as indicated
[c] number per 100 mL
[d] mg/m^2

3.1 PHOSPHORUS

A small but significant increase in total phosphorus was detected by trend analysis for the Cochrane and Bowness sites for 1979 to 1988 (Table 3, Figure 2 and 3), and median total phosphorus increased at Cochrane (Table 2). A significant increase in dissolved phosphorus since 1979 was also detected by trend analysis at Cochrane (Figure 4), but the slope estimate was negligible. This trend requires confirmation over a longer sampling period. The slope estimates in Table 3 provide an unbiased estimate of the approximate rate of change, but may be imprecise.

The slight increase in total phosphorus at Bowness could reflect increased shoreline scouring and construction impacts near this site. The spillway at Bearspaw Dam was upgraded in 1985, and flow at the sampling site appears to have increased since the intake structure for the new Bearspaw Water Treatment Plant was installed on the opposite bank.

Both total and dissolved phosphorus concentrations were lower at Carseland and Ronalane, downstream from Calgary, after the installation of phosphorus removal at Calgary sewage treatment plants (1982-83) than before (Table 2). For example, Figure 5 and 6 illustrate the change in phosphorus over time at the Carseland site. Previous reports have discussed this reduction (Cross et al. 1984, Charlton and Bayne 1986). Only the long term river network sites (Figure 1) had sufficient data before 1982 to test for significant differences in median phosphorus level.

Although total and dissolved phosphorus decreased greatly at sites downstream from Calgary after the installation of phosphorus removal in 1982-83, an increasing trend in dissolved phosphorus was

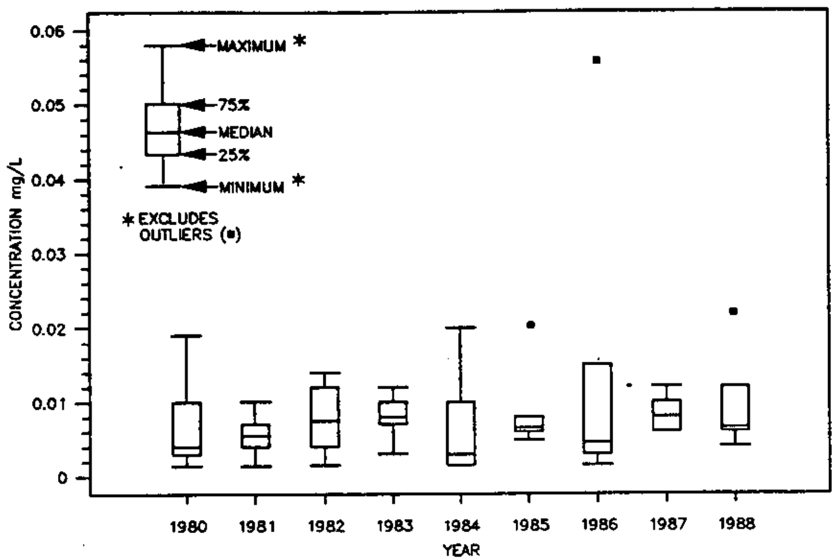


FIG.2 BOX AND WHISKER PLOT OF TOTAL PHOSPHORUS AT COCHRANE 00AL05BH0017

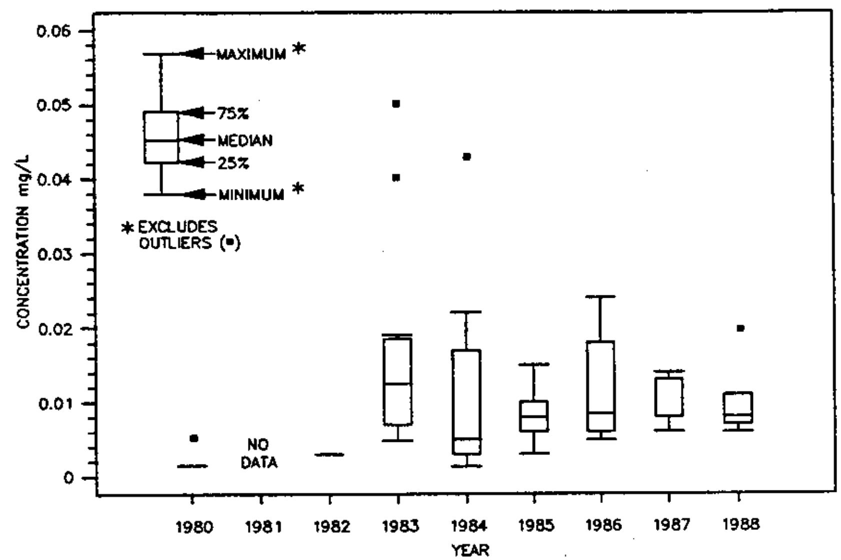


FIG.3 BOX AND WHISKER PLOT OF TOTAL PHOSPHORUS AT BOWNESS 00AL05BH2105

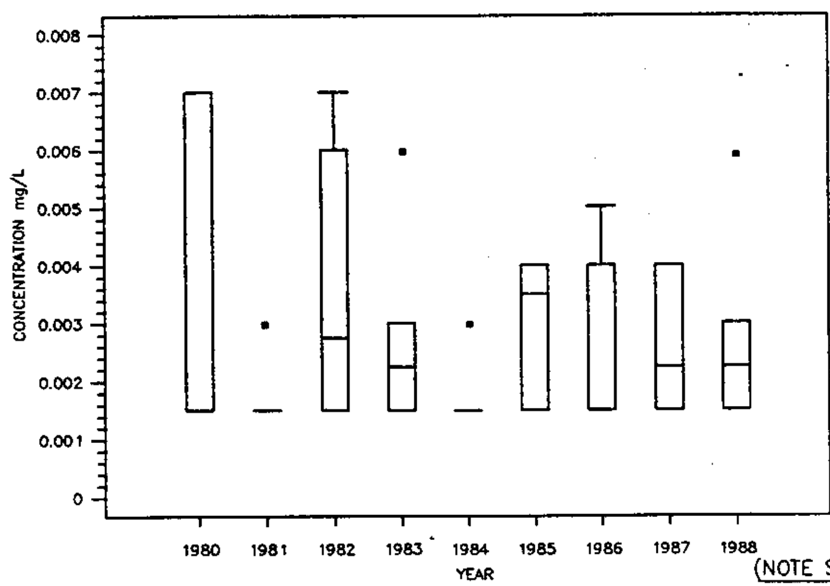


FIG.4 BOX AND WHISKER PLOT OF DISSOLVED PHOSPHORUS AT COCHRANE 00AL05BH0017

(NOTE SCALE CHANGES)

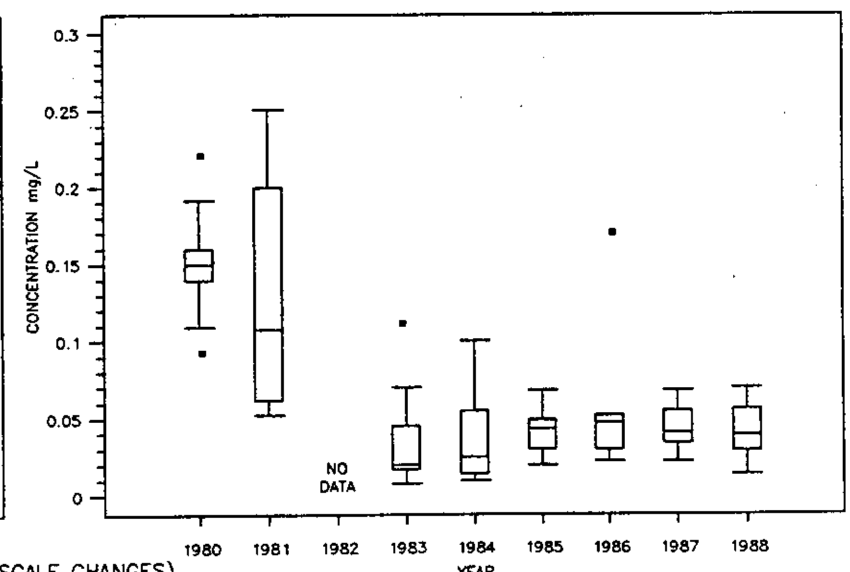


FIG.5 BOX AND WHISKER PLOT OF TOTAL PHOSPHORUS AT CARSELAND 00AL05BM2900

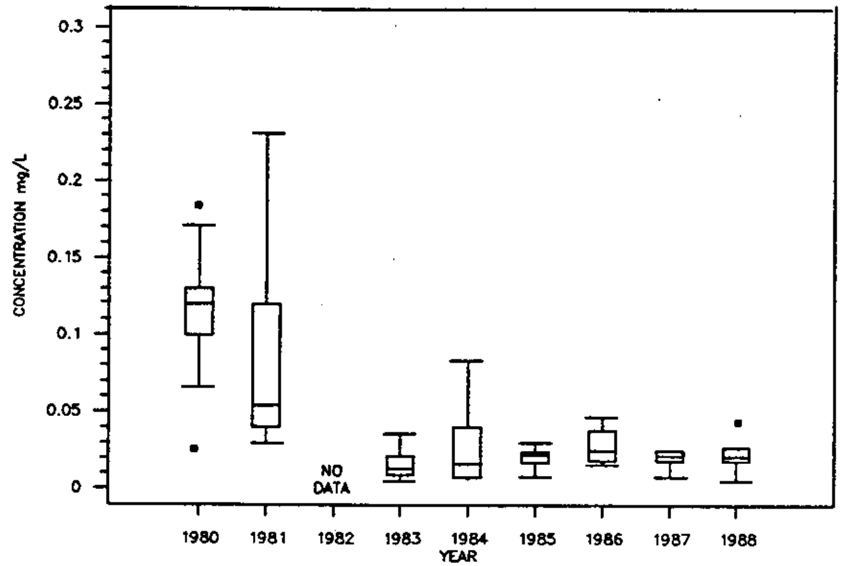


FIG.6 BOX AND WHISKER PLOT OF DISSOLVED PHOSPHORUS AT CARSELAND 00AL05BM2900

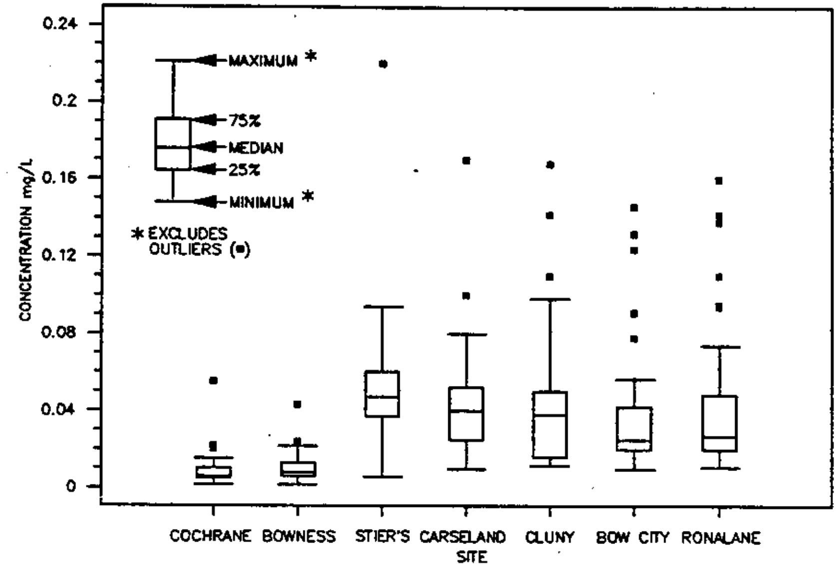


FIG.7 BOX AND WHISKER PLOT OF TOTAL PHOSPHORUS IN THE BOW RIVER,1984-1988

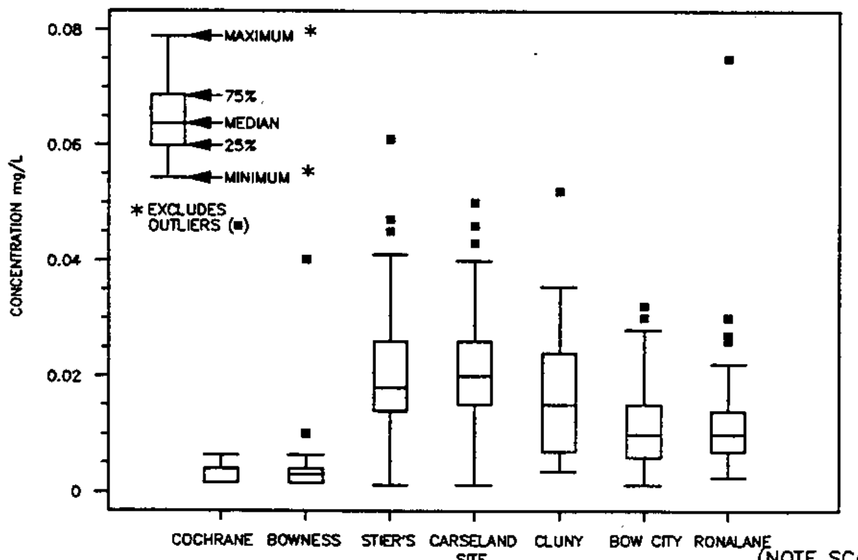


FIG.8 BOX AND WHISKER PLOT OF DISSOLVED PHOSPHORUS IN THE BOW RIVER,1984-1988

(NOTE SCALE CHANGES)

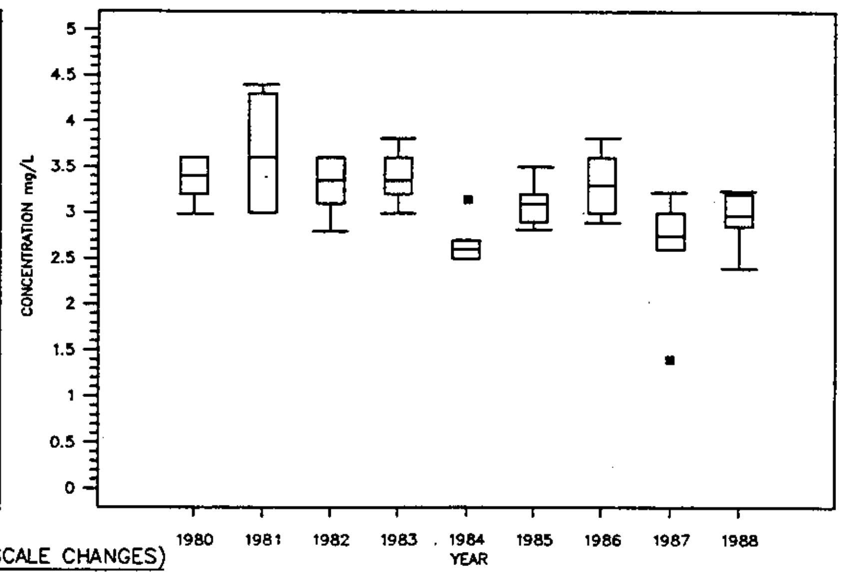


FIG.9 BOX AND WHISKER PLOT OF REACTIVE SILICA AT COCHRANE 00AL05BH0017

detected for Carseland from 1983 to 1988 (Figure 6, Table 3). The significant trends detected by the Kendall test reflect general increases or decreases in variables over time, rather than random or natural variation between years.

The small increases in phosphorus over time detected at Cochrane and Carseland could reflect increased phosphorus loading from sewage treatment plants (Figure 10) and urban stormwater runoff. Although total phosphorus loading to the Bow River from Calgary's two sewage treatment plants decreased by about 80% from 1982 to 1983 with the installation of phosphorus removal, phosphorus loading from these plants actually increased by 20% from 1983 to 1988 because of increased sewage volumes. Dissolved phosphorus was 40% of the total phosphorus in treated effluent from the Bonnybrook plant in 1987 and 1988. Annual discharge from the Canmore plant has also increased since 1979, but there are not enough phosphorus data or measured sewage flow data available for plants upstream from Calgary to derive reliable loading estimates.

Levels of both total and dissolved phosphorus were significantly higher at all sites below Calgary than at Cochrane or Bowness, when 1983 to 1988 data from each site were combined for analysis (Figure 7 and 8, Table 2). Total and dissolved phosphorus was generally highest at Stier's Ranch and Carseland. These two sites were not significantly different from one another. Although phosphorus levels generally declined with distance downstream from Calgary, the Bow City and Ronalane sites were not significantly different from one another (Table 2).

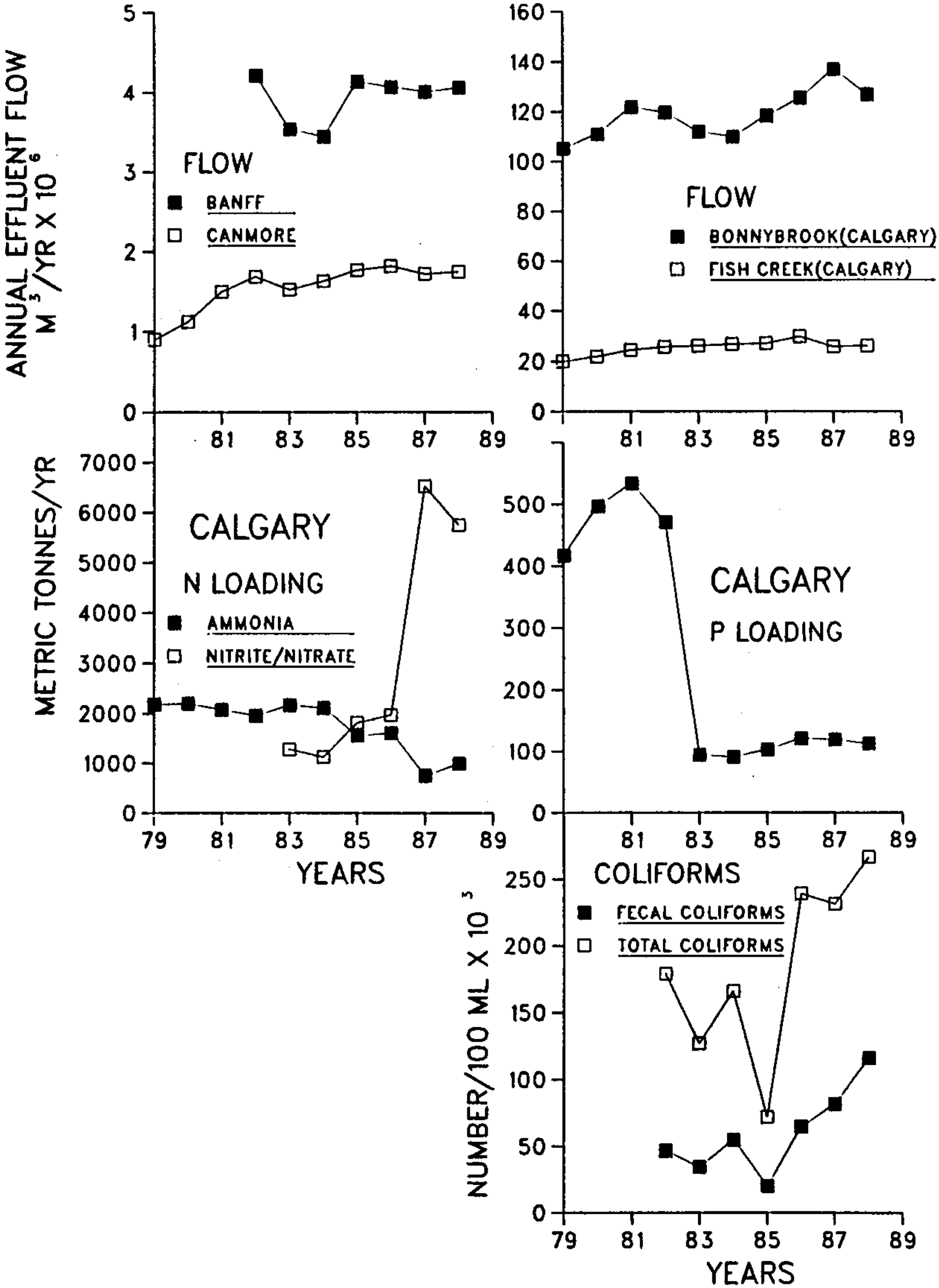


Figure 10. Annual effluent flow for sewage treatment plants from Banff to Calgary, total phosphorus, ammonia and nitrite/nitrate annual loading from both Calgary plants, and the arithmetic mean of monthly coliform counts for treated effluent from the Bonnybrook Wastewater Treatment Plant, 1979–1988.

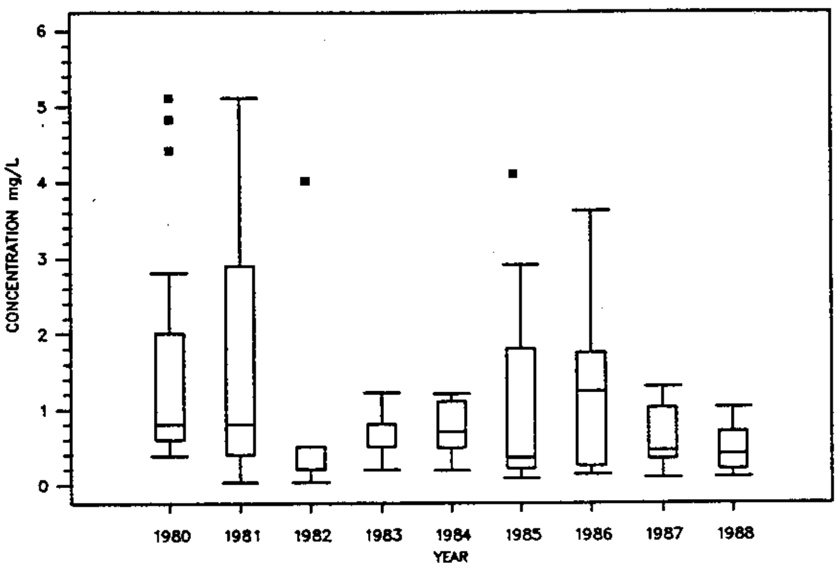


FIG. 11 **BOX AND WHISKER PLOT OF REACTIVE SILICA AT THE RONALANE BRIDGE** 00AL05BN2100

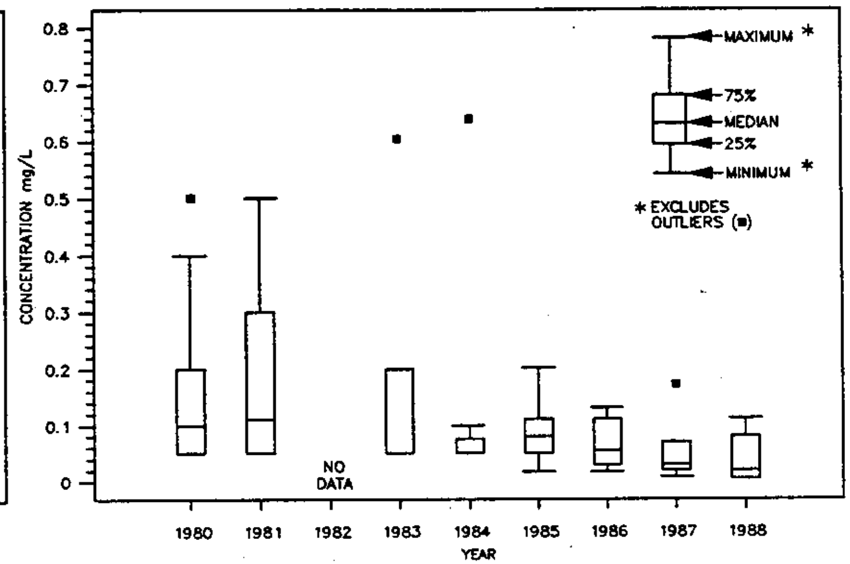


FIG. 12 **BOX AND WHISKER PLOT OF TOTAL AMMONIA AT CARSELAND** 00AL05BM2900

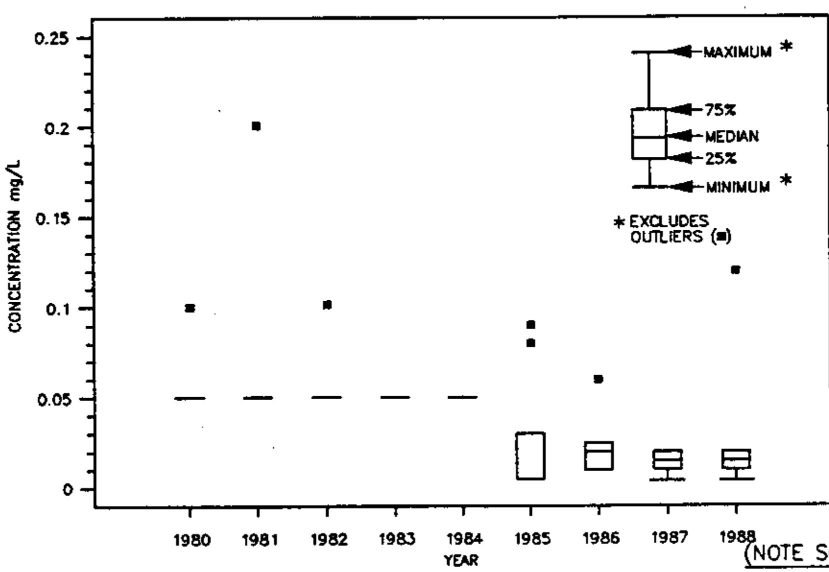


FIG. 13 **BOX AND WHISKER PLOT OF TOTAL AMMONIA AT THE RONALANE BRIDGE** 00AL05BN2100

(NOTE SCALE CHANGES)

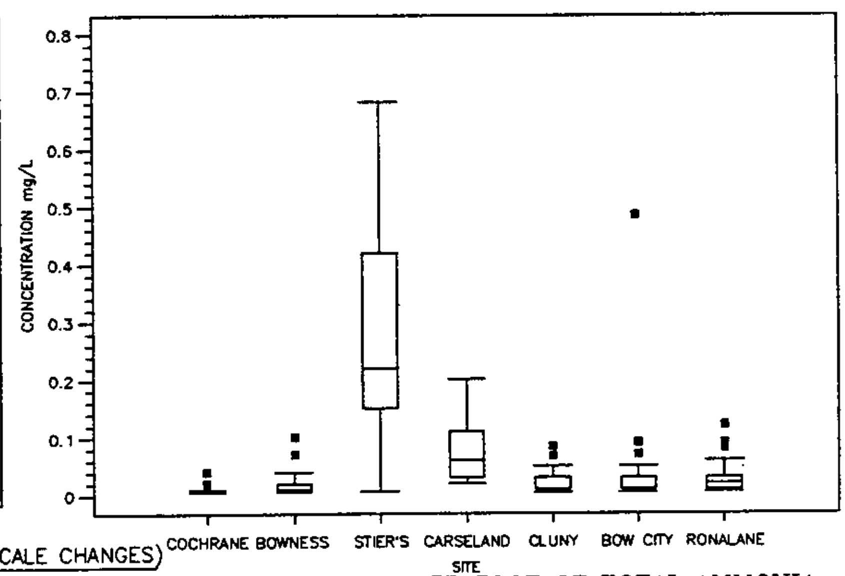


FIG. 14 **BOX AND WHISKER PLOT OF TOTAL AMMONIA IN THE BOW RIVER, 1985–1988**

3.2 REACTIVE SILICA

Reactive silica decreased significantly at the Cochrane site from 1979 to 1988 and at Ronalane from 1985 to 1988 (Figure 9 and 11, Table 3). This decline could reflect decreased groundwater flow or surface runoff in recent dry years, as these sources are often high in reactive silica (Hynes 1970). The decline in silica at these sites appears unlikely to limit total algal biomass. Hynes (1970) notes that silica in rivers is unlikely to reach levels that limit growth, and in any event would only limit the growth of diatom algae. Reactive silica levels were significantly higher at Bowness, followed by Stier's Ranch, than at sites further downstream (Table 2).

3.3 NITROGEN COMPOUNDS

A significant decline in ammonia after 1983 was detected for the Carseland site (Figure 12), but this decline could partly reflect a change to an analytical method with a lower detection limit from May 1985 onward at all sites. A significant decline in ammonia at Ronalane was also detected by trend analysis (Table 3, Figure 13). Ammonia at this site usually declined to the method detection limit of 0.1 mg/L in summer and fall before 1985, when the analytical method was changed (Figure 13). Values less than the detection limit in Figures 2 to 22 are set at one half the detection limit. The declining trend detected at Ronalane was significant both before and after the change in analytical method.

Decreased ammonia at these sites probably reflects declining ammonia loading to the Bow River from Calgary's sewage treatment plants, and reduced industrial ammonia discharge. From 1979 to 1988 ammonia loading to the Bow River from Calgary sewage treatment plants declined by 55%, with most of the decline after 1986 (Figure 10), when improved aeration was installed at Bonnybrook (B. Kobryn, City of Calgary, personal communication). Furthermore, Cominco Ltd. and Western Co-operative Fertilizer Ltd., the two main industries discharging ammonia directly to the Bow River, greatly reduced the amount of ammonia they discharge in 1987 (Alberta Environment 1990). Compared to municipal effluents, both plants remained relatively minor sources of ammonia. In 1988, Cominco's estimated annual ammonia loading of 4.97 metric tonnes (Alberta Environment 1990) was only 0.5% that of Calgary's sewage treatment plant loading.

None of the ammonia measurements at these sites from 1986 onward exceeded the CCREM ammonia guidelines to protect aquatic life, which vary with changes in temperature and pH (CCREM 1987). From 1979 to 1986, 7% of ammonia measurements throughout the year at Stier's Ranch exceeded these guidelines, mainly during November to April, but there were seldom exceedances at sites downstream from Carseland (Figure 14).

Nitrite+nitrate loading from Calgary's sewage treatment plants increased by 232% from 1986 to 1987 (Figure 10), after improved aeration was installed. Although no significant trends in river nitrite+nitrate concentration were detected, median total nitrogen was significantly lower after 1983 than before at both Carseland and Ronalane (Table 2). Total nitrogen was higher at Stier's Ranch, followed by Carseland, than at Bowness and Ronalane (Table 2).

3.4 ALGAE

Epilithic algal chlorophyll a did not change significantly over the period of analysis, except at the Bowness site (Figure 15), where it has declined significantly since 1984 (Table 3). As previously discussed, increased scour at Bowness could explain the decline at that site.

The lack of significant variation between years in epilithic algal chlorophyll a probably reflects negligible change in biomass at most sites. Current phosphorus levels in the Bow River may still exceed levels required for maximum algae growth. Bothwell (1985) reported that periphyton growth rates in the lower Thompson River were near maximum at a soluble reactive phosphorus concentration of only 3 - 4 µg/L.

The sampling method used is also subject to several forms of sampling bias and may fail to detect subtle trends. Rocks over 5 cm in diameter are visually selected, and sampling is limited to the substratum depth one can safely reach and wade. This depth limitation could cause significant bias where water levels fluctuate.

Epilithic algal chlorophyll a was significantly higher at each site below Calgary than at Bowness, and all sites tested differed significantly from one another (Figure 16, Table 2). It was highest at the Carseland site, followed by Stier's Ranch and Cluny. The Cluny site was excluded from statistical analysis due to a shorter sampling period. Values were significantly lower at Bow City than at Ronalane. Algal enrichment from Calgary appears to extend downstream to at least Cluny.

Site-specific characteristics such as high macrophyte biomass at Stier's Ranch and Bow City may suppress algal growth through shading.

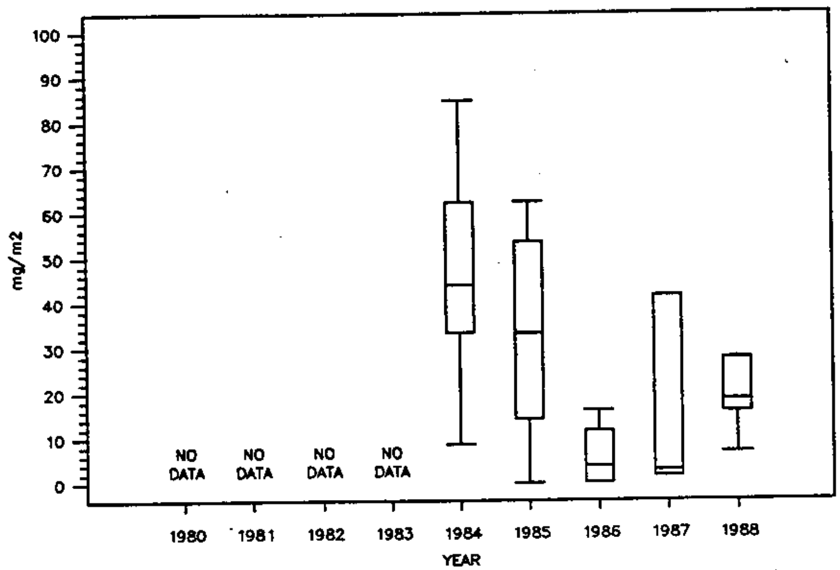


FIG. 15 **BOX AND WHISKER PLOT OF EPILITHIC CHLOROPHYLL a AT BOWNESS** 00AL05BH2105

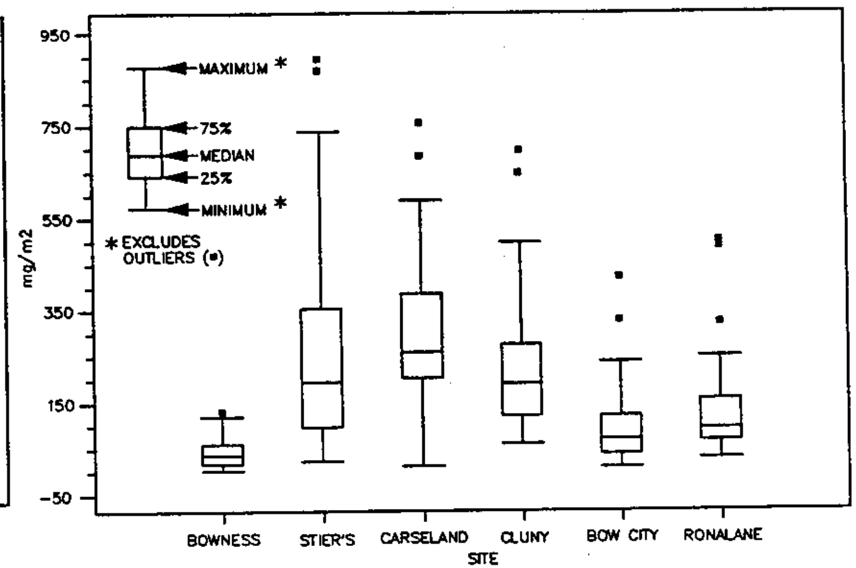
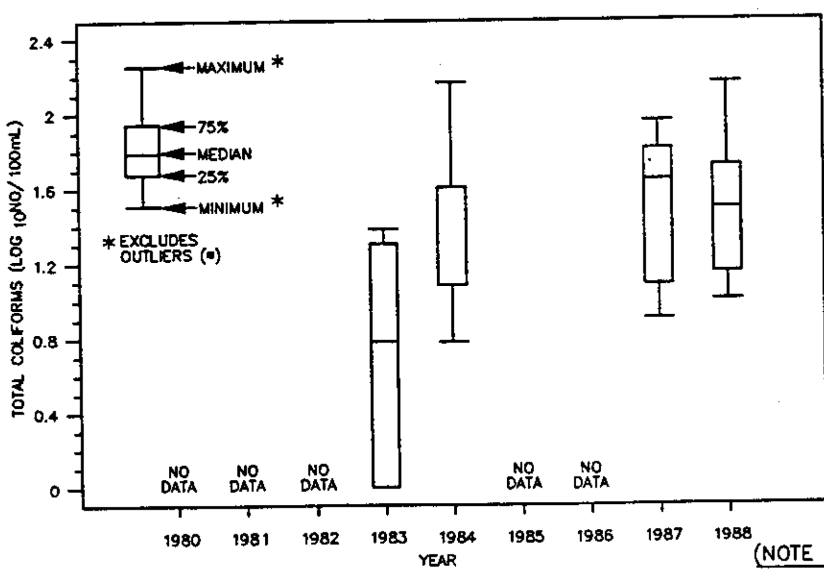


FIG. 16 **BOX AND WHISKER PLOT OF EPILITHIC CHLOROPHYLL a IN THE BOW RIVER, 1984 – 1988**



(NOTE SCALE CHANGES)

FIG. 17 **BOX AND WHISKER PLOT OF TOTAL COLIFORM COUNTS AT COCHRANE** 00AL05BH0017

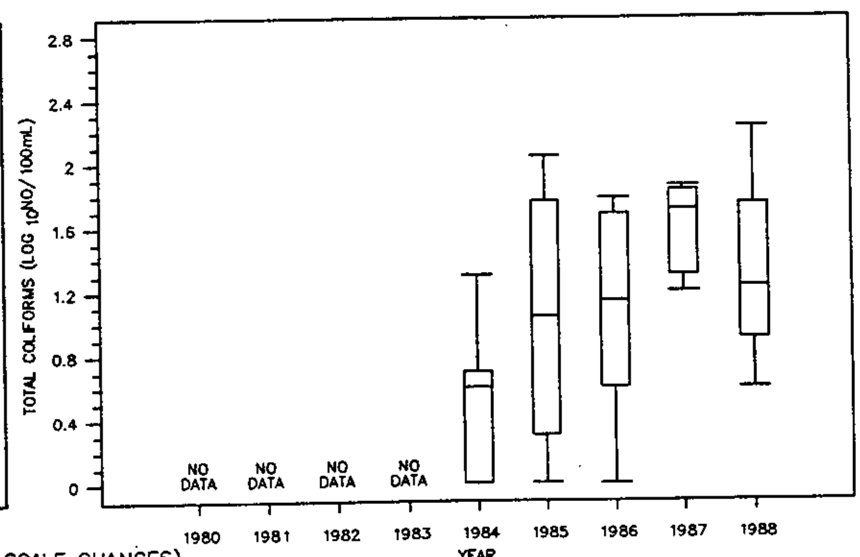


FIG. 18 **BOX AND WHISKER PLOT OF TOTAL COLIFORM COUNTS AT BOWNESS** 00AL05BH2105

Algal biomass at each of these two sites was lower than at sites further downstream from Calgary. Scouring by high flows may also cause site-specific reduction in algal biomass.

Phytoplankton chlorophyll a was excluded from statistical analysis. Since most of the taxa identified in Bow River phytoplankton samples originate from benthic algae, rather than true phytoplankton (Charlton et al. 1986), sampling for phytoplankton was discontinued in 1987 at all Bow River sites except long-term network sites.

3.5 COLIFORM BACTERIA

Total coliform counts at Cochrane, Bowness and Bow City increased significantly over the period of sampling and fecal coliforms increased at Bowness (Table 3, Figure 17 to 20). Coliform values were plotted as base 10 logarithms due to the large variance of the data. Trends were tested for 1979 to 1988 data from Cochrane and Ronalane, and 1983 to 1988 for other sites. Coliform counts at the Cochrane and Bowness sites increased at a far lower rate than at Bow City (Table 3), although these nonparametric slope estimates should be considered approximate indicators of the rate of change.

These results suggest a small but gradual increase over time in coliform counts at some sites from Cochrane to Bow City. The increase in coliform counts could result from several factors. Firstly, as the urban population in the basin has increased, treated sewage discharges (Figure 10) have also increased. Urban runoff has likely also increased. Furthermore, the bacterial content of treated effluent from the Bonnybrook sewage treatment plant has increased over time

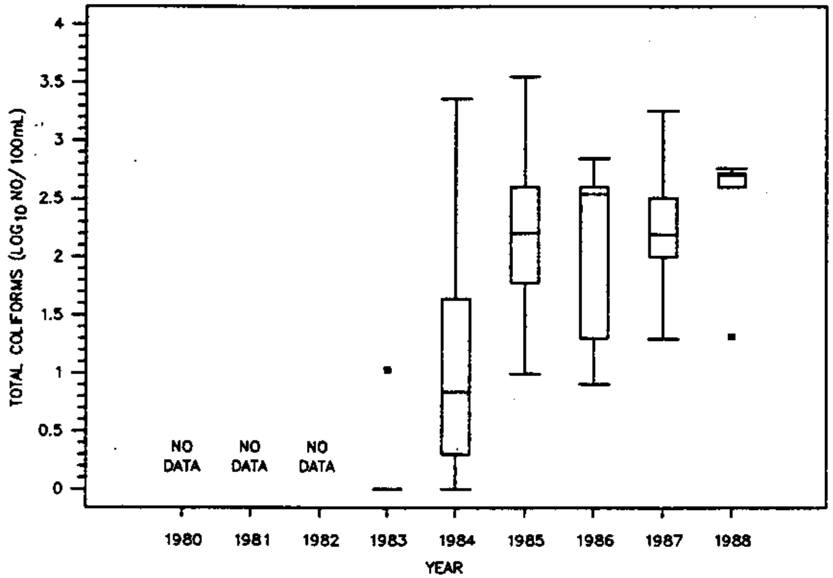


FIG. 19 BOX AND WHISKER PLOT OF TOTAL COLIFORM COUNTS AT BOW CITY 00AL05BN1400

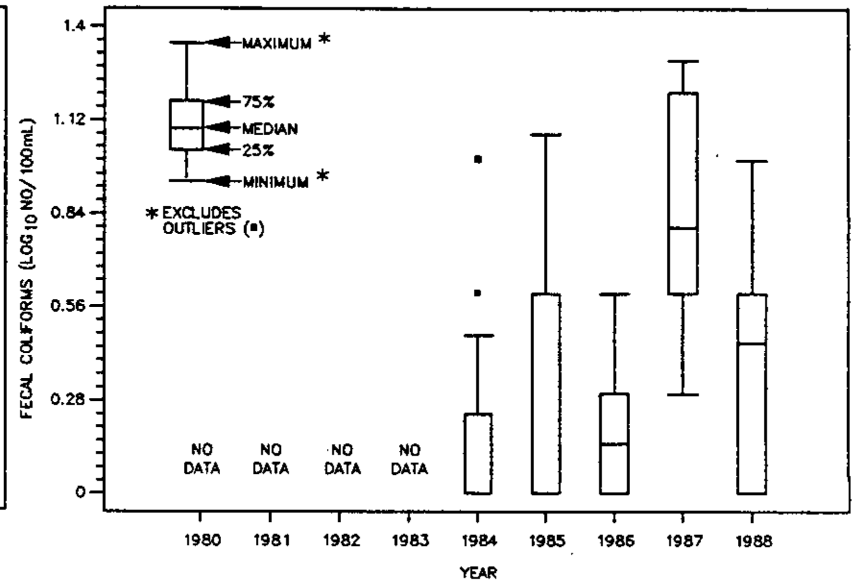


FIG.20 BOX AND WHISKER PLOT OF FECAL COLIFORM COUNTS AT BOWNESS 00AL05BH2105

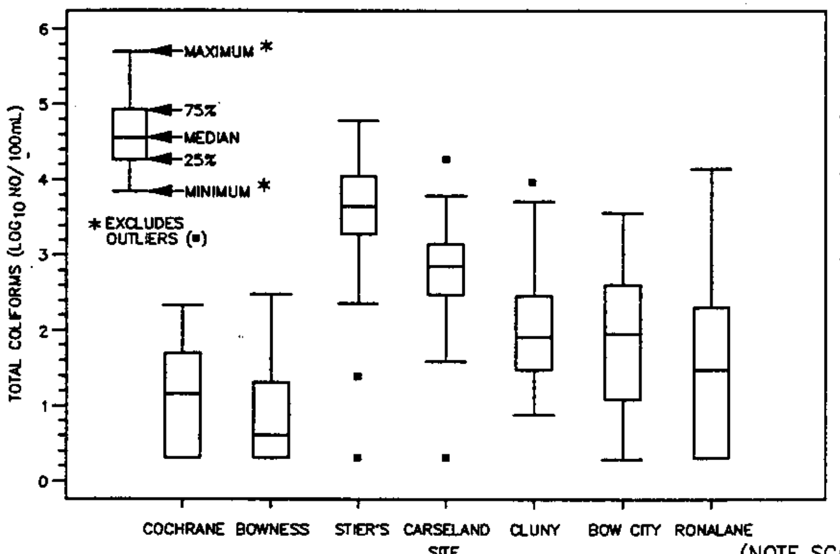


FIG.21 BOX AND WHISKER PLOT OF TOTAL COLIFORM COUNTS IN THE BOW RIVER, 1984-1988

(NOTE SCALE CHANGES)

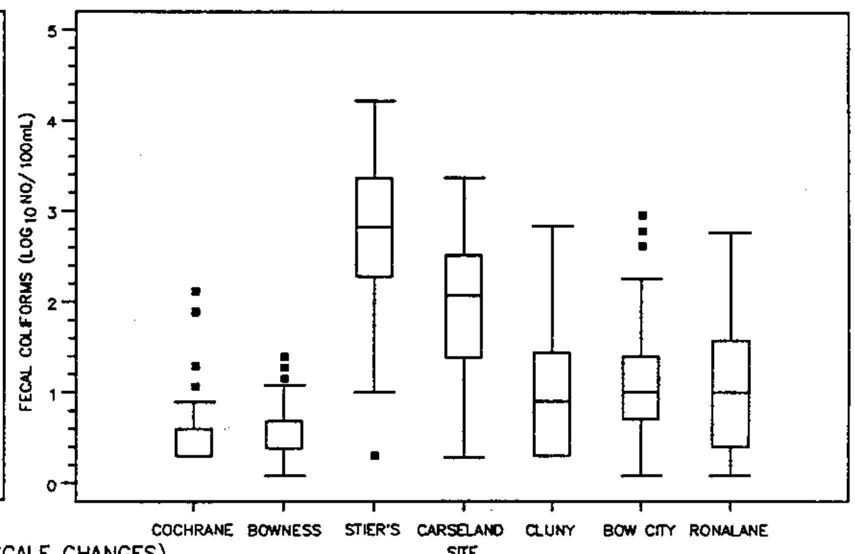


FIG.22 BOX AND WHISKER PLOT OF FECAL COLIFORM COUNTS IN THE BOW RIVER, 1984-1988

(Figure 10). Although the Cochrane and Bowness sites are upstream from Calgary's sewage treatment plants, they each receive treated effluent from communities even further upstream. Another factor which could contribute to higher coliform counts in some years is lower than average Bow River flow rates (Figure 23), which have occurred during this decade, and would reduce sewage dilution rates.

Total and fecal coliform counts were significantly higher at Stier's Ranch, followed by Carseland, than at all other sites each year, and counts at Stier's were significantly greater than those at Carseland (Table 2, Figure 21 and 22). Coliform counts at Stier's Ranch usually exceeded both the instantaneous Alberta Surface Water Quality Objective for direct contact recreation (maximum of 2400 total coliforms per 100 mL, or $\log_{10}$ of 3.380, in any sample) and the CCREM guideline for crop irrigation (maximum of 100 fecal or 1000 total coliforms per 100 mL in any sample). Both total and fecal coliform counts were generally lower at sites downstream from Carseland, usually below these guidelines. Counts at Bow City and Ronalane were not significantly different from one another. Although the lowest fecal and total counts were usually at either Bowness or Cochrane, results from Bowness were not significantly different from those at Bow City or Ronalane.

3.6 DISSOLVED OXYGEN

Dissolved oxygen at the Stier's monitor from November to April in 1984 to 1987 was generally well above the Alberta Surface Water Quality Objective of a minimum 5.0 mg/L at any time. However, values as

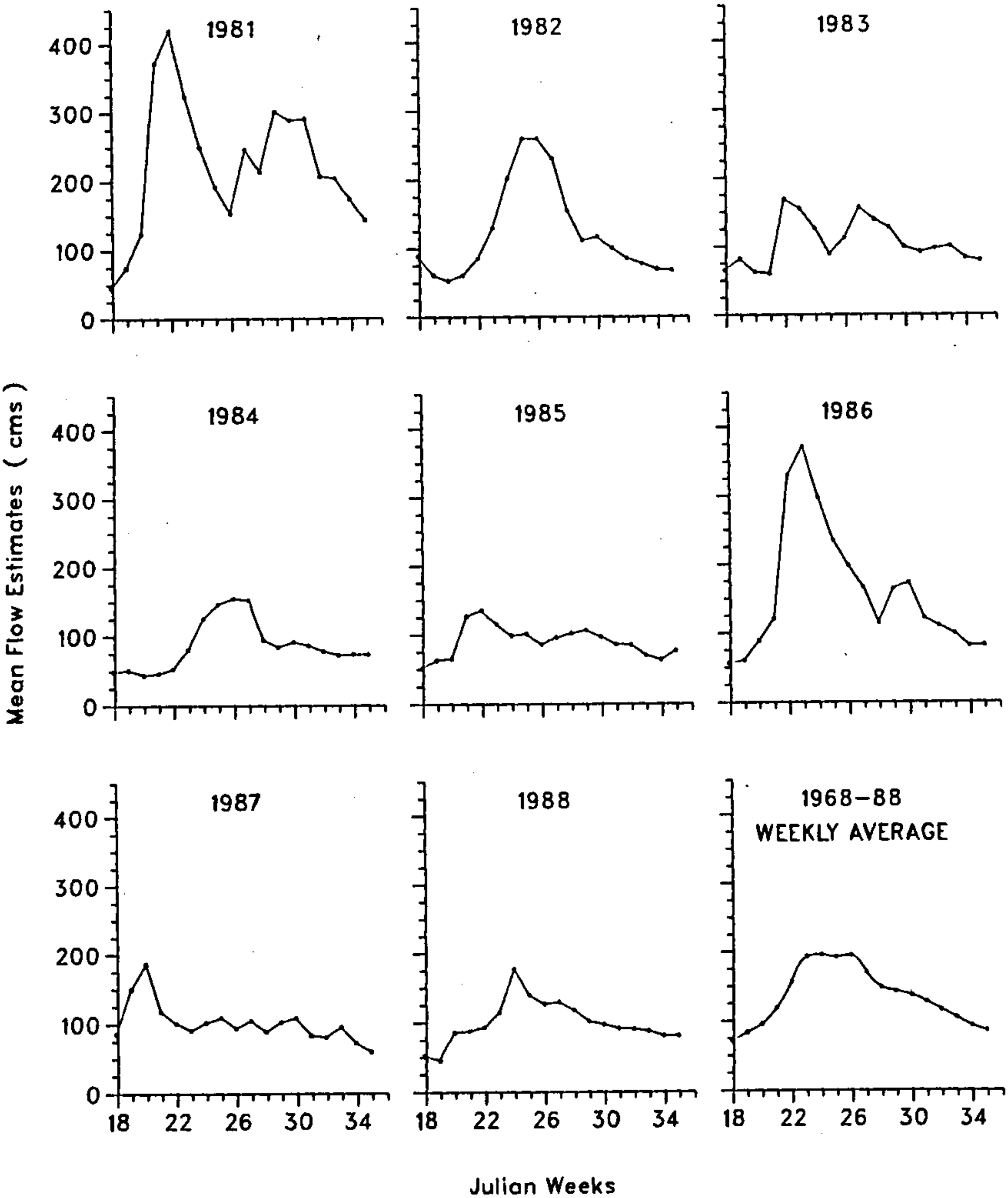


Figure 23. Weekly mean flow estimates for the Bow River downstream of the W.I.D. Weir for May to August from 1981 to 1988, and long term weekly averages from 1968 to 1988.

low as 2.5 mg/L were recorded early in the morning of May 29, 1984, and 75% of all days in May 1984 had at least one measurement under 5.0 mg/L (Figure 24). Although the lowest annual values were recorded in May, 1984, values below 5.0 mg/L were occasionally recorded during other months from May to September each year from 1984 to 1987. Furthermore, supersaturation commonly occurred in July and August, 1984 to 1987.

Some of the extreme values included in this analysis could reflect poor monitor performance, as has sometimes occurred in previous years (Cross et al. 1986). However, there is no record of significant malfunction or poor calibration at the Stier's monitor in May 1984, when the lowest values were recorded. Calibration of the monitor was verified bi-weekly using Winkler titrations (P. Schonekess, personal communication). Cross et al. (1986) also reported early morning dissolved oxygen concentration below 5 mg/L, using Winkler titration on samples from the Stier's Ranch site in July and August 1980. These results, using another method of measurement, confirm that values below the 5 mg/L guideline have occurred at this site.

Low interstitial oxygen conditions during spring may sometimes prevent or impair successful salmonid incubation downstream from Calgary. CCREM (1987) proposed a rigorous set of guidelines which include a minimum of 6.5 mg/L in interstitial water to protect cold-water fish embryos, and a minimum of 6.5 mg/L in the water column to protect adult fish. They also cite criteria that predict acute salmonid embryo mortality below a water column concentration of 6.0 mg/L. Values this low were recorded at Stier's Ranch during 1984, 1986 and 1987 in May and

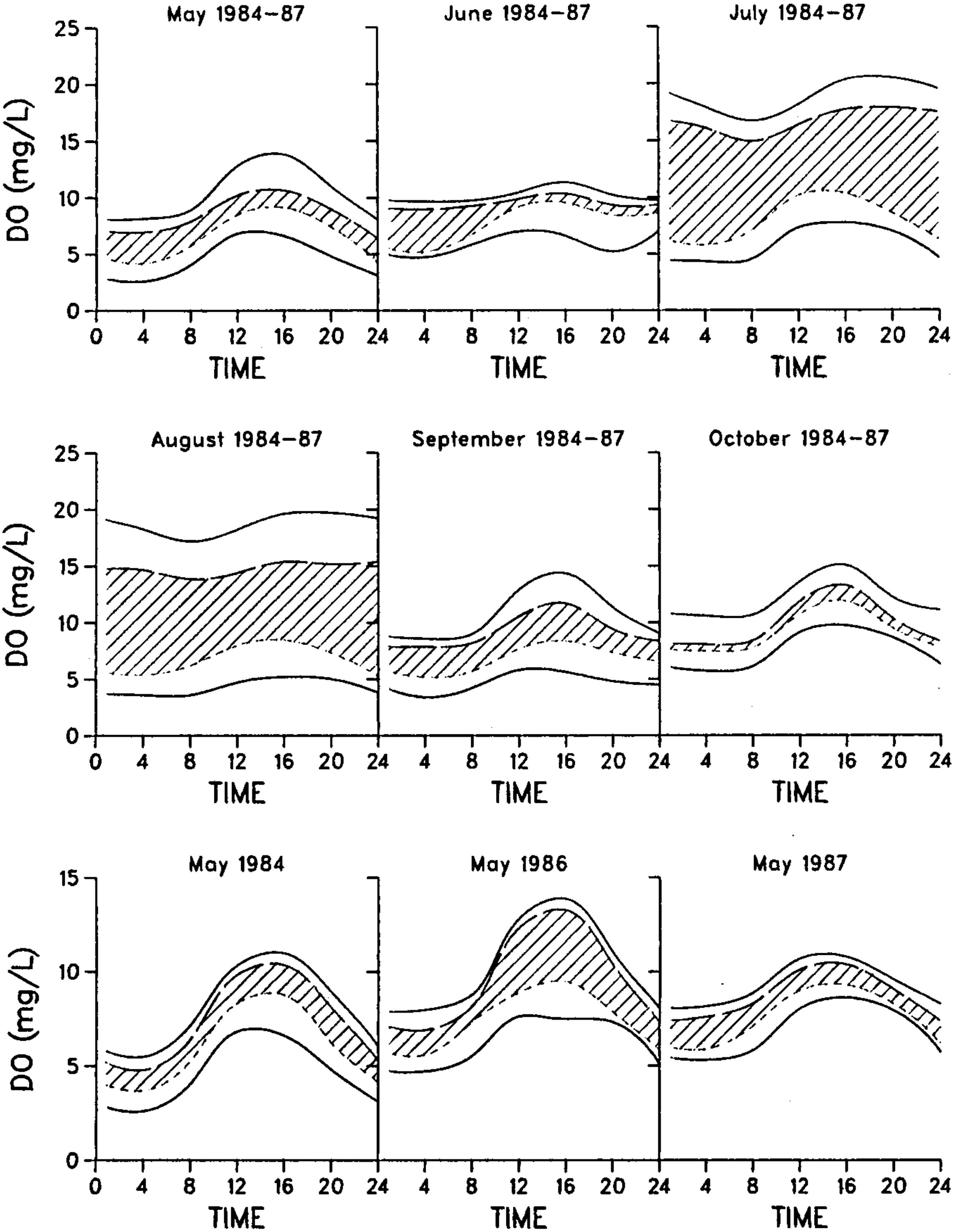


Figure 24. Diurnal oxygen curves from Stier's Ranch monitor data, May-October, 1984-87. Shading denotes all values each month between 25 and 75 percentiles. Other solid lines indicate minimum and maximum values.

June. This could account for the failure of previous surveys to document significant rainbow trout spawning in the Bow River downstream from Calgary, although such spawning occurs upstream (Sosiak 1984).

Plant respiration, unusually low flow in recent years, (Figure 23), and increased BOD from increased sewage discharge from Calgary (Figure 10) could all contribute to low dissolved oxygen values. The instream flow regime and effluent loading maintained below Calgary may no longer provide adequate protection against decreases in dissolved oxygen.

3.7 FALL MACROPHYTE BIOMASS

A significant decrease ($\underline{P} < 0.05$) in macrophyte biomass has occurred since 1983 at 6 of the 22 regularly sampled sites (Right bank sites M2, M3, M6, M7, M12; Left bank site M8) (Figures 25 and 26). Right and left bank sampling areas at each site have been treated as separate sites in this analysis. Biomass also appeared to decline at some other sites (e.g. Left bank site M6), but this was not a significant linear decrease ($\underline{P} > 0.05$). Biomass at most sites fluctuated significantly in a complex pattern from year to year. However, there was no significant change in biomass between years at Right bank site M5 and Left bank site M7.

These results suggest that macrophyte biomass has begun to decline since the installation of phosphorus removal at some, but not all, of the sampling sites. Most of the sites with a significant decline in macrophyte biomass were right bank sites; most were in the mixing zone for Calgary's sewage treatment plant effluent, which now has a lower

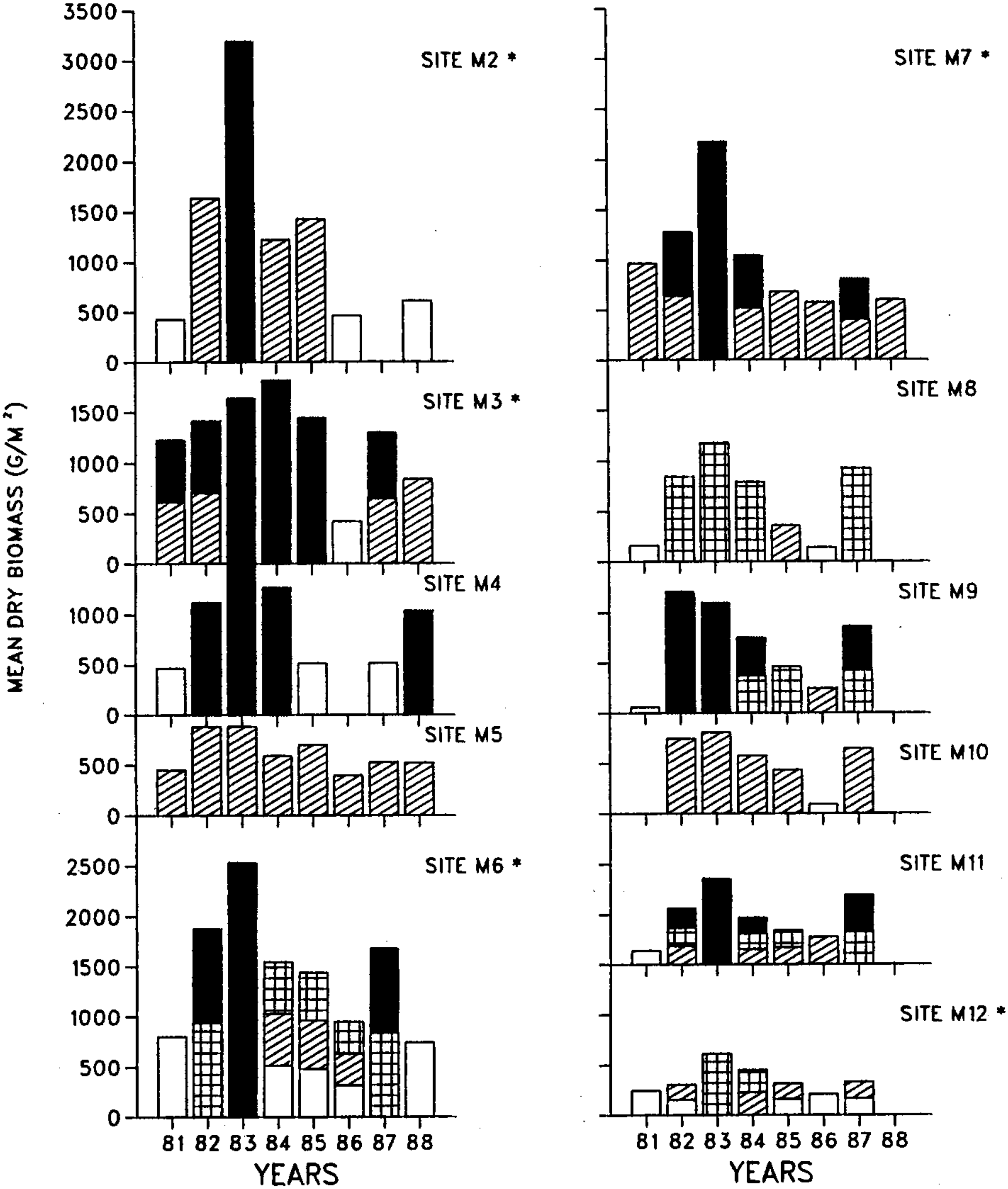


Figure 25. Mean, right–bank, macrophyte biomass in the Bow River, 1981–88. At each site, years that are not significantly different from one another have similar shading on at least part of the bar. Asterisks denote sites where biomass has declined significantly overall since 1983.

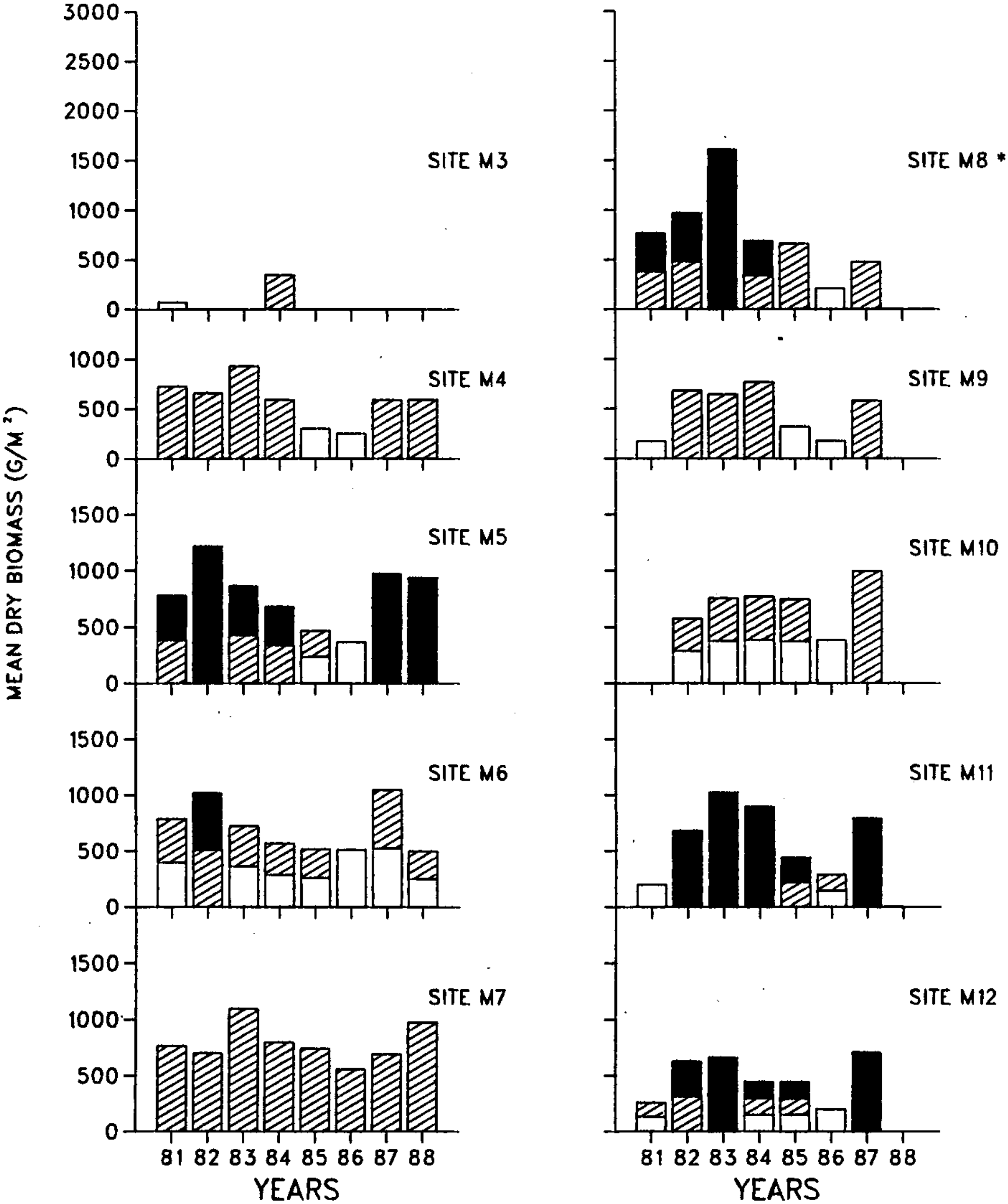


Figure 26. Mean, left-bank, macrophyte biomass in the Bow River, 1981-88. At each site, years that are not significantly different from one another have similar shading on at least part of the bar. Asterisks denote sites where biomass has declined significantly overall since 1983.

phosphorus concentration. Sites where biomass has declined may also be exposed to more vigorous scouring of sediments. Significant phosphorus deposits may still remain in sediments at more sheltered sites, those where no significant decline in biomass has occurred. Future biomass decrease at these sites may depend on further depletion of sediment phosphorus. Furthermore, real changes in biomass may have occurred at some sites, but may not be detected by this statistical analysis, given the small sample sizes collected most years. Site 10 (both right and left banks) has also been moved since the program began in 1981.

Further reductions in macrophyte biomass downstream from Calgary might be achieved using a scouring flow regime derived from an empirical relationship between fall biomass and flow. Hamilton et al. (1989) propose a modelling method to derive macrophyte scouring flows for the Bow River. The timing, duration and magnitude of flows required to scour macrophytes needs further investigation.

4.0 CONCLUSIONS

Total and dissolved phosphorus levels have been substantially reduced at sites downstream from Calgary, but remain higher at those sites than at upstream sites. In addition, since the installation of phosphorus-removal technology in 1983, there has been a small but statistically significant increase in river phosphorus concentrations at Carseland, perhaps reflecting the general increase in sewage volumes from Calgary. Silica has also declined at some sites in recent years, perhaps due to low rainfall or decreased groundwater flow. Total coliform counts increased gradually over the sampling period at Cochrane, Bowness and Bow

City, and fecal coliforms have increased at Bowness. Total and fecal coliform bacteria counts exceeded the Alberta Surface Water Quality Objective for direct contact recreation and the CCREM guideline for irrigation on most occasions at Stier's Ranch, and frequently at Carseland. Furthermore, morning dissolved oxygen measurements at the Stier's Ranch robot monitor site were sometimes below the Alberta Surface Water Quality Objective. These coliform and dissolved oxygen data may reflect a combination of lower than average river flows, effects of aquatic plant respiration on dissolved oxygen, population growth or urban development.

The biomass of epilithic algae has not significantly decreased since 1983 at sites downstream from Calgary, and has remained higher there than at Bowness. In contrast, fall macrophyte biomass has decreased significantly at some, but not all sampling sites.

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