WATER QUALITY SAMPLING OF THE LITTLE BOW RIVER AND MOSQUITO CREEK IN 1999

Prepared by:

Al Sosiak, M.Sc.
Limnologist

Water Sciences Branch
Water Management Division
Natural Resources Service

November, 2000

W0005

Pub. No: T/568
ISBN: 0-7785-1408-0 (Printed Edition)
ISBN: 0-7785-3032-9 (On-Line Edition)
Web Site: http://www3.gov.ab.ca/env/info/infocentre/publist.cfm

Any comments, questions, or suggestions regarding the content of this document may be directed to:

Environmental Monitoring and Evaluation Branch
Alberta Environment
10th Floor, Oxbridge Place
9820 – 106th Street
Edmonton, Alberta T5K 2J6
Phone: (780) 427-6277
Fax: (780) 422-6712

Additional copies of this document may be obtained by contacting:

Information Centre
Alberta Environment
Main Floor, Great West Life Building
9920 – 108th Street
Edmonton, Alberta T5K 2M4
Phone: (780) 944-0313
Fax: (780) 427-4407
Email: env.infocent@gov.ab.ca

EXECUTIVE SUMMARY

A water quality sampling program was initiated by Alberta Environment in the Little Bow River and Mosquito Creek basins in 1999. This program was intended to document the water quality impacts of agriculture and municipal wastewater discharge in these basins, and identify the most important loading sources (critical areas) for phosphorus, nitrogen, and total suspended solids (TSS). This information will be used by Alberta Environment and other stakeholders to develop a water quality protection plan for the proposed Little Bow River Reservoir. In their decision report for this project, the Joint Review Panel convened by the Natural Resources Conservation Board and the Canadian Environmental Assessment Agency (NRCB/CEAA Joint Review Panel) decided that the reservoir should be maintained in a mesotrophic state in order to provide the multi-purpose benefits that it was designed to achieve.

Additional water quality sampling has been conducted in 2000 throughout both the Little Bow River and Mosquito Creek basins and will be reported in the future. This new work was designed to confirm the location of the most important sources of nutrients and other constituents identified in 1999.

Mosquito Creek Basin: Detailed Results

- During the open water season in 1999 (March 24-September 1), the Nanton Waste Water Treatment Plant (WWTP) effluent was the largest point source of total dissolved phosphorus (TDP) and nitrite+nitrate entering either basin, and resulted in excessive growth of periphyton immediately downstream from Nanton. No adverse impact of this effluent on TSS, coliforms, dissolved oxygen (DO) or other forms of nitrogen was documented.

- Women's Coulee (formally Squaw Coulee), McMillan Creek, and other sources along Mosquito Creek between Women's Coulee and 104 Street also contributed significant loading of TDP, total Kjeldahl nitrogen (TKN) and total nitrogen (TN). McMillan Creek also contributed large amounts of nitrite+nitrate and ammonia to Mosquito Creek.

- The greatest total phosphorus (TP) loading to Mosquito Creek, 43% of the TP loading in this basin, appeared to occur between sites at Township Road 154 and Highway 529. However, most of this TP was in a particulate form that is less biologically available for uptake by aquatic plants than TDP. The high TP loading estimate for this reach may partially reflect a difference in sampling frequency between these two sites rather than a genuine difference in loading. Otherwise all nutrients generally declined in concentration along lower Mosquito Creek.

- Total dissolved phosphorus at three sites on Mosquito Creek has declined during the time period 1982-1999.

- Although various livestock operations are located in the Nanton Creek basin, these operations contributed relatively little phosphorus and nitrogen to this tributary of Mosquito Creek during 1999. Mosquito Creek contributed 65% of the watershed TP loading to the future Little Bow River Reservoir site, and 37% of the TDP loading during March 24-September 1, 1999.

- Both *E. coli* and fecal coliforms frequently exceeded water quality guidelines for contact recreation and irrigation at the site on Mosquito Creek downstream from Highway 534 at 104 Street. Coliforms at other sites exceeded guidelines infrequently.

- Women's Coulee contributed more suspended sediment than any other source along Mosquito Creek. Potential sources of TSS along Women's Coulee include bank erosion near the Old Women's Buffalo Jump, and other erosion further downstream. Diffuse runoff or other sources that have not been identified also contributed TSS to Mosquito Creek near Nanton in 1999.

- Of the variables that were tested, only turbidity has increased at three sites on Mosquito Creek over the time period 1982-1999. DO was above the water quality guideline at all sites on Mosquito Creek during the day, but occasionally declined below this guideline at night at Highway 529.

- Enhanced phosphorus removal will reduce dissolved phosphorus loading from the Nanton WWTP by 78-85%, and reduce downstream concentrations by about 65%. This reduction would help meet the NRCB/CEAA Joint Review Panel recommendation to reduce phosphorus loading from Mosquito Creek, and should be sufficient to reduce periphyton biomass downstream from Nanton.

<u>Little Bow River: Detailed Results</u>

- The largest sources of TP loading to the Little Bow River occurred between Highway 2 and 658 Avenue sites. The most important sources of TDP, ammonia, TKN and TN also appeared to occur along the same reach, between 168 Street and 658 Avenue. However, additional nonpoint sources contributed appreciable TDP, especially near the reservoir FSL (Full Supply Level) site, and contributed ammonia to the reach ending at Highway 534. The greatest loading of nitrite+nitrate occurred between High River and Highway 2. TP concentration declined along the Little Bow River at downstream sampling locations.

- Frank Lake discharged briefly in 1999 and was not a significant source of nutrients. A separate mitigation plan to reduce long-term nutrient discharges from Frank Lake is under development.

- The largest sources of TSS along the Little Bow River occurred between Highway 2 and the site upstream from the Frank Lake outlet. Potential sources of TSS along the Little Bow River included bank erosion at two sites near Highway 2.

- High levels of periphyton biomass were documented along the Little Bow River at the sites at Highway 2 and downstream from the future reservoir. Elevated TSS, which would reduce light penetration to the riverbed, may have inhibited periphyton growth in other areas of this river.

- Fecal coliforms exceeded water quality guidelines for contact recreation and irrigation only at the site on the Little Bow River at 658 Avenue. The water quality guideline for *E. coli*, the preferred microbiological indicator, was rarely exceeded at any site.

- DO was above the water quality guideline at all sites on the Little Bow River during the day but often fell well below the guideline at night at Highway 533, due to nocturnal respiration by macrophytes.

- The concentration of TP and ammonia declined slightly at one location during 1982-99, but otherwise no significant changes over time were detected at two sites on the Little Bow River.

ACKNOWLEDGEMENTS

I thank all technical and professional staff of Alberta Environment who assisted in the sampling program and report preparation. Bridgette Halbig (Water Sciences Branch, AENV) assisted in data compilation and report preparation. Steven Ellert (Natural Resources Service, Prairie Region) prepared the site location and loading figures. Review comments on the draft report were provided by Dave Trew (Water Sciences Branch), Alan Pentney (Environmental Services, Prairie Region) and John Englert (Alberta Public Works, Supply and Services).

I also thank Shirley Pickering of the Upper Little Bow Water Users Association and Diana Andrews of the Lower Mosquito Creek Water Users Association for their comments on the sampling design and assistance in site selection.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

The Alberta government will construct the Little Bow River Reservoir at the confluence of the Little Bow River and Mosquito Creek. The Joint Review Panel convened by the Natural Resources Conservation Board and the Canadian Environmental Assessment Agency (NRCB/CEAA Joint Review Panel) (Application #9601) has approved this project subject to certain requirements (NRCB 1998). These requirements include a plan to reduce livestock disturbances to riparian habitats and water quality along project-related water bodies. Furthermore, the Panel recommended that a Little Bow River Reservoir Water Quality Protection Plan be prepared immediately and implemented before the reservoir is filled. The NRCB/CEAA Joint Review Panel determined that these plans are needed to ensure that the multi-purpose objectives of the proposed Little Bow River Reservoir are realized. In particular, the Panel recommended that a watershed initiative should be implemented, with the goal of reducing phosphorus loading to the new reservoir and achieving mesotrophic water quality in the Little Bow River Reservoir.

A program intended to reduce phosphorus loading to the proposed reservoir would likely involve improvements in wastewater treatment at Nanton and improvements in riparian zone, livestock and crop management. Before implementing these changes, critical areas that contribute the bulk of the phosphorus loading should first be identified. Identification of these areas will ensure that available resources are used to reduce phosphorus loading from the most important sources.

An intensive sampling program designed to document the water quality impacts of agriculture and municipal wastewater discharge in the Little Bow River and Mosquito Creek basins was conducted by the Water Management Division, AENV in 1999. This report presents the results of the first spring and summer season of sampling in these basins. The objectives of this report are as follows:

a) Document the concentration of phosphorus, nitrogen, coliforms, suspended sediments, dissolved oxygen and periphytic algae at sites throughout these basins during the spring and summer (March 24-September 1, 1999), prior to any mitigation program. Periods of high runoff during spring and summer are probably the period of greatest movement of these constituents into the Little Bow River and Mosquito Creek;

b) Where feasible, estimate the mass flux of phosphorus, nitrogen and total suspended sediments (TSS). Mass flux calculations estimate the total mass of material moving past a site during the period of sampling. These estimates should provide a better indication of aquatic impact than comparisons of concentration, which fluctuate with flow;

c) Use concentration and mass flux to identify the most important loading sources (critical areas) for phosphorus, nitrogen, and TSS;

d) Evaluate the impact of the current discharge from the Nanton wastewater treatment plant (WWTP) on water quality in Mosquito Creek, and changes in downstream concentration that would be expected if the Nanton wastewater is reduced to 0.7 mg/L total phosphorus (TP) (Pentney 1999) by enhanced phosphorus removal;

e) Statistically-evaluate changes in concentration over the period of water quality sampling (1982-99). This analysis was designed to determine whether water quality in these basins has changed in recent years.

2.0 METHODS

2.1 SAMPLING SITES AND ANALYSIS

Samples were collected for water chemistry and coliform counts at the sites listed in Figure 1. Composite TP samples, consisting of aliquots taken over the entire day every three hours, were collected by automated samplers (ISCO 6700) from March 24 - September 1, 1999 (Table 1).

Other variables (except coliforms) were grab sampled weekly at automated sampler sites throughout this time period, thereafter these sites were sampled once per month year-round. Coliforms were sampled weekly during the spring but otherwise once per month. Except as noted below, other sites upstream from the reservoir in Figure 1 were sampled for nutrients and fecal coliforms and *E. coli* weekly during spring runoff (March 24-June 11, 1999), but were otherwise sampled monthly year-round. Three automated sampling sites (AB05AC0160, AB05AC0066, AB05AC0100) and the Little Bow River at Carmangay (AB05AC0190) (Figure 1) were also sampled monthly for the complete list of variables monitored at the provincial LTRN/Index sites, except for pesticides and priority pollutants. Hydrolab meters were used to measure dissolved oxygen, pH, conductivity and temperature at each site on all sampling days. Datasondes were used to record the same variables hourly during June 15-August 31 at the sites indicated above and in the Little Bow River immediately downstream from the proposed reservoir.

Sites in Table 2 had intermittent flow, and were occasionally sampled ($N \leq 3$) during periods of high runoff.

Flow gauges were operated throughout the sampling period and used to provide daily flow estimates for all sites with automated samplers, except for the sites downstream from Nanton (site AB05AC0150) and downstream from the Cayley Hutterite Colony (AB05AC0116). Flow at the former site was estimated by adding daily mean flows at sites AB05AC0140 and AB05AC0130. A flow gauge was also operated at Women's Coulee at 690 Avenue near Mosquito Creek (AB05AC0120), which did not have an automated sampler.

Town of Nanton staff provided chemical and flow measurements on the WWTP final effluent. Otherwise all chemical analysis was by Maxxam Analytics Inc., and the Provincial Health Laboratory for Southern Alberta provided coliform counts. Split samples of the WWTP final effluent were analyzed at Maxxam Analytics Inc. once per season, to provide quality assurance on the Nanton chemical analysis.

To permit numerical analysis, values less than detection limits were replaced by values one-half the detection limit. Data were then compared to the Alberta Water Quality Guidelines (ASWQG) and the Canadian Environmental Quality Guidelines (CEQG) (AENV 1999, CCME 1999). Differences in median concentration upstream and downstream of Nanton and between individual years were then tested using a Kruskal-Wallis one-way analysis of variance ($\alpha = 0.05$), followed by an Experimentwise Kruskal-Wallis Multiple Comparison Test.

Variables with at least four years of data during the 1982-99 period were then tested for monotonic trends (gradual increasing or decreasing concentration). Variables were first tested with the Kruskal-Wallis test for seasonality. Variables exhibiting significant seasonality were tested for monotonic trends using the Seasonal Kendall Test, with (SKWC) or without (SKWOC) correction for significant serial correlation, using procedures in the computer program WQHYDRO (Aroner 1994). Data that did not display significant seasonal variation were tested for monotonic trends using the Mann-Kendall test. As recommended by Ward et al. (1990), a 0.10 level of statistical significance was used to assess the results of all trend tests.

2.2 CURRENT AND PREDICTED MASS LOADING

For each site, the mass loading of each variable was estimated by six different methods using the computer program FLUX 4.5 (Walker, W.W. 1996). The method that produced the lowest coefficient of variation was selected for further analysis in each case. Different methods were sometimes selected for different variables because these methods varied in their accuracy depending on the relationship between flow and concentration for each variable (Walker, W.W. 1996). Whenever there were sufficient measurements, data were stratified by season or flow to reduce error and bias in the predictions. The loading of nutrients and TSS to each reach between sampling sites was estimated by subtracting mass flux at the upstream end of the reach from mass flux at the downstream end. To estimate nonpoint source (NPS) mass loading directly to various reaches, mass from tributaries and the Nanton WWTP effluent (only downstream from Nanton, site AB05AC0150) were subtracted from mainstem loading estimates. Estimates with a coefficient of variation < 0.2 were not considered suitable for mass balance analysis (Walker, W.W. 1996).

It was not possible to estimate historic mass loading to most sites prior to 1999. Most sites did not have flow measurements prior to 1999, and mass flux could not be calculated. Furthermore, it was not possible to derive acceptable loading estimates for a few variables at some sites using 1999 data due to unexpectedly high variance.

TDP following enhanced phosphorus removal was estimated by multiplying 0.700 mg/L by the ratio of TDP:TP in the final effluent in 1999 (4.4/5.2). Phosphorus loading from the Nanton WWTP following enhanced phosphorus removal was then estimated by substituting a constant 0.700 mg/L TP and 0.592 mg/L (ratio times 0.7 mg/L) total dissolved phosphorus (TDP) into the FLUX file for the Nanton WWTP in 1999, and assuming the same flow rates for the final effluent.

Mass loading from nonpoint sources near Nanton (or channel uptake, if negative) was estimated by subtracting all measured loading from the difference between sites upstream and downstream from the Nanton WWTP, as follows:

Diffuse runoff/channel uptake = loading (site AB05AC0150) - loading (AB05AC0140) - loading (Nanton WWTP) - loading (AB05AC0130)

Changes in fully-mixed concentration downstream from the Nanton WWTP following enhanced phosphorus removal were estimated by adding the instantaneous mass contributed by the Nanton WWTP, Nanton Creek and Mosquito Creek upstream from Nanton, and dividing the total mass by the combined flow each day.

3.0 RESULTS AND DISCUSSION

3.1 PHOSPHORUS

Phosphorus and nitrogen are essential plant nutrients. Excessive phosphorus can cause an increase in the growth of aquatic plants, which can result in low levels of dissolved oxygen through plant respiration at night, impede water flow and affect aesthetics. Total phosphorus includes both particulate and dissolved forms of this nutrient. Total dissolved phosphorus is a better indicator of the amount of phosphorus available for aquatic plant growth than total phosphorus (Bradford and Peters 1987).

Mosquito Creek Basin

The concentration of TP usually exceeded the Alberta Surface Water Quality Guideline (ASWQG) of 0.05 mg/L in Mosquito Creek both upstream and downstream from Nanton (Figure 2). This variable was significantly higher downstream from Nanton than immediately upstream in 1999. However, relatively high concentrations of TP were also measured in Mosquito Creek at the other two sites immediately upstream from Highway 2 (Figure 2) - downstream from the Cayley Hutterite Colony, downstream from Highway 534 at 104 St. - and also at Highway 529.

Mass flux estimates for each sampling site during March 24-September 1 have been compiled in Table 3. To help identify the most important sources of each constituent, the changes in mass between each adjacent pair of sampling sites have been plotted in Figures 3, 5, 11, 16, 17, 18, and 27. The ten greatest loadings in both basins have been assigned ranks in these figures. Note that tributary and effluent loading has been subtracted from the difference in mass between sites, to estimate direct contribution from NPS loading along each reach.

High TP loading from McMillan Creek, Women's Coulee and nonpoint source loading along Mosquito Creek appeared to account for increased TP levels at sites between Highway 534 and Highway 2 (Figure 3). Although the largest TP loading over the entire basin occurred in the reach ending at Highway 529 (Figure 3, Table 3), 86.5% of the TP load at this site was particulate phosphorus, which is less biologically available for uptake by aquatic plants than TDP. The large TP loading to this site could reflect bank erosion, or resuspension of TP from the creek channel from sources further upstream. Interestingly, an equivalent mass of TP settled or was removed by biological uptake between Highway 529 and the site near Reservoir FSL (Figure 3) in 1999.

The high TP loading estimate for the reach ending at Highway 529 may partially reflect a difference in sampling frequency between that site and both sites immediately upstream (Table 1) rather than a genuine difference in loading. Automated samplers used at sites such as Highway 529 would have sampled storms and other runoff events between sampling trips more effectively than the less frequent grab sampling used at the two upstream sites. Accordingly, mass flux may have been under-estimated at any of the grab sampling sites.

The concentration of TDP was also significantly higher downstream from Nanton than immediately upstream in 1999 (Figure 4). The Nanton WWTP contributed the highest TDP loading in both basins (Figure 5). The next highest TDP loading occurred at Mosquito Creek downstream from Highway 534 at 104 Street, followed by Women's Coulee near Cayley and McMillan Creek near the mouth (Figure 5). Dissolved phosphorus concentrations declined and the TDP mass decreased at Mosquito Creek at Township Road 160, and each site further downstream in Mosquito Creek, presumably as a result of biological uptake and sedimentation.

Although the Nanton Creek watershed contains two large feedlots, and various smaller livestock operations, this tributary of Mosquito Creek contributed relatively small TP and TDP loading to Mosquito Creek. It represented only 2.0 and 3.3% respectively, of the total loading to both basins upstream of the proposed reservoir. Cumulative TP loading to each site along Nanton Creek are in Table 3, and the net contribution to each reach, or loss of material, are illustrated in Figure 3. Phosphorus levels were much higher in McMillan Creek than in Nanton Creek (Figure 6 and 7). Loading from Springhill Creek (TP: 41.8, TDP: 12.5 kg) was similar to the change in mass in Nanton Creek upstream and downstream from Tophat Feeders (TP: 39.4, TDP: 15.1 kg) (Figure 3). This suggests that the two livestock operations had similar small impacts on phosphorus levels in Nanton Creek during the runoff that occurred in 1999.

Mosquito Creek contributed 1798 kg, or 65% of the watershed TP loading from both streams to the future reservoir site, but only 284.6 kg (37%) of TDP loading during March 24-

September 1, 1999. This analysis is based on loading estimates from the final sites on lower Mosquito Creek and the Little Bow River, at the Reservoir FSL boundary (Figure 1, Table 3).

Little Bow River

Total phosphorus concentration in the Little Bow River increased greatly from 168 St. to 658 Avenue and usually exceeded the ASWQG of 0.05 mg/L in this reach (Figure 8). The greatest increase in TP mass occurred in the reach ending at 658 Avenue, but appreciable TP loading to the Little Bow River also occurred in the other two reaches between Highway 2 and 658 Avenue. A large increase in TDP mass, second largest over both basins, occurred at the 168 St. site (Figure 5), and median TDP concentration increased most between 168 Street and 658 Avenue (Figure 9). These results suggest that the largest sources of phosphorus loading along the Little Bow River occurred in the three reaches upstream from 168 Street, the Frank Lake outlet and 658 Avenue in 1999. Although Frank Lake discharged regularly during the spring and summer of 1996, 1997 and 1998, very low discharge ($\leq$0.002 m^3/s) from Frank Lake was measured during April 1-12, 1999. There was otherwise no significant flow from Frank Lake observed during regular visits to the Basin 3 outlet in 1999. It was not possible to derive acceptable TDP loading estimates for the sites on the Little Bow River upstream from Frank Lake or at 658 Avenue, due to high variance during spring runoff.

Net deposition of TP occurred at each site downstream from 658 Avenue, and 1077.3 of the 1454.4 kg entering the river upstream from the proposed reservoir was deposited over all the study reaches (Figure 3). However, the TP mass in the Little Bow River at Reservoir Full Supply Level (FSL) (959.7 kg) still exceeded the mass diverted from the Highwood River by 377 kg (65%).

TP and TDP levels were relatively high in the three samples that were collected in Little Bow Creek, which receives urban runoff from High River. However, TP and TDP concentrations changed little downstream from High River (Figure 8 and 9), and TP mass declined (Figure 3). This implies that urban runoff and other sources had little impact on phosphorus levels in the Little Bow River in 1999.

TP concentrations and mass decreased at the two sites along the Little Bow River downstream from 658 Avenue, presumably as a result of biological uptake and net sedimentation. Unlike the Mosquito Creek basin, TDP concentration and mass continued to increase gradually along the lower basin at each site downstream from 658 Avenue. This finding suggests additional smaller sources of TDP along the lower basin. The largest increase in TDP concentration and mass at these lower sites occurred at the site near Reservoir FSL.

3.2 NITROGEN

Nitrogen is another essential nutrient for aquatic plants. Excessive nitrogen can also lead to increased growth of aquatic plants, and the same concerns associated with phosphorus. In addition, high levels of nitrate can impair drinking water quality; ammonia and nitrite may be toxic to aquatic life. Total nitrogen analysis measures all forms of nitrogen. Nitrite is typically low in surface waters, except below discharge points for wastewater treatment plants. Nitrite and nitrate are often measured together. Total Kjeldahl nitrogen (TKN) is a measure of ammonia and organic nitrogen. Nitrite, ammonia, and TKN are often high in wastewater.

Mosquito Creek Basin

Median nitrite+nitrate concentration increased greatly at Nanton, and was highest in Mosquito Creek immediately downstream from the town (Figure 10). The Nanton WWTP effluent contributed the largest mass loading of nitrite+nitrate to Mosquito Creek and the Little Bow River (Figure 11). Like dissolved phosphorus, nitrite+nitrate declined in Mosquito Creek downstream from Township Road 160. The concentration and mass loading of all four forms of nitrogen (nitrite+nitrate, ammonia, TKN, TN) from McMillan Creek was also relatively high (Figures 11, 12, 13, 14, 15, 16, 17, 18). The concentration of TKN and TN was moderately high in Women's Coulee (Figures 19, 20). However, mass loading of TKN and TN were high at Women's Coulee at 690 Avenue near Mosquito Creek, and Mosquito Creek downstream from Highway 534 at 104 Street (with loading from Women's Coulee excluded)(Figures 17, 18). This analysis suggests that, except for ammonia, the Nanton WWTP effluent and activities upstream from sites on McMillan Creek, Women's Coulee and Mosquito Creek (downstream from Highway 534 at 104 Street) were the major sources of nitrogen in the Mosquito Creek basin.

Ammonia loading to Mosquito Creek followed a different pattern than other forms of nitrogen. Ammonia concentrations were moderately high and occasionally exceeded the new CEQG guidelines for this variable (CCME 1999) both upstream and downstream from Nanton (Figure 21). However, there was no significant change in ammonia concentration in Mosquito

Creek at Nanton. Like nitrite+nitrate, ammonia levels gradually declined downstream from Township Road 160, presumably due to nitrification or biological uptake. Except for McMillan Creek and an unidentified loading source near Nanton, ammonia loading to Mosquito Creek was relatively low compared to loading to the Little Bow River (Figure 16).

The loading and concentration of each form of nitrogen was much higher in Springhill Creek than at the site on Nanton Creek downstream from Tophat Feeders (Figures 11, 12, 13, 14, 15, 16, 17, 18). This implies that the feedlot on Springhill Creek had a greater influence on nitrogen levels than the other feedlot. However, as for phosphorus, Nanton Creek contributed relatively small nitrogen loading to Mosquito Creek. Loading of nitrite+nitrate could not be estimated at Nanton Creek at Highway 2, but the mass of ammonia, TKN and TN at Nanton Creek near the mouth was at most 3.6% of the loading from all sources in both basins (Table 3). These findings imply that some intensive livestock operations in these watersheds had a relatively small impact on nutrient levels, at least under the conditions that occurred during the sampling program in 1999.

McMillan Creek was sampled occasionally ($N = 3$) at Meridian Street (Figure 1) in order to assess whether activities upstream from this street had a greater impacts than sources further downstream. Levels of nitrite+nitrate and ammonia in McMillan Creek at Meridian Street were higher than at the routine sampling site near the mouth (Figures 12, 13). These findings suggest that the major nitrogen loading sources on McMillan Creek were upstream from Meridian Street.

Little Bow River

Within the Little Bow River basin upstream from Mosquito Creek, the concentration of most forms of nitrogen (ammonia, TKN, TN) was highest from 168 Street to Highway 534 (Figure 22, 23, 24), and near Reservoir FSL. However, individual forms of nitrogen varied somewhat in the pattern of concentration and mass. The largest increase in the mass of TKN and TN along the Little Bow River occurred at 168 Street and upstream from the outlet of Frank Lake (Figure 17, 18), respectively. The Highwood River also contributed a large mass of TKN and TN to the headwaters of the Little Bow River. Although ammonia mass increased substantially at these same sites, the highest concentrations occurred at Highway 534, and the largest change in ammonia mass occurred between 658 Avenue and Highway 534 (Figure 16).

This suggests that some source contributed appreciable ammonia between these two sites. As with phosphorus, these findings suggest that the most important sources of ammonia, TKN and TN appeared to be from 168 Street to 658 Avenue in 1999, but additional sources contributed ammonia at sites further downstream.

Nitrite+nitrate concentration and mass followed a somewhat different spatial pattern than other forms of nitrogen in the Little Bow River. Median nitrite+nitrate concentrations were highest at Highway 2 and 168 Street, and declined somewhat further downstream (Figure 25). The greatest increase in concentration and mass of nitrite+nitrate occurred between the site at the Highwood Diversion in High River and Highway 2 (Figure 11). This implies that some unidentified source in this reach contributed appreciable nitrite+nitrate in 1999. Possible sources could include the Little Bow Creek, (Figure 1, 12), agricultural sites near High River, or urban runoff which is sometimes high in nitrogen. Nitrite+nitrate concentration was relatively high in a few samples ($N = 3$) collected from the Little Bow River at the north crossing of Highway 2A, which is upstream from the confluence with the Little Bow Creek, and may be influenced by urban drainage from High River (Figure 1, 25).

3.3 TOTAL SUSPENDED SOLIDS

Total suspended solids is a measure of the total amount of suspended particles such as fine silt and clay, organic matter and small organisms in water. Suspended solids can carry nutrients and contaminants, are sometimes aesthetically undesirable and can kill aquatic life when they settle on a stream bottom. Turbidity is an indirect measure of suspended solids and clarity. Turbidity meters measure the degree to which light is scattered and absorbed as it passes through a sample.

Mosquito Creek Basin

Median total suspended solids (TSS) concentration and mass in Mosquito Creek, measured as non-filterable residue, peaked below Women's Coulee and gradually declined with settling at sites further downstream (Figure 26, 27, Table 3). Similarly, turbidity peaked below Women's Coulee and declined greatly at sites further downstream (Figure 28). Although the TSS loading estimate for the Women's Coulee site had a low coefficient of variation (CV = 0.080), which suggests it is accurate, TSS samples were not collected at this site for the entire summer, only weekly during March 24 to June 8. TSS mass flux estimates at this site should be confirmed by additional sampling over the entire season. Other TSS loading to Mosquito Creek is suggested by the increased range of TSS concentration at Nanton and upstream from Highway 529, but the concentration of TSS in Mosquito Creek did not change significantly at Nanton. It should be noted that mass flux estimates for TSS with acceptable accuracy could not be estimated at two sites in the Mosquito Creek basin (Table 3).

Bank erosion was found during an aerial survey in February 1, 1999, along the stream in Women's Coulee, just downstream from the end of the canal at Secondary Road 540, and may partially account for the high TSS in Women's Coulee at 690 Avenue. An inspection of this area of erosion during high flows on May 12, 2000 determined that banks are being undercut (Figure 29) and are crumbling. The owner of the adjacent land indicated that this undercutting has caused the channel to move in recent years. The channel bed appeared to consist of soft clay in this reach, which may erode during higher flows. Bank erosion was apparent over about 500 m of stream that extends from a culvert opposite owner's residence (Figure 30), to about 100 m downstream from the Old Women's Buffalo Jump (Figure 31). Additional bank erosion occurs immediately downstream from the sampling site on Women's Coulee at 690 Avenue (Figure 1). TSS and turbidity were also relatively high in MacMillan Creek near the mouth, and Springhill Creek (Figure 32, 33).

Little Bow River

The concentration and mass of TSS in the Little Bow River increased greatly at both 168 Street and the site upstream from the Frank Lake outlet (Figure 27, 34). These findings suggest that significant bank erosion or other sources of TSS occur in the reaches upstream from these two sites. Similarly, turbidity was high at sites at 168 Street and upstream from the Frank Lake outlet, but the median turbidity level remained high at 658 Avenue (Figure 35).

Two potential sources of TSS have been identified along the Little Bow River between Highway 2 and 168 Street. There was significant bank erosion at two locations (N 50° 32' 35.9" W 113° 48' 22.7", Figure 36)(N 50° 31' 26.2", W 113° 47' 59.6", Figure 37). In 1999, TSS declined gradually along the Little Bow River downstream from the Frank Lake outlet. Both TSS mass and concentration at the site near Reservoir FSL were lower than levels upstream, but still exceeded mass and concentration at High River (Figure 34, Table 3).

3.4 COLIFORMS

Fecal coliforms are found in the intestinal tract of warm-blooded animals. They are a useful indication of contamination from sewage or manure. However, some fecal coliform tests will also detect bacteria that are not restricted to animal fecal contamination. *E. coli* is one species of fecal coliform bacteria, and is generally considered the preferred indicator for fecal contamination. Fecal coliforms and *E. coli* can affect the suitability of water for irrigation, contact recreation and drinking water. The tentative irrigation guideline for fecal coliforms is intended to protect consumers of irrigated produce that is typically eaten raw.

Mosquito Creek Basin

There was no significant change in *E. coli* or fecal coliform counts in Mosquito Creek downstream from Nanton, compared to upstream (Figure 38 and 39). Far greater coliform counts were found at sites immediately upstream from Nanton. Both *E. coli* and fecal coliforms exceeded the respective CEQG guidelines for contact recreation (resampling criterion) and irrigation at the site downstream from Highway 534. Fecal coliforms alone frequently exceeded CEQG guidelines at some sites on Nanton Creek (Figure 40 and 41).

Little Bow River

Along the Little Bow River, both *E. coli* and fecal coliform counts peaked at the site at 658 Avenue and thereafter decreased greatly (Figure 42, 43). Only fecal coliform counts frequently exceeded the CEQG guidelines and only at the 658 Avenue site (Figure 43). *E. coli*, the preferred indicator of water quality for contact recreation, only exceeded the CEQG guideline on rare occasions at 658 Avenue (Figure 42). It should be noted that coliform samples were collected weekly during the spring (until June 7), but only monthly during the summer months when contact recreation would be more apt to occur.

3.5 PERIPHYTIC ALGAL BIOMASS

Periphytic chlorophyll *a* is an indicator of the biomass of algae growing on stones or similar objects on a streambed. It is a useful measure of the level of nutrient enrichment in a stream.

Mosquito Creek Basin

Periphytic biomass, as epilithic chlorophyll *a*, increased greatly in Mosquito Creek downstream from Nanton (Figure 44). Biomass there alone greatly exceeded 150 mg/m^2 over the season, above which periphyton biomass can be considered a nuisance (Welch et al. 1988). As discussed below, the lush growth of periphyton downstream from Nanton is probably caused by dissolved nutrients from the Nanton WWTP.

Little Bow River

Along the Little Bow River, epilithic chorophyll *a* exceeded 150 mg/m^2 only at Highway 2 and downstream from the proposed reservoir (Figure 45). High periphytic biomass at these locations could reflect the stimulating effects of dissolved nutrients, and increased light where turbidity is lower. Nitrite+nitrate levels first increased greatly along the Little Bow River at Highway 2. Although phosphorus and nitrogen concentrations were lower downstream from the reservoir than in some reaches, dissolved phosphorus levels there were well above concentrations required for excessive periphytic biomass in the Bow River (Sosiak 2000). TSS and turbidity were relatively low at Highway 2 and downstream from the proposed reservoir (Figure 34, 35).

3.6 AQUATIC MACROPHYTES

Aquatic macrophytes are large aquatic plants of all types. They are another useful indicator of the level of nutrient enrichment in a stream. Aquatic macrophytes can cause depletion of dissolved oxygen, and can clog water withdrawal intakes. Only macrophytes that are totally submerged were sampled in the Little Bow River in 1999.

Macrophyte biomass was lower in the Little Bow at Carmangay in 1999 than in 1990, but results for the two years were similar at Highway 533 (Table 4). Mean TDP and nitrite+nitrate concentrations during the open water season in the Little Bow River at Carmangay (EMA 1995) were much higher than in 1999. This change in nutrient levels, or other factors, could account for observed change in macrophyte biomass at this site.

3.7 DISSOLVED OXYGEN

Adequate levels of dissolved oxygen are essential for the maintenance of aquatic life, and affect the degree to which a water body can assimilate waste. Excessive growth of aquatic plants and decomposition of organic matter can cause low levels of dissolved oxygen. High temperatures can also reduce the solubility of oxygen in water.

Mosquito Creek Basin

DO measured during the day was generally lower at Highway 529 than at other locations on Mosquito Creek (Figure 46). Datasonde records indicated that DO in Mosquito Creek declined to 4.73 mg/L at Highway 529 at 06:00 on August 4, 1999, the lowest measurement in 1999, but was otherwise above the 5.0 mg/L ASWQG at all the monitoring sites during daytime sampling trips (Figure 47). The pattern and timing of DO concentration at Highway 529 is consistent with nocturnal oxygen depletion caused by high macrophyte biomass, as was recorded at this site in 1990 (EMA 1995). DO concentrations were not significantly different downstream from Nanton in 1999, compared to upstream (Figure 46). Accordingly, there is little evidence of oxygen depletion during the open water season immediately downstream from Nanton.

These results suggest that DO downstream of Nanton was generally within an acceptable range for non-salmonid fish (Table 21 in EMA 1992) during the open water season in 1999. However, near anoxic conditions were recorded in the headwaters of Mosquito Creek during the winter of 1982 (Appendix I), when much of the channel was frozen to the creek bottom (Hamilton and Brassard 1983).

Little Bow River

Along the Little Bow River, DO was well above the 5 mg/L ASWQ guideline during the day at all sites (Figure 48), but declined to 3.59 mg/L at 04:00, August 21, 1999 during datasonde monitoring at Highway 533 (Figure 49). As in Mosquito Creek, oxygen depletion at this site was probably caused by nocturnal respiration by macrophytes (Table 4).

3.8 SPATIAL COMPARISONS

Plots of the concentration of key water quality variables in Mosquito Creek in 1982, 1990, 1998 and 1999 are in Appendix I, Figures 1 to 6. It should be noted that the sampling period and methods were different in these four years. The 1999 sampling program was far more intensive than previous sampling, and used automated daily sampling of TP. Sample sizes are included in these figures.

The concentrations of TP, TDP and nitrite+nitrate were significantly higher downstream from Nanton than upstream in 1999 and 1990 (Appendix I, Figure 1, 2, 3), but these variables did not differ significantly between these two sites in 1982. These findings suggests that the concentration of these variables changed more at Nanton in recent years, but the reason for these changes can not be determined from the available data.

3.9 TEMPORAL COMPARISONS

Small but statistically significant declines in TDP and total ammonia were detected in data from the site in the Little Bow River at the Highwood River. No significant changes over time were otherwise detected for the Little Bow River sites over the time period 1982 to 1999. TDP also declined appreciably at all sites tested on Mosquito Creek, and TP declined significantly in Mosquito Creek upstream from Nanton at Highway 2. Turbidity increased at all three sites (Table 6). The reason for the declines in TP and TDP, and increases in turbidity, can not be determined from the available data.

There were insufficient data to test sites upstream from Women's Coulee for monotonic trends. Sufficient flow data for trend analysis were only available for the Little Bow River at the Highwood River, and Mosquito Creek at Highway 529. No flow trends were detected at these two locations. It therefore seems unlikely that changes in flow could account for the trends in nutrients and turbidity that were detected.

There was little snow in the Mosquito Creek basin in the winter of 1999. Accordingly, there was concern that 1999 sampling results would be less influenced by agricultural runoff and might not be representative of recent conditions. Although flows were slightly above average in the late spring and summer of 1999 at Highway 529, flows were below average when sampling began on March 24, 1999 (Table 5). Similarly, flows were below average during early spring at this site during the previous sampling years in March 1982 (monthly mean, 0.207 m^3/s) and March 1990 (0.086 m^3/s). Accordingly, nutrient loading from spring snowmelt may have been below average in all these sampling years.

It should be noted that flows at all sampling sites on the Little Bow River, and sampling sites downstream from Women's Coulee on Mosquito Creek, are regulated during the irrigation season. Flow and concentration at sites in unregulated sections of Mosquito Creek will be more influenced by surface runoff than sites in regulated reaches.

4.0 CURRENT AND PREDICTED MASS LOADINGS

4.1 CURRENT MASS LOADING TO MOSQUITO CREEK NEAR NANTON

Mass loading to Mosquito Creek near Nanton in 1999 is summarised in Table 3, and Figures 50, 51 and 52. Only total and dissolved phosphorus, total suspended sediment, ammonia, total Kjeldahl nitrogen and total nitrogen loading estimates were used in mass balance analysis. Other variables had coefficients of variation $\geq$0.2 (Table 3), which indicates that there is a higher level of uncertainty in some loading estimates and they are not suitable for modelling and other applications (Walker 1996).

These loading estimates suggest that the Nanton WWTP contributed more dissolved phosphorus and nitrite+nitrate to Mosquito Creek than any other source in both basins (Figures 5, 11, 50, 51). Loading of these variables from the Nanton WWTP were 170 and 192% of the upstream loading (at site AB05AC0140) respectively (Table 3). These two dissolved nutrients are readily absorbed by aquatic plants, and probably account for the large increase in periphytic algae (Figure 44) and more abundant macrophytes (EMA 1995) in Mosquito Creek downstream from Nanton, compared to upstream. In the Bow River, dissolved phosphorus and nitrite+nitrate were the best chemical predictors for periphytic and macrophyte biomass (Sosiak 2000). Similarly, the amount of chlorophyll *a* in the water column nearly doubled below Nanton (Table 3). This variable could either reflect true river phytoplankton, or scoured periphytic algae.

The Nanton WWTP also contributed 581 kg total phosphorus (Figure 3, 50) and 123 kg ammonia (Figure 16, Table 3), or 37 and 59% of the upstream loading respectively. Nanton WWTP loading resulted in an increase in the downstream concentration of both variables. However, Nanton WWTP loading of ammonia was relatively small compared to other sources in this reach of Mosquito Creek.

The Nanton WWTP contributed large numbers of *E. coli* and fecal coliforms to Mosquito Creek, but counts were actually higher at sites upstream from Highway 2, than downstream from Nanton (Figures 38, 39). This finding suggests an upstream source is contributing significant numbers of coliforms. Lower values downstream of Nanton could reflect die-off of coliforms along Mosquito Creek. Only ten coliform tests over the period March 24-June 9 were available for the Nanton WWTP final effluent, for use in loading estimates.

The Nanton WWTP contributed a very small loading of suspended sediments (0.1% of upstream loading), compared to all other sources measured in this reach of Mosquito Creek (Figure 27, 52).

4.1.1 Loading from Diffuse Runoff and Other Sources near Nanton

The residual analysis indicated that diffuse runoff, and other sources near Nanton that were not sampled directly contributed material to Mosquito Creek between sampling sites at Highway 2 and Range Road 281 (Figure 1). This analysis suggests that NPS loading in this reach contributed 251,355 kg of TSS to Mosquito Creek (27% of the upstream loading at Highway 2), 246.9 kg of TP (16%), and 1081.4 kg of TKN (11%) and 278.4 kg of ammonia (134%)(Table 3).

This analysis also found a net loss of -137 kg TDP near Nanton (Figure 5, 50). Sedimentation or uptake by aquatic plants may cause this loss of TDP in this reach. Alternatively, phosphorus data reported by the Town of Nanton may be inaccurate, and this could account for the apparent loss. Nanton WWTP phosphorus measurements were about 51% higher than QAQC samples analysed at Maxxam Laboratories Ltd. for AENV (Table 7). Results for other variables did not differ greatly between laboratories. With the TDP loading from the Nanton WWTP reduced by 51% to account for this discrepancy, the residual near Nanton would be only 22 kg TDP, which suggests there is little NPS loading of TDP in this reach.

Sources near Nanton contributing TSS to Mosquito Creek cannot be determined from the available data. A survey of Mosquito Creek near Nanton by AENV revealed extensive bank erosion downstream from the golf course, some natural and some caused by cattle, which may be contributing TSS.

4.2 IMPACT OF ENHANCED PHOSPHORUS REMOVAL ON CONCENTRATION AND MASS LOADING

Under enhanced phosphorus removal (0.7 mg/L TP), the estimated discharge from Nanton WWTP during the 1999 sampling program would have been 83.1 kg TP and 70.3 kg TDP, an 86 and 85% reduction from the current phosphorus discharge (Table 3), respectively. This change would greatly reduce phosphorus loading to Mosquito Creek from this point source, as recommended by the NRCB/CEAA Joint Review Panel (NRCB 1998). However, estimates of current loading from the WWTP were based on data supplied by the Town of Nanton. If these phosphorus data were in fact too high, the reduction in TDP loading would be about 78%.

The estimated TP concentration at the edge of the mixing zone for Nanton WWTP under enhanced phosphorus removal was virtually the same as that measured at the downstream monitoring site, while TDP was somewhat higher (Table 8). This analysis predicted that downstream concentrations would decrease by about 36% for TP and 65% for TDP. Downstream TP concentrations do not decrease as much as the WWTP loading under enhanced phosphorus removal, because other sources would still contribute a large loading to this reach. At 0.079 mg/L, median TP downstream of Nanton will still exceed the ASWQG of 0.05 mg/L after enhanced phosphorus removal, unless other controls on phosphorus loading to this basin are implemented. Stream and reservoir modelling could be used to set target phosphorus concentrations and refine predicted stream concentrations under the Little Bow River Reservoir Water Quality Protection Plan.

A decrease in aquatic plant biomass downstream from Nanton should occur following enhanced phosphorus removal, even if there are no other changes in phosphorus loading. The predicted median TDP concentration at the edge of the mixing zone under enhanced phosphorus removal (0.016 mg/L) was identical to that measured in Mosquito Creek at Highway 529 (Figure 4) in 1999, where periphytic biomass (as epilithic chl *a*, Figure 44) was much lower than below Nanton. This suggests that reduced TDP concentration should result in reduced periphyton biomass downstream from Nanton.

5.0 CONCLUSIONS

Mosquito Creek Basin

1. During the open water season in 1999, the Nanton WWTP effluent increased TDP and nitrite+nitrate concentrations in Mosquito Creek and resulted in excessive growth of periphyton immediately downstream from Nanton. This effluent contributed a greater loading of these dissolved nutrients than any other source in both basins. No adverse impact of the effluent on TSS, coliforms, DO or other forms of nitrogen was documented.

2. Women's Coulee, McMillan Creek, and other sources along Mosquito Creek between Women's Coulee and 104 Street also contributed significant loading of TDP and nitrogen to Mosquito Creek.

3. The greatest TP loading to Mosquito Creek from NPS occurred between sites at Township Road 154 and Highway 529. However, most of this TP was particulate phosphorus that is less biologically available for uptake by aquatic plants than TDP. Furthermore, the high TP loading estimate for this reach may partially reflect a difference in sampling frequency between these two sites rather than a genuine difference in loading. Otherwise all variables generally declined in concentration due to deposition, biological uptake and other factors along lower Mosquito Creek.

4. Based on loading estimates for each stream at the reservoir FSL boundary, Mosquito Creek contributed 65% of the watershed TP loading to the future Little Bow River Reservoir site, and 37% of the TDP loading during the sampling period.

5. Both *E. coli* and fecal coliforms frequently exceeded water quality guidelines for contact recreation and irrigation at the site on Mosquito Creek downstream from Highway 534 at 104 Street. Coliforms at other sites exceeded guidelines infrequently, which suggests that coliform levels would not affect water uses at these other locations.

6. Although several large feedlots and various other livestock operations are located in the Nanton Creek basin, these operations contributed relatively little phosphorus and nitrogen to this tributary of Mosquito Creek under the conditions that occurred during sampling in 1999.

7. Results from 1999 suggest that Women's Coulee contributed more suspended sediment than any other source along Mosquito Creek. Potential sources of TSS along Women's Coulee include bank erosion near the Old Women's Buffalo Jump, and other erosion further downstream. Diffuse runoff or other sources that cannot be identified also contributed TSS to Mosquito Creek near Nanton in 1999.

8. DO was above the water quality guideline at all sites on Mosquito Creek during the day, but occasionally declined below this guideline at night at Highway 529.

9. TDP at sites on Mosquito Creek that were tested for temporal trends has declined in recent years and turbidity has increased, but water quality was otherwise similar in 1999 to results from recent years.

10. Enhanced phosphorus removal will reduce dissolved phosphorus loading from the Nanton WWTP by 78-85%, and reduce downstream concentrations by about 65%. This reduction would help meet the NRCB/CEAA Joint Review Panel recommendation to reduce phosphorus loading from Mosquito Creek, and should be sufficient to reduce periphyton biomass downstream from Nanton.

<u>Little Bow River</u>

1. Results from 1999 suggest that the largest sources of TP loading to the Little Bow River occurred between Highway 2 and 658 Avenue sites. TP concentration declined further downstream. The most important sources of TDP, ammonia, TKN and TN appeared to be between 168 Street and 658 Avenue, but additional sources contributed significant TDP and ammonia to the Little Bow River further downstream. In particular, other sources contributed appreciable ammonia to the reach ending at Highway 534, and TDP to the reach ending near Reservoir FSL. The greatest loading of nitrite+nitrate occurred between High River and Highway 2.

2. Nuisance periphyton biomass was documented along the Little Bow River at the sites at Highway 2 and downstream from the reservoir. Elevated TSS, which reduced light penetration to the riverbed, may have inhibited periphyton growth in other areas of this river.

3. The largest sources of TSS occurred between Highway 2 and the site upstream from the Frank Lake outlet. Potential sources of TSS along the Little Bow River included bank erosion near Highway 2.

4. Fecal coliforms frequently exceeded water quality guidelines for contact recreation and irrigation only at the site on the Little Bow River at 658 Avenue. The water quality guideline for *E. coli*, the preferred microbiological indicator, was rarely exceeded at any sites on the Little Bow River.

5. DO was above the water quality guideline at all sites on the Little Bow River during the day but often fell well below the guideline at night at Highway 533, due to nocturnal respiration by macrophytes. At times, DO levels in the Little Bow River at Highway 533 would not be suitable for salmonid fish.

6. No major changes in water quality variables over time were detected at the sites on the Little Bow River where sufficient data were available for testing.

6.0 RECOMMENDATIONS

1. The data collected during 2000 should be used to verify the conclusions reached in this report.

2. The results from both years should be used to develop a water quality protection plan for the proposed Little Bow River Reservoir.

7.0 LITERATURE CITED

Alberta Environment. 1999. Surface water quality guidelines for use in Alberta. Environmental Sciences Division and Water Management Division, Edmonton, AB

Aroner, E.R. 2000. WQHYDRO. Version 2036. Water quality/hydrology/graphics/analysis system. User's Manual. P.O. Box 18149, Portland, OR.

Bradford, M.E. and Peters, R.H. 1987. The relationship between chemically analyzed phosphorus fractions and bioavailable phosphorus. Limnol. Oceanogr. 32(5): 1124-1137.

Canadian Council of Ministers of the Environment. 1999. Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment, Winnipeg.

Environmental Management Associates. 1992. Temperature and dissolved oxygen criteria for Alberta fishes in flowing waters. Prepared for the Alberta Fish and Wildlife Division, Edmonton, AB.

Environmental Management Associates. 1995. Little Bow River Project: Water quality assessment. Prepared for Alberta Public Works, Supply and Services, Edmonton.

Hamilton, H.R. 1983. Little Bow River basin study. Water quality evaluation 1982. Environmental Assessment Section, Planning Division, Alberta Environment, Calgary.

Natural Resources Conservation Board. 1998. Little Bow project/Highwood diversion plan application to construct a water management project to convey and store water diverted from the Highwood River. Report of the NRCB/CEAA Joint Review Panel, Application #9601 - Alberta Public Works, Supply and Services.

Pentney, A. December 15, 1999. Nanton - Proposed tertiary wastewater treatment plant. Memorandum. Environmental Services, Prairie Region, Alberta Environment.

Sosiak, A.J. 2000. Long-term response of periphyton and macrophytes to reduced municipal nutrient loading to the Bow River (Alberta, Canada). In preparation. Water Sciences Branch, Water Management Division, Alberta Environment.

Walker, W.W. 1996. Simplified procedures for eutrophication assessment and prediction: user manual. Prepared for U.S. Army Corps of Engineers. U.S.A.E. Waterways Experiment Station, Vicksburg, Mississippi. Instruction Report W-96-2.

Ward, R.C., J.C. Loftis, H.P. DeLong, H.F. Bell. 1990. Ground water quality data analysis protocol. Journal of the Water Pollution Control Federation. 1938-1945.

Welch, E.B., Jacoby J.M., Horner, R.R., and M.R. Seeley. 1988. Nuisance biomass levels of periphytic algae in streams. Hydrobiol. 157: 161-168.

8.0 TABLES

Table 1. Sites routinely sampled during March 24 to September 1, 1999, and sampling frequency. Sites have been arranged according to their position in each watershed, starting with the site furthest upstream in the Little Bow River.

WDS Station No.	WDS Station Name	Sample Type[b]	*N*[c]
Little Bow River			
AB05AC0066 [a]	Little Bow River at Highwood River Control Structure and WSC Gauge	A, Q	164
AB05AC0080	Little Bow River at Hwy. #2 Southeast Of High River	A, Q	162
AB05AC0085	Little Bow River at 168 St.	G	14
AB05AC0089	Little Bow River upstream Of Frank Lake Confluence	G	14
AB05AC0093	Little Bow River at 658 Ave.	A, Q	144
AB05AC0096	Little Bow River at Hwy. 534	G	14
AB05AC0100 [a]	Little Bow River at Highway #533 east of Nanton	A, Q, D, M	162
AB05AC0102	Little Bow River at Reservoir FSL	G	14
Mosquito Creek			
AB05AC0108	Mosquito Creek downstream of Confluence with Cross Creek	G	14
AB05AC0110	Mosquito Creek at Highway #534-west of Connemara	A, Q	160
AB05AC0114	Macmillan Creek near the Mouth	G	14
AB05AC0116	Mosquito Creek downstream of Cayley Hutterite Colony	A	155
AB05AC0120	Women's Coulee at 690 Ave. near Mosquito Creek	G, Q	14
AB05AC0122	Mosquito Creek downstream of Hwy. 534 at 104 St.	G	14
AB05AC0140	Mosquito Creek upstream of Nanton at Hwy. 2	A, Q	147
Nanton Creek			
AB05AC0125	Nanton Creek 2.5 Km upstream of Springhill Creek	G	14
AB05AC0126	Springhill Creek at Purcell Rd.	G	14
AB05AC0127	Nanton Creek at Hwy. 533	G	14
AB05AC0128	Nanton Creek downstream of Tophat Feeders	G	14
AB05AC0130	Nanton Creek at Highway #2	A, Q	154
Mosquito Creek continued			
AB05AC0150	Mosquito Creek downstream from Nanton near Range Road 281	A	150
AB05AC0153	Mosquito Creek at Twp. Road 160	G	14
AB05AC0156	Mosquito Creek at Cranappy Farms	G	14
AB05AC0160 [a]	Mosquito Creek at Hwy. #529 east Of Parkland	A, Q, D	156
AB05AC0170	Mosquito Creek near the Mouth	G	14
Little Bow River continued			
AB05AC0175	Little Bow River downstream of Reservoir	G, D	6
AB05AC0190 [a]	Little Bow River at Carmangay	G, M	6
AB05AC0210	Little Bow River at Inlet to Travers Reservoir	G	6

[a] Sites sampled for LTRN/Index variable list
[b] Sample type: A (daily TP composite by automated sampler, other nutrients weekly grab)
G (weekly grab samples all variables in spring upstream reservoir, otherwise monthly)
D (hourly temperature, dissolved oxygen, conductivity, pH by datasonde)
M (single macrophyte biomass survey)
[c] TP sample size during March 22-September 1, 1999

Table 2. Sites sampled during high runoff.

WDS Station No.	WDS Station Name
AB05AC0073	Little Bow Creek at Hwy 23
AB05AC0076	Little Bow River at Hwy 2a North Crossing
AB05AC1260	Unnamed Tributary to Mosquito Creek downstream Masabi Ranch Reservoir
AB05AC1270	Unnamed Tributary to Mosquito Creek downstream May Reservoir
AB05AC1280	Unnamed Tributary to Little Bow River downstream Of Chinook Feeders
AB05AC0112	MacMillan Creek at Meridian St.

Table 3. Mass flux (coefficients of variation in parentheses) during March 24-September 1, 1999 at sites in the Mosquito Creek and Little Bow River basins. Less reliable estimates (CV ≥ 0.2) are in bold italics.

Variables[a]	TP kg	TDP kg	TSS kg	NO_2+NO_3 kg	TKN kg	NH_3 kg	TN kg	Chl *a* kg
Mosquito Ck. d/s Cross Ck.	81.8 (0.053)	33.2 (0.173)	27,966 (0.123)	76.7 (0.191)	1004.1 (0.086)	33.5 (0.074)	1080.3 (0.083)	NA
Mosquito Ck. At Hwy 534	145.8 (0.128)	22.1 (0.140)	46,057 (0.119)	92.2 (0.170)	1417.8 (0.071)	47.9 (0.197)	1506.8 (0.071)	9.9 (0.074)
MacMillan Ck. near Mouth -	371.6 (0.086)	87.5 (0.087)	244,158 (0.149)	968.7 (0.156)	1926.2 (0.076)	250.5 (0.133)	2624.9 (0.041)	NA
Mosquito Ck. d/s of Cayley Colony	705.5 (0.051)	176.9 (0.087)	117,988 (0.099)	549.5 (0.180)	3718.3 (0.058)	188.0 (0.193)	4358.8 (0.075)	NA
Women's Coulee near Cayley	800.5 (0.123)	101.2 (0.083)	2,144,475 (0.080)	***38.8 (0.351)***	3887.3 (0.015)	65.8 (0.021)	3921.1 (0.019)	***33.2 (0.369)***
Mosquito Ck. d/s Hwy 534	1741.8 (0.100)	383.2 (0.121)	1,498,869 (0.158)	655.0 (0.194)	11466.6 (0.062)	363.2 (0.135)	12910.9 (0.081)	NA
Mosquito Ck. u/s Nanton at Hwy 2	1565.9 (0.070)	277.0 (0.163)	943,348 (0.088)	756.7 (0.155)	9895.2 (0.099)	208.0 (0.177)	10664.9 (0.101)	149.2 (0.224)
Nanton Ck. u/s Springhill Ck.	18.2 (0.088)	4.4 (0.114)	8,450 (0.166)	60.2 (0.118)	364.9 (0.054)	15.0 (0.065)	422.3 (0.036)	NA
Springhill Ck. At Purcell Road	41.8 (0.067)	12.5 (0.093)	13,601 (0.081)	139.5 (0.101)	289.8 (0.074)	53.2 (0.094)	428.4 (0.036)	NA
Nanton Ck. at Hwy 533	51.4 (0.052)	19.4 (0.070)	20,541 (0.071)	125.7 (0.195)	820.3 (0.040)	100.0 (0.188)	952.8 (0.021)	NA
Nanton Ck. d/s Tophat Feeders	90.8 (0.085)	34.5 (0.133)	36,529 (0.096)	91.9 (0.172)	1078.5 (0.073)	98.4 (0.088)	1176.0 (0.059)	NA
Nanton Ck Near Mouth	133.1 (0.103)	29.5 (0.183)	16,112 (0.101)	105.2 (0.241)	1030.1 (0.074)	47.0 (0.173)	1141.8 (0.069)	16.9 (0.317)
Nanton WWTP	581.4 (0.067)	470.4 (0.086)	1,134 (0.029)	1451.9 (0.128)	1298.5 (0.191)	123.2 (0.059)	2792.0 (0.085)	NA
Nanton WWTP as % of u/s loading	37.1%	169.8%	0.1%	191.9%	13.1%	59.2%	26.2%	NA
Other Loading/Loss Near Nanton	246.9	-137.0	251,355	-	1081.4	278.4	262.5	NA
Mosquito Ck d/s Nanton	2527.3 (0.074)	639.9 (0.104)	1,211,949 (0.125)	2499.8 (0.124)	13305.2 (0.094)	656.6 (0.185)	14861.2 (0.093)	239.0 (0.125)
Mosquito Ck at TP Rd. 160	1987.7 (0.143)	556.1 (0.093)	1021421 (0.292)	2514.7 (0.152)	11805.4 (0.045)	694.6 (0.138)	14375.0 (0.038)	NA
Mosquito Ck at Cranappy Farms	1856.0 (0.186)	495.1 (0.184)	***504,021 (0.316)***	***1914.1 (0.268)***	13290.2 (0.065)	638.6 (0.172)	14354.6 (0.111)	NA
Mosquito Ck at HW 529	3919.7 (0.097)	480.9 (0.103)	1,291,232 (0.116)	1826.6 (0.199)	14483.5 (0.082)	304.2 (0.181)	16229.6 (0.088)	282.9 (0.175)
Mosquito Ck near FSL	1798.0 (0.075)	284.6 (0.153)	435,088 (0.135)	***1788.7 (0.207)***	13026.3 (0.047)	392.0 (0.084)	14127.0 (0.090)	NA
Little Bow at Highwood R.	582.6 (0.180)	***69.3 (0.375)***	***244,833 (0.276)***	376.6 (0.139)	4228.5 (0.153)	133.1 (0.097)	4725.5 (0.149)	***14.0 (0.214)***
Little Bow at Highway 2	527.3 (0.070)	135.2 (0.185)	298,927 (0.134)	754.0 (0.116)	4962.6 (0.117)	187.9 (0.144)	5718.5 (0.101)	28.8 (0.130)

Table 3. Continued.

Variables[a]	TP kg	TDP kg	TSS kg	NO_2+NO_3 kg	TKN kg	NH_3 kg	TN kg	Chl *a* kg
Little Bow R. at 168 St.	1046.1 (0.064)	378.8 (0.010)	1,190,123 (0.157)	510.1 (0.169)	7435.0 (0.084)	336.7 (0.094)	8036.2 (0.077)	NA
Little Bow R. upstream of Frank L	1439.4 (0.069)	***443.6 (0.371)***	1,713,441 (0.109)	476.1 (0.173)	8596.7 (0.086)	487.5 (0.072)	11422.5 (0.087)	40.7 (0.101)
Little Bow R. at 658 Avenue.	1981.7 (0.051)	***302.2 (0.251)***	1,253,056 (0.139)	457.2 (0.181)	9595.9 (0.059)	613.1 (0.186)	10122.3 (0.063)	55.2 (0.169)
Little Bow R. at Hwy. 534	1004.6 (0.102)	321.7 (0.156)	867,824 (0.147)	550.8 (0.127)	10464.8 (0.111)	940.2 (0.079)	11194.2 (0.121)	NA
Little Bow R. at Hwy 533	978.9 (0.048)	362.4 (0.094)	501,986 (0.155)	583.4 (0.097)	9033.4 (0.060)	966.8 (0.089)	9621.3 (0.052)	***40.9 (0.286)***
Little Bow R. at Reservoir FSL	959.7 (0.139)	478.2 (0.196)	342,457 (0.099)	562.5 (0.094)	9300.1 (0.097)	1083.9 (0.100)	9852.7 (0.102)	NA
Little Bow R. downstream Reservoir	***2753.6 (0.222)***	663.9 (0.096)	NA	***671.2 (0.218)***	21757.0 (0.099)	536.7 (0.198)	22731.9 (0.113)	417.4 (0.113)
Little Bow R. at Carmangay	1237.2 (0.124)	282.1 (0.194)	653,381 (0.142)	61.2 (0.188)	14406.0 (0.077)	***372.0 (0.336)***	14441.0 (0.076)	***405.8 (0.292)***
Little Bow R. at Travers Reservoir inlet	1329.9 (0.158)	***118.9 (0.217)***	NA	59.5 (0.186)	16332.3 (0.159)	***359.8 (0.343)***	16391.8 (0.159)	***384.5 (0.427)***

[a] Abbreviations: TP (total phosphorus), TDP (total dissolved phosphorus), TSS (total suspended solids, as NFR), NH_3 (total ammonia), NO_2+NO_3 (nitrite+nitrate), TN (total nitrogen), Chl *a* (water column chlorophyll *a*), *E. coli* (*Escherichia coli*), F. coli (fecal coliforms), u/s (upstream), d/s (downstream) NA (no data available), hyphen (CV of at least one loading estimate too high for mass balance calculation).

Table 4. Aquatic macrophyte dry biomass (g/m^2) at sampling sites on the Little Bow River in 1990 and 1999.

WDS Site Code	Site Name	Date	Mean Biomass g/m^2	Range g/m^2
AB05AC0100	Little Bow River at Highway #533 East of Nanton	17-Aug-90	353.9	165.2-567.2
AB05AC0100	Little Bow River at Highway #533 East of Nanton	29-Aug-90	360.4	87.4-630.8
AB05AC0100	Little Bow River at Highway #533 East of Nanton	30-Aug-99	488.0	78.5-2552.3
AB05AC0190	Little Bow River at Carmangay	28-Aug-90	357.0	158.8-681.5
AB05AC0190	Little Bow River at Carmangay	30-Aug-99	38.1	0-162.5

Table 5. Mean monthly flows (m^3/s) at the Water Survey of Canada Station 05AC031 on Mosquito Creek at Highway 529[a]

Years	Mar	Apr	May	Jun	Jul	Aug	Sep
1982-96	0.664	0.444	0.912	1.36	1.36	0.867	0.769
1999 [b]	0.278	0.655	1.01	1.51	1.48	1.07	0.742

[a] WSC site name: "Mosquito Creek near the mouth". This is the same location as WDS site AB05AC0160
[b] Preliminary data that has been approved for release by WSC

Table 6. Significant monotonic trends in physical and chemical variables in the Little Bow River and Mosquito Creek during 1982-99.

Sites	Sen Slope (Units/Year) for Significant Trends					
	Flow m^3/s	Turbidity NTU	TP mg/L	TDP mg/L	NH_3 Mg/L	NO_2+NO_3 mg/L
Little Bow at High River	NS[b]	NS	-<0.001	NS	-<0.001	NS
Little Bow at HW 533	NA[c]	NS	NS	NS	NS	NS
Mosquito Creek upstream Nanton	NA	+0.800	-0.003	-0.006	NS	NS
Mosquito Creek downstream Nanton	NA	+0.769	NS	-<0.001	NS	NS
Mosquito Ck at HW 529	NS	+0.748	NS	-<0.010	NS	NS

[a] Abbreviations: TP (total phosphorus), TDP (total dissolved phosphorus), NH_3 (total ammonia), NO_2+NO_3 (nitrite+nitrate),
[b] NS: no statistically- significant trend detected
[c] NA: insufficient data for analysis

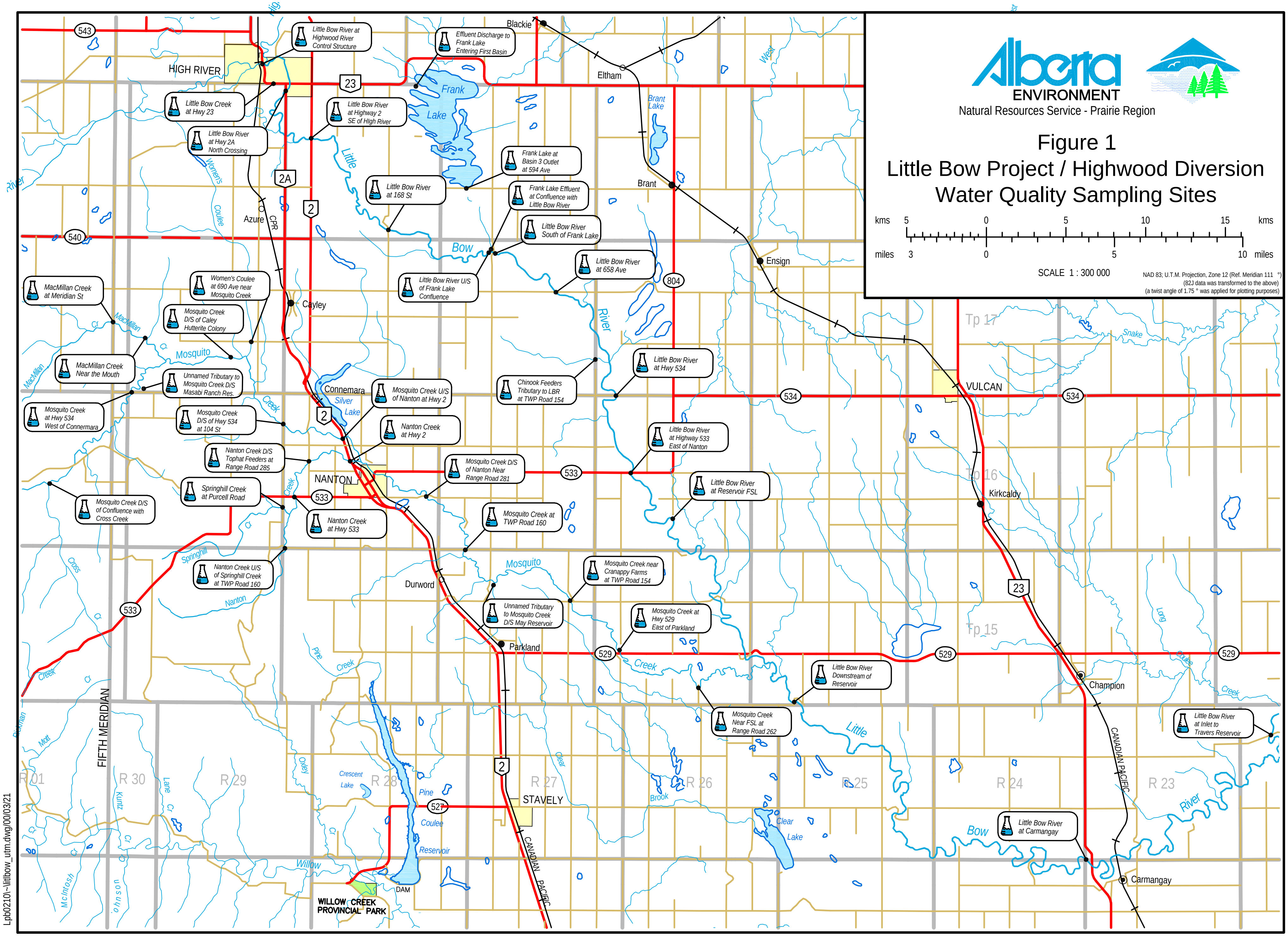
Table 7. Comparison of phosphorus results from two different laboratories for the Nanton WWTP final effluent in 1999.

Laboratory	Mean TP mg/L	Mean TDP mg/L	*n*	Sampling Period
Nanton WWTP	5.22	4.39	16	03/31/99-12/21/99
Maxxam	3.41	2.91	3	04/21/99-10/18/99

Table 8. Current phosphorus concentration at sites in Mosquito Creek near Nanton (March 24-September 1, 1999) and predicted concentration downstream from the Nanton WWTP after enhanced phosphorus removal (0.7 mg/L TP).

Sites	Median Flow m^3/s	Median TP Mg/L	Median TDP mg/L
Concentration at stream sampling sites (1999), current and predicted effluent concentration			
Mosquito Ck. Upstream of Nanton at Hwy 2	1.080	0.073	0.012
Nanton Creek at Highway 2	0.065	0.059	0.025
Nanton Wastewater Plant (current discharge)	0.008	5.200	4.400
Nanton Wastewater Plant (after enhanced removal)	0.008	0.700	0.592
Mosquito Ck. Downstream of Nanton at Range Road 281	1.165	0.121	0.030
Current and predicted concentration at edge of mixing zone			
Fully mixed Mosquito Ck [P] (current conditions, 1999 data)	1.174	0.122	0.045
Fully mixed Mosquito Ck. [P] (after enhanced P removal)	1.174	0.079	0.016
% reduction following enhanced P removal		35.7%	64.7%

9.0 FIGURES



Lpb0210\~\litlbow_utm.dwg/00/03/21

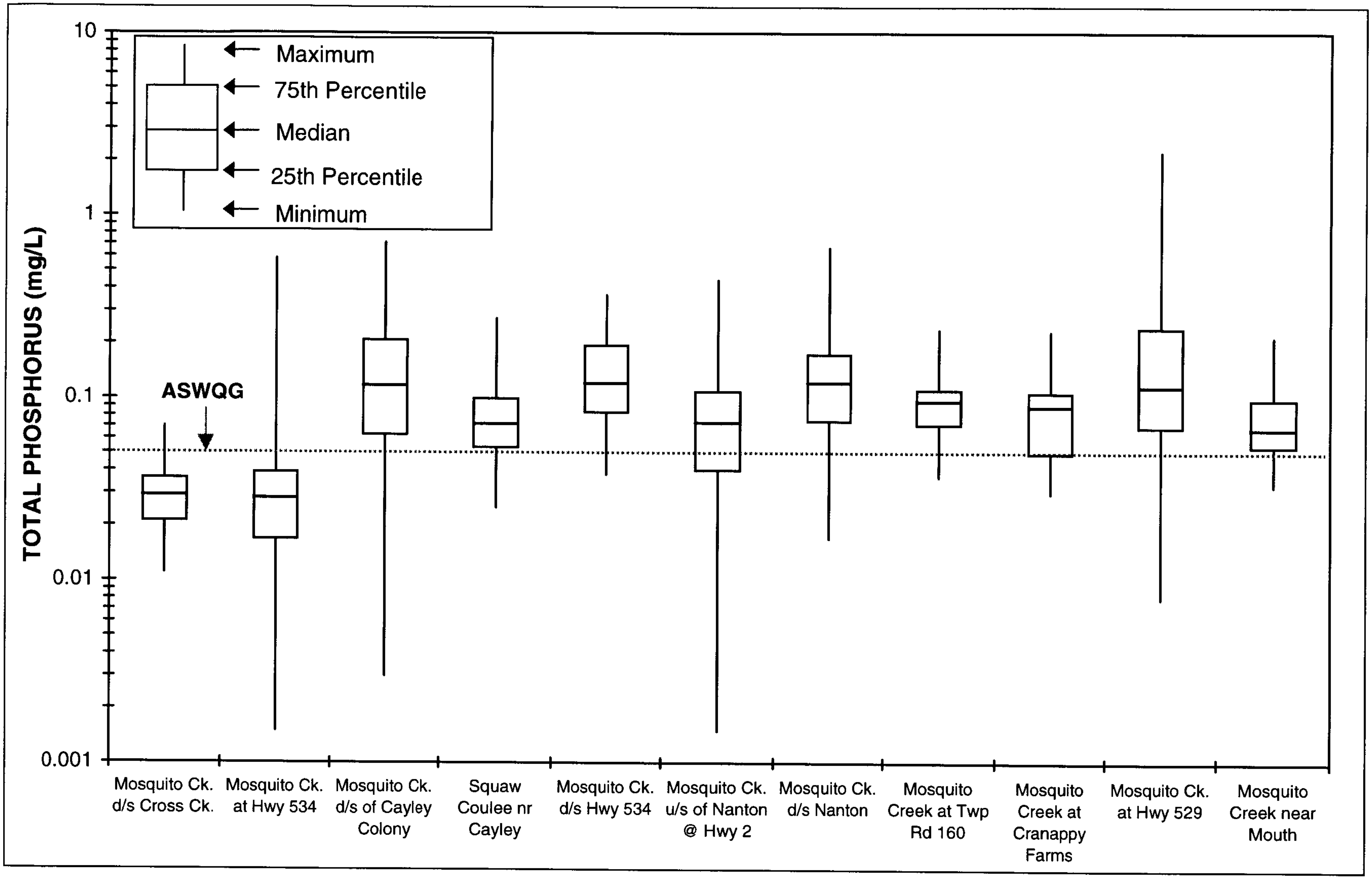
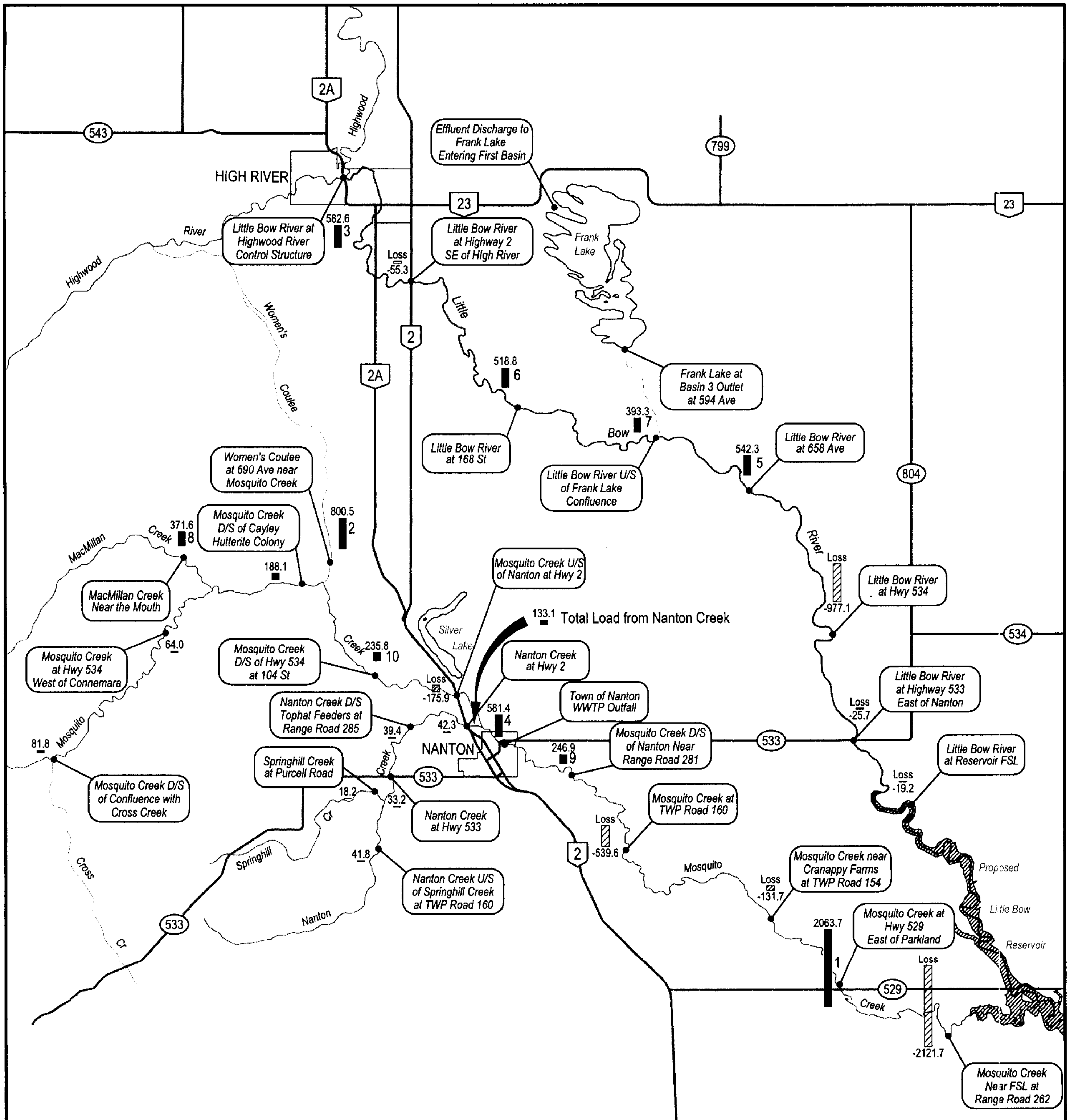


Figure 2. Concentration of total phosphorus at Mosquito Creek sites, March 24-September 1, 1999.



Total Phosphorus

Legend:

Loss
-539.8
Decrease in mass between sites

800.5
2
Increase in mass between sites
Rank

Alberta ENVIRONMENT
Natural Resources Service - Prairie Region

0 5 10 15 kms
0 5 10 miles
SCALE 1 : 250 000

NAD 83; U.T.M. Projection, Zone 12 (Ref. Meridian 111 °)
(82J data was transformed to the above)
(a twist angle of 2 ° was applied for plotting purposes)

Lpb0210\~litlbow_gain_loss_letter.dwg/00/11/03

Figure 3. Loading and loss (deposition, biological uptake)of total phosphorus (kg) between sampling sites along the Little Bow River and Mosquito Creek upstream of the proposed Little Bow Reservoir during March 24-September 1, 1999.

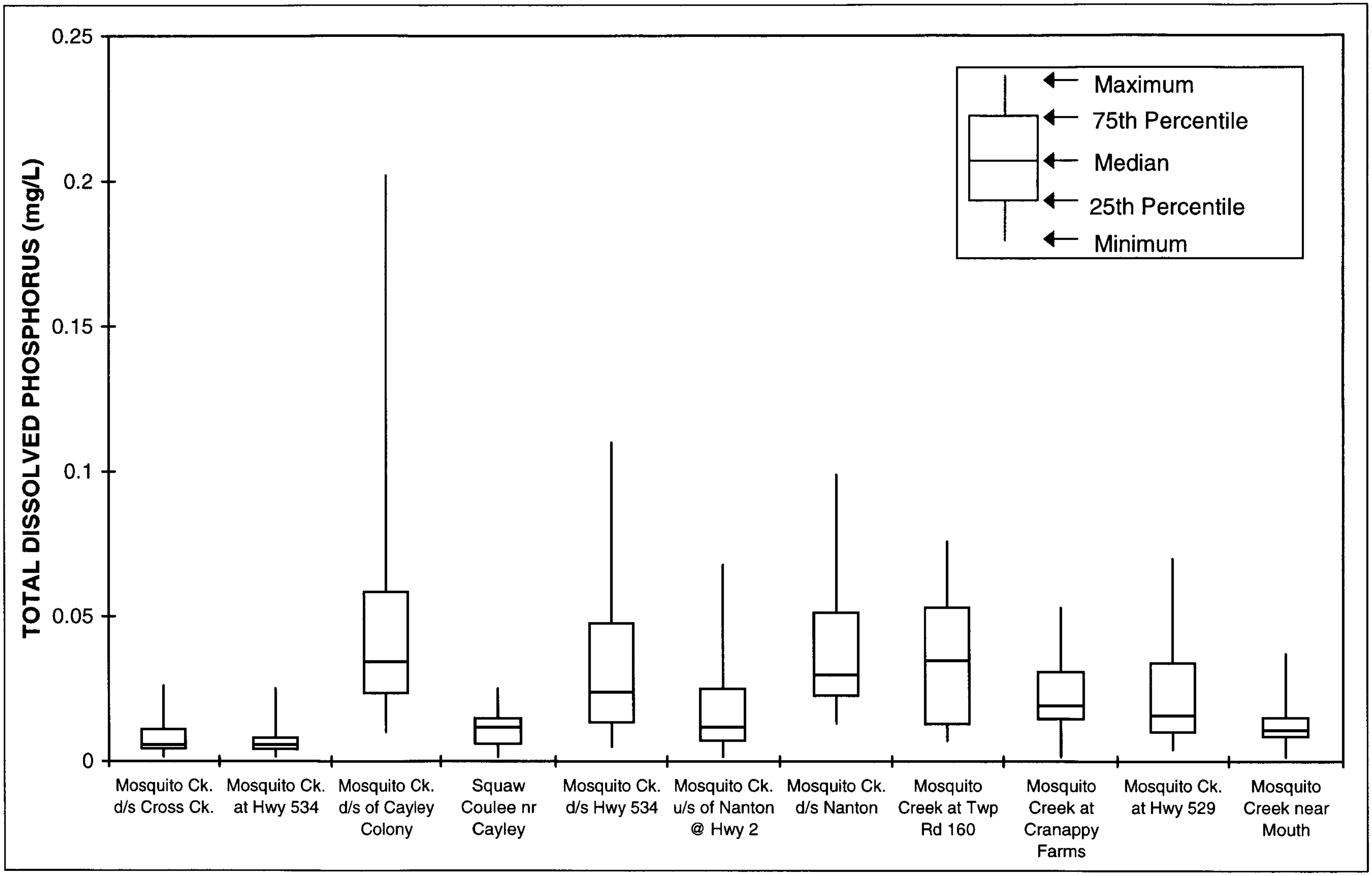
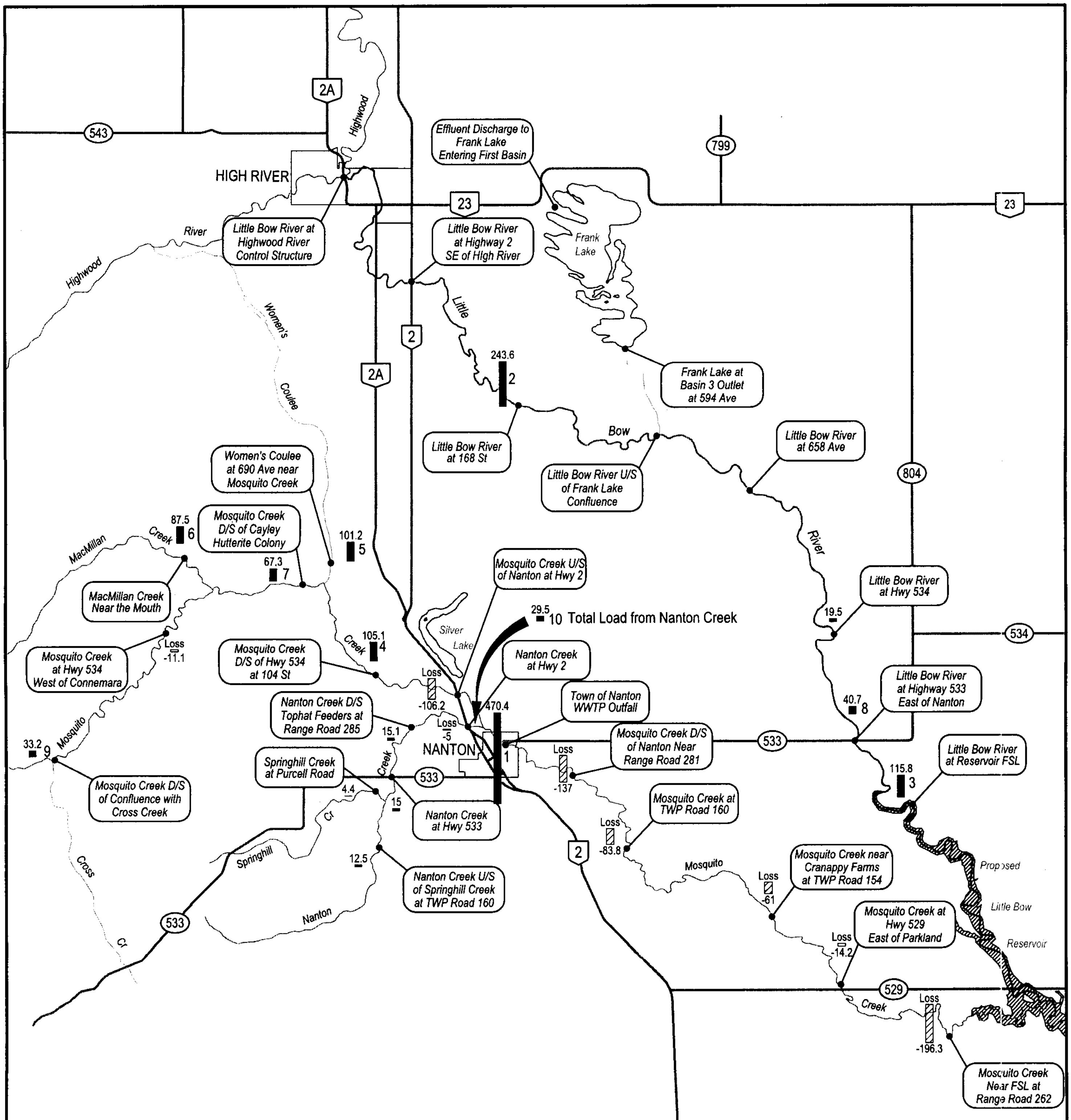


Figure 4. Concentration of total dissolved phosphorus at Mosquito Creek sites, March 24-September 1, 1999.



Total Dissolved Phosphorus

Alberta ENVIRONMENT
Natural Resources Service - Prairie Region

Legend:
Loss -83.8 — Decrease in mass between sites
243.6 — Increase in mass between sites
2 — Rank

0 5 10 15 kms
0 5 10 miles
SCALE 1 : 250 000

NAD 83; U.T.M. Projection, Zone 12 (Ref. Meridian 111 °)
(82J data was transformed to the above)
(a twist angle of 2 ° was applied for plotting purposes)

Lpb0210\~\litlbow_gain_loss_letter.dwg/00/11/03

Figure 5. Loading and loss (deposition, biological uptake) of total dissolved phosphorus (kg) between sampling sites along the Little Bow River and Mosquito Creek upstream of the proposed Little Bow Reservoir during March 24-September 1, 1999.

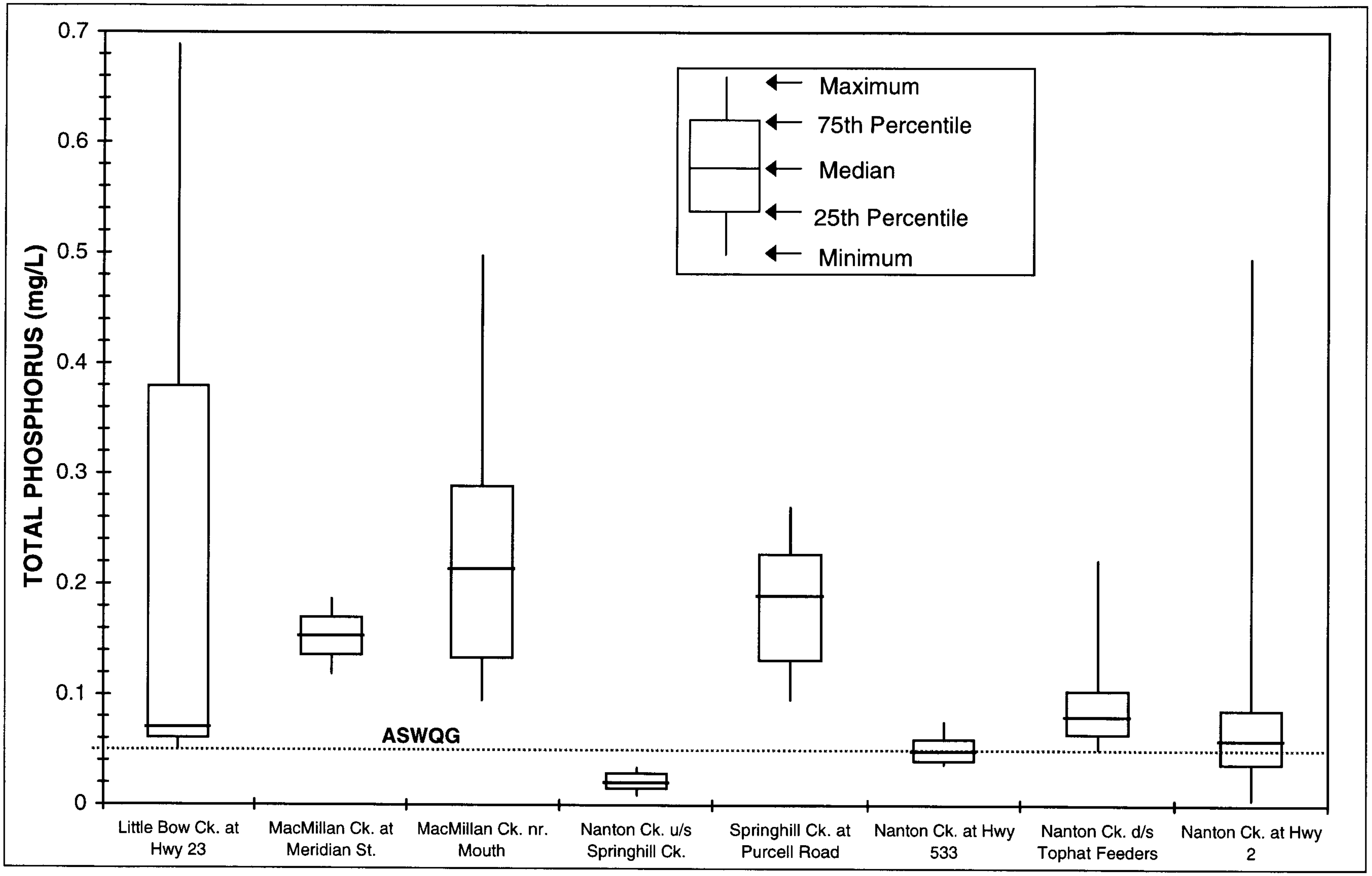


Figure 6. Concentration of total phosphorus at Little Bow, Nanton, MacMillian and Springhill Creek sites, March 24-September 1, 1999.

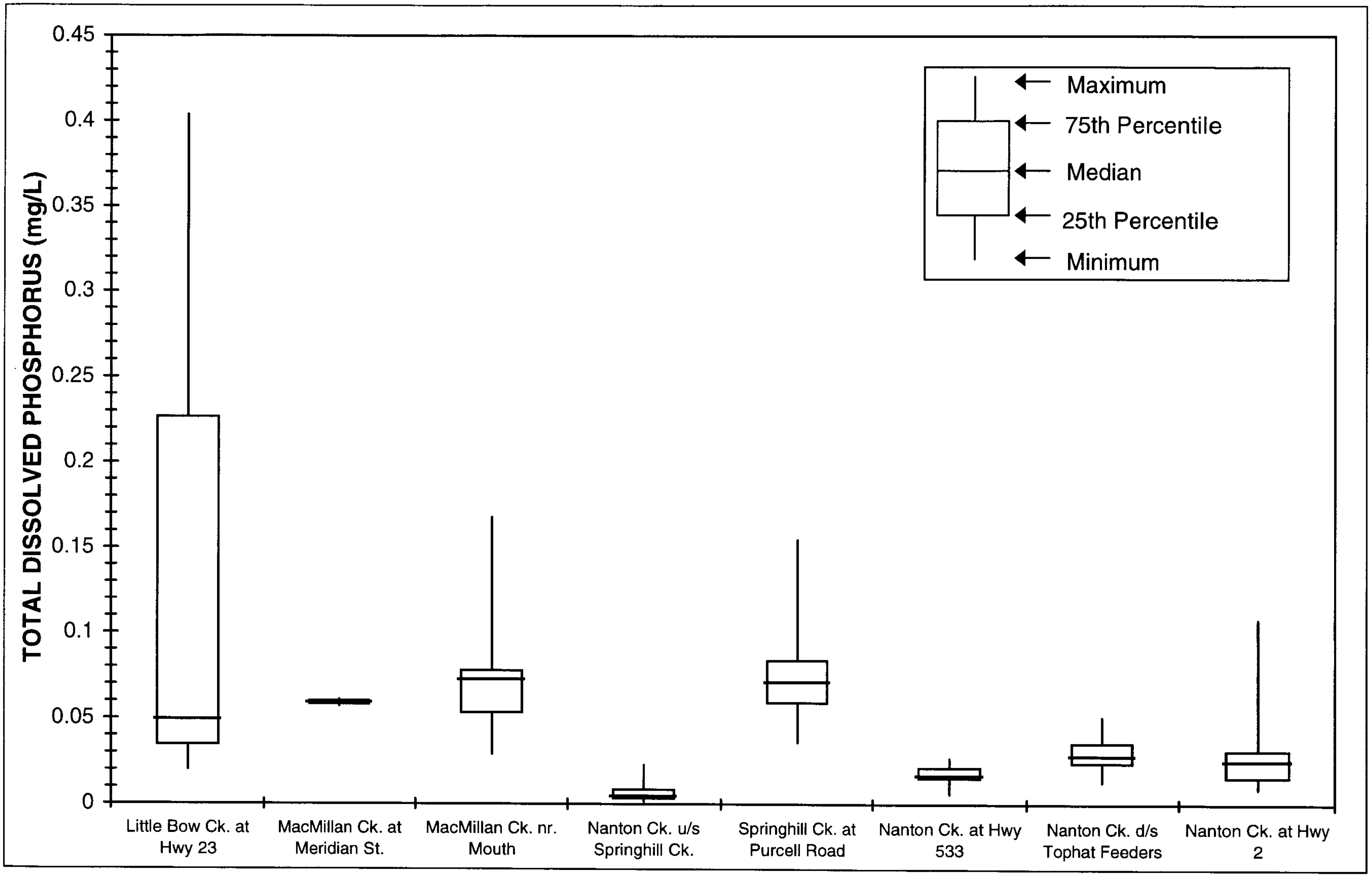


Figure 7. Concentration of total dissolved phosphorus at Little Bow, Nanton, MacMillian and Springhill Creek sites, March 24-September 1, 1999.

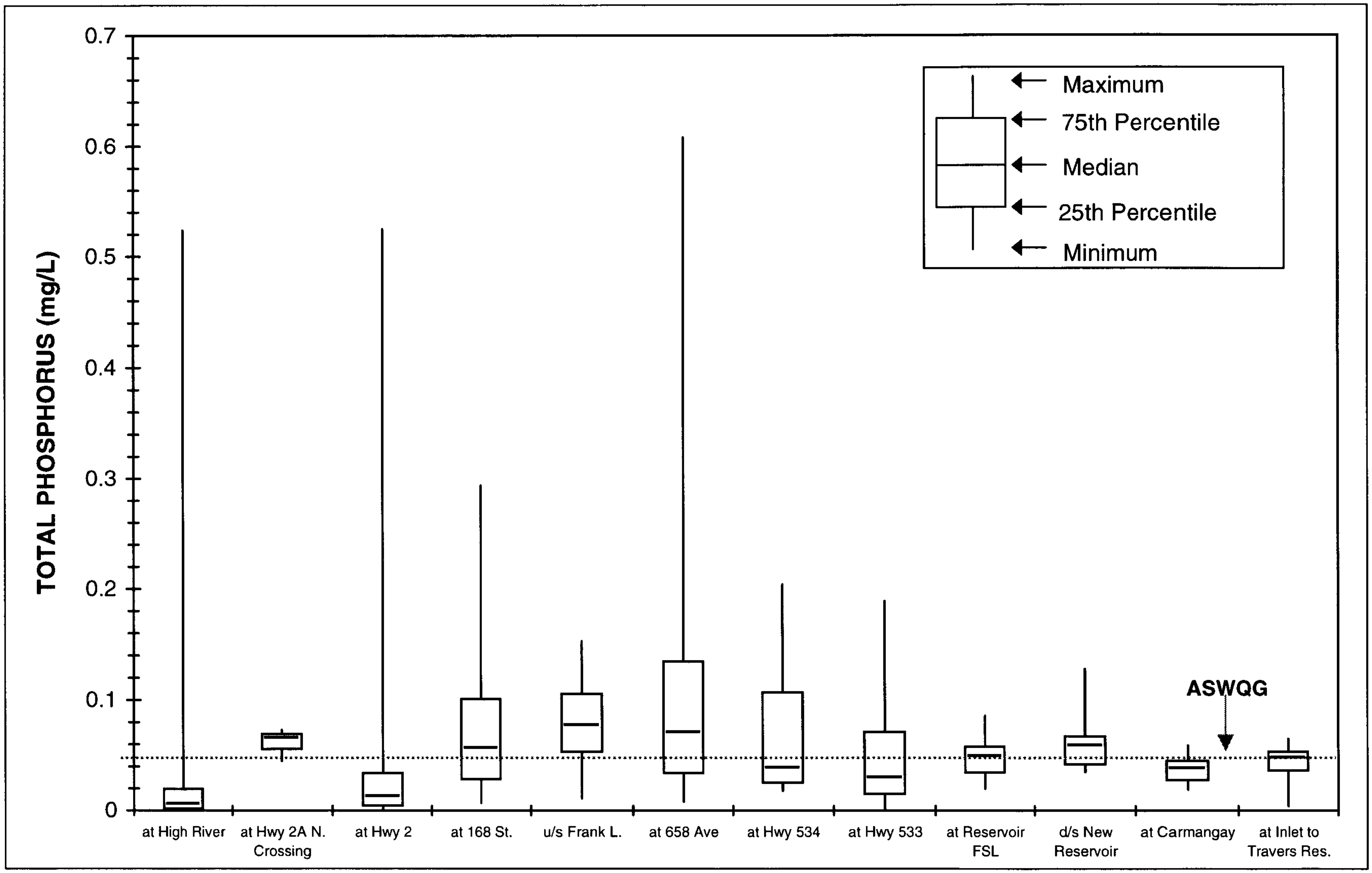


Figure 8. Concentration of total phosphorus at Little Bow River sites, March 24-September 1, 1999.

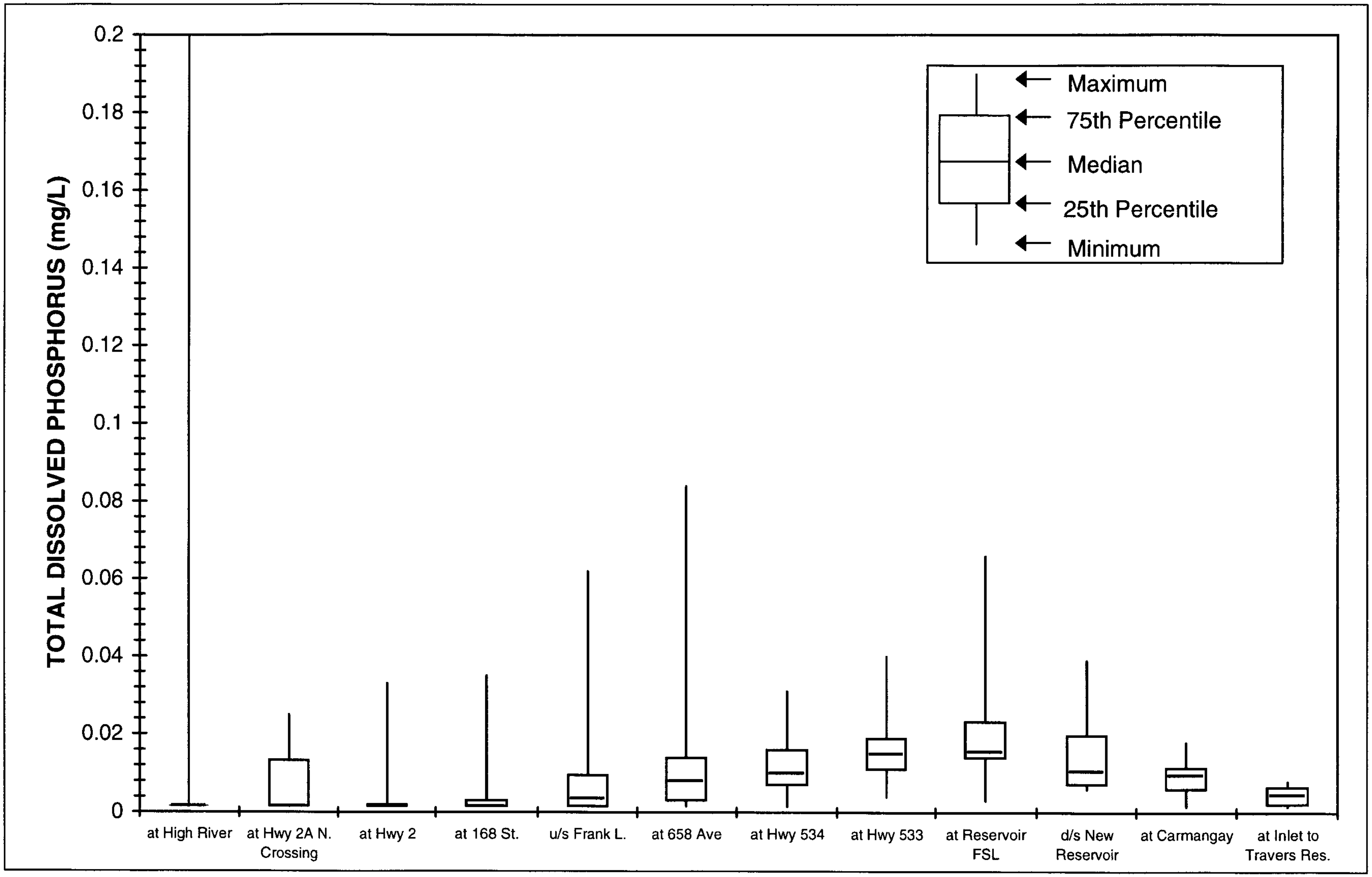


Figure 9. Concentration of total dissolved phosphorus at Little Bow River sites, March 24-September 1, 1999.

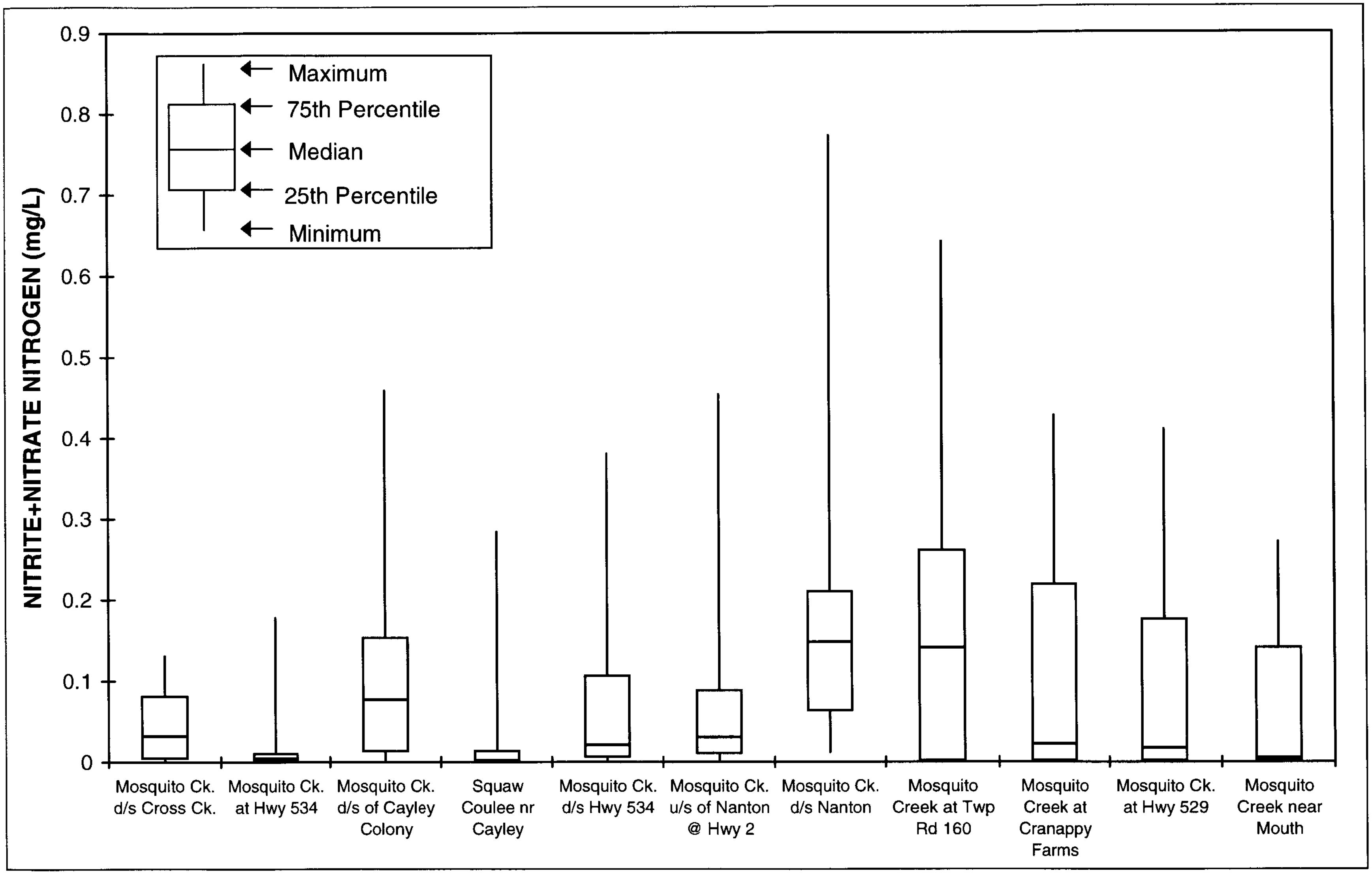
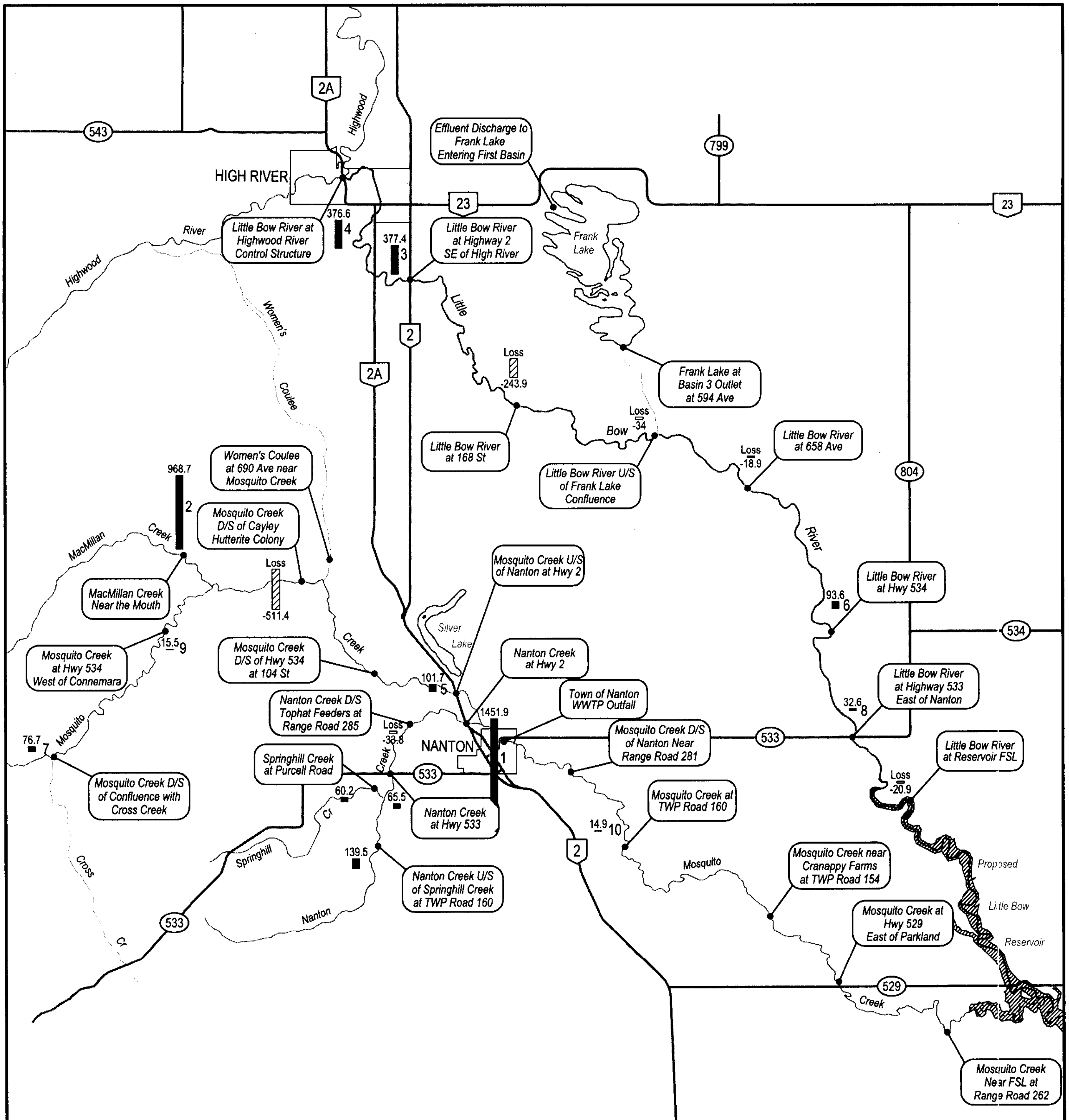


Figure 10. Concentration of nitrite+nitrate nitrogen at Mosquito Creek sites, March 24-September 1, 1999.



Nitrite+Nitrate

Legend:

Loss -243.9 — Decrease in mass between sites

377.4 3 — Increase in mass between sites; Rank

Alberta ENVIRONMENT
Natural Resources Service - Prairie Region

0 5 10 15 kms
0 5 10 miles
SCALE 1 : 250 000

NAD 83; U.T.M. Projection, Zone 12 (Ref. Meridian 111 °)
(82J data was transformed to the above)
(a twist angle of 2 ° was applied for plotting purposes)

Lpb0210\~\litbow_gain_loss_letter.dwg/00/11/03

Figure 11. Loading and loss (biological uptake, degradation) of nitrite+nitrate (kg) between sampling sites along the Little Bow River and Mosquito Creek upstream of the proposed Little Bow Reservoir during March 24-September 1, 1999.

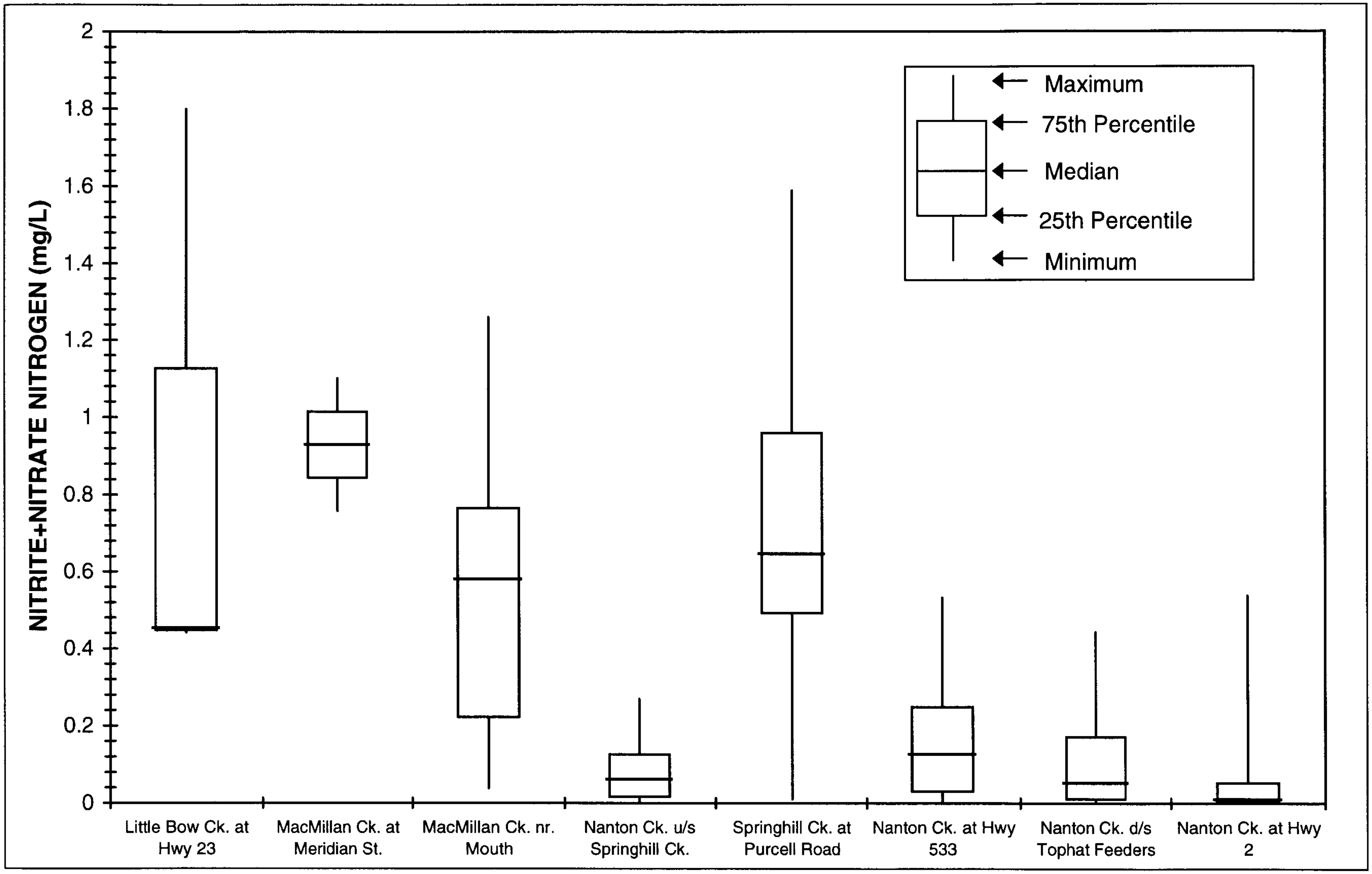


Figure 12. Concentration of nitrite+nitrate nitrogen at Little Bow, Nanton, MacMillian and Springhill Creek sites, March 24-September 1, 1999.

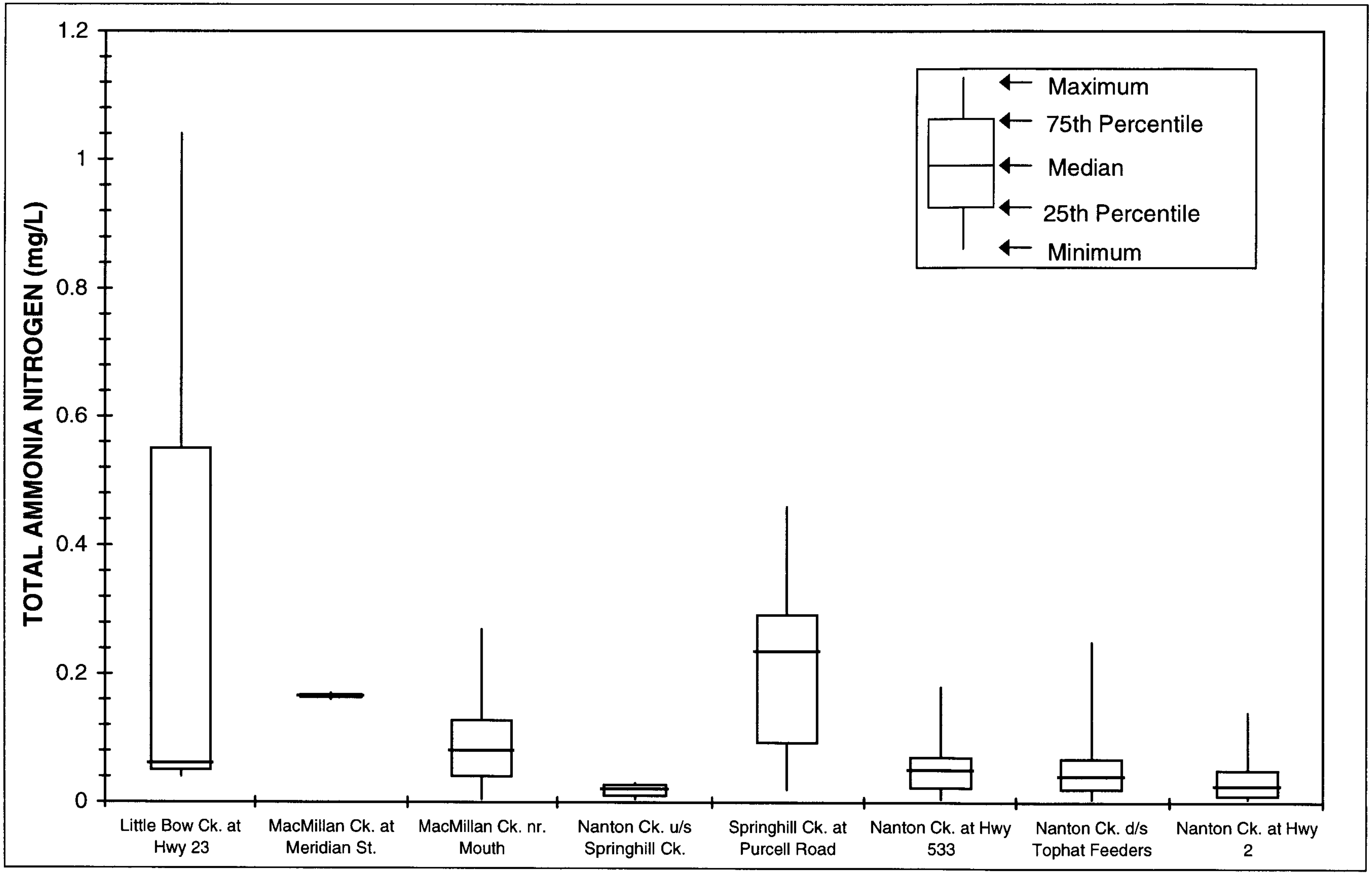


Figure 13. Concentration of total ammonia nitrogen at Little Bow, Nanton, MacMillian and Springhill Creek sites, March 24-September 1, 1999.

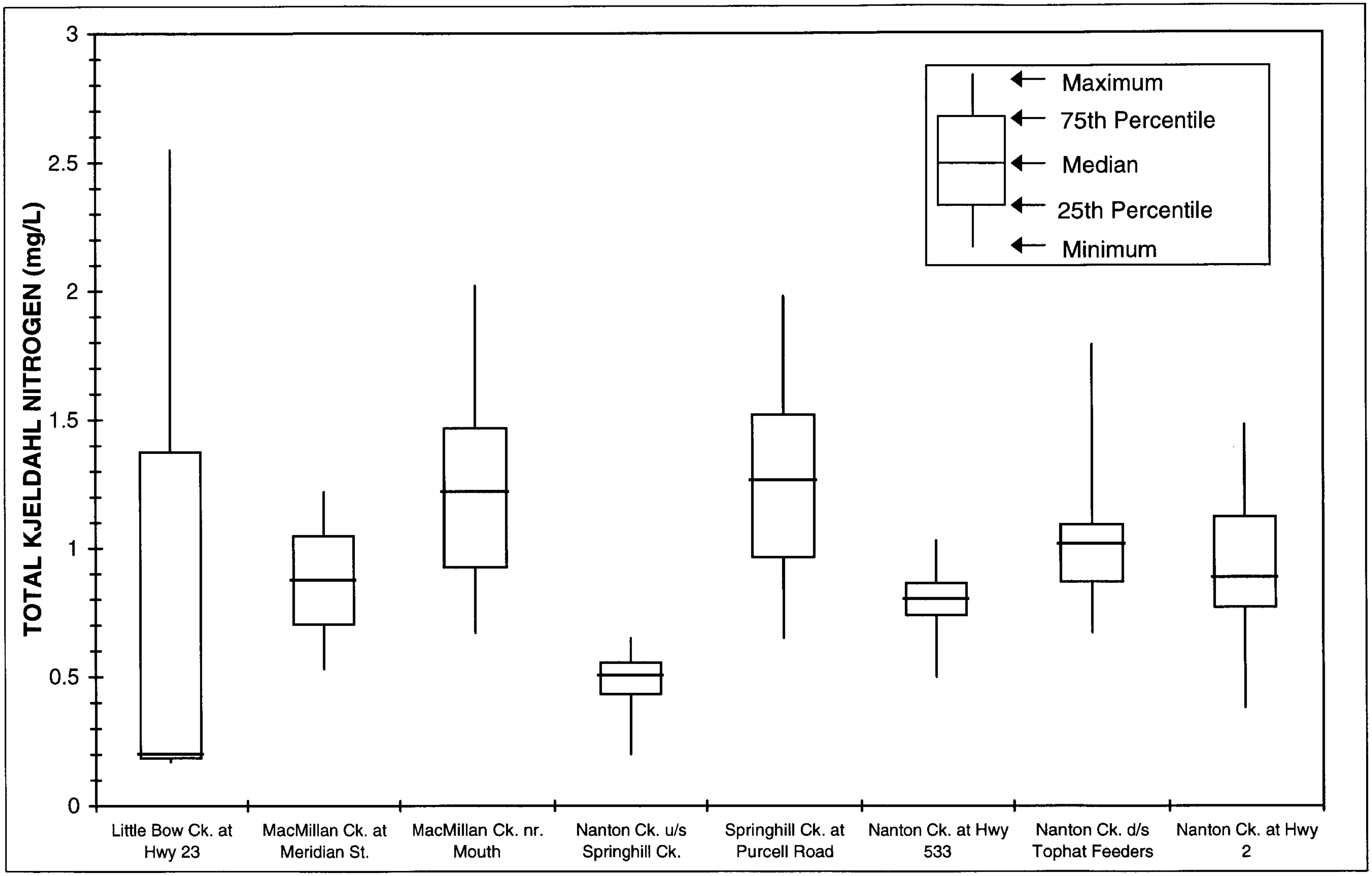


Figure 14. Concentration of total Kjeldahl nitrogen at Little Bow, Nanton, MacMillian and Springhill Creek sites, March 24-September 1, 1999.

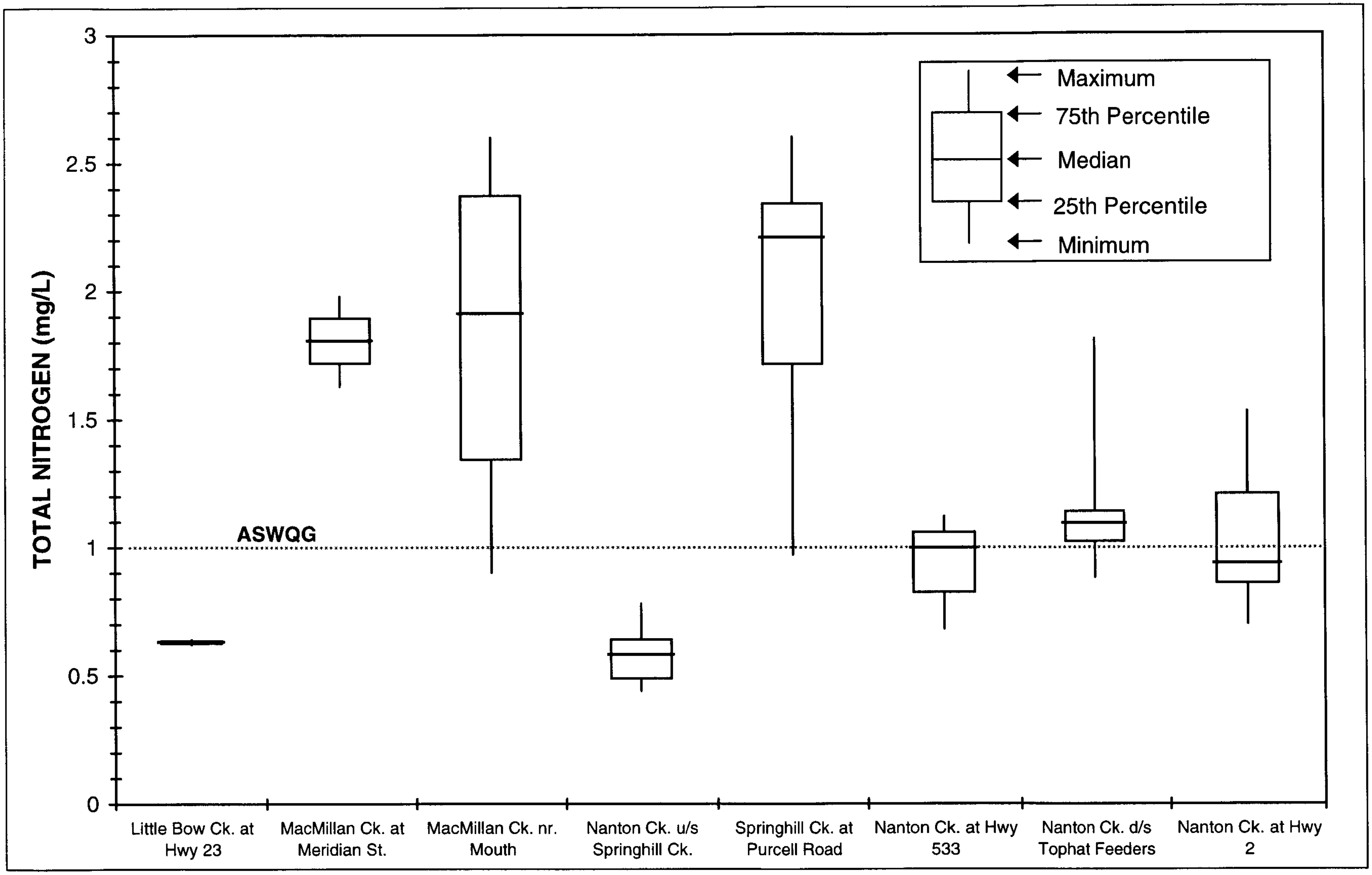
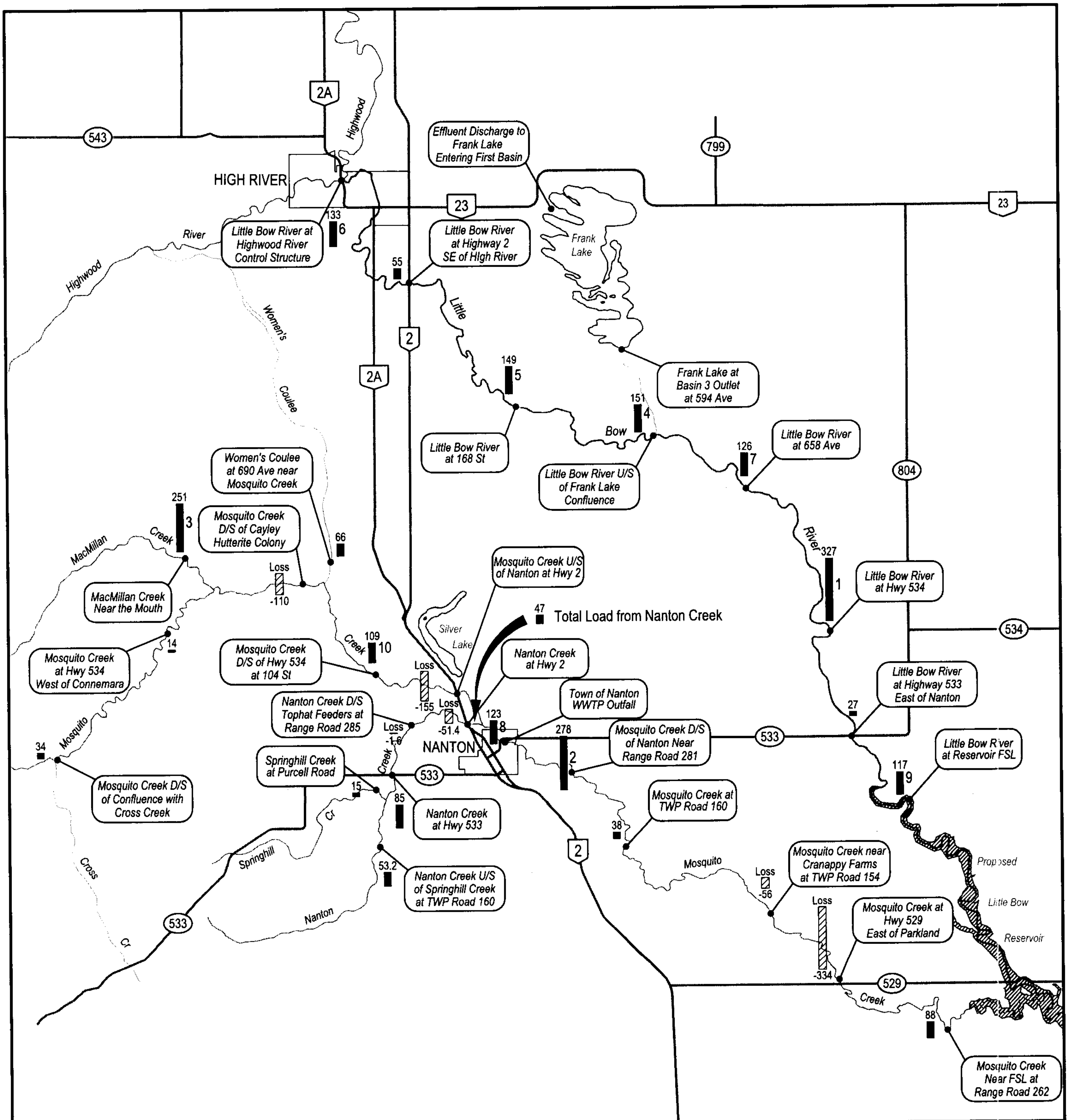


Figure 15. Concentration of total nitrogen at Little Bow, Nanton, MacMillian and Springhill Creek sites, March 24-September 1, 1999.



Total Ammonia

ALBERTA ENVIRONMENT

Natural Resources Service - Prairie Region

Legend:

Loss -110 — Decrease in mass between sites

151 4 — Increase in mass between sites; Rank

0 5 10 15 kms

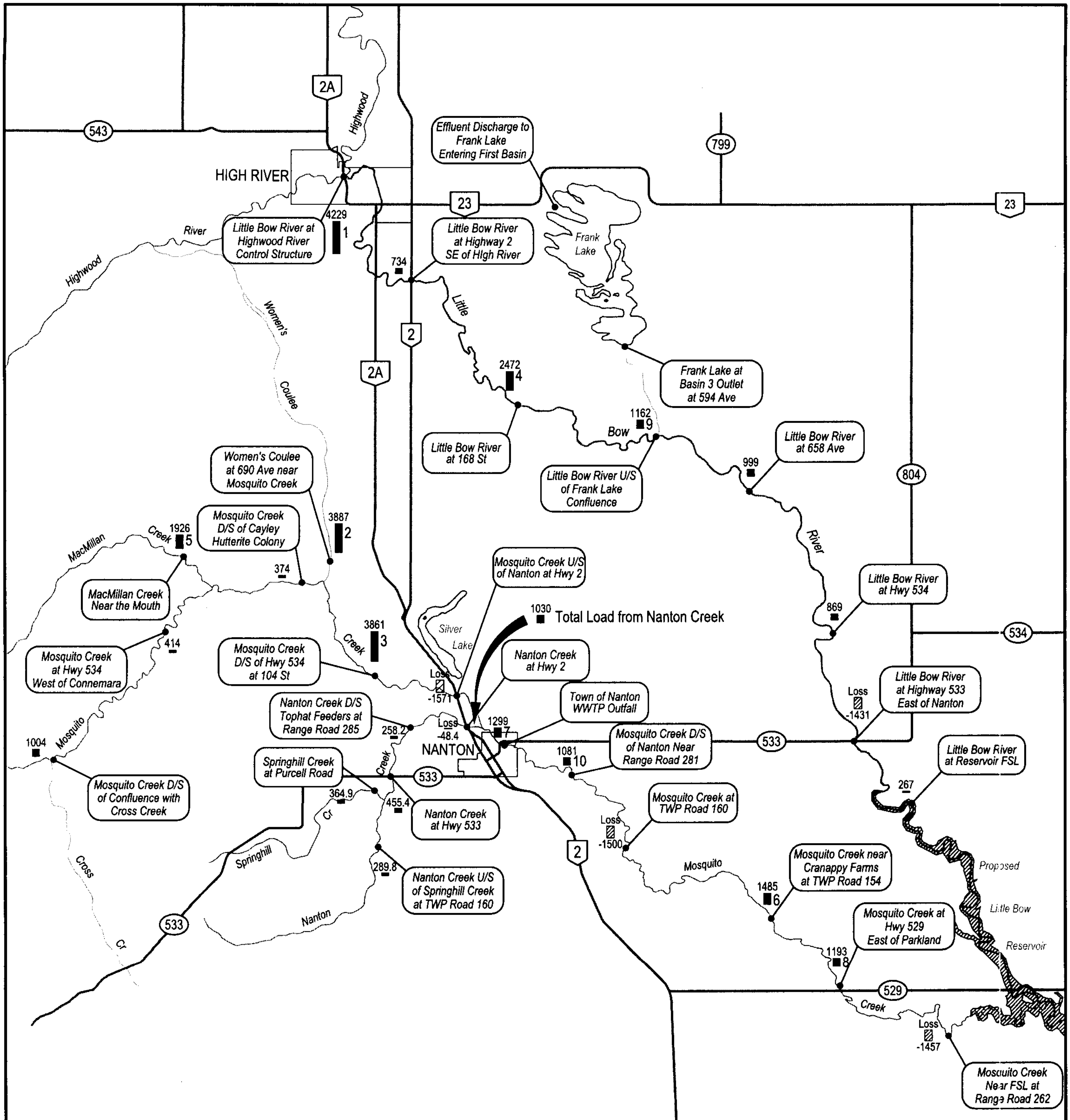
0 5 10miles

SCALE 1 : 250 000

NAD 83; U.T.M. Projection, Zone 12 (Ref. Meridian 111 °)
(82J data was transformed to the above)
(a twist angle of 2 ° was applied for plotting purposes)

Figure 16. Loading and loss (biological uptake, degradation) of total ammonia (kg) between sampling sites along the Little Bow River and Mosquito Creek upstream of the proposed Little Bow Reservoir during March 24-September 1, 1999.

Lpb0210\~\littbow_gain_loss_letter.dwg/00/11/03



Total Kjeldahl Nitrogen

Legend:

Increase in mass between sites

Decrease in mass between sites

Rank

Alberta ENVIRONMENT

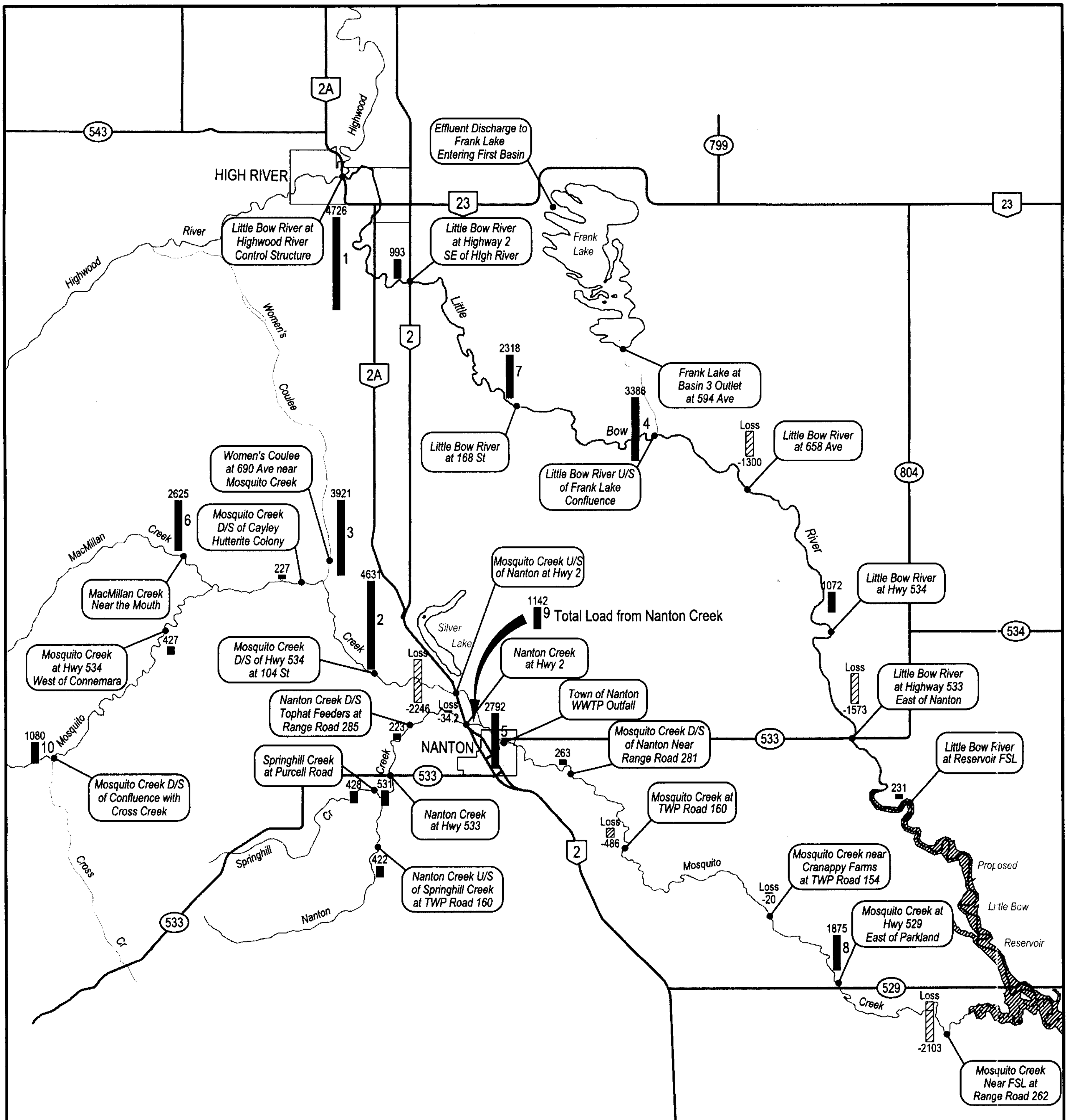
Natural Resources Service - Prairie Region

SCALE 1 : 250 000

NAD 83; U.T.M. Projection, Zone 12 (Ref. Meridian 111 °)
(82J data was transformed to the above)
(a twist angle of 2° was applied for plotting purposes)

Lpb0210\~\littbow_gain_loss_letter.dwg/00/11/03

Figure 17. Loading and loss (biological uptake, degradation) of total Kjeldahl nitrogen (kg) between sampling sites along the Little Bow River and Mosquito Creek upstream of the proposed Little Bow Reservoir during March 24-September 1, 1999.



Total Nitrogen

Legend:

Loss -1300 — Decrease in mass between sites

1875 8 — Increase in mass between sites; Rank

Alberta ENVIRONMENT

Natural Resources Service - Prairie Region

0 5 10 15 kms

0 5 10 miles

SCALE 1 : 250 000

NAD 83; U.T.M. Projection, Zone 12 (Ref. Meridian 111 °)
(82J data was transformed to the above)
(a twist angle of 2 ° was applied for plotting purposes)

Lpb02101~liitbow_gain_loss_letter.dwg/00/11/03

Figure 18. Loading and loss (biological uptake, degradation) of total nitrogen (kg) between sampling sites along the Little Bow River and Mosquito Creek upstream of the proposed Little Bow Reservoir during March 24-September 1, 1999.

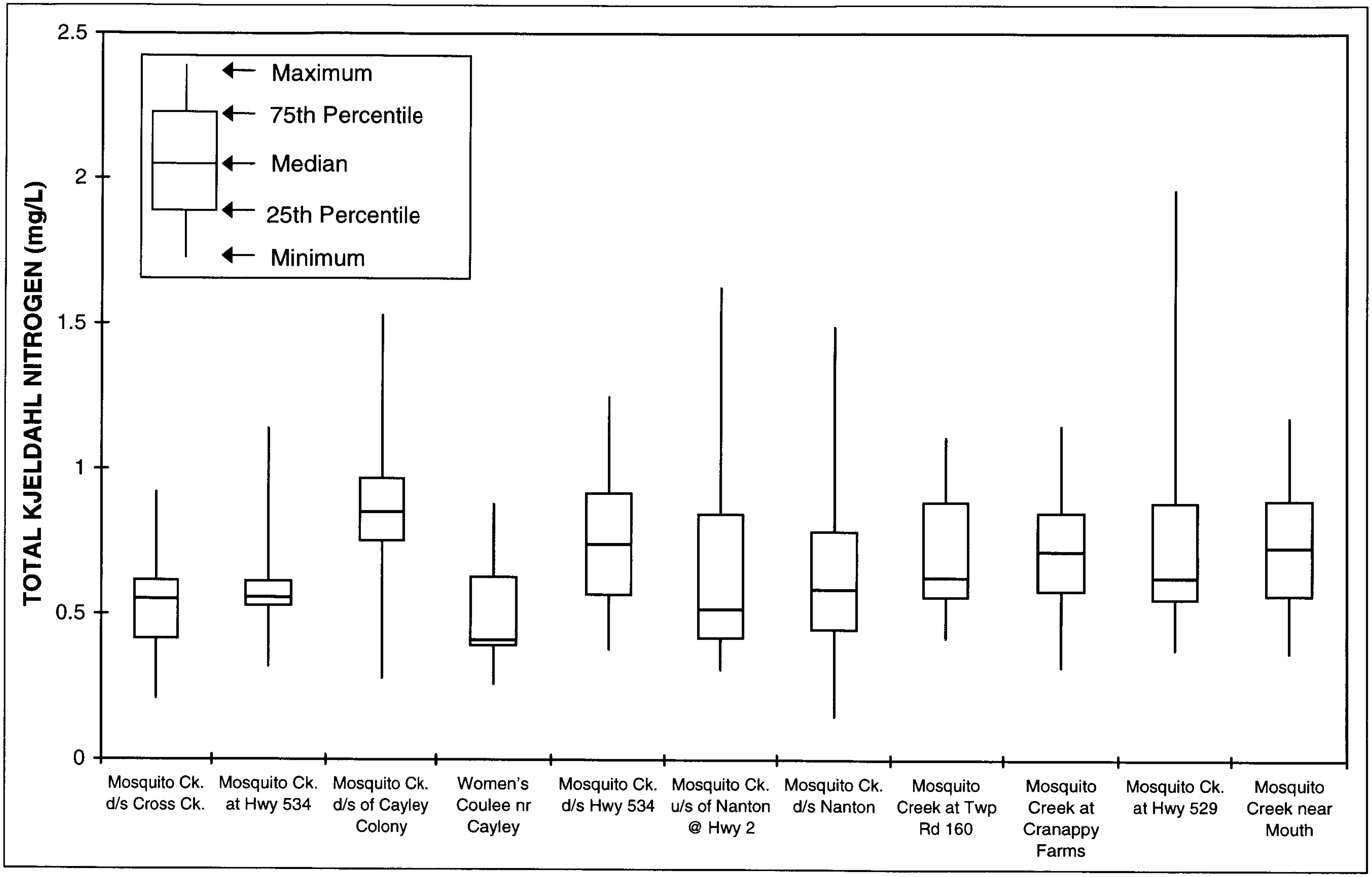


Figure 19. Concentration of total Kjeldahl nitrogen at Mosquito Creek sites, March 24-September 1, 1999.

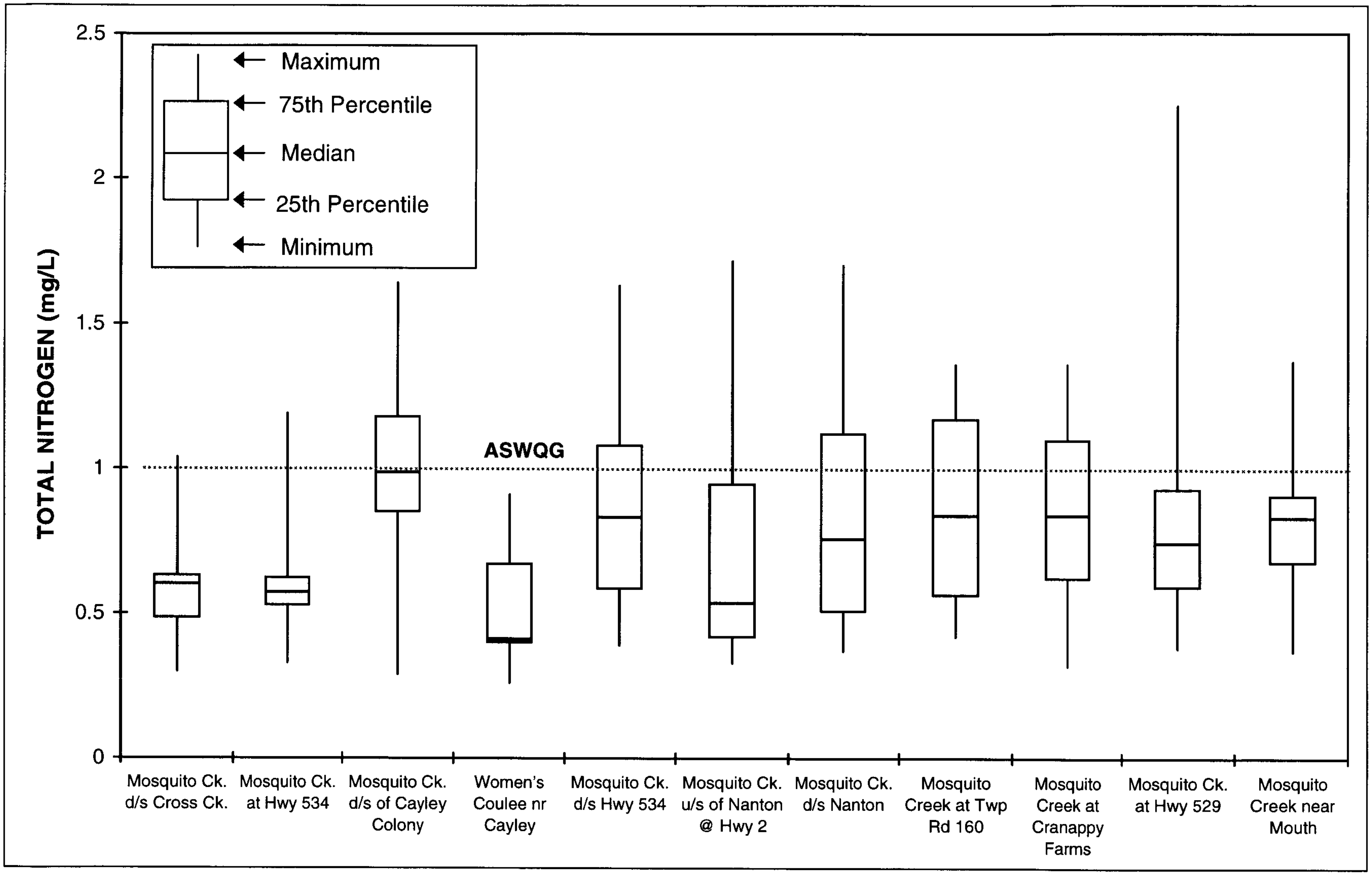


Figure 20. Concentration of total nitrogen at Mosquito Creek sites, March 24-September 1, 1999.

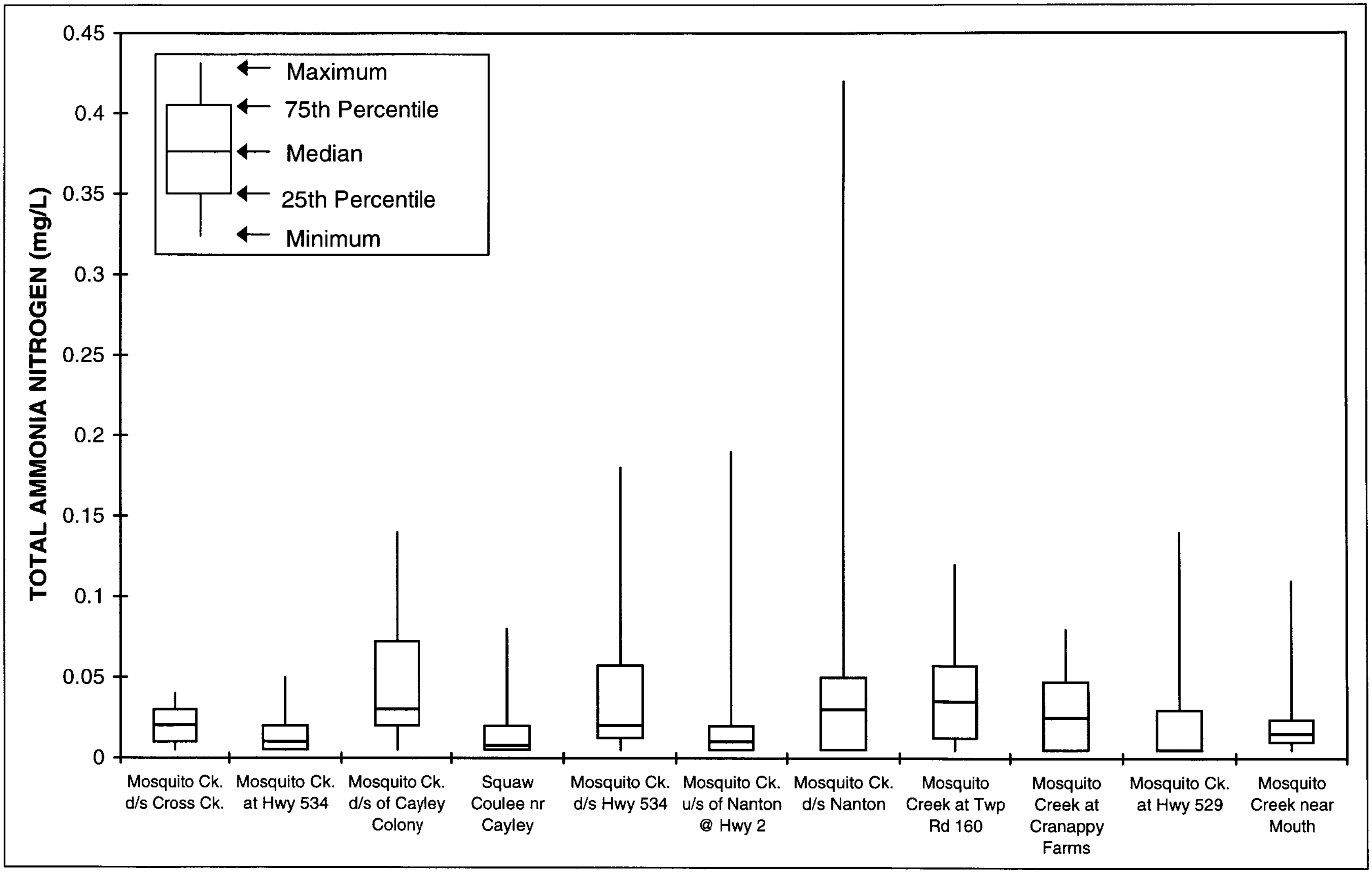


Figure 21. Concentration of total ammonia nitrogen at Mosquito Creek sites, March 24-September 1, 1999.

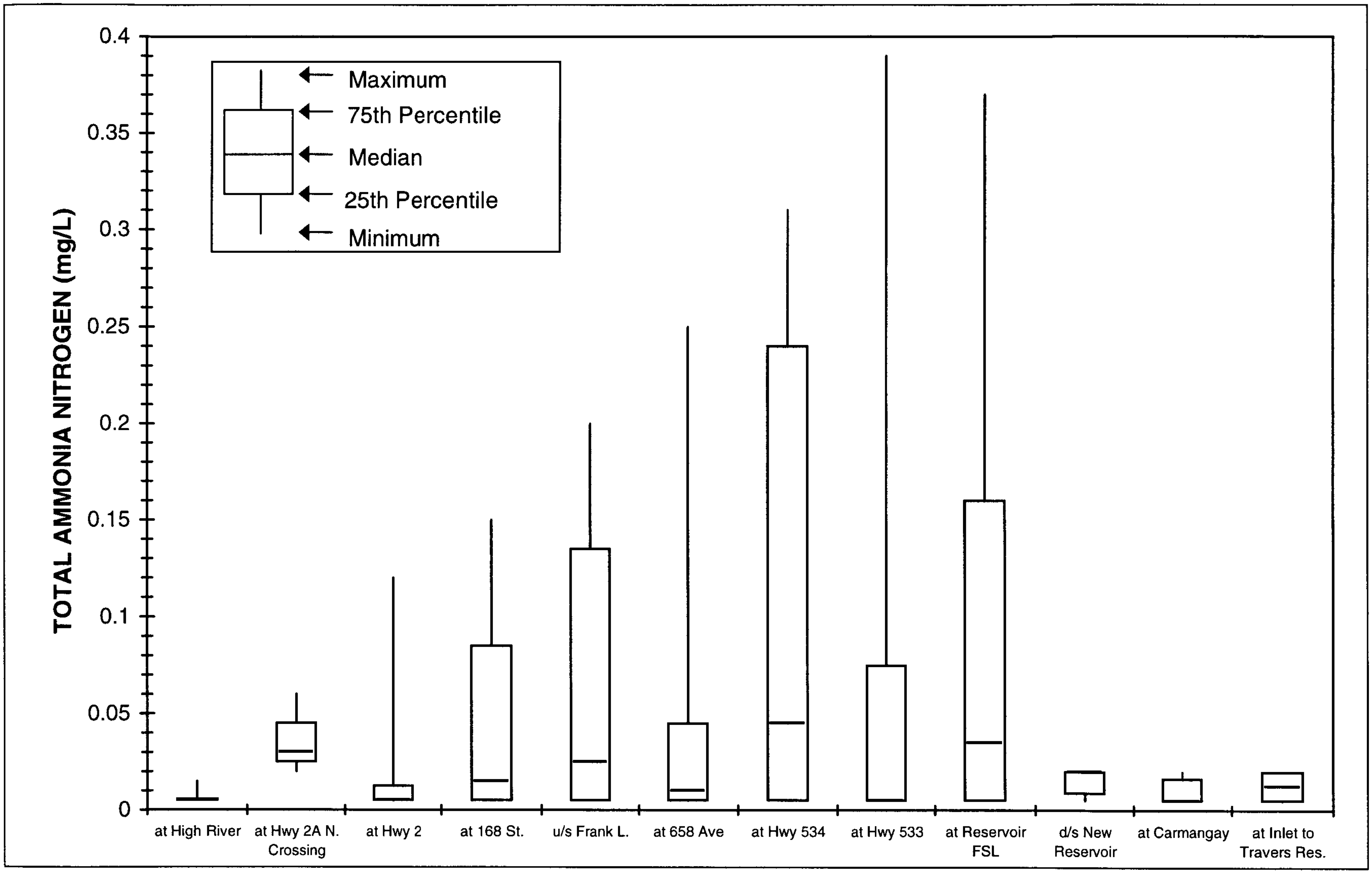


Figure 22. Concentration of total ammonia nitrogen at Little Bow River sites, March 24-September 1, 1999.

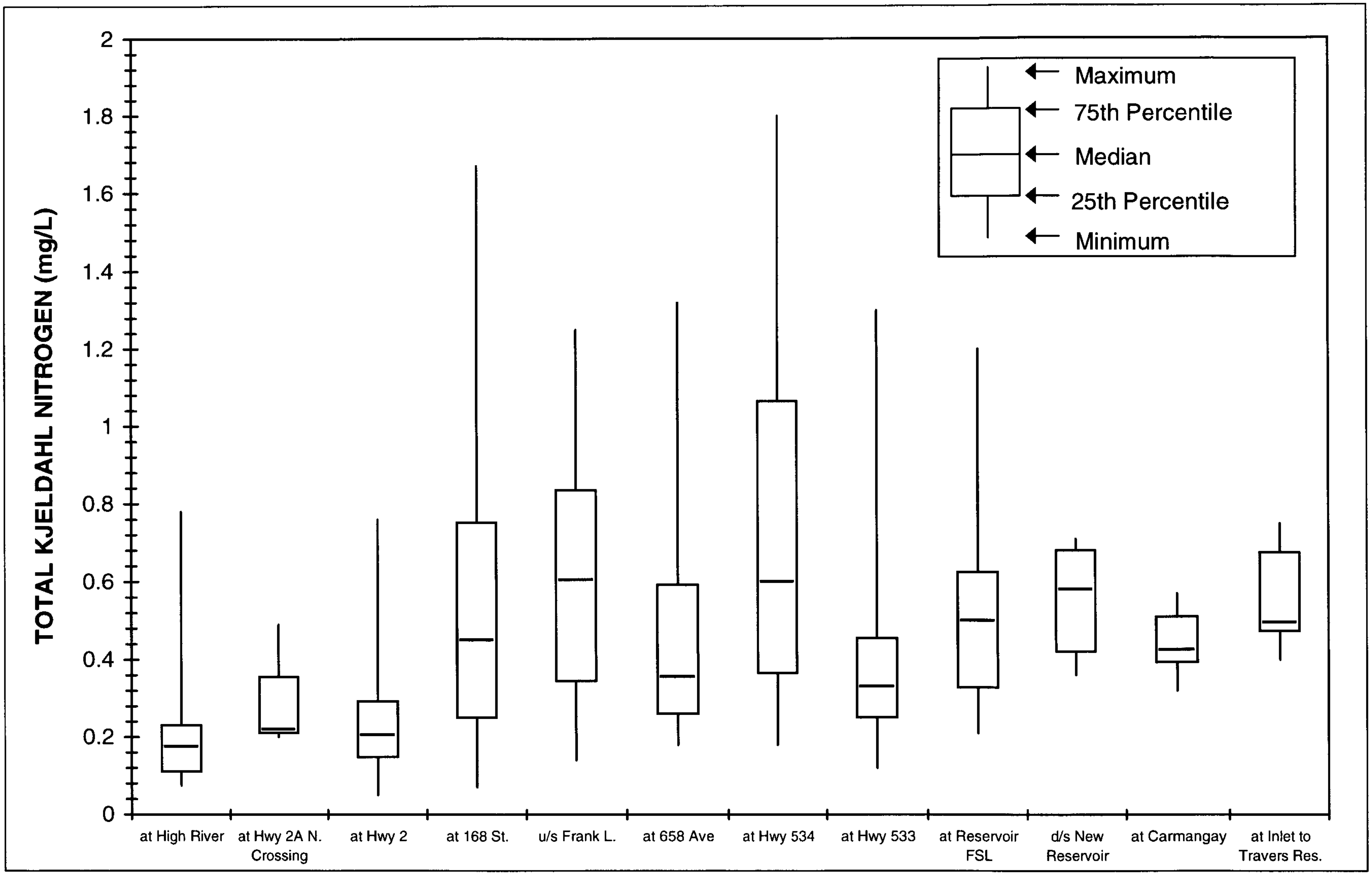


Figure 23. Concentration of total Kjeldahl nitrogen at Little Bow River sites, March 24-September 1, 1999.

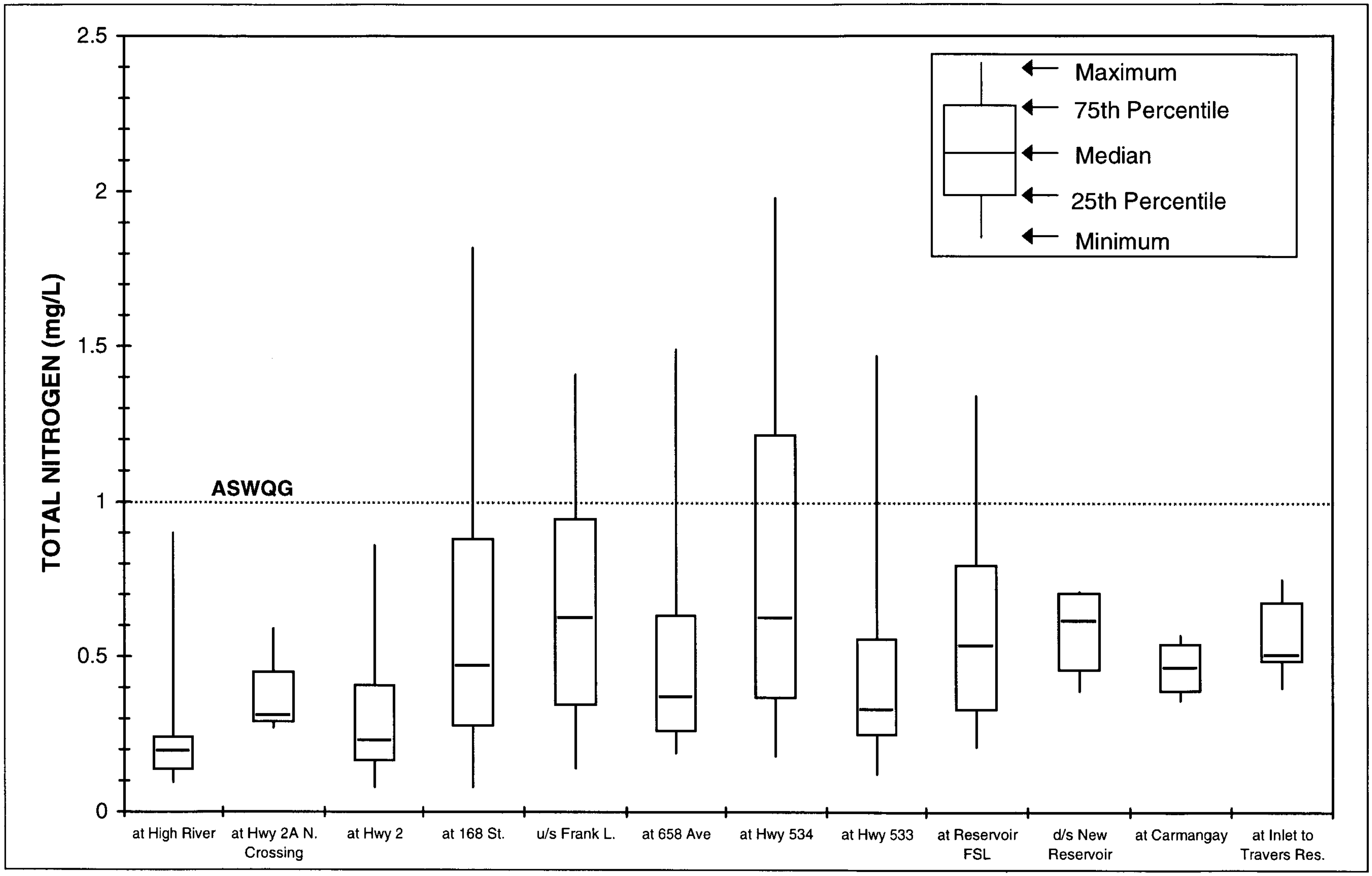


Figure 24. Concentration of total nitrogen at Little Bow River sites, March 24-September 1, 1999.

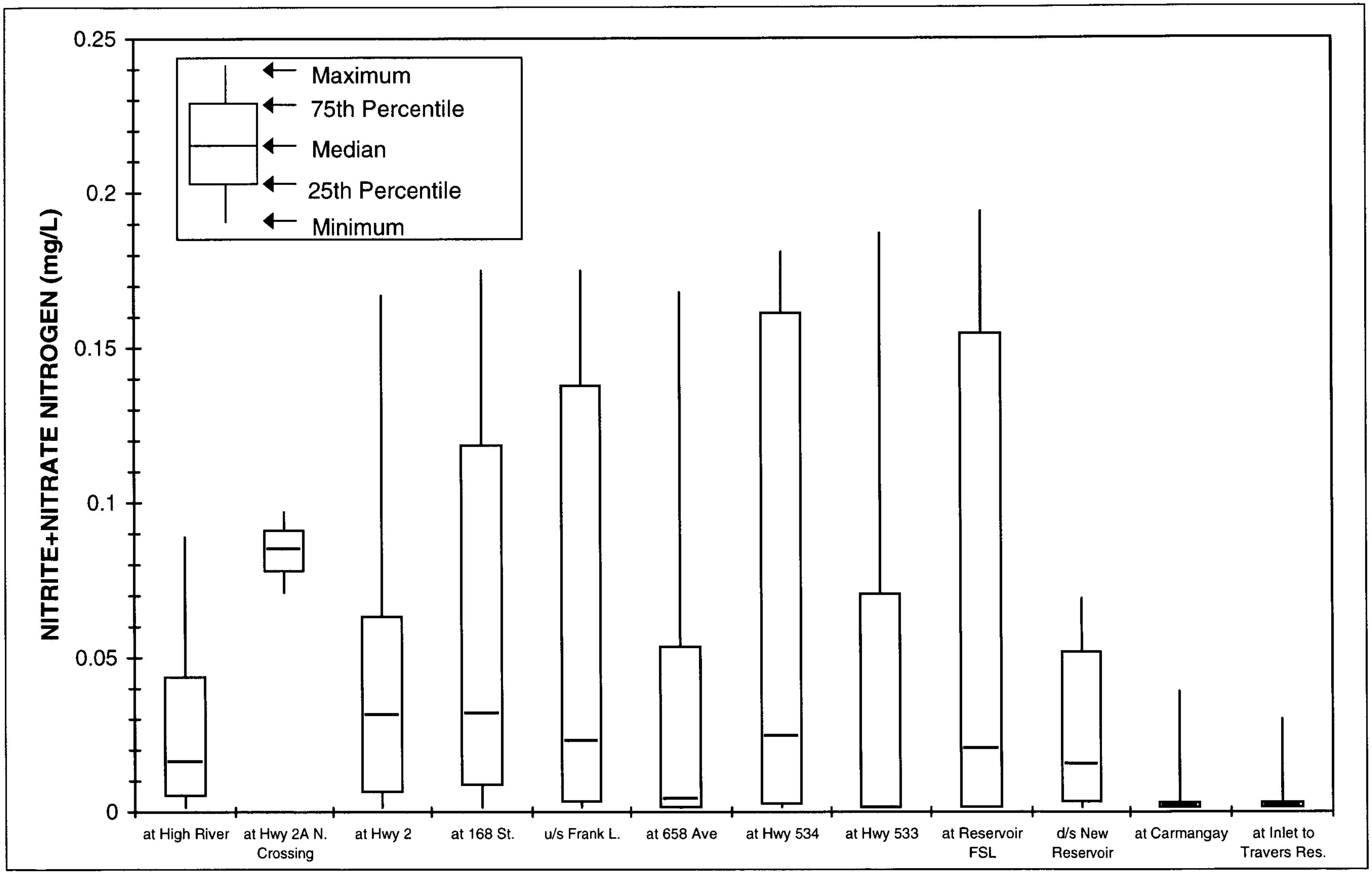


Figure 25. Concentration of nitrite+nitrate nitrogen at Little Bow River sites, March 24-September 1, 1999.

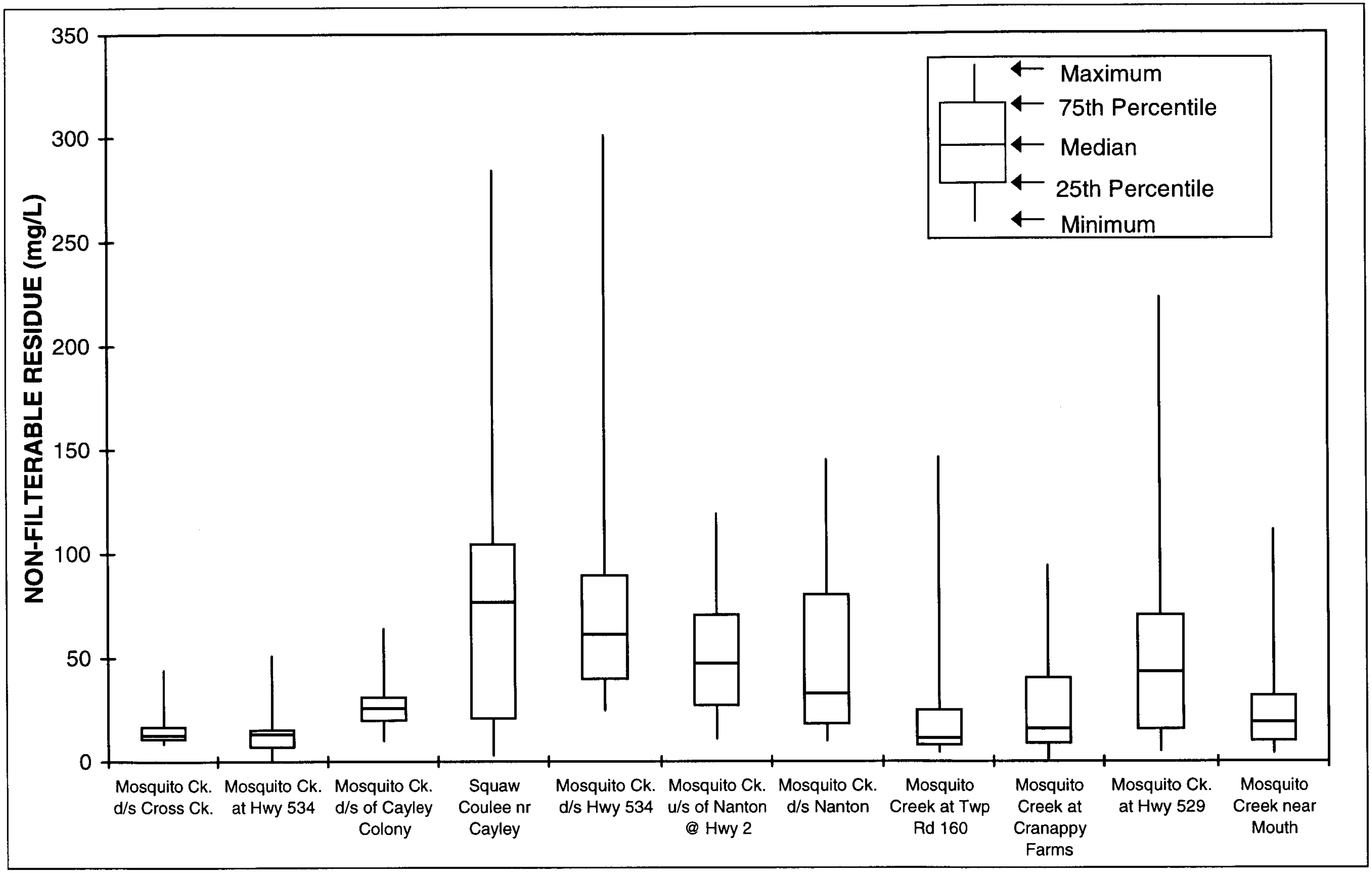


Figure 26. Concentration of non-filterable residue at Mosquito Creek sites, March 24-September 1, 1999.

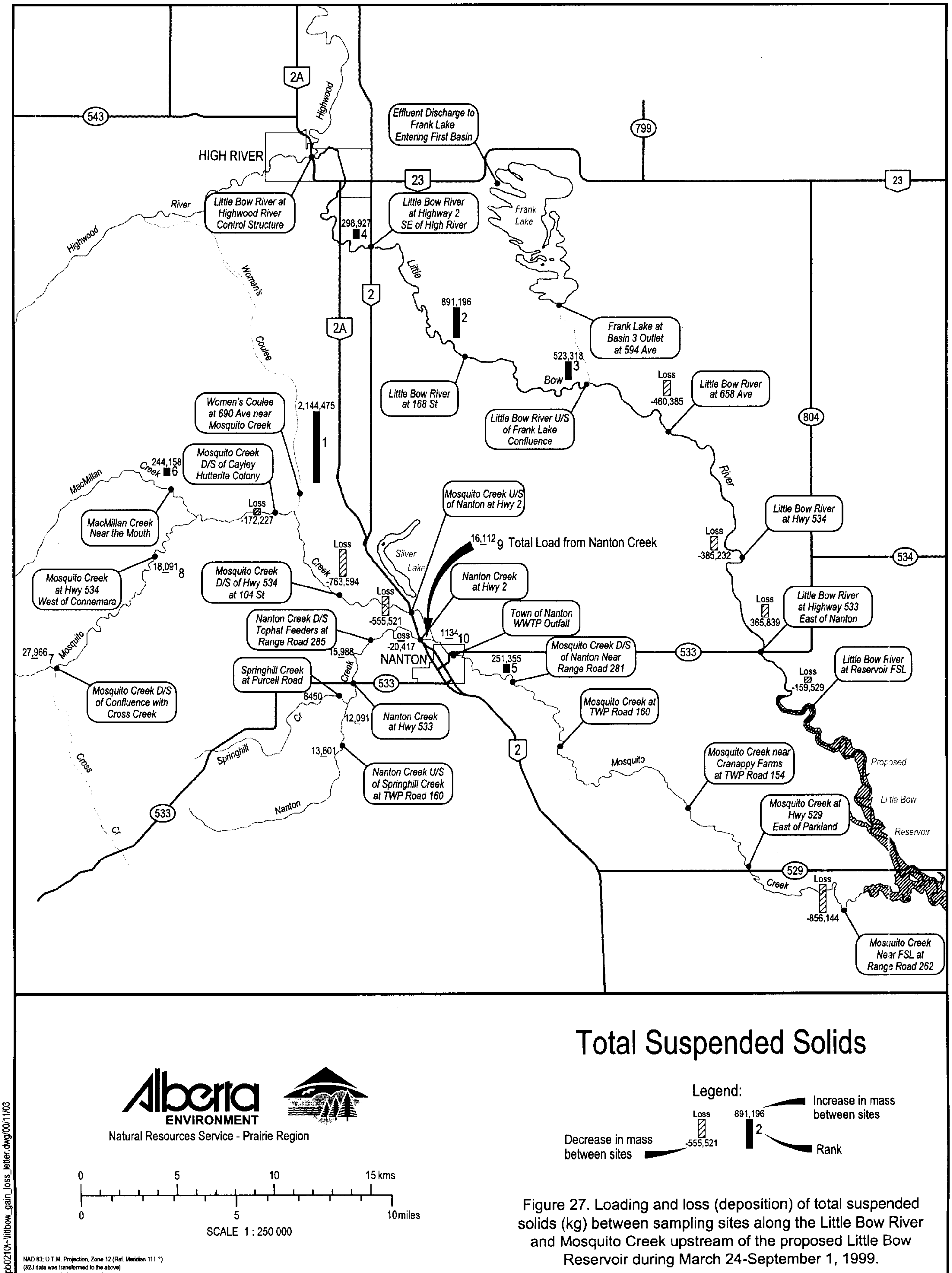


Figure 27. Loading and loss (deposition) of total suspended solids (kg) between sampling sites along the Little Bow River and Mosquito Creek upstream of the proposed Little Bow Reservoir during March 24-September 1, 1999.

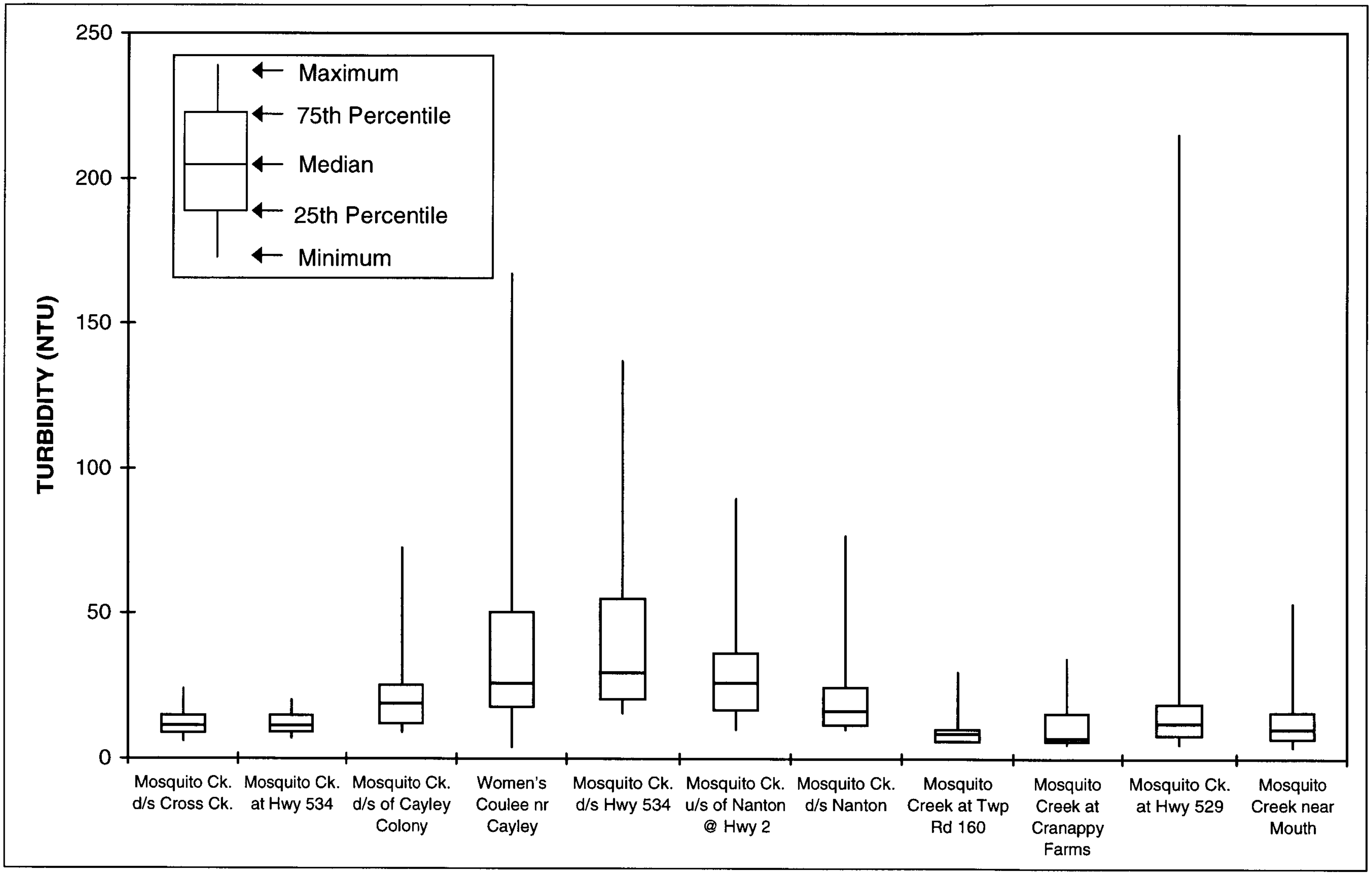


Figure 28. Turbidity at Mosquito Creek sites, March 24-September 1, 1999.

Figure 29. Undercut bank along Women's Coulee downstream from Secondary Road 540.

Figure 30. Eroding bank downstream from culvert near the owner’s residence.

Figure 31. Downstream end of reach with bank erosion near Old Women's Buffalo Jump.

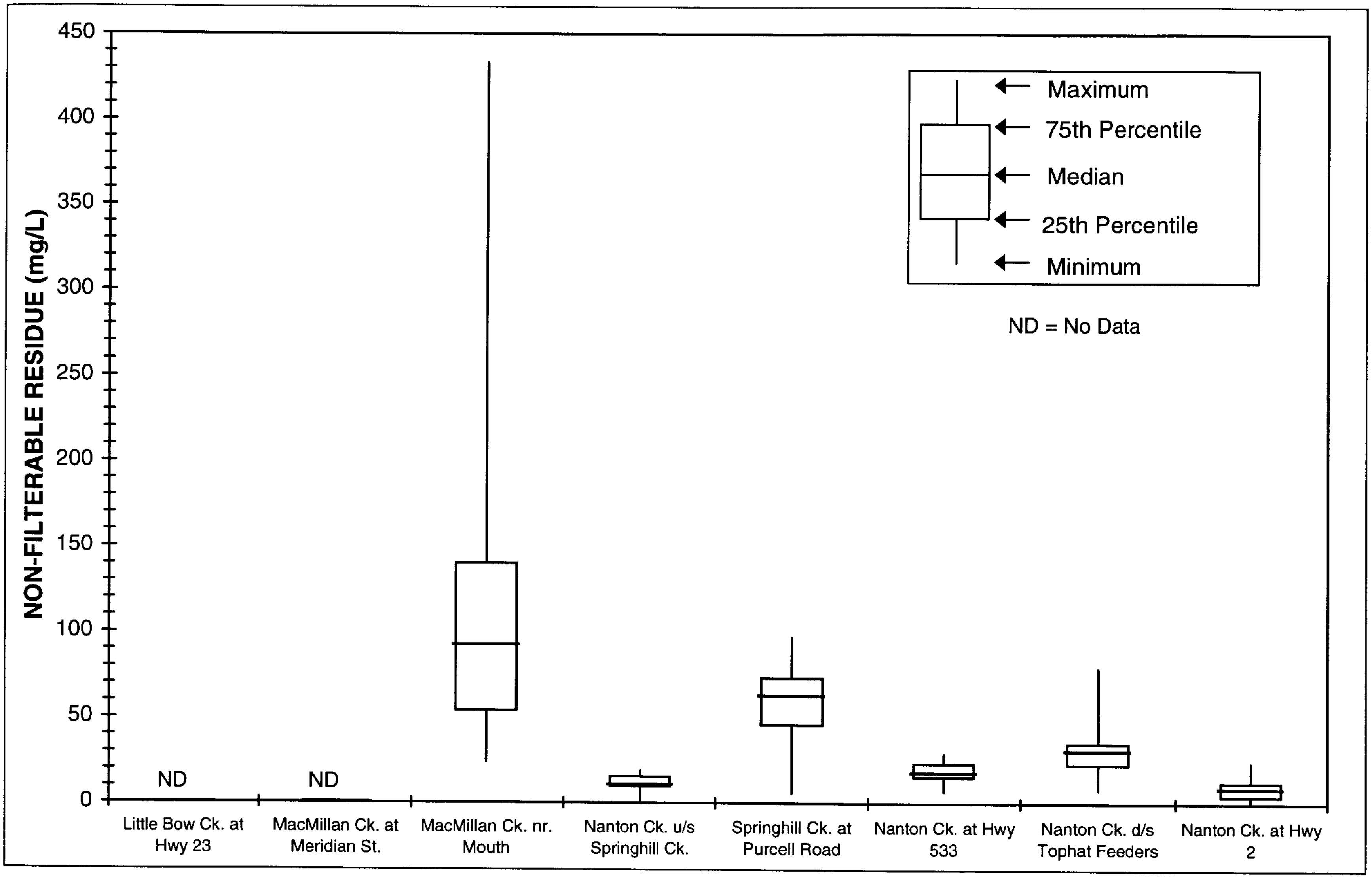


Figure 32. Concentration of non-filterable residue at Little Bow, Nanton, MacMillian and Springhill Creek sites, March 24-September 1, 1999.

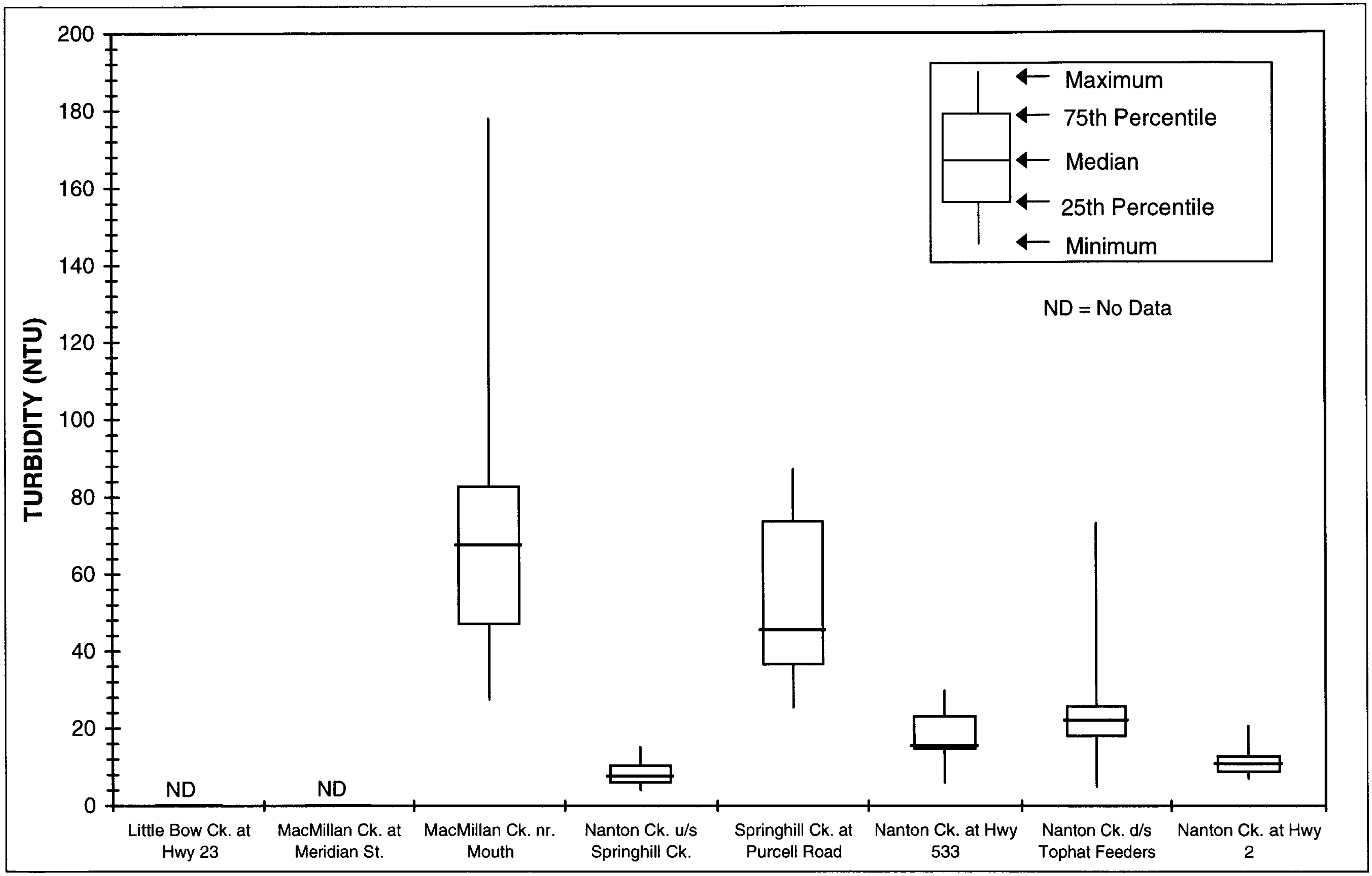


Figure 33. Turbidity at Little Bow, Nanton, MacMillian and Springhill Creek sites, March 24-September 1, 1999.

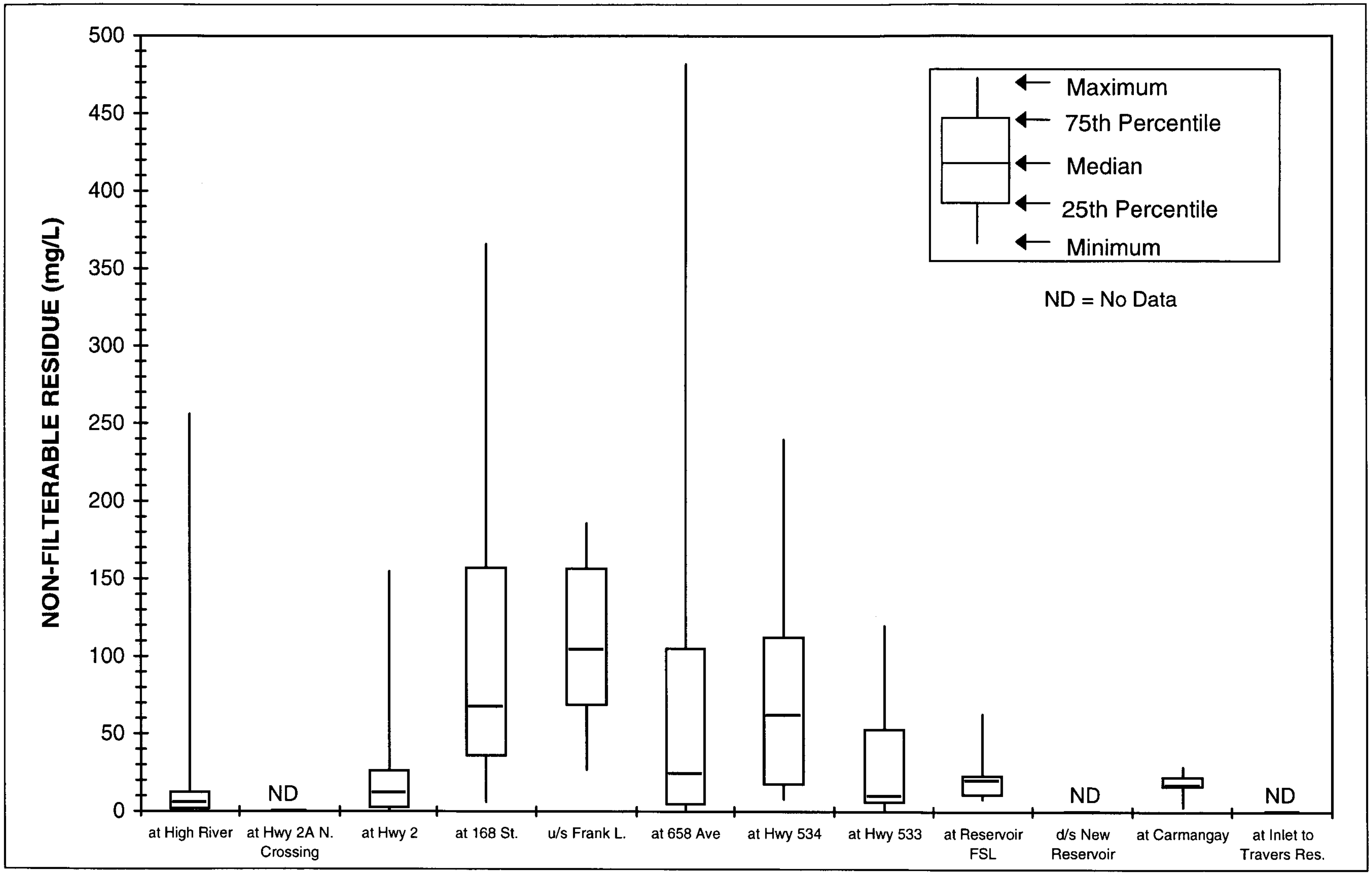


Figure 34. Concentration of non-filterable residue at Little Bow River sites, March 24-September 1, 1999.

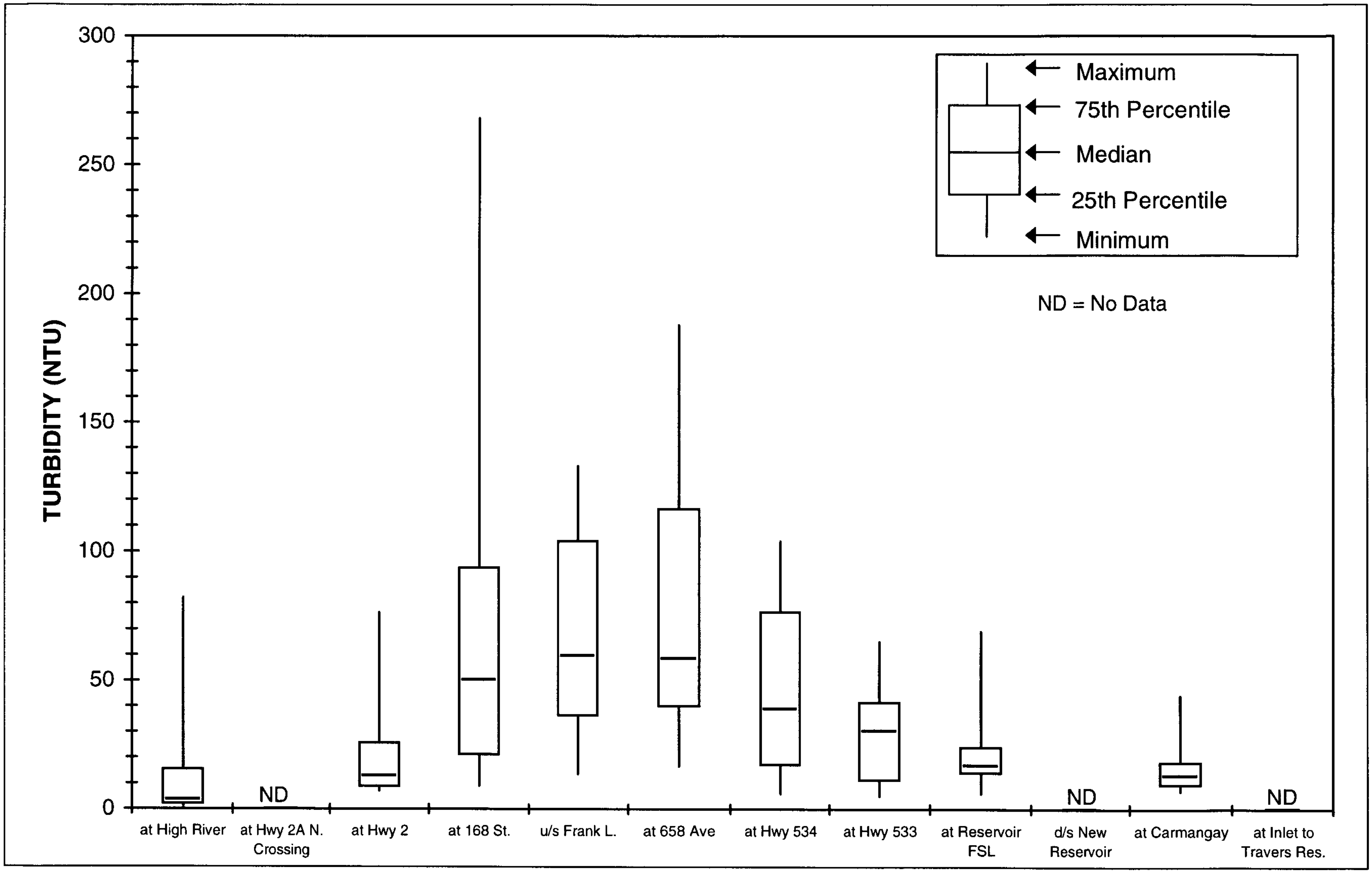


Figure 35. Turbidity at Little Bow River sites, March 24-September 1, 1999.

Figure 36. Erosion along Little Bow River between Highway 2 and 168 St.

Figure 37. Erosion along Little Bow River between Highway 2 and 168 St.

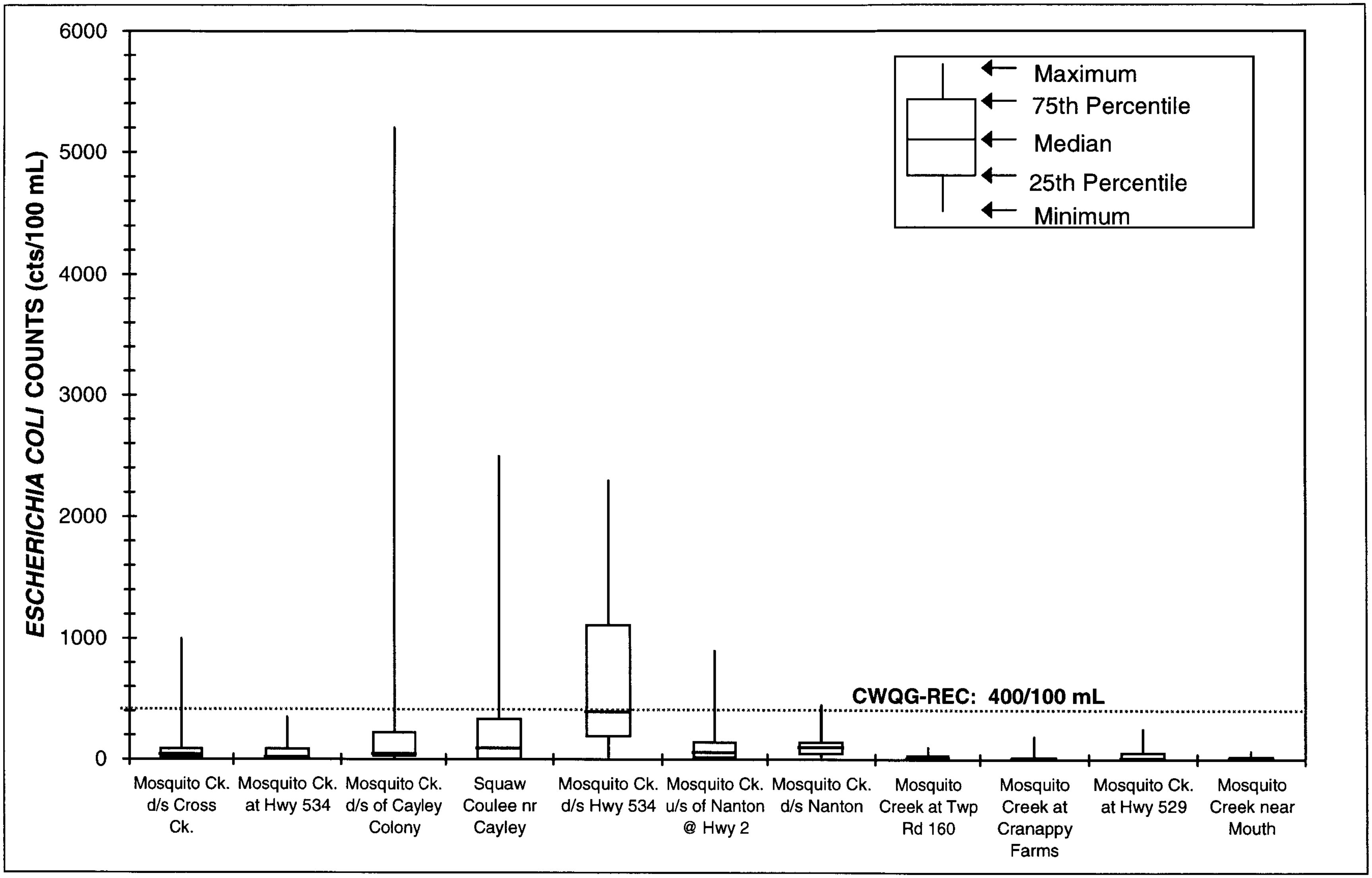


Figure 38. ***Escherichia coli*** **counts at Mosquito Creek sites, March 24-September 1, 1999.**

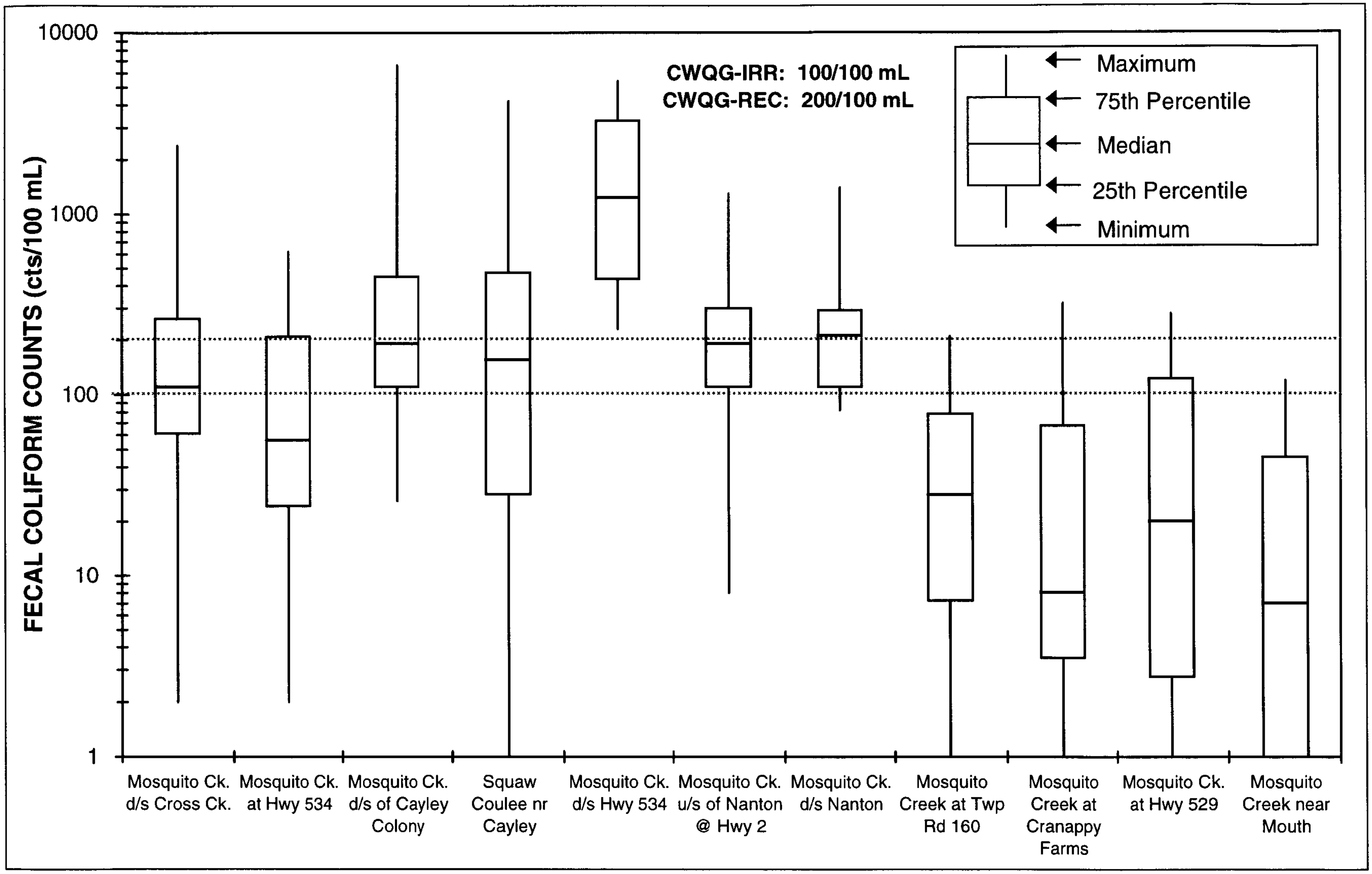


Figure 39. Fecal coliform counts at Mosquito Creek sites, March 24-September 1, 1999.

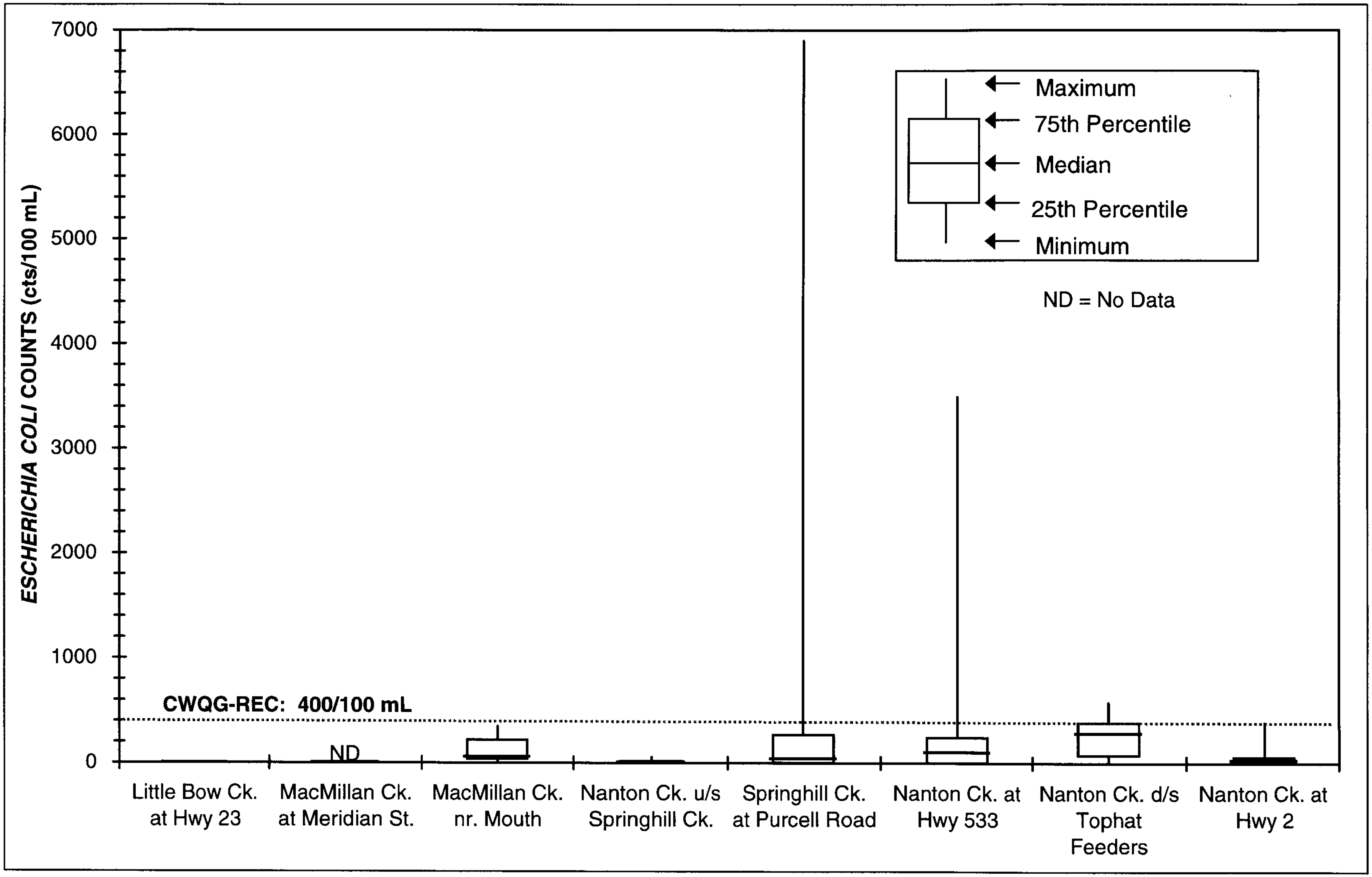


Figure 40. ***Escherichia coli*** **counts at Little Bow, Nanton, MacMillian and Springhill Creek sites, March 24-September 1, 1999.**

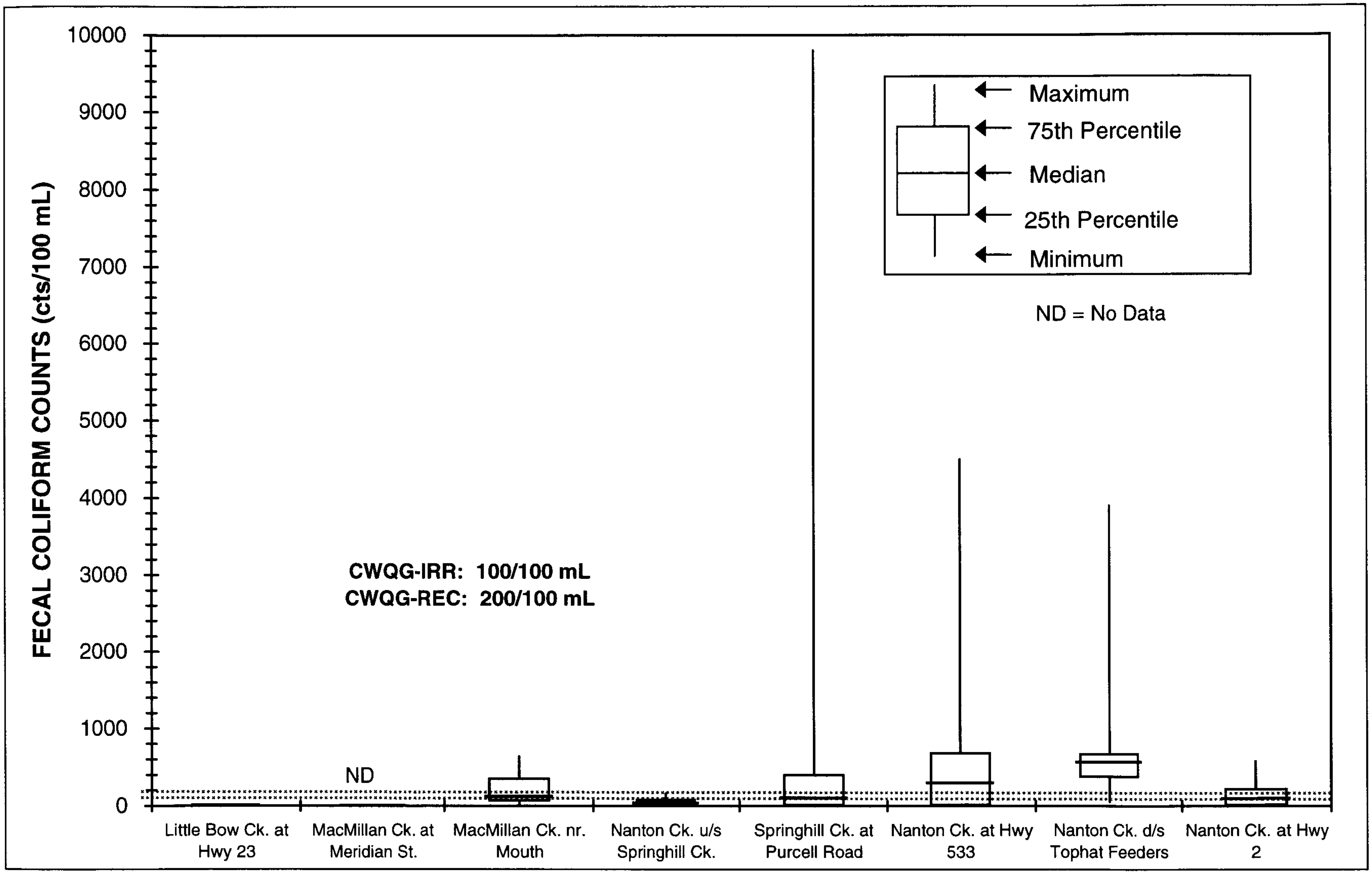


Figure 41. Fecal coliform counts at Little Bow, Nanton, MacMillian and Springhill Creek sites, March 24-September 1, 1999.

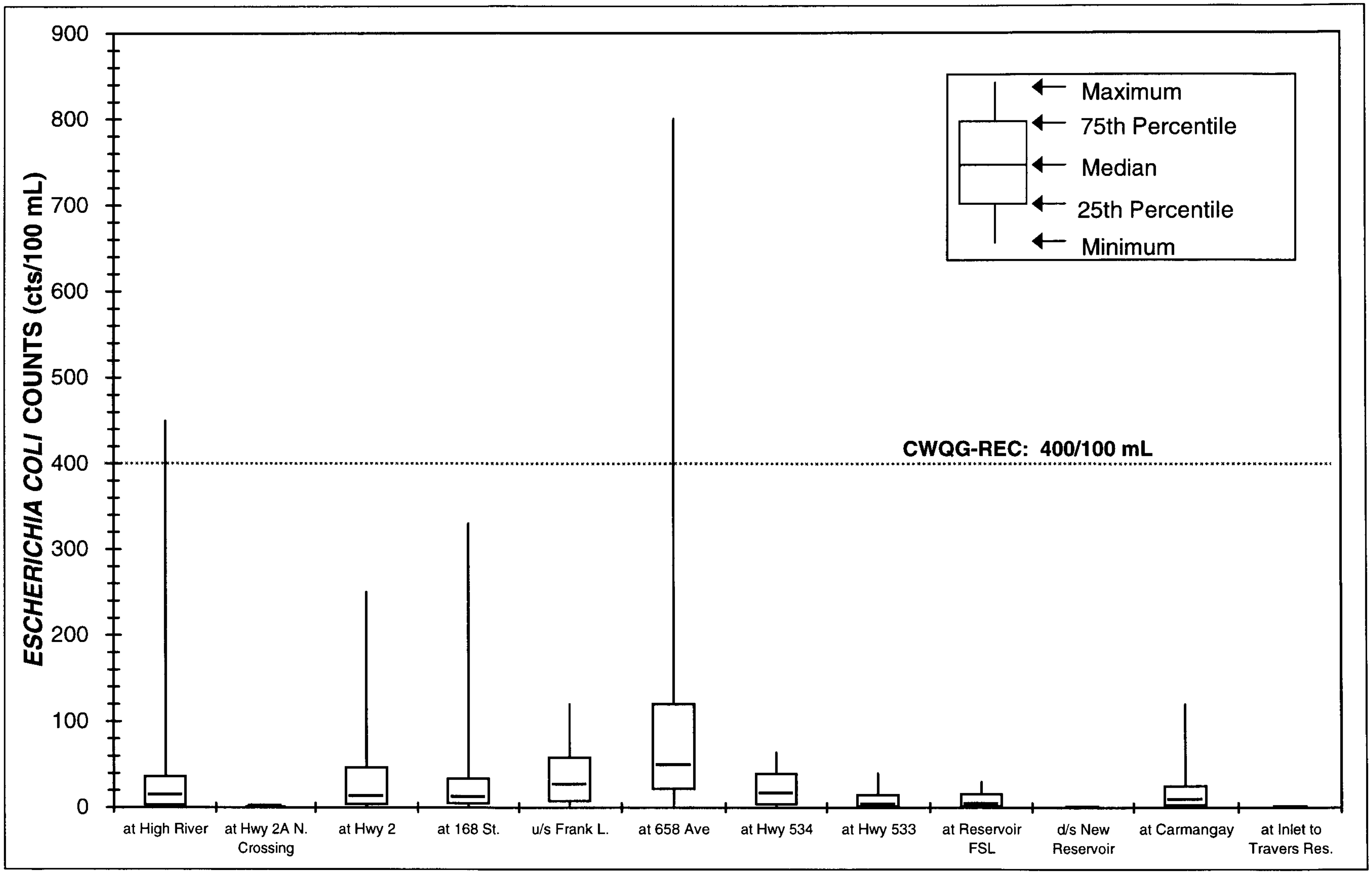


Figure 42. ***Escherichia coli*** **counts at Little Bow River sites, March 24-September 1, 1999.**

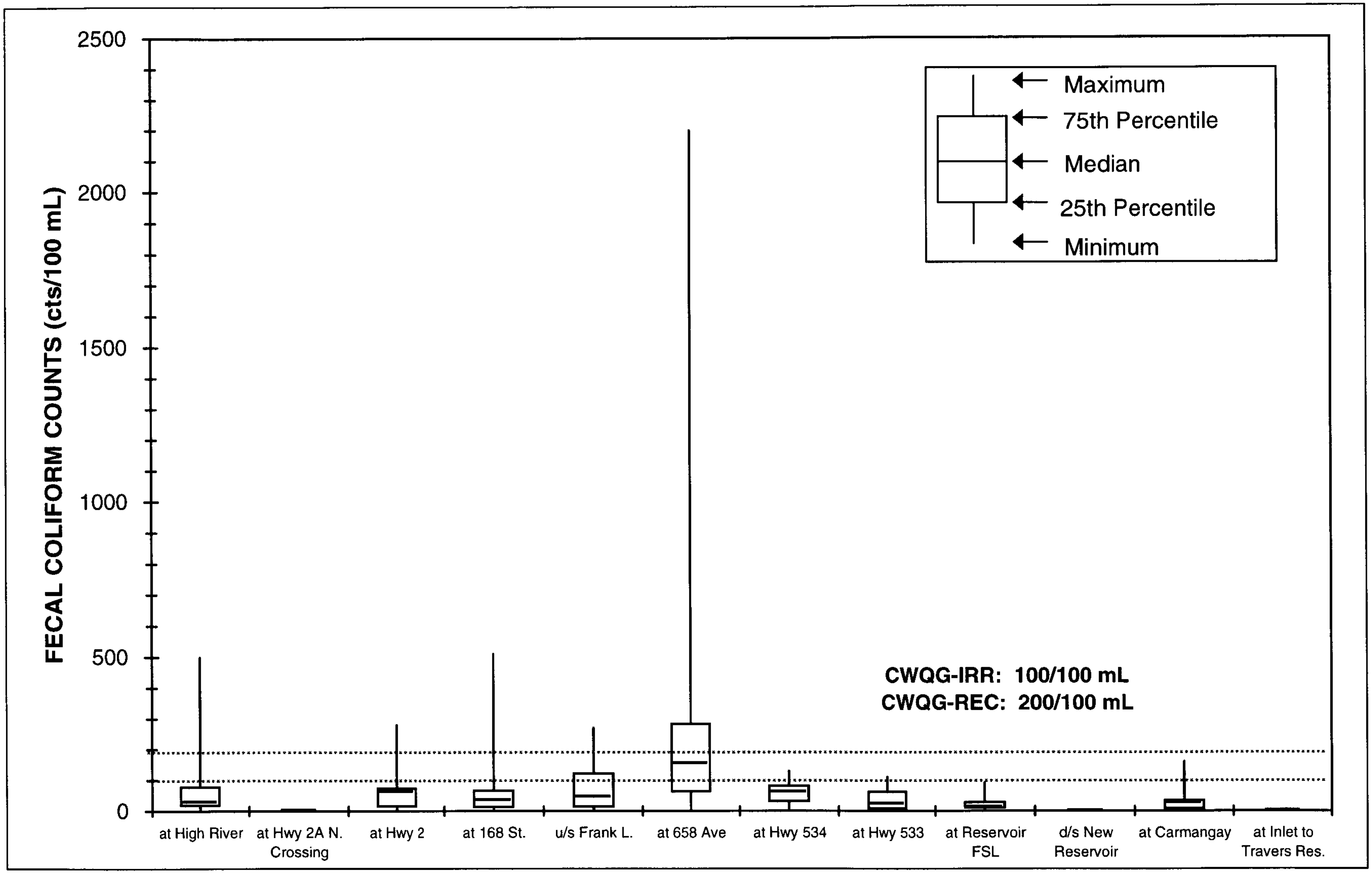


Figure 43. Fecal coliform counts at Little Bow River sites, March 24-September 1, 1999.

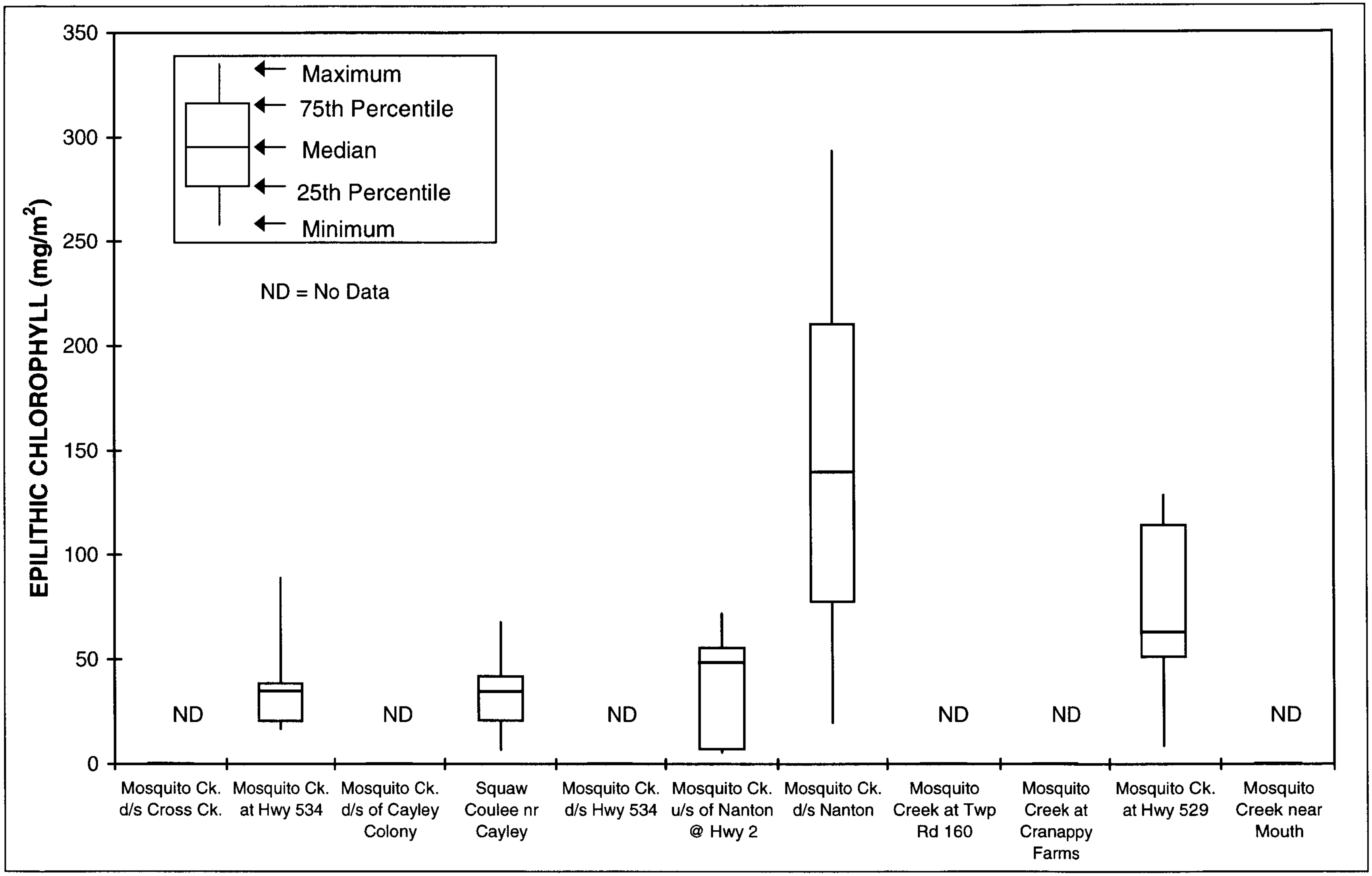


Figure 44. Concentration of epilithic chlorophyll *a* at Mosquito Creek sites, March 24-September 1, 1999.

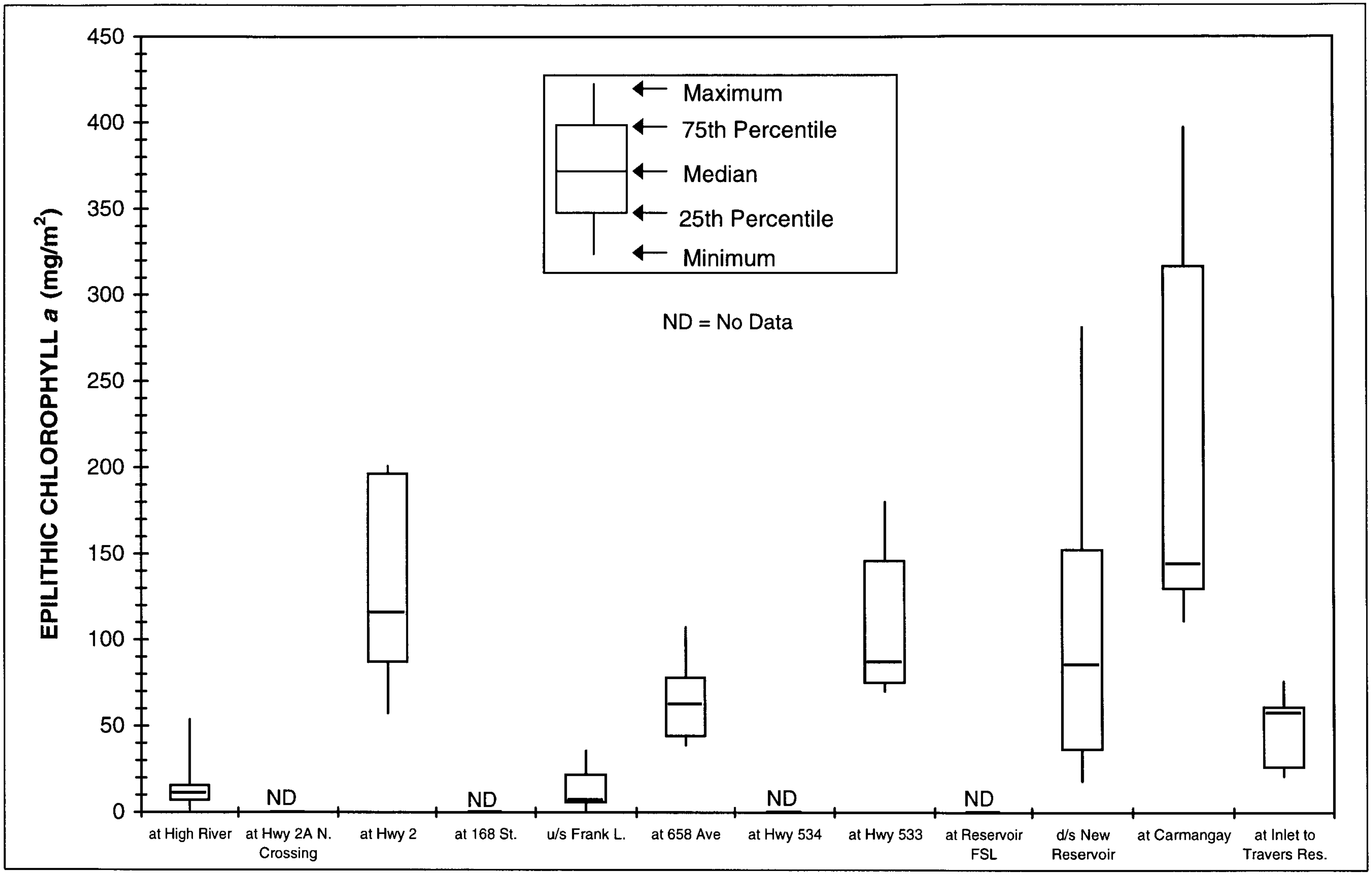


Figure 45. Concentration of epilithic chlorophyll *a* at Little Bow River sites, March 24-September 1, 1999.

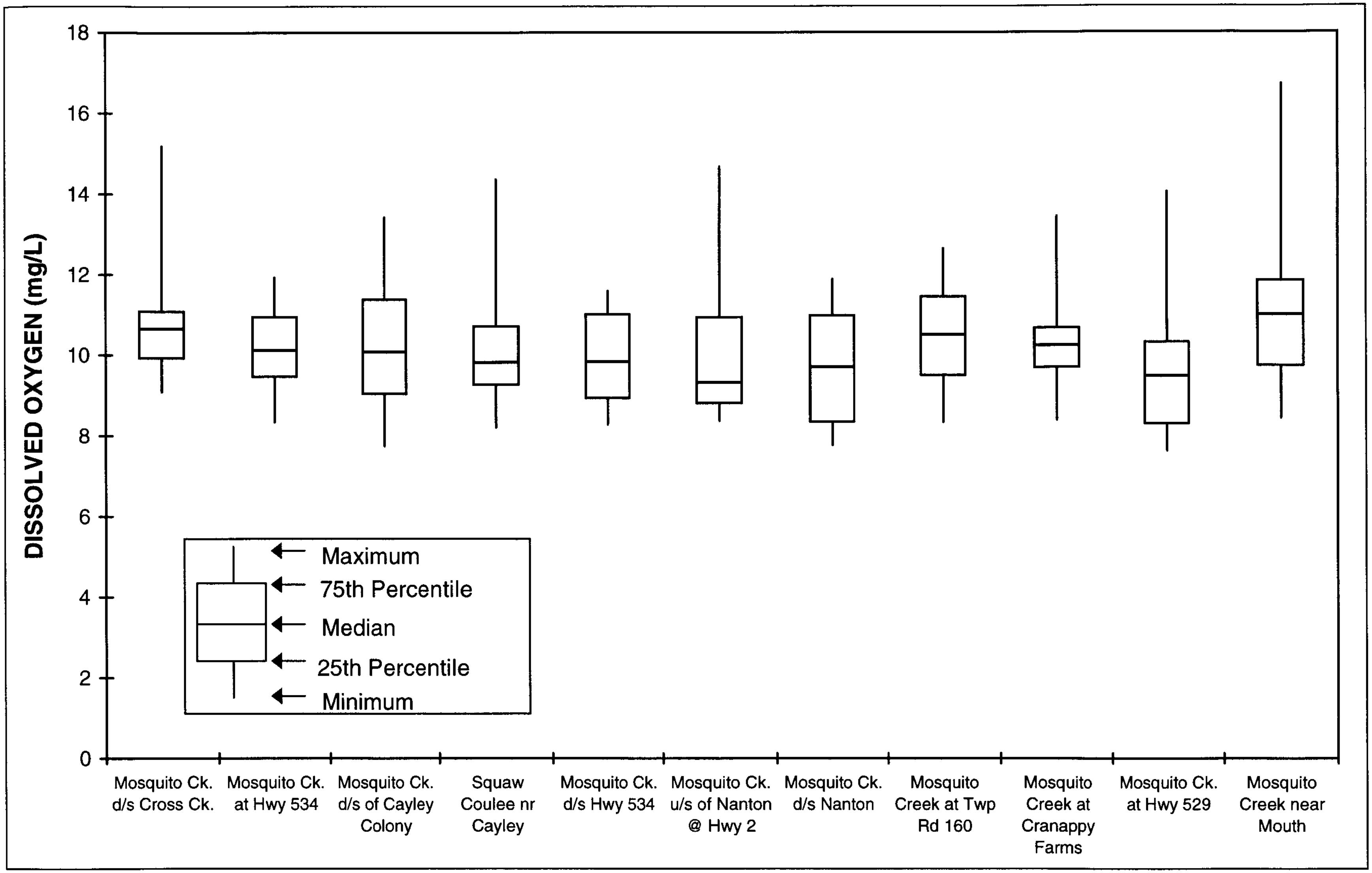


Figure 46. Concentration of dissolved oxygen at Mosquito Creek sites, March 24-September 1, 1999.

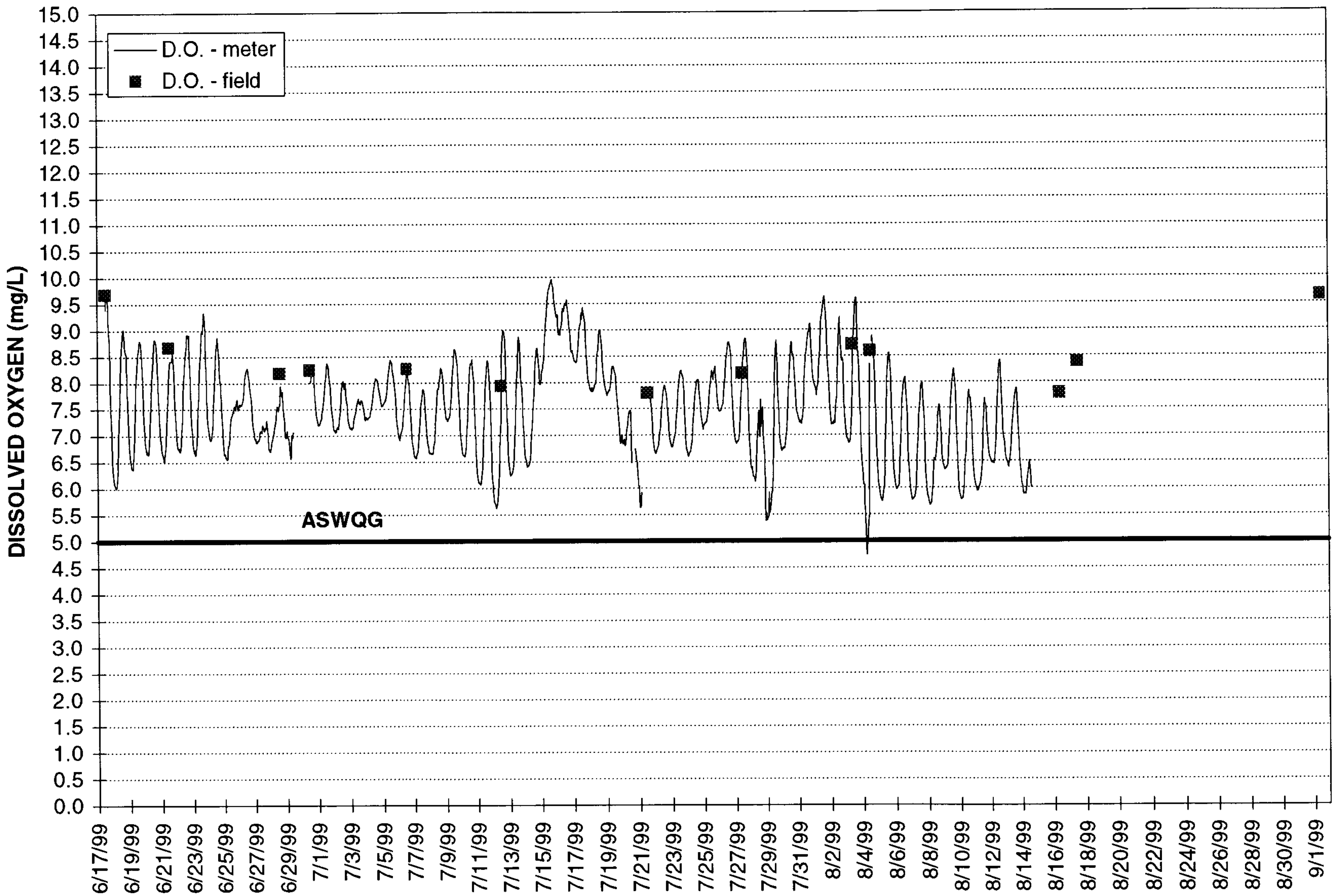


Figure 47. Concentration of dissolved oxygen in Mosquito Creek at Hwy 529, June 17 to September 1, 1999.

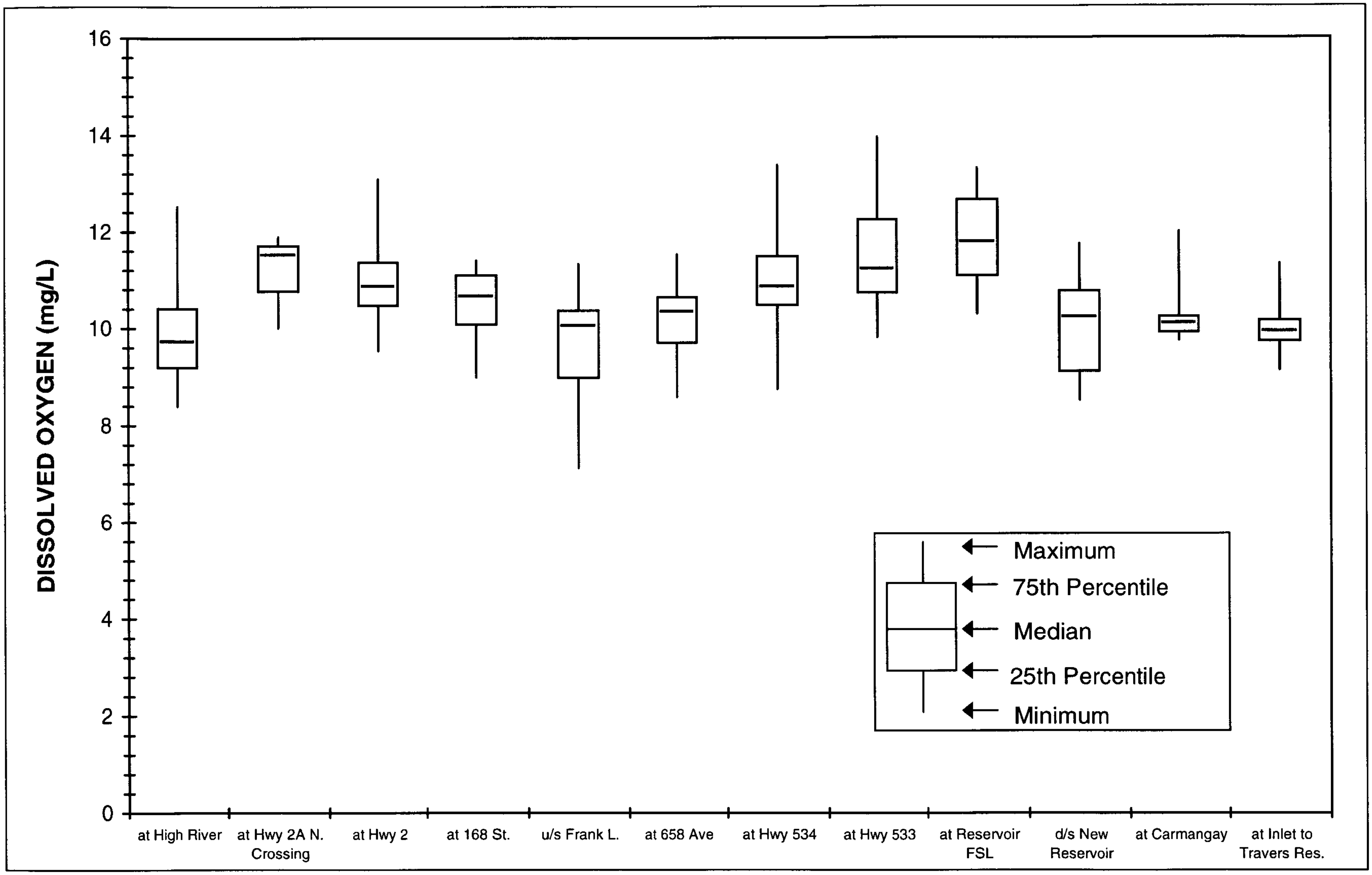


Figure 48. Concentration of dissolved oxygen at Little Bow River sites, March 24-September 1, 1999.

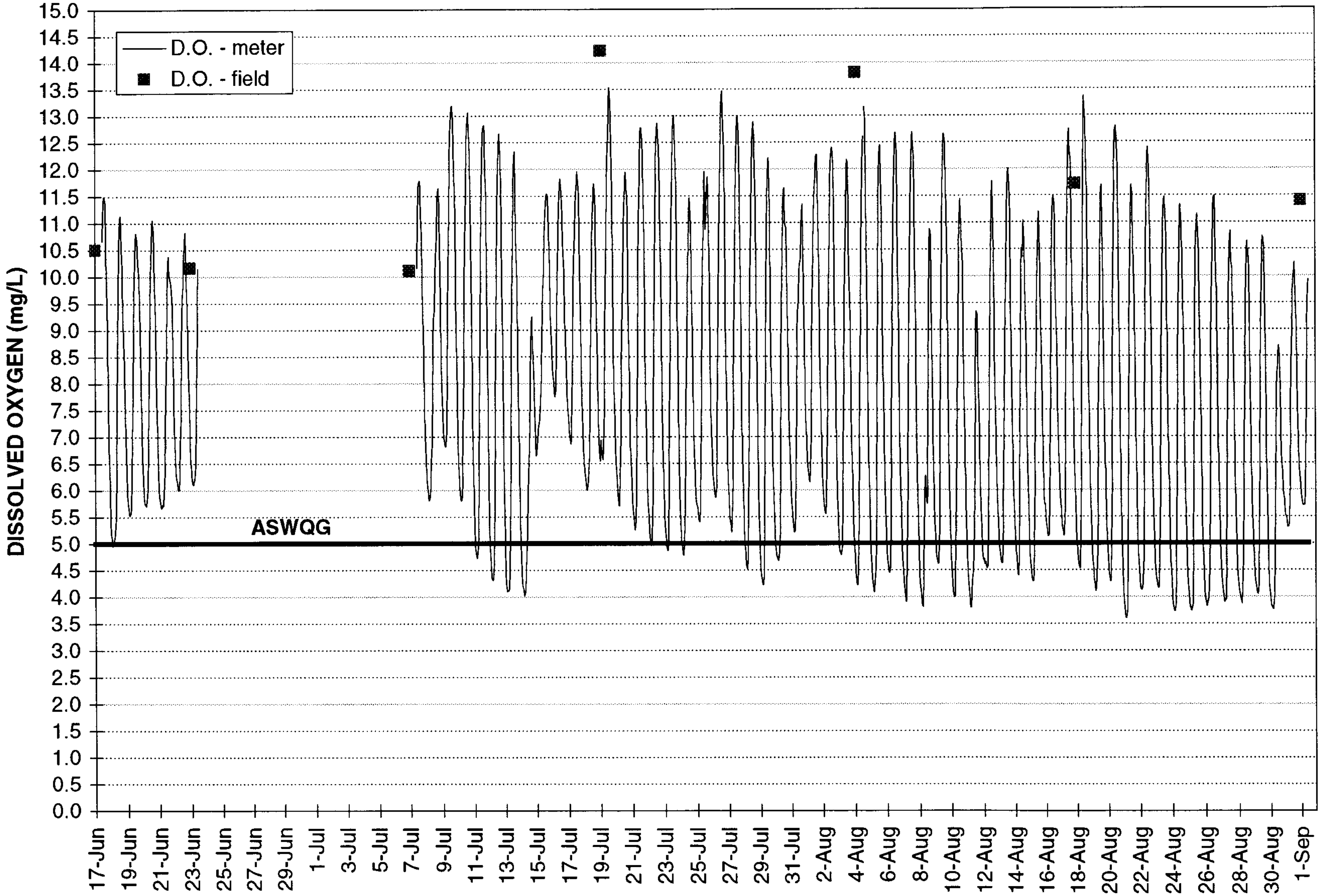


Figure 49. Concentration of dissolved oxygen in the Little Bow River at Hwy 533, June 17 to September 1, 1999.

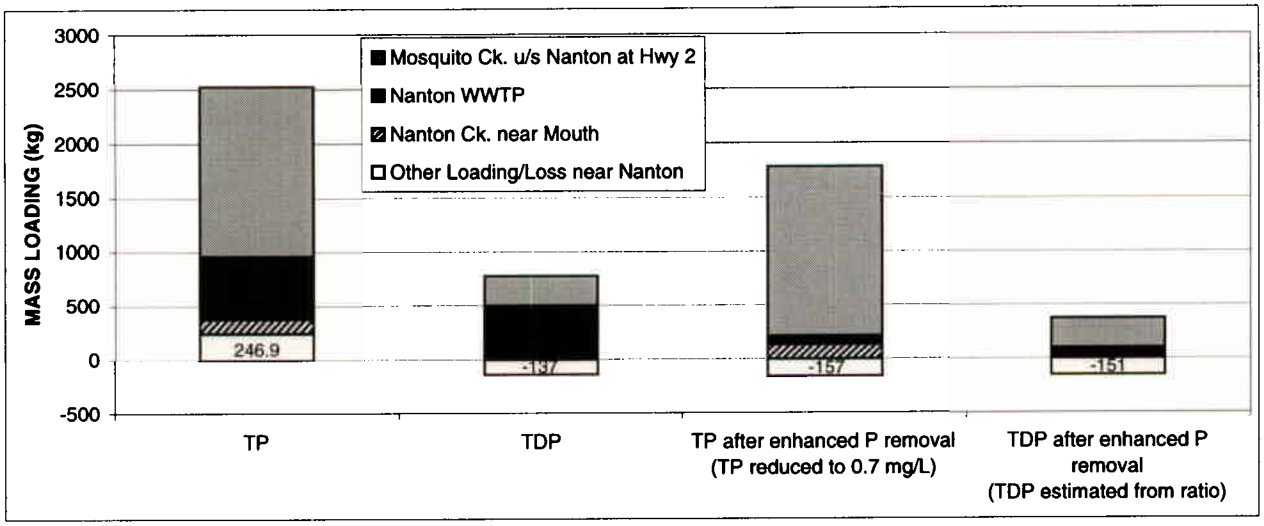


Figure 50. Mass loading of TP and TDP near Nanton during the Little Bow/ Highwood water quality study, March 24-September 1, 1999, and under enhanced phosphorus removal.

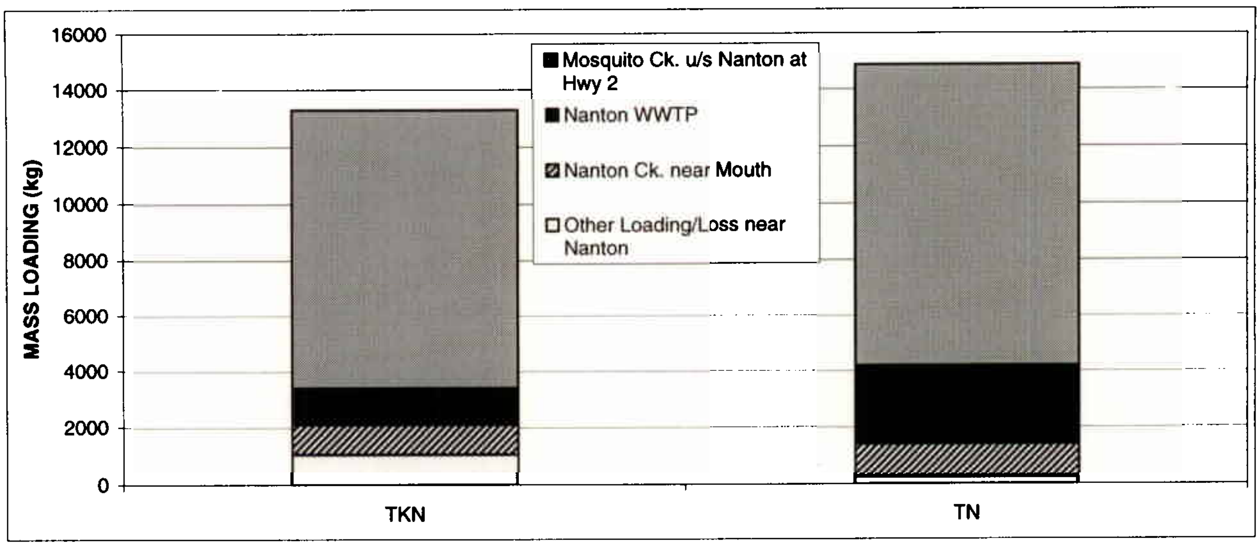


Figure 51. Mass loading of nitrogen fractions near Nanton during the Little Bow/Highwood water quality study, March 24-September 1, 1999.

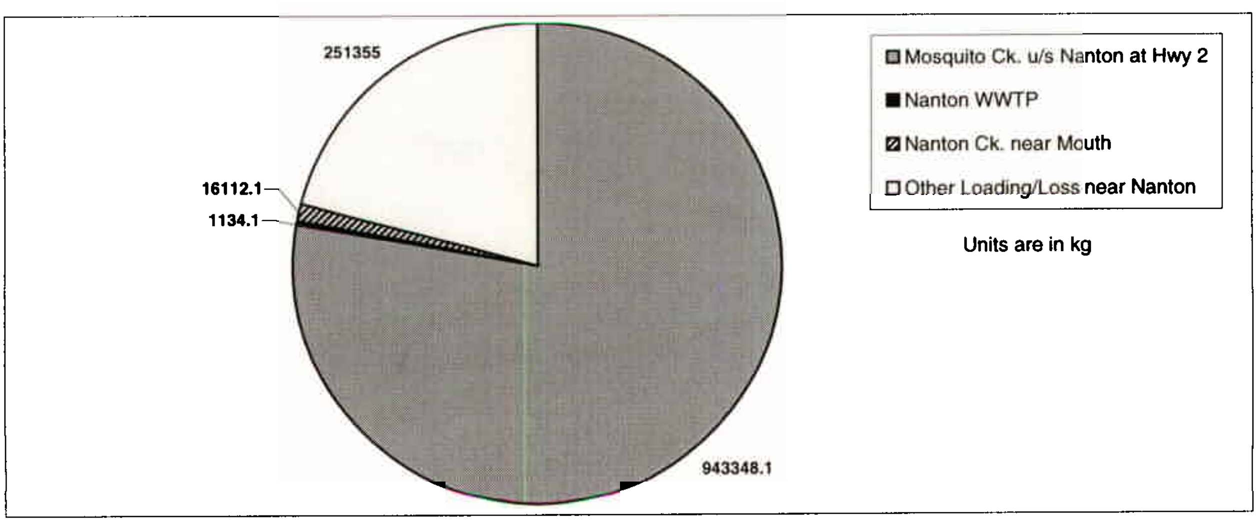
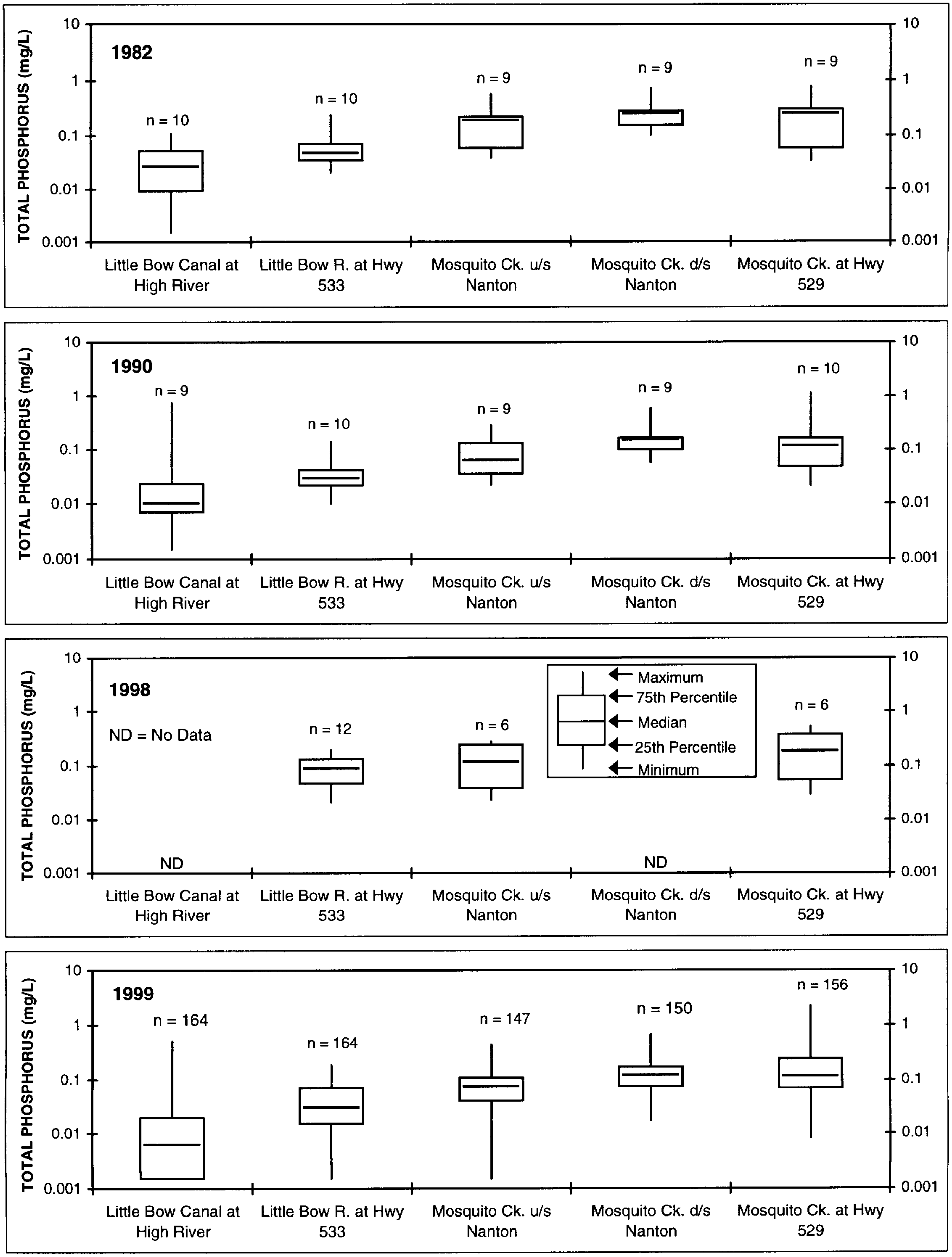


Figure 52. Mass loading of total suspended solids near Nanton during the Little Bow/Highwood water quality study, March 24-September 1, 1999.

10.0 APPENDICES

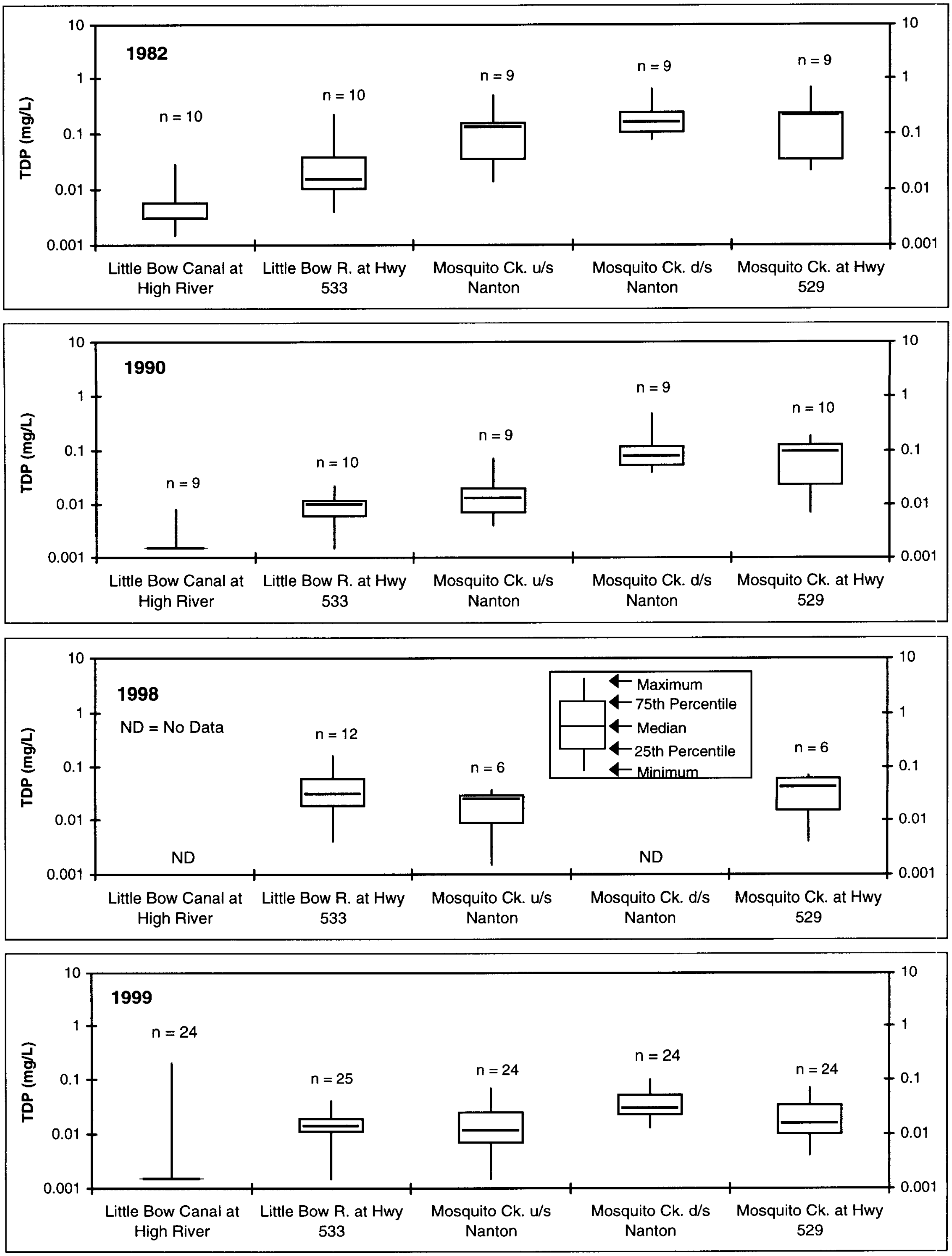
Appendix I.

Figure 1. Box & whisker plots of total phosphorus at five sites on Mosquito Creek and the Little Bow River, 1982, 1990, 1998 and 1999.

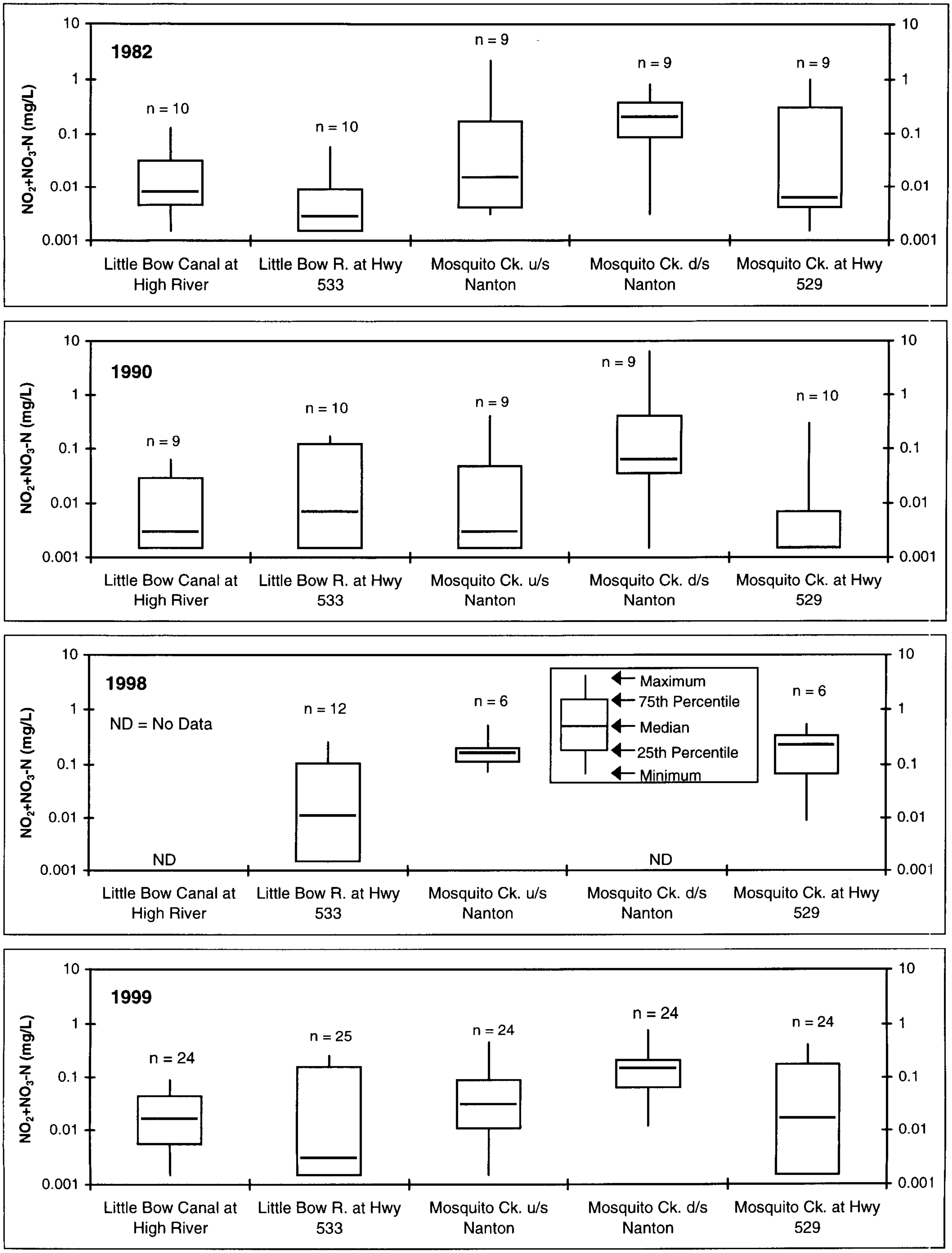


Appendix I.

Figure 2. Box & whisker plots of total dissolved phosphorus at five sites on Mosquito Creek and the Little Bow River, 1982, 1990, 1998 and 1999.

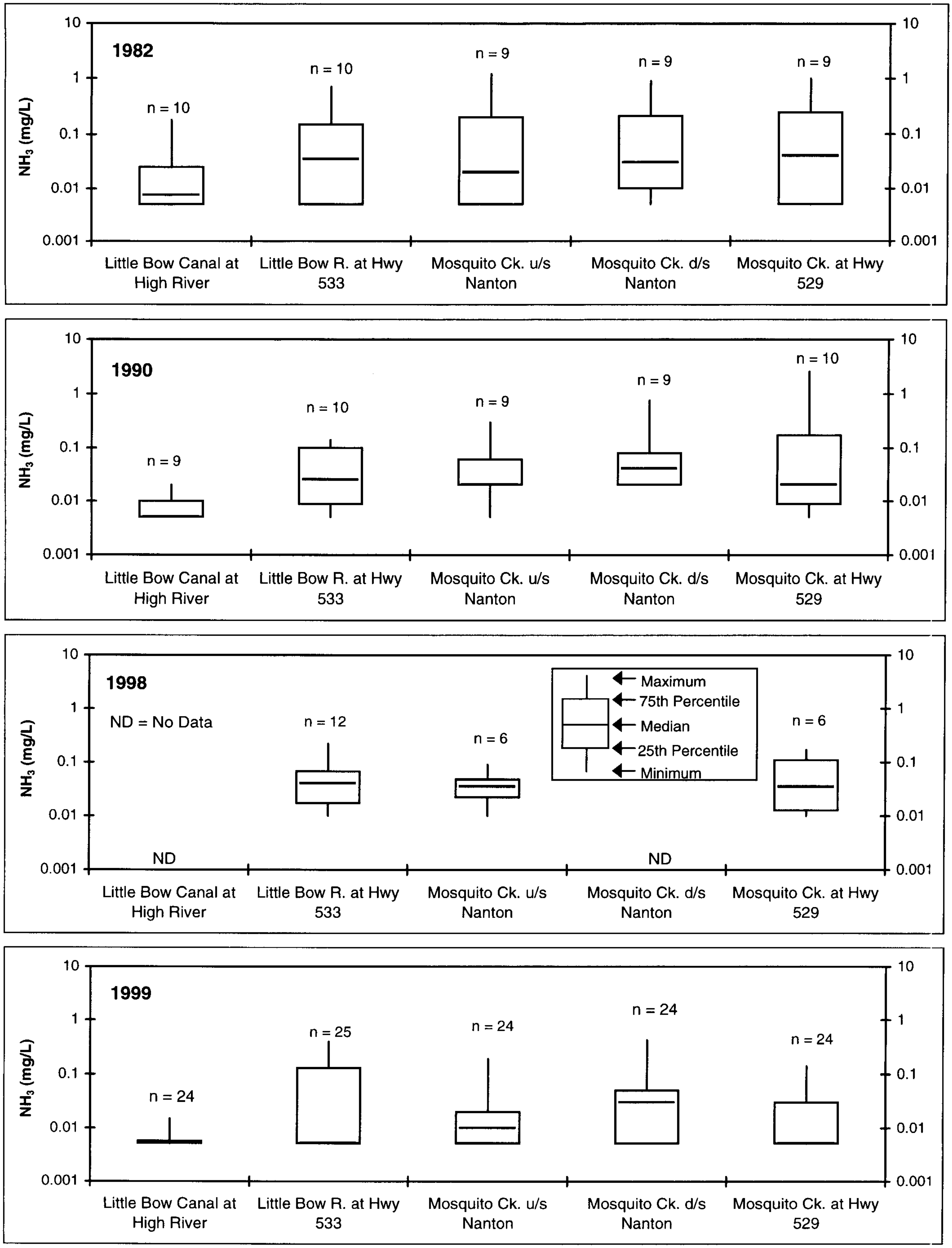


Appendix I.
Figure 3. Box & whisker plots of nitrite+nitrate nitrogen at five sites on Mosquito Creek and the Little Bow River, 1982, 1990, 1998 and 1999.



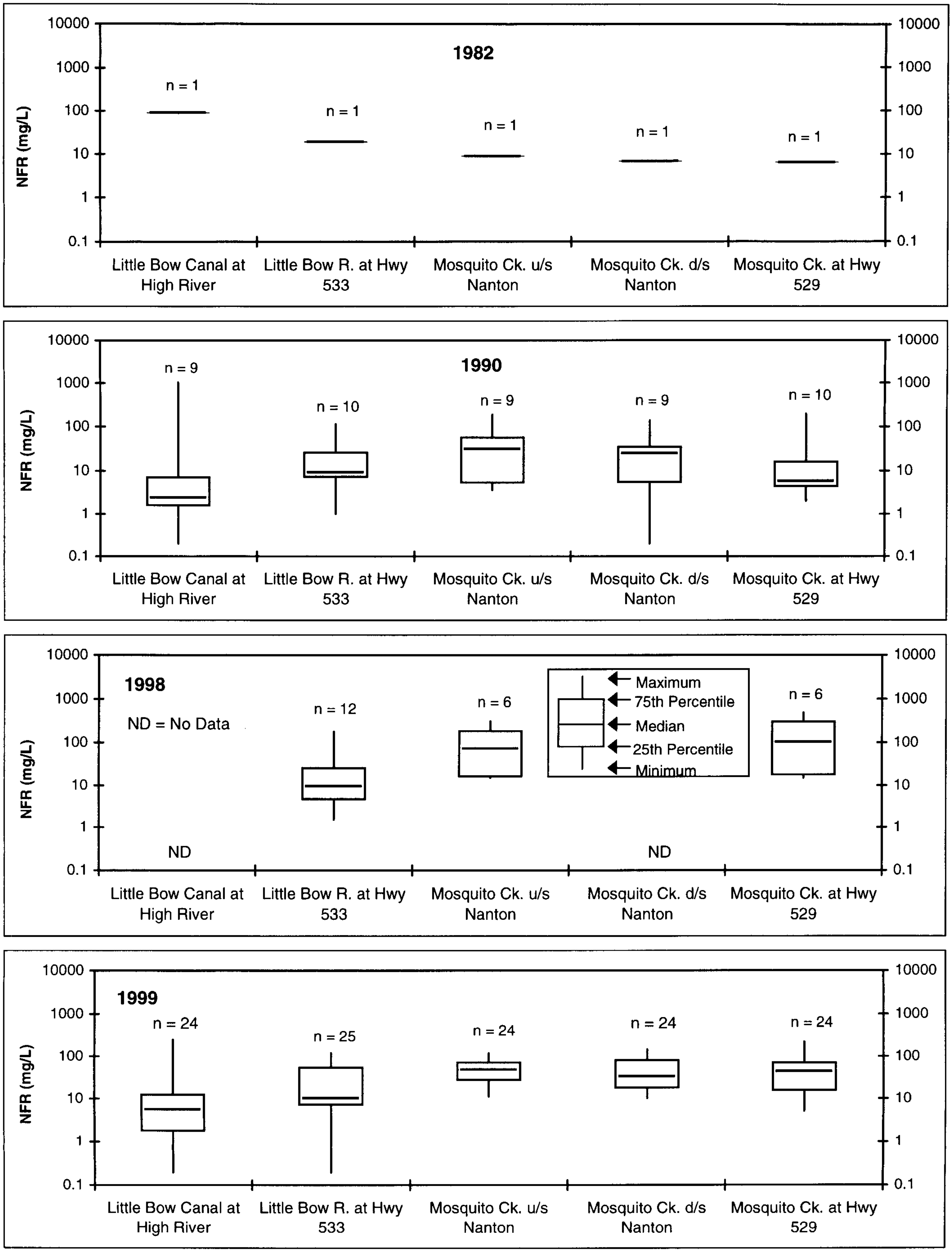
Appendix I.

Figure 4. Box & whisker plots of ammonia nitrogen at five sites on Mosquito Creek and the Little Bow River, 1982, 1990, 1998 and 1999.



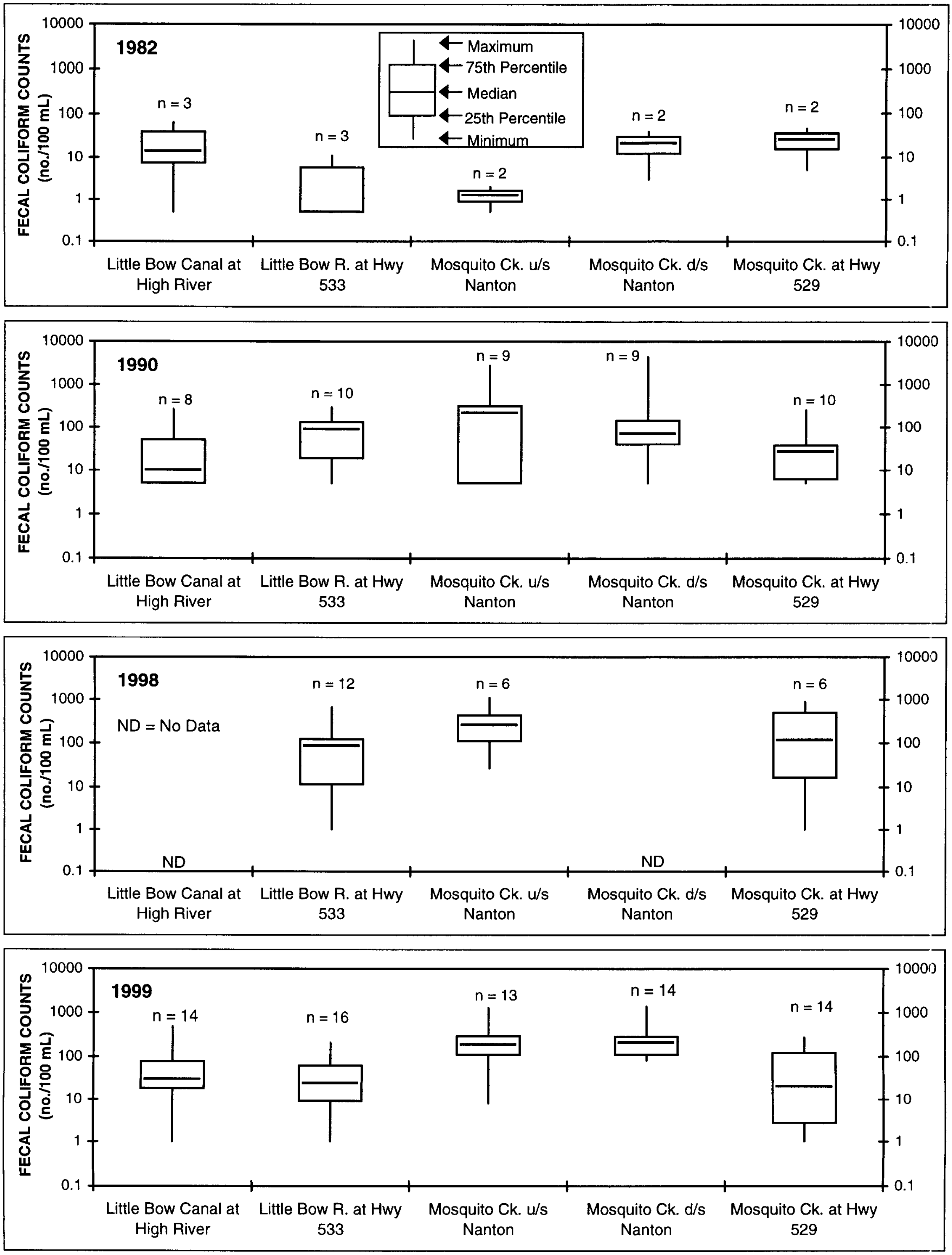
Appendix I.

Figure 5. Box & whisker plots of non-filterable residue at five sites on Mosquito Creek and the Little Bow River, 1982, 1990, 1998 and 1999.



Appendix I.

Figure 6. Box & whisker plots of fecal coliform counts at five sites on Mosquito Creek and the Little Bow River, 1982, 1990, 1998 and 1999.



Appendix I.

Figure 7. Box & whisker plots of dissolved oxygen at five sites on Mosquito Creek and the Little Bow River, 1982, 1990, 1998 and 1999.