Water Quality Study of Waiparous Creek, Fallentimber Creek and Ghost River

Final Report
Prepared by:

Daniel Andrews Ph.D.
Clearwater Environmental Consultants Inc.

Prepared for:

Alberta Environment

Project 2005-76
February, 2006

Clearwater Environmental Consultants

1510 Kensington Road N.W.
Calgary, Alberta T2N 4P2
P 403.214.7545
F 403.270.0640
www.clearwaterenv.ca

Pub No. T/853
ISBN: 0-7785-4574-1 (Printed Edition)
ISBN: 0-7785-4575-X (On-Line Edition)

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

Environmental Management
Southern Region
Alberta Environment
3rd Floor, Deerfoot Square
2938 – 11th Street, N.E.
Calgary, Alberta T3E 7L7
Phone: (403) 297-5921
Fax: (403) 297-6069

Additional copies of this document may be obtained by contacting:

Information Centre
Alberta Environment
Main Floor, Oxbridge Place
9820 – 106th Street
Edmonton, Alberta T5K 2J6
Phone: (780) 427-2700
Fax: (780) 422-4086
Email: env.infocent@gov.ab.ca

EXECUTIVE SUMMARY

Increased usage of the Ghost -Waiparous basin for random camping and off-highway vehicles (OHVs) has raised concerns among stakeholders that these activities are affecting water quality in the Ghost, Waiparous and Fallentimber Rivers. This report to Alberta Environment attempts to determine whether there is a linkage between these activities and water quality in these three rivers and documents baseline water quality prior to the implementation of an access management plan by the Alberta Government.

Water quality monitoring of these rivers was conducted by Alberta Environment during 2004 and 2005. Continuous measurements of turbidity (as a surrogate for total suspended solids), pH, conductivity, dissolved oxygen and temperature were taken in Waiparous Creek, upstream at the Black Rock Trail and downstream at the Department of National Defense base from early May to late July, 2004. These two stations encompass an extensive area of the Waiparous basin where random camping and OHV activities are common. In addition to the measurements of turbidity, monthly and bimonthly grab samples were taken at three stations along each river for a suite of parameters that included major ions, nutrients and metals. Measurements of vehicular numbers from activity monitors at three sites within the Waiparous basin were provided by Sustainable Resource Development. These measurements are thought to reflect the number of campers and OHV activity in the Waiparous drainage basin. The key parameter indicative of land disturbance and water quality degradation was total suspended solids (TSS).

The continuous measurements of TSS identified a large number of loading events with major episodes occurring on May 21-24, June 6-9, June 10-17 and June 30-July 07. These loading events corresponded closely to periods of high flow and precipitation with flow explaining 49 % of the variance in TSS. High levels of vehicular activity were associated with weekends and only with TSS episodes when rain occurred on the weekends. Downstream TSS concentrations were significantly greater than upstream concentrations and many downstream TSS loading events could not be matched to corresponding upstream events. Over the entire monitoring period (May 21 to July 26), the total loading of suspended solids at the downstream station was two orders of magnitude greater than the loading upstream (1,265,412 kg vs. 36.566 kg). TSS loading was extremely episodic in nature with 46 % of the total downstream loading occurring during one event (June 10 to 17).

The monthly/bimonthly monitoring quality parameters identified a number of peaks and upstream-downstream differences in water quality variables. Most of these differences were associated with high TSS events or normal seasonal cycling. There were very few exceedances of water quality guidelines. This monthy/bimonthly monitoring program did not record much of the detail and intensity of major TSS events.

Trend analysis did not detect any increase in TSS in the Bow River downstream of the Ghost River discharge.

Sediment loading coefficients express loading per unit area of drainage basin and permit comparison of loading between river systems. Sediment loading coefficients in the lower regions of the Waiparous and Ghost Rivers were much greater than would be expected in rivers draining a similarly forested environment in the upper foothills of southern Alberta and were even greater than loading coefficients in streams draining agricultural lands at lower elevations where sediment erosion is a common problem.

A weight of evidence argument was used to link recreational activities with the large increase in sediment load between the upstream and downstream stations on Waiparous Creek. The mechanism of sediment release best explaining the observations involved the erosion of tracks caused by OHVs at fording points across the streams. Pictorial evidence supporting this mechanism was provided for one rain event on Fallentimber Creek.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

LIST OF PHOTOS

Page

1 INTRODUCTION

1.1 Objective

Increased use of the Ghost-Waiparous basin for random camping and off-highway vehicles (OHVs) has raised concerns among stakeholders that these activities are affecting water quality in the Ghost, Waiparous and Fallentimber Rivers. In order to address these concerns, Alberta Environment has retained Clearwater Environmental Consultants Inc. to conduct a water quality study on the Ghost-Waiparous River Basin with the following goals:

1. To determine baseline water quality conditions in the Ghost-Waiparous River Basin
2. To determine the potential impacts of off-highway vehicle use and random camping in the Ghost River basin and other potentially affected basins (e.g., Fallen Timber Creek)
3. To determine whether there is a significant deterioration in downstream water quality in the Bow River related to OHV activities.

Recognizing that a cause-and-effect linkage between OHV usage and water quality in the Ghost-Waiparous Basin is difficult to prove conclusively, this report takes a weight-of evidence approach. Trends and changes in water quality are identified downstream of areas of high recreational activity. Key water quality parameters in the study include suspended solids, turbidity, nutrients, metals and bacteria. Possible causes and mechanisms to explain the observed changes in these parameters are then examined and evaluated. Conclusions are drawn based on the information available.

1.2 Environmental Setting

The study area includes three watercourses: the Ghost River, Waiparous Creek and Fallentimber Creek. For simplicity, these will be referred to in this document as the Ghost River-Waiparous basin. These streams are located within the Upper Foothills sub-region of the Rocky Mountains, approximately 50 km northwest of Calgary (Figure 1).

The landscape on the west side of the basin is dominated by ridged and rolling mountains. The majority of the area east of the mountains consists of foothills with gently sloping valleys and ridged heights of land between the valleys. Most valleys have open meadows and grasslands on level, wet terrain (BRBC 2005).

Sub-alpine and alpine habitats exist at upper elevations of the basin with exposed limestone bedrock, sandstone and shale and alpine meadows. Vegetation at this elevation consists of shrubs, graminoids, stunted alpine fir, sedges and herbs. The sub-alpine habitat is dominated by Engelmann spruce and lodgepole pine forests. The majority of the area to the east of the mountains is montane habitat composed of white spruce, balsam poplar, aspen, lodgepole pine, Douglas Fir and limber pine. Some grasses and shrubs are found dispersed among the montane habitat as the landscape changes to foothills parkland at the mouth of the Ghost River (BRBC 2005).

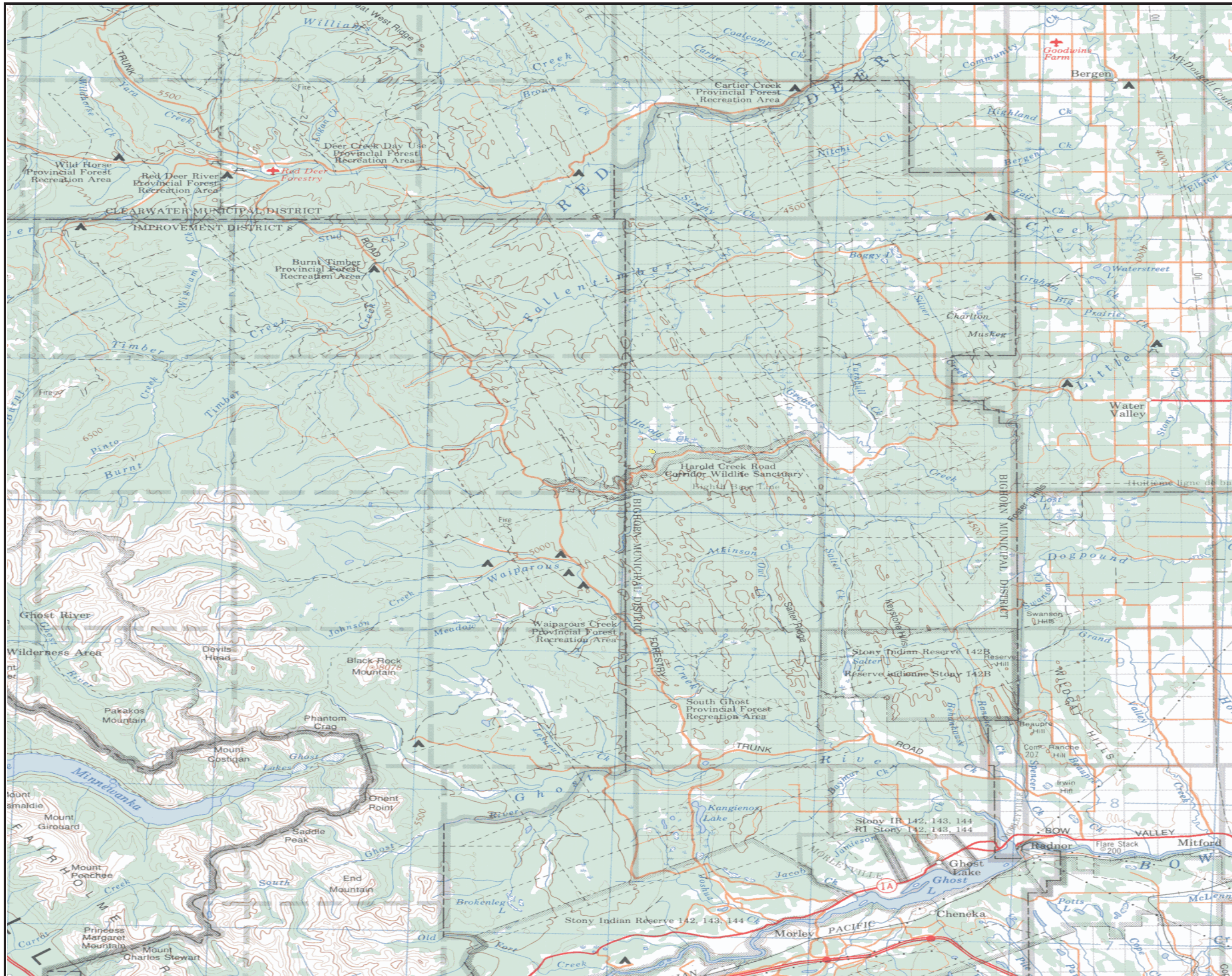
Soil thickness varies with location from up to 1 m in depth in level areas to less than 5 cm in depth on slopes (AMEC 2001). Most soils are composed of sand, clay, silt and organic matter, with sand being the dominant material. The soils in this area tend to be highly susceptible to erosion and compaction from disturbance.

A diverse range of wildlife is found within the basin. Mountain goat and bighorned sheep are found at higher elevations with mule deer, elk, moose, black bear, grizzly bear, coyote, beaver, red squirrel, lynx and marten at lower elevations (AFLW 1988). Fish species in the Ghost River include brook, bull and cutthroat trout, longnose dace, mountain whitefish and longnose sucker. Waiparous Creek supports populations of brook and bull trout and mountain whitefish, while Fallentimber Creek provides habitat for mountain whitefish and brown, brook and bull trout (GRSIRP 1988).

1.3 Description of Individual Drainage Basins

1.3.1 Ghost River

The Ghost River is one of the major tributaries of the Bow River, discharging to the Bow River upstream of the Ghost Dam approximately 15 km west of Cochrane. The drainage area of the Ghost River basin is approximately 953 km^2 and includes the Waiparous Creek drainage basin. Much of the land (340 km^2) is part of the Alberta Forest Reserve. The Ghost Wilderness Area is located in the upper north portion of the Ghost River drainage basin, while the northern portion of the Don Getty Wildland Park is found to the east of the Ghost Wilderness Area. The Stoney Reserve No.142 (Nakoda Nation) and five Provincial Forest Recreation Areas are also located within the drainage basin.



LOCATION OF GHOST WAIPAROUS AND FALLENTIMBER RIVERS

Clearwater Environmental Consultants

NTS Topo Map 82 0
Scale 1 : 350,000

DATE 12/08/05

JOB NO. 2005-76

FIGURE 1

Flow in the Ghost River is influenced by the diversion of part of the North Ghost River to Lake Minnewanka. Peak flows occur during June while base flows occur during the winter. Between 1911 and 1983, the monthly average flow of the Ghost River at the mouth ranged from 2.47 m^3/s in February to 12.4 m^3/s in June.

1.3.2 Waiparous Creek

Waiparous Creek is a major tributary of the Ghost River and flows south-east to meet the Ghost River at the settlement of Benchlands. The drainage area is approximately 321 km^2. The creek flows through North Ghost Provincial Forest Recreation Area, Waiparous Creek Provincial Forest Recreation Area and Ghost Airstrip Group Camp Provincial Forest Recreation Area. Between 1966 and 2001, the monthly average flow of Waiparous Creek at the mouth ranged from 0.38 m^3/s in January to 5.63 m^3/s in June.

1.3.3 Fallentimber Creek

Fallentimber Creek is located north of the Ghost River basin. The stream flows northeast towards its confluence with the Red Deer River which is located just south of Sundre. The total drainage area is approximately 526 km^2. The monthly average flows of Fallentimber Creek at the mouth ranged from 0.407 m^3/s in March to 6.01 m^3/s in July. Winter flow data are not available.

1.4 Land Use

1.4.1 Commercial Grazing

Commercial livestock grazing within the area is regulated over a four month season from June 15 to October 15 with 1,583 Animal Unit Months (AUMs) available each season to the Ghost River Planning Area (AMEC 2001). Livestock management is limited due to the assortment of trail systems and lack of control mechanisms such as fences. Areas where valley bottoms are adjacent to watercourses have the greatest amount of use by livestock. The total area available in the Ghost-Waiparous drainage basin for livestock is 147 km^2 or 11.5 % of the total drainage area. The total area available in the Fallentimber drainage basin for livestock is 144 km^2 (AMEC 2001) or 27.4 % of the area of this basin.

1.4.2 Resource Development

Oil and gas exploration and development and timber harvesting have been occurring in the Ghost River Planning Area for decades (GRSIRP 1988). Oil and gas developments have resulted in many seismic trails, exploration and access roads, pipelines and powerlines. Current practices are to conduct seismic surveys using hand cut lines only and to limit the area of surface disturbance. Old developments have been reclaimed and operational facilities and pipelines are maintained to industry standards.

Timber harvesting is an ongoing activity in the Forest Reserve. Some small areas north of Fallentimber Creek were clear-cut in 2001. Timber resources in the Ghost-Waiparous drainage basin are predominantly immature, the result of fires in the early 1900s, while those in the Fallentimber drainage basin are more mature. Pine and spruce are the commercial species most often harvested.

1.4.3 Recreation / OHV Users

The provincial forest recreation areas within the Ghost-Waiparous and Fallentimber drainage basins are heavily used during the summer. They consist of camping facilities, picnic sites and staging areas. There are four provincial forest recreation areas within the Ghost-Waiparous drainage and two recreation areas in the Fallentimber Creek drainage basin.

Over the past three decades, the number of people visiting the Ghost River Planning Area for recreational purposes has increased dramatically. Recreational activity was noted to have increased since 1977 when Kananaskis was closed to OHVs (AMEC 2001b). Recreational visitors come to the area to horseback ride, hike, hunt, camp and operate various types of OHVs. OHV use and random camping is widespread in the area and has lead to localized impacts on terrain, vegetation, water quality, and fish habitat. Random camping and OHV use have been facilitated by the availability of many exploration roads, logging roads and seismic cut lines.

2 METHODS

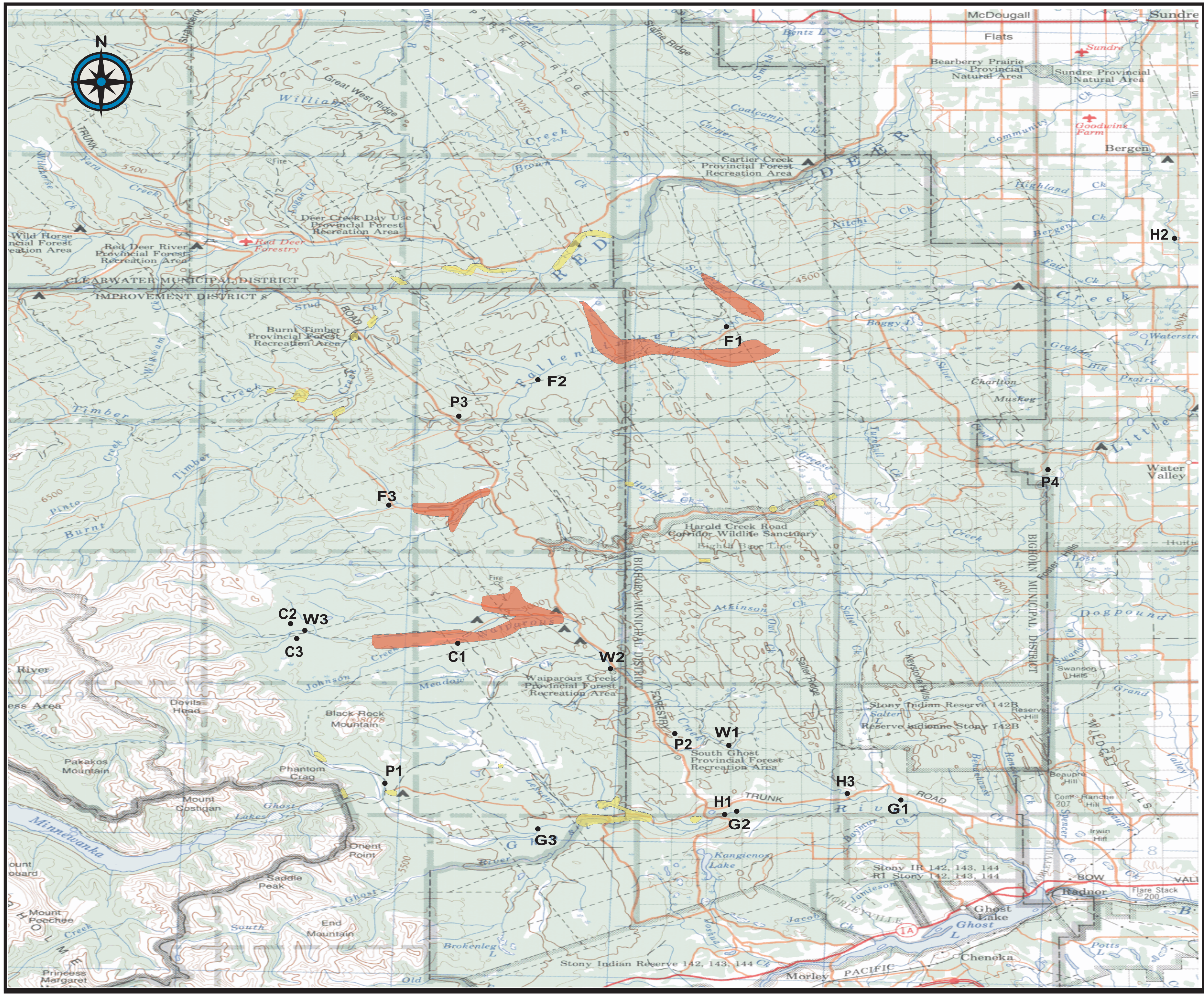
2.1 Data Sources and Field Measurements

Data sources for this study included the following:

1. Continuous measurements of turbidity, conductivity, pH, temperature and dissolved oxygen collected by Hydrolab datasondes in Waiparous Creek above and below areas of uncontrolled campling and OHV use
2. Bimonthly or monthly grab samples collected for water quality parameters at three sampling sites each on Waiparous Creek, Fallentimber Creek and the Ghost River
3. Long term water quality monitoring data collected by Alberta Environment in the Bow River at Exshaw and Cochrane (upstream and downstream of the confluence with the Ghost River)
4. Daily measurements of current on the Waiparous River, Fallentimber Creek and the Ghost River, collected by the Water Survey of Canada and Alberta Environment
5. Precipitation data for 2004 from regional Environment Canada stations
6. Vehicular activity counts at three stations near Waiparous Creek frequented by OHVs collected by Alberta Sustainable Resource Development

2.1.1 Continuous Measurements by Hydrolab Datasonde in Waiparous Creek

Hydrolab datasondes (model 4a) with self-cleaning turbidity sensors were deployed between May 21 and July 26, 2004 in Waiparous Creek at Station W3 (Black Rock Trail Crossing) representing conditions upstream of the potentially affected areas and Station W1 (Department of National Defence Cadet Camp), representing downstream conditions (Figure 2; Table 1). Measurements of turbidity, conductivity, pH, dissolved oxygen and temperature were logged at 15 minute intervals to create a database of between 3691 and 5029,readings (depending on the variable) between these dates. Following protocols developed by Alberta Environment (AENV), transient outliers, the result of air bubbles and debris, were identified and eliminated from the turbidity dataset.



LEGEND

Sampling Sites

G1 Ghost River at Benchlands

G2 Ghost River at Richards Road

G3 Ghost River upstream of South Ghost River

W1 Waiparous creek at DND Cadet Camp

W2 Waiparous Creek at HWY 40 Bridge

W3 Waiparous Creek above Black Rock Trail

F1 Fallen Timber Creek upstream of 3rd Bridge (Hunter Valley Road)

F2 Fallen Timber Creek at Benjamin Creek Road

F3 Fallen Timber Creek upstream of ford above Stormy Creek

Weather Stations

P1 Ghost Diversion

P2 Ghost RS

P3 Fallentimber Creek

P4 Water Valley

Hydrometric Stations

H1 Ghost River above Waiparous Creek

H2 Fallentimber Creek near Sundre

H3 Waiparous Creek at Mouth

Location of Traffic Counters on Waiparous Creek

C1 Johnson Creek Bog

C2 Waiparous Creek past Margaret Lake turn-off across the ford

C3 Margaret Lake Trail past turnoff at the ford on Waiparous Creek

Random Camping Areas

Registered Camping Site

High use areas

Moderate use areas

LOCATION OF SAMPLING SITES AND AREAS OF EXTENSIVE RECREATIONAL USE

Clearwater Environmental Consultants

NTS Topo Map 82 0
Scale 1 : 350,000

DATE 12/08/05

JOB NO. 2005-76

FIGURE 2

Table 1 Location and Designation of Grab and Datasonde Sampling Stations for Water Quality on the Ghost River, Waiparous Creek and Fallentimber Creek

Station	Description	AENV Station	Latitude	Longitude
Ghost River				
G1	Benchlands	AB05BG0010	51° 16' 51.7" N	114° 48' 13.0" W
G2	At Richards Road	AB05BG0040	51° 16' 11.6" N	114° 55' 30.3" W
G3	U/S of South Ghost River	AB05BG0030	51° 15' 46.5" N	115° 1' 38.3" W
Waiparous Creek				
W1	At DND Cadet Camp	AB05BG0080	51° 19' 27.2" N	114° 55' 47.2" W
W2	At Highway 40 Bridge	AB05BG0050	51° 22' 05.2" N	114° 59' 30.2" W
W3	At Black Rock Trail Crossing	AB05BG0020	51° 23' 34.0" N	115° 11' 57.4" W
Fallentimber Creek				
F1	U/S Ford above Stormy Creek	AB05CA0440	51° 35' 56.2" N	114° 53' 44.5" W
F2	At Benjamin Creek Road	AB05CA0430	51° 33' 36.7" N	115° 2' 43.9" W
F3	U/S 3rd Bridge Hunter Valley Road	AB05CA0420	51° 28' 34.9" N	115° 8' 33.1" W

2.1.2 Bimonthly / Monthly Grab Sampling Program

Grab samples were collected bimonthly or monthly for water quality parameters at a total of 9 sampling stations on the three rivers. Locations and coordinates of each sampling station are provided in Table 1 and Figure 2. AENV sampling protocols were applied during sample collection (AENV 2002). Data from the monitoring program were used to describe water quality conditions along the length of the three rivers, seasonal changes in water quality and upstream-downstream trends that might indicate the effects of disturbance in the drainage basins. The parameters included in the grab sampling program are listed in Table 2.

Table 2 Summary of Water Quality Parameters for the Grab Sampling Program

Fecal coliforms	Total Kjeldahl Nitrogen	Dissolved & Total organic carbon
Escherichia. coli	Total Ammonia	True Colour
Dissolved oxygen	Nitrate + Nitrite	Total Dissolved Solids
Temperature	Nitrite	Total Alkalinity
pH	Reactive Silica	Total & Dissolved metals
Total phosphorus	TSS (non-filterable residue)	Fluoride
Orthophosphate	Turbidity	Total cyanide
Total dissolved phosphorus		

2.1.3 Long Term Water Quality Monitoring on the Bow River

Water quality data on the Bow River, collected under AENV under the Long Term River Network (LTRN) monitoring program, were examined at two stations - upstream of Exshaw Creek (00AL05BE0650) and at Cochrane (00AL05BH0017). The former station represents conditions on the Bow River upstream of the discharge of the Ghost River and the latter, conditions downstream of the discharge. Trends at these stations were examined in an attempt to detect potential effects of the discharge of the Ghost River on water quality in the Bow River.

2.1.4 River Discharge and Precipitation

Daily river discharge (flow) was obtained from AENV for the Waiparous River near the mouth (Station 05BG006), Fallentimber Creek near Sundre (Station 05CA012) and the Ghost River above Waiparous Creek (Station 05BG010) for 2004. The area of the drainage basin above each of the nine water quality sampling stations was determined graphically using Memory Map (V5). The proportion of the drainage basin above each hydrometric (flow) monitoring station was calculated for each of the nine stations and was used to estimate the daily flow at each station. Precipitation data for 2004 were obtained from local Environment Canada weather monitoring stations that included Fallentimber Creek, Water Valley Ghost Diversion and Ghost River S (Table 3; Figure 2).

Table 3 Location of Weather and Hydrometric Stations

Station Name	Station Type	Map Symbol	Coordinates		
			Latitude (Deg. Min. Sec)	Longitude (Deg. Min. Sec)	Elevation (m)
Ghost Diversion	Precipitation	P1	51 17 22	115 08 18	1600
Ghost River S	Precipitation	P2	51 19 23	114 57 30	1465
Fallentimber Creek	Precipitation	P3	51 32 06	115 06 00	1754
Water Valley	Precipitation	P4	51 29 50	114 42 41	1190
Ghost R. above Waiparous (05BG010)	Hydrometric	H1	51 16 15	114 55 18	1332
Fallentimber Creek Near Sundre (05CA012)	Hydrometric	H2	51 39 11	114 39 11	1196
Waiparous Creek at Mouth (05BG006)	Hydrometric	H3	51 16 58	114 50 15	1256

2.1.5 Vehicular Activity Counts

Vehicular activity was measured by TrafX counters placed at three locations near Waiparous Creek by personnel from Alberta Sustainable Resource Development (ASRD) (Table 4; Figure 2). Using the Excel program *TRAFXreporter,* the data from the counters were accumulated by day and charted by date.

Table 4 Location of Traffic Counters on Waiparous Creek

Counter No.	Map Symbol	Location	Latitude (Deg. Min. Sec)	Longitude (Deg. Min. Sec)
PLFD#5	C1	Waiparous Creek Past Margaret Lake turn-off across the ford	51 23 32	115 11 55
PLFD#4	C2	Johnson Creek Bog	51 23 16	115 06 20
PLFD#6	C3	Margaret Lake Trail past turnoff at the ford on Waiparous Creek	51 23 38	115 11 43

2.2 Data Analysis

2.2.1 General

To permit numerical analysis of the water quality data, values less than detection limits were replaced by values equal to one-half the detection limit. Statistical analyses were conducted using Systat 11, TableCurve (Systat) and Excel spread sheets. Statistical significance was determined at the 5% level of significance.

2.2.2 Analysis of Data from the Hydrolab Datasonde Deployed on Waiparous Creek

In order to relate the turbidity measurements from the Hydrolab datasonde to TSS, a relationship was developed between the two parameters using monitoring data from the 2004 monthly/bimonthly sampling program in which both parameters were measured on each sample. Several curve-fitting routines were examined including TableCurve (SYSTAT) to provide the best fit to the data.

In order to examine the potential effects of random camping activities on Waiparous Creek, upstream-downstream comparisons were conducted on the datasonde variables (temperature, conductivity, dissolved oxygen, turbidity and total suspended solids). For each variable, the two populations (upstream and downstream) were tested for homogeneity of variance. As the variances were significantly different in all cases, a non-parametric Mann-Whitney U test was used for the comparisons.

The correlations between these 5 variables and flow at the downstream station (DND Base W1) were examined on daily averages of the data by using a Spearman correlation analysis. This non-parametric analysis was used rather than a simple Pearson correlation analysis because the variables were non-normal and could not be easily normalized through a variety of transformations. The correlations were tested for significance ($P<0.05$) using Bonferroni probabilities to reduce the possibility of Type 1 errors (reporting a relationship or effect when none is really present).

The turbidity measurements from Stations W1 and W3 on the Waiparous Creek provided 4628 and 4001 observations, respectively, over the two month period. Using the relationship between turbidity and TSS derived above, the turbidity readings at each station were converted to TSS and plotted as a function of time. A data smoothing (Loess) routine was applied to aid in interpreting the data. The daily flow measurements from the mouth of the Waiparous Creek were corrected proportionately for the area of the drainage basin above W1 and W3 and then multiplied by the individual measurements of TSS for each 15 minute interval to obtain the loading rate in units of kg/day for each 15 minute interval. The absolute load in kg for each 15 minute interval was calculated using a trapezoidal approximation. Both loading (kg/d) and the absolute load (kg) were plotted as a function of time.

Detailed plots of TSS, loading and absolute load were examined to identify loading events at the upstream and downstream stations. TSS events were compared visually to rainfall events, hydrologic events and peaks in vehicular activity. Loading events expressed in units of absolute load (kg) were examined in detail and characterized. When upstream loading events could be matched to downstream events, the two events were compared statistically. Since the variances were often significantly different, a non-parametric test (Mann-Whitney U) was used for these upstream/downstream comparisons. Total loading (kg) for the monitoring period (May 21-July 26) was calculated for both the upstream station at Black Rock Trail (W3) and the downstream station at the DND Cadet Camp (W1).

2.2.3 Analysis of the Monthly and Bimonthly Sampling Program

The monitoring data from the bimonthly and monthly grab sampling program were summarized and plotted in box plots to illustrate the median, range and variability of the data as well as the presence of extreme values and outliers. Potential differences in water quality between upstream and downstream stations on the three river systems (Waiparous Creek, Fallentimber Creek and Ghost River) were examined by comparing the mean or median concentration of each parameter at each of the three stations on each river. The homogeneity of the three variances was first examined using Barlett's test. When the variances were not significantly different, an analysis of variance (ANOVA) was applied to test for differences between the three means. When significant differences were detected by ANOVA, pairwise comparisons of the means were conducted using Tukey's test. When the variances at each station were significantly different, a non-parametric test (Kruskal-Wallis) was applied to test for significant differences between the three median values. When the medians were found to be significantly different, the variables were transformed logarithmically to render the variances homogeneous and the means were compared using Tukey's test. The counts for fecal coliform bacteria and Escherichia coli (E. coli) bacteria were so variable that suitable transformations to render the variances homogenous and conduct pairwise comparisons on the means could not be found.

2.2.4 Loading Calculations and Export Coefficients

Sediment mass loading (kg) over the monitoring period was calculated for Waiparous Creek from the turbidity data as described in Section 2.2.3. For the Ghost River and Fallentimber Creek, sediment mass loading in kg/y was estimated from the bimonthly and monthly monitoring data between May 2004 and April 2005 using the computer program FLUX supported by the US Army Corps of Engineers. The FLUX program produces an estimate of mass loading by six different methods. The method producing the smallest coefficient of variation was selected. Mass loading using FLUX was calculated for the Ghost River at Richard's Road (G2) and for Fallentimber Creek above Stormy Creek (F1). Export coefficients were calculated by dividing the mass loading at each station by the drainage area above each. The export coefficients at each station were compared to values calculated from published AENV reports on other Alberta river systems (Sosiak 2000; 2004). The rivers included:

- The Little Bow River
- The Mosquito Creek
- The Upper Elbow River

2.2.5 Analysis of Long Term Data on the Bow River

Trends in TSS in the Bow River, upstream of the Ghost River discharge at Exshaw and downstream at Cochrane, were examined in order to determine whether potential increases in TSS discharge from the Ghost River into the Bow River in the last 5-10 years could be detected as increased TSS levels in the Bow River. TSS was chosen as the principal indicator of effects on water quality in the Bow River. TSS data available from long-term monitoring stations at Exshaw and Cochrane were first tested for seasonality using the Kruskal-Wallis non-parametric test on the monthly populations. Once seasonality was evaluated, the presence of monotonic trends was tested using the seasonal Kendall Test unadjusted for flow. The software for this test was published as an EXCEL spreadsheet by Bill Vant at Environment Waikato, New Zealand (Environment Waikato 2004).

3 RESULTS

3.1 Drainage Basins Delineation and Flow Corrections at each Monitoring Station

The drainage basins for the three streams ranged from 321 km^2 for Waiparous Creek to 933.43 km^2 for the Ghost River to 526.5 km^2 for Fallentimber Creek (Table 5; Figure 3). Table 5 also presents the catchment areas for each of the water quality monitoring stations and proportions of the drainage basin above each hydrometric (flow) monitoring station used to calculate daily flow at each station.

3.2 Background Information: Flows, Precipitation and Vehicular Activity

River flows and precipitation at the three flow monitoring stations over the turbidity monitoring period May 23 to July 26 indicate, as expected, that rain events correspond to periods of high flow (Figure 4). Major rain events were noted between May 19 to 25, June 11 to 18, and June 29 to July 5 and July 17 to 23. These events occurred at slightly different times and at different intensities at the three stations. The data from the Ghost RS station are probably most representative of the study area. The vehicular activity peaks occur primarily on weekends and long weekends (Figure 5).

DATE	JOB NO.	FIGURE 3
11/16/05	2005-76	

Clearwater Environmental Consultants

NTS Topo Map 82 0
Scale 1 : 350,000

DELINEATION OF THE CATCHMENT BASINS FOR THE GHOST RIVER, WAIPAROUS CREEK AND FALLENTIMBER CREEK

LEGEND

- Ghost Drainage Basin (red line)
- Waiparous Drainage Basin (black line)
- Fallentimber Drainage Basin (purple line)

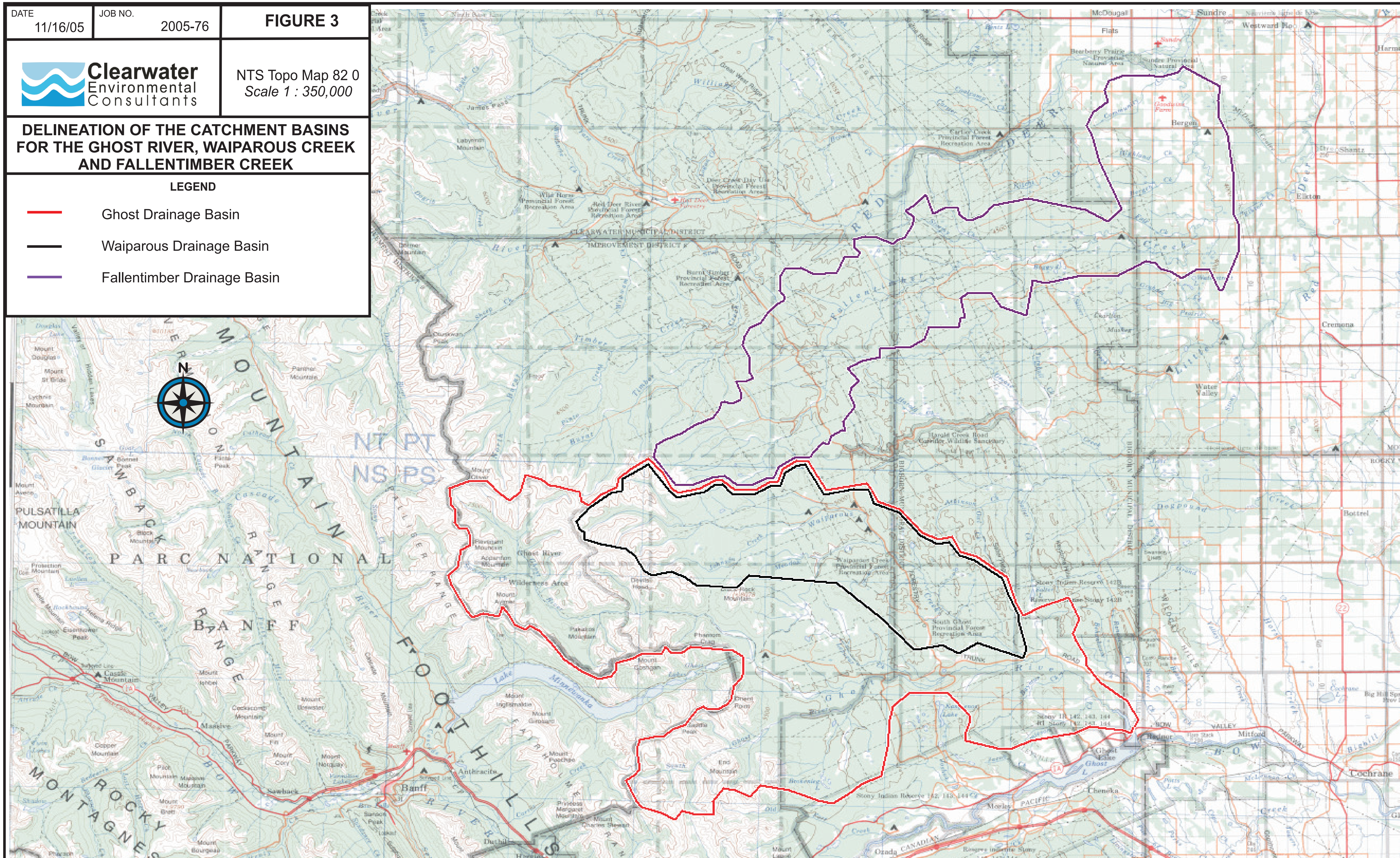


Figure 4 Flows and Precipitation during the Automated Turbidity Monitoring Period (May 23 to July 26)

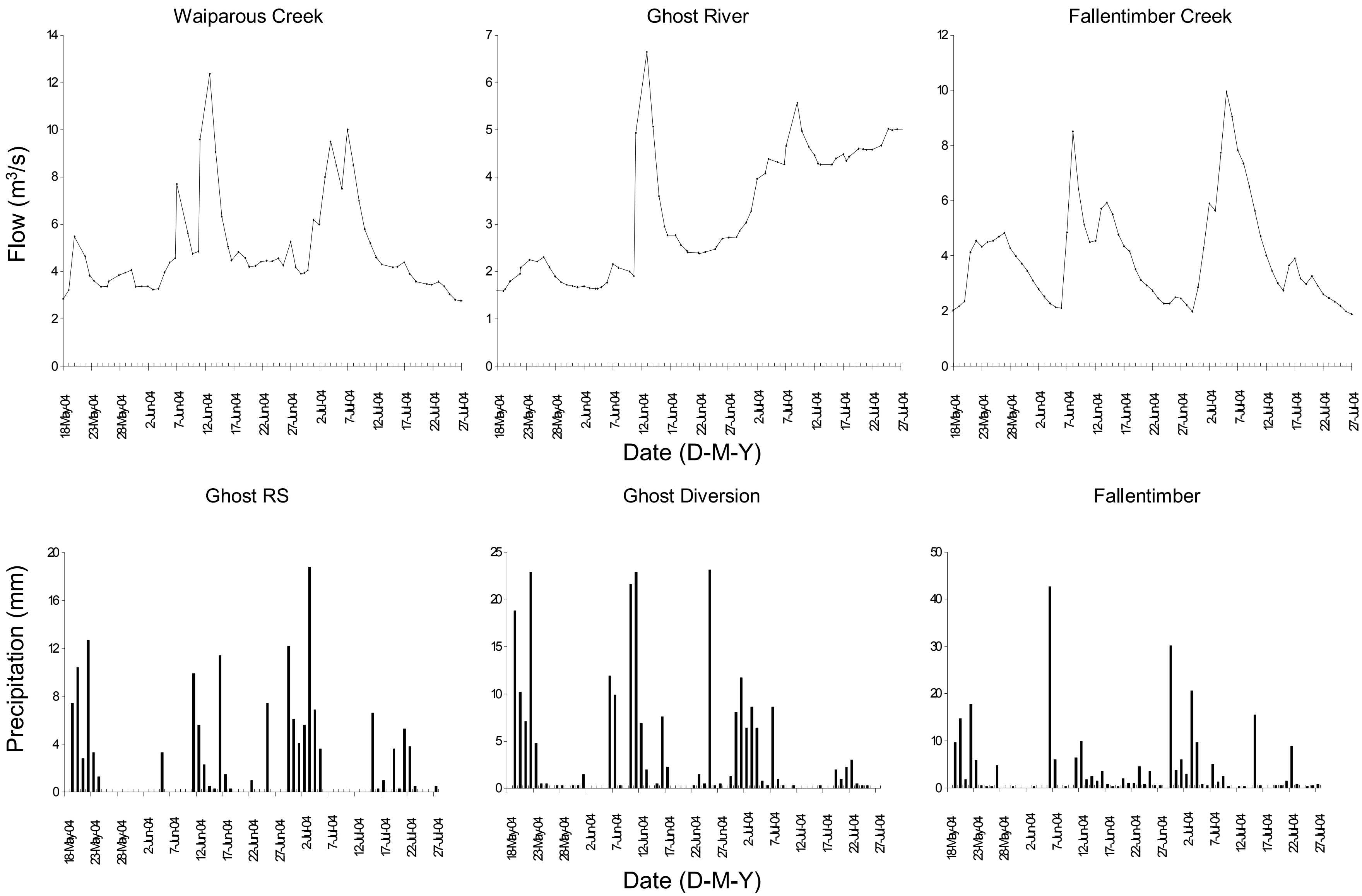
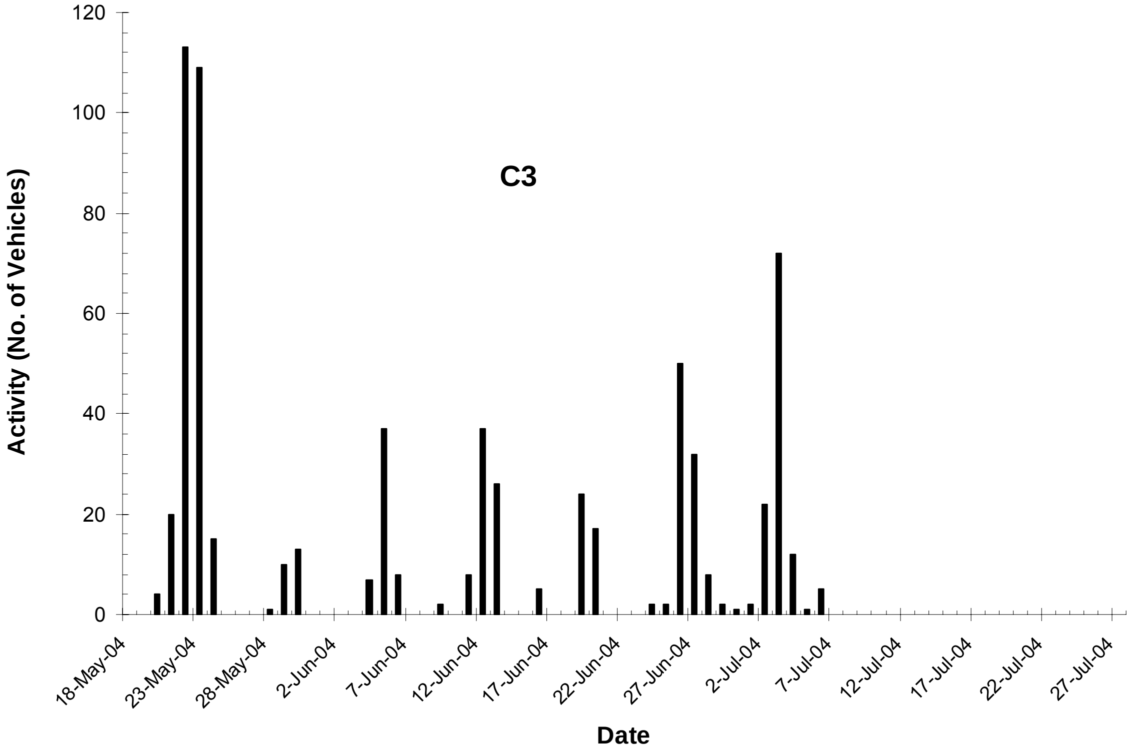


Figure 5 Vehicular Activity at Margaret Lake Trail (C3) and Margaret Lake Turnoff (C2) near Waiparous Creek



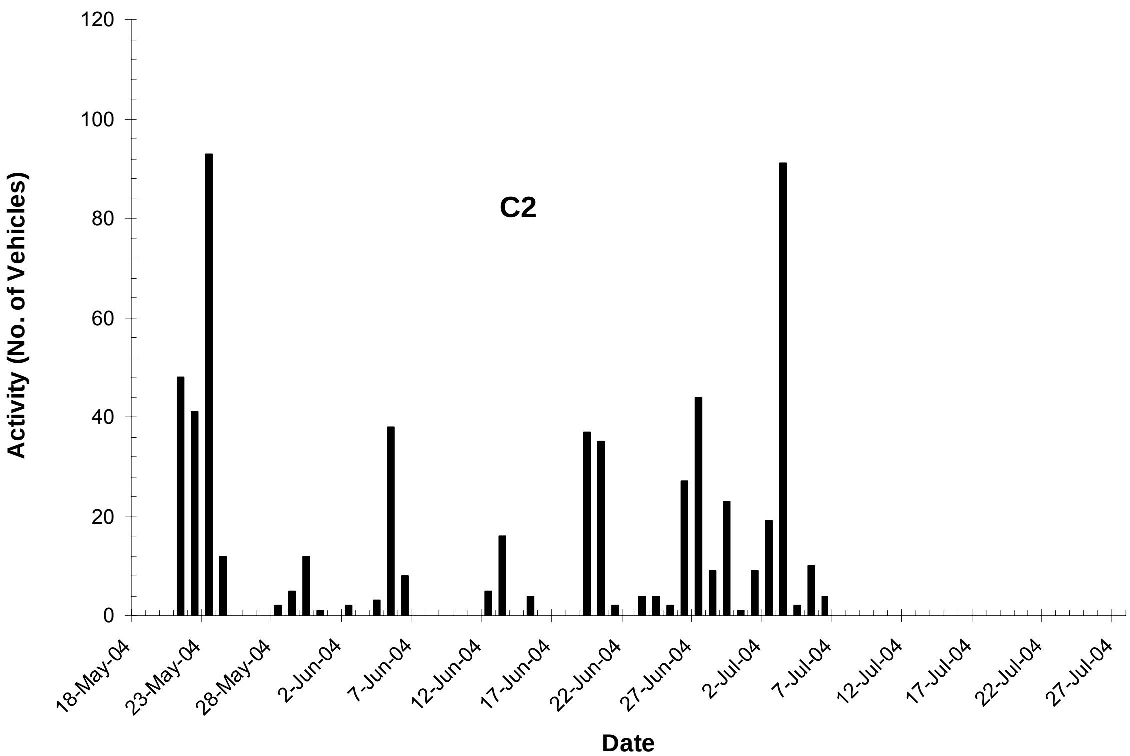


Table 5 Area of Drainage Basin above each Water Quality Monitoring Station and Proportion of Basin above each Flow Monitoring Station

Waiparous Creek			Fallentimber Creek			Ghost River		
Location	**Area (km^2)**	**% of Basin above Hydrom. Station**	**Location**	**Area (km^2)**	**% of Basin above Hydrom. Station**	**Location**	**Area (km^2)**	**% of Basin above Hydrom. Station**
W3	57.68	17.97	F3	21.76	4.13	G3	268.75	52.63
W2	221.39	68.96	F2	156.45	29.72	G2	510.62	100[1]
W1	272.83	84.99	F1	250.48	47.58	G1	862.41	168.9
Between W1 and flow monitoring station	48.19		Between F1 and flow monitoring station	275.99		Between G1 and mouth of Ghost Lake	71.02	
Total Drainage	321.02			526.47			933.43	

[1]Assumed that the flow at G2 is equivalent to that at the monitoring station H1 (05BG010).

3.3 Relationship between Turbidity and TSS

The relationship between turbidity and TSS, determined from the 2004 grab sampling program, was complex and non-linear. There was a great deal of scatter at the lower values of turbidity. Using TableCurve 2D, the best fit to the entire dataset was a complex logarithmic equation that explained about 98 % of the variance. However, in including the majority of the points that were clustered at the lower end of the scale (less than 10 NTU), this regression lost accuracy at the higher values of turbidity that were far fewer in number in this small dataset. As turbidity events occurred in the Waiparous where values over 500 NTU were recorded, accuracy at the higher values of turbidity was considered essential in order to calculate TSS loading. In addition, this "best-fit" equation was discontinuous at zero values of turbidity and there were a large number of zero values in the turbidity records.

A plot of TSS vs. turbidity for values or turbidity less than 20 NTU shows that the relationship is approximately logarithmic with a regression explaining about 78 % of the variance (Figure 6). A simple logarithmic relationship such as that in Figure 6 is often obtained in turbidity-TSS data (CCME 2002). A linear relationship fit the data for values of turbidity greater than 20 NTU and explained about 99.7 % of the variability, although based on very few data points (Figure 7). In order to calculate TSS from the values of turbidity the following formulae were used:

For turbidity values less than 20 NTU

$TSS = 1.0988*Turbidity^{0.7749}$.

For turbidity values greater than 20 NTU

TSS = 1.3735 * Turbidity – 11.989.

Figure 6 Plot of log TSS vs. log Turbidity for Turbidity Values less than 20 NTU

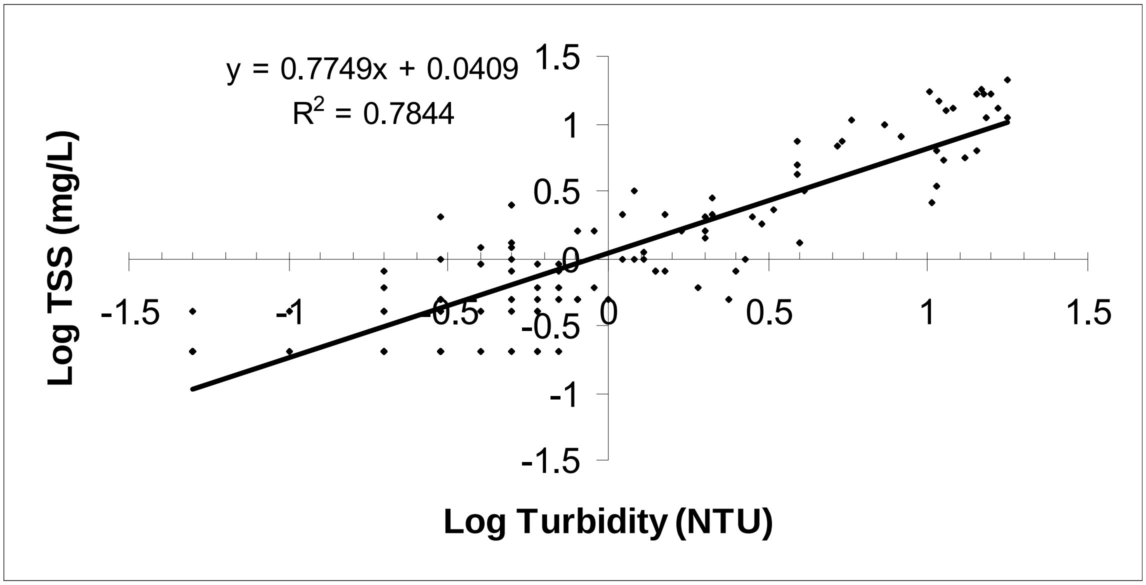
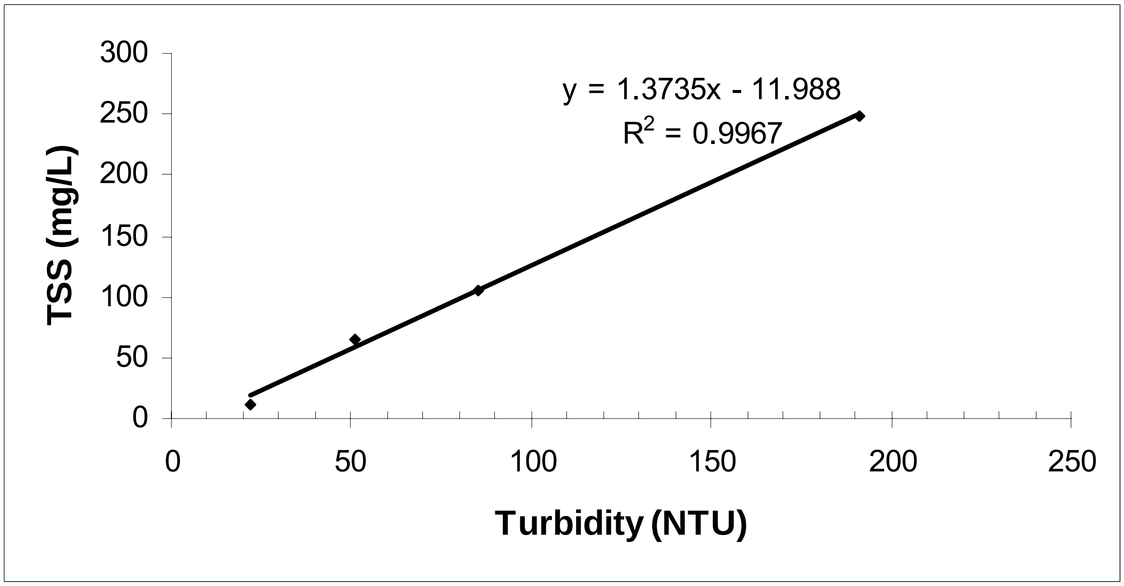


Figure 7 Plot of TSS vs. Turbidity for Turbidity greater than 20 NTU



3.4 Analysis of the Data from the Automated Hydrolab Probes

The information from the Hydrolab probes deployed on the Waiparous River in 2004 is summarized in Table 6. Significant differences ($p<0.005$) in all 6 parameters (temperature, pH, conductivity, dissolved oxygen and TSS) were observed between the upstream station at Black Rock Trail (W3) and the downstream station at the DND camp (W1). Temperature, pH and conductivity were significantly greater downstream while oxygen was greater upstream. Both turbidity and TSS were considerably greater at the downstream station. The mean turbidity was 6.5 NTU at Black Rock Trail compared to 40.0 NTU at the DND station. The corresponding values of TSS were 6.7 mg/L and 48.7 mg/L, respectively.

Table 6 Summary of Data Collected from the Hydrolab Probes Deployed Upstream (U/S) of Areas Potentially Affected by Random Camping Activities at Black Rock and Downstream (D/S) at the DND Base.

	Temperature ^{0}C		pH (units)		Conductivity (µS/cm)	
	U/S	D/S	U/S	D/S	U/S	D/S
N of cases	4895	5029	4895	4881	3691	3212
Minimum	1.8	1.9	7.82	7.68	0.187	0.238
Maximum	15.8	21.4	8.38	8.44	0.275	0.331
Median	6.1	10.9	8.16	8.29	0.241	0.292
Mean	6.6	11.1	8.152	8.248	0.243	0.295
Standard Dev	2.7	3.5	0.134	0.144	0.02	0.022
SW P-Value[1]	0.000		0.000	0.000	0.000	0.000
	Dissolved O_2 (mg/L)		**Turbidity (NTU)**		**TSS (mg/L)**	
	U/S	**D/S**	**U/S**	**D/S**	**U/S**	**D/S**
N of cases	4133	3481	4001	4628	4001	4628
Minimum	7.6	6.99	0.0	0.0	0.0	0.0
Maximum	11.38	12	284.7	1825	379	2495
Median	9.84	8.9	0.8	6.8	0.92	4.9
Mean	9.758	8.944	6.52	40.0	6.7	48.7
Standard Dev	0.731	0.86	20.49	119.3	25.8	162
SW P-Value	0.000	0.000	0.000	0.000	0.000	0.000

[1] Shapiro Wilks test for normality. All the parameters were considered non-normal
Note: All Differences were Statistically Significant (Mann-Whitney U test: $P<0.05$)

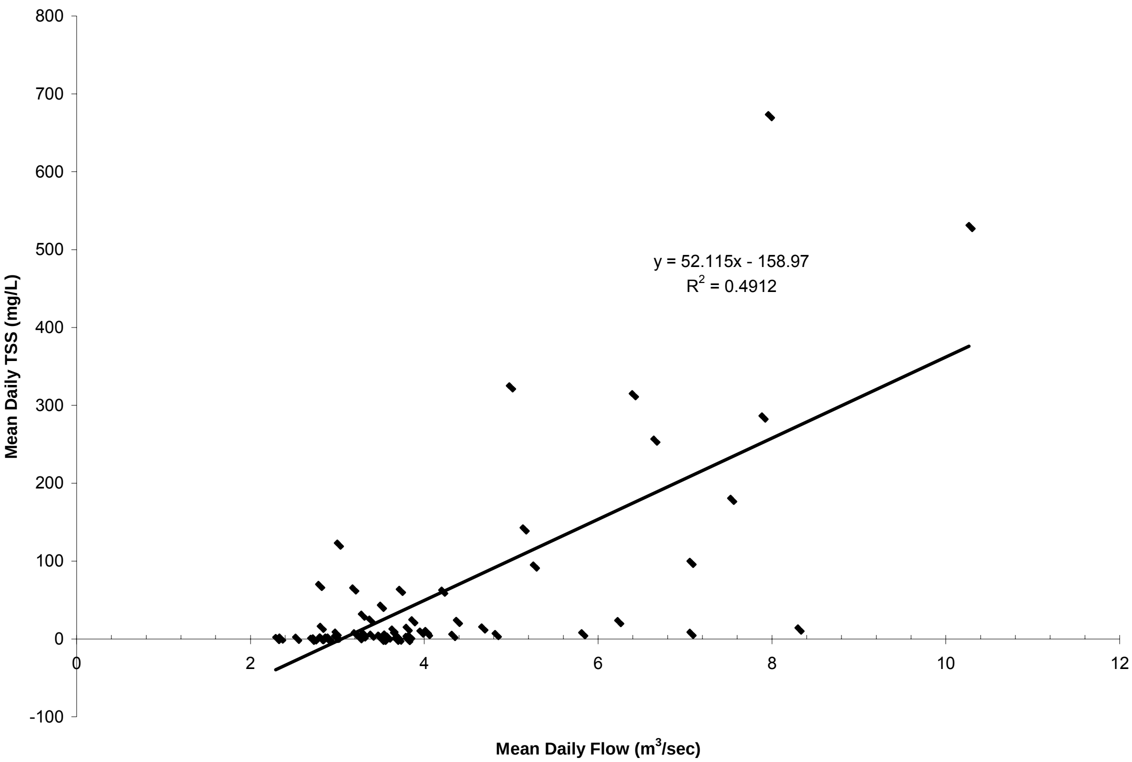
The interrelationships between the daily averages in these six parameters and flow at the downstream station (DND Base; W1) were examined in the Spearman correlation analysis. Statistically significant relationships were observed between temperature and conductivity (positive), temperature and dissolved oxygen (negative), pH and conductivity (positive), conductivity and dissolved oxygen (negative), and turbidity/TSS and corrected flow (positive; Table 7). These relationships largely reflect the normal inter-relationships between chemical and physical parameters during the course from spring to summer conditions. For example, during spring runoff, when the river is flush with cool meltwaters, temperatures are usually low, conductivity is low (waters more dilute) and oxygen solubility is relatively high relative to summer conditions. The positive relationship between daily mean TSS and flow was further investigated by regressing TSS on the latter (Figure 8). The relationship was significant ($P<0.05$) with flow explaining about 49 % of the variance in TSS.

Table 7 Correlation matrix for Daily Mean values of Temperature, pH, Conductivity, Dissolved Oxygen, Turbidity, and TSS in the Hydrolab Datasonde Probe.

	Temp	**pH**	**Conductivity**	**Diss. O_2**	**Turbidity**	**TSS**
Temp						
pH	+					
Conductivity	+	+				
Dissolved O_2	-	-	-			
Turbidity	-	-	-	+		
TSS	-	-	-	+	+	
Flow	-	-	-	+	+	+

Significant Relationships based on Bonnferroni Probabilities are Shaded ($P<0.05$).

Figure 8 Regression of Daily Mean TSS on Daily Mean Flow Rates



3.5 TSS and Loading Analysis

Plots of the TSS concentrations recorded by the automated probes indicate a large number of individual events or episodes of high TSS (Figure 9, 10). Most of these occur as minor events upstream which correspond to major events downstream with a small lag time between the two. These episodes are best viewed in the low range of the data (Figure 10). Major TSS episodes occurred on May 21 to 24, June 6 to 9, June 10 to 17 and June 30 to July 07. Many of the major episodes consist of a complex succession of minor events which cannot be easily resolved one from the other. Not all events downstream corresponded directly to events upstream (for example the event on July 16). In general, the magnitudes of the downstream events are considerably greater than those of the upstream events. For example, the downstream episode on June 7 peaked at 900 mg/L, while the corresponding upstream peak was only 44 mg/L.

Figure 9: TSS Concentrations in Waiparous Creek taken with the Automated Turbidity Probes: Full Range of the Data.

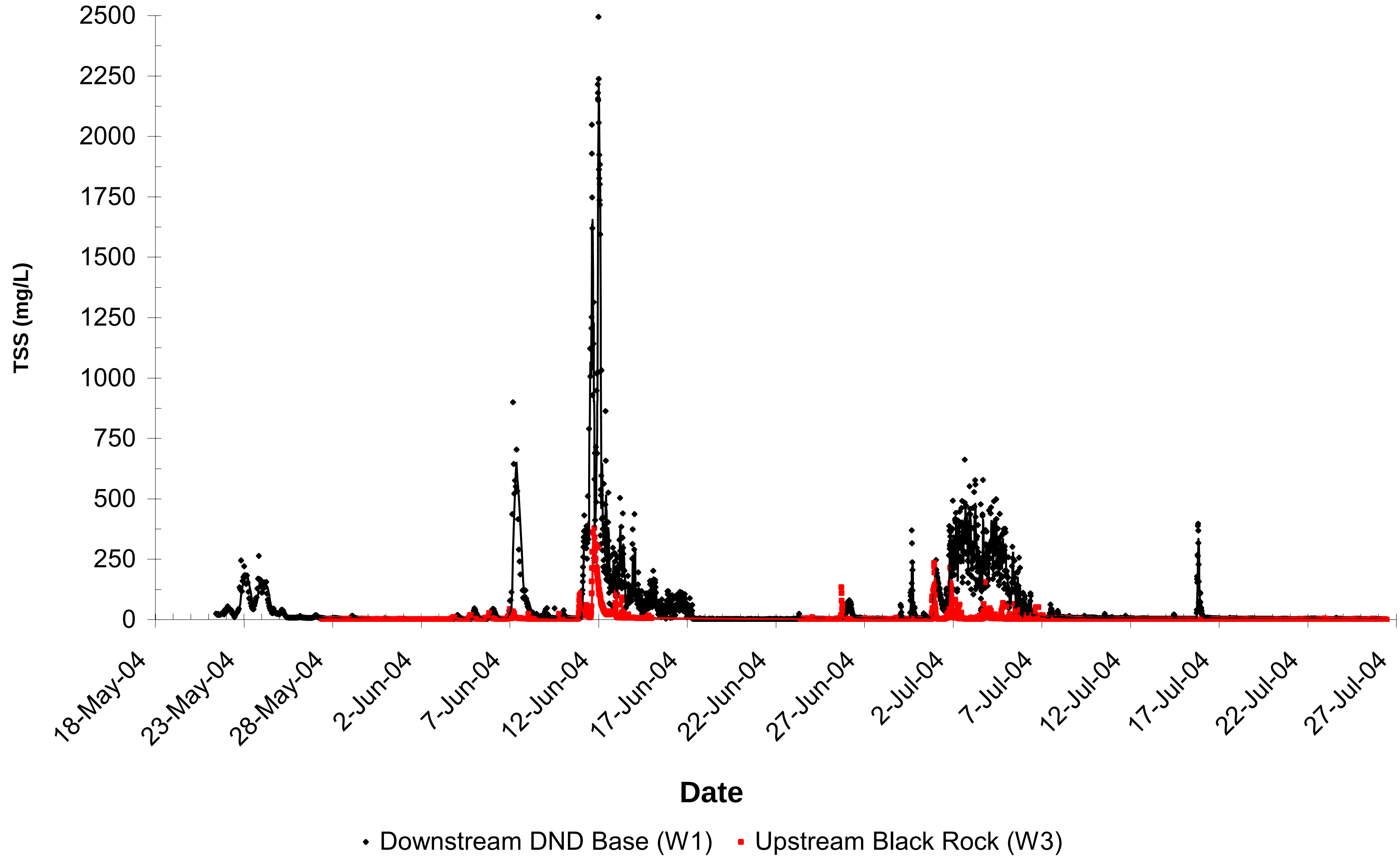
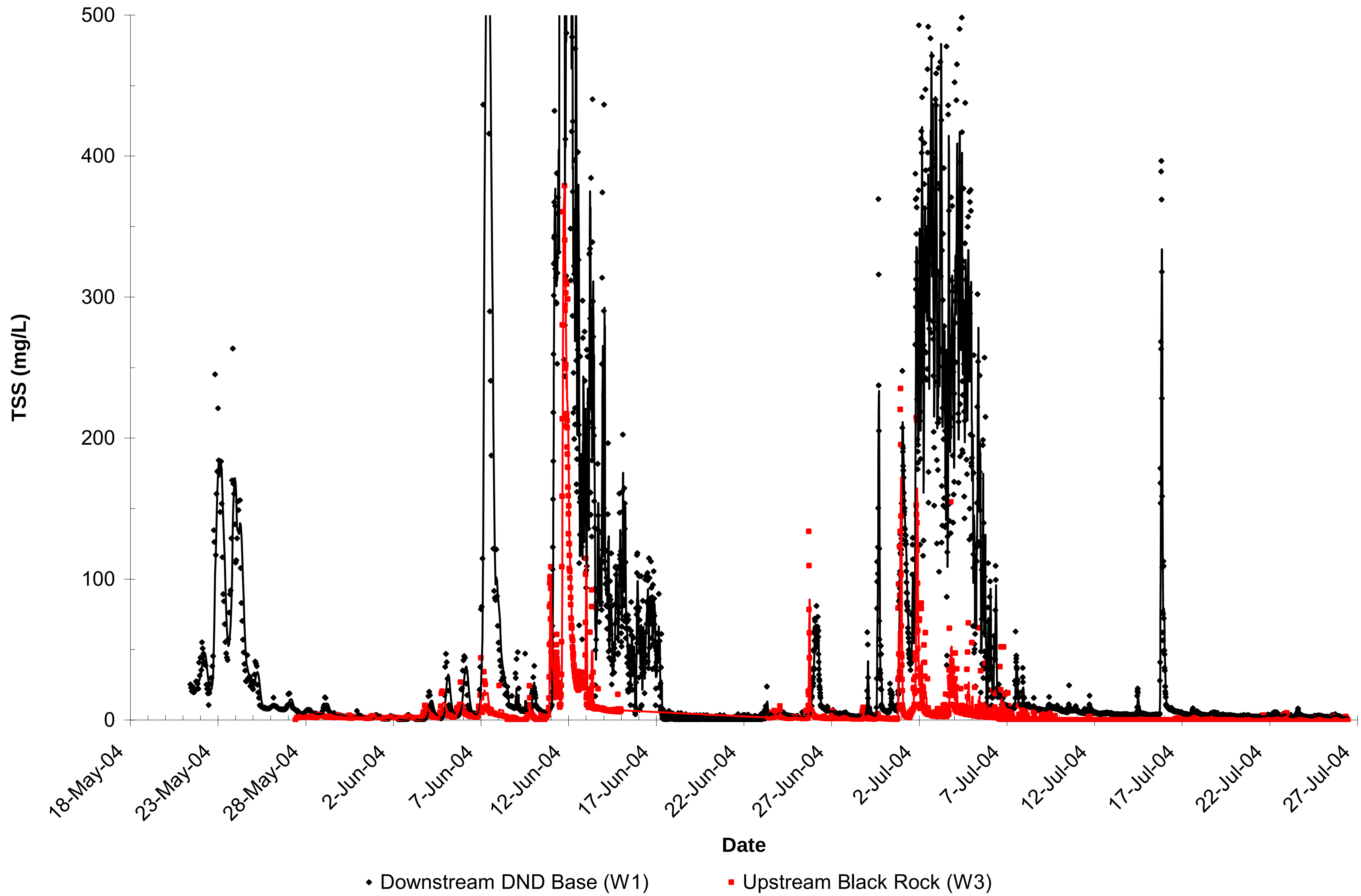


Figure 10: TSS Concentrations in Waiparous Creek taken with the Automated Turbidity Probes: Lower Data Range



The relationships between TSS on Waiparous Creek, flow, precipitation at the Ghost RS station (P2) and vehicular activity at the Margaret Lake Trail turnoff (C3) indicate that TSS events coincided well with flow and precipitation events (Figure 11). The major TSS episodes could all be traced to similar episodes of elevated flow and precipitation. These results suggest that sediment release in the Waiparous drainage basin was largely the result of bed or bank erosion. Vehicular activity at Margaret Lake trail corresponds much better with weekends and long weekends, with the first major event recording activity on the Victoria Day weekend (Figure 11). There were a number of significant vehicular events (e.g., No. 2 and No. 4) which did not correspond at all to peaks in TSS, flow or precipitation. These observations suggest that when vehicular activity peaks do correspond with TSS and flow, it is the result of rain occurring on that weekend.

The instantaneous loading of TSS in kg/day throughout the monitoring period on Waiparous Creek (Figure 12) is quite similar in form to the TSS concentration profile. Maximum rates of instantaneous loading occurred during the four major TSS episodes: May 21 to 24 (68,300 kg/d), June 6 to 9 (497,000 kg/d), June 10 to 17 (1,980,000 kg/d) and June 30 to July 07 (339,000 kg/d).

The plots of absolute loading in kg, calculated by multiplying the loading rates by the time increment (15 minutes) between each reading on the turbidity probe are similar to the other plots (Figures 13 and 14). The sums of the values of the red and black points in Figure 13 represent the total loading in kg at the upstream and downstream stations, respectively. A total of 22 distinct downstream loading events are identified from the lower range of the data (Figure 14) and have been characterized in Table 8. The table identifies the downstream event, the corresponding upstream event (when this can be resolved), the peaks and total loadings for each. Due to the complexity of the larger loading episodes and the fact that many downstream peaks did not correspond with events upstream (e.g., Events 17 to 22), there were only 8 events where upstream events could be matched with downstream events. In all eight matched cases, the peaks and total loading estimates were greater downstream. The matched events were compared statistically using the non-parametric Mann-Whitney U test and in all eight cases, the downstream event (population of load values) was significantly greater than the upstream event (population of load values). By summing the estimates of load for each 15 minute logging interval, the total sediment loads over the entire monitoring period (May 21 to July 26) were calculated to be 36,566 kg upstream at Black Rock Trail and 1,265,412 kg downstream at the

DND camp. The difference (1,228,864 kg) represents the amount of material that entered the stream between the two stations.

The extreme episodic nature of TSS loading in the Waiparous Creek is illustrated in Table 8 showing the total loading at the DND base downstream for the four major TSS events identified above. The major event between June 11 and June 17, a mere 6 days, accounted for 46.9 % of the total loading. In total, the four events accounted for 91.9 % of the total sediment loading over the monitoring period.

Figure 11 TSS in Waiparous Creek in Relation to Flow, Precipitation and Vehicular Activity

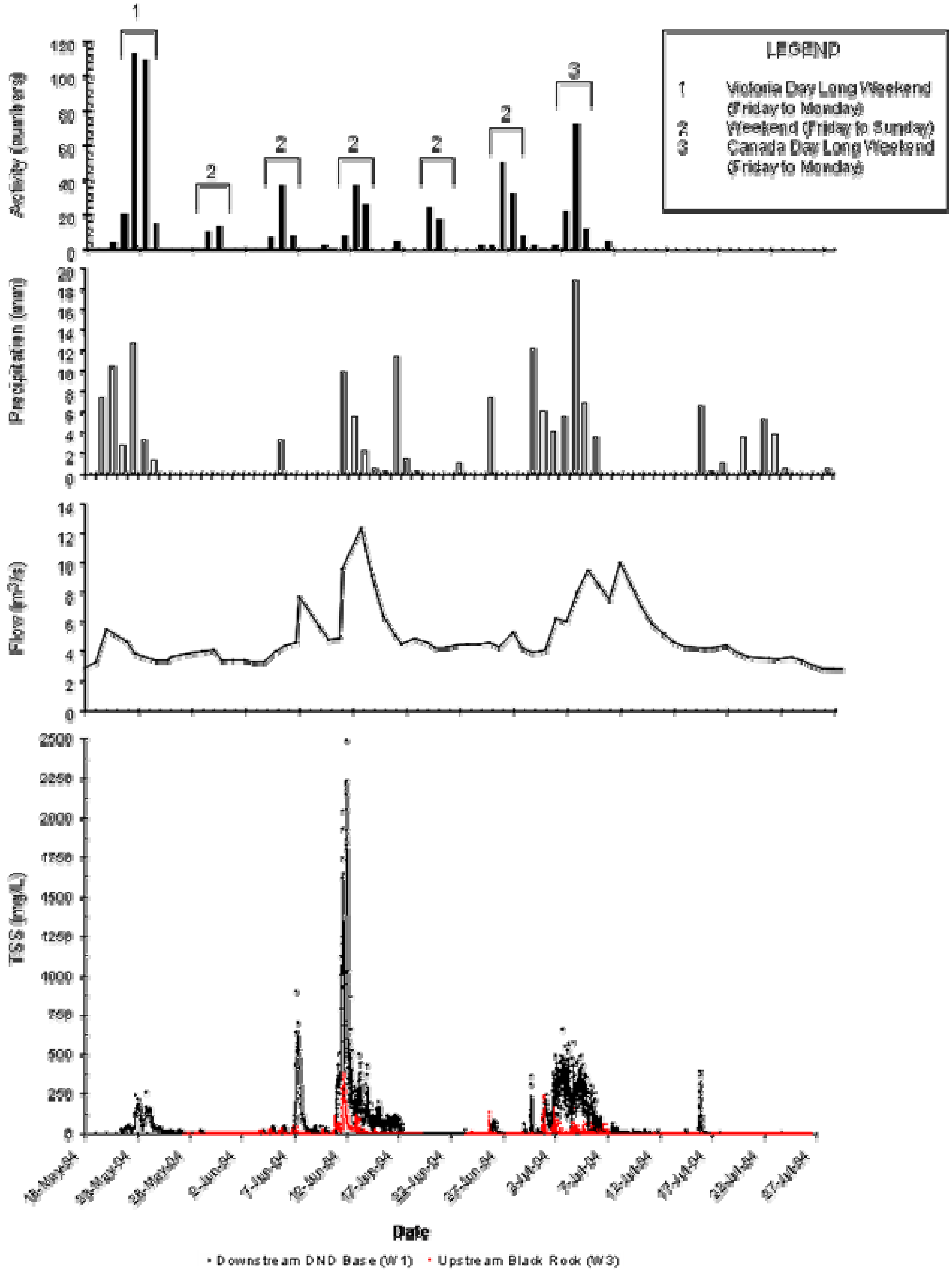


Figure 12: Instantaneous Rates of TSS Loading in Waiparous Creek from the Automated Turbidity Probes

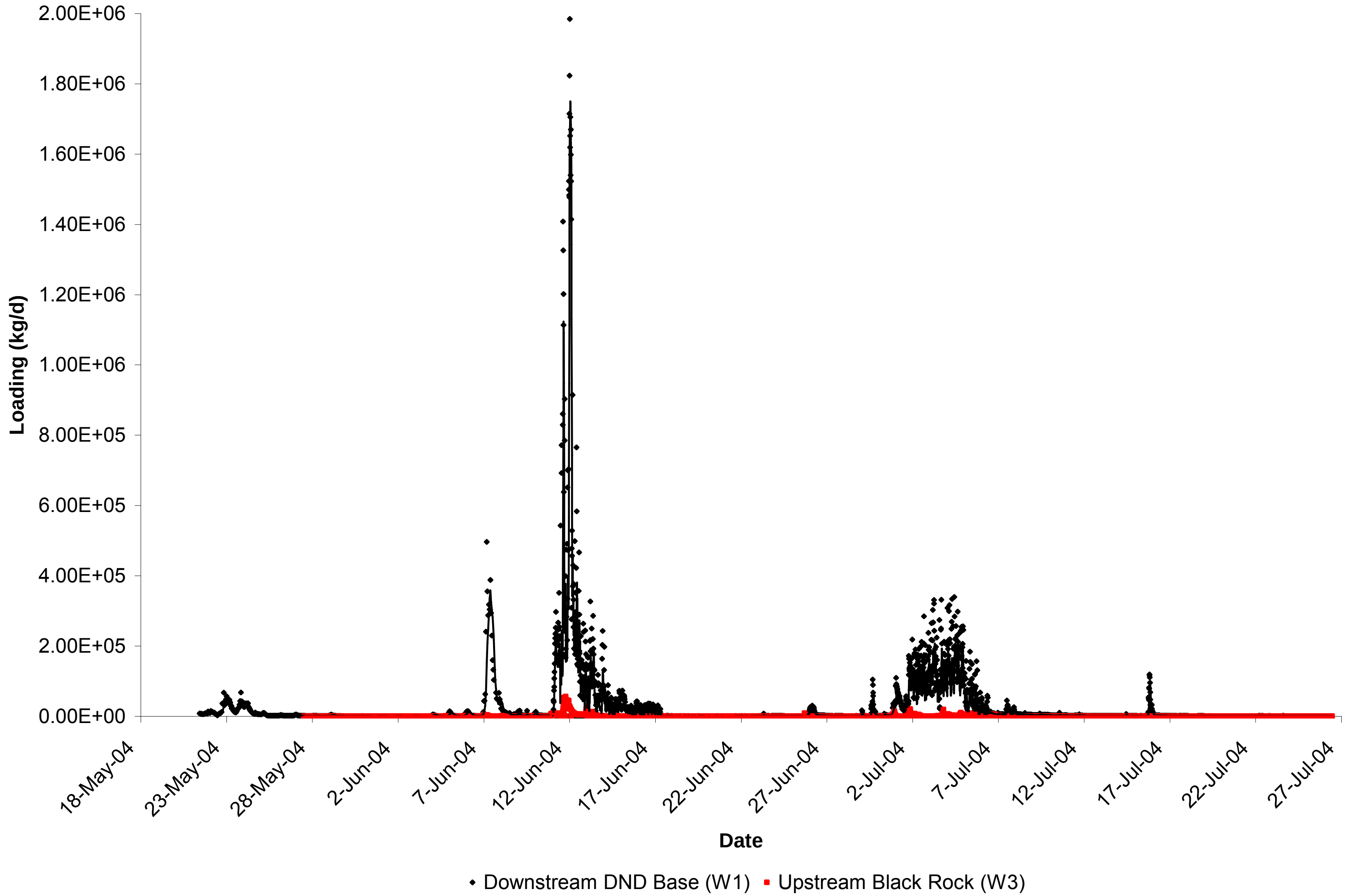


Figure13 : Absolute Loading of TSS in Waiparous Creek Calculated by Integrating Loading Rates for each 15 Minute Logging Interval

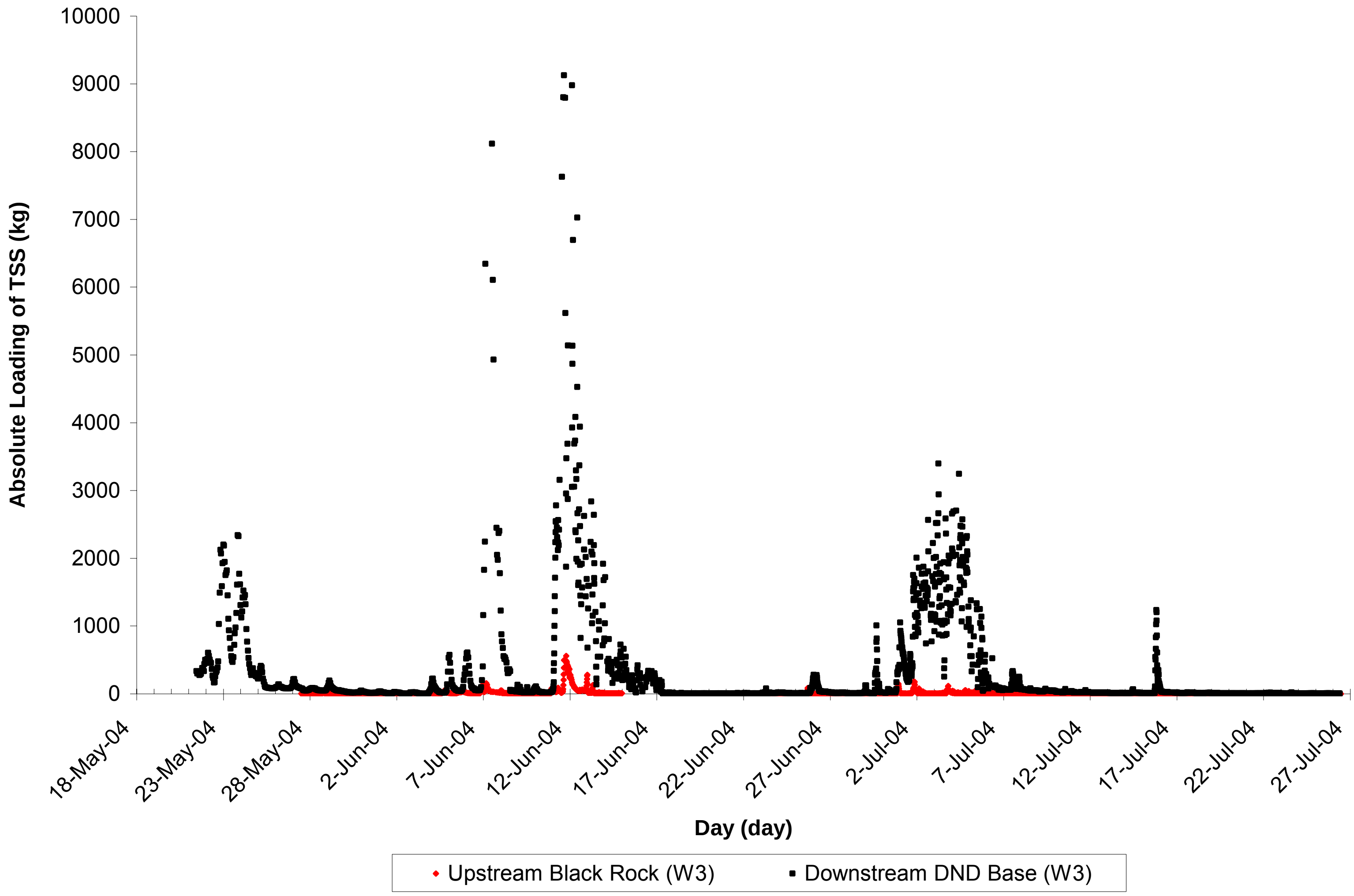


Figure 14: Absolute Loading of TSS in Waiparous Creek– Lower Range of Data to show Details of the Loading Peaks

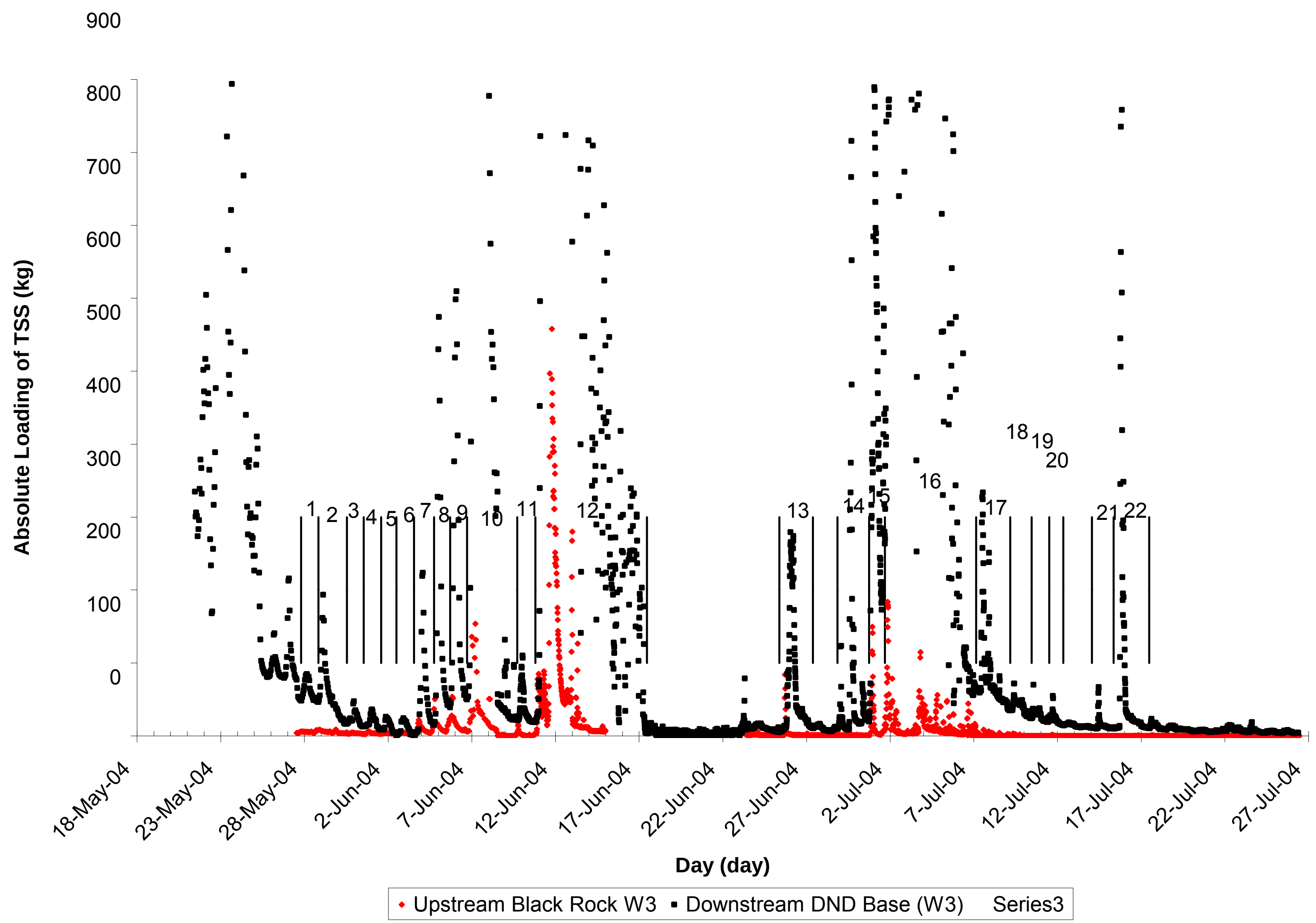


Table 8 Analysis of 22 Loading Events in the Waiparous Creek.

Event Number (See Figure 14)	Date of Distinct Peak Upstream	Date of Distinct Peak Downstream	Peak (Total) Loading in Upstream Event (kg)	Peak (Total) Loading in Downstream Event (kg)	Delta Time (Days)
1	None	May 28	-	84.7	
2	None	May 29	-	193.4	
3	None	May 30	-	47.6	
4	None	June 01	-	36.4	
5	None	June 02	-	22.4	
6	None	June 02	-	24.6	
7	3-Jun-04	4-Jun-04	21.8 (211)	223.5 (1,557)	0.25
8	4-Jun-04	5-Jun-04	50.5 (268)	574.2 (3,485)	0.25
9	5-Jun-04	6-Jun-04	53.6 (496)	609.6 (5,050)	0.25
10	7-Jun-04	7-Jun-04	153.8 (1,569)	17,768 (168,173)	0.00
11	9-Jun-04	10-Jun-04	15.4 (175)	110.0 (3,633)	0.25
12	Not resolvable	11-Jun-04	-	14,241	
12	11-Jun-04	Not resolvable	88.4	-	-
12	11-Jun-04	12-Jun-04	557 (15,353)	19,835 (451,669)	0.23
12	13-Jun-04	Not resolvable	280.1		
12	Not resolvable	13-Jun-04		2,837.5	
13	25-Jun-04	26-Jun-04	83.9 (507)	279.3 (11,132)	0.34
14	Not resolvable	29-Jun-04	-	1,010	
15	30-Jun-04	1-Jul-04	149.4 (1,375)	1,051 (32,250)	0.10
16	1-Jul-04	Not resolvable	176.2	-	-
16	3-Jul-04	Not resolvable	114.8	-	-
16	Not resolvable	3-Jul-04	-	3,396	
16	4-Jul-04	Not resolvable	56	-	-
16	5-Jul-04	Not resolvable	48	-	-
16	6-Jul-04	Not resolvable	44	-	-
17	None	7-Jul-04	-	333.6	-
18	None	9-Jul-04	-	71.9	-
19	None	10-Jul-04	-	70.2	-
20	None	11-Jul-04	-	51.7	-
21	None	14-Jul-04	-	67.0	-
22	None	15-Jul-04	-	1,235	-

Shaded indicates Events where the Upstream and Downstream Events are Matched.
Total Load for each Event is in brackets. Total loads downstream were significantly greater than upstream loads ($p<0.05$). Hyphens indicate where corresponding loading peaks could not be identified.

Table 9 Partitioning the TSS Loading at the DND Camp during Four Major TSS Events

Dates of TSS Event	Loading (kg)	% of Total Loading
May 21-May 26	74,732	5.91
June 06 – June 09	166,497	13.2
June 11 – June 17	592,925	46.9
June 30-July 07	327,655	25.9
Total Loading (May 21-July 26)	1,265,412	

3.6 Analysis of 2004 Monthly Monitoring Program

The results of the monthly and bimonthly water quality sampling program in 2004 and early 2005 are presented as boxplots, showing the range and distribution of each parameter at each station, and as time-traces that show seasonal changes (Figures 15,16). Summary statistics of the monitoring data and results of the statistical tests to determine upstream/downstream trends are found in Tables 10 and11).

Dissolved Oxygen

Adequate levels of dissolved oxygen are required for maintenance of aquatic life. Oxygen levels are reduced by decomposition of organic materials, plant respiration and high temperatures which decrease oxygen solubility. Levels of dissolved oxygen decreased at all stations during the summer months under elevated temperatures (Figures 16.1). Oxygen concentrations were slightly greater at the downstream stations in the Waiparous and Ghost Rivers although this trend was only statistically significant in the latter. Mean oxygen concentrations at the Benchlands station were significantly greater than concentrations at Richards Road (Table 11; $P<0.05$). On no occasion did oxygen levels fall below the Alberta chronic guideline for protection of aquatic life (6.5 mg/L).

Water Temperatures

Water temperature influences chemical and biological processes in a stream including productivity, diversity of fish communities and oxygen solubility. Water temperatures ranged from near zero values during the winter in all three streams to 12.84 °C in Waiparous Creek in late July (Figure 15.2; Table 10). A strong seasonal increase in temperature during the summer months, peaking in late July and early August, was evident at all stations and rivers (Figure 16.1). The median temperature decreased slightly at the downstream stations of all three river systems although none of these differences was statistically significant. As the guidelines for temperature in AENV (1999) refer to changes from previously recorded values, these temperatures cannot be discussed in terms of exceedances or non-exceedances. Taylor and Barton (1992), however, proposed an upper acute criterion of 22 °C for common sport fish in Alberta. By this criterion, the water temperatures in all three streams would be suitable for all sport fish.

pH

The pH expresses the concentration of hydrogen ions which indicates the balance between acid and base chemical species in the water. The pH ranged from 6.5 units on Fallentimber Creek (classified as an outlier in the boxplots) to 8.26 units in the Ghost River (Figure 15.3; Table 10). The time traces do not suggest a strong seasonal change in pH except for a small but consistent decrease in Fallentimber Creek through the winter (Figure 16.2). Median values of pH in the Ghost River increased significantly at the downstream stations (Table 11). The mean values at both the middle (Richards Road) and downstream (Benchlands) stations were significantly greater than the values at the upstream site, although there was no significant difference between the two. Values of pH showed considerable variability with several extreme values and outliers indicated in the boxplots. With the exception of the outlying value of pH 6.5 at Fallentimber Creek in September, all values of pH were well within the CCME water quality guideline of 6.5 to 9.0.

Conductivity

Conductivity is a measure of the ability of water to conduct an electrical current. As the ability to conduct a current is determined by the concentration of charged ionic species, conductivity provides an indirect measure of ionic concentrations in the water. Conductivity ranged from 121 μS/cm in Fallentimber Creek to 333 μS/cm in the Ghost River (Table10). The conductivity of all three rivers shows a considerable increase from low values in the spring, during the flush of dilute meltwater, to higher values in the summer and winter when basal flow rates prevail (Figure 16.2). The boxplots indicate that the downstream stations on the Waiparous had greater values of conductivity than the upper station at Black Rock Trail (Figure 15.4). Both downstream stations (at Hwy 40 Bridge and DND Camp) were significantly greater in conductivity than the upstream station although the difference between the middle and downstream stations was not significant (Table 11). There are currently no surface water quality guidelines for conductivity.

Coliform Bacteria

Fecal coliform bacteria, found in the intestinal tract of warm-blooded animals, provide an indication of contamination from sewage or animal feces. *E. coli* is one species of fecal coliform bacteria. High levels of fecal coliform bacteria can affect the suitability of water for irrigation, recreation (e.g., swimming) and as a source of drinking water. Levels of fecal coliform bacteria in all three streams peaked in June and late July/early August corresponding to periods of high rates of flow and sediment load (Figure 16.3). Fecal coliform bacteria ranged from 0 /100 mL in the upstream station at Waiparous Creek to 340 /100mL in Fallentimber Creek (Table 10). In general, fecal coliform bacteria were greater in number in Fallentimber Creek than in the Ghost River or Waiparous Creek and greater at the downstream stations. Fallentimber Creek was inconsistent with this trend and showed slight decreases in median values at the mid and downstream stations. These upstream-downstream trends were statistically significant in Waiparous Creek and Ghost River but not in Fallentimber Creek (Table 11). Exceedances of the irrigation guideline (100 / 100mL) occurred once each on the Ghost River and Waiparous Creek and on three occasions on Fallentimber Creek. There were two exceedances of the recreational guideline (200/100mL) in Fallentimber Creek at the upstream and midstream stations, respectively.

E. coli showed very similar trends as fecal coliform bacteria. Peaks were evident during periods of high flow and high sediment loads in June and late July/early August (Figure 16.3). Again, levels of *E. coli* were greater in Fallentimber Creek than in the Ghost River or Waiparous Creek and greater at the downstream stations. The exception again was Fallentimber Creek where median levels decreased downstream. Upstream-downstream differences were only significant on Waiparous Creek (Table 11). There were no exceedances of the recreational guidelines for *E. coli* (400 /100mL) in any of the three rivers.

Phosphorus

Phosphorus is an essential plant nutrient which, in excess, can cause increased growth of aquatic plants and algae. Excessive algal growth can result in decreased levels of oxygen at night, when respiration exceeds photosynthesis, and the development of nuisance algae on rock substrates (periphyton). Phosphorus is measured as two forms. Total phosphorus (TP) includes both particulate and dissolved forms while total dissolved phosphorus (TDP) includes only the dissolved forms. TDP, being more reactive and easily absorbed by aquatic plants, is a better measure of the phosphorus available for plant and algal growth.

Total phosphorus ranged from a low of 0.002 mg/L, found in all the rivers to 0.192 mg/L in the Ghost River (Table 10). In general, median concentrations of TP were quite low at 0.004 mg/L in both the Ghost River and Waiparous Creek and 0.009 mg/L in Fallentimber Creek. Significant peaks in TP were evident in all three rivers during episodes of high flow and high levels of suspended solids in early June (Figure 16.4). No significant upstream-downstream differences in TP were observed in any of the three rivers (Table 11). Exceedances of the Alberta surface water quality guidelines for TP (0.005 mg/L) occurred once in the Ghost and Waiparous Rivers and twice in Fallentimber Creek, all during the June TSS episode.

TDP was very low in all the streams. Median concentrations of TDP were barely detectable in the Ghost and Waiparous Rivers (0.002 mg/L) and only 0.005 mg/L in Fallentimber Creek (Table 10). Maximum values were 0.012 mg/L and 0.011 mg/L in the Ghost River and Fallentimber Creek, respectively. Peaks in TDP are evident during the episodes of high flow and TSS in early June and late July (Figure 16.4). There were no significant upstream-downstream trends in TDP in any of the streams (Table 11). The large difference between levels of TP and TDP indicates that much of the phosphorus is bound to suspended particles. There are no water quality guidelines published for TDP.

Nitrogen

Nitrogen, like phosphorus, is another essential nutrient for aquatic plants. Excessive amounts of nitrogen can cause increased growth of nuisance algae and decreased oxygen concentrations during periods of algal decomposition. High levels of ammonia and nitrite may be toxic to aquatic life. Ammonia is a measure of reduced inorganic nitrogen while Total Kjeldahl Nitrogen (TKN) includes all reduced forms of nitrogen including both inorganic (ammonia) and organic species. Nitrate and nitrite are usually measured together. Total nitrogen (TN) accounts for all forms of N including oxidized forms (nitrate + nitrite) and reduced forms (TKN). While nitrite is normally low in natural waters, nitrite, ammonia and TKN can be elevated downstream of wastewater discharges.

Levels of nitrite were all very low and most values were below detection limits (less than 0.003 mg/L N). Nitrite concentrations never approached the CCME guideline of 0.06 mg/L. As nitrite levels were extremely low and mostly non-detectable, the variable “nitrates” (nitrate + nitrite) consisted almost entirely of the nitrate ion. Nitrates ranged from 0.002 mg/L (detection limit) on all three rivers to 0.270 mg/L in Waiparous Creek (Table 10). Peaks in nitrates were evident in Waiparous Creek and Fallentimber Creek, corresponding to the spring peaks in flow and TSS in

June noted above (Figure 16.6). Nitrates also increased gradually during the winter only to fall precipitously in February and March when the light returned and rates of algal photosynthesis increased. Median values were highest in the Ghost River (0.214 mg/L) and least in Fallentimber Creek (0.022 mg/L). The median concentration in Waiparous Creek (0.172 mg/L) was similar to that in the Ghost River. The low concentrations in Fallentimber Creek were observed at all three sites along the river. Nitrates were significantly greater at the two downstream stations in Waiparous Creek than at the upstream station at Black Rock Trail. Overall, levels of nitrates never approached the CCME guideline for nitrates of 2.94 mg/L.

In general, ammonia concentrations were low in all the streams. Ammonia ranged from non-detectable in all three streams to 0.110 mg/L, observed once in Fallentimber Creek (Table 10). The time traces and boxplots show that ammonia in 2004-2005 was quite variable. Spring peaks are evident in Ghost River and Fallentimber Creek and, in general, higher values occurred during the summer months (Figure 16.5). Median values were highest in Fallentimber Creek (0.020 mg/L), although the boxplots indicate few differences between the three streams. There were also no significant differences between stations in any of the three streams (Table 11). Ammonia concentrations at no time approached the CCME surface water quality guideline for this variable which ranged from 0.171 to 7.32 mg/L for the range of pH and temperatures encountered in these streams.

TKN ranged from non-detectable in all three streams to 0.820 mg/L in Fallentimber Creek (Table 10). Median concentrations of TKN were greatest in Fallentimber Creek (0.170 mg/L) and least in the Ghost River (0.060 mg/L), although the boxplots suggest there is little difference in this parameter between the three streams. Spring and summer peaks in TKN were evident in all streams. No significant upstream-downstream differences in TKN were detected in any of the streams (Figure 16.6; Table 11). There are no water quality guidelines for TKN.

As TN is largely dominated by the values of TKN, the seasonal plots and values of TN are similar to those of this parameter. TN ranged from 0.163 mg/L in Waiparous Creek to 0.854 mg/L in Fallentimber Creek. Median concentrations were similar in all three streams, ranging from 0.262 mg/L in Fallentimber Creek to 0.292 mg/L in Waiparous Creek. Spring and summer peaks were evident (Figure 16.5). There were no significant upstream-downstream differences in TN detected in any of the streams (Table 11). There was no exceedance of Alberta's water quality guideline for TN of 1 mg/L.

TSS/Turbidity

Because of the strong relationship between turbidity and TSS, trends in these two variables were almost identical and only TSS is discussed here. TSS ranged from non-detectable, in all three streams, to 249 mg/L in the Ghost River. Median values ranged from 0.6 mg/L in the Ghost River to 1.8 mg/L in Fallentimber Creek. The mean values were generally an order of magnitude greater than the median values, a fact suggesting that TSS has a highly skewed distribution (Table 10). The skewed distribution of TSS is the result of its episodic nature. Significant peaks in TSS occur in the spring and summer (Figure 16.7), corresponding to the major events recorded in the detailed TSS monitoring conducted on Waiparous Creek (Section 3.4.1). Comparisons between the TSS in the two sets of data indicate that the bimonthly measurements missed the intensity of major TSS events. For example, the major TSS event on June 7 to 9 on the Waiparous Creek reached an estimated maximum TSS of 2,500 mg/L as determined from the turbidity probe, compared to a peak of only 105 mg/L recorded in the bimonthly monitoring. The time traces also indicated that significant TSS events occurred in Waiparous Creek after removal of the turbidity probes in late July (Figure 16.7). The loading estimate calculated from the turbidity probe data for May 21 to July 26 (1,265,412 kg) therefore, underestimates total annual loading. In contrast to the results from the continuous turbidity probe (Table 6), no significant upstream-downstream differences in TSS were detected in the bimonthly grab samples in any of the three streams (Table 11). Turbidity, however, was significantly greater at the downstream stations in all streams. The failure to detect statistically significant upstream-downstream differences in TSS is likely the result of the infrequency of sampling in the grab sampling program. Many of the high TSS episodes taking place between the bimonthly and monthly sampling intervals were simply missed with the result that upstream-downstream differences in TSS could not be detected statistically.

Metals

Traces of selected metals measured at the downstream station on each river showed two distinct seasonal trends (Figures 16.7 to 16.10). The highly soluble major cations such as sodium and magnesium decreased in concentration during the springmelt and increased in the fall and winter when basal flows predominate. Some trace metals, however show an opposite trend. Dissolved iron and aluminum actually peaked during the spring melt, perhaps the result of their association with the high particulate loads at this time. Iron may also increase in concentration during the spring runoff from an increase in drainage of coloured waters from fens in the stream's catchment basin. Aluminum exceeded the CCME water quality guideline (100 μg/L) on one occasion each in Waiparous and Fallentimber Creeks. Iron exceeded the CCME guideline (300 μg/L) on one occasion in Fallentimber Creek. Most trace metals were below detection and no other guideline exceedances were observed.

Table 10 Summary of the 2004-2005 Monthly and Bimonthly Monitoring Data on the Ghost, Waiparous and Fallentimber Rivers

Parameter	Units	N	Min.	Max.	Med.	Mean	Standard Deviation	Skewness
Ghost River								
Fecal coliform bacteria	No./100mL	34	1	120	1	9.44	22.89	4.02
Escherichia coli	No./100mL	34	5	87	1	7.00	17.02	3.82
pH	pH units	32	7.47	8.26	7.93	7.92	0.18	-0.66
Conductivity	µS/cm	32	249	333	299	298	19.71	-0.87
Temperature	^{o}C	32	-0.2	8.9	4.6	4.7	2.8	-0.04
Turbidity	NTU	34	0.1	191.0	0.4	7.6	32.6	5.70
Total Suspended Solids	mg/L	34	0.2	249.0	0.6	10.0	42.5	5.72
Dissolved Oxygen	mg/L	32	9.5	13.0	10.9	11.0	1.0	0.38
Alkalinity	mg/L	12	149	159	154	154.2	2.79	-0.03
Sodium	mg/L	12	2	5	3.1	3.38	1.04	0.74
Magnesium	mg/L	12	11.3	15.1	12.45	12.6	0.998	1.41
Potassium	mg/L	12	0.5	1	0.7	0.675	0.136	1.06
Calcium	mg/L	4	47.1	49.4	48.3	48.3	1.01	0
Filterable Residue	mg/L	12	166	230	197	195.83	15.92	0.21
Total Phosphorus	mg/L	34	0.002	0.192	0.004	0.011	0.033	5.465
Total Dissolved Phosphorus	mg/L	34	0.002	0.012	0.002	0.003	0.002	1.881
Dissolved Organic Carbon	mg/L	12	0.3	3.1	0.7	1.2	1.0	0.96
Nitrates	mg/L	34	0.002	0.258	0.214	0.20	0.06	-2.49
Ammonia	mg/L	34	0.005	0.060	0.015	0.018	0.014	1.17
Total Kjeldahl Nitrogen	mg/L	34	0.025	0.680	0.060	0.122	0.159	2.35
Total Nitrogen	mg/L	34	0.203	0.875	0.283	0.323	0.127	2.90
Fluoride	mg/L	12	0.090	0.140	0.115	0.11	0.02	-0.17

Table 10 Summary of the 2004-2005 Monthly and Bimonthly Monitoring Data on the Ghost, Waiparous and Fallentimber Rivers Cont.

Parameter	Units	N	Min.	Max.	Med.	Mean	Standard Deviation	Skewness
Waiparous Creek								
Fecal coliform bacteria	No./100mL	40	0	110	1	8.00	18.14	4.88
Escherichia coli	No./100mL	40	0	77	1	5.69	13.06	4.62
pH	pH units	41	7.80	8.32	8.70	8.55	0.12	-0.03
Conductivity	µS/cm	41	218	367	282	287	43.58	0.20
Temperature	^{o}C	41	-0.1	12.8	4.9	4.7	4.1	0.20
Turbidity	NTU	40	0.1	85.1	0.7	4.6	13.6	5.59
Total Suspended Solids	mg/L	40	0.2	105.0	0.8	5.9	16.8	5.51
Dissolved Oxygen	mg/L	41	8.7	12.8	10.5	10.8	1.2	0.11
Alkalinity	mg/L	13	133	202	154	164.3	22.30	0.23
Sodium	mg/L	13	3	6.3	5.4	4.98	0.99	-0.81
Magnesium	mg/L	13	9.2	12.9	10.9	11.2	1.27	0.07
Potassium	mg/L	13	0.6	1.9	0.7	0.85	0.33	3.10
Calcium	mg/L	4	44.6	58.1	51.5	51.5	5.83	-0.06
Filterable Residue	mg/L	13	140	244	190	194.77	34.18	-0.08
Total Phosphorus	mg/L	39	0.002	0.098	0.004	0.009	0.016	4.701
Total Dissolved Phosphorus	mg/L	39	0.002	0.009	0.002	0.003	0.002	0.967
Dissolved Organic Carbon	mg/L	13	0.7	5.2	1.6	2.2	1.4	0.83
Nitrates	mg/L	39	0.095	0.270	0.172	0.18	0.05	0.33
Ammonia	mg/L	39	0.005	0.050	0.020	0.018	0.013	0.95
Total Kjeldahl Nitrogen	mg/L	39	0.025	0.370	0.090	0.125	0.087	1.13
Total Nitrogen	mg/L	39	0.163	0.625	0.292	0.302	0.089	1.36
Fluoride	mg/L	13	0.060	0.120	0.090	0.09	0.02	-0.15

Table 10 Summary of the 2004-2005 Monthly and Bimonthly Monitoring Data on the Ghost, Waiparous and Fallentimber Rivers Cont.

Parameter	Units	N	Min.	Max.	Med.	Mean	Standard Deviation	Skewness
Fallentimber Creek								
Fecal coliform bacteria	No./100mL	45	1	340	10	32.87	65.66	3.22
Escherichia coli	No./100mL	45	1	260	6	26.24	51.69	3.10
pH	pH units	45	6.50	8.11	7.83	7.78	0.28	-2.84
Conductivity	μS/cm	45	121	347	250	238	67.71	-0.17
Temperature	^{o}C	45	-0.1	11.1	3.4	3.8	3.9	0.40
Turbidity	NTU	45	0.2	111.0	2.1	8.6	18.1	4.62
Total Suspended Solids	mg/L	45	0.2	158.0	1.8	8.4	25.1	5.34
Dissolved Oxygen	mg/L	45	8.9	12.4	11.2	10.9	1.0	-0.31
Alkalinity	mg/L	12	81	184	150	144.4	35.04	-0.64
Sodium	mg/L	12	6.8	13.6	11	10.7	2.26	-0.65
Magnesium	mg/L	12	4.4	10.7	9.05	8.2	2.06	-0.58
Potassium	mg/L	12	0.7	2.2	0.9	1.0	0.393	3.00
Calcium	mg/L	4	25	49.1	39.15	38.1	10.5	-0.47
Filterable Residue	mg/L	12	102	218	167	165.50	41.52	-0.27
Total Phosphorus	mg/L	45	0.002	0.152	0.009	0.015	0.025	4.223
Total Dissolved Phosphorus	mg/L	45	0.002	0.011	0.005	0.005	0.003	0.450
Dissolved Organic Carbon	mg/L	12	2.0	9.7	3.6	4.8	3.0	0.87
Nitrates	mg/L	45	0.002	0.157	0.022	0.04	0.04	1.07
Ammonia	mg/L	45	0.005	0.110	0.020	0.020	0.019	2.90
Total Kjeldahl Nitrogen	mg/L	45	0.025	0.820	0.170	0.230	0.152	1.61
Total Nitrogen	mg/L	45	0.570	0.854	0.262	0.271	0.146	1.72
Fluoride	mg/L	12	0.070	0.120	0.105	0.10	0.02	-0.61

Table 11 Summary of Results of Kruskal-Wallis and ANOVA Tests for Differences between Stations on each River [1]

Parameter	Waiparous Creek		Ghost River		Fallentimber Creek	
	Variances Significantly Different	Concentrations Significantly Different	Variances Significantly Different	Concentrations Significantly Different	Variances Significantly Different	Concentrations Significantly Different
Fecal coliform bacteria	+	+[2]	+	+[2]	+	-
Escherichia coli	+	+[2]	+	-	-	-
Oxygen	-	-	+	+	-	-
pH	-	-	-	+[3]	+	-
Temperature	-	-	-	-	-	-
Conductivity	-	+[3]	-	-	-	-
Nitrates	-	+[3]	+	-	-	-
Total Phosphorus	+	-	+	-	+	-
Total Dissolved Phosphorus	-	-	-	-	-	-
Turbidity	+	+[3]	+	-	+	-
Total Kjeldahl Nitrogen	-	-	+	-	-	-
Total N	-	-	+	-	-	-
Ammonia	-	-	-	-	+	-
Total Suspended Solids	+	-	+	-	+	-

[1] A plus indicates statistically significant differences in concentrations between upstream and downstream stations;
[2] Stations significantly different by Kruskall-Wallis test (downstream sites > upstream site) but could not be formally compared pair-wise because the variables could not be normalized;
[3] Concentrations at both downstream stations were greater than those at the upstream station in pairwise comparisons.

Figure 15.1 : Water Quality Monitoring Program 2004-2005 – Box Plots Dissolved Oxygen

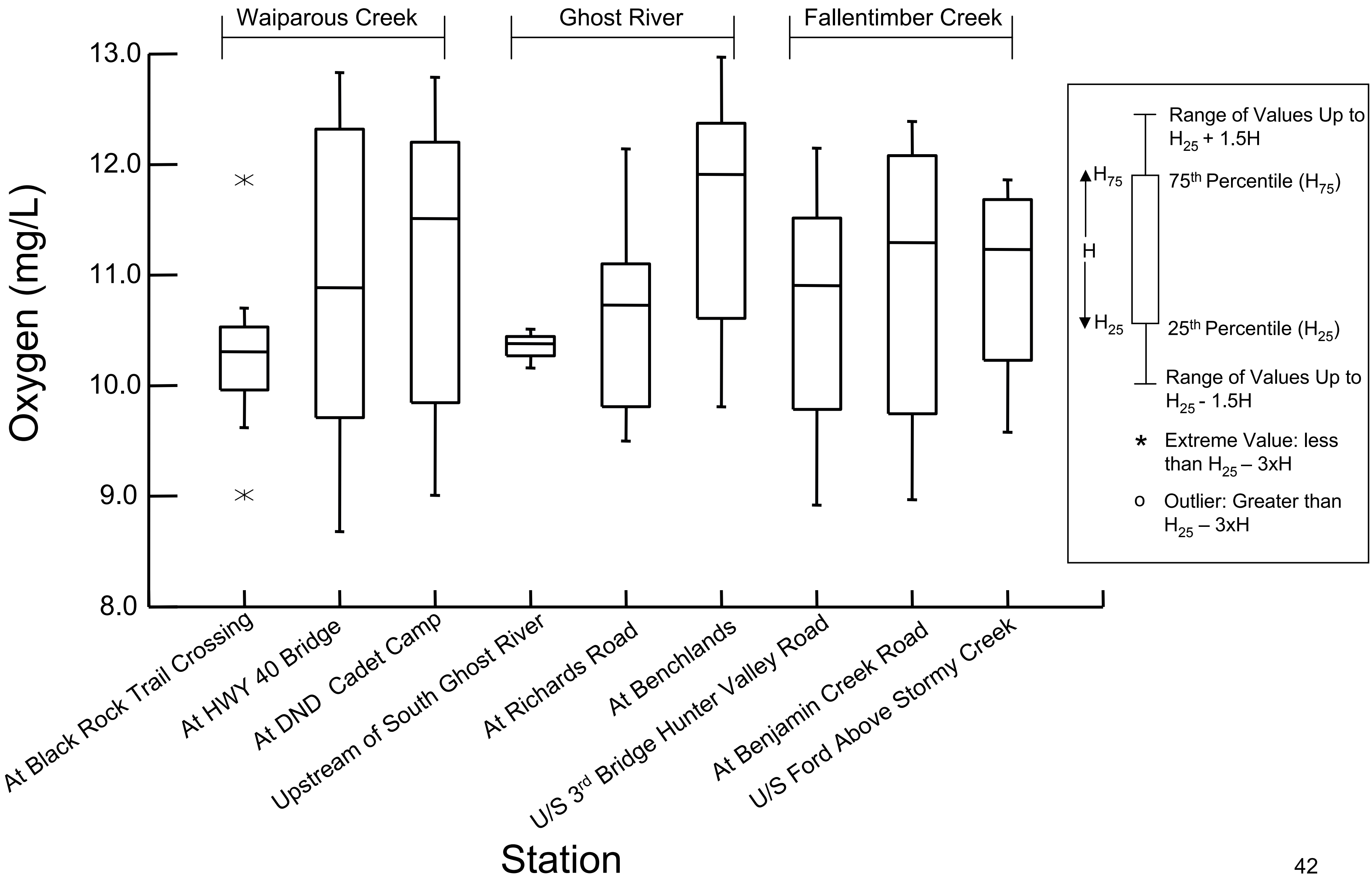


Figure 15.2 : Water Quality Monitoring Program 2004-2005 – Box Plots Temperature

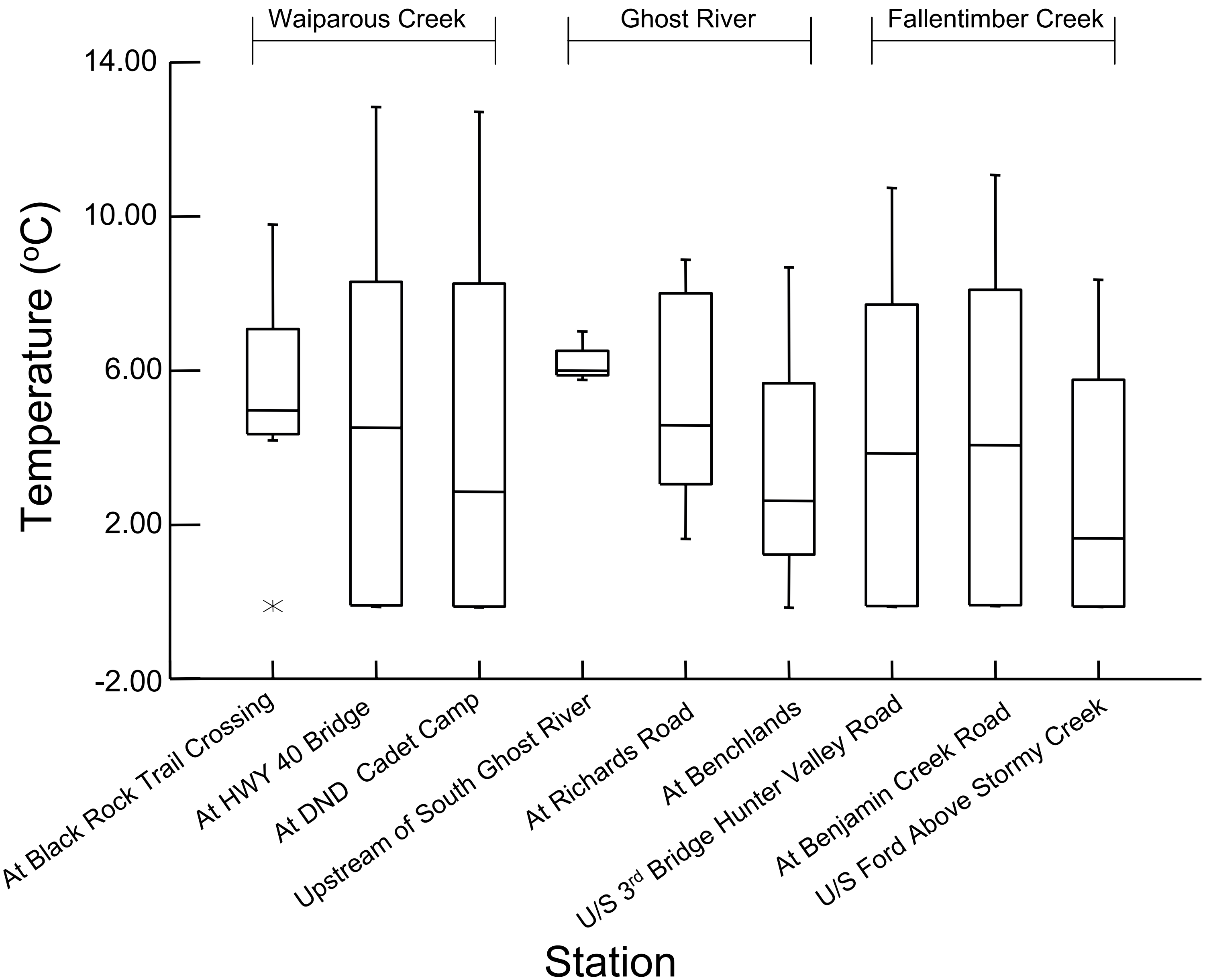


Figure 15.3 : Water Quality Monitoring Program 2004-2005 – Box Plots Field pH

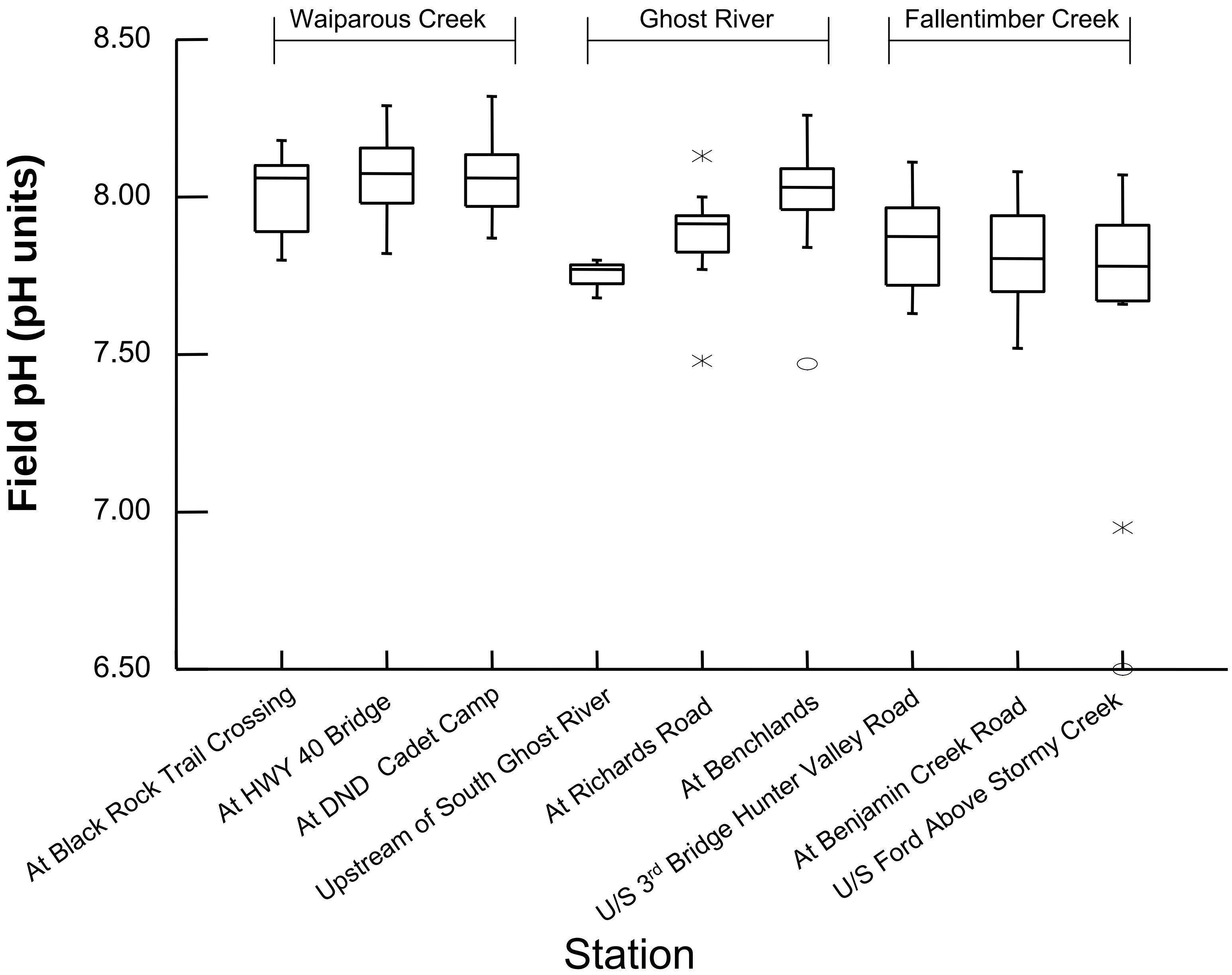


Figure 15.4 : Water Quality Monitoring Program 2004-2005 – Box Plots Field Conductivity

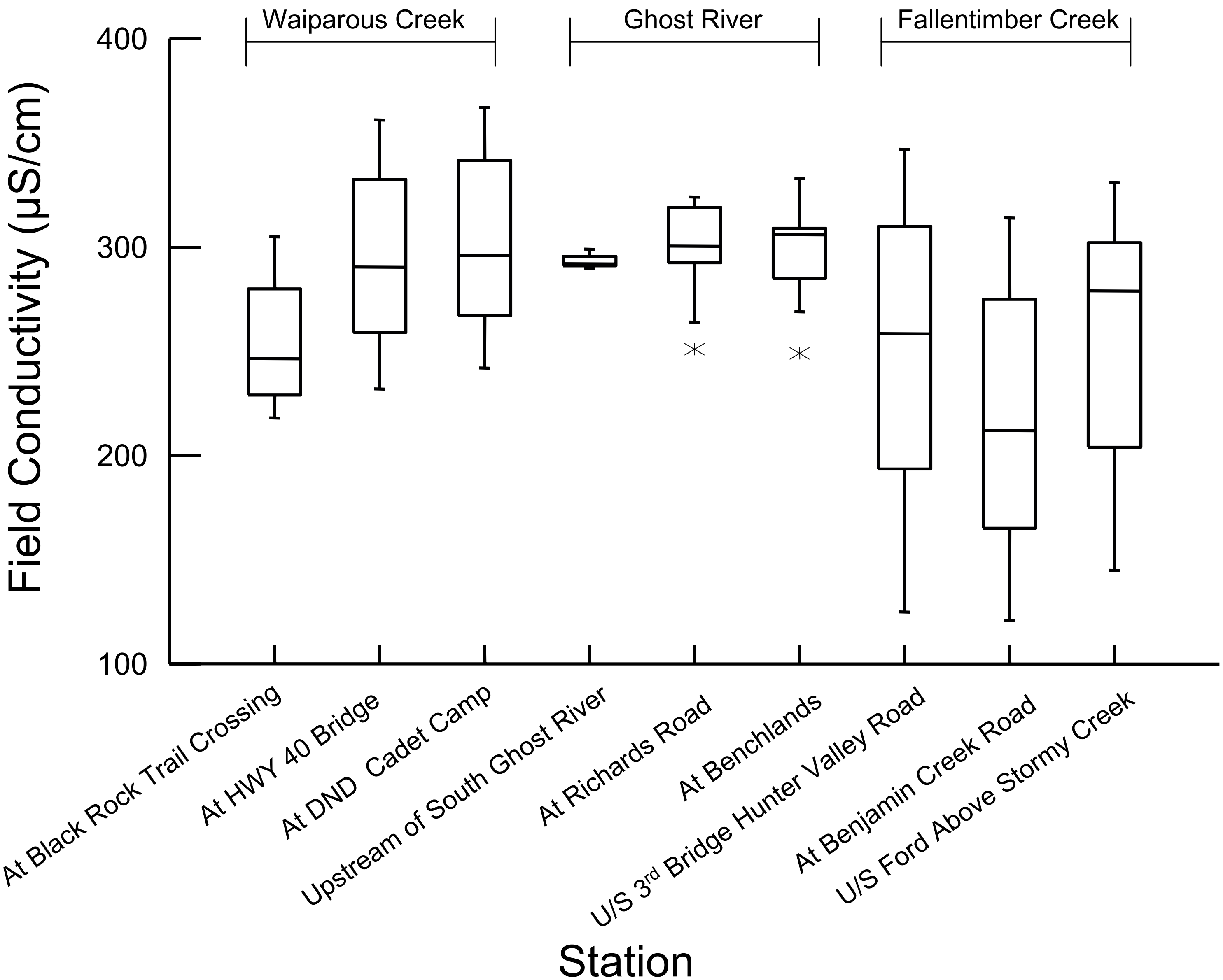


Figure 15.5 : Water Quality Monitoring Program 2004-2005 – Box Plots Fecal Coliforms

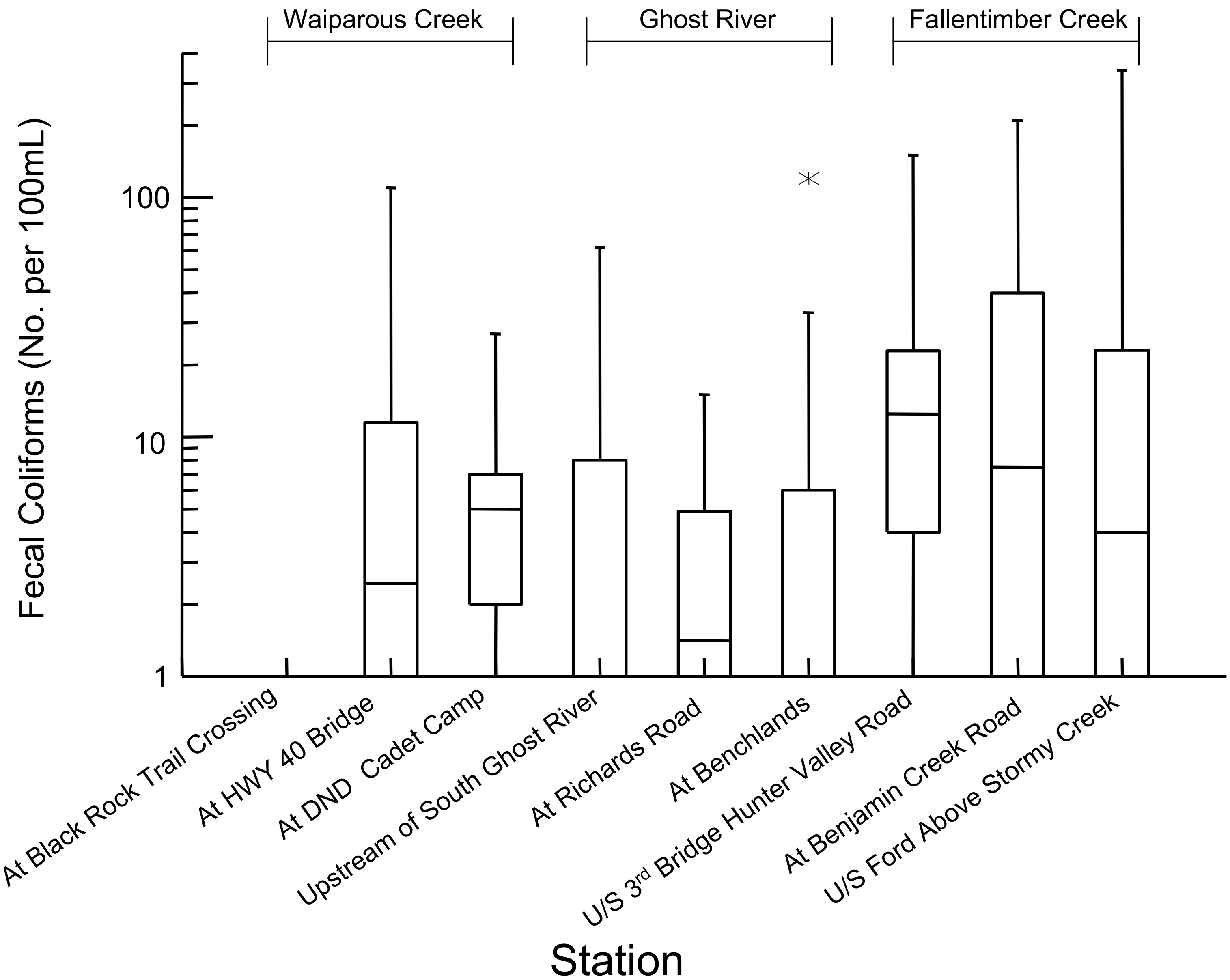


Figure 15.6 : Water Quality Monitoring Program 2004-2005 – Box Plots E. Coli

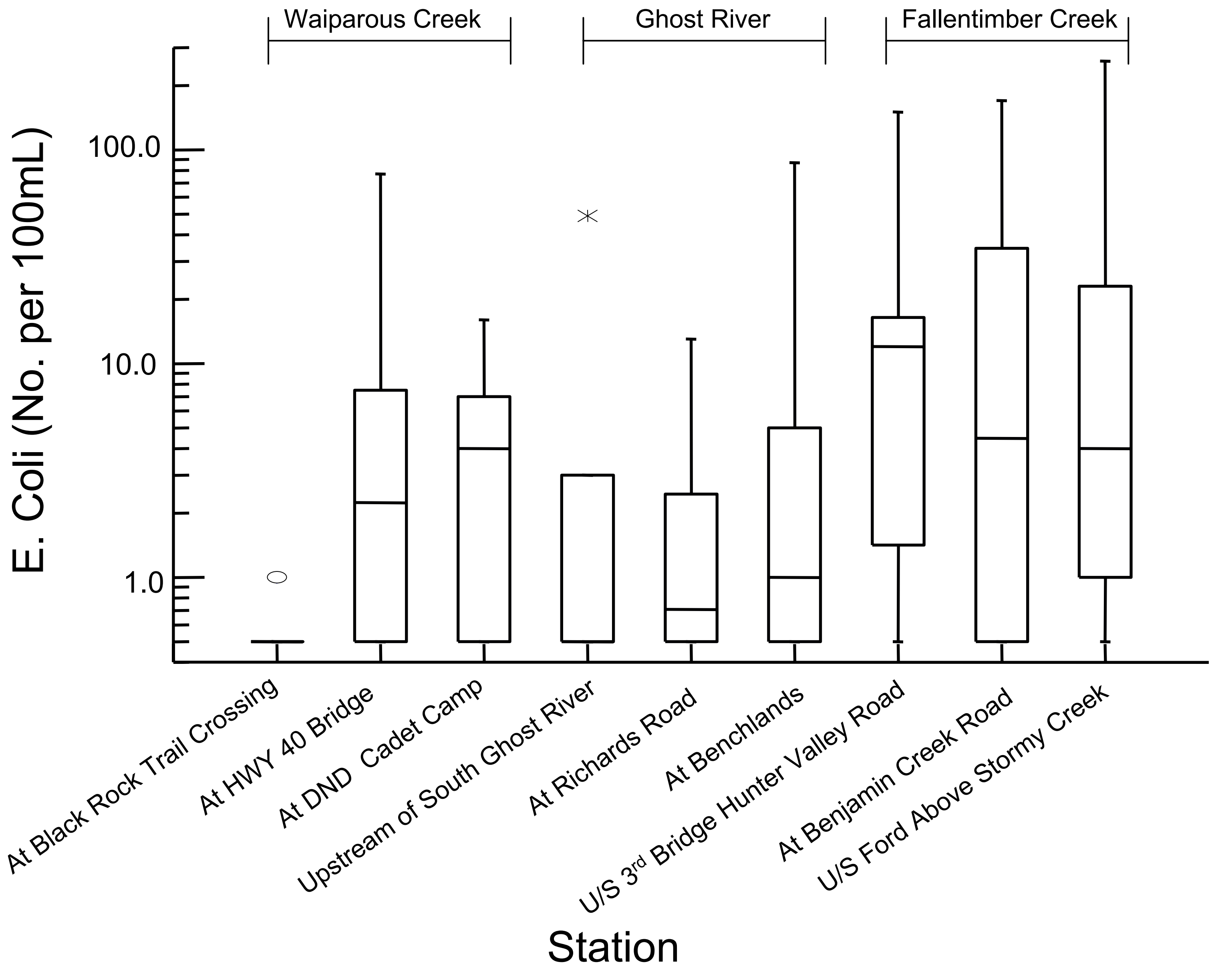


Figure 15.7 : Water Quality Monitoring Program 2004-2005 – Box Plots Total Phosphorus

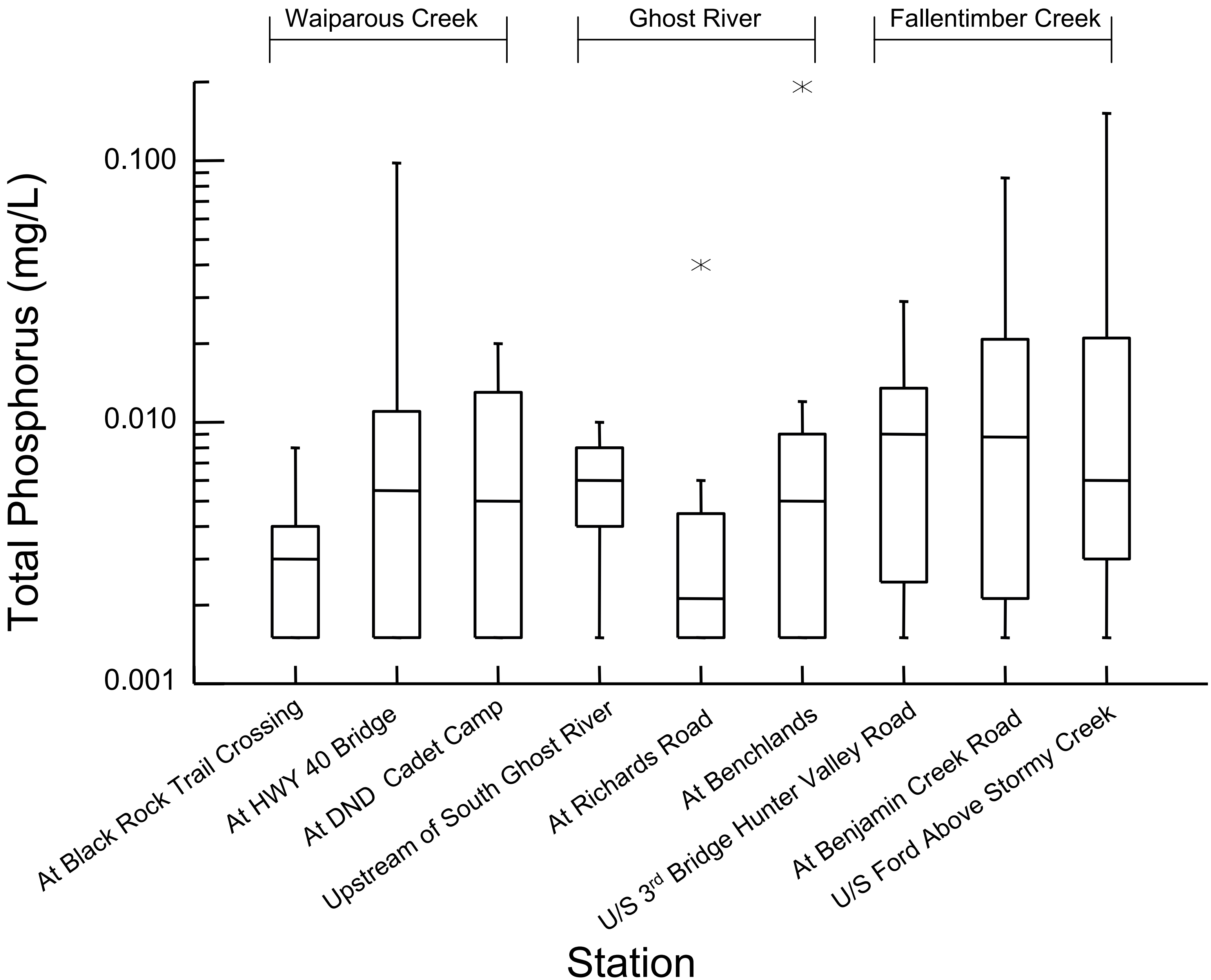


Figure 15.8 : Water Quality Monitoring Program 2004-2005 – Box PlotsTotal Dissolved Phosphorus

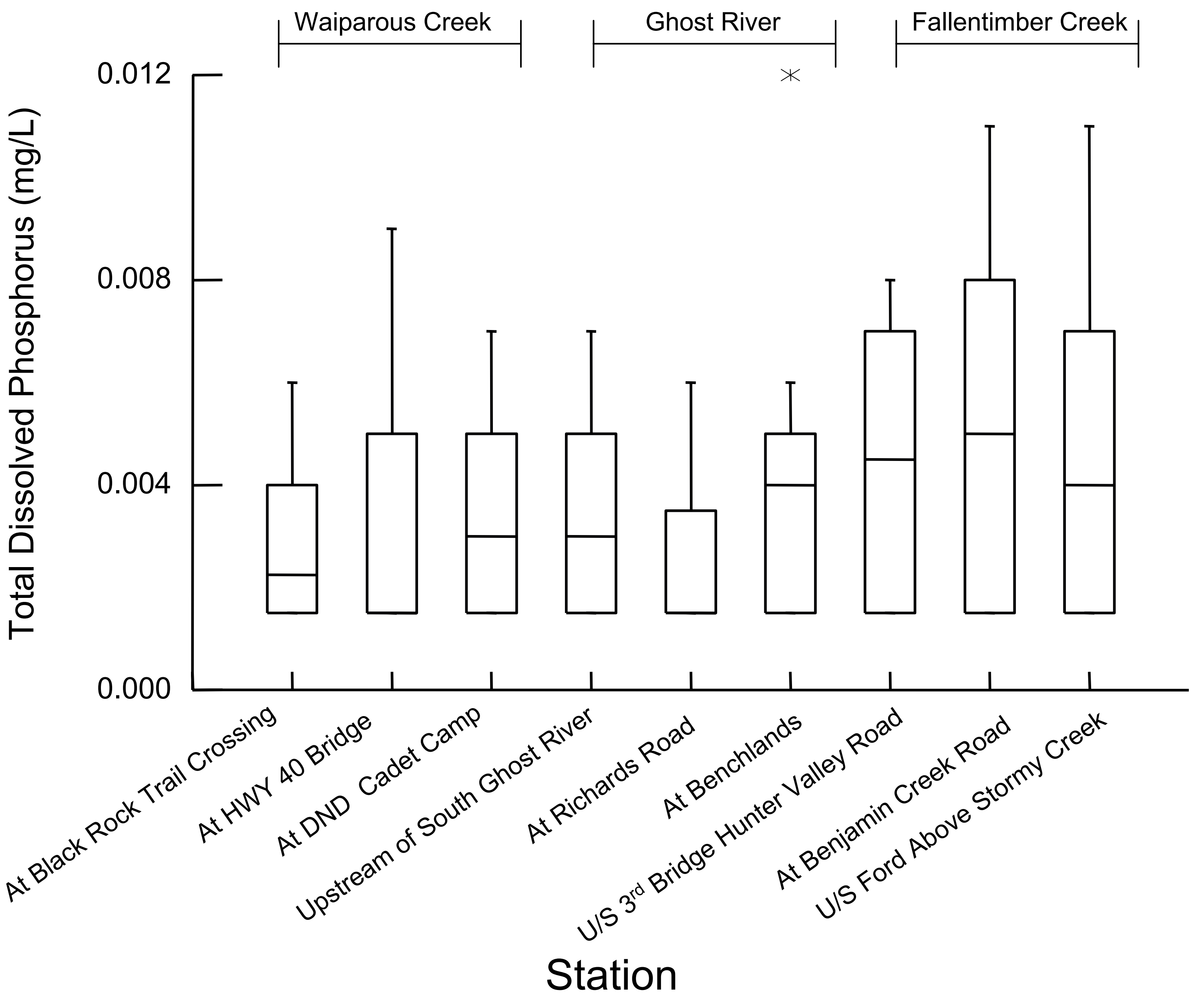


Figure 15.9 : Water Quality Monitoring Program 2004-2005 – Box Plots Nitrates

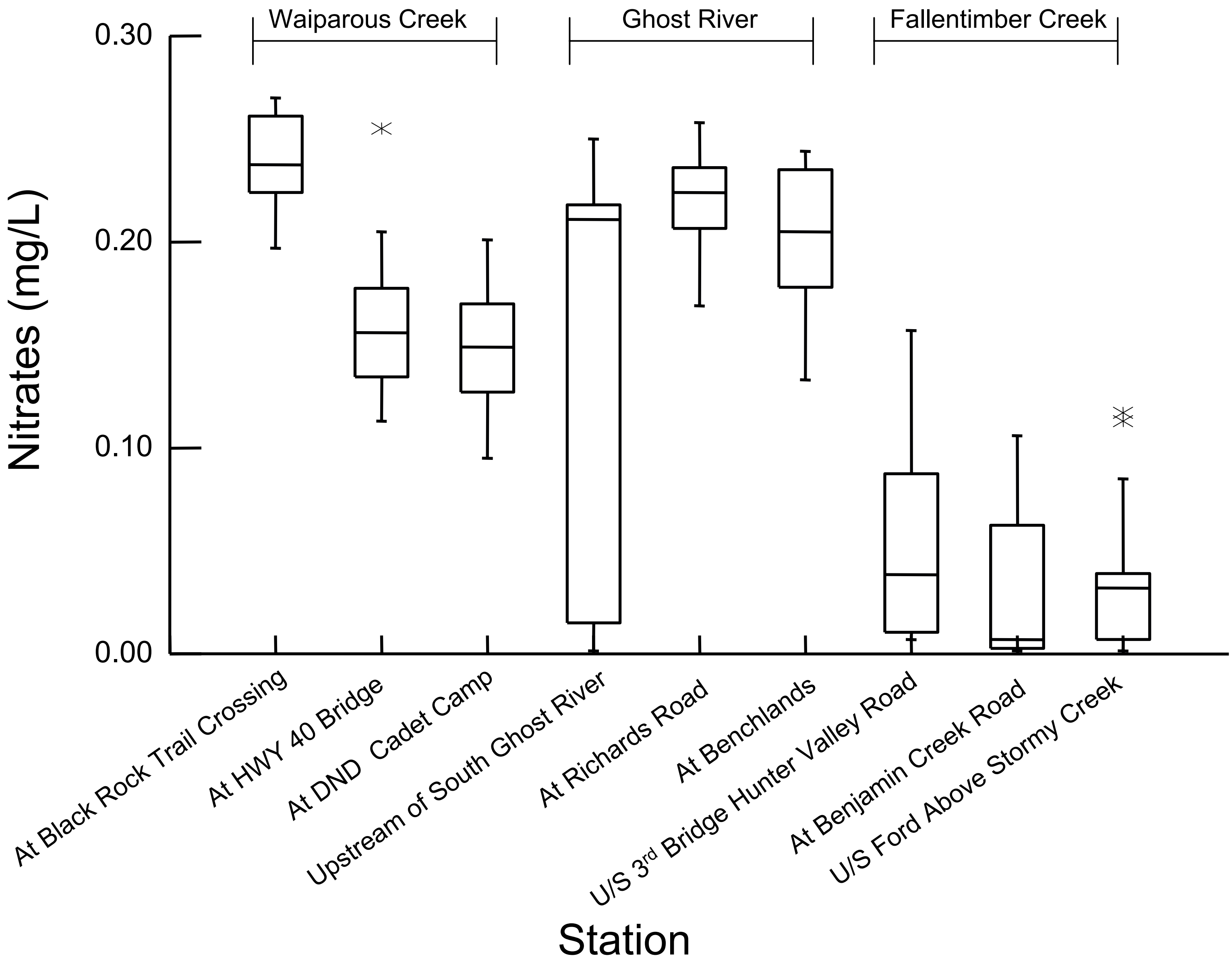


Figure 15.10 : Water Quality Monitoring Program 2004-2005 – Box Plots Total Ammonia

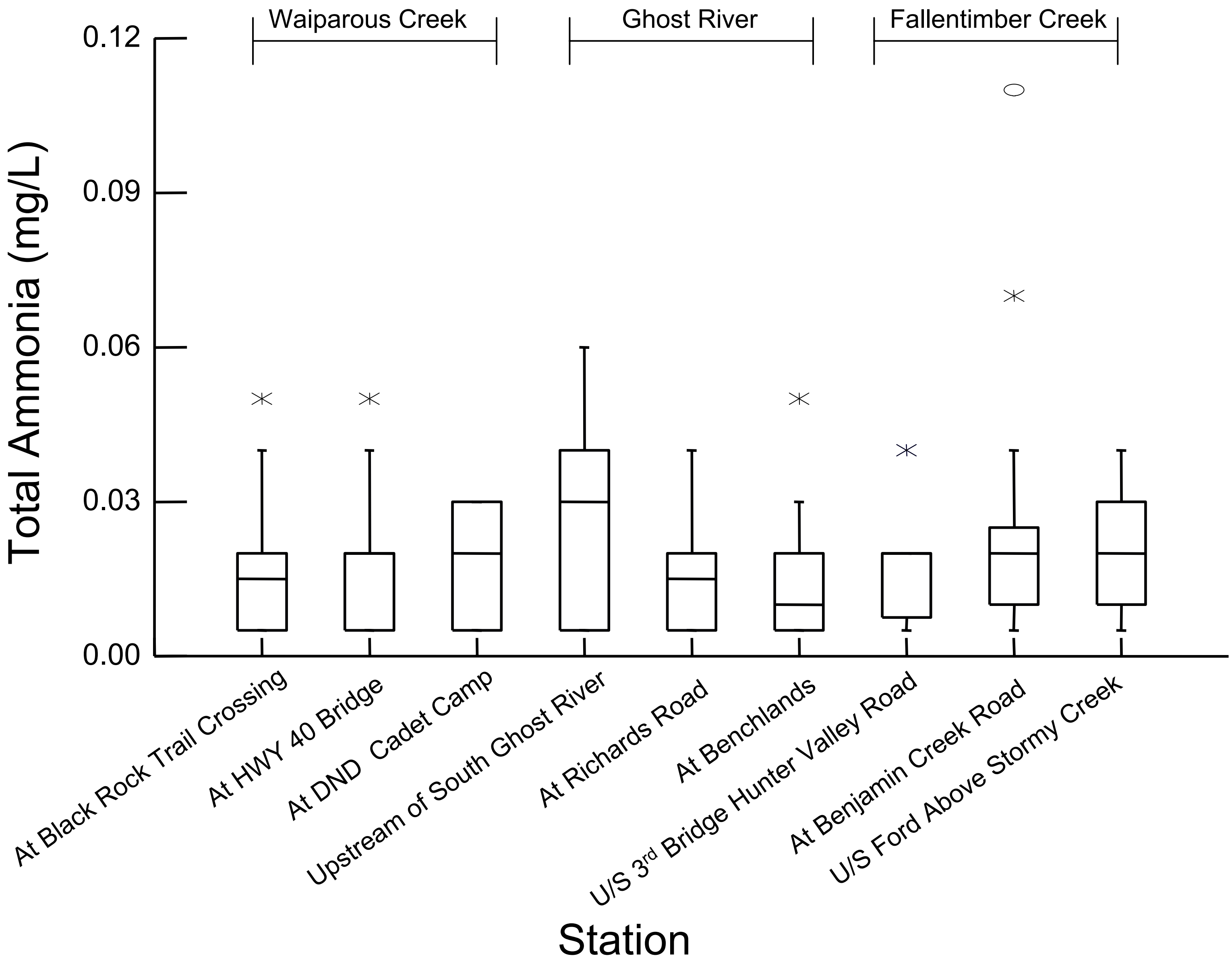


Figure 15.11 : Water Quality Monitoring Program 2004-2005 – Box Plots Total Kjeldahl Nitrogen

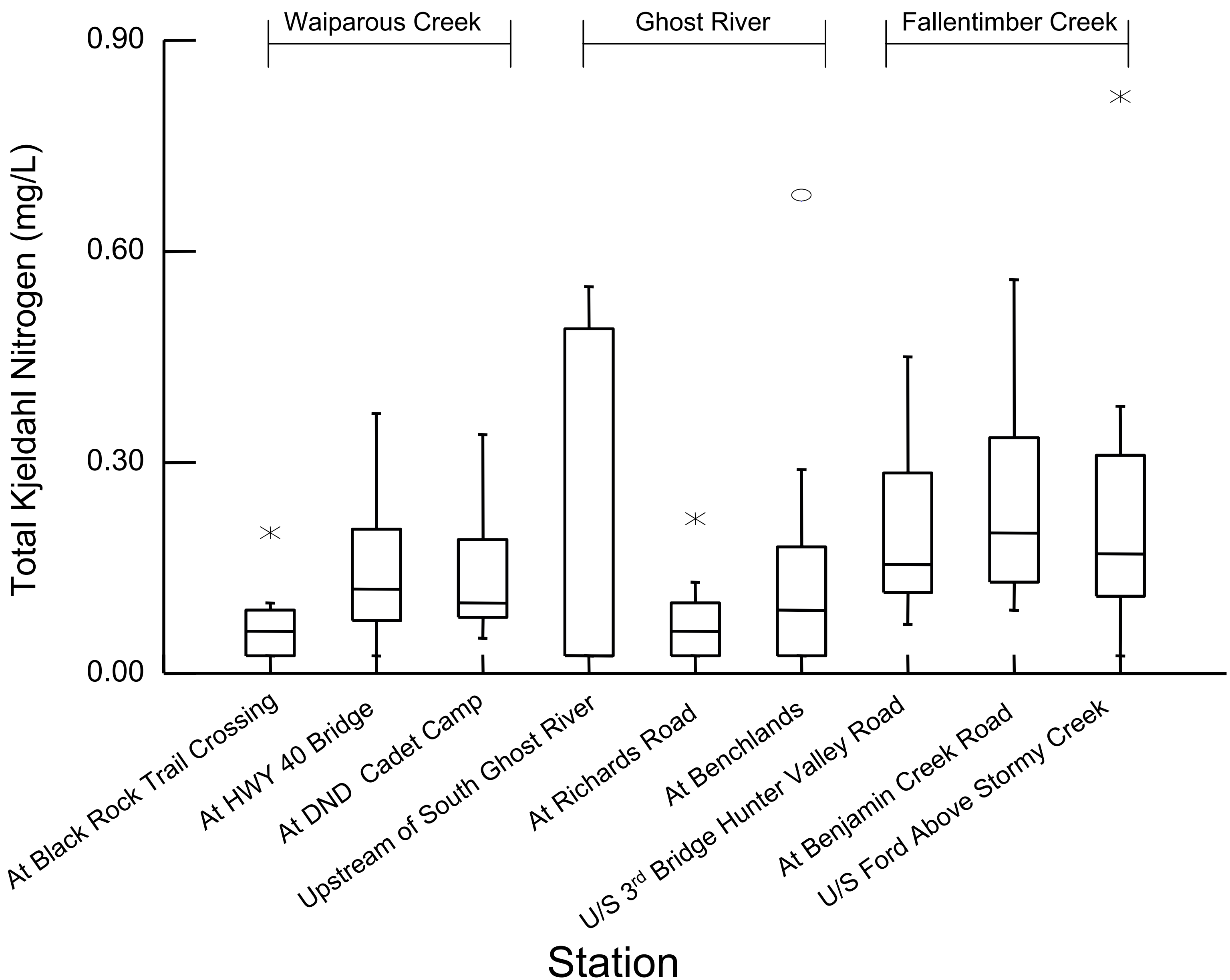


Figure 15.12 : Water Quality Monitoring Program 2004-2005 – Box Plots Total Nitrogen

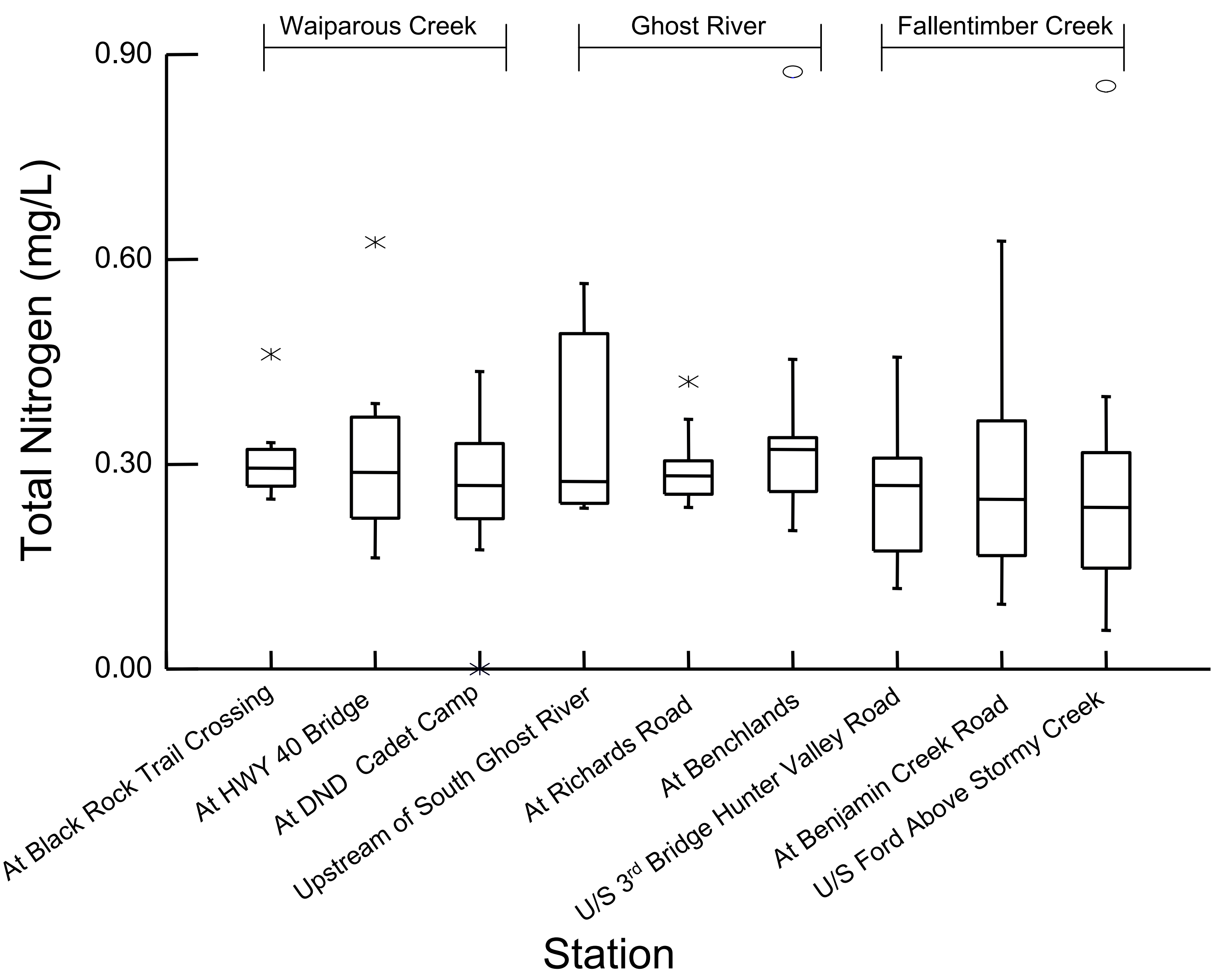


Figure 15.13 : Water Quality Monitoring Program 2004-2005 – Box Plots Turbidity

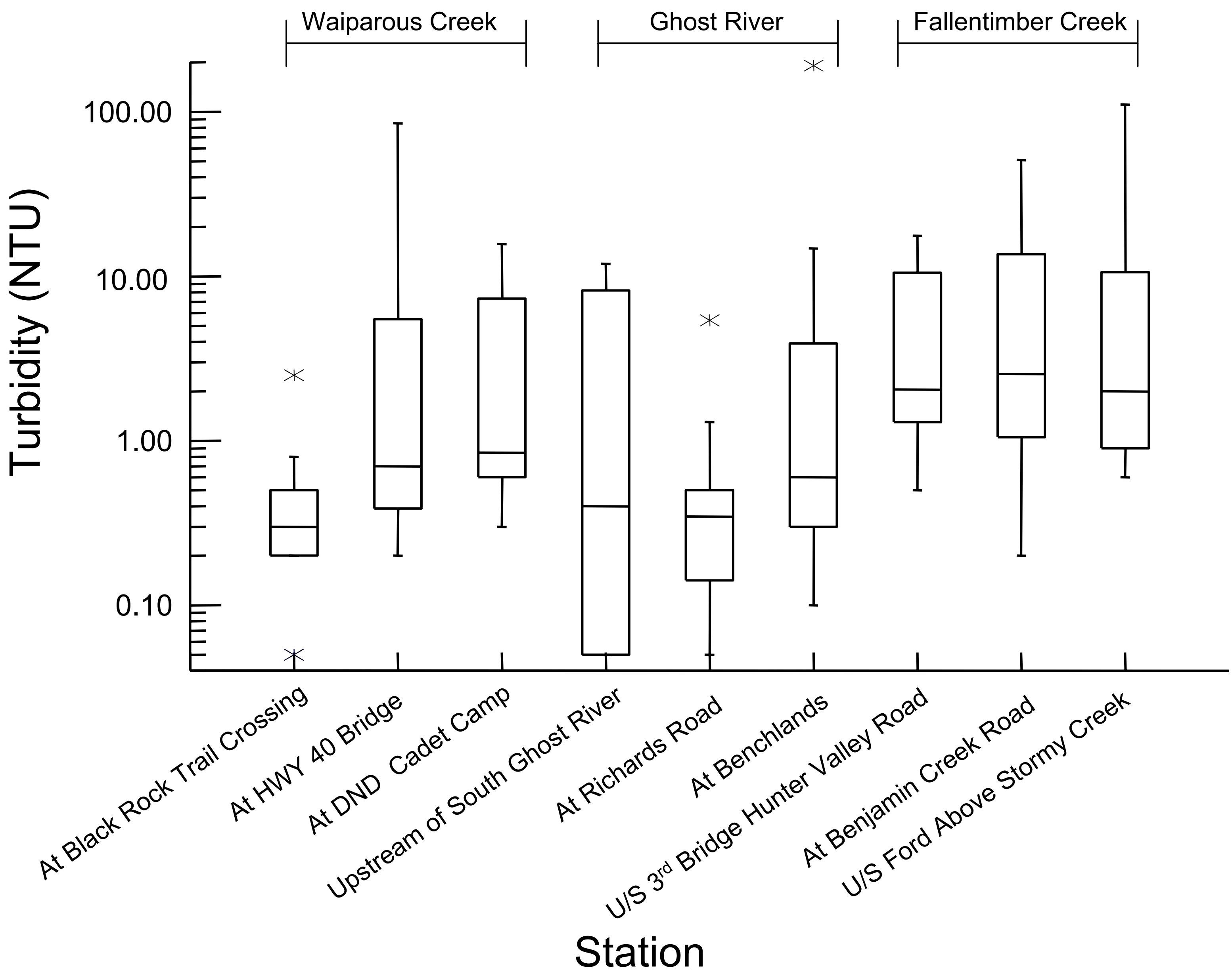


Figure 15.14 : Water Quality Monitoring Program 2004-2005 – Box Plots Total Suspended Solids

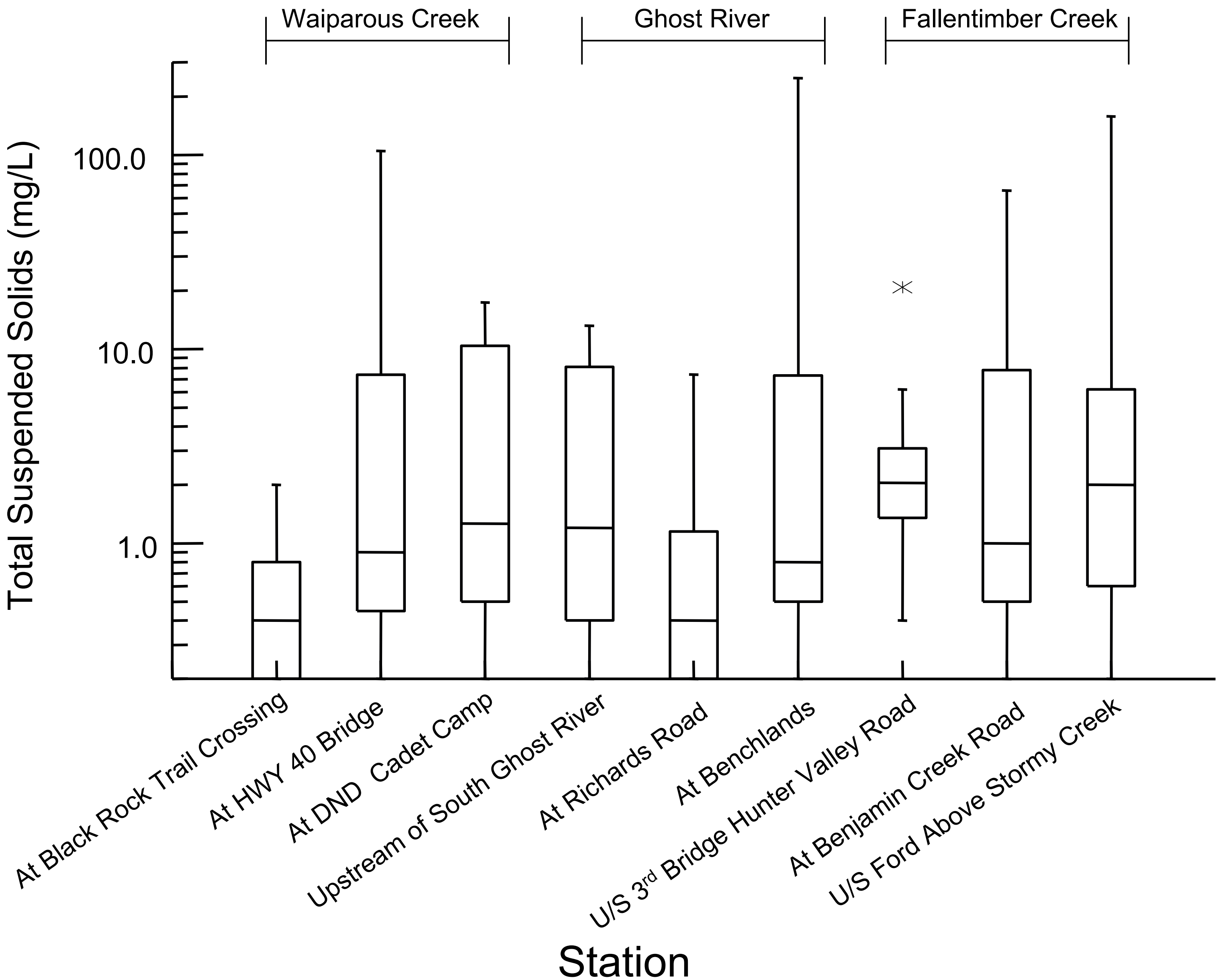


Figure 16.1 : Seasonal Trends in Water Quality Parameters: Oxygen, Temperature

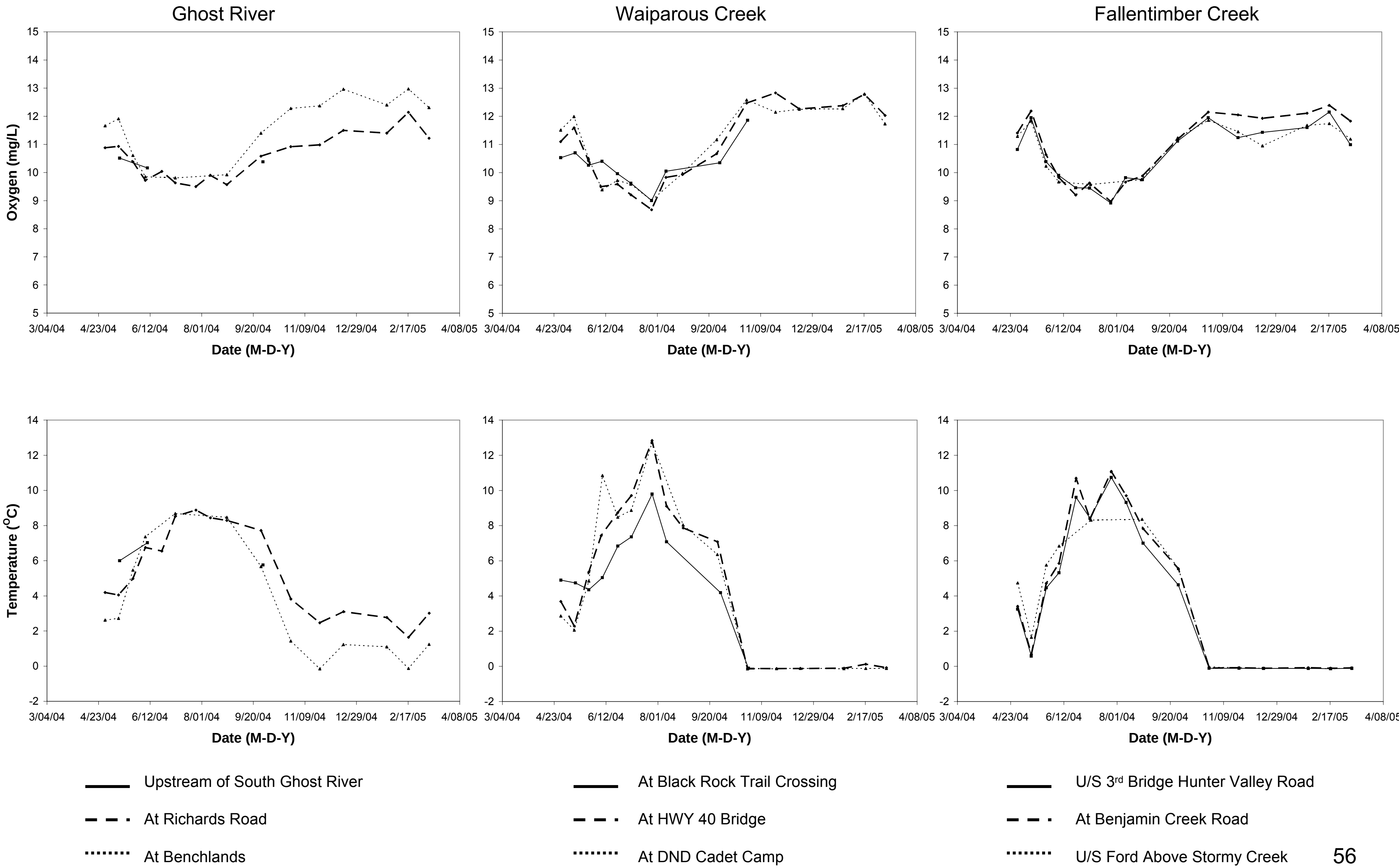


Figure 16.2 : Seasonal Trends continued: pH, Conductivity

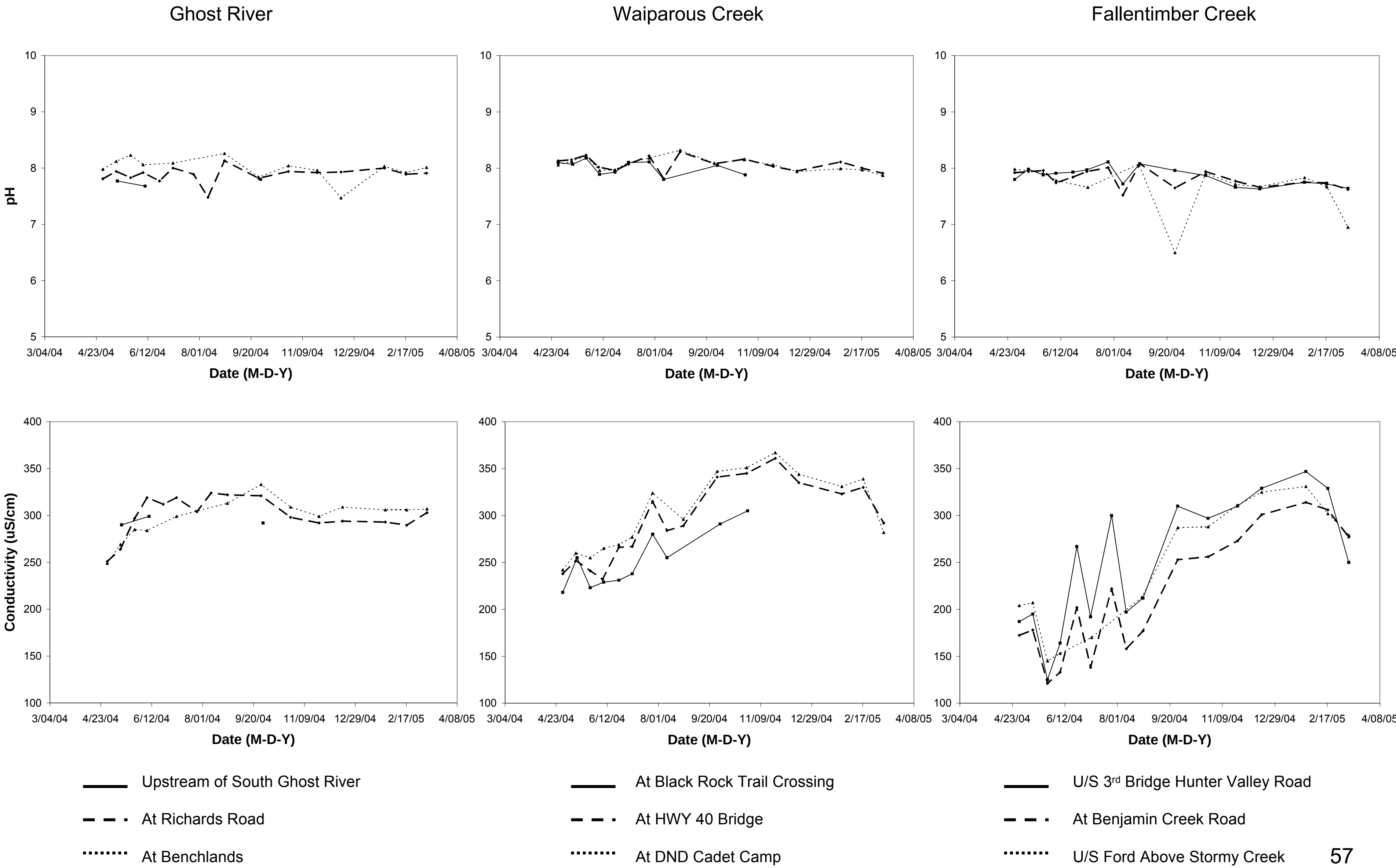


Figure 16.3 : Seasonal Trends continued: Fecal Coliforms, E. Coli

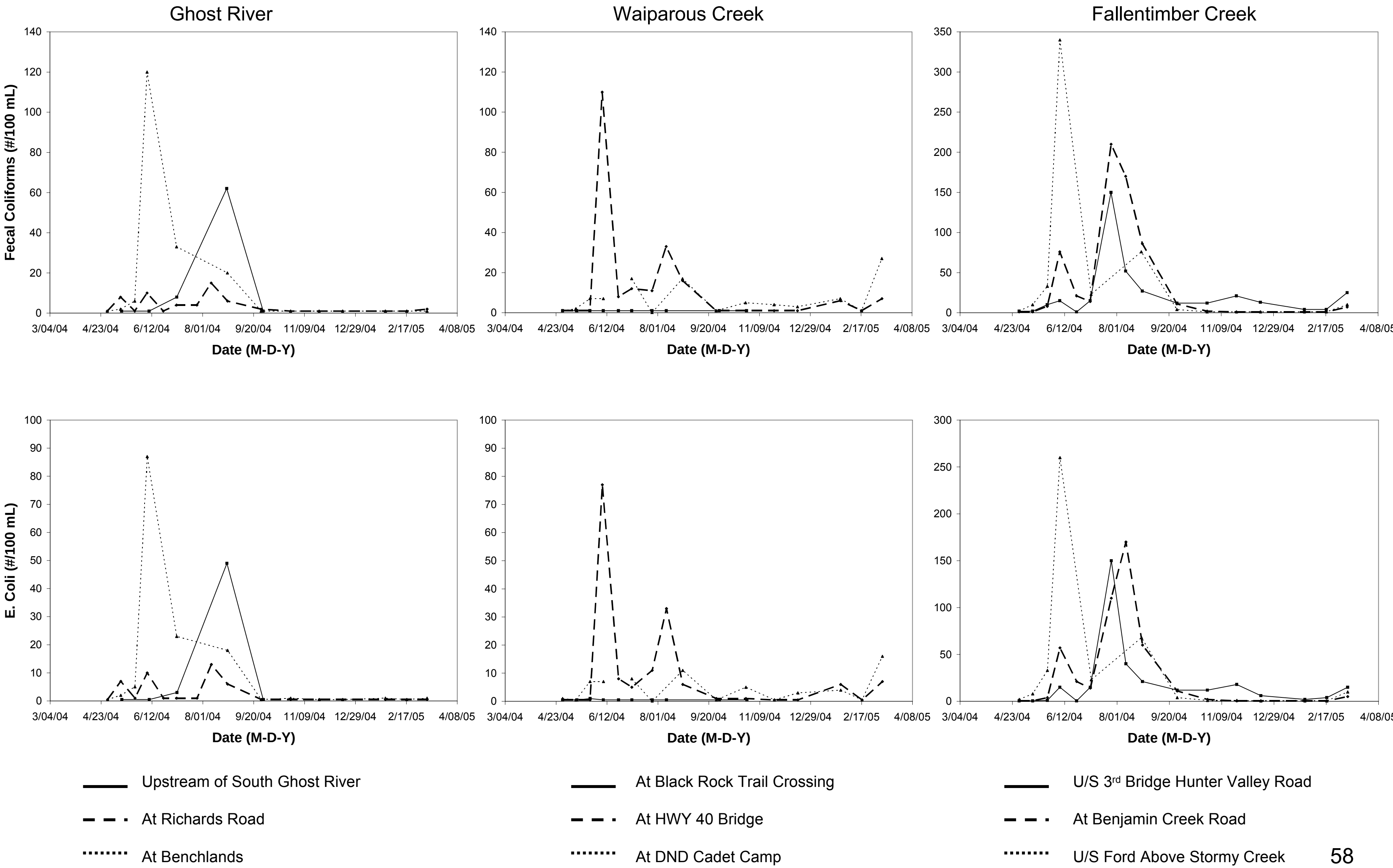


Figure 16.4 : Seasonal Trends continued: Total Phosphorus, Total Dissolved Phosphorus

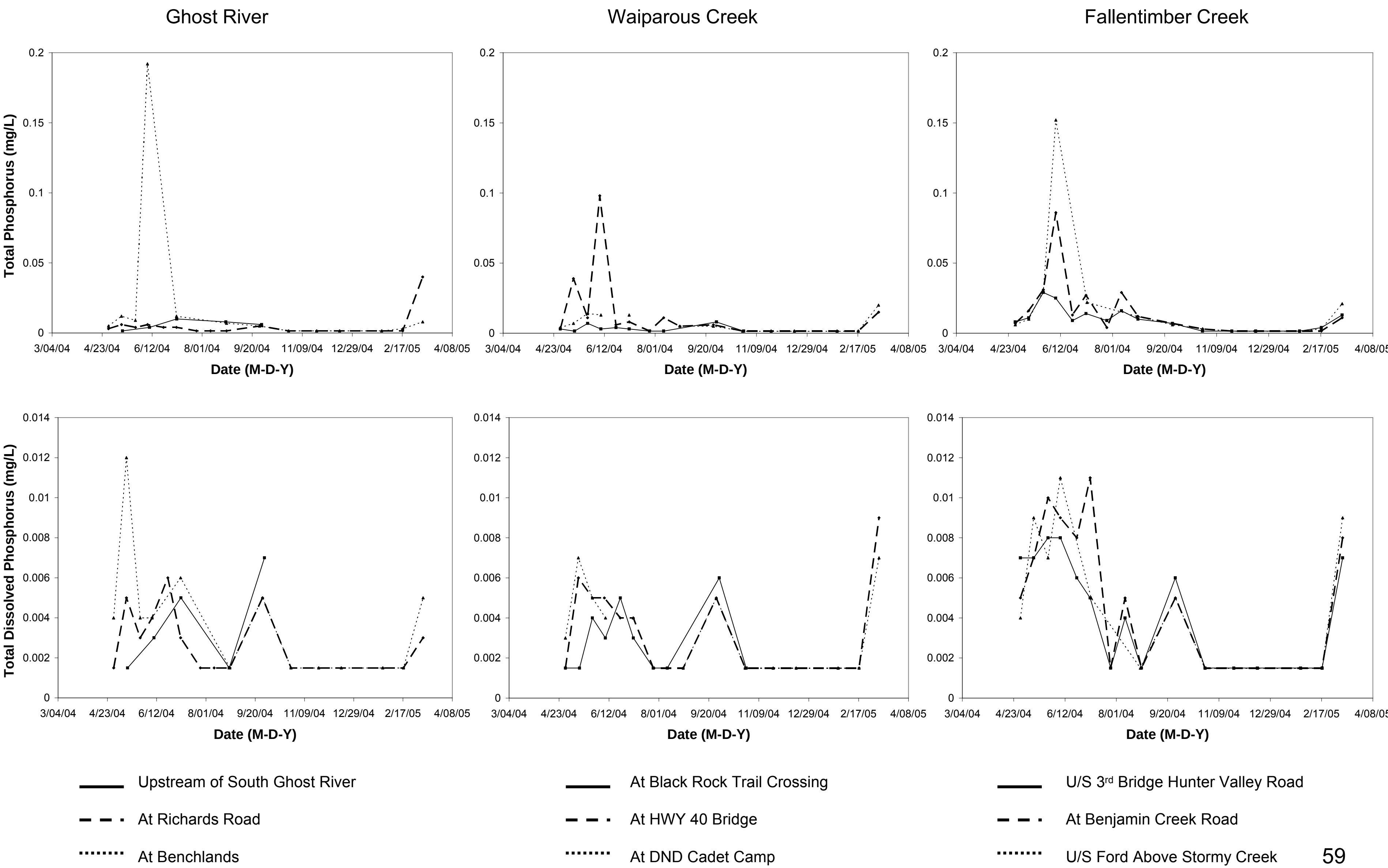


Figure 16.5 : Seasonal Trends continued: Total Nitrogen, Ammonia

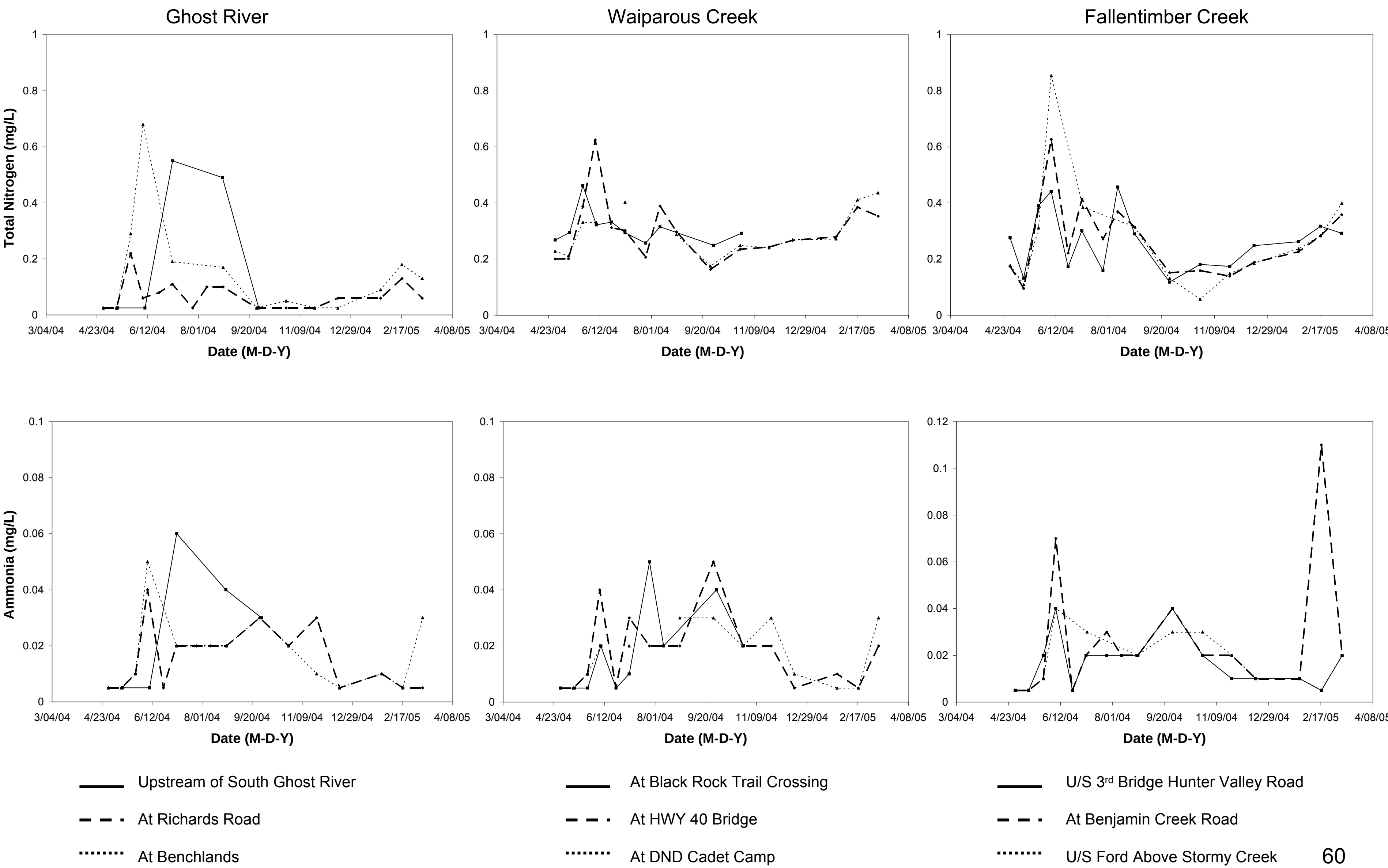


Figure 16.6 : Seasonal Trends continued: Nitrogen, Total Kjeldahl Nitrogen

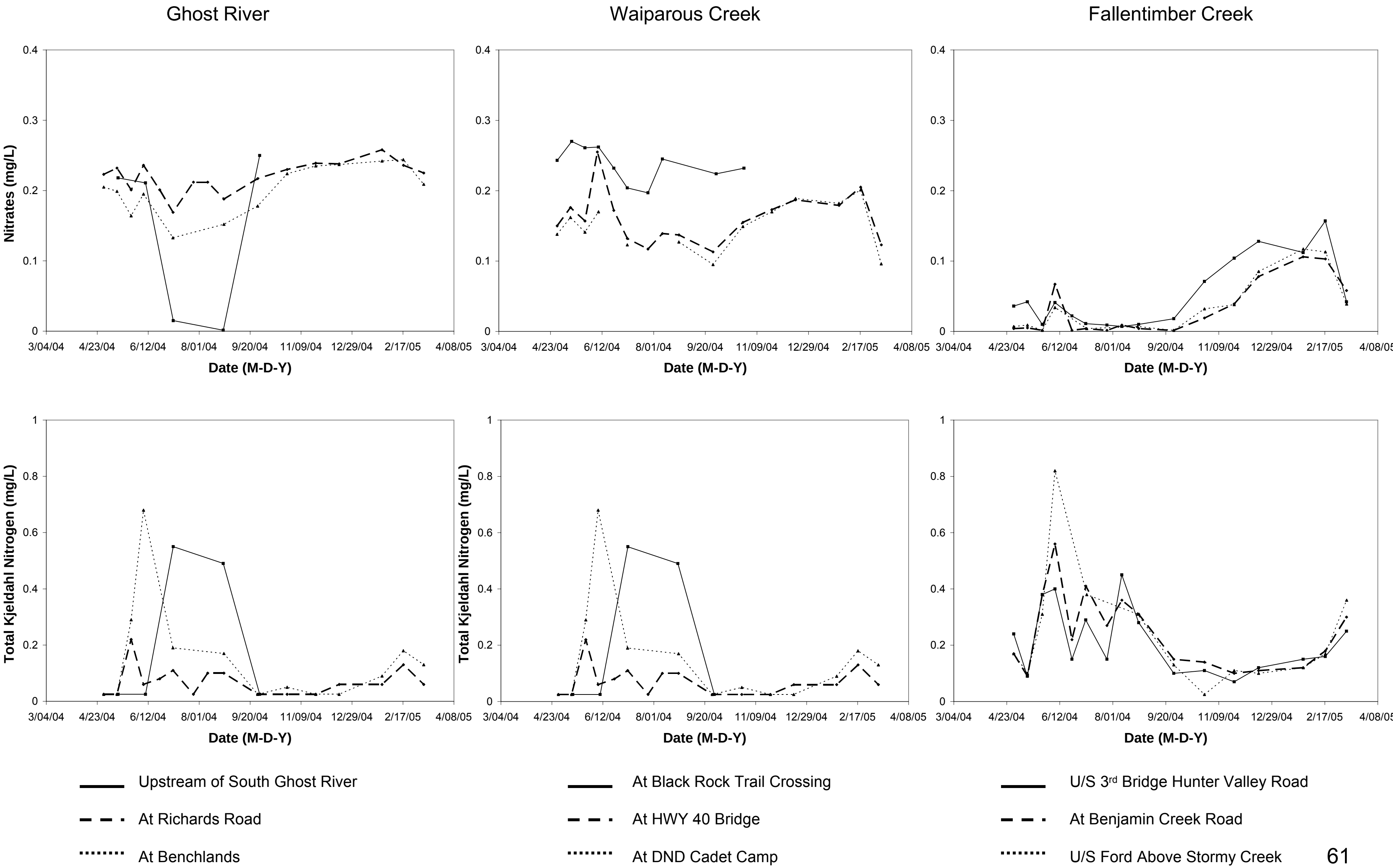


Figure 16.7 : Seasonal Trends continued: Total Suspended Solids, Dissolved/Filtered Sodium

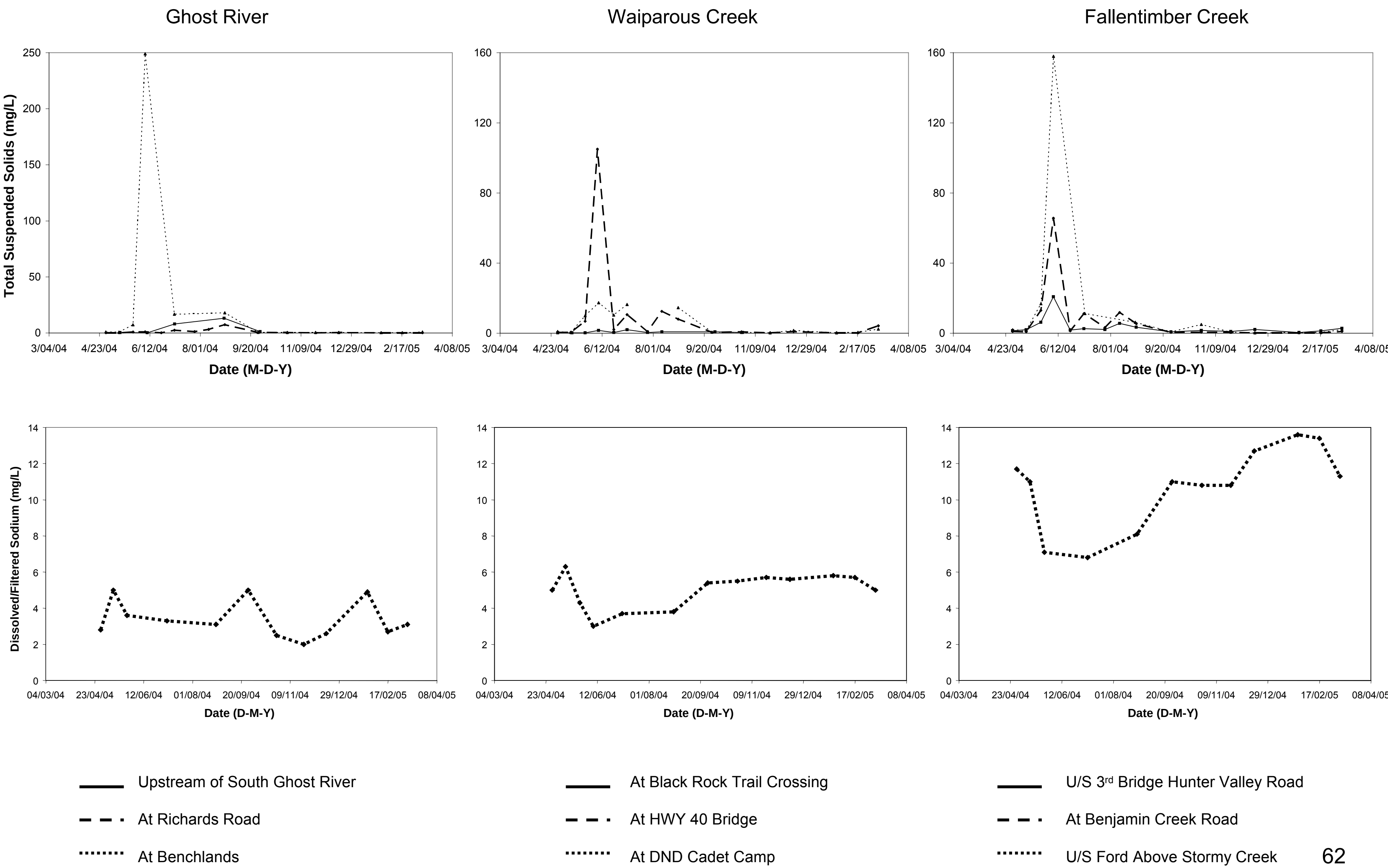


Figure 16.8 : Seasonal Trends continued: Dissolved/Filtered Magnesium, Dissolved Zinc

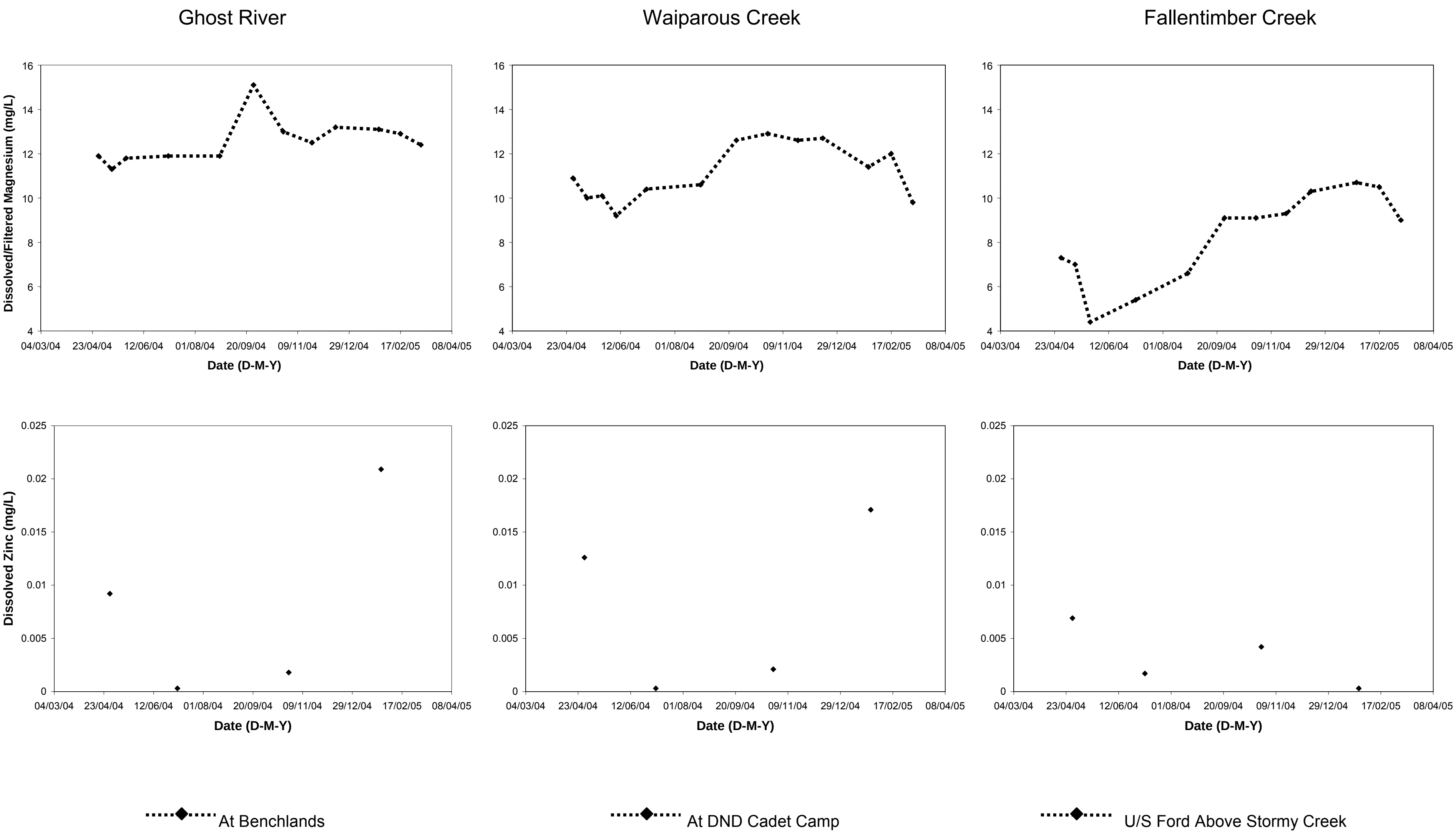


Figure 16.9 : Seasonal Trends continued: Dissolved Molybdenum, Dissolved Iron

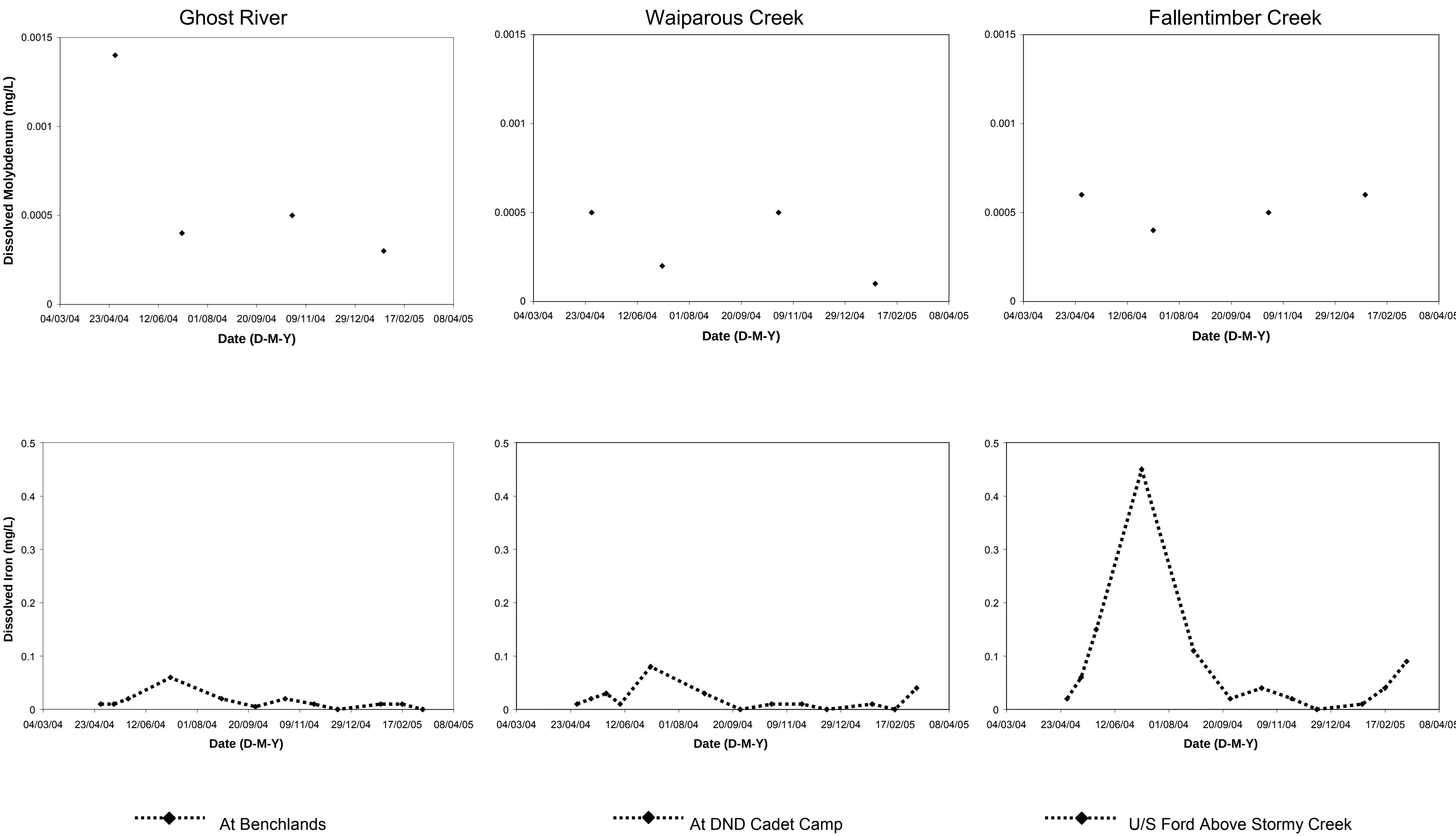
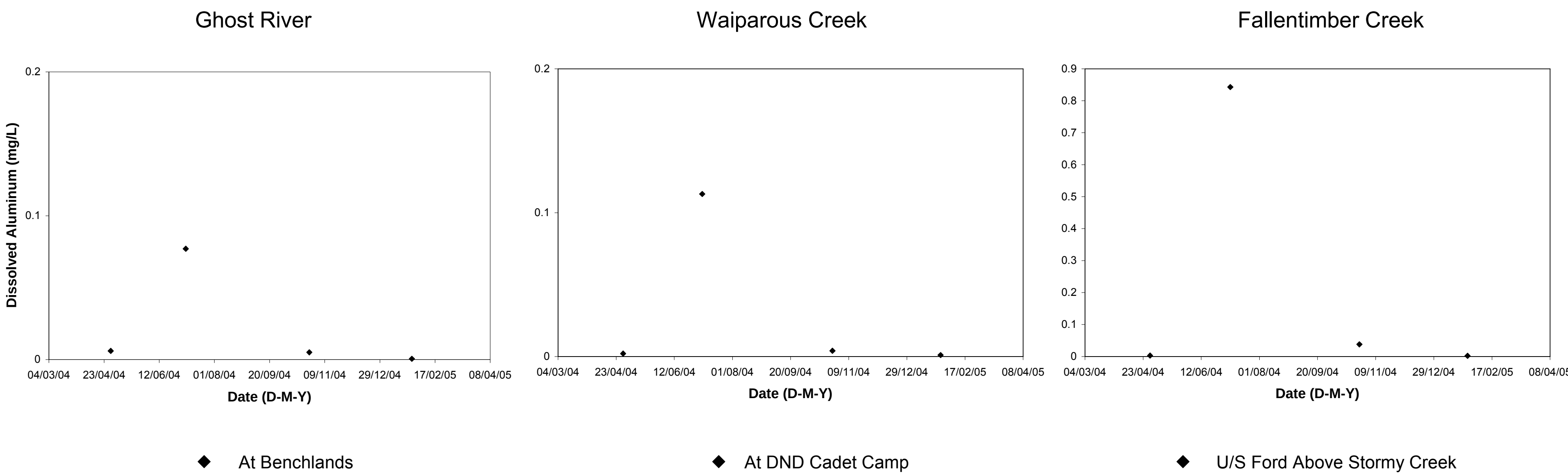


Figure 16.10 : Seasonal Trends continued: Dissolved Aluminum



3.7 Trends in TSS in the Bow River Upstream and Downstream of the Ghost River Discharge

Trends in TSS were examined in the Bow River at two long-term monitoring stations to determine whether changes in the water quality of the Ghost River discharging to the Bow River were detectable in the Bow River itself. Data were obtained from a station upstream of the confluence at Exshaw and a station downstream of the confluence at Cochrane. Only 6 complete years of TSS data were available for the Exshaw station while 20 years were available for the Cochrane site. Plots of TSS at both stations showed distinct seasonal trends with elevated levels during the spring melt and, in some years, during the fall as well (Figures 17a and 17b). These seasonal trends were statistically significant (Kruskal-Wallis test; $P<0.05$). The seasonal Kendall test that adjusts for these seasonal trends showed that over the 6 years of data at the Exshaw station and over the 20 years of data at the Cochrane station there have been no significant increases in TSS in the Bow River (Table 12). These results suggest that discharge of TSS from the Ghost River has had no detectable effect on sediment loads in the Bow River.

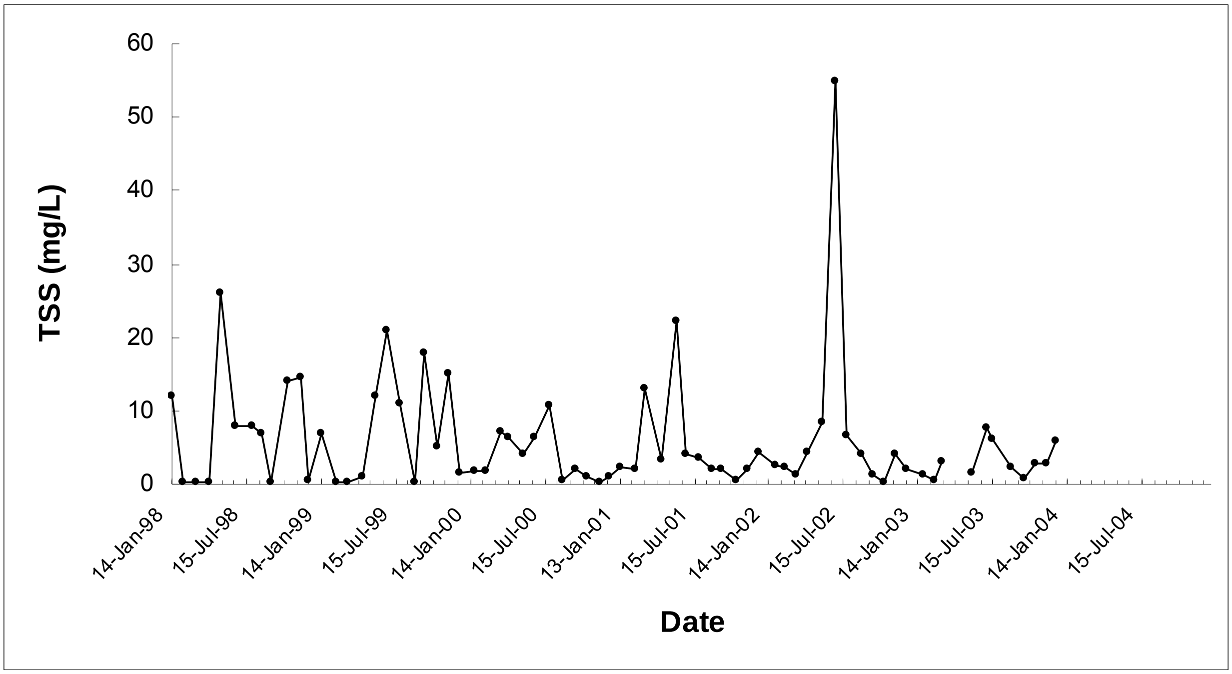
Table 12 Results of Seasonal Kendall Test on TSS Data from Exshaw and Cochrane Stations on the Bow River

	Exshaw	Cochrane
Median	2.8000	1.0
Sample Size	71	227
Seasonal Kendall Slope Estimator	-0.325	0.000
Mann Kendall Statistic S	-8.00	-86.0
Variance of S	328.33	9697
Test statistic Z	-0.386	-0.863
Probability	0.699[1]	0.388[1]

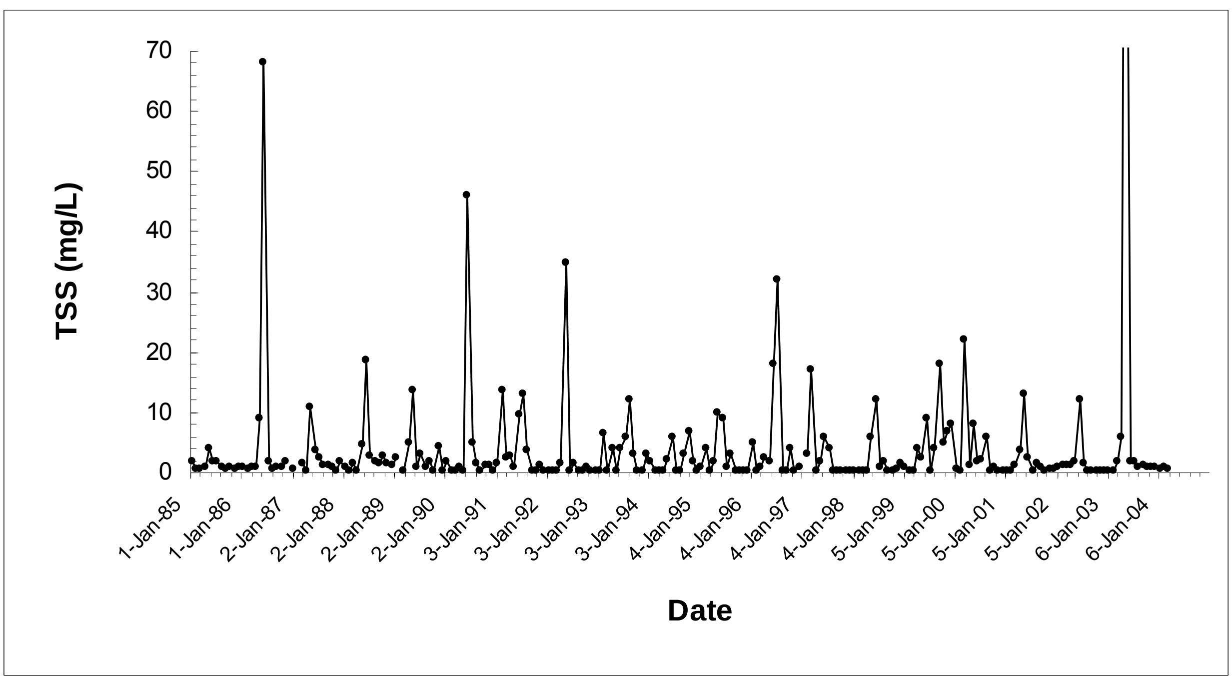
[1] not significant

Figure 17 Monthly Concentrations of TSS in the Bow River at Exshaw (A) and Cochrane (B).

A



B



3.8 TSS Loading Coefficients

The rates of loading or release of suspended material in the three rivers of this study were compared to rates of loading in other Alberta rivers by calculating loading coefficients. The loading coefficient represents the total mass of TSS in kg carried by the river divided by the area of the drainage basin that serves as the source of the suspended material. Loading coefficients for TSS were calculated for Waiparous Creek at three locations - upstream of the Black Rock Trail station (W3), upstream of the DND station (W1) and the area between the two stations. The loading coefficients for Waiparous Creek were calculated from the turbidity measurements collected by the automated probes and apply to the monitoring period May 21 to July 26, 2004. On an annual basis, the loading coefficients on Waiparous Creek would be even higher. The loading coefficients for Fallentimber Creek and the Ghost River were annual values calculated using the FLUX program with data from the 2004 monthly/bimonthly monitoring program. The loading coefficients from this study were compared in Table 13 to values calculated from two studies conducted by Alberta Environment - one on the Little Bow River and the other on the Upper Elbow River (Sosiak 2002; 2004).

The TSS loading coefficient for Waiparous Creek upstream of Black Rock trail (W3) was 6.34 kg/ha compared to 47.1 kg/ha at the DND camp, downstream. The loading coefficient at the downstream station was calculated using the entire drainage basin above this station. Waiparous Creek has therefore accumulated more than 7 times the load of TSS on an areal basis between the two monitoring stations. These two stations encompass the bulk of the unsupervised camping areas on Waiparous Creek (Figure 2). The loading coefficient between the two stations, calculated by subtracting mass loads at the two stations and dividing by the drainage area between them was even greater at 57.12 kg/ha. The loading coefficient for the Ghost River at Richards Road (G2) is of comparable magnitude (47.0 kg/ha), while that for Fallentimber Creek at Hunter Valley Road (F1) was an order of magnitude less (8.71 kg/ha).

Most of the streams in the Alberta Environment study of the Little Bow River drain agricultural lands in the lower foothills where high sediment loads are frequently observed. Strictly speaking, the streams in the Little Bow River study are not directly comparable to the Waiparous-Ghost study area, which is largely forested and drains lands classified as alpine, montane and upper foothills. The TSS loading coefficient for Waiparous Creek at the DND camp (47.1 kg/ha) over three months monitoring is, nevertheless, greater than all but three sites on the Little Bow River and one site on Women's Coulee near Cayley. These four sites were noted in the report as having upstream bank erosion that contributed to their high sediment flux (Sosiak 2000).

The study on the Upper Elbow River which drains a forested area similar to the Ghost-Waparous region, was most relevant for comparisons of sediment loading. The portion of the Elbow River upstream of the Bragg Creek station, in particular, resembles the Ghost-Waiparous study region in terrain, vegetative cover and land usage. The loading coefficients on Waiparous Creek at the DND station and the Ghost River at Richards Rd, downstream of the unsupervised camping areas, were greater than the loading coefficients at all eight water bodies in the Elbow River study on all three years of the study except for four sites on the Elbow River itself during 2002. The year 2002 was identified by Sosiak and Dixon (2004) as an unusual year with a high volume and high peak flow regime in the Elbow River (and tributaries). The total annual volume of flow in the Elbow River in 2002 was considerably greater than average (by 126 %) as was the spring runoff peak discharge (by 267 %). These conditions lead to the unusually high loading coefficients for the Elbow River in that year. In more normal years (1999, 2000), the station above Bragg Creek on the Elbow River had loading coefficients of 12.04 kg/ha and 1.74 kg/ha, respectively. These were similar in magnitude to loading coefficient of 6.34 kg/ha at the upstream station on Waiparous Creek.

In summary, the sediment loading coefficients in the lower regions of the Waiparous and Ghost Rivers are much greater than would be expected in rivers draining a similarly forested environment in the upper foothills of southern Alberta and are generally greater than loading coefficients in streams draining agricultural lands at lower elevations. On Waiparous Creek, a large proportion of this loading occurs between the stations upstream and downstream of areas identified in Figure 2 as used extensively for unsupervised camping activities involving off highway vehicles.

Table 13 Sediment Loading Coefficients in this Study Compared to Other Alberta Rivers

Location/Study	Drainage Area (km^2)	Total Loading (kg)	Export Coefficient (kg/ha)	Total Flow m^{3}X1000[1]	Median Daily Flow (m^3/s)[1]	Monitoring Period
This Study 2004-2005						
Waiparous at DND Camp (W1)	272.83	1.29E+06	47.11		3.32	May 01 - Aug 01
Waiparous at Black Rock trail (W3)	57.68	3.66E+04	6.34		0.70	May 01 - Aug 01
Waiparous Between W1 and W3	215.15	1.23E+06	57.12			May 01 - Aug 01
Fallentimber at Hunter Valley Rd.(F1)	250.5	2.18E+05	8.71		1.39	May 01 - Oct. 26
Ghost River at Richards Rd.(G1)	510.6	2.40E+06	47.04		2.456	May 01 – Dec 31
Little Bow River Study (1999)						
Little Bow River at Highway 2	53.7	2.99E+05	55.67	22991	1.49	March 24-Sept 01
Little Bow River at 168th St.	72.6	1.19E+06	164	22780	1.48	March 24-Sept 01
Little Bow River above Frank Lake	104.7	1.71E+06	164	22420	1.47	March 24-Sept 01
Little Bow River at Township Road 174	566.1	1.25E+06	22.13	21764	1.48	March 24-Sept 01
Little Bow River at Highway No. 534	706.9	8.68E+05	12.28	20066	1.47	March 24-Sept 01
Little Bow River at Highway No. 533	793.3	5.02E+05	6.33	19121	1.46	March 24-Sept 01
Little Bow River above Little Bow Reservoir	833.5	3.42E+05	4.11	19121	1.46	March 24-Sept 01
Little Bow River at Carmangay	2777.5	6.53E+05	2.35	19789	1.35	March 24-Sept 01
MacMillan Creek near the Mouth	124.8	2.44E+05	19.56	302	0.00	March 24-Sept 01
Mosquito Creek at Cranappy Farms	950.9	5.04E+05	5.30	12314	0.99	March 24-Sept 01
Mosquito Creek at Highway No. 2	527.4	9.43E+05	17.89	12711	0.98	March 24-Sept 01
Mosquito Creek at Highway No. 529	962.7	1.29E+06	13.41	12265	1.00	March 24-Sept 01
Mosquito Creek at Highway No. 534	213.6	4.61E+04	2.16	1019	0.06	March 24-Sept 01
Mosquito Creek at Twp Road 16-0	861.5	1.02E+06	11.86	12688	0.99	March 24-Sept 01
Mosquito Creek below Cayley	371.7	1.18E+05	3.17	1321	0.07	March 24-Sept 01
Mosquito Creek below Cross Creek	138.8	2.80E+04	2.01	662	0.04	March 24-Sept 01
Mosquito Creek below Highway No. 534	519.5	1.50E+06	28.85	12711	0.98	March 24-Sept 01
Mosquito Creek below Nanton Creek	805.1	1.21E+06	15.05	12924	0.98	March 24-Sept 01
Mosquito Creek near the Mouth	987.1	4.35E+05	4.41	12265	1.00	March 24-Sept 01
Nanton Creek 2.5 km above Springhill Ck.	59.1	8.45E+03	1.43	138	0.00	March 24-Sept 01
Nanton Creek at Highway No. 2	127.9	1.61E+04	1.26	212	0.00	March 24-Sept 01
Nanton Creek at Highway No. 533	112.9	2.05E+04	1.82	196	0.00	March 24-Sept 01
Nanton Creek below Tophat Feeders	119.7	3.65E+04	3.05	204	0.00	March 24-Sept 01
Springhill Creek at Purcell Road	40.5	1.36E+04	3.36	44	0.00	March 24-Sept 01
Squaw Coulee near Cayley	76.5	2.14E+06	280	11555	1.02	March 24-Sept 01

Table 13 Sediment Loading Coefficients in this Study Compared to Other Alberta Rivers Cont.

Location/Study	**Drainage Area (km^2)**	**Total Loading (kg)**	**Export Coefficient (kg/ha)**	**Total Flow m^3X1000[1]**	**Median Daily Flow (m^3/s)[1]**	**Monitoring Period**
			Elbow River Study (1999-2002)			
Elbow River Above Bragg Cr. (1999)	791.2	9.52E+05	12.04			March to Sept
Elbow River Above Bragg Cr. (2000)	791.2	1.37E+05	1.74			March to Sept
Elbow River at Above Bragg Cr. (2002)	791.2	5.73E+07	724.20			March to Sept
Elbow River at Highway 22 Bridge (1999)	870.8	1.24E+06	14.29			March to Sept
Elbow River at Highway 22 Bridge (2000)	870.8	2.64E+05	3.03			March to Sept
Elbow River at Highway 22 Bridge (2002)	870.8	1.01E+08	1160.67			March to Sept
Elbow River at Twin Bridges (1999)	1050.5	2.82E+06	26.87			March to Sept
Elbow River at Twin Bridges (2000)	1050.5	3.95E+05	3.76			March to Sept
Elbow River at Twin Bridges (2002)	1050.5	1.06E+08	1005.69			March to Sept
Elbow River at Weasel Head Bridge (1999)	1211	3.62E+06	29.88	254100[2]		March to Sept
Elbow River at Weasel Head Bridge (2000)	1211	1.13E+06	9.30	156900[2]		March to Sept
Elbow River at Weasel Head Bridge (2002)	1211	6.35E+07	524.34	321800[2]		March to Sept
Bragg Ck. (1999)	47.5	3.15E+04	6.64		0.23	March to Sept
Bragg Ck. (2000)	47.5	3.70E+03	0.78		0.23	March to Sept
Bragg Ck. (2002)	47.5	1.96E+05	41.34		0.22	March to Sept
Springbank Ck. (1999)	32.4	5.07E+02	0.16		0.02	March to Sept
Springbank Ck. (2000)	32.4	4.52E+02	0.14		0.01	March to Sept
Springbank Ck. (2002)	32.4	2.77E+02	0.09		0.02	March to Sept
Lott Ck. (1999)	84.9	3.45E+03	0.41		0.25	March to Sept
Lott Ck. (2000)	84.9	5.92E+03	0.70		0.29	March to Sept
Lott Ck. (2002)	84.9	1.26E+04	1.48		0.34	March to Sept
Milburn Ck (1999)	36.2	4.72E+03	1.30		0.03	March to Sept
Milburn Ck (2000)	36.2	2.84E+03	0.78		0.03	March to Sept
Milburn Ck (2002)	36.2	6.25E+02	0.17		0.03	March to Sept
Pirmez Ck. (1999)	12.5	1.34E+04	10.71		0.38	March to Sept
Pirmez Ck. (2000)	12.5	1.60E+04	12.81		0.39	March to Sept
Pirmez Ck. (2002)	12.5	2.53E+04	20.25		0.44	March to Sept

[1] Flow estimates refer to monitoring period

[2]Elbow River flow above Glenmore Reservoir

4 DISCUSSION

The study on the Waiparous-Ghost basin was initiated in order to determine whether there are demonstrable effects of unsupervised camping and OHV activities on water quality. The water quality parameter of greatest concern was the TSS concentration although other parameters such as nutrients and trace metals might also be affected by these activities.

Demonstrating an effect (or lack of effect) of unsupervised camping and OHV activities on water quality in the study rivers is equivalent to proving a cause-and-effect relationship between these activities and specific changes in water quality variables. As is often the case, such a cause-and-effect relationship is difficult to prove conclusively. The default approach is to examine the facts and apply a weight-of-evidence reasoning to explain the observed facts. This weight-of-evidence approach involves two steps. The first step will be to list what we have learned from the monitoring studies and from other sources of information. The second step will be to weigh the information supporting and refuting a cause-and-effect relationship between camping activities and a key water quality parameter of concern (in this case TSS) and come to the most logical conclusion.

4.1 What Has Been Established in the Monitoring Study

The following facts have been established by the study and subsequent data analyses:

- As expected, high flow rates on the river coincide with precipitation events. In particular, three major high flow-rain events were noted during May to August 2004:
    - May 21-May 26
    - June 06 - June 09
    - June 11 - June 17
    - June 30 - July 07
- Peaks in vehicular activity coincided largely with weekends (Friday-Sunday) and long weekends (Friday–Monday)
- When the entire population of readings from the Hydrolab probes on Waiparous Creek was considered, significant increases in TSS were observed downstream. The mean TSS concentration increased from 6.7 mg/L at the upstream station to 48.7 mg/L at the downstream station. Flow explained 49 % of the variance in TSS.

- When the continuous turbidity readings were examined in detail, very significant TSS and loading events were identified on Waiparous Creek with the following characteristics:
  - A large number of downstream TSS/loading events were evident, some corresponding to distinct upstream events
  - Major TSS/loading episodes occurred on May 21 to 24, June 6 to 9, June 10 to 17, June 30 to July 07, corresponding to periods of high flow and precipitation
  - TSS/loading events were only associated with periods of high vehicular activity when rain occurred on the weekend
  - In all cases where upstream TSS/loading events could be matched with downstream events, the magnitude of the events were significantly greater downstream than upstream
  - Over the monitoring period (May 21 to July 26), the total loading of suspended solids at the downstream station at the DND base was two orders of magnitude greater than the loading upstream at Black Rock Trail (1,265,412 kg vs. 36,566 kg)
  - TSS loading was extremely episodic in nature with 46 % of the total downstream loading occurring during one event (June 11 to 17).
- The monthly/bimonthly monitoring for water quality parameters identified a number of peaks and upstream/downstream differences. Most of these differences were associated with high TSS events or normal seasonal cycling. There were very few exceedances of water quality guidelines. This infrequent monitoring failed to capture much of the detail and intensity of major TSS events documented by the continuous turbidity readings. Upstream and downstream sites were not significantly different in TSS although turbidity was statistically greater downstream in Waiparous Creek
- There was no apparent increase in TSS in the Bow River downstream of the confluence with the Ghost River
- Sediment loading coefficients express loading per unit area of drainage basin and permit comparison of loading between river systems. Sediment loading coefficients in the lower regions of the Waiparous and Ghost Rivers were much greater than

would be expected in rivers draining a similarly forested environment in the upper foothills of southern Alberta and were often greater than loading coefficients in streams draining agricultural lands at lower elevations where sediment erosion is a common problem.

4.2 Weight-of-Evidence Analysis

Section 4.1 indicates that high TSS events in Waiparous Creek are associated with high flow and precipitation events with flow accounting for 49 % of the daily mean values of TSS. These facts indicate that bank or bed erosion is indeed part of the mechanism of sediment release. The correspondence of upstream events with downstream events (matched peaks) in the detailed TSS profiles suggests that the phenomenon by itself is a natural event.

What may not be natural is the magnitude of sediment release in Waiparous Creek between the upstream and downstream stations. The sediment loading at the downstream station was two orders of magnitude greater that that upstream, with the difference (1,228,846 kg) attributable to that portion of the drainage basin between the stations. The high mass of sediment release from this area is reflected in high loading coefficients calculated for this reach of the river. The loading coefficient upstream of the potentially affected area was only 6.34 kg/ha, compared with 57.12 kg/ha between the two stations and 47.1 kg/ha at the downstream station. The downstream loading coefficients were high both compared to the upstream coefficient and to similar environments such as the Upper Elbow River near Bragg Creek. They were even higher than most of the streams draining agricultural lands in the drainage basin of the Little Bow River and Mosquito Creek where higher sediment loading rates are expected.

Having determined that higher than normal rates of sediment release occur between the upstream and downstream stations on Waiparous Creek, it is necessary to examine potential sources and mechanisms of this release. Sediment release occurs from activities such logging, grazing and construction that promote erosion. This portion of the drainage basin of Waiparous Creek has had at least 50 years of resource development that has included logging, well site construction and seismic surveys. All of these activities resulted in the construction of access roads, many of which were found in the riparian zone of the rivers. Many of these roads were used only during winter conditions when the ground was frozen. Restriction of road usage to winter limited the release of silt to the creek by erosion (Roger Meyer, personal communications). What has changed in the last 10 years is the accessibility of these roads, especially during the wet summer months when they are most susceptible to erosion. OHVs, large trucks and dirt bikes have proliferated as weekend recreational vehicles and the usage of these roads during the summer months has increased considerably. These vehicles are often used under wet conditions when the risk of erosion and silt discharge to the rivers is highest.

Identifying increased OHV use on roads and tracks in the riparian zone as the potential source of increased sediment loading in these rivers requires a plausible mechanism to explain how this occurs. It is evident from this study that sediment release is occurring under high flow conditions and that bank or bed erosion is involved. Two mechanisms involving OHVs have been proposed to explain these high rates of sediment loading. In the first mechanism, vehicles operating in the stream bed during periods of high activity directly suspend the sediments. The second mechanism is indirect. The OHV activities cause tracks and ruts alongside the river that promote erosion and sediment release during rain events.

The first mechanism is poorly supported by the data. This mechanism does not account for the relationship between TSS events and flow. High levels of vehicular activity correlated more with weekends than with TSS events. On several occasions, high levels of vehicular activity were recorded on days when TSS events were not observed at all. When vehicular activity and TSS events coincided, it was probably because it rained during the weekend. Intuitively, it is hard to conceive of sufficient vehicular activity within the rocky stream bed of the Waiparous that could account for a TSS peak such as that occurring between June 11 and June 17 when 46.9 % of the sediment loading was observed. High TSS was also observed at night when vehicular activities in the stream beds were likely curtailed.

The second hypothesis fits the set of observations well and is supported by direct observations. Under this mechanism, sediment release would be erosional in origin (as observed), correlated well with rain and flow events but poorly correlated with vehicular activity. Examination of the study area showed an extensive network of rutted tracks and gullies along the rivers. As the vehicles normally ford the stream at strategic points, these tracks often run at right angles to the river. A slight rainfall can result in a dramatic sediment release. Such a release was recorded photographically on July 13 2005 at Fallentimber Creek at the Benjamin Creek Road Station minutes after a light rainfall occurred. Photos 1 and 2 show a significant release of silt into the river from both banks where a OHV path fords the river but a clear river upstream. The third photo shows the two silt plumes, one from each side, merging just a few metres downstream. The fourth photo shows a view of the silt plume, now almost fully mixed, downstream from the bridge.

There is growing body of evidence that erosional effects by OHV activities can have dramatic effects on water quality and, in extreme cases, on river stability. While few peer-reviewed publications seem to have documented these effects, there are abundant references to the problem in forest management publications such as those produced by the U.S. Department of Agriculture Forest Service and in publications by conservation groups (e.g., USDA–FS 2004; IWLA 2005). Wender and Walker (1998) reported on four watersheds in the Daniel Boone National Forest showing an evolution towards higher width/depth ratios and increases in bank erosion as a result of elevated sediment loads. These effects on channel morphology were related directly to the densities of OHV roads and trails in each watershed. Changes in channel morphology were accompanied by decreases in macroinvertebrate densities and a population shift towards more sediment tolerant species. In general, these problems appear to be increasing in recent years in response to increased usage of OHVs. The US Department of Agriculture Forest Service reports that between 1995 and 2000 the yearly sales of OHVs in the United States increased by 135% (USDA–FS 2006).

4.3 Conclusions of Analysis

A direct cause-and-effect relationship between OHV usage and water quality in the study rivers cannot be proven conclusively. However, the evidence from these studies strongly suggests that increased OHV activity has affected water quality. Increases in TSS loads in the Waiparous and Ghost rivers, although natural during rain and high flow events, are likely exacerbated by erosion from tracks used by OHVs running near and across the rivers at fording locations. These tracks may have been constructed for other purposes (e.g, logging) but their usage has increased with the proliferation in OHVs. While other water quality parameters are not greatly affected, increases in nutrients, bacteria and certain metals (e.g., aluminum and iron) are associated with these high TSS loads. The high TSS loads may also have significant ecological effects downstream when the sediments are deposited in slower flowing reaches of the rivers. There is no evidence to suggest that these sediment loads are affecting water quality of the Bow River downstream of the Ghost River discharge.

Photos 1-4: Sediment Plumes in Fallentimber Creek at Benjamin Creek Road from OHV Tracks (after light rainfall)

5 REFERENCES

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

AENV 2002. Water quality sampling methods. Alberta Environment, Water Monitoring Group, Compliance Branch, Northern and Southern Regions.

AMEC. 2001b. Range Inventory of the Ghost River Range Allotment. AMEC Earth and Environmental Ltd.

AMEC. 2001a. Range Inventory of the Upper Fallentimber Range Allotment. AMEC Earth and Environmental Ltd.

IWLA. 2005. ATV Position Statement of the Walter J. Breckenridge Chapter of the Izaak Walton League of America. www.breckenridgeikes.org/chap_resolutions.htm

BRBC. 2005. The 2005 Report on the Bow River Basin. Report to the Bow River Basin Council.

Environment Waikato. 2004. Trends in river water quality in the Waikato Region, 1987-2002. Environment Waikato Regional Council Technical Report 2004/02, New Zealand.

GRSIRP. 1988. Ghost River Sub-Regional Integrated Resource Plan. 1988. Alberta Forestry Lands and Wildlife.

Sosiak, A. 2000. Water quality sampling on the Little Bow River and Mosquito Creek in 1999. Alberta Environment Report no. T/568.

Sosiak, A. and J. Dixon. 2004. Impacts on water quality in the Upper Elbow River Alberta Environment Report no. T/740.

USDA–FS 2004. Unmanaged Recreation. US Department of Agriculture Forest Service Fact Sheet www.fs.fed.us/projects/four-threats/#recreation.

Wender, B. and J. Walker. 1998. Changes in Stream Condition in Response to Off Highway Vehcule Use in Forested Watersheds of the Daniel Boone National Forest 1998 Kentucky Water Resources Annual Symposium Proceedings February 11, 1998. Holiday Inn North, Lexington, KY.

USDA–FS .2006. Off-Highway Vehicles. Frequently asked questions. US Department of Agriculture Forest Service. www. Fs.fed.us/r3/ohv/faq/index.shtml.