University of Alberta

Water Quality Indicators for Cumulative Environmental Effects Assessment in the Bow and Red Deer River Basins, Alberta, Canada

by

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Abstract

The overall objective of the research project was to evaluate the use of water quality as an indicator of cumulative environmental effects in the mountains and foothills of Alberta, Canada. Two categorical indices were created to quantify cumulative human activity in the study watersheds and then their utility was compared. Water quality of the study basins was assessed over two years by assessment of water chemistry and benthic macroinvertebrate community structure. The water quality observations were then compared with the Cumulative Activity Indices (CAIs) for each watershed and correlations were calculated.

Benthic macroinvertebrate metrics were not significantly correlated with the CAI scores but some water chemistry parameters were. There was evidence that a critical threshold may exist in aquatic systems beyond which water quality will manifest cumulative environmental disturbance. Observations showed measurable chemical and biological changes immediately downstream of point sources of pollution, while a consistent widespread response to watershed disturbance was not seen.

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1.0 Research Context

Assessment of cumulative environmental effects is a difficult but necessary component of environmental impact assessment (Ross 1994). There are many possible approaches to cumulative effects assessment. Methods may focus on only one ecosystem component and evaluate the impacts of several projects on it, or the effects of several projects may be considered for numerous ecosystem components. Environmental practitioners are left to decide, sometimes with a dearth of information, how to best approach cumulative effects assessment for each particular situation. For some time water quality has been considered as a potential indicator of cumulative effects. This research evaluates the use of water quality as an indicator of cumulative effects in the Rocky Mountains and Foothills of Alberta, and attempts to provide direction to environmental practitioners regarding the response of water quality to watershed disturbance in this region.

Few scientific studies have considered indicators of cumulative environmental effects in mountainous areas. Some work has quantified the effect of specific activities on water quality (Wilhm and Dorris 1966, Hobbie and Likens 1973, Taylor and Roff 1986), although cumulative impacts of human development on mountain streams have not been well documented. Some studies have considered only the general land use in a basin (Rothrock et al. 1998) and others have detected cumulative downstream change in water quality, but not in a mountain landscape (Bolstad and Swank 1997). Previous workers have measured different water quality parameters; physicochemical and microbial measurements have been made (Bolstad and Swank 1997), as well as macroinvertebrate biological assessments (Rothrock et al. 1998). Mountain areas are ecologically sensitive and act as storage and purification systems for water for areas downstream (Williams et al. 1993). Effective assessment of cumulative effects is essential in mountainous regions for the protection of water resources.

The notion of creating categorical indices of biological integrity to better manage continuous ecological data is not a new one (Hilsenhoff 1977, Karr 1981). Using a categorical index to summarize and more simply represent continuous ecological community information has been effective in representing the degree of ecosystem impairment and biological health. This leads one to believe that such an approach may be useful in dealing with another type of continuous data; creating a categorical index for geographical data may effectively indicate the cumulative amount of human activity and disturbance in a watershed.

This research used an index-creation approach to quantify land use and human disturbance in mountainous watersheds, and then built upon previous impact assessment research by comparing that information with metrics of water quality.

2.0 Research Methods

The first task undertaken in this research was the creation of an index for use in classifying and quantifying the amount of watershed disturbance in the study basins. The index was necessary to simplify the task of comparing human activity to water quality in the study rivers and their tributaries. A geographic information system (GIS) was used to quantify human activity and watershed characteristics for several categories in each basin and then two methods for summarizing that information were compared. The results of the summation of the land use data were called "Cumulative Activity Indices" or CAIs, and each study watershed was assigned a CAI score to represent the amount of watershed disturbance.

Since one of the objectives of the research was to contrast cumulative human activity with water quality indices, the next step was to assess the quality of the water in the study rivers. Twenty sampling sites were selected on the Bow and Red Deer Rivers and their tributaries. Water samples were taken for chemical analyses, and benthic macroinvertebrate community structure was observed over two years. The water quality observations were then compared with the CAIs for each watershed and correlations were calculated.

3.0 Findings and Future Directions

Benthic macroinvertebrate water quality metrics were not significantly correlated with the CAI scores calculated for the study watersheds while some water chemistry parameters were. The correlation of water chemistry observations with CAI score could not, however, be attributed uniquely to the influence of human disturbance as other natural factors may have been involved. Evidence was observed for a threshold beyond which water quality will manifest cumulative environmental disturbance. Observations showed measurable chemical and biological changes immediately downstream of point sources of pollution, while a consistent widespread response to watershed disturbance was not seen.

The notion of a critical threshold after which nutrient-poor lotic systems cannot assimilate further human disturbance without changing state should be further investigated. That work could have particular importance for land use and aquatic system management in Canada's mountain national parks. Aquatic problems in Banff National Park are attributed to human activities (Schindler 2000), and continuing human development within the mountain parks may be bringing aquatic systems nearer such a critical threshold.

As this work constitutes only a preliminary investigation of the complex problem of cumulative effects assessment, ecosystem managers should employ the precautionary principle when making development decisions and continue the chemical and biological monitoring of these watersheds. The mountain national parks provide a rare opportunity for study of natural systems, but only insofar as they remain undeveloped.

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II. THE DEVELOPMENT AND COMPARISON OF TWO CUMULATIVE ACTIVITY INDICES TO MEASURE WATERSHED DISTURBANCE USING A GEOGRAPHIC INFORMATION SYSTEM

1.0 Introduction

1.1 Research Context

There is active debate within the environmental community about the nature of cumulative environmental effects and their appropriate assessment. Inconsistent methods are applied when completing a cumulative effects assessment (CEA). The definition of boundaries is a subjective process, the adjacent projects to include in the assessment are difficult to identify, and how to measure the potential for environmental impact is often unclear. Although a basic framework exists to provide direction to those who practice cumulative effects assessment (Hegmann 2001), the process involves value judgments and prediction making.

A categorical index may allow environmental practitioners to summarize large amounts of land use data and make that information more accessible for cumulative effects assessment. This paper compares two methods of creating Cumulative Activity Indices (CAI) using spatial information collected from a geographic information system (GIS). One approach categorized the data from each land use variable to assign a cumulative activity score; the score was relative to watersheds in the study area that experienced very little human activity. The other approach simply compared the watersheds to each other using the raw continuous-type data gleaned from the GIS. The categorical approach was consistent with the methods employed in other ecological health assessments, and created an index more closely representative of actual conditions in the field.

1.2 Cumulative Effects Assessment

Cumulative environmental effects are "changes to the environment caused by an activity in combination with other past, present, and reasonably foreseeable human activities" (Alberta Environment 2002). The assessment of cumulative effects of proposed activities requiring impact assessment is mandatory under federal and provincial environmental impact assessment legislation (Alberta Environmental Protection and Enhancement Act and Canadian Environmental Assessment Act); however, the assessment of cumulative effects is difficult (Ross 1994). Assessing cumulative effects is an important component of a comprehensive environmental impact assessment because projects and undertakings do not take place in isolation. It is common sense that a number of simultaneous projects in an area, or several projects in succession, will have a cumulative impact on the natural and social environment and that those impacts should be considered. Neglecting the effective and complete assessment of cumulative effects may render the environmental impact process ineffective. There is a dearth, however, of effective methods for quantifying and assessing cumulative effects; a simple and accurate method of quantifying and evaluating the amount of human disturbance in a defined system would be a positive first step toward meaningful cumulative effect assessment.

1.3 Indices of Environmental Health

The notion of creating categorical indices to assess and compare ecological health was introduced in the late twentieth century in work presented by Hilsenhoff (1977) and Karr (1981), among others. Hilsenhoff was among the first ecologists to use benthic macroinvertebrate community structure to evaluate ecological health and Karr worked with similar ideas using fish and bird communities. The focus of their work was the manipulation of quantitative data into categorical indices of environmental health based on the observed condition of the sample sites. The data used in the creation of the indices were collected at numerous sites, and the indices were generalized for use in a specific study region. The categorical characterization of ecological health was effective because natural variation in living systems lends itself to a coarser presentation of information. Condensing continuous variables into categories constrains the natural variation to some extent and makes the assessment of ecological health more meaningful. This previous work provides the foundation on which this research is based. This work compares a categorical and a non-categorical evaluation of cumulative human disturbance in mountain watersheds, and the principles used in the construction of the categorical index are drawn from other ecological health assessments.

1.3.1 Hilsenhoff's Biotic Index

Hilsenhoff (1977) used invertebrate community structure to assess water quality in streams. His original biotic index assigned tolerance values from 0 to 5 to arthropod genera and species based on their ability to withstand organic and nutrient pollution. Organic pollution decreases the concentration of dissolved oxygen in streams, which in turn, affects each organism's ability to survive in that stream (Hilsenhoff 1987). A weighted average of tolerance values is calculated for a site based upon the abundance of each taxon; this weighted average is termed the Biotic Index (BI). A BI near 0 indicates excellent water quality, while a BI near 5 indicates very poor water quality.

The Hilsenhoff Biotic Index system was modified after ten years of data collection and analysis. Hilsenhoff revised the tolerance values so that they ranged from 0 to 10 to improve resolution, and included regional keys for identifying organisms (Hilsenhoff 1987). Further discussion resulted in the development of a family level biotic index (FBI) (Table 2.1) to facilitate rapid field assessment of stream water quality by experienced biologists (Hilsenhoff 1988). This revision of the BI was compared with the finer taxonomic resolution of the earlier BI. The FBI was somewhat less accurate and more frequently erroneous than the genus or species level BI, but still useful as a tool in the initial assessment of water quality.

1.3.2 Karr's Index of Biological Integrity

James Karr also developed a system for measuring biological integrity based on his work with fish and birds. Karr's Index of Biological Integrity (IBI) uses several metrics of community composition to generate a total IBI score for a site (Karr 1981, 1987, 1991). The IBI score is relative to an "ecologically healthy" regional reference site and is based on the arbitrary categorical division of results based on observed ecological health. Each metric used in the assessment is assigned one of three ratings (5, 3, or 1) based on the expected results for that metric at an ecologically healthy site. Several metrics are used in the calculation of the total IBI score for a sample site. The metrics measure properties such as species richness and composition, trophic composition, and organism abundance and condition (Karr 1991). The sum of ratings for each site are totaled to give a total score, which indicates biotic integrity (Table 2.2). Karr's Index of Biological Integrity has been used to assess ecological health using fish and bird communities as indicators (Karr 1991), and can be adapted for use with other ecological communities in a study region.

1.3.3 Bowman's Ecological Integrity Scores

In a more recent use of categorical indices of ecological health in the study area, Bowman (2002) established several guidelines correlating water quality measures with ecological integrity (Table 2.3). These ranges of values result from water chemistry and benthic macroinvertebrate samples taken upstream and downstream of waste water treatment plants in the mountain parks.

1.4 Using GIS to Measure Land Use

GIS has become a common tool used in the analysis of spatial information, and is defined by Davis (2001) as "a computer-based technology and methodology for collecting, managing, analyzing, modeling, and presenting geographic data for a wide range of applications". GIS facilitates use of electronic geographic data to provide spatially-based information about a particular area, and is used in numerous fields including planning, geology, engineering, ecology, hydrology, archaeology, and surveying (Davis 2001).

Intuitively land use and other environmental variables have an influence on the presence and structure of some communities, and using a GIS is an efficient method of quantifying that influence. MacNally et al. (2003) used a GIS in modeling butterfly species richness as a function of environmental variables in the Great Basin, and Tong and Chen (2002) used a GIS to model the relationship between land use and surface water quality in Ohio. Wang (2001) integrated water quality observations with land use data in a GIS to map the human influence on stream water quality in Ohio. A GIS was the most accurate, precise, and efficient tool to use to evaluate the natural and human-influenced characteristics of the study basins.

1.5 Research Objectives

The objectives of this study were to:

1. Evaluate previous scientific research that created indices of environmental quality.
2. Create and evaluate two different indices of cumulative human activity for use in the Rocky Mountains and Foothills of Alberta, Canada.
3. Create a variable representing cumulative human activity for future work investigating the association between cumulative human activity and water quality.

2.0 Materials and Methods

2.1 Study Area

The Bow and Red Deer Rivers originate in the Rocky Mountains of Alberta within the boundary of Banff National Park of Canada. The Bow River flows south through the park through the towns of Lake Louise, Banff, and Canmore, Alberta before reaching the city of Calgary where it is the primary source of municipal drinking water. The Red Deer River flows east through Banff National Park and exits the park in the shadow of Warden Rock after approximately thirty- five kilometers and continues through the town of Sundre toward Red Deer, Alberta (Figure 2.1).

Twenty sample watersheds were selected, six on each of the principal rivers (Bow and Red Deer) and one at the outlet of each of four tributaries on the two principal rivers (Figure 2.2, see Table 2.4 for site codes). Sampling sites on the Bow River ranged in elevation from 1345 to 1950 m ASL and from 1215 to 1798 m ASL on the Red Deer (Table 2.4). A watershed is defined as an area of land for which all surface water drains to a single outlet point; in this study a watershed may be the entire catchment area of a creek or only a portion that drains to a single point. The term "study basin" refers to all watersheds studied in the larger Bow or Red Deer River watersheds. For example, "Bow study basin" refers to the ten sample points and corresponding watersheds located on the Bow River and its tributaries.

The alpine, subalpine, and montane ecozones are represented in the study area (Parks Canada 2003a). The alpine ecozone is dominated by a ground cover of rock, ice, and snow, with small patches of alpine meadows and shrubs (Ibid.). The subalpine ecozone is dominated by lodgepole pine (*Pinus contorta* Engeim. (P. murrayana Baif. of Barrell)), Englemann spruce (*Picea engelmannii* (Parry) Engelm.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt), and dwarf shrub meadows. The montane ecozone is the smallest in Banff National Park and is characterized by a cover of Rocky Mountain Douglas fir (*Pseudotsuga menziesii* var. glauca (Beissn.) Mayr), trembling aspen (*Populus tremuloides* Michx.), lodgepole pine (*Pinus contorta*), and patches of grassland on south facing slopes. Wetter areas in the montane zone also support communities of white spruce (*Picea glauca* (Moench) Voss.) and balsam poplar (*Populus balsamifera* L. spp balsamifera).

The portion of the Bow River basin studied is 59% vegetated and 7.2% permanent ice and snow, and the Red Deer River study basin is 65% vegetated and 3.4% permanent ice and snow. The study area receives an average annual precipitation of 268.1 mm of rain and 266.5 cm of snow (Parks Canada 2003b). The average daily high temperature is 8.2 °C and average daily low temperature is -6.6 °C.

With the notable exceptions of the Banff and Lake Louise townsites the study basins are sparsely populated. The Bow River basin is a major international tourist destination and experiences a large amount of visitation year-round; approximately 4.6 million person-visits are recorded in Banff National Park annually (Parks Canada 2003c), with the majority in the Bow Valley. The Trans Canada Highway and a railway corridor also pass through the Bow Valley. The upper Red Deer River basin sees only light recreational use throughout the year. Beyond the national park boundary the Red Deer basin is used for recreation, oil and gas extraction, ranching, and forestry.

2.2 Programs and Data

A Geographic Information System (GIS) was used to quantify human activity in each basin. The ArcView 3.2 (ESRI 2002) program was used as the foundation program for the GIS; Spatial Analyst, Geoprocessing (ESRI 2002), and HEC-PrePro 2.0 (Olivera et al. 1998) extensions were employed. Spatial data were obtained from Natural Resources Canada (NRCan) and Statistics Canada (StatsCan) via the University of Alberta Library; several data sets were used to build the GIS (Table 2.5).

2.3 Steps in Building the GIS

Each land use or human activity theme was added to a single view in the ArcView project. Theme attributes are defined in the data dictionary for the NTDB (Table 2.6). Because each theme was added in pieces according to each area of the GIS covered by a 1:50 000 National Topographic System (NTS) map sheet, the pieces were merged into a respective single theme. For example, all of the pieces of railway theme from several NTS areas were merged into a single composite theme called "Railways". Both roads and limited use roads were merged into a single theme.

The data were delivered in geographic format in units of decimal degrees. Although the most appropriate format for entering information from several sources into a single GIS project, this projection does not allow calculations in meaningful units. The newly created composite themes were projected to Universal Transverse Mercator (UTM) Zone 11 in units of meters.

To begin the process of delineating the study watersheds the CDED digital elevation model (DEM) data were imported into a new view in the GIS project. Using the HEC-PrePro 2.0 extension, sinks in the DEM were identified and filled. Sinks are cells with no possibility for drainage, usually created in error, and must be filled to allow calculation of flow direction. The flow direction and flow accumulation grids were calculated for the DEM using HEC-PrePro. From the flow accumulation grid streams were identified; streams were defined as cells having an accumulation greater than 2500 cells. This stream definition produced a theme that matched well with the watercourse theme from the NTDB maps. The streams were burned into the DEM to facilitate further analyses.

The locations of sampling sites were added to the view as a theme and the underlying cells in the DEM were marked as outlets for the stream system. HEC-PrePro was used to calculate the watershed for each of the outlets, and the resulting polygon was converted to a shapefile. The shapefile (named "All Watersheds") was then split into twenty separate themes, each corresponding to the watershed for an outlet. These themes were added to the first view containing the NTDB information.

2.4 Analysis Using the GIS

Each of the composite human activity themes was clipped by the "All Watersheds" theme using the Geoprocessing Wizard (ESRI 2002a). This eliminated all areas in the GIS outside the study area, and therefore reduced processing time during calculations. Each human activity theme was then clipped by each of the individual watershed themes. For each watershed the attributes of each human activity theme were recorded from the theme attribute table (counts) or calculated using the ArcView map calculator (length and area calculations).

2.5 Creation of the Cumulative Activity Indices

Two indices of cumulative environmental effects were created to quantify human activity within each study watershed and the results of each index were compared. Eleven categories of land use or anthropogenic development were measured in the GIS for each watershed in both methods (Table 2.7). Not all of the themes originally added to the GIS were used in analyses. The results for each site are cumulative and include enumeration of all area in the total study basin upstream from that sampling site. For example, site Bow River 6 is the furthest site downstream on the Bow River and its land use values represent the entire Bow basin upstream from that point.

2.5.1 Cumulative Activity Index A

In the creation of index A the raw data measured in the GIS were normalized by the area for each basin to render the observations comparable (i.e., presented in units of value/km^2). Each normalized category of land use data was ranked and percentiles were calculated for each observation. A value of 1, 2, 3, or 4 cumulative activity points (CaP) was assigned to each observation based on its percentile ranking; 1 point indicates low human activity in the watershed and 4 points indicates significant human activity (Table 2.8).

Three categories of spatial data, which may indicate the ability of a watershed to assimilate disturbance were also evaluated. Percent of watershed covered by vegetation, percent as wetlands, and stream length were added to the human activity categories. Cumulative activity points were assigned opposite to the human activity categories, i.e., small observations in these categories mean lower assimilation capacity, and therefore are assigned more cumulative activity points.

All cumulative activity points among categories were then summed for each watershed (Formula 2.1). Since the observations were all in units divided by watershed area, the sum of activity points allows direct comparison among watersheds, with higher values indicating greater cumulative activity.

$$\text{(2.1)} \quad \text{Cumulative Activity Index Score} = \text{SUM}_{\text{CaP}}(\text{Vegetated Area} + \ldots + \text{Deep Wells})$$

An example calculation is presented in Appendix A.

2.5.2 Cumulative Activity Index B

The maximum value calculated in the GIS for each land use category defined above was noted and used in the analysis. The maximum values observed in this study were considered the highest amount of human disturbance, and no observations were considered to be no disturbance.

For each watershed the value for each land use category was divided by the maximum value for that category ($Category_{site}/Category_{max}$). Therefore, a basin having the maximum amount of development in a particular category was assigned a value of 1, while one having none of that category of development was assigned a value of 0; the units for this measure are also defined as Cumulative Activity Points (CaP). The total CaP over all eleven categories for each watershed was summed to obtain a raw score (Formula 2.2).

$$(2.2)\quad CaP_{site} = SUM((Population_{site}/Population_{max}) + \ldots + (Wells_{site}/Wells_{max}))$$

The watersheds studied varied in area. Since there is no common denominator, the raw CaP scores must be normalized for comparison. The most meaningful way to normalize the CaP scores is to calculate them as a ratio of Cumulative Activity Points per unit area. In this way the rate of human activity per unit area can be considered for each watershed (Formula 2.3). Intuitively, a greater rate of activity per unit area will result in a greater degradation of water quality at the watershed's outlet. All CAI scores calculated using Method B were multiplied by 1000 to facilitate presentation.

$$(2.3)\quad \text{Cumulative Activity Index Score} = CaP_{site}/Area_{site}$$

An example calculation is presented in Appendix A.

2.6 Field Observations

During water quality sampling as outlined in Chapter 2 field observations of human activity in the study watersheds were made. These observations included in-stream structures, substrate composition, presence of attached algae, adjacent land use, obvious point sources of pollution, and any other notable activity in the watershed.

2.7 Statistical Analyses

The CAP scores calculated for each sample site using Methods A and B were converted to Z-scores to be comparable. Because the observations were from a small sample size and violated the assumptions of most parametric tests, a Sign

Test for Median Difference was applied to the differences of the paired Z-scores testing statistical significance at $\alpha = 0.10$ (Milton 1992). Since no differences were equal to zero it was not necessary to differentiate the test into a conservative and a non-conservative approach.

The null hypothesis tested was that the mean of Method B subtracted from the mean of Method A would be less than or equal to zero; in other words, that the mean Z-scores for the two methods were equal or that the mean of Method A was less than Method B. Rejecting the null hypothesis would indicate that the mean Z-score of Method A was greater than the mean Z-score of Method B. Alpha was set at 0.10 as this is preliminary research and, at this point, the benefit of detecting a significant difference in means is greater than the cost of drawing a false conclusion. As work continues it would be appropriate to reduce the acceptable probability of Type I error (or alpha value) to increase confidence in the findings (Warren 1986).

3.0 Results and Discussion

3.1 Index Comparison Results and Discussion

Cumulative Activity Index (CAI) scores ranged from 26 at Red Deer River 1 to 49 at Burnt Timber Creek 1 and Red Deer 6 using Method A, and from 0.279 at Tyrrell Creek to 4.46 at Wildhorse Creek using Method B (Table 2.9). The mean CAI score using Method A was 34 and the median score was 32, while Method B had a mean score of 1.61 and a median score of 1.35.

All land use and development categories measured ranged from a low of zero to various high end values (Table 2.10). The entire study area has a mean permanent population density of two persons per square kilometer and a population of 7797 persons as of the 2001 Canadian census (Statistics Canada 2001).

The Sign Test for Median Difference indicated that there was a difference between the two methods of watershed disturbance rankings at $\alpha = 0.10$

(Table 2.11), and that the disturbance scores calculated by Method B were significantly lower overall. Graphical presentation of the data also indicates a remarkable difference between the two methods (Figure 2.3).

The Cumulative Activity Index scores are used as the primary measurement of human activity in each study watershed. The scores are an indicator of the amount of human activity per unit of watershed area and assimilation capacity of the watersheds. Although the methods employed in the calculation of these scores could be applied to other watersheds, the values obtained serve only as a comparison among these specific sites and have no quantitative meaning in other applications.

The Cumulative Activity Index scores calculated using Method A were more representative of the conditions observed in the field than those calculated by Method B. Method A clearly detected the exit of the Red Deer River from Banff National Park (with a corresponding jump in CAI score) and had fewer anomalies than Method B (such as the extremely high value for Wildhorse Creek). Using Method A all of the tributary watersheds had lower CAI scores than the corresponding paired point on the main river (Bow or Red Deer) as was expected since the calculations for the main river sample sites are cumulative. Some tributary watersheds exhibited higher CAI scores than their paired main river site with Method B, which is possible, but not likely given observed conditions. The CAI scores calculated using Method A increased in a more consistently than the Method B scores which is consistent with the idea that a watershed will accumulate more human activity farther from its source.

Sites Bow 3 and Bow 4 exhibited the greatest qualitative deterioration in water quality and substantial human impact in the field as indicated using Method A; the results of Method B did not support these field observations. This difference may be explained because the relative weight of a waste water treatment plant in Method B was light compared to the percentile ranking in Method A, and sites Bow 3 and 4 are influenced by the waste water treatment plant in Lake Louise.

Method B of calculating Cumulative Activity Index scores uses watershed area to normalize the land use categories in the final step of calculation, and as such, may exaggerate the score of small watersheds. Wildhorse Creek is a very small watershed (23 km^2) and using Method B was assigned the highest CAI score, 47% greater than the next highest score (Bow 3). Since Bow 3 in reality appears to have a greater cumulative amount of human activity, and more significant activity for aquatic systems, the score for Wildhorse Creek may be magnified beyond what is representative of actual conditions. Method A uses watershed area in the initial step of the calculation process and then those values are ranked by percentile groups. This group ranking in Method A appears to reduce the importance of absolute watershed area as indicated by the more reasonable result of Bow 3 being 58% greater than Wildhorse Creek, and Wildhorse Creek being comparable in magnitude to neighbouring sites.

The scores calculated using Method A are categorical compared to the continuous nature of Method B. The percentile grouping of the raw results and then assigning one of four categorical scores to those groups in Method A provides a coarser result than the assignment of continuous values in Method B. Since the assessment of cumulative environmental impacts is not a precise task, it is more appropriate to categorize the data rather than assign discrete values. Ties of CAI score are likely between watersheds using Method A; however, ties are reasonable in that watersheds may have different activities and land uses occurring but those activities may have a similar cumulative impact when considered as a whole. The continuous nature of the CAI variable calculated using Method B presents a false sense of precision in the representation of cumulative effects.

3.2 Promise for Future Use and Development

Although the values obtained using the GIS and calculated indices are relevant only to this study area, the methods used may be applied to other areas. The CAIs appeared to represent the actual human activity present in and assimilation capacity of the watersheds, with CAI-A being the better performing index. The immediate application will be as a predictor variable in the water quality portion (Chapter III) of this research; wider application in the assessment of cumulative effects is also possible with continued development.

4.0 Conclusions

Of the two methods examined for calculating cumulative activity indices, the method that categorized normalized human activity and land use data and assigned index scores by watershed (Method A) was more representative of actual conditions in the study watersheds. The tabulation of human activity data and then normalizing by watershed area as a last step with no categorization (Method B) was less effective in representing actual watershed conditions in the study area.

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Table 2.1. Water quality evaluation as assessed by the Family Biotic Index (from Hilsenhoff 1988).

Family Biotic Index	Water Quality	Degree of Organic Pollution
0.00 - 3.75	Excellent	Organic pollution unlikely
3.76 - 4.25	Very good	Possible slight organic pollution
4.26 - 5.00	Good	Some organic pollution probable
5.01 - 5.75	Fair	Fairly substantial pollution likely
5.76 - 6.50	Fairly poor	Substantial pollution likely
6.51 - 7.25	Poor	Very substantial pollution likely
7.26 - 10.00	Very poor	Severe organic pollution likely

Table 2.2. Total Index of Biological Integrity scores, class of site, and general attributes of that site for twelve fish community metrics (from Karr 1991).

Total IBI Score (Sum of 12 Ratings)	Integrity Class of Site	Attributes
58 - 60	Excellent	Comparable to the best situations without human disturbance; all regionally expected species, including most intolerant; full array of age classes and trophic structure.
48 - 52	Good	Species richness somewhat below expectation, especially due to the loss of the most intolerant forms; some species are present with less than optimal abundances or size distributions; trophic structure show some signs of stress.
40 - 44	Fair	Signs of additional deterioration include loss of intolerant forms, fewer species, highly skewed trophic structure; older age classes of top predators may be rare.
28 - 34	Poor	Dominated by omnivores, tolerant forms, and habitat generalists; few top carnivores; growth rates and condition factors commonly depressed; hybrids and diseased fish often present.
12 - 22	Very poor	Few fish present, mostly introduced or intolerant forms; hybrids common; disease, parasites, fin damage, and other anomalies regular.
0	No fish	Repeated sampling finds no fish.

Table 2.3. Bowman's ranges of ecological integrity for water quality parameters sampled in mountain park rivers (from Bowman 2002).

Ecological Integrity Rating ⇨	**Good**		**Fair**		**Poor**		**Very Poor**	
Score	4		3		2		1	
Range	Min	Max	Min	Max	Min	Max	Min	Max
Water Chemistry Metrics (µg/L)								
TP	2.0	4.8	4.9	42	43	79	80	116
SRP	0.70	1.1	1.2	35	36	69	70	102
TDN	55	89	90	255	256	420	421	586
NO2+NO3	53	92	93	200	201	309	310	417
NH4+	0.00	7.5	7.6	31	32	54	55	77
Benthic Macroinvertebrate Metrics								
# Ephemeroptera taxa	5.0	8.0	4.0	4.9	3.0	3.9	2.0	2.9
% Ephemeroptera	29	66	20	28	10	19	2	9
% Chironomidae	3	31	32	50	51	68	69	87
Hilsenhoff Biotic Index	2.0	4.0	4.1	4.6	4.7	5.1	5.2	5.6

TP: total phosphorus concentration
SRP: soluble reactive phosphorus concentration
TDN: total dissolved nitrogen concentration
NO2+NO3: nitrate + nitrite nitrogen concentration
NH4+: ammonium nitrogen concentration

Table 2.4. Study watershed characteristics including Universal Transverse Mercator (UTM) coordinates, elevation, watershed area, stream length at sampling location, and dominant land use characteristic.

Site Name	Site ID	Dominant Characteristic	UTM Location (NTS Zone 11U)	Elevation (m ASL)	Area (km^2)	Stream Length (km)
Red Deer River Basin						
Red Deer 1	RD1	National park	0574834/5722821	1798	273.63	53.66
Red Deer 2	RD2	National park	0585173/5725314	1683	551.25	107.29
Tyrrell 1	TY1	National park	0584965/5725440	1685	46.21	7.93
Red Deer 3	RD3	Ya Ha Tinda ranch	0601202/5731832	1565	862.70	170.45
Bighorn 1	BH1	Bighorn camp	0600790/5732619	1572	57.55	9.19
Red Deer 4	RD4	Dogrib burn	0612994/5723545	1494	985.61	196.59
Wildhorse 1	WH1	Dogrib burn	0614245/5724122	1478	23.49	3.90
Red Deer 5	RD5	Oil/gas/forestry	0631892/5722750	1338	2149.36	431.19
Burnt Timber 1	BT1	Oil/gas activity	0626912/5717026	1432	320.65	65.95
Red Deer 6	RD6	Campground	0648274/5730189	1215	2488.34	496.09
Bow River Basin						
Bow 1	BW1	Septic field	0536997/5725376	1950	18.44	1.62
Bow 2	BW2	Hostel	0545873/5719911	1828	161.14	24.57
Mosquito 1	MS1	Wilderness	0546523/5720096	1843	50.28	7.34
Bow 3	BW3	Lake Louise WWTP	0559524/5694442	1529	822.29	154.03
Pipestone 1	PS1	Wilderness	0557179/5697972	1530	304.18	54.51
Bow 4	BW4	Highway adjacent	0584698/5675137	1400	1646.41	310.15
Redearth 1	RE1	Lodge	0582877/5675285	1432	152.73	30.32
Bow 5	BW5	Highway adjacent	0593195/5669082	1382	1992.50	373.46
Healy 1	HY1	Ski resort	0591977/5667800	1456	236.90	45.05
Bow 6	BW6	Park boundary	0612044/5664958	1345	3919.42	750.47

Table 2.5. Data sets used in MESA project and their attributes.

Data Set Name	Source	Scale	Units	Projection	Format
National Topographic Database (NTDB)	NRCan	1:50 000	Decimal Degrees	Geographic	Vector
Updated Roads Network (URN)	NRCan	1:50 000	Decimal Degrees	Geographic	Vector
Canadian Digital Elevation Data (CDED)	NRCan	1:250 000	Decimal Degrees	Geographic	Raster
Dissemination Areas (DA)	StatsCan	1:50 000	Decimal Degrees	Geographic	Vector
Administration Boundaries	NRCan	1:50 000	Decimal Degrees	Geographic	Vector

Table 2.6. Land use and human activity themes in sequence of addition to the GIS.

	Theme	Definition	Size
1	NTS Limits	National Topographic System territorial limits	N/A
2	Park Boundaries	Boundaries of National Parks of Canada	N/A
3	Roads	Any useable road	N/A
4	Limited Use Roads	Road that is suitable for use only in a certain season (e.g. winter or dry season); or a cart track suitable for use only by an all-terrain vehicle	N/A
5	Bridges	Bridge for use by vehicles	> 5 m length
6	Railways	Operational railway	> 150 m length
7	Trails	Trail for use by persons or animals	N/A
8	Transmission Lines	Corridor for electric transmission lines	> 500 m length
9	Aerial Cableways	Device that carries skiers up a slope; or cable other than a ski lift	> 100 m length
10	Cutlines	Cleared corridor of vegetation for exploration or firebreak	> 500 m length
11	Pipelines	Above or underground pipeline	> 500 m length
12	Wells	A well for petroleum, or if for water to supply a municipality	N/A
13	Campsites	Established campsite	N/A
14	Small Buildings	Building for any use	< 30 m^2
15	Built Up Area	Urbanized or industrial areas	N/A
16	Vegetated Areas	Area of vegetation; if wooded area, at least 35% covered by trees or shrubs > 2 m in height	N/A
17	Wetlands	Bog, fen, marsh	N/A
18	Permanent Snow and Ice	Includes glaciers, ice caps, snow fields	N/A
19	Waterbodies	Lake, stream, river, flooded area	> 25 m width
20	Watercourses	Stream or river, < 25 m in width	> 500 m length
21	Toponyms	Place names used on paper maps	N/A

Table 2.7. Categories of land use, human activity, and watershed assimilation capacity used from the GIS in calculation of Cumulative Activity Indices.

Percent vegetation	Bridges	Waste water treatment plants
Percent wetland	Railways (km)	Roads (km)
Petroleum wells	Cutlines (km)	Area built up (ha)
Permanent population	Ski lifts (m)	Stream length at outlet (km)
Permanent backcountry camps	Trails (km)	

Table 2.8. Percentile ranking, cumulative activity points, and associated level of human activity.

Percentile	Cumulative Activity Points	Level of Human Activity
Human Activity and Land Use Categories		
0 - 25	1	Low or absent human activity in watershed
26 - 50	2	Moderate human activity in watershed
51 - 75	3	High level of human activity in watershed
76 - 100	4	Maximum level of human activity in watershed
Watershed Assimilation Capacity Categories		
0 - 25	4	Lowest assimilation capacity
26 - 50	3	Moderate assimilation capacity
51 - 75	2	High assimilation capacity
76 - 100	1	Maximum assimilation capacity

Table 2.9. Cumulative Activity Index scores and calculated z-scores for each watershed using Methods A and B.

Watershed	CAI Score (Method A)	CAI Score (Method B)	Z-Score (Method A)	Z-Score (Method B)
Tyrrell Creek 1 (TY1)	26	0.28	-1.11	-1.18
Red Deer River 2 (RD2)	27	0.323	-0.98	-1.13
Red Deer River 1 (RD1)	27	0.35	-0.98	-1.11
Mosquito Creek 1 (MS1)	30	1.68	-0.58	0.07
Healy Creek 1 (HY1)	29	1.65	-0.71	0.03
Redearth Creek 1 (RE1)	27	1.11	-0.98	-0.45
Red Deer River 3 (RD3)	32	0.53	-0.32	-0.96
Bighorn Creek 1 (BH1)	31	0.85	-0.45	-0.67
Bow River 1 (BW1)	33	1.27	-0.19	-0.30
Pipestone River 1 (PS1)	32	1.24	-0.32	-0.33
Bow River 2 (BW2)	36	1.29	0.20	-0.28
Red Deer River 4 (RD4)	35	0.69	0.07	-0.82
Wildhorse Creek 1 (WH1)	31	4.46	-0.45	2.53
Burnt Timber Creek 1 (BT1)	31	1.72	-0.45	0.10
Red Deer River 5 (RD5)	35	1.35	0.07	-0.23
Red Deer River 6 (RD6)	34	1.65	-0.06	0.04
Bow River 3 (BW3)	49	3.55	1.91	1.72
Bow River 6 (BW6)	47	2.30	1.65	0.61
Bow River 4 (BW4)	49	2.89	1.91	1.14
Bow River 5 (BW5)	48	2.99	1.78	1.23

Table 2.10. Categories of land use and human activity and their maximum values.

Category of Land Use or Development	Maximum Value	Maximum Normalized Value
Permanent Population	7797 persons	1.99 pers/km^2
Roads	556 km	0.30 km/km^2
Bridges	66	0.03 /km^2
Railway	124 km	0.05 km/km^2
Cutlines	545 km	0.81 km/km^2
Ski Lifts	41 543 m	50.06 m/km^2
Small Buildings	516	0.22 /km^2
Permanent Backcountry Camps	17	0.02 /km^2
Trails	1186 km	0.61 km/km^2
Sewage Treatment Plants	2	0.0012 /km^2
Built Up Area	156 ha	0.04 ha/km^2
Wells	40	0.09 /km^2

Table 2.11. Hypotheses and test statistics for Sign Test for Median Difference.

	Sign Test of M_{A-B}
n	20
N	6
α	0.10
H_o	$M_{A-B} \leq 0$
H_a	$M_{A-B} > 0$
P value	$P = [N \leq 6 \mid p = 0.5] = 0.0577$
Conclusion	Reject H_o

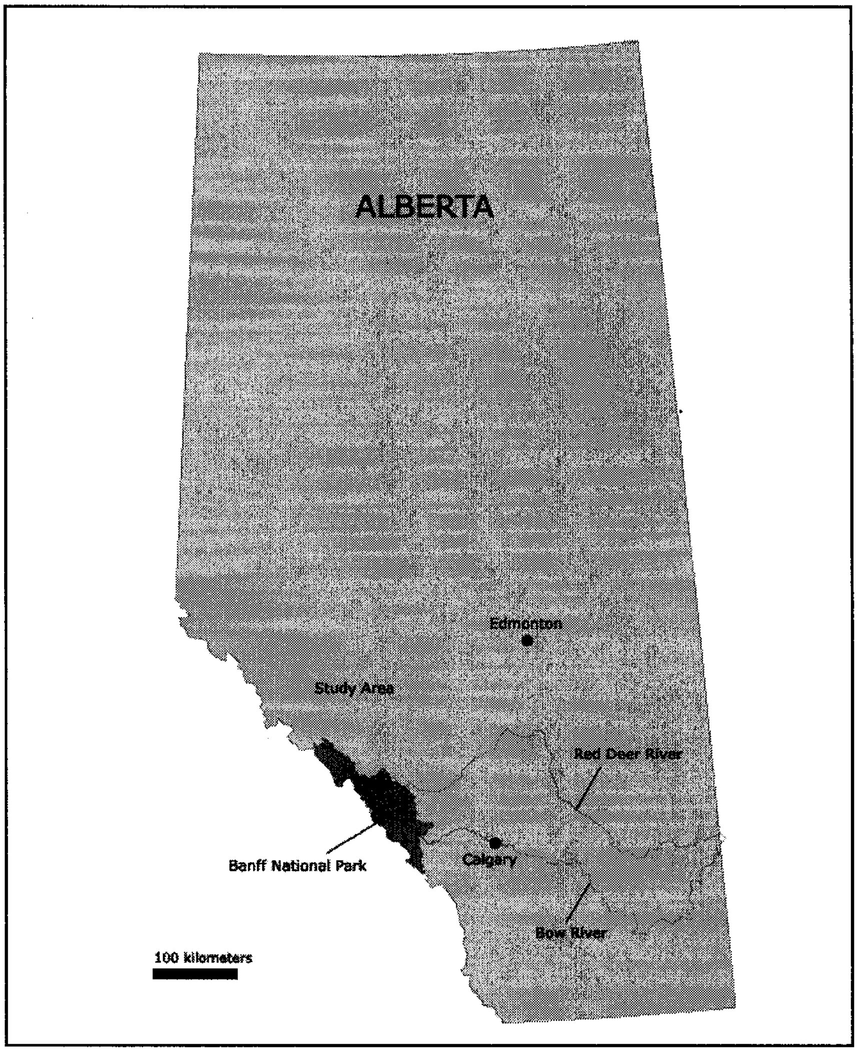

Figure 2.1. Map of the study area including Banff National Park boundaries and major cities.

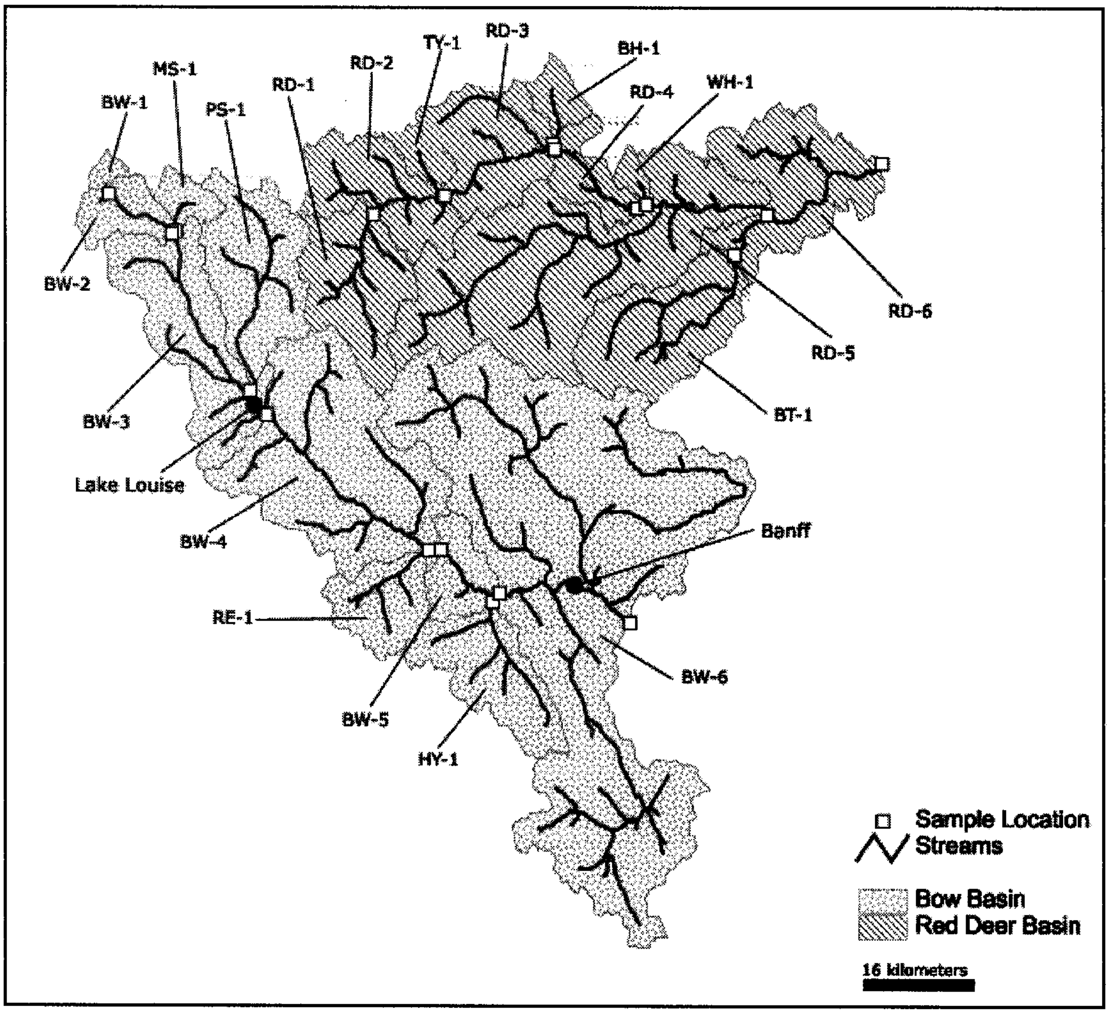

Figure 2.2. Location of sampling sites and extent of each watershed in the Red Deer and Bow River study basins.

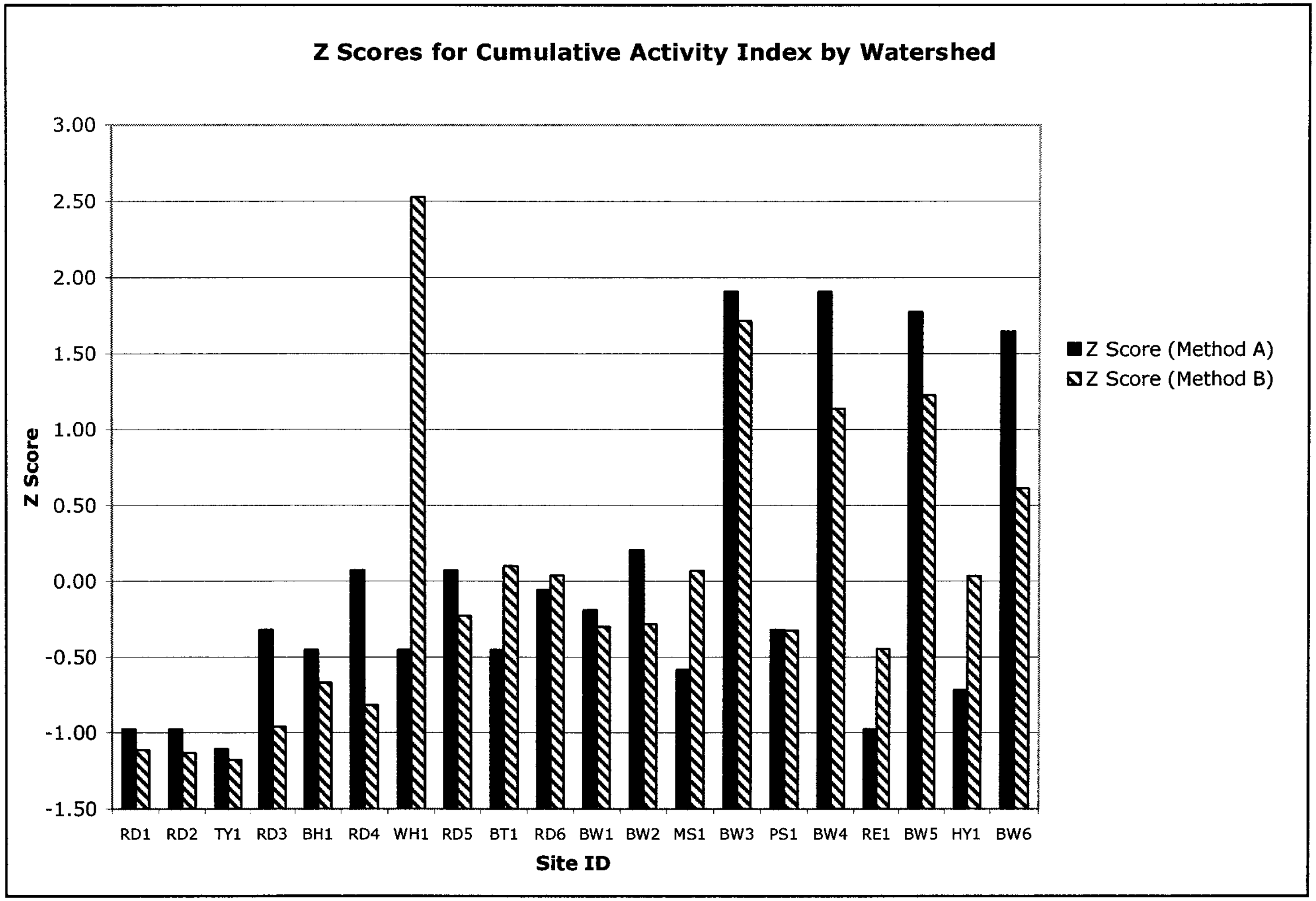

Figure 2.3. Plot of z-scores for each CAI calculation method by study site.

III. THE EFFICACY OF USING WATER CHEMISTRY AND BENTHIC MACROINVERTEBRATES AS INDICATORS OF CUMULATIVE ENVIRONMENTAL EFFECTS IN MOUNTAIN STREAMS

1.0 Introduction

1.1 Research Context

The assessment of cumulative environmental effects is a difficult but necessary component of environmental impact assessment (Ross 1994). The best approach for assessing cumulative effects is often debated; should environmental practitioners evaluate the effect of all projects in a region on all ecosystem components, or should they focus their efforts on one or two particularly sensitive components? This research evaluates the use of water quality as an indicator of cumulative effects in the Rocky Mountains and Foothills of Alberta, and attempts to provide direction to environmental practitioners regarding the response of water quality to watershed disturbance in this region.

The Bow and Red Deer Rivers originate in the Rocky Mountains in Banff National Park of Canada, and flow toward the cities of Calgary and Red Deer, Alberta, respectively. Their upper reaches flow through areas of wilderness with sporadic human development and through a diversity of landscapes. The variety of human activities that occur in the watersheds of these river systems, which otherwise possess similar natural characteristics, make these rivers an effective case study for investigating the cumulative effects of human activity on water quality.

The scientific literature regarding indicators of cumulative effects is sparse, particularly in mountainous regions. Studies of the impact of particular industries and activities on stream water quality have been completed (Wilhm and Dorris 1966, Hobbie and Likens 1973, Taylor and Roff 1986); however, the cumulative effect of human disturbance on water quality of mountain streams has not been thoroughly investigated. Some studies have considered only the general land use of a basin (Rothrock et al. 1998) and others have detected cumulative downstream change in water quality, but not in a mountainous area (Bolstad and Swank 1997). The response variables measured in previous research has varied; some studies focused on physicochemical and microbial parameters (Bolstad and

Swank 1997), while others used macroinvertebrate communities as a biological assessment (Rothrock et al. 1998). It is known that mountain areas are ecologically sensitive and that they provide an important source of water for areas downstream (Williams et al. 1993), as does the Bow River for Calgary. Understanding the relationship between cumulative human activity and water quality is a fundamental step in managing these important sources of water.

An index for quantifying the type and magnitude of cumulative environmental effects (named the Cumulative Activity Index or CAI) was created in Chapter 2. The CAI categorized continuous land use and human disturbance data obtained from a geographic information system (GIS) and used that information to assign a score of watershed disturbance to each of the study watersheds. The CAI scores were used as predictor variables for water quality in this research.

In this research several water quality parameters were measured in the Bow and Red Deer River basins including basic chemistry, nutrient and trace metal concentrations, and benthic macroinvertebrate community structure. To meet the study objectives those water quality parameters were then compared with the CAI scores to learn if a relationship existed.

1.2 Research Objectives

The objectives of the study were to:

1. Quantify water quality in the Bow and Red Deer Rivers and selected tributaries using benthic macroinvertebrate metrics and water chemical properties as indicators.
2. Examine annual, seasonal, and site to site trends in water quality in the study basins.
3. Compare changes in water quality with the type and magnitude of land use change in the drainage basins.
4. Evaluate the use of water quality as an indicator of cumulative environmental effects in mountainous areas of Alberta.

2.0 Materials and Methods

2.1 Study Area

The Bow and Red Deer Rivers originate in the Rocky Mountains of Alberta within the boundaries of Banff National Park of Canada. The Bow River flows south through the national park through the towns of Lake Louise, Banff, and Canmore, Alberta before reaching the city of Calgary where it is the primary source of municipal water. The Red Deer River flows east through Banff National Park and exits the park in the shadow of Warden Rock after approximately thirty five kilometers and continues through the town of Sundre toward Red Deer, Alberta (Figure 2.1). These two river systems were chosen as a case study because they both have headwaters in a national park, they travel through similar landscapes, and are underlain by similar regional geology; the two rivers have many natural characteristics in common. The Bow and Red Deer valleys, however, experience different types and intensities of human activity. Since one objective of this research is to compare changes in water quality with land use changes, two river systems with similar natural features and different human uses were chosen. Further details regarding the ecology and human activities in the study area may be found in Chapter 1.

2.2 Site Selection

Twenty sample sites were selected, six on each of the principal rivers (Bow and Red Deer) and one at the outlet of each of four tributaries on the two principal rivers (Figure 2.2). The sampling site on each of the principal rivers located nearest the source was intended as a reference site with which to compare the others within that drainage basin. Sampling sites on the Bow River ranged in elevation from 1345 to 1950 m ASL and from 1215 to 1798 m ASL on the Red Deer (Table 2.4).

The tributary watershed sample sites were selected to represent a range of watershed sizes and dominant land uses. The tributary sample sites were paired with sample sites on the main stream to determine if the tributary was contributing contaminants to the main stream and if the main stream was diluting the effects of tributary inlets. Location of sites was constrained to the upper reaches of both the Red Deer and Bow Rivers to be consistent with the objective of investigating CEA indicators in mountainous areas of Alberta.

For the purposes of data analysis the sampling in the Bow River and the Red Deer River basins were considered independently. One basin was not used as a reference or control for the other, although trends observed in the separate systems were compared.

2.3 Parameter Selection

2.3.1 Cumulative Activity Scores

Two indices of cumulative environmental effects, CAI-A and CAI-B, were created in previous research to quantify human activity and disturbance assimilation capacity within each study watershed (Chapter 2). Spatial analysis data created from National Topographic Database (NTDB) information and analyzed in ArcView (ESRI 2002) were used in the creation of each index; eleven land use variables were incorporated in the CAIs (Table 2.7). The CAI scores for each site are cumulative and include enumeration of all area in the study basin upstream from that sampling site. For example, Bow River 6 is the furthest site downstream on the Bow River and its land use values represent the activities occurring in the entire Bow basin upstream from that point.

As the index scores calculated using Index B were very small values, the scores reported are multiplied by 1000. The scores are relative to each other only so this magnification has no effect on the presentation or interpretation of results. The scores calculated using CAI-A and CAI-B were used as the independent variable representing watershed disturbance with which to compare the water chemistry and benthic macroinvertebrate metric data collected in the field.

2.3.2 Water Chemistry

Various water chemistry variables were measured including basic parameters and ions, trace extractable metals, nutrients, and field measurements (Table 3.1).

Basic water chemistry parameters measured included pH, hardness, alkalinity, conductivity, and common ions. These parameters provide a basic characterization of water quality indicating acidity, neutralization capacity, and salinity. Concentrations of common ions (Ca^{++}, Mg^{++}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, NO_3^{-}, HCO_3^{-}) are highly variable in surface and ground waters due to geological, climatic, and geographical conditions (Chapman and Kimstach 1996). Increased sodium concentration may be indicative of sewage or industrial effluent input to the stream, or of road salt use within the watershed. Potassium is used in fertilizers, and may enter surface waters from industrial or agricultural runoff. Chlorine is usually present in solution as chloride ions, and is produced by all the previously listed sources. Sulfate is present in surface and ground waters as a result of weathering of subsurface lithological units or because of industrial discharge.

Nutrient concentrations (TP, SRP, TKN, NH_4^{+}, NO_3^{-} + NO_3^{-}) were measured to provide an indication of organic pollution. Mountain streams are naturally nutrient-poor and nutrient concentrations above background levels are often attributed to human activity. Phosphorus contributed to the Bow River by the Lake Louise and Banff townsites is largely biologically available and thus is a concern in relation to eutrophication and excessive algal growth (Schindler 2000).

Trace amounts of metals (Al, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Zn) are usually present in surface and ground waters as a result of geological weathering (Chapman and Kimstach 1996). These metals have a natural wide range of concentration (0.1 to 0.001 μg/L), and may increase because of human activities including industry, pesticides, and fertilizers (McNeely 1979). Increased metal concentrations can be toxic to some aquatic organisms, and metals may also bioaccumulate in higher animals (e.g., fish).

2.3.3 Benthic Macroinvertebrates

The abundance and composition of aquatic faunal communities is a useful indicator of river health and biotic integrity (Karr 1981, Harris and Silveira 1999). Benthic macroinvertebrates in particular are used as key indicators of stream water quality (Hynes 1960, Weber 1973 cited in Rothrock et al. 1998). Benthic macroinvertebrates are used as indicators of water quality because they have life spans of up to three years and have limited mobility for most of that time. Therefore, the aquatic environment influences these organisms to a significant degree for much of their life. Macroinvertebrates are influenced by variation in streamflow, physical attributes of the stream such as sediment load and habitat structure, and chemicals including nutrients and pollutants (Rothrock et al. 1998). Macroinvertebrate populations represent "near-term" variation in the quantity and quality of the water in which they live (Plafkin et al. 1989).

Benthic macroinvertebrate samples were classified to the taxonomic level of Family and several variable metrics were calculated (Table 3.2). The key to using benthic macroinvertebrates as an indicator of water quality is to describe the abundance and composition of the populations being sampled. Macroinvertebrates respond differently to different types of environmental stress, and hence the use of several metrics will increase the reliability and sensitivity of the observations.

2.4 Sampling Methods

2.4.1 Water Chemistry

Water chemistry was sampled at each site once in 2002 and once in 2003. The Red Deer basin was sampled in fall 2002 and spring 2003 while the Bow basin was sampled in fall 2002 and fall 2003. One water sample per sampling occasion was deemed sufficient as the rivers being sampled were fast flowing and well mixed, and it was thought that one sample would provide a representative view of the rivers' chemical properties at each site.

A grab sample was collected in bottles provided by the laboratories and was taken from swiftly flowing stream water approximately 1 m from shore and at a depth of 10 cm. EnviroTest Laboratories (ETL) provided three bottles, one each for the routine ion analyses, nutrient analyses, and trace extractable metal analyses. The University of Alberta Limnology Laboratory (Limno Lab) provided one bottle for sample collection. All bottles were rinsed three times with stream water before collecting the sample and the sampler wore latex or nitrile gloves to prevent contamination. Samples were collected working downstream to upstream to prevent disturbing the substrate and therefore contaminating the sample.

The sample bottles were of various sizes and materials and some samples were preserved for storage and transport (Table 3.3). Acid preservative was added to the water samples as per laboratory instructions to prevent degradation of the sample. All samples were kept cool (approximately 4° C) and delivered to the lab within five days.

Water was analyzed at EnviroTest Laboratories in Edmonton, Alberta and at the University of Alberta Limnology Laboratory in Edmonton, Alberta; not all analyses were completed at both facilities. At a level of detection of 0.02 mg/L in the 2002 samples total Kjeldahl nitrogen (TKN) and total phosphorus (TP) were not detected by the ETL analyses, except for very few outlying results. The levels of detection of the analysis methods were not sensitive enough to detect nutrients at the low concentrations normally found in mountain streams. The methods of analysis were modified for the 2003 sampling and a different facility (Limno Lab) was used to detect nutrients (TKN, TP, SRP, NH_4^+, NO_2+NO_3) at a 1 μg/L level of detection for TP, SRP, NH_4^+, and NO_2+NO_3 and 20 μg/L for TKN. The increased sensitivity enabled detection of nutrient parameters and is recommended for future work in this region. Standard analytical methods were employed at the labs and are listed in Appendix C.

2.4.2 Benthic Macroinvertebrates

Benthic invertebrates were sampled at the same time as water chemistry. The Bow basin sites were not sampled at the same time as the Red Deer basin sites as the stream channel cross-section and flood hydrograph do not permit safe or effective sampling on the Bow River at times of high discharge. The river in many places has steep banks, and therefore high discharge results in a sharp drop off into fast-moving water greater than 50 cm in depth. This fast moving deep water renders the BMI sampling equipment ineffective and is a danger to researchers.

Effective BMI sampling on the Bow River and its tributaries can only take place when the streams are ice free and are flowing at less than 60% of peak discharge; these conditions usually occur in late summer or early autumn. The Red Deer River, in contrast, generally has a shallow-sloped cross section and increased discharge floods a greater area of the gravel flood plain; while the water is quickly moving, it is not deeper than 30 cm and sampling is possible during high discharge. The Red Deer River can be sampled for BMIs whenever it is ice free, generally from May to November.

Three quantitative macroinvertebrate samples were taken at each site in each year. Preliminary work indicated that three samples were sufficient to capture the faunal diversity at each site; few or no new taxa were identified with more than three samples. Several macroinvertebrate samples were collected in spring 2002; five samples were collected at each of three sites and classified in the lab. It became apparent during classification and when the number of species versus area sampled relationship was plotted that three samples were sufficient to capture most of the macroinvertebrate community diversity.

A number of methods exist for the assessment of stream benthic macroinvertebrate communities. Some methods recommend field sampling and then processing the collected samples in a laboratory; these methods usually advise classifying organisms to the genus or species level (Hilsenhoff 1987). Other researchers have found that the time and expertise required to complete species level assessment of benthic invertebrate communities is not proportional to the increase in information obtained, and that rapid field assessments are appropriate. This is particularly true for situations when a rapid assessment is required for use by non-specialized environmental practitioners (Hilsenhoff 1988), which is an objective of this research. The US Environmental Protection Agency (USEPA) has published the most comprehensive reference for rapid bioassessment of streams, including periphyton, benthic macroinvertebrates, and fish (Barbour et al. 1999). Rapid bioassessment of streams has become a common method of quickly and cheaply determining the degree of impairment of streams, and was the method employed in this work. Rapid bioassessment was chosen for the practical reason of making the results of this research accessible to non-specialist environmental practitioners.

Benthic macroinvertebrate (BMI) samples were taken at each site. A Surber sampler was used for collection and had an area of 0.1 m^2. Each of three BMI samples was a composite of two applications of the Surber sampler. BMI samples were taken from the stream bed at a place where the flow velocity was approximately 0.5 m/s and the water depth was 10 to 30 cm. Samples were collected working downstream to upstream to prevent disturbing the substrate and therefore biasing the sample.

When sampling, the Surber sampler was placed in the current and pressed into the substrate. All rocks within the sampler's frame were rubbed to dislodge any organisms clinging to the rocks, and then the substrate was stirred for 20 seconds using a sturdy metal rod. The water was allowed to clear for 20 seconds after stirring. This process was repeated in another location upstream for each of three samples.

Once the invertebrates were collected, the net of the Surber sampler was turned inside out and the contents of the sampler were washed with water into a pan using a wash bottle. Organisms were picked from the pan for 15 minutes and placed in a sample cup. Since some samples contained a large amount of nearly microscopic and impossible to identify young organisms, the 15 minute time limit was established. Otherwise, the researchers could spend significant time picking organisms that could not be identified in the lab with the microscopy equipment available and achieve no significant gain in data. The objective of this research was to evaluate a practical method of water quality quantification, not to perform a complete BMI census. When picking was complete the sample was preserved in 90% isopropyl alcohol and water to an alcohol concentration of approximately 70%.

Identification and counting of BMIs in the lab began with the alcohol preservative being decanted from the sample cup. All organisms were placed in a gridded tray in case subsampling was necessary. At this time all BMIs were sorted into Order groups to facilitate identification, and then group by group, the organisms were identified to Family level. A stereomicroscope (ten times magnification) was used to aid in the identification of small structures. When necessary dichotomous keys were also used to aid in identification (Merritt and Cummins 1996, Clifford 1991). Upon identification, organisms were replaced in the sample container and preserved in fresh alcohol.

2.5 Data Quality Control

Standard and consistent sampling procedures were followed when collecting water and BMI samples. Laboratory identification of BMI samples was completed by the author and identifications were confirmed by an independent consultant. Both laboratories used for water analyses were accredited and employed standard methods of analysis. Blank samples of deionized water were submitted for analysis, unknown to the operator, for quality assurance. EnviroTest Laboratories provided quality assurance and quality control reports with all test results.

2.6 Statistical Analyses

Descriptive statistics were first calculated for the observed data using the Statistical Analysis Software (SAS) "proc univariate" command; as most of the variables exhibited non-normal distributions, further statistical analyses were limited to procedures that did not assume data were distributed normally. The most effective analysis to meet the study objectives was the calculation of Spearman's correlation coefficients for pairs of variables of interest.

Spearman's correlation coefficient is calculated as a function of the ranks of a paired set of data, and is interpreted in a similar fashion to other measures of correlation. Values near 1 indicate a strong positive correlation, values near -1 indicate a strong negative correlation, and values about 0 are indicative of no correlation between variables (Milton 1992). The Spearman coefficient (r_s) can be squared to approximate the value of r^2. The Spearman method is not appropriate to use to measure correlation when there is a large number of tied rankings (Milton 1992).

Spearman's correlation coefficients were calculated using the SAS "proc corr" command. Correlations were declared significant at α=0.10. Alpha was set at

0.10 as this is preliminary research and at this point the benefit of detecting a significant difference in means is greater than the cost of drawing a false conclusion. As work continues it would be appropriate to reduce the acceptable probability of Type I error (or alpha value) to increase confidence in the findings (Warren 1986).

3.0 Results and Discussion

3.1 Land Use Evaluation

The watersheds studied varied in size and distance from the source to the sampling point. The watersheds were approximately 50% covered by vegetation (Table 3.4). Some watersheds had very little human activity, while others were significantly developed (Table 3.5). All categories of human use measured in the GIS had a minimum value of zero except for "kilometers of trails". Since the majority of the watersheds are contained entirely within Banff National Park, instances of no measured human activity were expected as such activity is restricted by law in the national park. The rank of each watershed according to CAI score is presented in Table 3.6. The rankings using the two methods were different.

Because of the cumulative nature of the land use variables (each site includes all upstream watersheds in addition to itself), the raw results of human activity generally increased for sites further downstream. When normalized by area, however, the variables did not necessarily increase because some downstream watersheds may have had raw values of zero in some categories. For example, watershed BW-3 had 0.0012 waste water treatment plants per km^2 (WWTP). The next two watersheds contributing to the variable (WWTP) are RE-1 and BW-4, which had no treatment plants but did add area to the denominator in the calculation. Therefore, the value for waste water treatment plants at BW-4 dropped to 0.0006 km^{-2}. This characteristic of the data set is important when comparing Cumulative Activity Index scores with water quality data.

When compared to the water quality data for each study basin by year of sampling, CAI-A had 26 statistically significant correlations and CAI-B had 25

(α=0.10). This indicates they are comparable in their ability to predict water quality parameters based on their calculation of amounts of human activity and watershed development. CAI-A, however, upon comparison with observed field conditions better represented the characteristics of the watersheds.

3.2 Water Chemistry

The pH of sampled water in both study basins was consistently slightly basic with a range of 8.10 to 8.38. Conductivity dropped in the Red Deer basin from 2002 to 2003, while it was stable in the Bow basin (Table 3.7).

Water chemistry parameters measured in both years from the Bow basin sites were similar from year to year. As sampling took place at the same time each year and discharge was similar, equal results for chemical parameters were expected. However, a distinct change was observed in chemical parameters in the Red Deer basin from year to year. The pH and water temperature were higher in 2003 (spring) than in 2002 (fall) (Figures 3.1, 3.2). All other chemical parameters (conductivity, TDS, hardness, SO_4^{2-}) were lower for all sites in spring 2003 compared to fall 2002 (Figures 3.3, 3.4, 3.5, 3.6). This decrease may be explained by the large increase in discharge in 2003 due to spring runoff, which diluted the ions and trace metals. Much of the runoff in the mountains and foothills originates from snowmelt. The parameters that decreased in concentration are sourced primarily from ground water discharge (Drever 1997), and would be diluted by the relatively ion-poor snowmelt.

Observed nutrient levels were significantly greater in the spring of 2003 in the Red Deer basin compared to the fall of 2003 in the Bow basin. Ammonium concentration averaged 5.26 µg/L in the Red Deer basin and 2.70 µg/L in the Bow basin (Figures 3.7, 3.8). Nitrate + nitrite averaged 113.33 µg/L in the Red Deer basin and 20.58 µg/L in the Bow basin (Figures 3.9, 3.10). Total Kjeldahl nitrogen had a mean value of 194.65 µg/L in the Red Deer basin and 152.68 µg/L in the Bow basin (Figures 3.11, 3.12). Phosphorus concentrations were also higher in the Red Deer basin in spring 2003 compared to the fall in the Bow basin. Soluble reactive phosphorus had a mean concentration of 2.32 µg/L in the Red Deer basin and 1.40 µg/L in the Bow basin (Figures 3.13, 3.14). Total phosphorus concentration averaged 22.67 μg/L in the Red Deer basin and 4.55 μg/L in the Bow basin (Figures 3.15, 3.16).

Elevated stream water nutrient concentrations are associated with spring runoff because of increased solute delivery to the stream channel; nutrient concentrations also increase after wildfire (Tiedemann et al. 1978, Spencer and Hauer 1991). A portion of the Red Deer basin including watersheds RD-3, RD-4, and WH-1 burned in the Dogrib wildfire of 2002, and spring 2003 was the first melt runoff since the fire. Elevated nutrient levels in these watersheds and those downstream may be affected by this post wildfire nutrient flush in addition to normal spring melt nutrient pulses.

Turbidity was also higher in the Red Deer basin in spring 2003 (average 9.53 NTU) than in the fall in the Bow basin (average 1.50 NTU), which supports the postulation of a spring melt nutrient pulse. Turbidity is a proxy measure of the sediment load in the water column. Nutrients dissolved in stream water are primarily sourced from surface runoff and since suspended load concentration in rivers is greatest during periods of high runoff (Trenhaile 1998), turbidity may be associated with elevated nutrient levels. Site RD-4, which is immediately downstream of the Dogrib burn area, exhibited the greatest turbidity at 32.00 NTU as well as the highest TP concentration at 58.10 μg/L.

Other unusually high nutrient concentrations, when compared with the rest of the study sites, may be influenced by activities immediately adjacent to the sampling site. BH-1, at which the highest NH_4^+ and SRP concentration were observed (10.82 μg/L and 5.10 μg/L, respectively) is located near the waste manure dump at the Bighorn Campground on the Ya Ha Tinda ranch. Nutrient species, including phosphorus and ammonium, are associated with animal manure, and this site experiences heavy visitation by trail riding groups; during summer sampling several dozen horses were observed at the campground. The manure dump may be contributing nutrients to the stream via overland flow or groundwater.

3.3 Benthic Macroinvertebrate Metrics

Abundance and number of taxa dropped in the Red Deer basin from 2002 to 2003, but were stable in the Bow basin (Figures 3.17, 3.18). The percentage of communities composed of Ephemeroptera, Plecoptera, and Trichoptera taxa was less in the Bow basin than the Red Deer basin at both times of sampling (Figures 3.19, 3.20); the percentage composed of Chironomidae was greater in the Bow basin than the Red Deer basin in both years (Figures 3.21, 3.22).

Hilsenhoff Biotic Index (HBI) values ranged from 2.41 at WH-1 and BW-1 to 6.58 at BW-3 in 2003. In 2003 HBI values ranged from 2.03 at BW-6 to 6.69 at BW-3. (Figures 3.23, 3.24)

The total abundance of BMIs in the Red Deer basin was lower in spring 2003 than in fall 2002. This decline in abundance is likely due to time of year; fewer organisms would be expected in spring compared to fall. The life history of BMIs is dependent on the principle of degree days, i.e. the product of a number of days multiplied by the mean temperature of those days. The same time period at a higher temperature will have a greater number of degree days, and hence more rapid maturation of aquatic invertebrates. Several generations of BMIs would have emerged by fall because of warm summer temperatures, while in the spring the mean temperature was cooler and fewer generations would have reproduced, resulting in a lower mean abundance.

The total number of taxa in the Red Deer basin was also smaller in spring 2003. This is not easily explained; however, only the hardier taxa may have survived the winter and been able to reproduce immediately upon ice break up in spring. The number of taxa may have been greater in fall because the warm summer days provided the opportunity for a diverse community to develop.

Since the Bow basin sites were sampled in the same season in both years there was no consistent difference in BMI metrics for all sites from year to year. This observation supports the conclusion that the year to year variation in metrics measured in the Red Deer basin is rooted in seasonal changes in environmental conditions.

The Red Deer basin exhibited no distinct trend in between site variation within sample years. The BMI communities at most sites at most times of sampling were representative of good water quality according to the metrics employed. Two exceptions, however, are noted. The percentage of Ephemeroptera taxa at RD-1 dropped from 0.83 to 0.47 from 2002 to 2003, although the total percentage of Ephemeroptera, Plecoptera, and Trichoptera taxa remained large at 1.00 in 2002 and 0.92 in 2003. This indicates the reduction in Ephemeroptera in 2003 was replaced with Plecoptera and Trichoptera, which are also generally pollution intolerant. Although the cause of this change in community structure is unknown, it does not indicate a significant deterioration in water quality at this site as the community remained composed of pollution-intolerant taxa.

The other notable anomaly in the Red Deer basin is the jump in percentage of Ephemeroptera taxa at WH-1 from 2002 to 2003. Again, this change in the proportion of Ephemeropterans is not accompanied by a change in the total proportion of Ephemeroptera, Plecoptera, and Trichoptera taxa. This indicates a slight improvement in water quality from 2002 to 2003. Since the land use in the watershed did not change dramatically in this time period the change could be explained by the effect of the Dogrib wildfire of 2002. When sampling in September 2002 a large amount of charcoal was observed in stream sediment, and none was observed by spring 2003. Although further investigation is necessary to pursue this explanation, the presence of charcoal in the stream was the only noticeable change in conditions that could explain a change in BMI community structure.

At two sites on the Bow River (BW-1 and BW-3) significant amounts of periphyton were observed in 2002 and 2003, and an unidentified fibrous substrate cover was observed at BW-3 in both years. Both of these sites are associated with point sources of nutrient input; at BW-1 a septic field for a lodge operation is located adjacent the river and BW-3 is positioned within 1 km downstream of the Lake Louise waste water treatment plant. The proportion of the community composed of Ephemeroptera taxa at both of these sites was lower than at any other in 2002 and 2003. The proportion of Ephemeroptera, Plecoptera, and Trichoptera taxa was also relatively smaller at BW-1 in 2003 and

BW-3 in both years, and the proportion of chironomid taxa was greatest at these sites in 2003. No nutrient concentration measured in 2002 or 2003 was graded more poorly than "fair" using the Bowman scale at these sites. The septic field at BW-1 was installed in 1996 and the degradation in water quality observed in 2003 may indicate that the waste plume from this field is more closely approaching the stream's hyporehic zone. This indicates that although point sources of nutrient addition may not be sufficient to dramatically alter nutrient concentration in the stream, the influence of point source nutrient addition will change BMI community composition. Therefore, very small additions of nutrients can change the ecological structure of benthic communities.

The total abundance at sites BW-4 and BW-5 increased over the sampling period, and the proportion of the community composed of Ephemeroptera decreased at BW-5 during the same period. Substrate covering similar to the unidentified material at BW-3, not seen in 2002, was observed at both of these sites in 2003. The substantial degradation in water quality as indicated by BMI community composition at BW-3 may be affecting these downstream sites as well.

BW-6 experienced a reduction in percentage of Chironomidae, an increase in percentage of EPT taxa, an increase in percentage of Ephemeroptera, and a decrease in total abundance during the sampling period. This change in community structure generally indicates an improvement in water quality in the form of a reduction in nutrient concentration.

The calculated HBI values were distributed as expected. The sites that exhibited the greatest signs of ecological impairment scored high on the HBI, and those that exhibited conditions of good water quality scored low. The HBI was moderately correlated with total phosphorus concentration which supports Schindler's (2000) postulation that rivers in Banff National Park are phosphorus-limited. HBI values increased for most watersheds in the Red Deer basin from fall 2002 to spring 2003. This is in concordance with the increased nutrient concentrations observed in the Red Deer basin in 2003, possibly due to a spring runoff nutrient pulse.

3.4 Bowman Ecological Integrity Scores

For the variables also assessed and assigned ranges of values with corresponding ecological integrity ratings and numerical scores by Bowman (2002), those ratings were calculated (Table 3.8). The Redearth Creek watershed had a perfect ecological integrity score of 24 with a rating of "good" for all variables, while watershed BW-3 had the lowest ecological integrity score of 17 with ratings from "good" to "very poor".

3.5 Statistical Analyses Results

Most variables were not normally distributed and violated other assumptions of parametric tests. The Spearman's correlation coefficients are reported for all parameters that had statistically significant correlation (α=0.10). "N/S" represents pairs of variables that did not have significant correlation.

In 2002 in the Red Deer River study basin Fe^{2+}, Sr, conductivity, total dissolved solids, Ca^{2+}, and SO_4^{2-} were significantly correlated with index A, index B, or both (Table 3.9). No invertebrate metrics had significant correlations with CAI indices. Mg^{2+} was also significantly correlated with CAI-A in 2003 in the Red Deer basin, in addition to the same parameters as 2002 (Table 3.10). In 2003 nutrients, turbidity, and common ions were also analyzed and a number of these parameters exhibited significant correlation with the indices.

In 2002 in the Bow River study basin only Fe^{2+} and Sr were correlated with either of the cumulative activity indices (Table 3.11). None of the invertebrate metrics had significant correlation with the CAI in the Bow basin in 2002. In 2003 the Bow basin only saw correlation in ETL variables Fe^{2+} and Sr. As analyzed by the Limno Lab, Cl^-, Na^+, turbidity, NH_4^+, and total phosphorus exhibited significant correlation with at least one of the indices as calculated by Spearman's method (Table 3.12).

HBI values were not correlated significantly with either CAI index in 2002 or 2003. The HBI was, however, moderately correlated with total phosphorus in the Red Deer and Bow basins in 2003 (r= 0.51 in both cases). Spearman correlation coefficients (α=0.10) indicate non-significant weak negative correlation between the Bowman ecological integrity scores and CAI-A and CAI-B in the Red Deer Basin (r= -0.05 and -0.21 respectively) and significant negative correlation with CAI-A and CAI-B in the Bow basin (r= -0.64 and -0.59).

3.6 General Interpretation of Results

In general, the expected response of water chemistry to watershed disturbance was not observed. Nutrient concentrations were analyzed at a very sensitive level of detection, and except for a few instances, were within acceptable amounts for mountain streams and rivers. At some sites, however, a greater amount of biological activity was qualitatively noted (e.g. increased periphyton, greater BMI total abundance) and recent work (Bowman 2002) has indicated that additions of nutrients may become locked up in biomass and therefore not detected by chemical analysis of water. No guidelines exist in Alberta for assessing water quality using biomass (e.g. periphyton abundance), however the Government of British Columbia has recently begun to develop guidelines for monitoring mountain stream water quality using chlorophyll *a* concentration as an indicator of algae (MWLAP 2001).

The correlations observed between water chemistry and the Cumulative Activity Indices do not indicate suitability of the CAIs for use as a tool to estimate and predict cumulative environmental effects. The water chemistry parameters that correlated with the CAIs were parameters not commonly associated with human activity; however, these parameters normally change as a function of distance from a river's source. For example, hardness and alkalinity may increase away from a river's source in areas of carbonaceous geology (like the study area) as a result of weathered minerals and associated solutes being delivered to the stream by groundwater and surface runoff (Drever 1997). The CAI scores may have increased downstream because those areas of the study basins were more easily accessed by people, and hence had greater amounts of disturbance, resulting in the correlation. If the correlations had also been observed in parameters directly and uniquely linked to human activity (e.g. heavy metals used in industry, nutrient concentration), then the CAIs could be used in the assessment of cumulative effects.

BMI community structure appeared to respond dramatically to localized sources of pollution, but not to disturbance at the watershed scale. At sites located immediately adjacent to sources of pollution large changes in community structure were observed, most notably the increase in proportion of Chironomidae as a function of nutrient-contributing activity. This conclusion does not, however, mean that small changes in these communities are not occurring. It is possible that the BMI communities are approaching a critical threshold after which cumulative disturbance will be easily observed in community structure.

3.7 Critical Assimilation Threshold

The absence of elevated nutrient concentrations at most sampling points indicates that a critical threshold after which the ecosystem cannot assimilate additions has not been reached; the same is true for BMI community structure metrics in most watersheds. The important point is that greater than normal nutrient concentrations were measured at some sites, and BMI communities indicative of unhealthy environmental conditions were also observed in some watersheds.

The existence of evidence of ecosystem disturbance such as algal accumulation on the stream bed, although upon a slim minority of sampling occasions, indicates the accumulation of environmental stress within the system. The critical threshold of disturbance magnitude is being reached at some locations at particular points in time; the Bow River exhibits biological signs of stress below the Lake Louise waste water treatment plant (BW-3) and the Red Deer River exhibits chemical indications of stress below the Dogrib wildfire area (RD-4). These mesoscale manifestations of watershed disturbance introduce the possibility that similar macroscale (i.e. basin wide) disturbances are occurring but have not yet reached a magnitude at which we are prepared to measure them with traditional methods.

3.8 Recommendations for Future Experimental Design and Methods

Upon reflection, changes in experimental design and methods could be made to further research to improve the efficiency, efficacy, and predictive ability of the research. Ideally, both study basins would be sampled at the same point in the year to generate parallel sampling design to facilitate interpretation. A certain amount of ingenuity and exploration of sites would be necessary to permit sampling the Bow River and its tributaries during high discharge in spring. However, the existence of two data sets collected in a parallel nature would aid in the analysis and interpretation of the results.

Although expensive, collection of water samples using an automatic composite sampler would make the water chemistry analyses more meaningful. The discharge of mountain streams varies over the course of a day, and hence so does their ion, nutrient, and other contaminant concentration. A composite water sample collected over a longer time period (e.g. 7 to 10 days) would provide a better picture of the average concentration of water quality parameters (Canter 1985) The addition of hydrocarbon analyses to the suite of water chemistry parameters would be useful to better detect the impacts of human activity because natural amounts of hydrocarbon in stream water are virtually undetectable (McNeely 1979). Any hydrocarbons detected would indicate a human-caused impact on the watershed. Such analyses are often prohibitively expensive, but this information may render the Cumulative Activity Indices more effective in assessing cumulative disturbance in these watersheds.

The level of taxonomic resolution used in BMI identification could be increased to genus or species level to provide a finer level of detail in community evaluation. For this study, however, the level of family was used as one of the objectives was to evaluate a method of cumulative effects assessment that would be practical for use by environmental practitioners. Family level BMI identification is possible by most people with a biological background; genus or species level identification requires specialized skills and the work of technicians dedicated to entomological taxonomy. Such identifications are time consuming and costly, while family level identification can be performed in the field by skilled general biologists.

The last recommendation for improving the methods and results in future work is to evaluate watershed disturbance at a finer scale using GIS. As smaller scale digital information becomes available it will become easier to complete this type of work. Using current resources, digitized airphotos and on-the-ground locating of disturbances would improve the resolution of the land use evaluation. Such an undertaking, however, would become a research project of its own.

3.9 Future Research and Management Recommendations

The next logical step to continue this research is to pursue discovery of the critical threshold at which large nutrient-poor watersheds cannot assimilate further human disturbance and exhibit significant signs of stress. This approach would be strengthened by incorporating the previously mentioned techniques for improving the already completed work.

Managers within and outside Banff National Park should continue the chemical and biological monitoring at the sample sites. This work provides a solid baseline from which to monitor ecological change in these basins, and with the observation of some signs of stress, further observation is imperative. In particular, the sites currently exhibiting signs of stress should be regularly examined and management actions should be taken to mitigate the associated sources of disturbance.

Geographic information systems are a powerful tool in assessing watershed disturbance as demonstrated by this work. Ecosystem managers should employ this method of disturbance assessment to select other locations within the basins at which to further monitor ecosystem health. Those watersheds with the greatest amount of disturbance and lowest assimilation capacity should be identified as priorities for monitoring.

4.0 Conclusions

Benthic macroinvertebrate community metrics were not significantly correlated with calculated indices of cumulative activity in the Bow and Red Deer River basins. Several water chemistry parameters were correlated with the cumulative activity indices, although association with human activity within the watersheds was not clear. There is evidence that a critical threshold may exist beyond which the study basins will manifest cumulative environmental disturbance, although at most sampling sites that threshold has not yet been reached. It is imperative that ecosystem managers continue to monitor the effects of human activity on the study basins both within and outside Banff National Park, make efforts to mitigate the existing disturbance, and prevent future disturbances.

5.0 References

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Table 3.1. Water chemistry variables analyzed at Enviro Test Labs and the University of Alberta Limnology Lab.

	Enviro Test Labs	University Limnology Lab
Basic parameters and ions	pH, conductivity, HCO_3, CO_3, OH, alkalinity, ion balance, TDS, hardness, Ca, K, Mg, Na, SO_4, Fe, Mn, Cl	pH, conductivity, HCO_3, CO_3, alkalinity, Ca, K, Mg, Na, SO_4, Cl, turbidity
Trace extractable metals	Ag, Al, As, B, Ba, Be, Bi, Cd, Co, Cr, Cu, Mo, Ni, Pb, Sb, Se, Sn, Sr, Ti, Tl, U, V, Zn	None
Nutrients	TKN, TP, NO_2+NO_3, NO_2, NO_3	TKN, TP, SRP, NH_4+, NO_2+NO_3
Field measurements	pH, conductivity, temperature	pH, conductivity, temperature

Table 3.2. Benthic macroinvertebrate community structure metrics used as variables.

Total abundance	Total number of taxa	Percent Ephemeroptera, Plecoptera, Trichoptera
Percent Ephemeroptera	Percent Chironomidae	

Table 3.3. Bottles for collection of water samples and preservatives added at sampling.

	Laboratory	Routine Ions	Nutrients	Metals	All Analyses
Bottle material	ETL	Polyethylene	Polyethylene	PETE	
	Limnology Lab				Polyethylene
Bottle size	ETL	500 mL	500 mL	250 mL	
	Limnology Lab				1000 mL
Preservative added	ETL	None	1:1 H_2SO_4	20% HNO_3	
	Limnology Lab				None
Kept cool?	ETL	Yes	Yes	Yes	
	Limnology Lab				Yes

Table 3.4. Average watershed characteristics calculated by GIS.

	Red Deer River Basin	Bow River Basin
Watershed area (km^2)	776	930
Stream length at sample point (km)	154	175
Sample dist from source (km)	41.2	44.6
% Watershed vegetated	55.5	48.8

Table 3.5. Minimum, maximum, and mean values obtained for each land use and human activity category using GIS.

Category	Minimum	Maximum	Mean
Percent vegetation (decimal)	0.29	0.94	0.52
Percent wetland (decimal)	0	0.0058	0.0014
Stream length at outlet (km)	1.62	750.47	165
Permanent population	0	7797	472
Roads (km)	0	555.61	100
Bridges	0	66	10
Railways (km)	0	123.77	16
Trails (km)	8.12	1186.02	274
Cutlines (km)	0	544.71	53
Ski lifts (m)	0	41 543	7003
Permanent backcountry camps	0	17	4
Waste water treatment plants	0	2	0.30
Area built up (ha)	0	156	8
Petroleum / deep water wells	0	40	4
Small buildings outside built up areas	0	516	72

Table 3.6. Watershed ranks and scores calculated using Cumulative Activity Indices A and B.

Watershed ID	Index A Score	Index A Rank	Index B Score (x 1000)	Index B Rank
TY-1	26	20	0.28	20
RD-1	27	19	0.35	18
RD-2	27	18	0.33	19
RE-1	27	17	1.11	14
HY-1	29	16	1.65	9
MS-1	30	15	1.68	7
BH-1	31	14	0.85	15
WH-1	31	13	4.46	1
BT-1	31	12	1.72	6
RD-3	32	11	0.52	17
PS-1	32	10	1.24	13
BW-1	33	9	1.27	12
RD-6	34	8	1.65	8
RD-4	35	7	0.69	16
RD-5	35	6	1.35	10
BW-2	36	5	1.29	11
BW-6	47	4	2.55	5
BW-5	48	3	3.02	3
BW-3	49	2	3.60	2
BW-4	49	1	2.92	4

Table 3.7. Summary of water quality parameters by study year for parameters that exhibited a unique or consistent trend.

	Red Deer River Basin		Bow River Basin	
Parameter	**2002**	**2003**	**2002**	**2003**
pH	8.1	8.4	8.1	8.2
Conductivity (dS/m)	0.37	0.25	0.25	0.23
Temperature (°C)	2.7	6.4	5.9	7.4
Turbidity (NTU)	*	9.53	*	1.50
NO_3+NO_2 (µg/L)	#	113.33	#	20.58
Ammonium (µg/L)	*	5.26	*	2.70
Total Kjeldahl nitrogen (µg/L)	#	194.65	#	152.68
Total phosphorus (µg/L)	#	22.67	#	4.55
Total abundance	50.3	26.9	53.1	57.2
Total number of taxa	7.4	4.8	6.7	6.7
% Ephemeroptera	0.68	0.81	0.52	0.43
% EPT	0.94	0.97	0.79	0.75
% Chironomidae	0.04	0.03	0.18	0.23

*Analysis not completed in year indicated.
#No concentration detected.

Table 3.8. Qualitative water quality ratings for select parameters in 2003 and ecological integrity score, according to Bowman (2002) assessment scale.

Site	TP	SRP	NH_4^+	NO_3+NO_2	% Eph	% Chr	Score (/24 max)
RD-1	Fair	Good	Good	Fair	Good	Good	22
RD-2	Fair	Good	Good	Fair	Good	Good	22
TY-1	Fair	Fair	Good	Poor	Good	Good	20
RD-3	Fair	Fair	Good	Good	Good	Good	22
BH-1	Fair	Fair	Fair	Good	Good	Good	21
RD-4	Poor	Fair	Good	Fair	Good	Good	20
WH-1	Fair	Fair	Fair	Fair	Good	Good	20
RD-5	Fair	Fair	Fair	Good	Good	Good	21
BT-1	Fair	Fair	Good	Fair	Good	Good	21
RD-6	Fair	Fair	Good	Good	Good	Good	22
BW-1	Good	Fair	Good	Good	Poor	Fair	20
BW-2	Fair	Good	Good	Good	Good	Good	23
MS-1	Good	Fair	Good	Good	Good	Good	23
BW-3	Fair	Good	Good	Good	V. poor	V. poor	17
PS-1	Good	Fair	Good	Good	Good	Good	23
BW-4	Good	Fair	Good	Good	Good	Good	23
RE-1	Good	Good	Good	Good	Good	Good	24
BW-5	Fair	Fair	Good	Good	Good	Good	22
HY-1	Good	Fair	Good	Good	Good	Good	23
BW-6	Fair	Fair	Good	Good	Good	Good	22

Table 3.9. Spearman's correlation coefficients (r) for measured parameters versus cumulative activity indices, Red Deer River basin, 2002.

Parameter	Cumulative Activity Index A	Cumulative Activity Index B
ETL Fe^{2+}	N/S	0.68
ETL Sr	0.83	N/S
ETL Conductivity	0.56	0.55
ETL Total Dissolved Solids	0.65	0.56
ETL Ca^{2+}	0.57	0.60
ETL SO_4^{2-}	0.72	N/S

ETL=EnviroTest Laboratories, N/S=not significant, LIM=Limnology Lab

Table 3.10. Spearman's correlation coefficients for measured parameters versus cumulative activity indices, Red Deer River basin, 2003.

Parameter	Cumulative Activity Index A	Cumulative Activity Index B
ETL Fe^{2+}	0.90	N/S
ETL Sr	0.68	0.59
ETL Conductivity	0.69	0.79
ETL Total Dissolved Solids	0.69	0.79
ETL Ca^{2+}	0.69	0.79
ETL Mg^{2+}	0.65	0.56
ETL SO_4^{2-}	0.62	N/S
LIM Na^+	N/S	0.96
LIM K^+	N/S	0.81
LIM Alkalinity	0.66	0.87
LIM Bicarbonate	0.66	0.87
LIM Conductivity	0.69	0.79
LIM pH	N/S	0.84
LIM Turbidity	0.59	N/S
LIM NH_4^+	0.59	0.55
LIM SRP	N/S	0.67
LIM Total phosphorus	0.64	N/S

ETL=EnviroTest Laboratories, N/S=not significant, LIM=Limnology Lab

Table 3.11. Spearman's correlation coefficients for measured parameters versus cumulative activity indices, Bow River basin, 2002.

Parameter	Cumulative Activity Index A	Cumulative Activity Index B
ETL Fe^{2+}	N/S	0.71
ETL Sr	0.54	0.62

ETL=EnviroTest Laboratories, N/S=not significant, LIM=Limnology Lab

Table 3.12. Spearman's correlation coefficients for measured parameters versus cumulative activity indices, Bow River basin, 2003.

Parameter	Cumulative Activity Index A	Cumulative Activity Index B
ETL Fe^{2+}	0.92	0.76
ETL Sr	0.53	N/S
LIM Cl^{-}	0.71	0.61
LIM Na^{+}	0.68	N/S
LIM Turbidity	0.78	0.66
LIM NH_4^{+}	N/S	0.64
LIM Total phosphorus	0.69	0.59
Total abundance	0.60	0.84

ETL=EnviroTest Laboratories, N/S=not significant, LIM=Limnology Lab

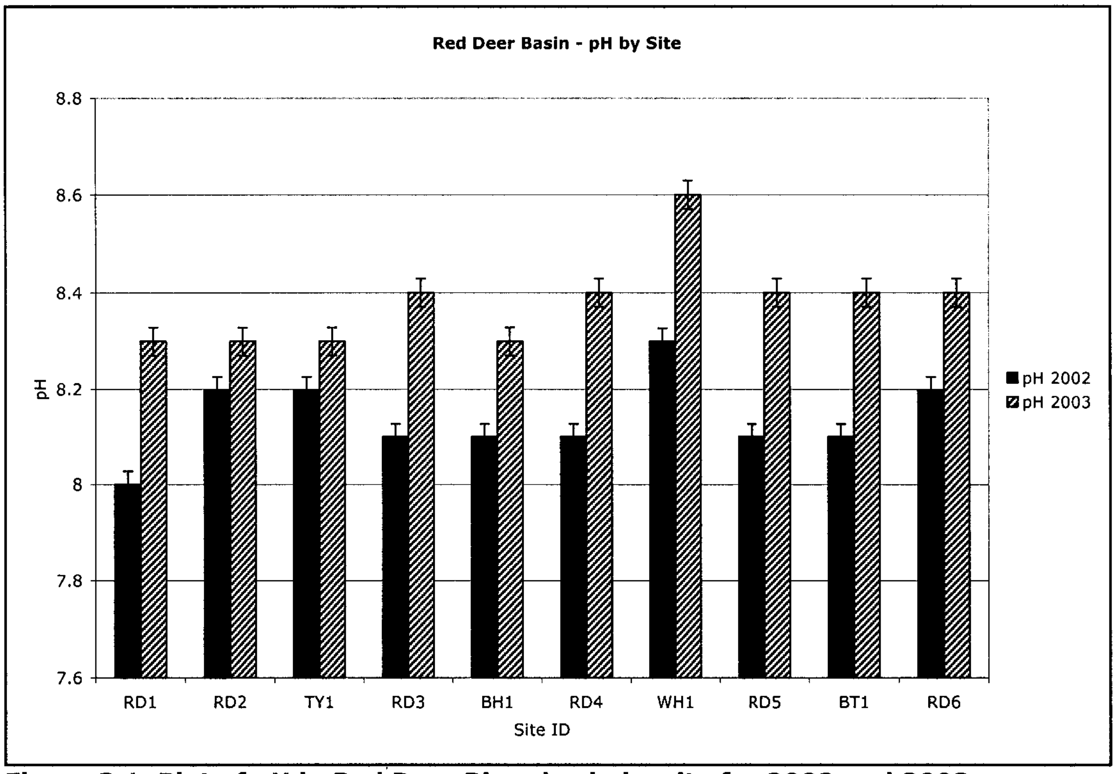

Figure 3.1. Plot of pH in Red Deer River basin by site for 2002 and 2003.

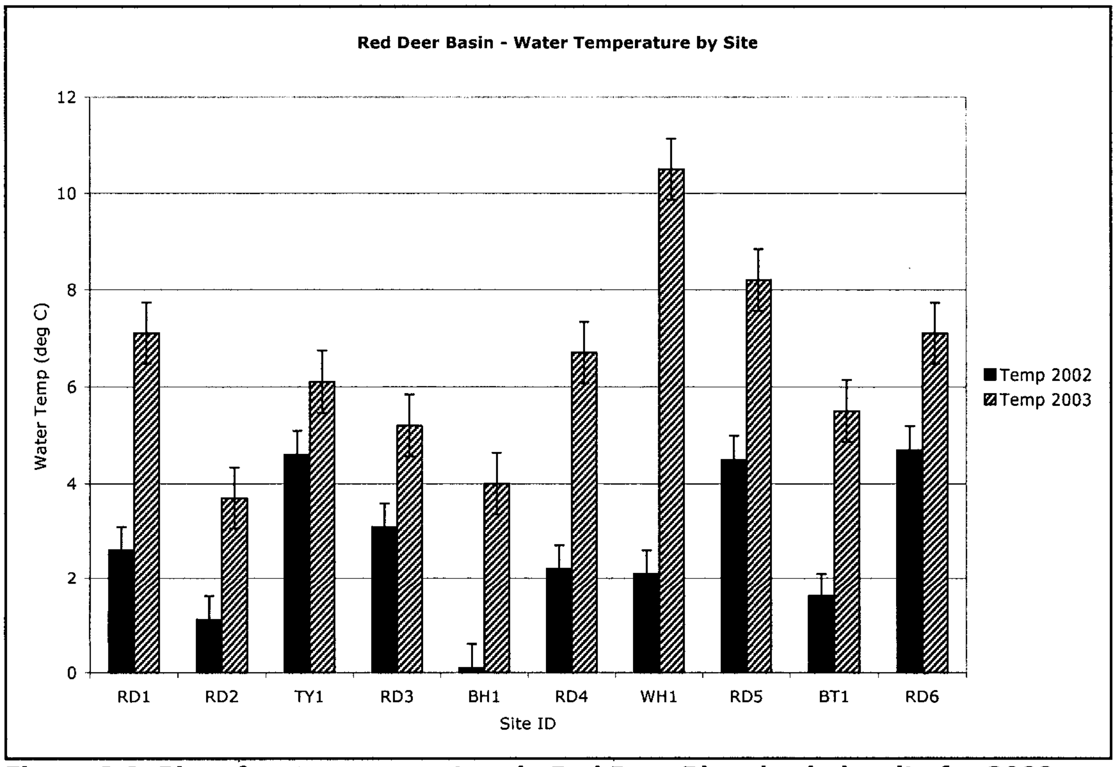

Figure 3.2. Plot of water temperature in Red Deer River basin by site for 2002 and 2003.

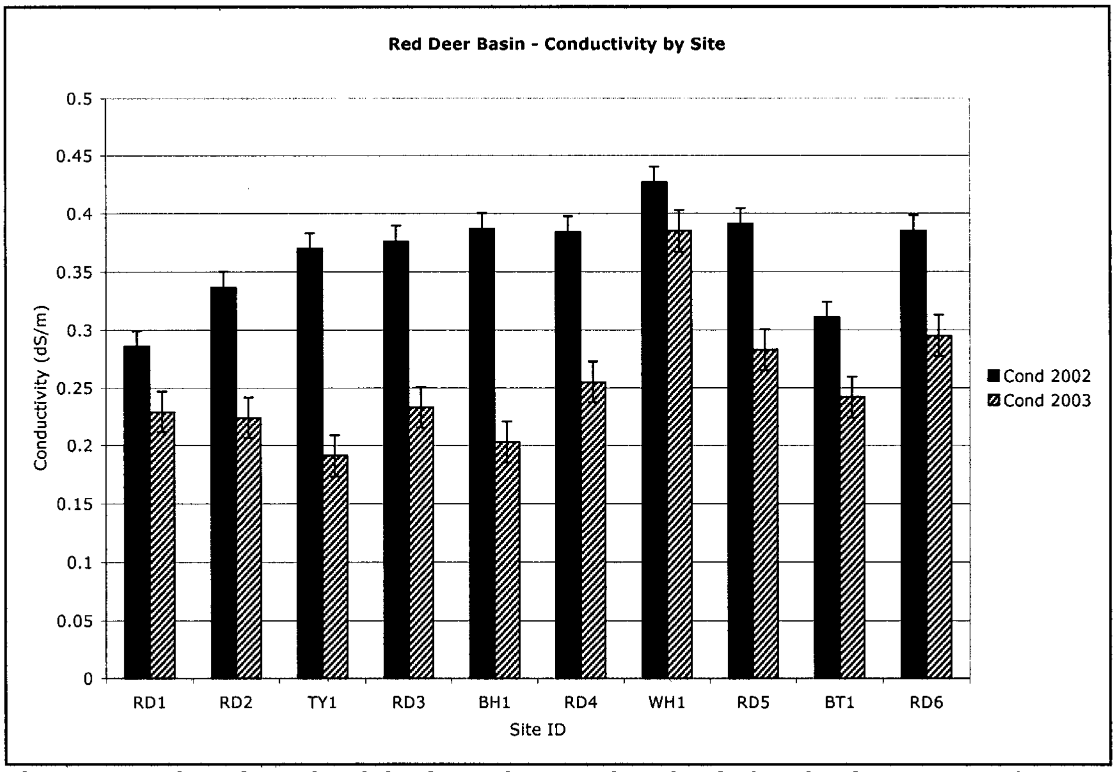

Figure 3.3. Plot of conductivity in Red Deer River basin by site for 2002 and 2003.

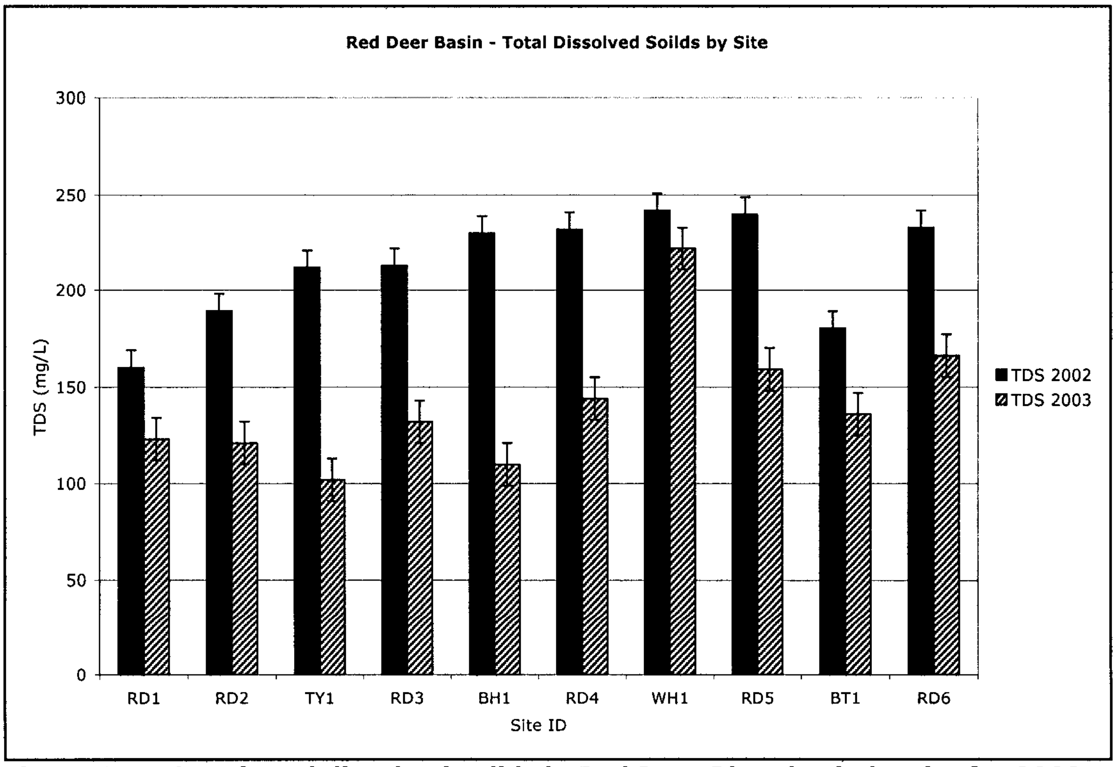

Figure 3.4. Plot of total dissolved solids in Red Deer River basin by site for 2002 and 2003.

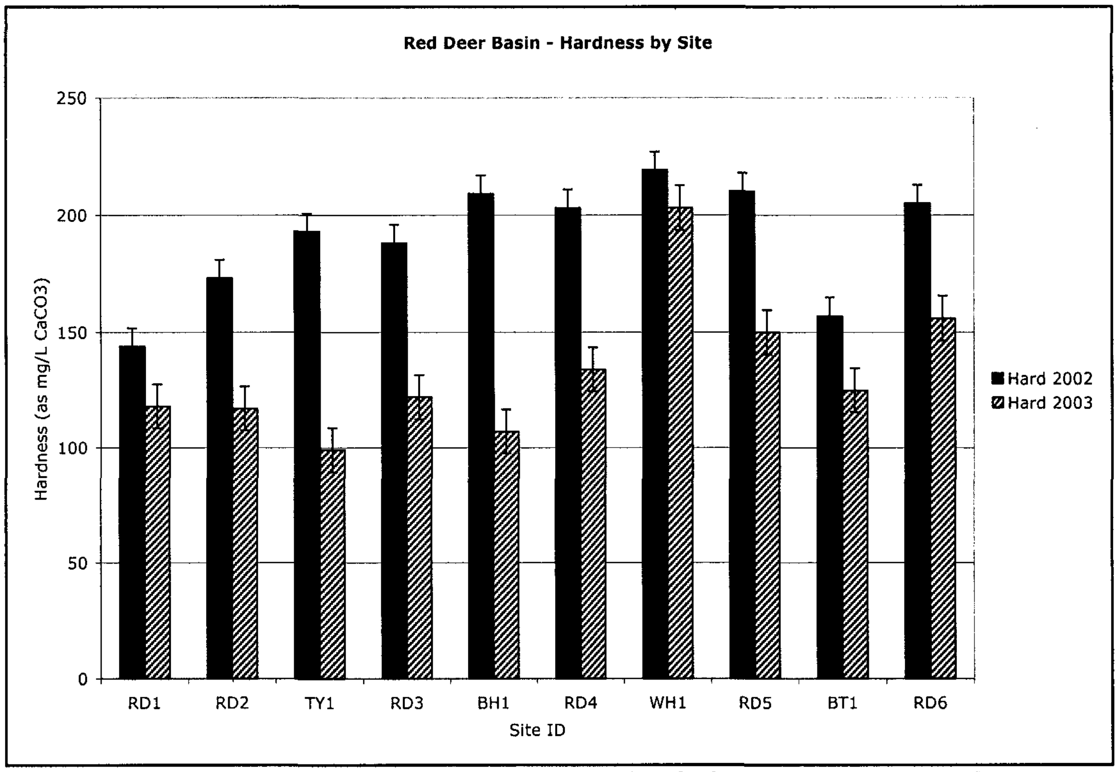

Figure 3.5. Plot of hardness in Red Deer River basin by site for 2002 and 2003.

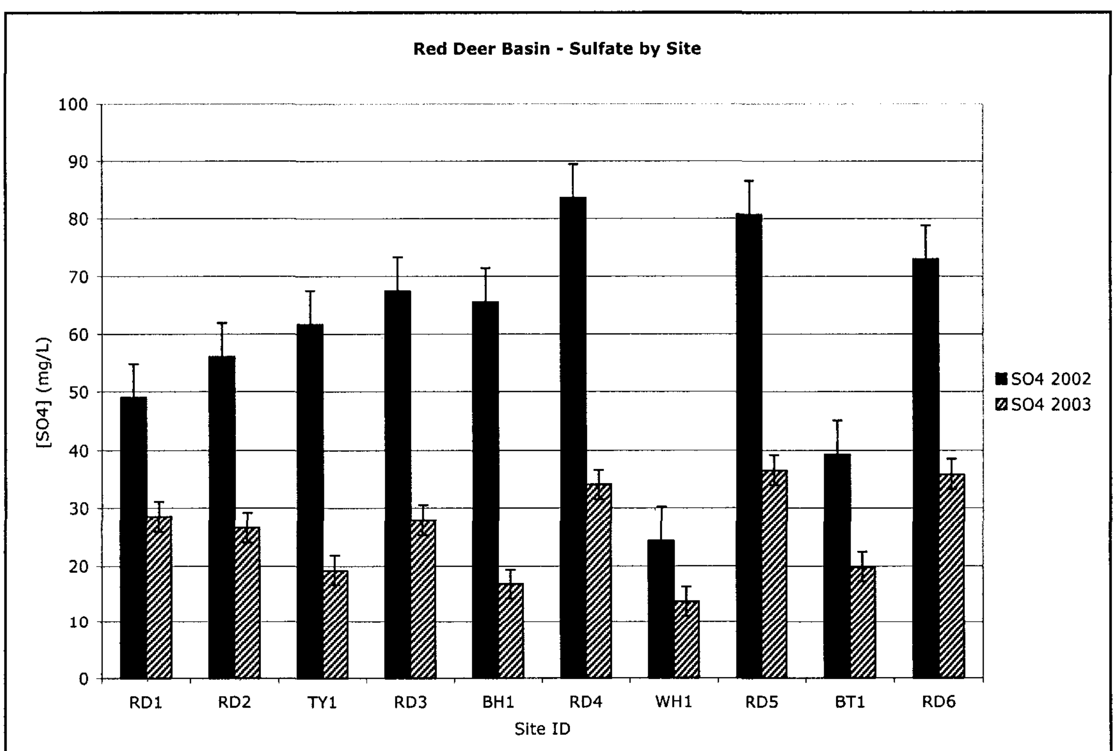

Figure 3.6. Plot of sulfate (SO_4^-) in Red Deer River basin by site for 2002 and 2003.

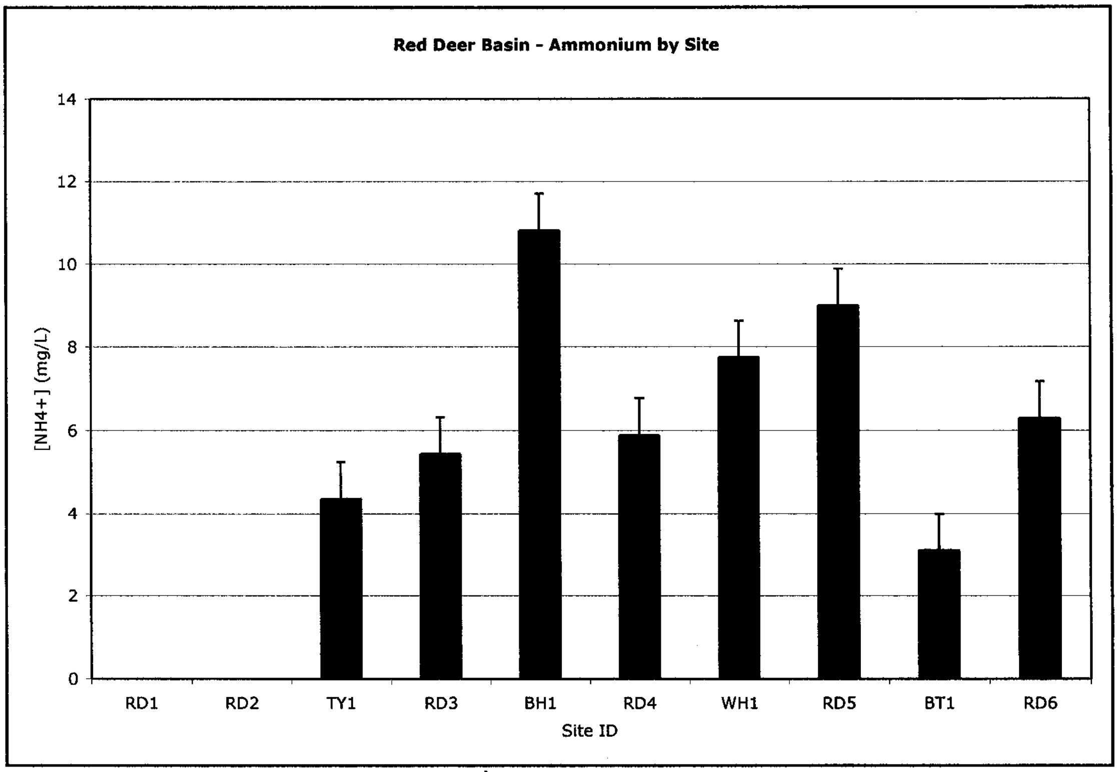

Figure 3.7. Plot of ammonium (NH_4^+) in Red Deer River basin by site for 2003.

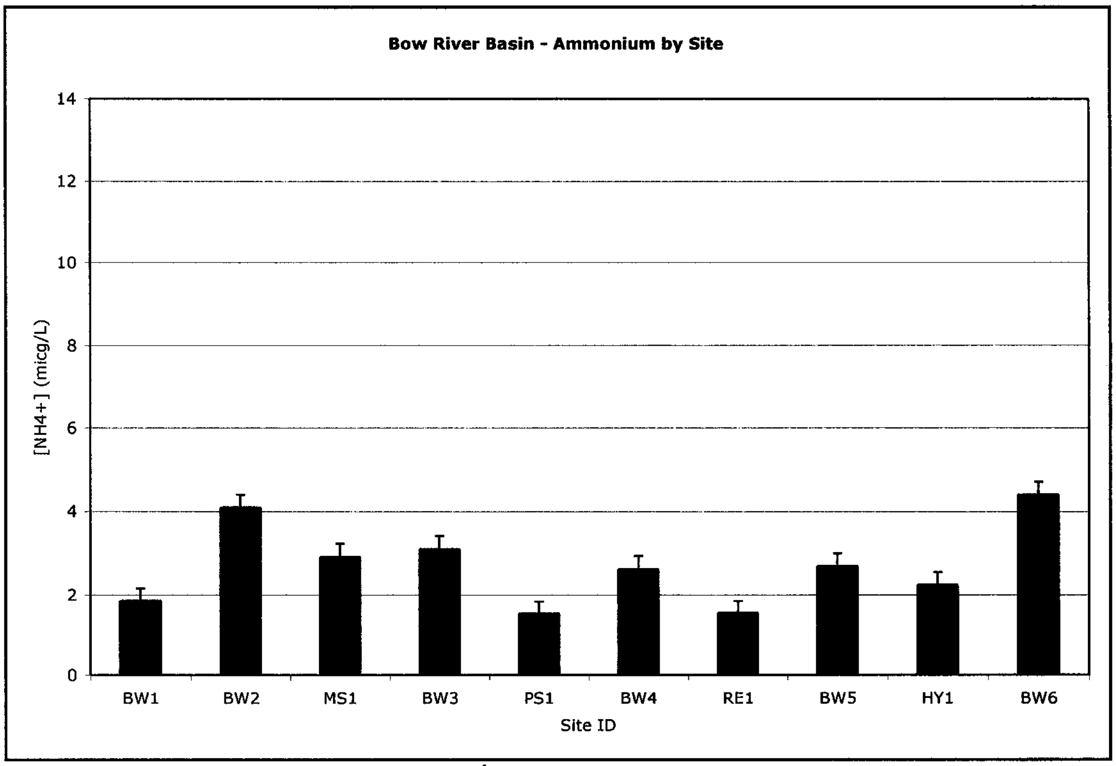

Figure 3.8. Plot of ammonium (NH_4^+) in Bow River basin by site for 2003.

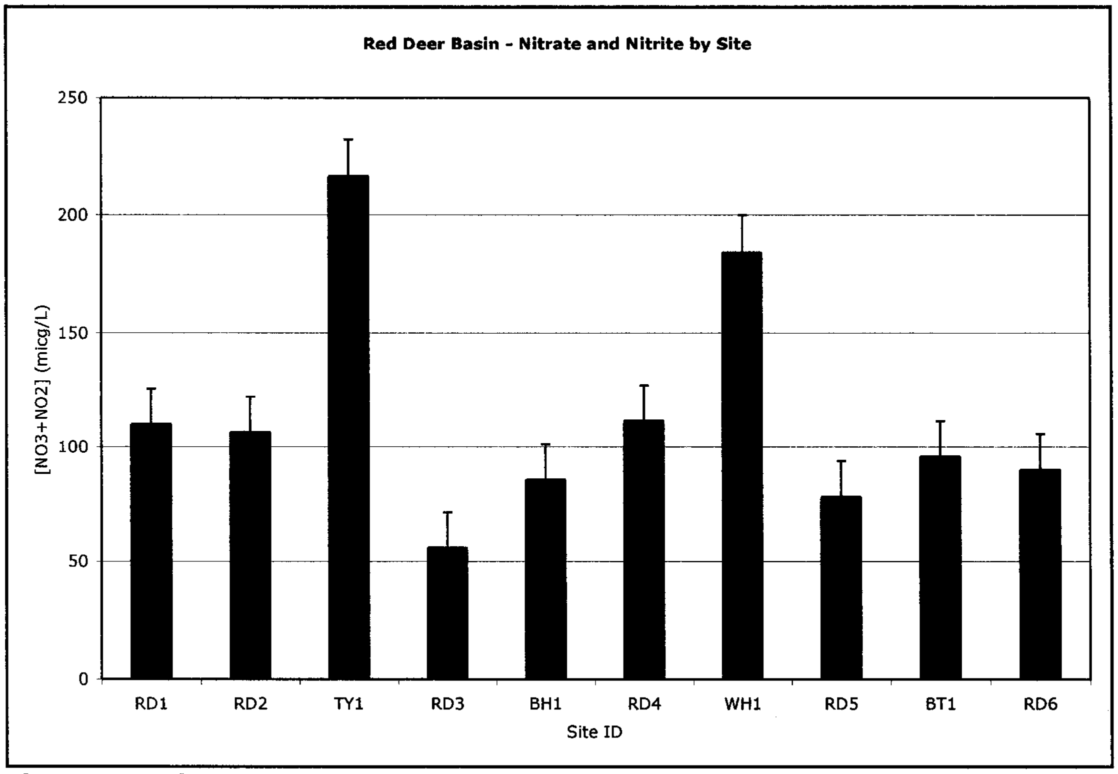

Figure 3.9. Plot of nitrate + nitrite in Red Deer River basin by site for 2003.

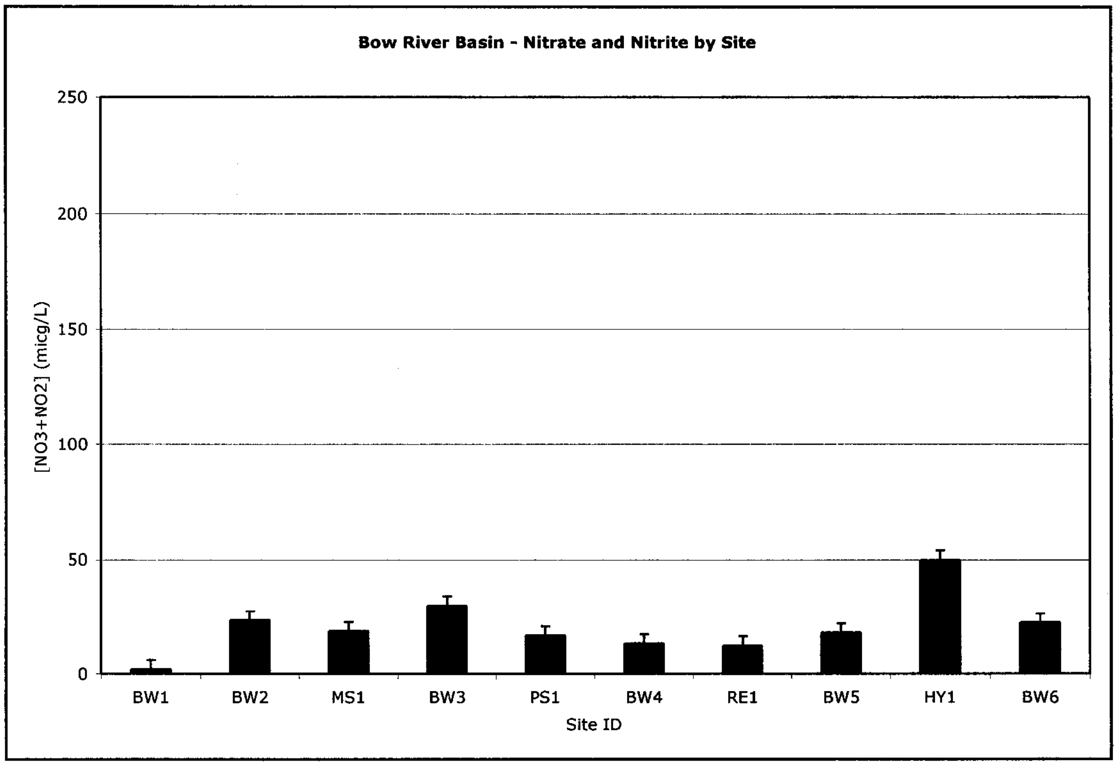

Figure 3.10. Plot of nitrate + nitrite in Bow River basin by site for 2003.

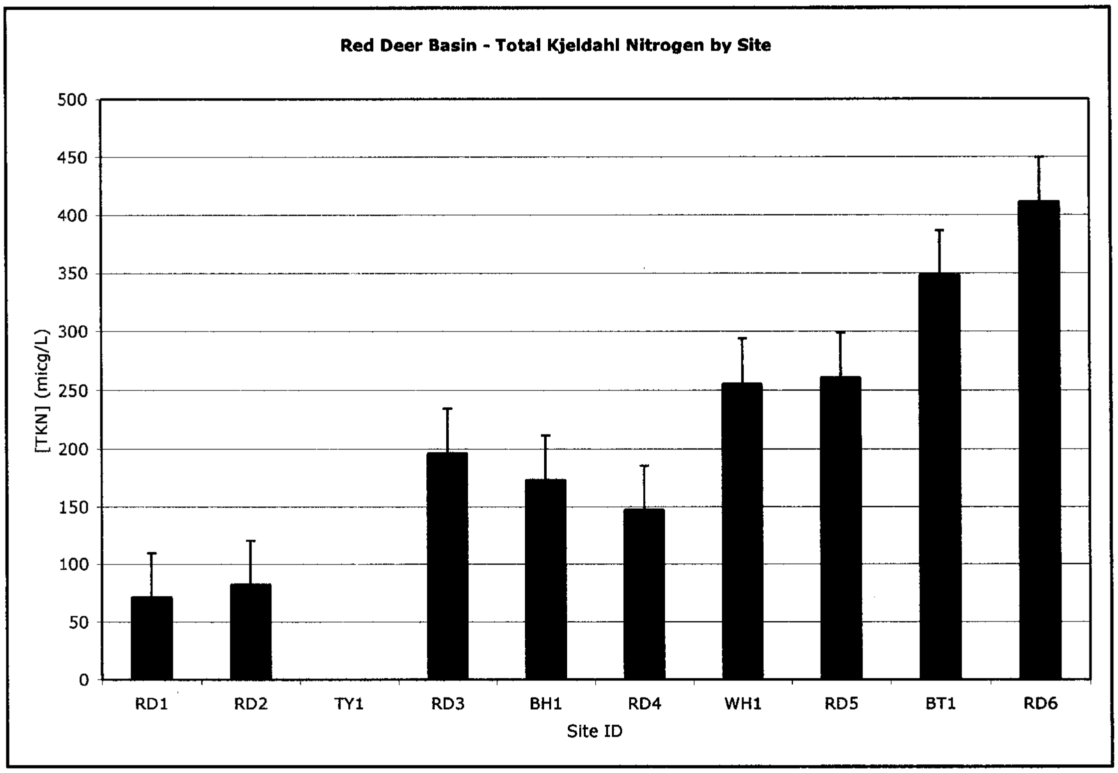

Figure 3.11. Plot of total Kjeldahl nitrogen (TKN) in Red Deer River basin by site for 2003.

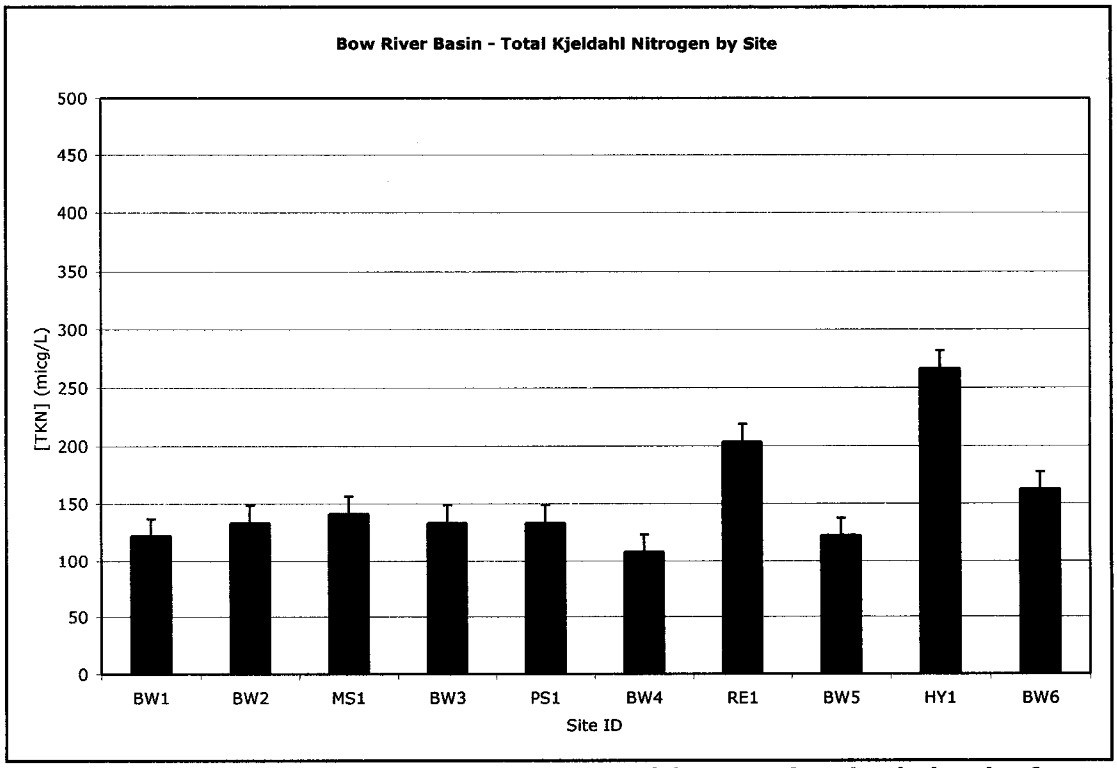

Figure 3.12. Plot of total Kjeldahl nitrogen (TKN) in Bow River basin by site for 2003.

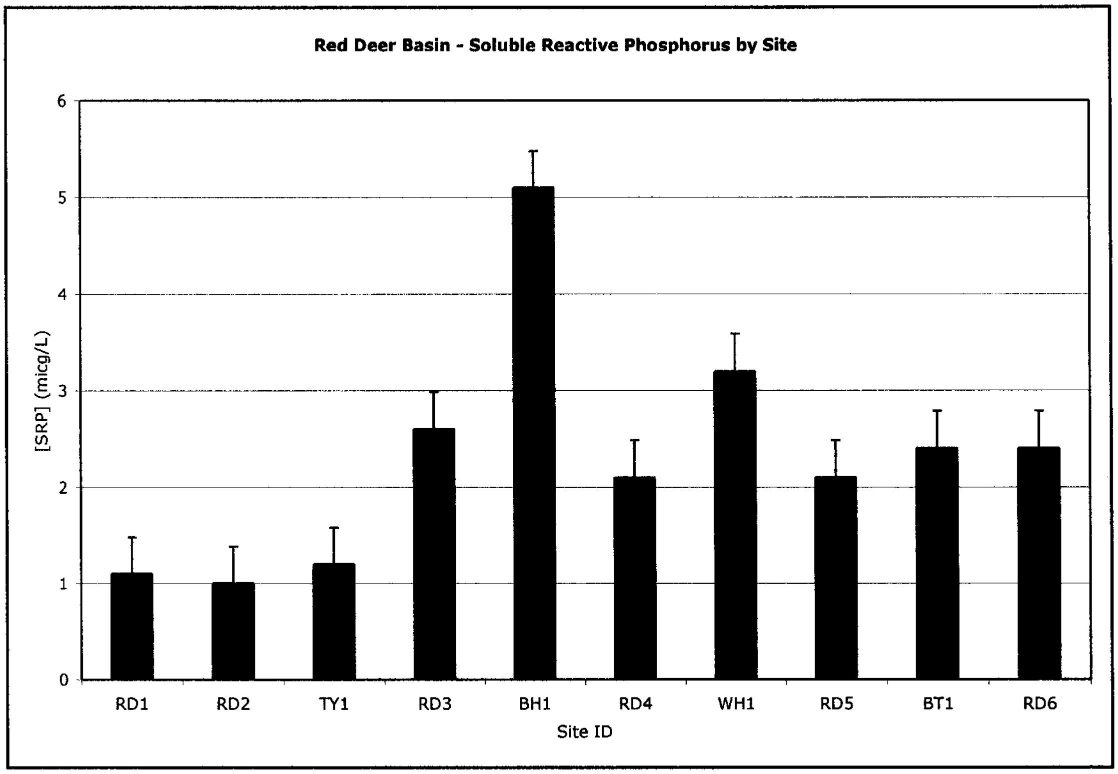

Figure 3.13. Plot of soluble reactive phosphorus (SRP) in Red Deer River basin by site for 2003.

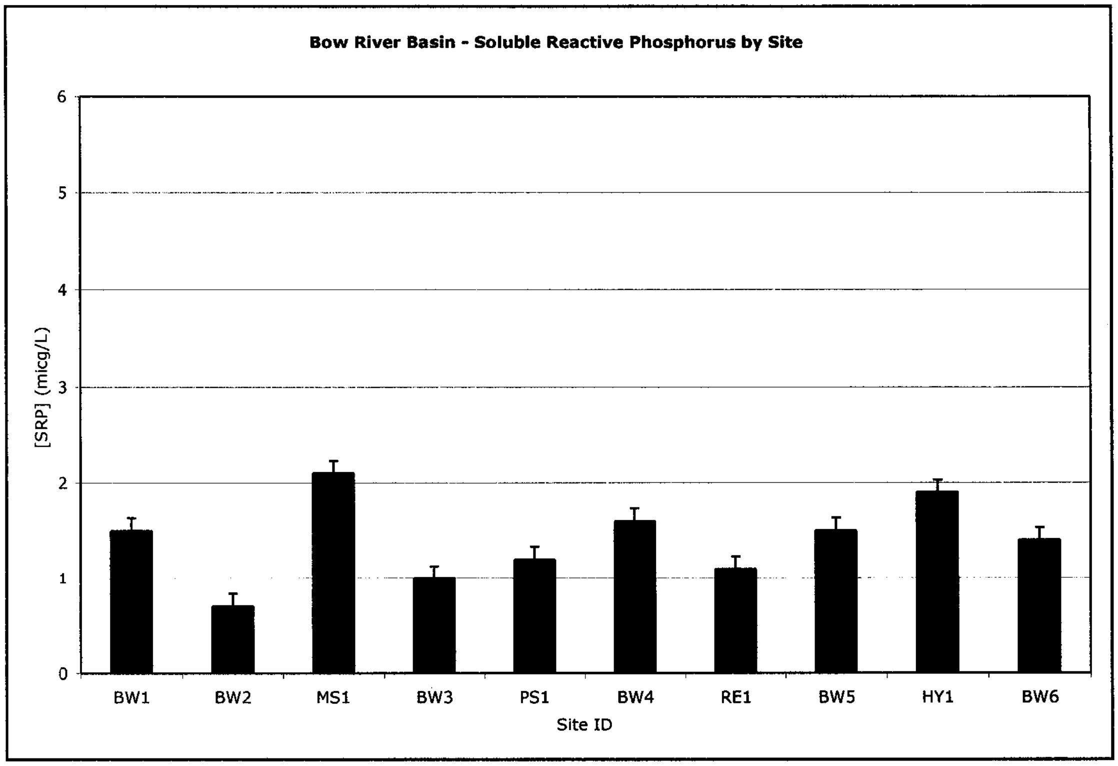

Figure 3.14. Plot of soluble reactive phosphorus (SRP) in Bow River basin by site for 2003.

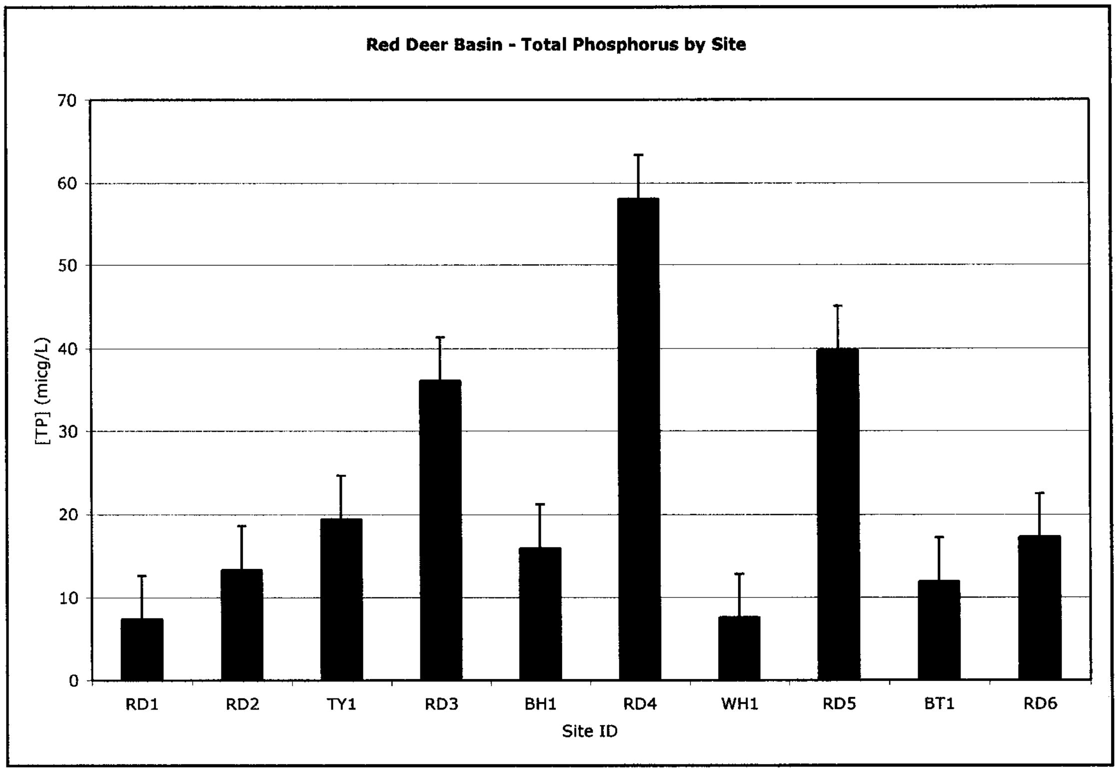

Figure 3.15. Plot of total phosphorus (TP) in Red Deer River basin by site for 2003.

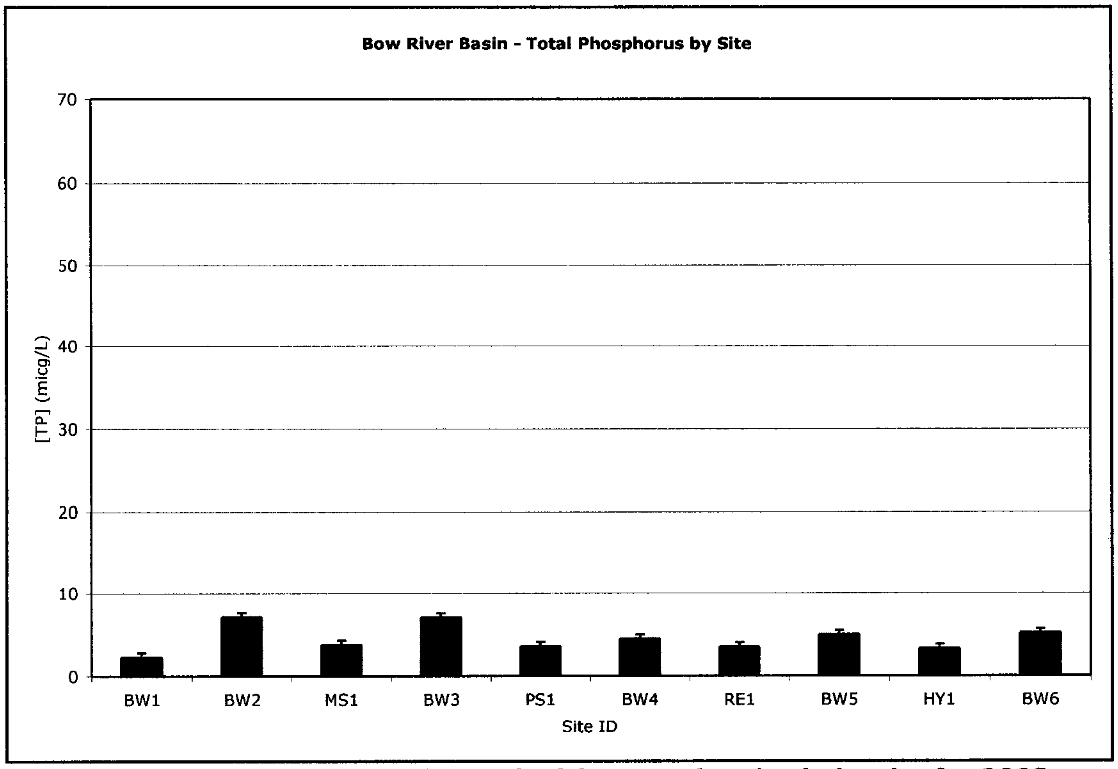

Figure 3.16. Plot of total phosphorus (TP) in Bow River basin by site for 2003.

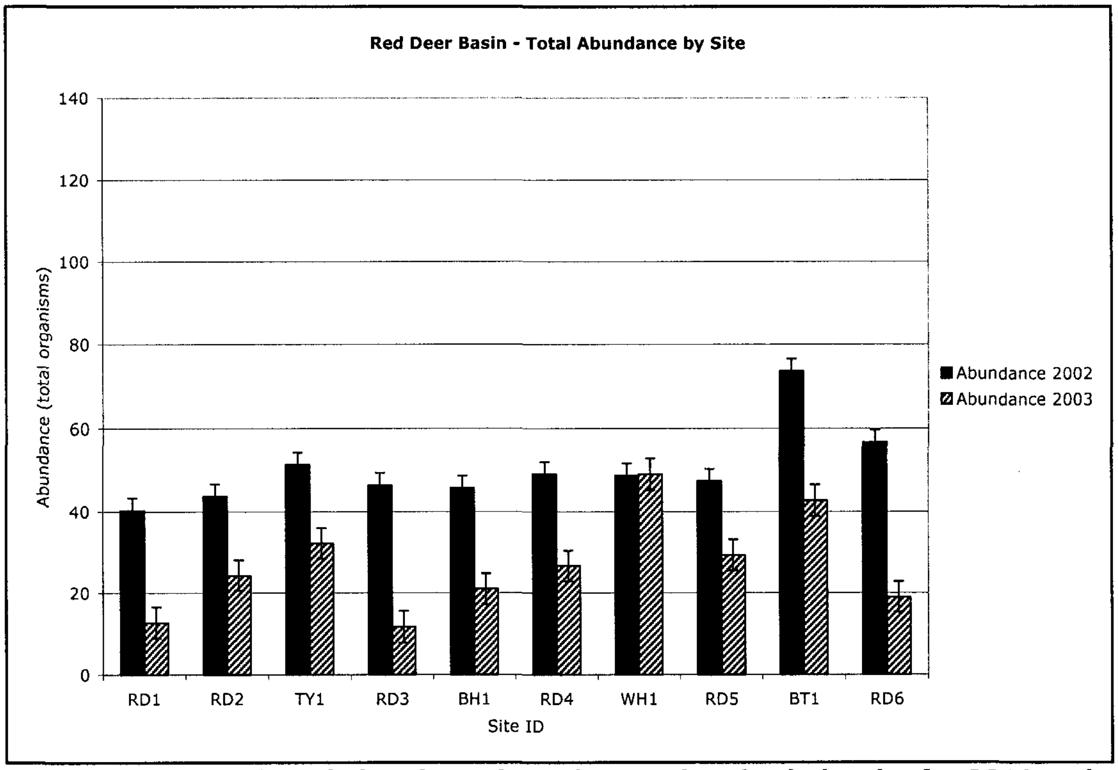

Figure 3.17. Plot of total abundance in Red Deer River basin by site for 2002 and 2003.

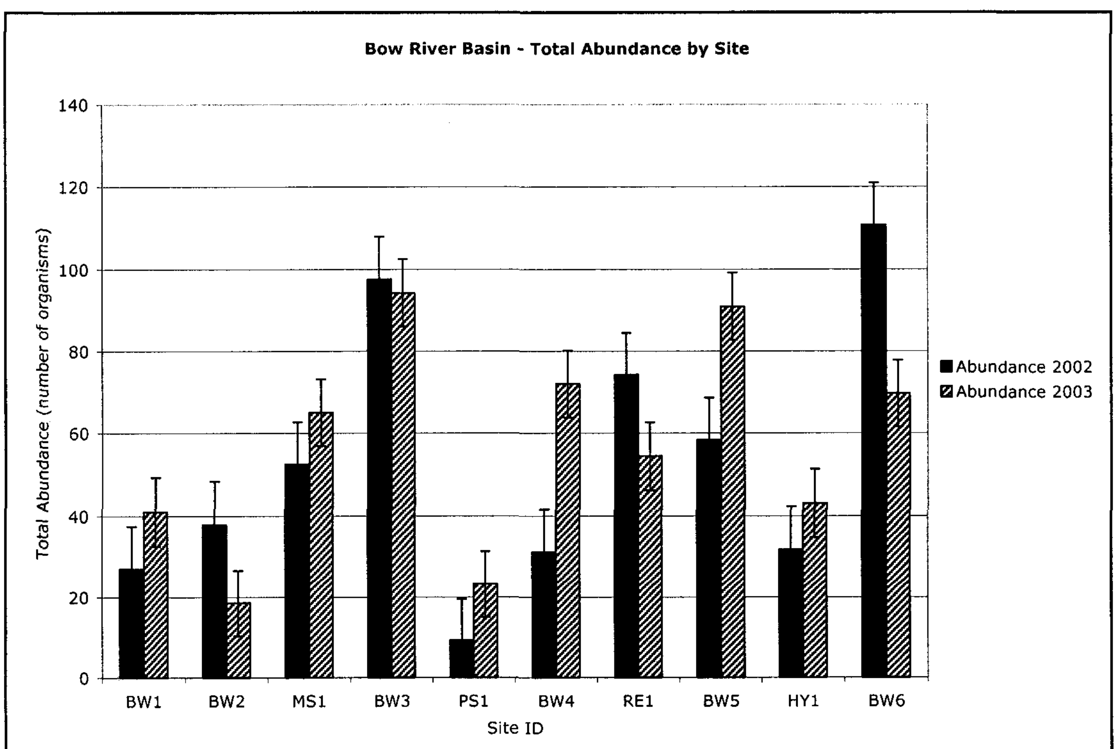

Figure 3.18. Plot of total abundance in Bow basin by site for 2002 and 2003.

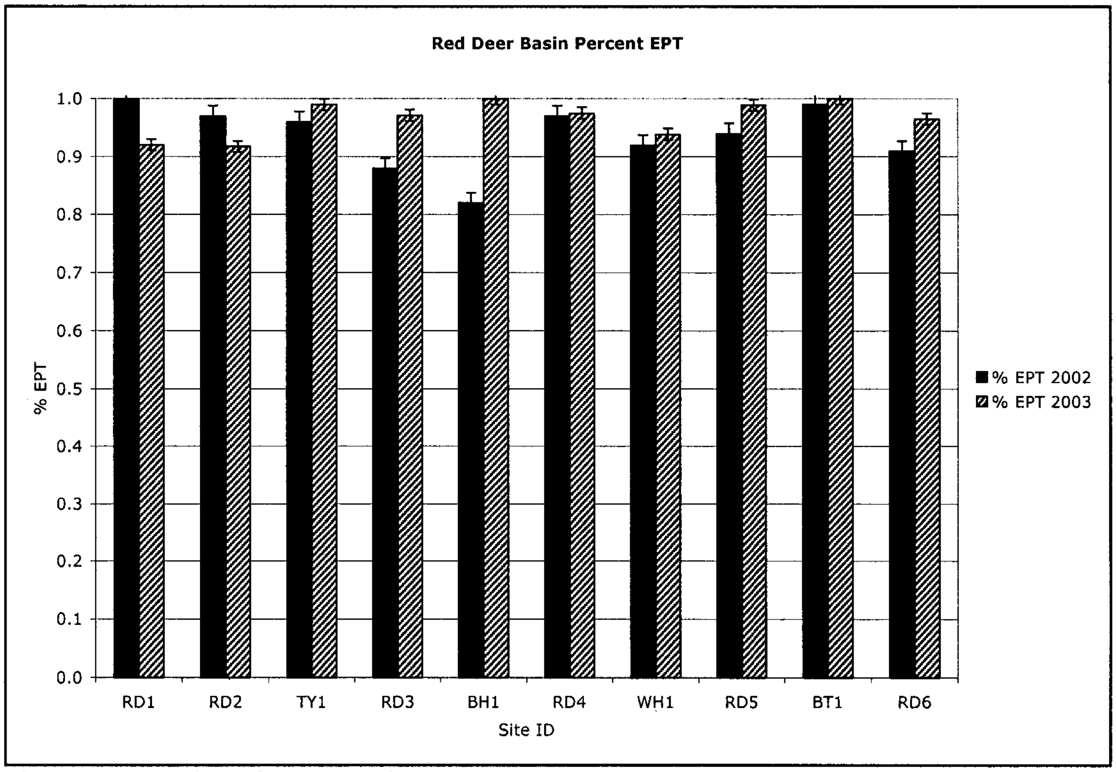

Figure 3.19. Plot of community percentage composed of Ephemeroptera, Plecoptera, and Trichoptera taxa in Red Deer River basin by site for 2002 and 2003.

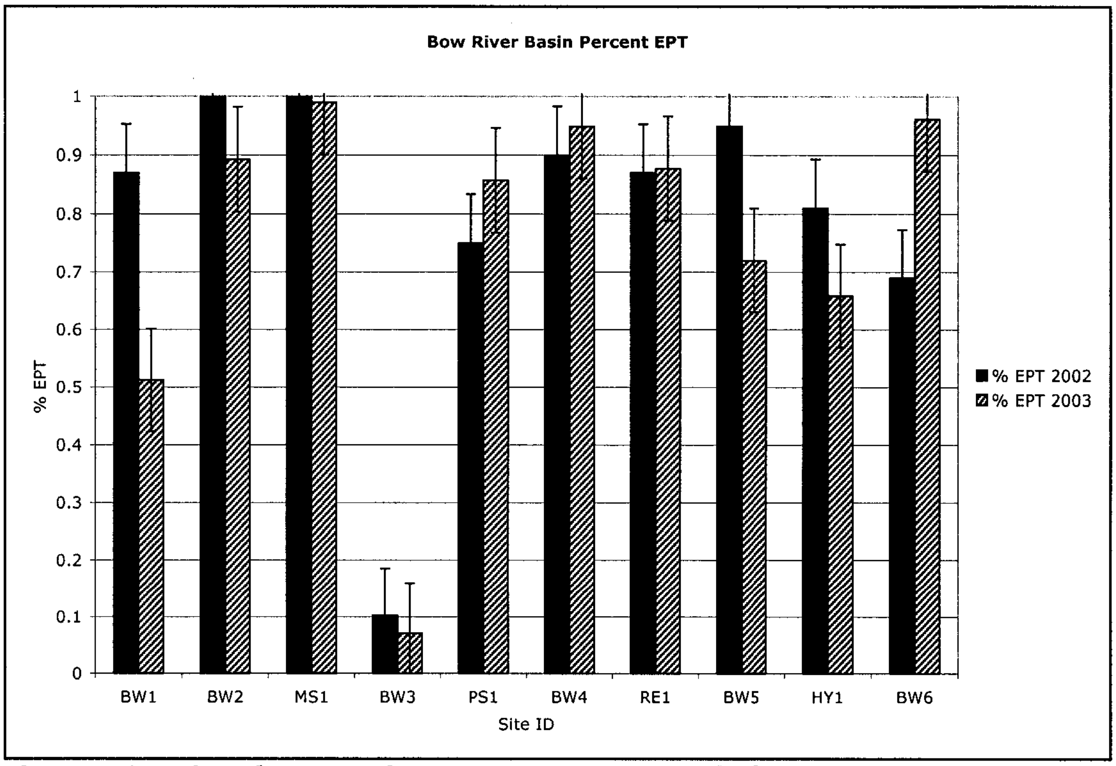

Figure 3.20. Plot of community percentage composed of Ephemeroptera, Plecoptera, and Trichoptera taxa in Bow River basin by site for 2002 and 2003.

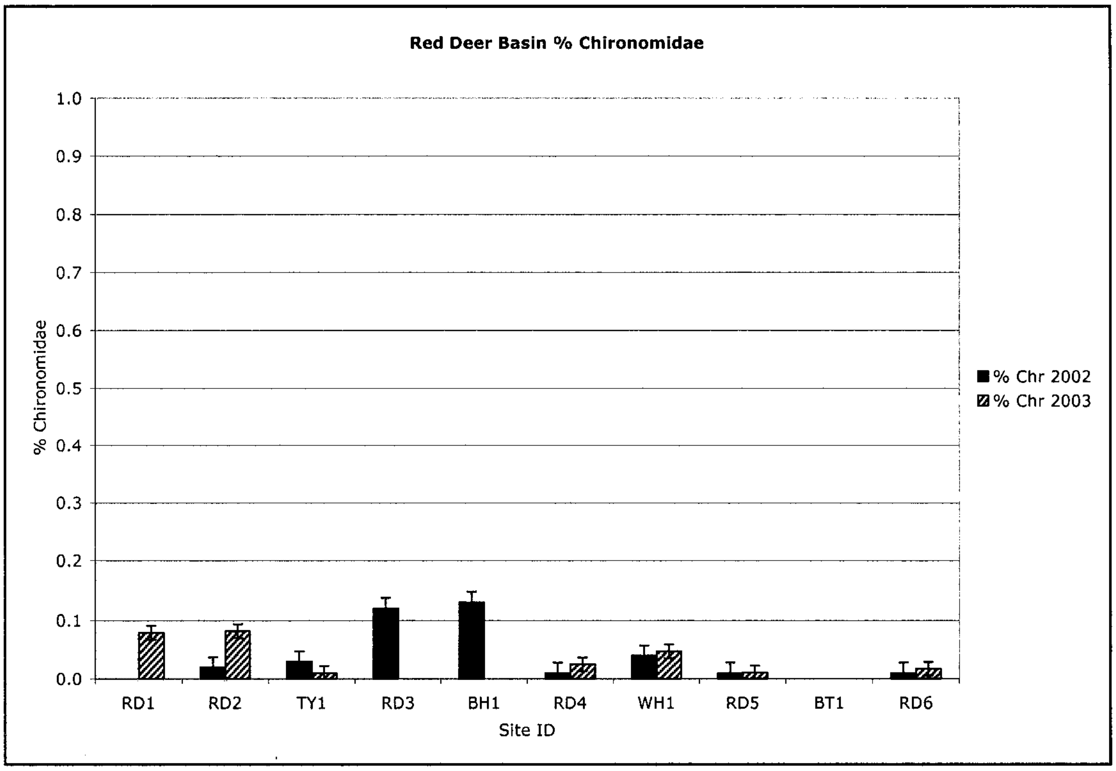

Figure 3.21. Plot of community percentage composed of Chironomidae taxa in Red Deer River basin by site for 2002 and 2003.

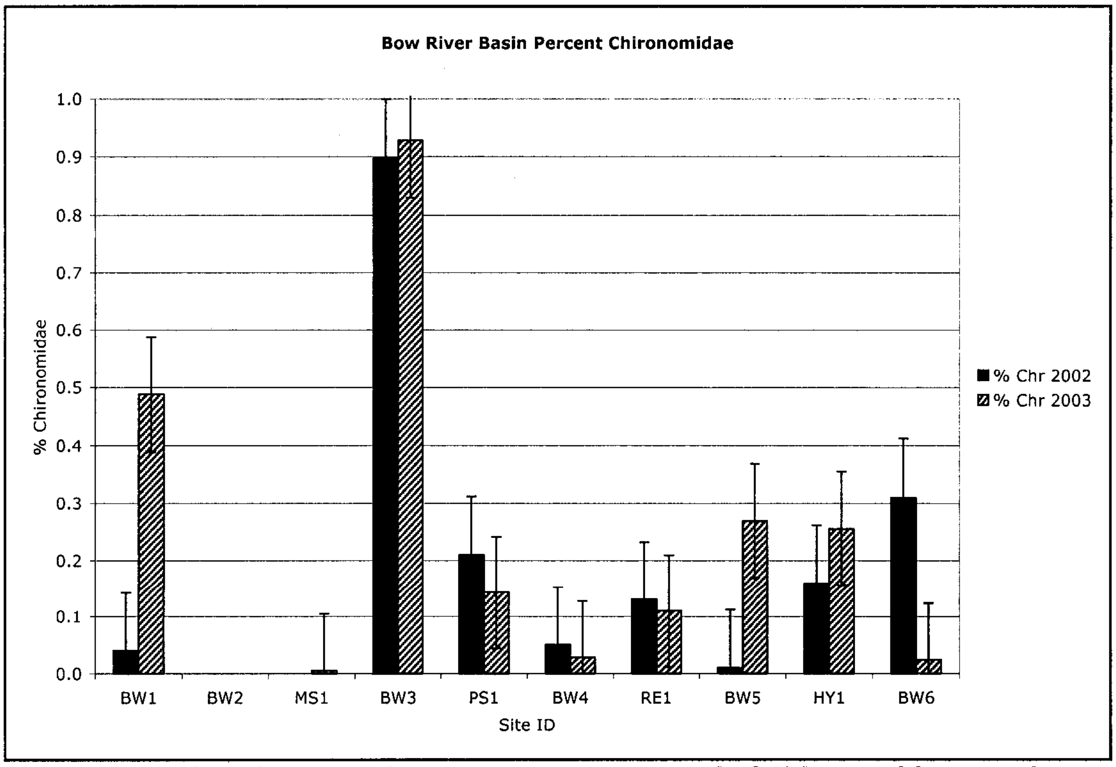

Figure 3.22. Plot of community percentage composed of Chironomidae taxa in Bow River basin by site for 2002 and 2003.

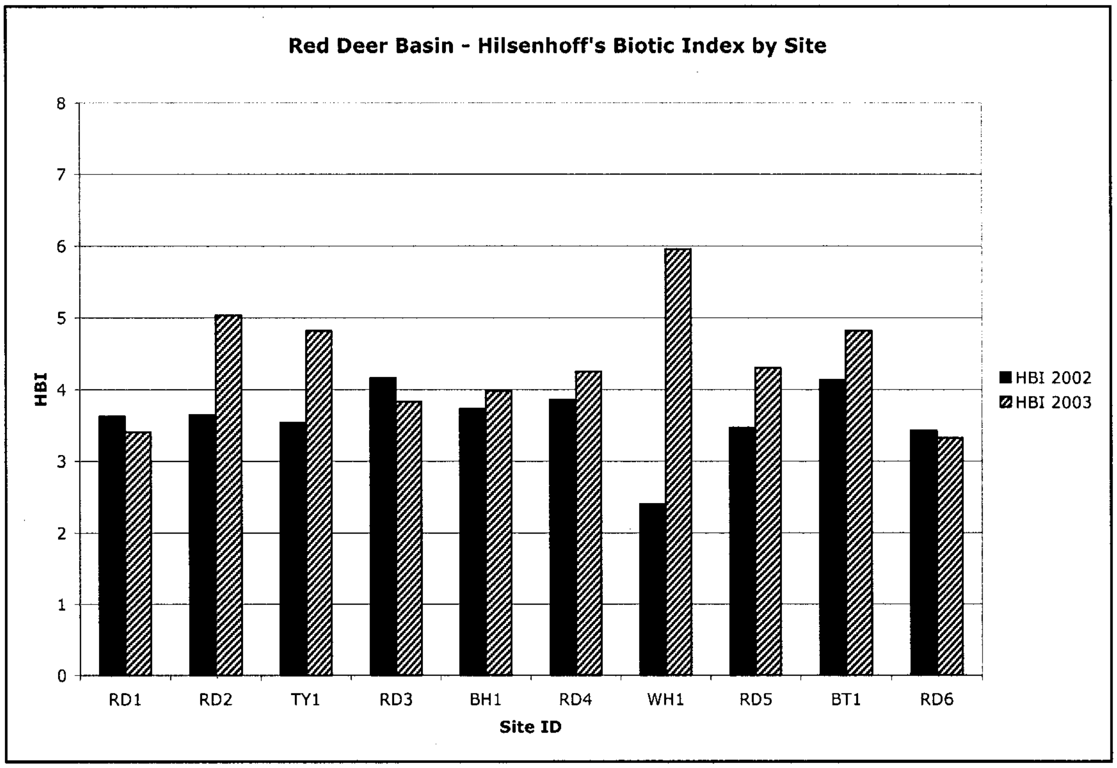

Figure 3.23. Plot of Hilsenhoff's Biotic Index (HBI) in Red Deer basin by site for 2002 and 2003.

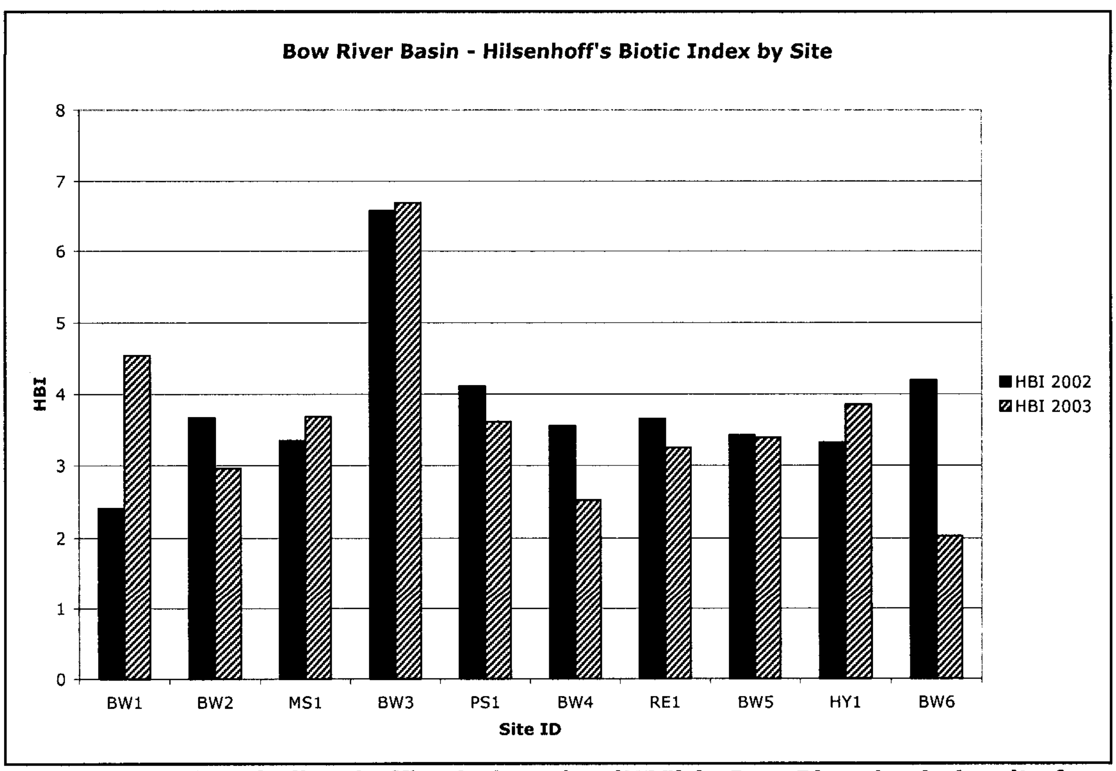

Figure 3.24. Plot of Hilsenhoff's Biotic Index (HBI) in Bow River basin by site for 2002 and 2003.

Appendix A

Glossary of Terms

BMI
Benthic macroinvertebrates

CAI
Cumulative activity index

CEA
Cumulative effects assessment

DEM
Digital elevation model; an electronic representation of the land's surface that assigns an elevation to particular points

GIS
Geographic information system

project
Collection of associated files and documents in the ArcView GIS used during a session

projection
Mathematical model that transforms the three-dimensional Earth's surface to a two-dimensional representation

stream burning
Reinforcing the stream drainage pattern in a GIS by lowering the elevation of the cells under the stream pattern by a defined increment; facilitates further analyses

study basin
The area of either the Bow River Basin or the Red Deer River Basin considered in this research

theme
Unit of management of features and their attributes in a GIS

view
Display of one or many themes for a specified area in a GIS

Z-score
Result of the conversion of a variable to a dimensionless variable with mean of zero and standard deviation of one

Example Calculations for Cumulative Activity Indices (CAIs).

Cumulative Activity Index A

Site: BW-6

Land Use Category (Normalized by Basin Area (/km^2))	Value	CaP
Vegetated Area (decimal)	0.59	2
Wetland Area (decimal)	0.0019	1
Permanent Population	1.99	4
Roads (km)	0.14	3
Bridges (#)	0.02	4
Railway (km)	0.03	4
Cutlines (km)	0.00	3
Ski Lifts (m)	10.60	3
Small Buildings (#)	0.13	4
Permanent Backcountry Camps (#)	0.00	3
Trails (km)	0.30	2
Waste Water Treatment Plants (#)	0.0005	4
Area Built Up (ha)	0.04	4
Deep Wells (#)	0.00	1

Cumulative Activity Index Score = SUM_{CaP}(Vegetated Area + ... + Deep Wells)
= 47

Cumulative Activity Index B

Site: BW-6

Land Use Category (Raw Data)	Value	Max Value	CaP
Permanent Population	7 797	7 797	1
Roads (km)	556	556	1
Bridges (#)	66	66	1
Railway (km)	124	124	1
Cutlines (km)	4.78	545	0.009
Ski Lifts (m)	41 543	41 543	1
Small Buildings (#)	516	516	1
Permanent Backcountry Camps (#)	17	17	1
Trails (km)	1186	1186	1
Waste Water Treatment Plants (#)	2	2	1
Area Built Up (ha)	155	155	1
Deep Wells (#)	0	40	0

CaP_{site} = SUM(($Population_{site}/Population_{max}$) + ... + ($Wells_{site}/Wells_{max}$))
= 10.009

Cumulative Activity Index Score = $CaP_{site}/Area_{site}$
= 10.009/3919 km^2
= 0.0026

Appendix B. Land Use and Human Activity Raw Data

Table 5.1. Raw land use and human activity data by watershed (cumulative totals).

Basin	% Wetland	% Vegetation	Permanent population	Roads (km)	Bridges (no)	Railways (km)	Cutlines (km)	Ski lifts (m)	Small buildings (no)	Permanent campsites (no)	Trails (km)	Waste water treatment plants	Built up area / townsites (ha)	Petroleum / deep water wells
RD-1	0.0003	0.35	0	0	0	0	0.00	0	1	1	42.8	0	0	0
RD-2	0.0013	0.35	0	0	0	0	0.00	0	2	1	141.0	0	0	0
TY-1	0.0000	0.29	0	0	0	0	0	0	0	0	15.3	0	0	0
RD-3	0.0009	0.43	0	3.7	1	0	26.0	0	9	2	294.4	0	0	0
BH-1	0.0000	0.63	0	3.2	1	0	1.9	0	0	0	29.5	0	0	0
RD-4	0.0011	0.48	0	31.4	1	0	67.9	0	11	2	348.2	0	0	2
WH-1	0.0058	0.94	0	7.1	0	0	19.1	0	0	0	8.3	0	0	2
RD-5	0.0018	0.60	0	216.3	12	0	317.2	0	41	5	741.9	0	0	30
BT-1	0.0022	0.84	0	42.3	3	0	83.3	0	0	1	81.5	0	0	6
RD-6	0.0047	0.65	0	324.6	15	0	544.7	0	85	7	855.4	0	0	40
Avg	0.0018	0.55	0	62.9	3.3	0	106.0	0.00	14.90	1.9	255.8	0	0	8.0
BW-1	0.0000	0.42	0	4.91	0	0	0	0	4	0	8.1	0	0	0
BW-2	0.0002	0.33	0	23.0	1	0	0	0	14	1	77.4	0	0	0
MS-1	0.0008	0.25	0	0	0	0	0	0	0	1	30.7	0	0	0
BW-3	0.0012	0.46	549	143.7	26	33.1	0	21 359	178	6	262.8	1	2	0
PS-1	0.0005	0.44	0	5.05	0	0	0	4 064	12	3	84.6	0	0	0
BW-4	0.0016	0.57	549	288.5	37	73.7	0	24 684	267	17	529.4	1	2	0
RE-1	0.0018	0.66	0	0	0	0	0	0	3	2	53.9	0	0	0
BW-5	0.0018	0.58	549	344.7	41	93.2	0	36 544	278	17	622.4	2	2	0
HY-1	0.0003	0.59	0	13.2	0	0	0	11 860	11	0	70.6	0	0	0
BW-6	0.0019	0.59	7797	555.6	66	123.8	4.8	41 543	516	17	1 186.0	2	156	0
Avg	0.001	0.49	944	137.9	17.1	32.4	0.47	14 005.4	128.3	6.4	292.6	0.6	18.0	0

Appendix C. Water Chemistry Analysis Methods

Table 6.1. Analyses conducted at Enviro-Test Laboratories.

Test Description	Analytical Method / Reference
Chloride (Cl)	APHA 4500 Cl E-Colorimetry
ICP Metals and SO_4 for routine water	APHA 3120 B-ICP-OES
Iron (Fe) Extractable	EPA 200.7
Extractable Trace Metals (Low Level)	EPA 6020
Manganese (Mn) Extractable	EPA 200.7
Total Kjeldahl Nitrogen (TKN)	APHA 4500N-C Digital Auto Colorimetry
Nitrate + Nitrite Nitrogen	APHA 4500 NO3H Colorimetry
Nitrite	APHA 4500 NO2B Colorimetry
Nitrate	APHA 4500 NO3H Colorimetry
Total Phosphorus (TP)	APHA 4500 PBE Auto Colorimetry
pH, Conductivity, and Alkalinity	APHA 4500-H, 2510, 2320

Table 6.2. Analyses conducted at University of Alberta Limnology Laboratory.

Test Description	Analytical Method / Reference
Sulfate (SO_4) and Chloride (Cl)	EPA 300.0
Ca, Mg, Na, K	Stainton et al. (1977)
Ammonium (NH_4)	Automated Berthelot Reaction
Nitrate + Nitrite	Automated Cu/Cd Reduction
Total Kjeldahl Nitrogen	Automated Berthelot Reaction
Soluble Reactive Phosphorus (SRP)	Murphy and Riley (1962)
Total Phosphorus (TP)	Menzel and Corwin (1965)
Turbidity	Hach Turbidimeter Model 2100A
pH	Fisher Scientific Accumet pH Meter 925
Conductivity	Radiometer/Copenhagen Model CDM 83
Alkalinity	APHA 2320