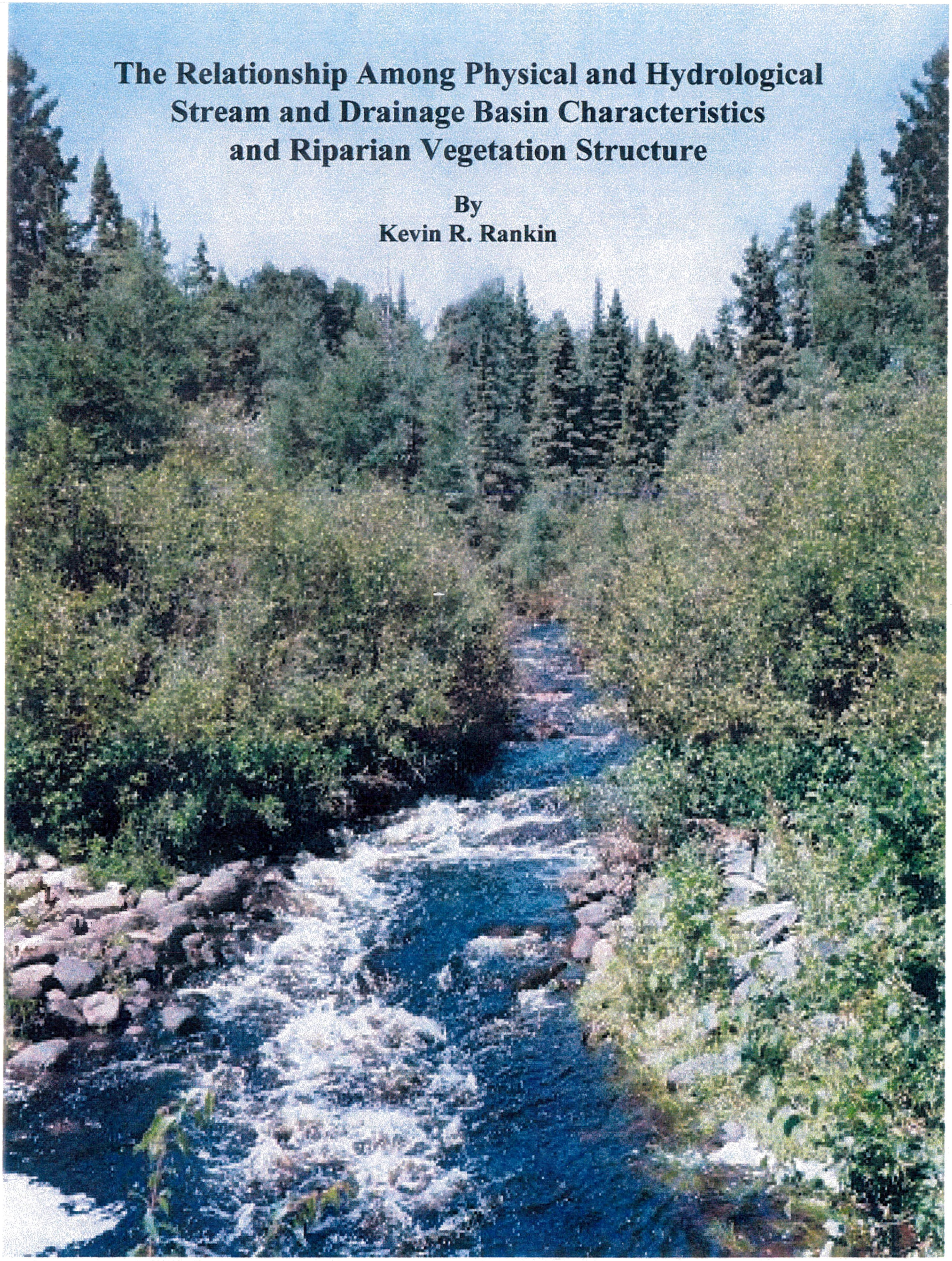
The Relationship Among Physical and Hydrological Stream and Drainage Basin Characteristics and Riparian Vegetation Structure

By
Kevin R. Rankin



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Kevin R. Rankin ©

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A CAUTION TO THE READER

ABSTRACT

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Key Words: riparian vegetation structure, watershed, stream, surficial geology, *Alnus rugosa*, *Picea mariana*.

The primary goal of this study was to examine the physical and biological structure of riparian zones along streams in the Boreal forest of Northwestern Ontario and to discover whether riparian structure was related to key hydrologic variables, including watershed area and surficial geology. The first objective was to verify the relationship between watershed area and physical and hydrological stream characteristics including discharge, temperature, and gradient. The second objective was to determine the variability in stream characteristics within a watershed scale based on differences in physical and hydrological drainage basin characteristics. The third objective was to describe the differences in the vegetation communities in riparian zones and upland communities. The fourth objective of the study examined riparian structure and composition along streams within watersheds that differ in physical and hydrological characteristics. The Mackenzie, Wolf, and Spruce River watersheds were used in a nested sampling design with watershed area class as a grouping variable. A total of 40 streams were sampled having approximately 1 (n = 12), 10 (n = 12), 40 (n = 8) and 100 (n = 8) km^2 watersheds. Stream discharge, temperature and gradient, and riparian width and slope were measured while surficial geology was evaluated. Riparian and upland plots were sampled on both sides of the stream and vegetation species were recorded. The results showed clear relationships among physical and hydrological stream and drainage basin characteristics and riparian vegetation structure. As drainage area increased, stream discharge and temperature increased and stream gradient decreased. Stream temperature and gradient were lowest in streams with meadow marsh riparian zones. Riparian width decreased while riparian slope increased with increases in drainage area. Riparian width was greatest, and riparian slope least in meadow marsh riparian zones, while the width was narrowest and slope greatest in conifer swamp riparian zones. Streams with both 1 and 10 km^2 watersheds had riparian zones which had lower vegetation species diversity than the surrounding upland timber zone. A discriminant function analysis revealed Speckled Alder, Aspen, and Beaked Hazel characterizing the riparian zones of smaller streams (1 km^2 watershed), grasses and sedges characterizing the riparian zones of intermediate sized streams (10 km^2 watershed), and Cedar, Honeysuckle and Currants characterizing riparian zones around large streams (100 km^2 watersheds). There was a positive relationship between drainage area and the drainage basin's surface roughness, width/depth ratio, and stream channel sinuosity, while there was a negative relationship between drainage area and the drainage basin's stream channel and basin slopes. This study characterized riparian vegetation structure along a stream continuum to understand better the structure and function of riparian communities and will be used as part of a first step towards assessing the possible effects of timber harvesting on aquatic ecosystems to ensure the effective management of riparian forest ecosystems.

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1.0 INTRODUCTION

A riparian zone refers to an area of unique biotic communities found along the shores of streams and lakes. It is the interface between the aquatic and terrestrial ecosystem which has uniquely defined characteristics (Holland *et al.*, 1991), and possesses an unusually diverse array of species and environmental conditions (Naiman and Décamps, 1997). Riparian vegetation can be found from the low water stream bank to the high water mark or seasonal flood plain. The width of the riparian zone is generally related to the size of the stream, position of the stream within the drainage network, hydrologic regime, and local geomorphology (Naiman and Décamps, 1997).

Riparian zones are functionally linked to streams and provide a variety of essential functions. The riparian vegetation acts as a transition zone between terrestrial and aquatic ecosystems (Malanson, 1993), balances allochthonous inputs to the stream channel (Vannote *et al.*, 1980; Wallis *et al.*, 1979), regulates the movement of both surface and subsurface flows (Brinson *et al.*, 1980), and prevents stream bank erosion (Beeson and Doyle, 1995). The riparian zone also provides critical habitat for a variety of terrestrial organisms (Malanson, 1993). Many studies have shown that the condition of the stream and riparian zone are linked, each providing an essential component for the other (Bren, 1993; Cummins *et al.*, 1995; Naiman and Décamps, 1997).

Riparian ecosystems are fundamental in the regulation and balance of the inflow and outflow of organic material and nutrients essential for the aquatic ecosystem (Shure and Gottschalk, 1985). The riparian zone acts as both a source and a sink for nutrients and organic matter for the aquatic ecosystem (Mulholland, 1992). It acts as an adsorption bank by trapping organics, nutrients and sediments in the riparian vegetation during overland and underground flows (Rostan *et al.*, 1987; Brinson *et al.*, 1980), while contributing nutrients to the stream through litterfall and decay (Grubaugh and Anderson, 1989). This regulation of allochthonous energy input is required by the ecosystem in varying amounts depending upon the stream's energy levels (Malanson, 1993).

Riparian vegetation contributes nutrients, dissolved organic matter, coarse and fine particulate organic matter and woody debris to the aquatic ecosystem (Grubaugh and Anderson, 1989). In smaller tributary streams, these allochthonous inputs are required by the stream because it derives most of its energy input from the surrounding riparian zone to maintain the aquatic food chain (Décamps, 1984; Vannote *et al.*, 1980). In these low productivity headwater streams, the riparian vegetation can control the inputs of sediment, carbon (Fiebig *et al.*, 1990), and adsorbed phosphorus, while contributing a slow input of phosphorus and nitrogen through leaf litter (Vannote *et al.*, 1980). Larger streams, with greater drainage areas, have relatively higher autochthonous energy production and are less dependent upon terrestrial energy inputs. Wood debris provides structure to the stream channel, capturing organic matter and erosional materials (Bilby, 1981; Macdonald and Keller, 1987), providing habitat for fish, macroinvertebrates and other terrestrial species (Harmon *et al.*, 1986; Meehan, 1991).

Riparian vegetation affects and regulates the movement of both surface and subsurface flows (Brinson *et al.*, 1980), acting as an overall control for the movement of energy and materials through the ecosystem (Shure and Gottschalk, 1985). The ability of the riparian zone to prevent eroded sediment (organic material and mineral soil from upland areas) from entering the stream is dependent upon its vegetation characteristics (Ryan and Grant, 1991; Griffiths, 1980). Rates of sediment movement are also dependent upon the soil type, root strength and resilience, microtopography (Griffiths, 1980), and bank slope (Trimble and Sartz, 1957). The amount of sediment trapped depends upon the geomorphology of the site and the spatial distribution of the riparian forest within the watershed (Schlosser and Karr, 1981). Riparian vegetation can also prevent stream channel and bank erosion. In an undisturbed regime, channel and bank erosion are the major sources of sediment transport into stream ecosystems, and are 30 times more prevalent on non-vegetated compared with vegetated banks which are exposed to currents (Beeson and Doyle, 1995).

The riparian zone is an integral component of a healthy aquatic and forest ecosystem (Naiman and Décamps, 1997). Riparian areas are used as a general landscape corridor as well as preferred habitat for a variety of terrestrial species (Malanson, 1993). Many species of small mammals (McComb *et al.*, 1993) and birds (Darveau *et al.*, 1995) have been reported to use the riparian habitat to a greater degree than the surrounding upland areas.

Disturbance of the riparian vegetation can affect stream ecosystems. From an aquatic perspective, disturbance of the riparian vegetation can cause increased sediment movement through the riparian zone and into the stream ecosystem (Malanson, 1993). Increased sediments in stream ecosystems can cause the lowering of dissolved oxygen levels, decreased fish and invertebrate feeding ability, destruction of spawning beds, and even the smothering of fish, invertebrates, and in-stream vegetation (Bren, 1993). Other undesirable elements such as aluminum, lead, cadmium, as well as toxic chemicals such as petroleum products and pesticides being transported in surface runoff, can also more easily enter the stream ecosystem through a disturbed riparian area (Malanson, 1993).

Stream bank or channel erosion is more likely to take place where there has been disturbance to vegetation or soil (Malanson, 1993). Disturbances resulting in erosion can be both natural or human caused (Mitsch *et al.*, 1979). Removal of the riparian vegetation through forest harvesting, agriculture, or urbanization are human induced disturbances which can result in stream bank erosion (Malanson, 1993). Disturbance of any type in the riparian zone can alter the cycling characteristics of this fragile part of the ecosystem.

Destruction of riparian vegetation has been shown to cause local extinction of bird communities and reductions in the ability of some populations to recolonize sites (Knopf and Samson, 1994). Immediately following forest harvesting activities, boreal forest bird densities reportedly increase in neighbouring riparian zones by 30 to 70 percent, declining to baseline numbers during the following years (Darveau *et al.*, 1995), showing the importance of the riparian zone to the terrestrial ecosystem.

In order to minimize or ameliorate the effects of land-use practices on aquatic ecosystems the use of riparian buffer zones has become an increasingly common land-use practice (Large and Petts, 1996). Riparian buffer zones are natural or semi-natural vegetated areas along stream margins (Large and Petts, 1996). It has been demonstrated that riparian buffers protect water quality by the removal of excessive amounts of sediment and nutrients carried in surface runoff after land use disturbances (Large and Petts, 1996, Naiman and Décamps, 1997).

In Ontario's Boreal forest, the primary land-use is forest harvesting. Forest harvesting has been demonstrated to produce many of the negative effects already discussed in a variety of forest types (Steedman and Morash, 1998). To reduce the potential of forest harvest activities resulting in excessive sediment transport into aquatic ecosystems, riparian management guidelines were introduced in the Ontario Ministry of Natural Resources Timber Management Guidelines for the Protection of Fish Habitat (OMNR, 1988). The OMNR guidelines prescribe slope-dependent riparian reserve areas (buffers) of 30 to 90 metres around all streams and lakes. These buffer strip widths are based on a model used to predict how far inorganic sediment travels down different slopes (Trimble and Sartz, 1957).

There is concern over Ontario's guidelines for two main reasons. Riparian structure and function are very complicated and are related to many factors other than slope. There has been insufficient research to determine whether the guidelines adequately protect enough riparian community to filter effectively the potential increase in surface sediment movement resulting from timber harvest activities and thereby protect aquatic habitat. Riparian communities in Ontario's Boreal forest have yet to be adequately characterized in terms of their structure and composition along a river continuum. This argues for the need of a drainage basin perspective for research on riparian habitats (Frissell *et al.*, 1986; Knopf and Samson, 1994).

However, the riparian forest can also be an important source of timber, with trees generally growing at a faster rate and with better form (Bren, 1993). This leads to economic pressures for increased harvesting in riparian reserve areas. Since the width of stream buffers generally encompasses a portion of merchantable timber, forest harvesting companies are required to leave these high value commercial trees behind in the buffer strips. There is concern that the current guidelines are too conservative and leave a reserve area larger than is necessary to protect riparian zone structure and function.

The variability in structure and function of riparian areas changes depending upon their location in the drainage basin (Vannote *et al.*, 1980). As drainage area increases, the energy levels of the aquatic ecosystem increase, creating very different ecosystems in structure and composition from headwaters to mouth. A variety of authors have discussed the relationship between drainage basin and stream ecosystems (Bilby, 1981;

Morisawa, 1968; Norris, 1993; Vannote *et al.*, 1980; *etc*). Geological characteristics of drainage basins can also have far reaching effects on hydrology at a variety of scales, particularly on constraining the nature and level of fluvial activity (Knighton, 1984). This further complicates the pattern of riparian structure and function along a river continuum. The goal of this study is to examine the physical and biological structure of riparian zones along streams in the Boreal forest and to determine if riparian structure is related to key hydrologic variables including watershed area and watershed surficial geology. The first objective is to verify that there is a relationship between watershed area and physical and hydrological stream characteristics including discharge, temperature and gradient. It is predicted that stream temperature and discharge will be positively related to watershed area while stream gradient will be negatively related to watershed area.

The second objective is to determine the variability in stream characteristics within a watershed scale based on differences in physical and hydrological drainage basin characteristics. Within 1 km^2 watersheds it is predicted that discharge variability will be associated with variation in surficial geology, percent lake and wetland area, and surface roughness within the watershed. It is hypothesized that an increasing dominance of bedrock surficial geology and decreasing surface roughness and lake and wetland area in the drainage basin will show increased discharge variability in small (1 km^2 drainage basin) tributary streams.

The third objective of the study is to describe the differences in the vegetation communities in riparian zones and upland communities. It is predicted that these two vegetation communities will be distinct due to differences in species' flood tolerances and that riparian zones will have higher species diversity than upland areas due to a richer nutrient regime (Naiman and Décamps, 1997).

Assuming that riparian vegetation communities are distinct from uplands, the fourth objective of the study is to examine riparian structure and composition along streams within watersheds that differ in physical and hydrological characteristics. It is predicted that there will be a relationship between watershed variables, including basin area, surface roughness and surficial geology, and riparian structure and composition. More precisely, it is predicted that drainage area is positively related to the width of the riparian zone, and drainage basin characteristics and riparian vegetation structure and composition are associated with basin area.

The discussion will address the need to characterize riparian vegetation structure along a river continuum as part of a first step towards assessing the possible effects of timber harvest on aquatic ecosystems. By predicting stream and riparian zone characteristics from geographic information system (GIS) measurements of drainage basins, possible indicators of the susceptibility of a stream to disturbance by forest harvesting may be found. This information can also be used to understand better the structure and function of riparian communities and ensure their effective management during timber harvest.

2.0 METHODS

2.1 Site Selection Procedures

2.1.1 Watershed Delineation

Watersheds in the Mackenzie, Wolf, and Spruce River systems were delineated in a nested sampling design with watershed area class as a grouping variable. Each of these watersheds are within the Lake Superior Basin of Northwestern Ontario's Boreal forest. In order to reduce the sample size required, watershed area was treated as a categorical variable with 4 categories. The size categories had a range of catchment areas within each (shown in parentheses) and are referred to as 1 (0.4-2.2 km^2), 10 (4.4-13.5 km^2), 40 (28.5-59.8 km^2) or 100 km^2 (70-169 km^2) (Figure 2.1). The watershed delineation was completed using a raster based digital elevation model (DEM) generated through the use of the Environmental Systems Research Institute's (ESRI) geographic information systems (GIS) software packages ARC/INFO and ArcView. Watershed boundaries were based upon the drainage basin's topographic divide as defined by the DEM.

Generation of the DEM was completed using ARC/INFO with the TIN (Triangulated Irregular Network) extension. To accomplish this, all Ontario Base Map (OBM) layers for each of the three river systems were edge-matched and map-joined using ARC/INFO to provide continuous coverage over the entire sampling area. The map extents of these

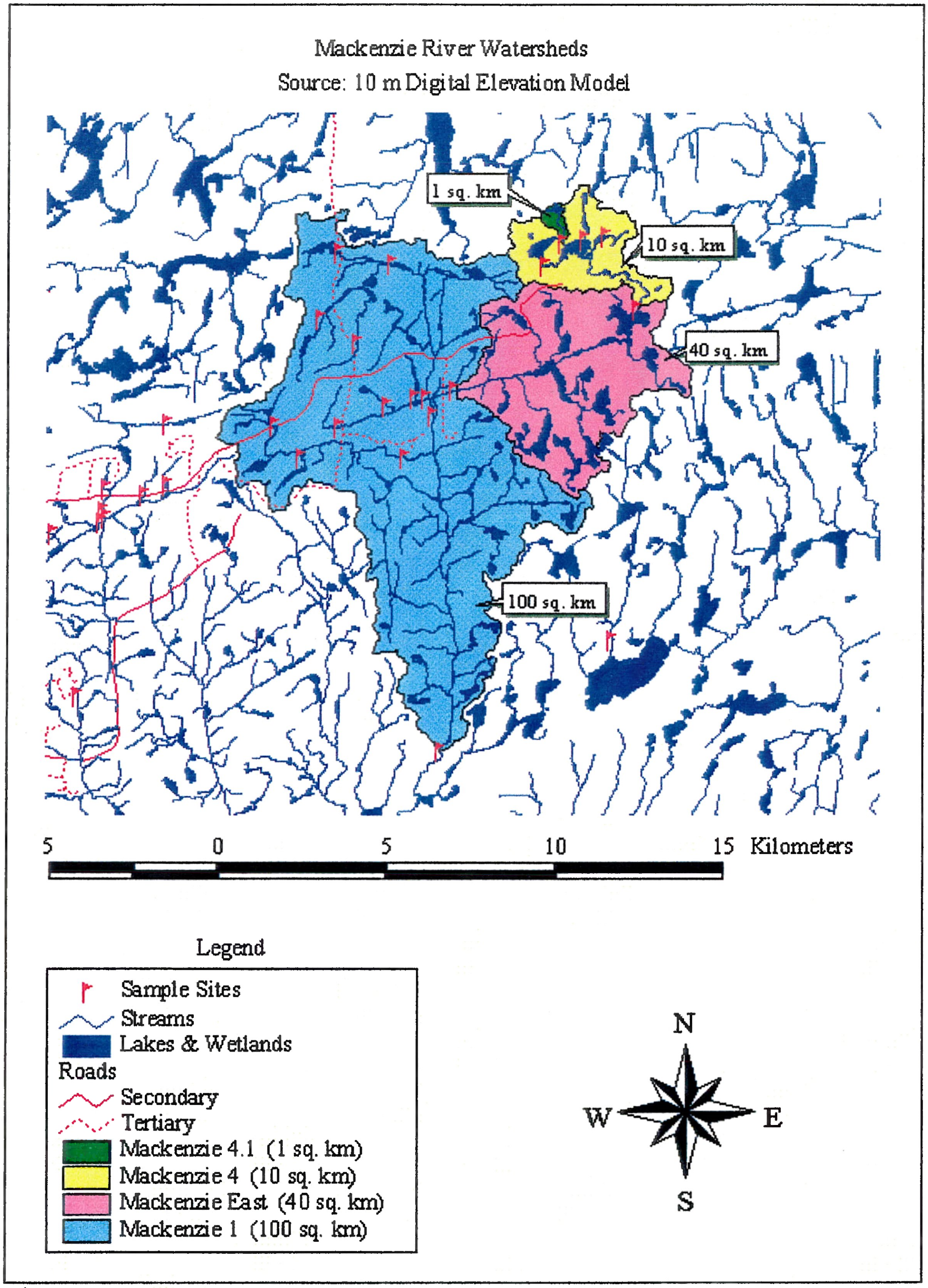

Figure 2.1. Illustration of the nested sampling design

OBM map sets extended beyond the topographic boundaries for the river systems being studied. Using ARC/INFO, a TIN was generated from the digital terrain model (DTM) points or contour vectors where the DTM was not available. A grid lattice with a 10 metre cell size was then created based upon the TIN for use as a DEM in ArcView.

In ArcView, the Spatial Analyst and Hydrological Modeling extensions were used to fill the sinks in the grid lattice (DEM). Sinks are the areas of the grid where the surface flow of water accumulates at a depression having no outlet. This is done to ensure that there is always an outlet for every possible cell on the grid. After filling the sinks, a flow direction grid was created from the filled grid indicating one of eight possible paths for surface runoff to flow for every cell (N, NE, E, SE, S, SW, W, NW). A flow accumulation layer was generated from the flow direction layer which calculated the number of cells which flowed into each cell on the grid and assigned a flow accumulation value to every cell. With these layers created the Hydrological Modeling extension was used to delineate watersheds and pour points where potential sampling sites (with approximate watershed areas of 1, 10, 40 or 100 km^2) could be located, basing the stream networks on the flow accumulation layer and delineating the topographic divides based on the filled DEM.

2.1.2 Site Selection

Final selection of actual sampling sites from the potential sites was based upon accessibility (road network) and time constraints (distance from Thunder Bay and length of field season). In general, the sites were selected in the Mackenzie, Wolf, and Spruce River drainage basins, with the majority of the sites being within the Mackenzie River basin (approximately 45 km northeast of Thunder Bay, Ontario, Figure 2.2). Information was gathered from a representative number of sites from each watershed area class (Table 2.1).

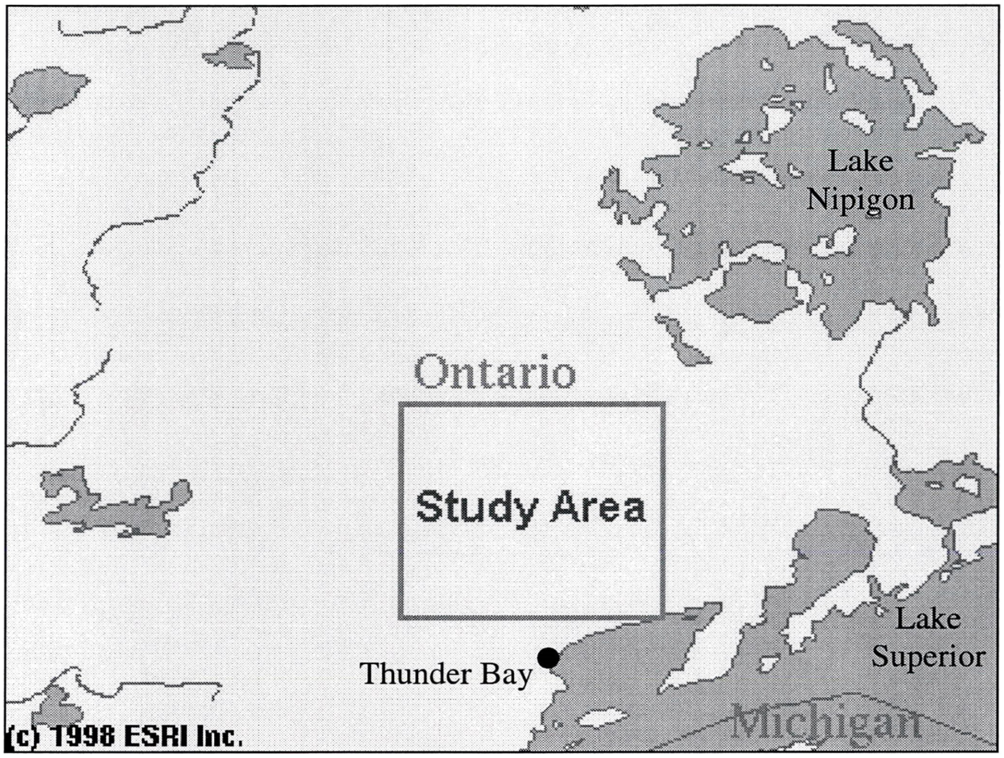

Figure 2.2. General location of the study watersheds within Northwestern Ontario.

Table 2.1. Total sites sampled within each watershed area class.

	Watershed Area Class				
	1 km²	10 km²	40 km²	100 km²	Total
Sample Sites	12	12	8	8	40

2.2 **Field Procedures**

2.2.1 Stream Sampling

Streams were sampled during the summers of 1997 and 1998 between May 20 and August 19 when the stream discharge was at base-flow. All sampling sites were outside the influence of any road corridor. At each site, stream temperature and discharge were measured. Discharge was measured at a point of relatively uniform cross-sectional flow in the stream. Water depth and velocity at 60% depth were measured using a Marsh McBinney flow meter at 20 points across a transect. Discharge (Q) was calculated using the formula:

$$[1] \qquad Q = \sum_{i=1}^{20} (\text{interpoint distance x depth x velocity})$$

To assess the discharge variability in small tributary streams (1 km^2 watershed area), periodic measurement of discharge was taken throughout the summer. This was done at a two week interval for ten tributary streams within the Mackenzie River watershed beginning on May 12, 1998 and ending August 28, 1998.

2.2.2 Physical Site Characteristics

Riparian width and slope was measured with three transects spaced at 20 metre intervals, downstream, middle and upstream, on both sides of the stream sampling site (3 per bank,

Figure 2.3). The middle transect extended either 30 metres up the bank or at least 10 metres into the upland zone, whichever was greater. This middle transect was used to assess the entire bank profile on both sides of the stream reach by measuring the slope and distance between each change in elevation along the transect. The gradient (% slope) of the homogeneous stream reach (ranging from 40 to 95.6 metres in length) was also measured. This was completed for all 40 sites using standard methods for each site. Detailed procedures and data collection sheets are given in Appendices I and II, respectively.

2.2.3 Vegetation Sampling

The riparian and upland vegetation was classified using the Wetland Ecosystem Classification (WEC, Harris *et al.*, 1996) and Forest Ecosystem Classification (FEC, Sims *et al.*, 1989) protocols for Northwestern Ontario. This involved assessing the percent cover of all trees, shrubs, and herbs by using 5 by 5 metre and 10 by 10 metre vegetation plots in the riparian and upland zones, respectively (Figure 2.3). At the middle bank transect, riparian plots were set along both sides of the stream bank with the downstream side of the plot being on the middle bank transect, while the upland plots were set at the end of the middle bank transect or at least 10 metres into the upland zone.

Soil was collected by core sampling to assist in WEC (Harris *et al.*, 1996) and FEC (Sims *et al.*, 1989) typing. This involved the assessment of the surface layer type and thickness, the organic matter and first mineral horizon type and thickness, depth to mottles (if

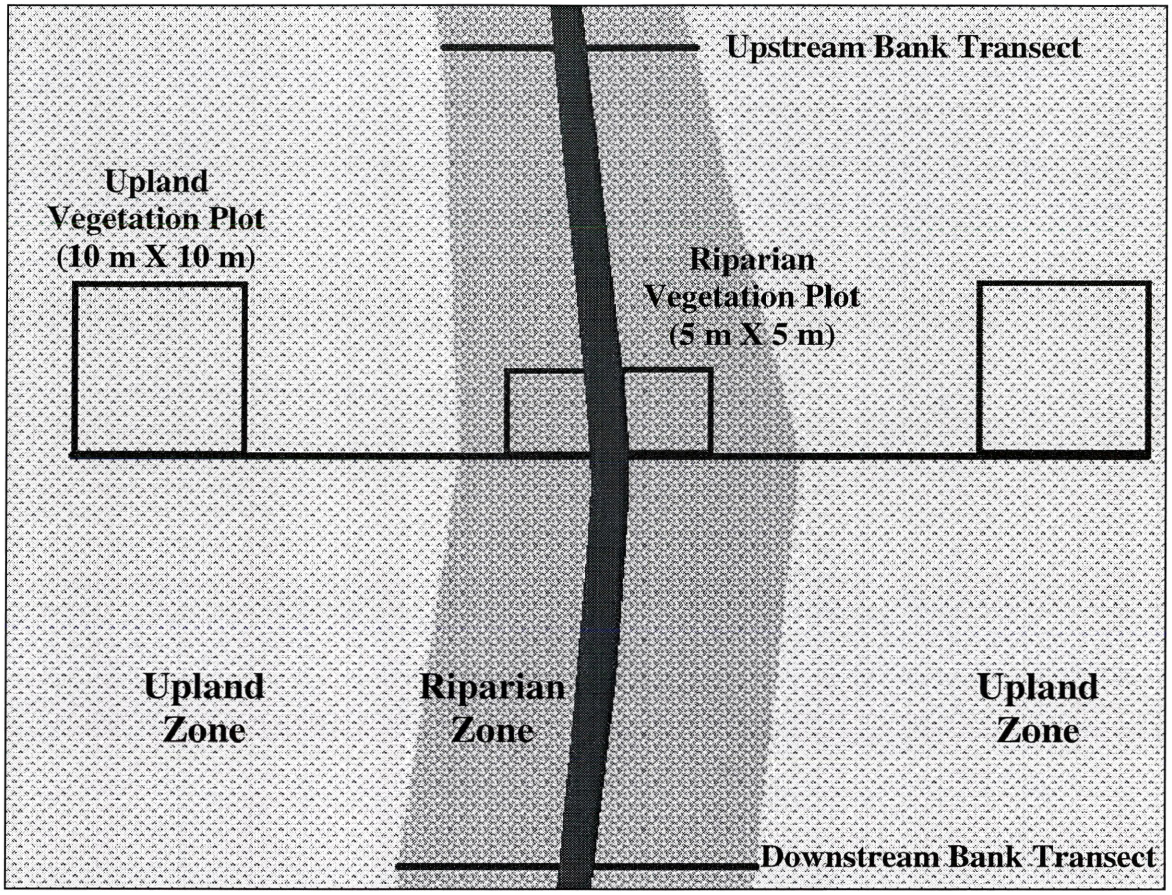

Figure 2.3. Site layout of bank transects and vegetation plots.

present), and the depth and type of restricting layer (Sims *et al.*, 1989). These samples were taken at the center of each of the vegetation plots in both the riparian and upland zones.

2.3 Lab Procedures

2.3.1 GIS Procedures

GIS was used to collect information on physical and hydrological drainage basin characteristics. These characteristics included basin shape, area of lake and wetlands, stream channel sinuosity, surface roughness, basin and stream channel slope, and surficial geology. Information for each characteristic was collected using ArcView software, while the generation of DEMs was accomplished using ARC/INFO. The calculation of some of these variables involved the measurement of such attributes as length, width and depth of the drainage basin (Figure 2.4), while the calculations used were as follows:

[2] Percent Area of Lake and Wetlands = [area of lakes and wetlands (ha) / total basin area (ha)] * 100

[3] Index of Basin Shape = length of basin (m) / width of basin (m)
(Note: Basin width measured at 50% of the basin length)

[4] Width to Depth Ratio = width of basin measured at 50% of basin length (m) / average depth of basin profile (m)

[5] Basin Slope = basin elevation change (m) / basin length (km)

[6] Stream Slope = change in elevation from headwaters to mouth (m) / length of stream channel (km)

[7] Index of Sinuosity = stream channel length (m) / overland stream distance (m) from headwaters to mouth

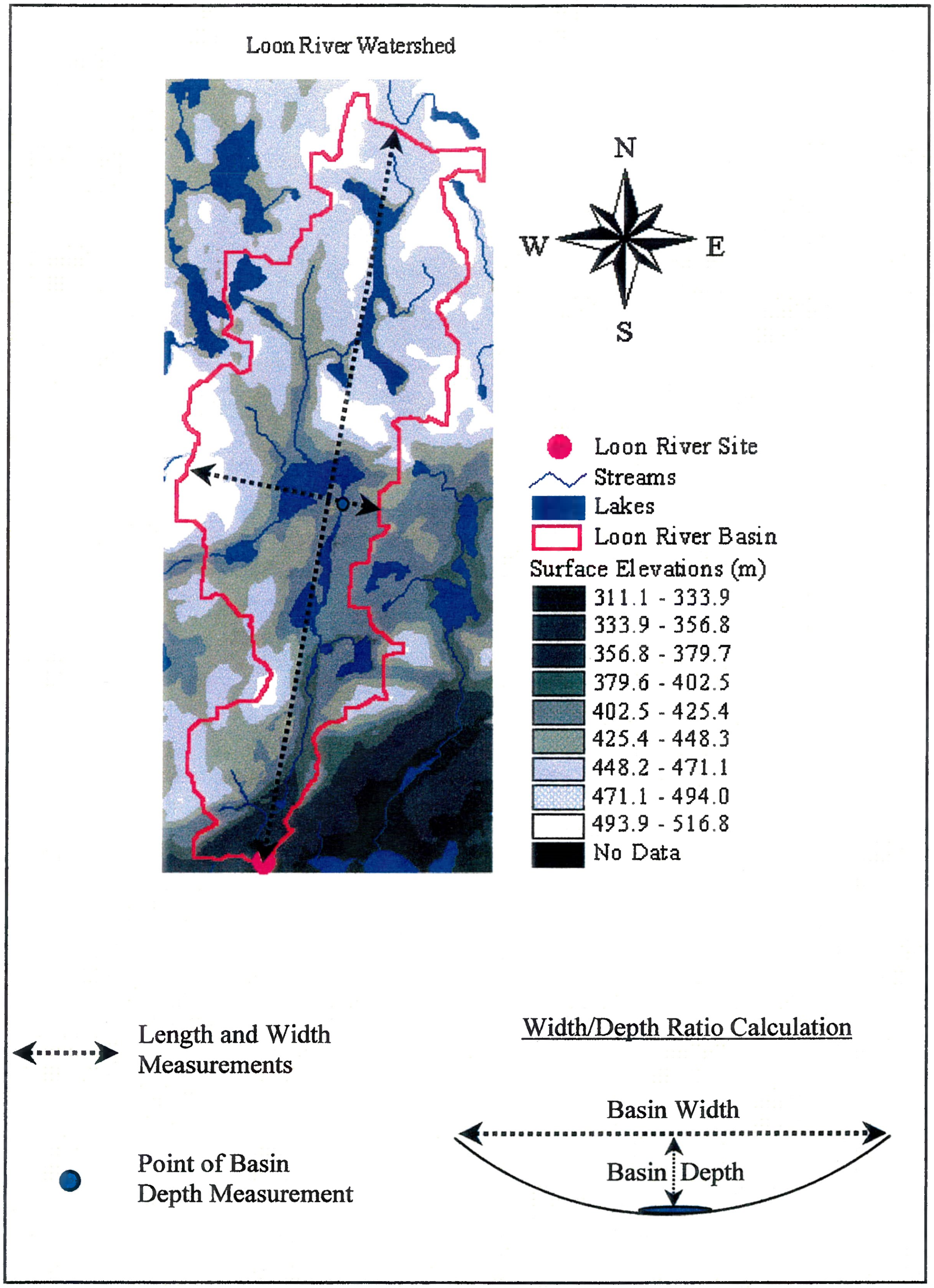

Figure 2.4. An example of the measurement of drainage basin variables.

[8] Index of Surface Roughness = Coefficient of Variation (CV) in elevation values within watershed (using a 25 by 25 m grid cell size) where:

CV = standard deviation / mean

The surficial geology of the drainage basin as well as the surrounding sampling site was assessed using Northern Ontario Engineering Geology Terrain Study maps (NOEGTS, 1985). This involved measuring the percentage of both the primary and secondary dominant and subordinate landforms, materials and drainage within the watershed.

2.3.2 Statistical Procedures

Within the four watershed area classes, data were collected at three distinct spatial scales: in-stream, riparian (immediately adjacent to the stream sampling site), and drainage basin. Therefore, the data were analyzed in this order of increasing spatial scale. Relationships within spatial scales were examined using grouping variables such as watershed area class, Wetland Ecosystem Classification group, and dominant surficial geology. All data collected was transformed where necessary to meet analysis assumptions of equal variance among groups.

Relationships among physical and hydrological stream characteristics, drainage basin area and WEC types were examined. This was completed in SPSS using a one-way analysis of variance (ANOVA) which tested for differences among group means, while

Tukey's Honestly Significant Difference (HSD) test (with $\alpha = 0.05$) indicated significant differences between individual group means.

Absolute discharge of small tributary streams (1 km^2 watersheds) was examined by date and geology using a 2-way ANOVA. The variability in discharge measurements was also examined for relationships with physical and hydrological stream and drainage basin characteristics. The discharge variability was calculated using the coefficient of variation. Analyses were completed using one-way ANOVAs to test for differences in the mean CV in discharge between bedrock and morainal dominated watersheds as well as site surficial geology.

At the riparian spatial scale a Discriminant Function Analysis (DFA) was used to determine the main species community differences between the riparian and upland zones. Common names of vegetation species were used in the analyses for simplification (Table 2.2). This analysis was also used to determine if the riparian zone has a distinctly different vegetation community from the upland zone. The species diversity of the riparian and upland vegetation communities were compared to test the hypothesis that diversity in vegetation communities differed between riparian and upland zones. The species diversity index was calculated using the following equation (Krebs, 1985):

$$[9] \quad \text{Species Diversity Index} = \frac{\text{total number of species found on site (or zone)}}{\text{grand total of all species found on all sites (or zones)}}$$

Table 2.2. Common and scientific names of vegetation species used in analyses (Source: Baldwin and Sims, 1993; Newmaster *et al.*, 1997).

Common Name	Scientific Name
Balsam Fir	*Abies balsamea* L. (Mill)
Mountain Maple	*Acer spicatum* Lam.
Speckled Alder	*Alnus incana* (Du Roi) Spreng.
Serviceberry	*Amelanchier spp.*
Anemone	*Anemone spp.*
Grasses	Poaceae and Cyperaceae
Bunchberry	*Cornus canadensis* L.
Red-Osier Dogwood	*Cornus stolonifera* Michx.
Beaked Hazel	*Corylus cornuta* Marsh.
Broom Mosses	*Dicranum spp.*
Ferns	Dryopteridaceae
Twinflower	*Linnaea borealis* L.
Honeysuckle	*Lonicera spp.*
Clubmosses	*Lycopodium spp.*
Wild-Lily-of-the-Valley	*Maianthemum canadense* Desf.
Black Spruce	*Picea mariana* (Mill.) BSP.
Trembling Aspen	*Populus tremuloides* Michx.
Currant spp.	*Ribes spp.*
Rasberry spp.	*Rubus spp.*
Willow spp.	*Salix spp.*
Ash spp.	*Sorbus spp.*
Sphagnum mosses	*Sphagnum spp.*
Early Meadow Rue	*Thalictrum dioicum* L.
Eastern White Cedar	*Thuja occidentalis* L.
Starflower	*Trientalis borealis* Raf.
Violets	Violaceae

To test whether species diversity differed between riparian and upland a 2 sample t-test was used ($\alpha = 0.05$) to compare the two zones around all the sample sites. A 2-way ANOVA (with a Tukey HSD test) was used to test whether there was a relationship between riparian and upland species diversity both within and among watershed area classes and WEC communities.

The relationship between the physical structure (width and slope) of the riparian zone with both watershed area class and WEC groups was examined using a one-way ANOVA (with a Tukey HSD test). The variability in the riparian width and slope measurements was also examined to show the degree of variation in measurements among the downstream, middle and upstream transects at each site. The degree of variation was calculated by using the coefficient of variation (standard deviation / mean) and tested for relationships among watershed area class with an ANOVA.

Within the riparian spatial scale, a DFA was used to examine how riparian vegetation differed among watershed area classes. Due to the constraints of the analysis and the number of field sample sites the 40 km^2 watersheds were dropped for the DFA of vegetation species. This analysis was important in revealing species composition differences in riparian communities which may be related to watershed area class.

To determine which physical and hydrological variables best differentiated watershed area classes, a DFA was used. One-way ANOVAs were used to further examine how physical and hydrological drainage basin characteristics varied among watershed area classes as well as surficial geology and WEC types.

3.0 RESULTS

3.1 Physical and Hydrological Stream Characteristics

Results of the *a priori* stratification of watershed areas consisted of streams with 1, 10, 40, or 100 km^2 watershed area classes (Table 2.1), riparian zones grouped into meadow marsh, conifer swamp, or hardwood swamp WEC types (Table 3.1), and dominant watershed surficial geology grouped into bedrock compared with morainal landforms (NOEGTS, 1985; Table 3.2).

Stream discharge significantly increased with watershed area (ANOVA, $F = 37.47$, $P < 0.001$). Streams with 100 km^2 watersheds had a significantly greater mean discharge than streams with 1, 10, and 40 km^2 watersheds (Tukey's HSD test, $\alpha = 0.05$); however, mean discharges in the later three watershed area classes were not significantly different from each other (Figure 3.1).

The mean stream temperature increased with watershed area class (ANOVA, $F = 5.93$, $P = 0.0023$). Streams with 100 km^2 watersheds, which had temperatures ranging from 12 to 23 °C, were significantly warmer than streams with both 1 and 10 km^2 watersheds, which had temperatures ranging from 7 to 21 °C (Tukey's HSD test, $\alpha = 0.05$, Figure 3.2). Streams with larger drainage basins accumulate greater amounts of solar radiation and surface runoff, which tends to be warmer than groundwater. However, an unexpected result was found when stream temperatures were separated by WEC groups.

Table 3.1. Count of Wetland Ecosystem Classification groups surveyed within each watershed area class.

	Wetland Ecosystem Classification Group				
Watershed Area Class (km^2)	Meadow Marsh	Conifer Swamp	Hardwood Swamp	non-classified	Total
1	2	0	10	0	12
10	5	1	5	1	12
40	0	4	4	0	8
100	0	2	6	0	8
Total	7	7	25	1	40

Table 3.2. Sample sites grouped into dominant watershed geology types.

	Dominant Watershed Landform			
Watershed Area Class (km^2)	Morainal Landform	Bedrock Landform	Other Landform	Total
1	6	6	0	12
10	4	7	1	12
40	3	5	0	8
100	2	5	1	8
Total	15	23	2	40

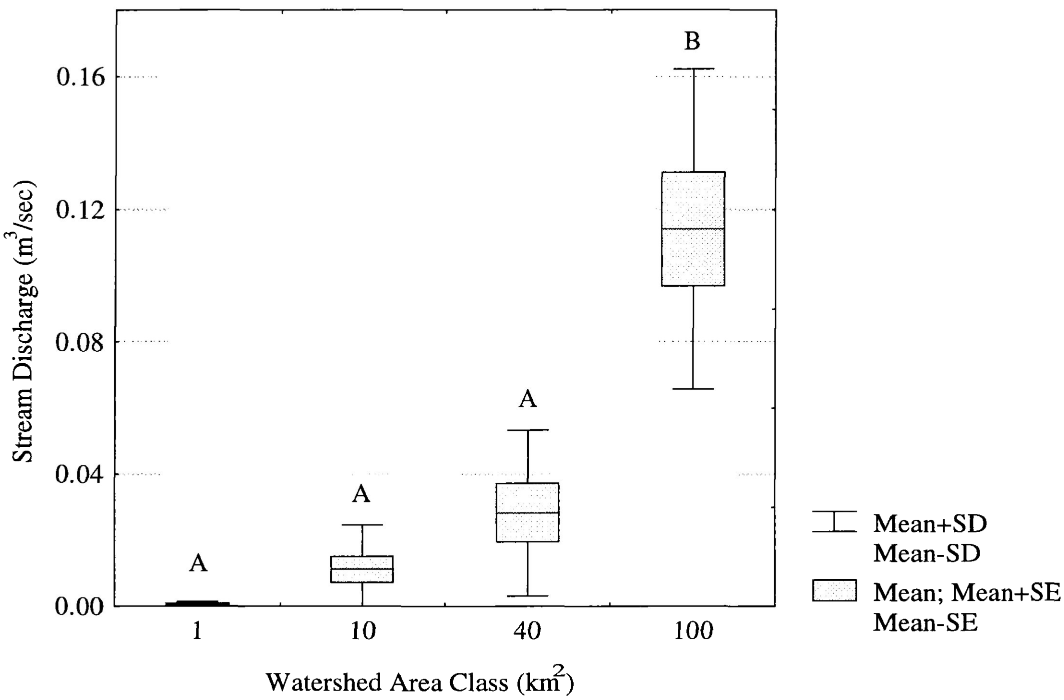

Figure 3.1. Mean and variability in stream discharge by watershed area class. Like groups of symbols (A or B) show watershed area classes which do not have significantly different mean stream discharges (Tukey's HSD test, $\alpha = 0.05$). Note: Boxplots illustrate the raw, untransformed data.

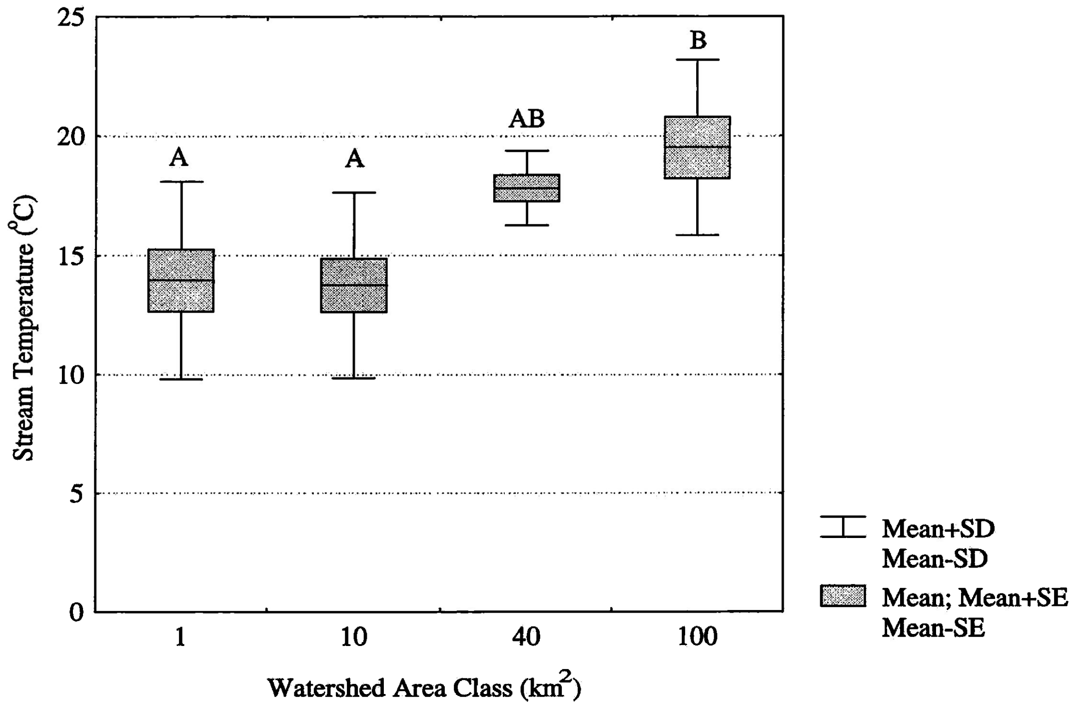

Figure 3.2. Mean and variability in stream temperature by watershed area class.

Streams with meadow marsh riparian zones were found to have significantly lower stream temperatures than those with either conifer or hardwood swamp riparian zones (ANOVA, $F = 6.68$, $P = 0.0141$, Tukey's HSD test, $\alpha = 0.05$, Figure 3.3). Streams with meadow marsh riparian zones also appeared to have the most variable temperatures (CV = 0.40), while streams with conifer and hardwood swamp riparian zones appeared to have the least variable temperatures (CV = 0.25, and 0.22, respectively).

Stream gradient tended to decrease with watershed area class, with smaller streams (1 km^2 basins) being steeper and more variable than larger streams (10 - 100 km^2) (Figure 3.4). This relationship was marginally significant among watershed area classes (ANOVA, $F = 2.53$, $P = 0.072$). However, when grouping streams by WEC groups (Figure 3.5), mean stream gradient was significantly lower in streams having Meadow Marsh riparian zones compared with streams having Conifer or Hardwood Swamp riparian zones (ANOVA, $F = 4.60$, $P = 0.039$ and Tukey-HSD test, $\alpha = 0.05$).

Within the 1 km^2 watersheds, absolute discharge measurements in watersheds with bedrock-dominated surficial geology did not differ from those with morainal-dominated surficial geology (2-way ANOVA, $F = 0.50$, $P = 0.48$). However, absolute discharge measurements did differ among sampling dates (2-way ANOVA, $F = 4.57$, $P = 0.001$). There was also no significant interaction between date sampled and geology in absolute discharge measurements (2-way ANOVA, $F = 1.27$, $P = 0.28$).

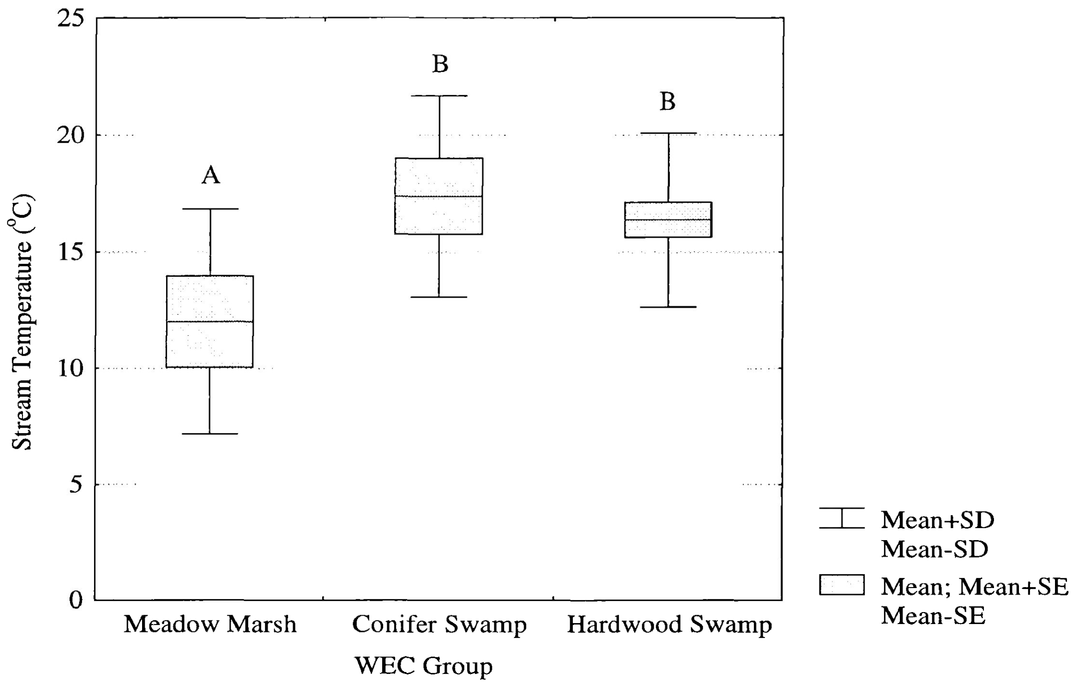

Figure 3.3. Mean and variability in stream temperature by WEC group.

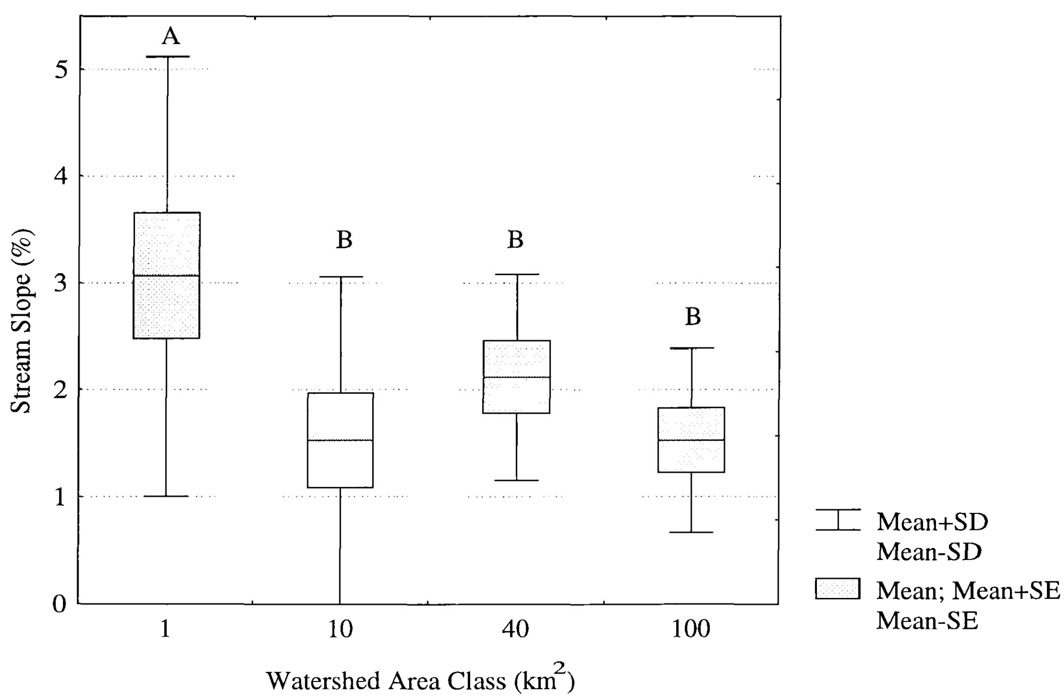

Figure 3.4. Mean and variability in stream gradient (site scale) by watershed area class.

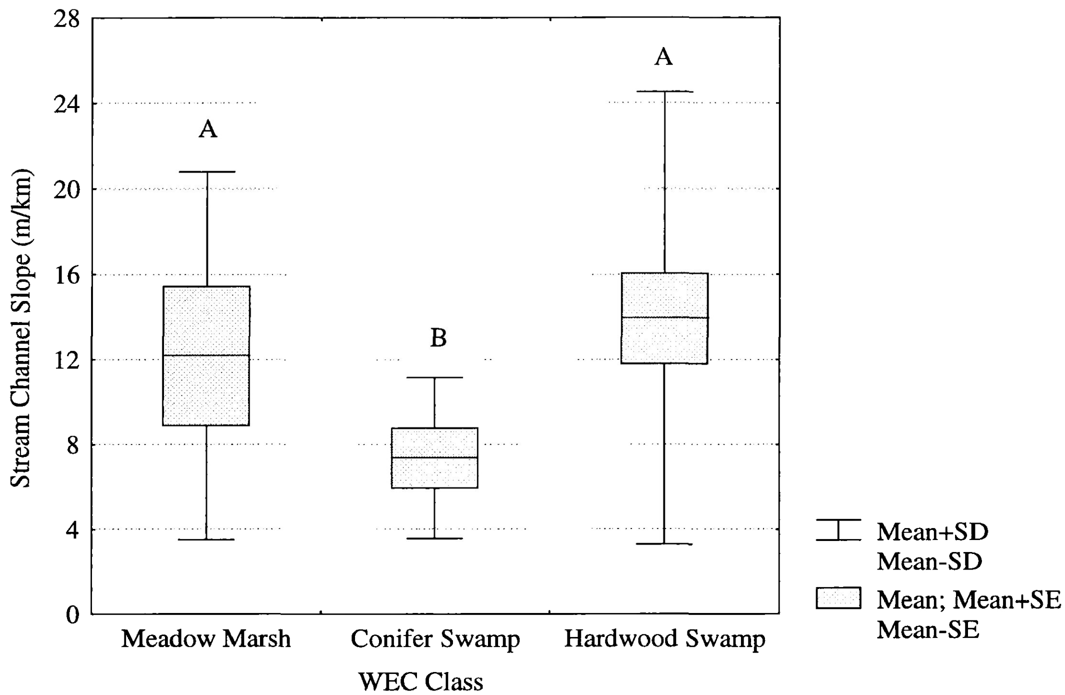

Figure 3.5 Mean and variability in stream gradient (site scale) by WEC groupings.

Streams with 1 km^2 watersheds having bedrock dominating either the watershed or the site surficial geology had higher mean coefficient of variations in discharge compared with morainal-dominated geology (ANOVA, $F = 6.21$, $P = 0.028$, and $F = 14.05$, $P = 0.006$, respectively). CV in discharge measurements ranged from 1.40 to 1.65 in bedrock-dominated watersheds and 0.98 to 1.55 in morainal-dominated watersheds. The ranges were similar for site surficial geology types, except that morainal sites had a range of 0.98 to 1.46 in CV of discharge measurements. Figures 3.6 and 3.7 illustrate the variablity in discharge of streams with 1 km^2 watersheds dominated by morainal and bedrock surficial geology, respectively.

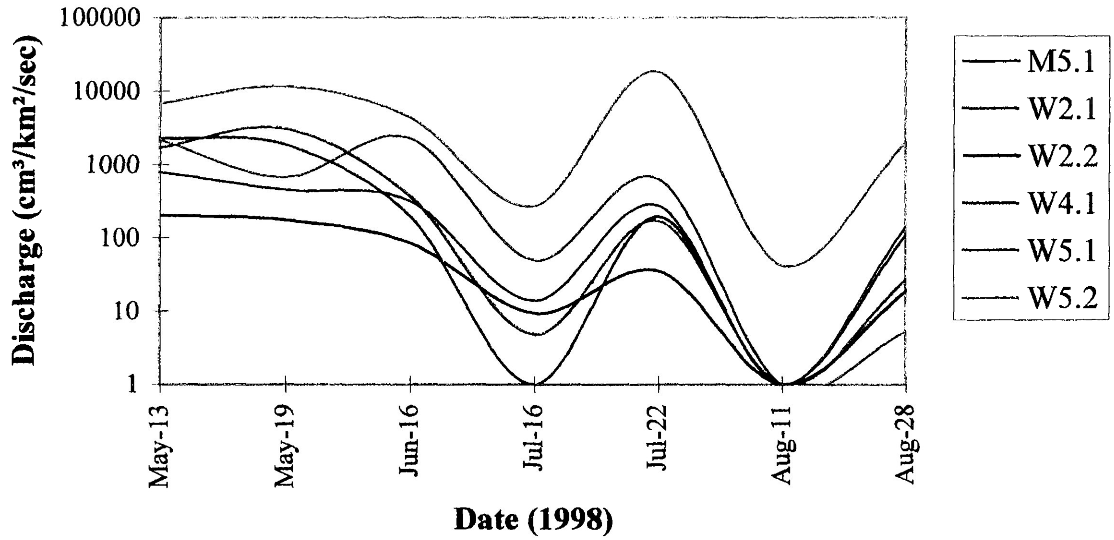

Figure 3.6. Discharge variability in watersheds with Morainal-dominated surficial geology.

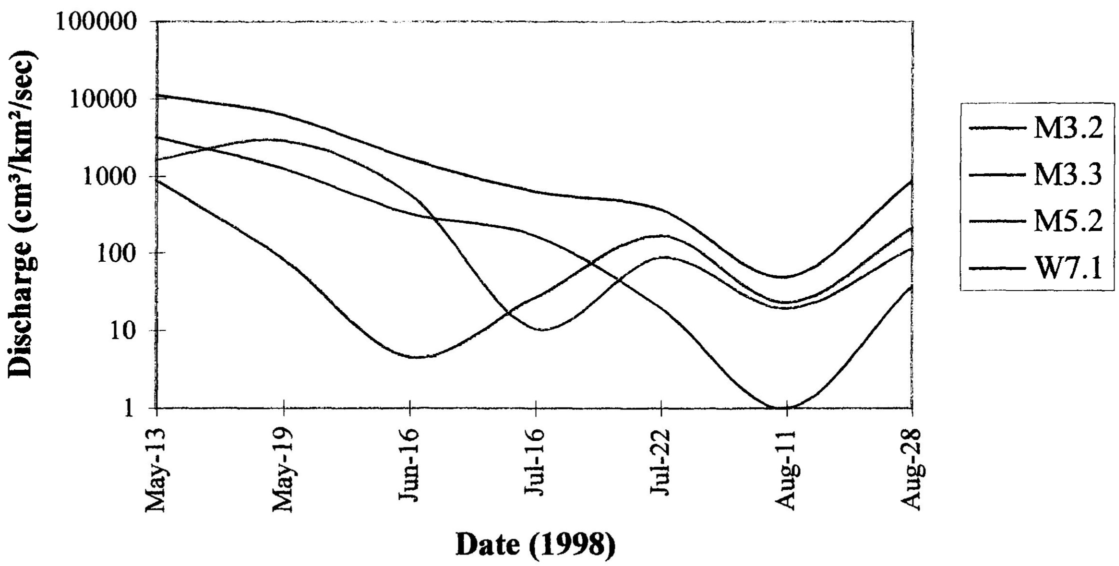

Figure 3.7. Discharge variability in watersheds with Bedrock-dominated surficial geology.

3.2 Riparian Vegetation Structure

There was a clear difference in vegetation structure between upland and riparian areas. Speckled Alder, Violets and grasses were the main species used by the DFA to classify the riparian zone, while Black Spruce, Balsam Fir, and Twinflower were the main species classifying the upland zone (Figure 3.8, Tables 3.3, 3.4). The DFA (canonical correlation coefficient of 0.86) correctly classified 77 of 80, and 78 of 80 plots in the riparian and upland zones, respectively, resulting in an overall classification efficiency of 97 percent.

Species diversity differed between riparian and upland zones with significantly higher diversity indices in the upland zone compared with the riparian zone of all streams (2-sample, $t = 3.59$, $P = 0.001$). Figure 3.9 illustrates the significant two-way interaction between the groupings of area class and riparian compared with upland revealed by a two-way ANOVA ($F = 3.19$, $P = 0.029$). The significant differences appear to occur in the riparian and upland zones within 1 and 10 km^2 rather than 40 and 100 km^2 watersheds. The differences also appear only in the riparian diversity indices, as the upland diversity indices among watershed area classes do not differ significantly.

Within riparian areas, species diversity was significantly higher in conifer and hardwood WEC types than in meadow marshes. Mean species diversity indices were 0.249 in conifer or hardwood WEC types and 0.106 in meadow marshes with standard deviations 0.064 and 0.055, respectively (ANOVA, $F = 26.23$, $P < 0.001$).

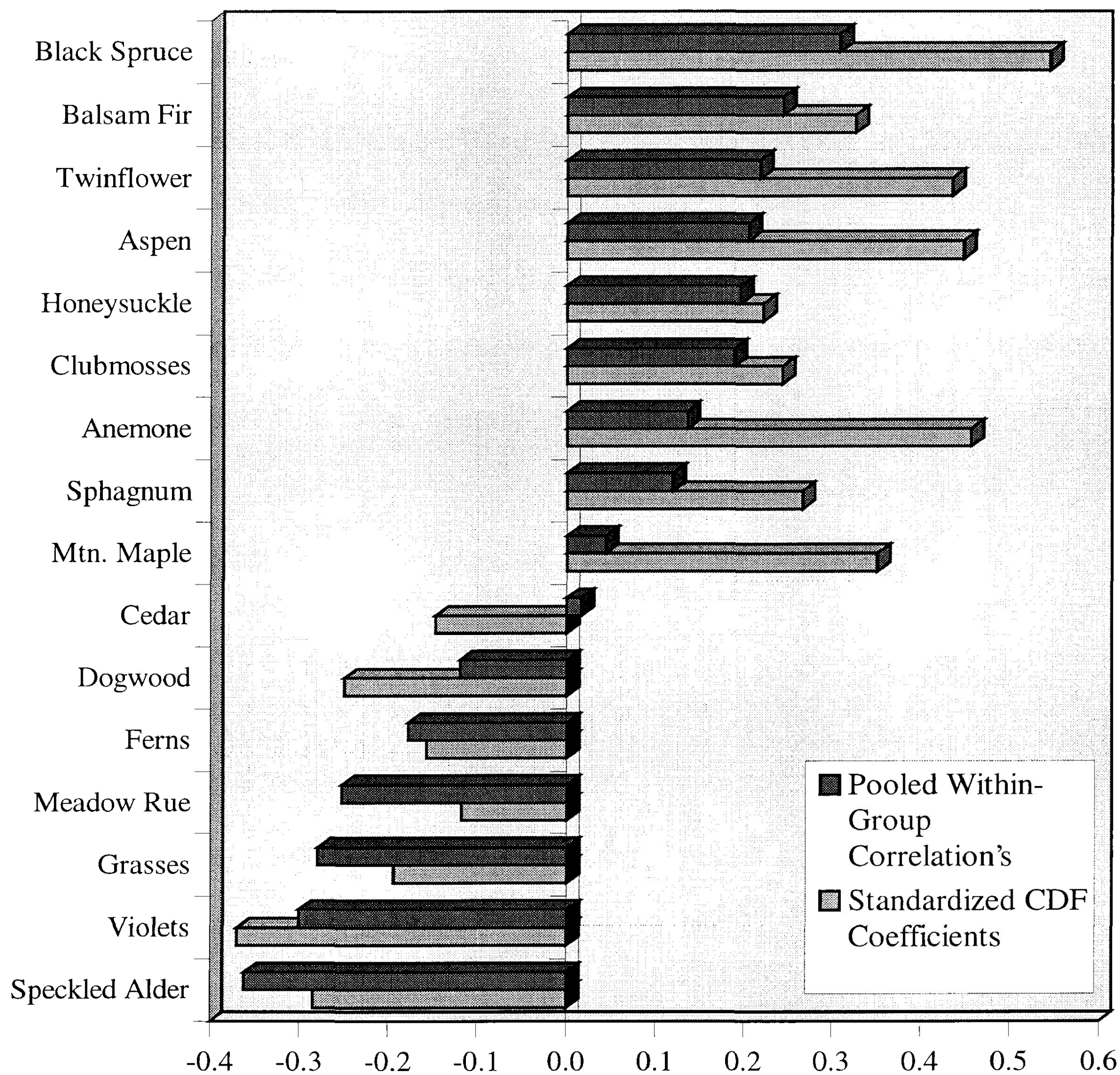

Figure 3.8. Riparian compared with upland vegetation species Discriminant Function Analysis results. High positive pooled within-group correlations and standardized CDF coefficients indicate species which were good indicators of upland habitat, while riparian indicators are shown by high negative values.

Table 3.3. Riparian compared with upland vegetation Discriminant Function Analysis results show a single significant function ($P < 0.05$) explaining 100 percent of the variation in the analysis. A high canonical correlation value indicates a form of "goodness of fit" in the classification results.

Fcn	Eigenvalue	Percent of Variation	Canonical Correlation	Wilks' Lambda	Chi-square	df	Significance
1	2.9185	100.0	0.8630	0.2552	198.029	26	< 0.0001

Table 3.4. Standardized Canonical Discriminant Function coefficients and pooled within-group correlations of riparian compared with upland vegetation Discriminant Function Analyses. As shown by the group centroids, a combination of high negative standardized CDF coefficients and pooled within-group correlations indicate species which were used by the DFA to separate riparian plots from upland vegetation sample plots and *vice versa*.

Variables	Standardized CDF Coefficients	Pooled Within-Group Correlations
Speckled Alder	-0.03990	-0.36175
Violets	-0.37044	-0.30084
Grasses	-0.19394	-0.27954
Early Meadow Rue	-0.11784	-0.25250
Ferns	-0.15734	-0.17721
Red-Osier Dogwood	-0.24932	-0.11936
Rasberry spp.	0.04007	-0.03801
Willow spp.	-0.12999	-0.01514
Currant spp.	0.09751	-0.01120
Starflower	-0.01955	-0.00833
Eastern White Cedar	-0.14666	0.01656
Beaked Hazel	0.43540	0.02340
Mountain maple	0.35090	0.04353
Serviceberry	-0.09175	0.04581
Wild-Lily-of-the-Valley	-0.31892	0.08796
Broom mosses	0.10590	0.11369
Ash spp.	0.00772	0.11587
Sphagnum mosses	0.26618	0.11900
Anemone	0.45682	0.13552
Lycopodium spp.	0.24355	0.18860
Honeysuckle	-0.28498	0.19551
Bunchberry	0.17168	0.20067
Trembling Aspen	0.44826	0.20493
Twinflower	0.22197	0.21789
Balsam Fir	0.32620	0.24399
Black Spruce	0.54476	0.30875
Group Centroids	riparian = -1.69766 upland = 1.69766	

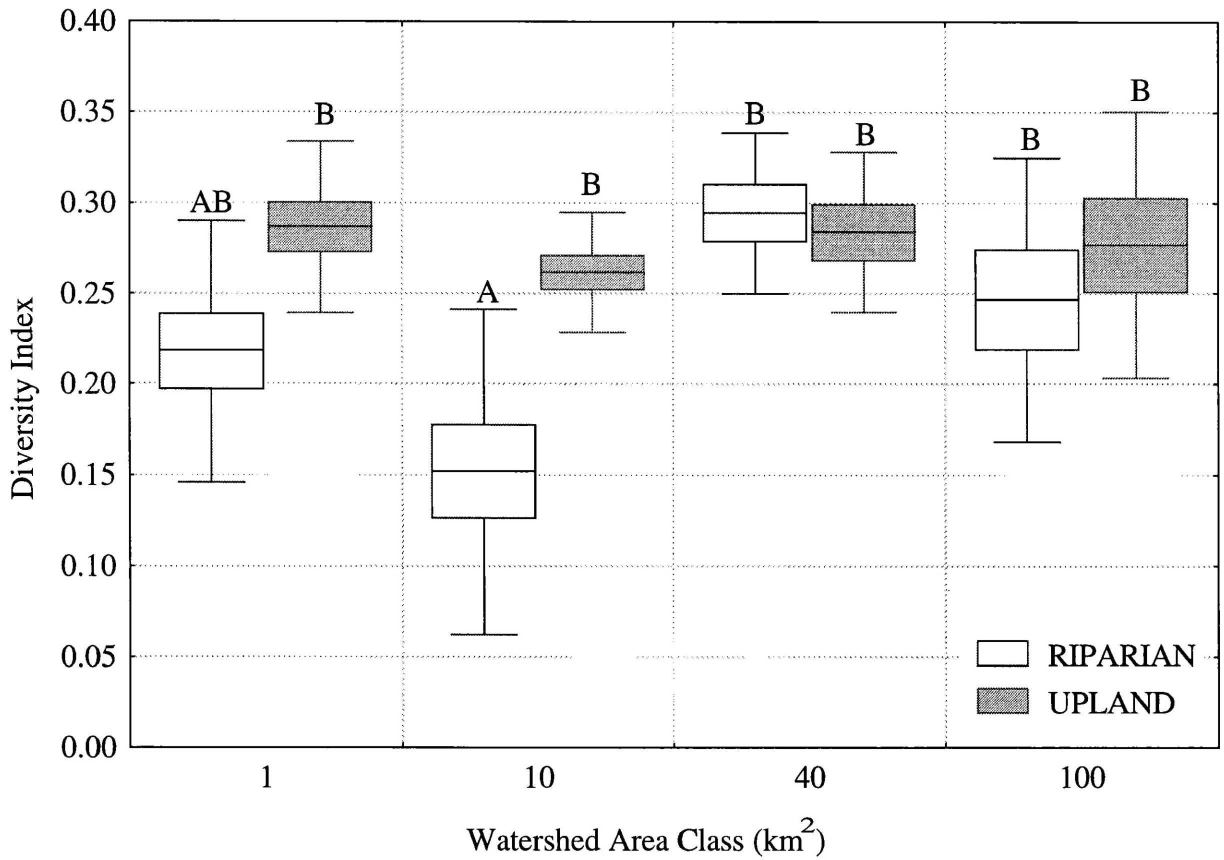

Figure 3.9. Riparian and upland species diversity indices grouped by watershed area class. Boxplots show mean, mean ±1 standard deviation and mean ±1 standard error.

Measurements of riparian zone width ranged from 0 to 85 metres, with a mean of 11.8 metres (Figure 3.10), while slope ranged from 0 to 170 percent, with a mean of 12.1 percent (Figure 3.11). In only 14 of 240 measurements was the riparian width greater than 30 metres, and in only 19 of 240 cases was the riparian slope greater than 30 percent. Streams with 1 - 10 km^2 watersheds had wider (ANOVA, $F = 9.45$, $P < 0.001$) and lower gradient (ANOVA, $F = 14.31$, $P < 0.001$) riparian zones than streams with 40 - 100 km^2 watersheds (Tukey's HSD test, $\alpha = 0.05$).

When applying the Timber Management Guidelines for the Protection of Fish Habitat (OMNR, 1988), 60 percent of the streams measured had a riparian slope of 0 to 15 percent which would require a 30 metre buffer, 15 percent a 50 m buffer (16 to 30 percent slope), 10 percent a 70 m buffer (31 to 45 percent slope), and 15 percent a 90 m buffer (46 to 60 percent slope) (Table 3.5). In only 13 of 240 measurements was the riparian zone wider than the prescribed buffer width (or 5.8 percent of cases), and in all of these specific cases the 30 m buffer zone was prescribed (15 percent slope or less) (Table 3.6).

Among WEC groups, conifer swamp riparian zones were significantly narrower (ANOVA, $F = 15.51$, $P < 0.001$) and more sloped (ANOVA, $F = 11.77$, $P < 0.001$) with a mean width of 5.8 metres and mean slope of 22.6 percent, than meadow marsh riparian zones which were the widest and least sloped, with a mean width of 19.4 metres and mean slope of 6.0 percent (Tukey-HSD test, $\alpha = 0.05$, Figures 3.12 and 3.13).

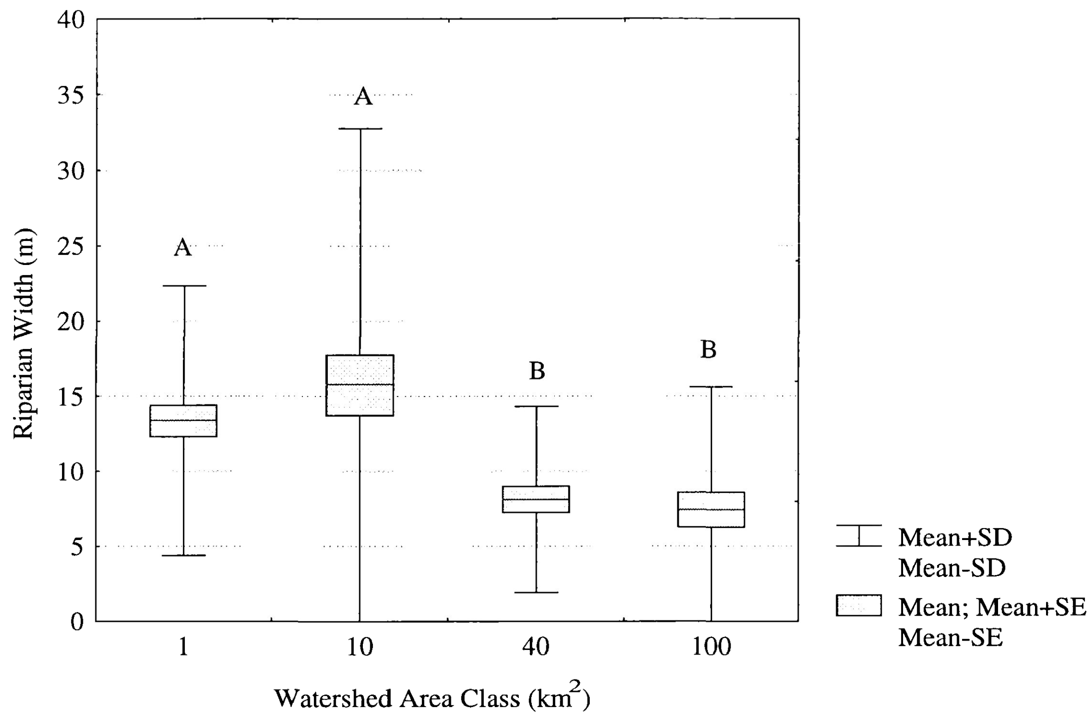

Figure 3.10. Riparian width by watershed area class.

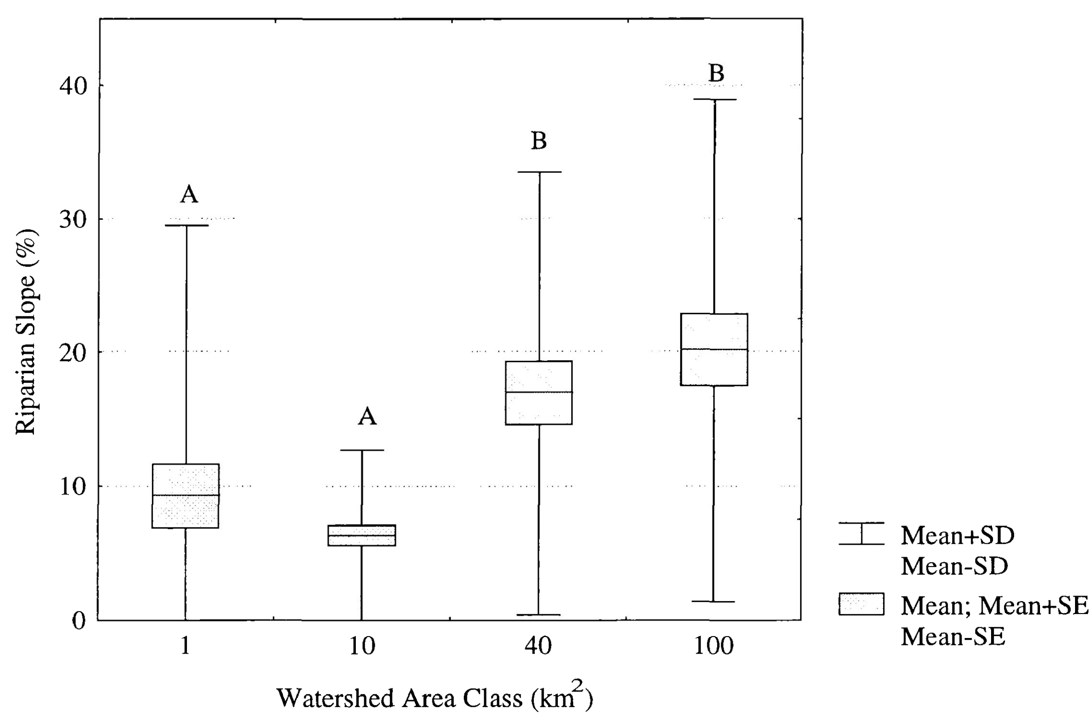

Figure 3.11. Riparian slope by watershed area class.

Table 3.5. Buffer widths which would be prescribed in each watershed area class using the Forest Management Guidelines for the Protection of Fish Habitat (OMNR, 1988).

Slope	Buffer Width	Watershed Area Class	# of Sites	Percent of Sites in Watershed Area Class
0 - 15%	30 m	1	9	75.0%
		10	11	91.7%
		40	2	25.0%
		100	2	25.0%
16 - 30 %	50 m	1	2	16.7%
		10		
		40	2	25.0%
		100	2	25.0%
31 - 45%	70 m	1		
		10	2	16.7%
		40	2	25.0%
		100		
46 - 60%	90 m	1	1	8.3%
		10		
		40	1	12.5%
		100	4	50.0%

Table 3.6. Total number of width measurements (transects) and sites by watershed area class in which the riparian zone width had the potential to be greater than the prescribed buffer width under the Forest Management Guidelines for the Protection of Fish Habitat (OMNR, 1988).

	Watershed Area Class				
	1 km^2	10 km^2	40 km^2	100 km^2	Total
Transects	4 of 72	7 of 72	1 of 48	1 of 48	13 of 240
Sites	3 of 12	4 of 12	1 of 8	1 of 8	9 of 40

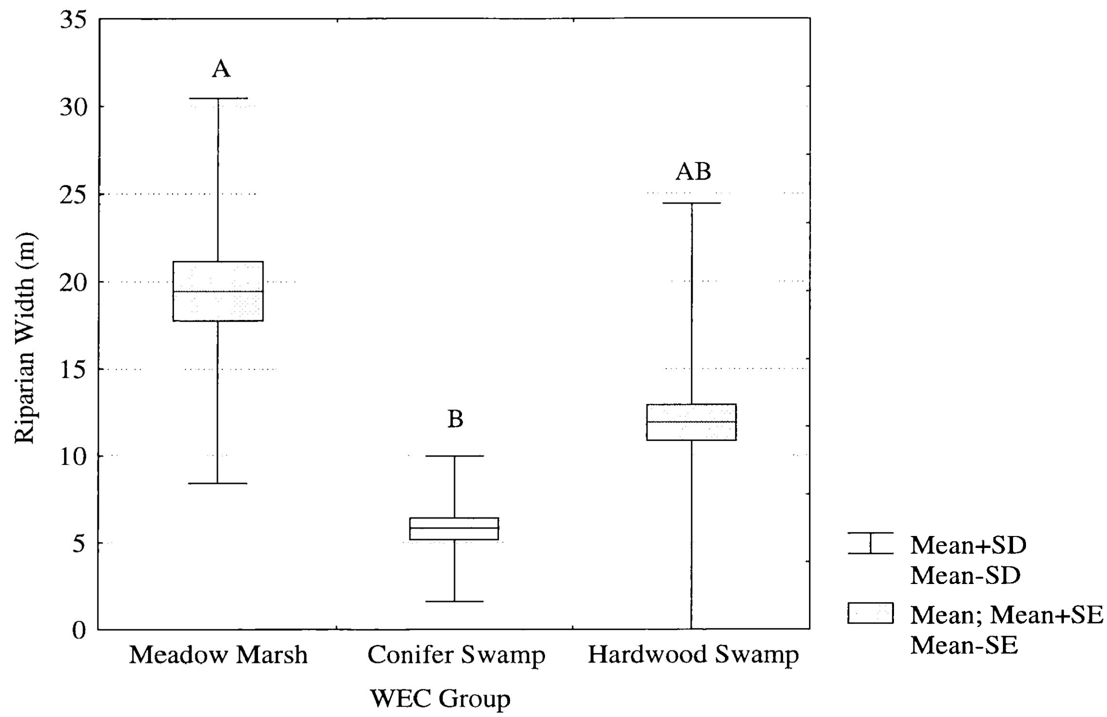

Figure 3.12. Riparian width by Wetland Ecosystem Classification grouping.

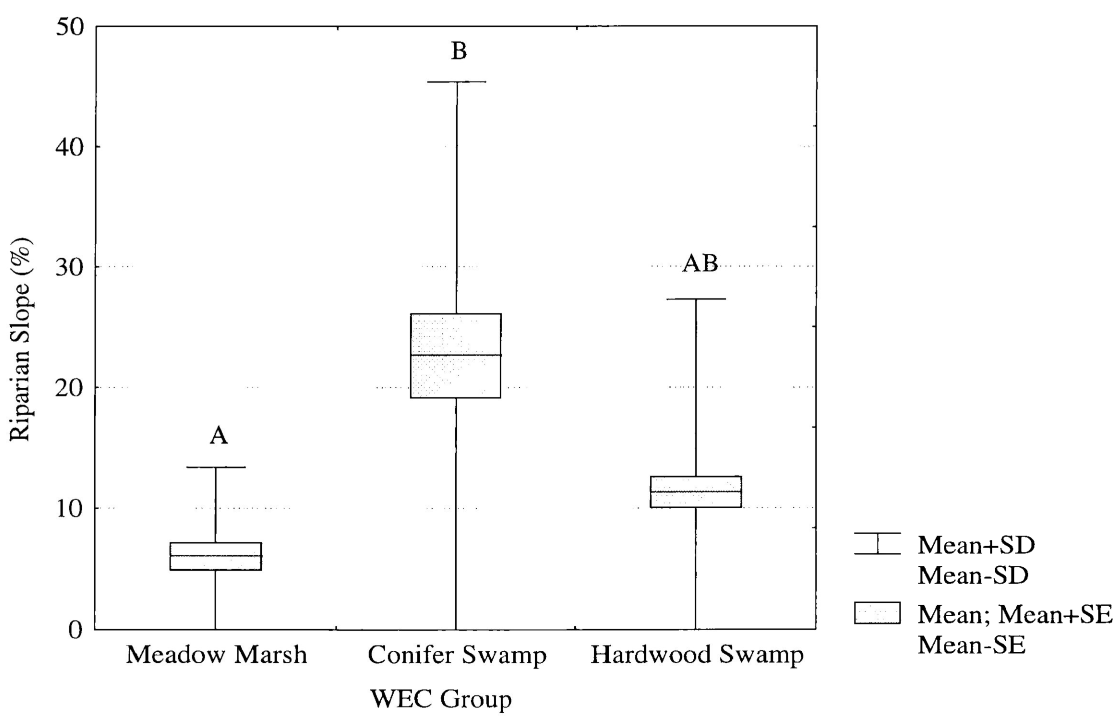

Figure 3.13. Riparian slope by Wetland Ecosystem Classification grouping.

Among watershed size classes there were no significant differences within site variability in riparian slope or width (ANOVA, $F = 0.33$, $P = 0.806$ and $F = 1.32$, $P = 0.284$, respectively). The coefficient of variation in riparian width measurements within a site ranged from 0 to 0.94 (Figure 3.14), while the CV in riparian slopes ranged from 0 to 2.13 (Figure 3.15), with the mean CV's being 0.49 and 0.61, respectively. This result shows that riparian slopes were more variable than riparian widths.

A Discriminant Function Analyses showed that vegetation communities differed among riparian zones in the different watershed area classes. As previously mentioned, due to the constraints of the analysis and the number of field sample sites, the 40 km^2 watersheds were dropped for the DFA of vegetation species. The analysis produced two significant functions ($P < 0.001$ and $P = 0.018$) which had canonical correlation coefficients of 0.66 and 0.51, respectively (Table 3.7). Seventeen of twenty-four, twenty-one of twenty four, and eight of sixteen cases were correctly classified in 1, 10, and 100 km^2 watershed groups, respectively, while the overall classification efficiency was 72 percent. Box's M test of the equality of group covariance matrices showed a significant difference in covariance matrices ($F = 6.32$, $P < 0.001$). However, since the analyses was used as an exploratory tool rather than an hypothesis testing tool, this result was not considered to invalidate the analysis. CDF coefficients, pooled within-group correlations and group centroids for each of the species (Table 3.8) revealed that riparian zones around streams with 1 km^2 watersheds differed from riparian zones around streams with 100 km^2 watersheds along function 1 mainly due to increasing amounts of Speckled Alder (CDFC = 0.636) and decreasing amounts of Cedar (CDFC = -0.644) (Figure 3.16).

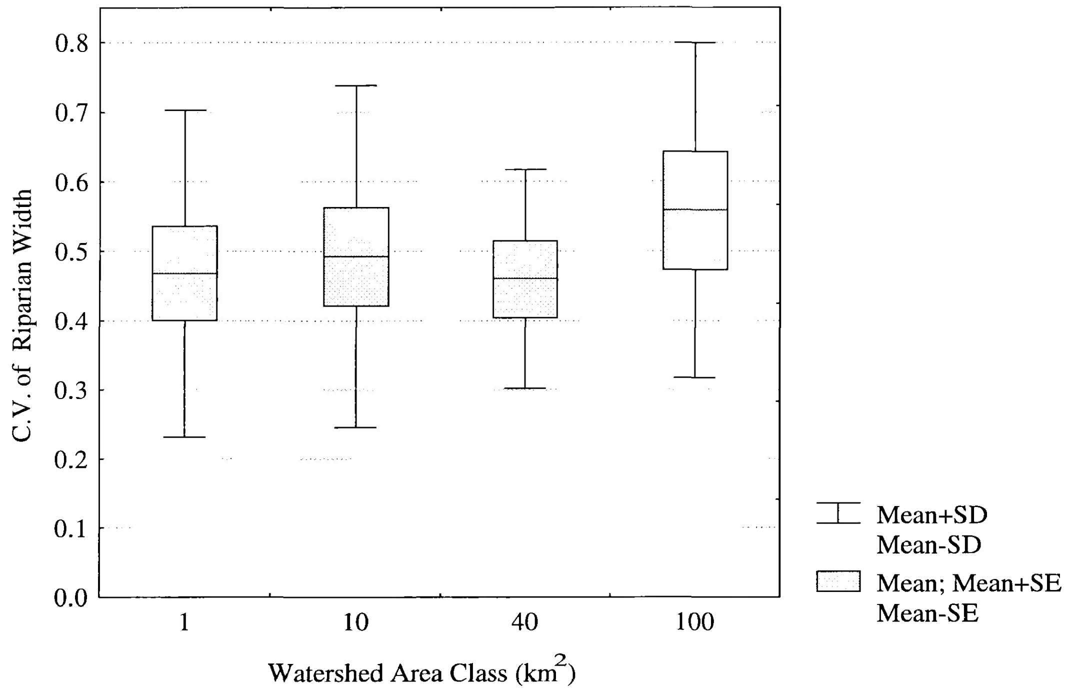

Figure 3.14. Coefficient of Variation in riparian width measurements among watershed area classes.

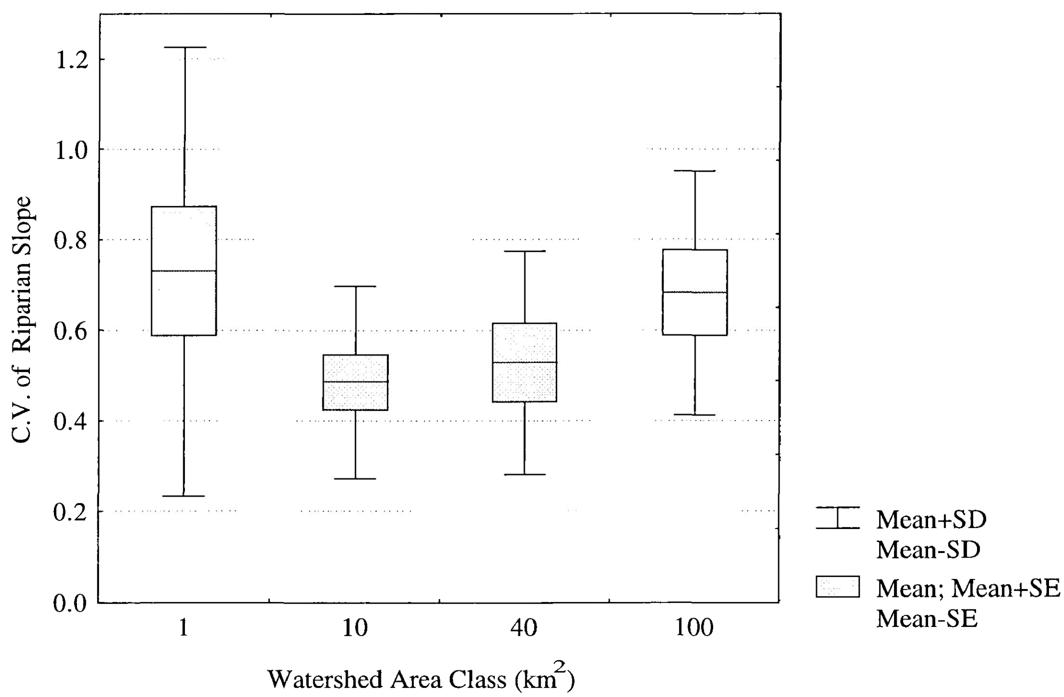

Figure 3.15. Coefficient of Variation in riparian slope measurements among watershed area classes.

Table 3.7. Discriminant Function Analysis results of riparian species grouped by watershed area class. Two significant functions ($P < 0.05$) were used in the analysis to separate riparian vegetation species among watershed area classes, with function 1 explaining over two-thirds of the variation.

Fcn	Eigenvalue	Percent of Variation	Canonical Correlation	Wilks' Lambda	Chi-square	df	Significance
1	0.7556	68.8	0.6560	0.4240	49.337	16	0.0000
2	0.3434	31.25	0.5056	0.7444	16.976	7	0.0176

Table 3.8. Standardized Canonical Discriminant Function coefficients and pooled within-group correlations for Discriminant Function Analysis results of riparian species grouped by watershed area class. As indicated by the group centroids for each watershed area class, riparian vegetation species with high positive compared to species with high negative standardized CDF coefficients and pooled within-group correlations separated 1 km^2 sites from 100 km^2 sites along function 1 while on function 2 species with high negative compared to high positive coefficients and correlations separated 10 km^2 from 1 and 100 km^2 sites.

Variables	Standardized CDF Coefficients		Pooled Within-Group Correlations	
	Function 1	Function 2	Function 1	Function 2
Eastern White Cedar	-0.64379	0.3952	-0.42758	0.3155
Honeysuckle	-0.62715	0.56816	-0.17143	0.38663
Currant spp.	-0.50732	-0.10754	-0.11725	0.08761
Ash spp.	0.36053	-0.06527	0.15992	0.19843
Grasses	0.44881	-0.27027	0.16661	-0.50412
Beaked Hazel	0.2753	0.24479	0.21102	0.11321
Trembling Aspen	0.59081	-0.05476	0.23497	0.28171
Speckled Alder	0.63551	0.75253	0.35939	0.70361

Group Centroids	Function 1	Function 2
1 km^2	0.91537	0.40586
10 km^2	-0.06762	-0.73721
100 km^2	-1.27162	0.49703

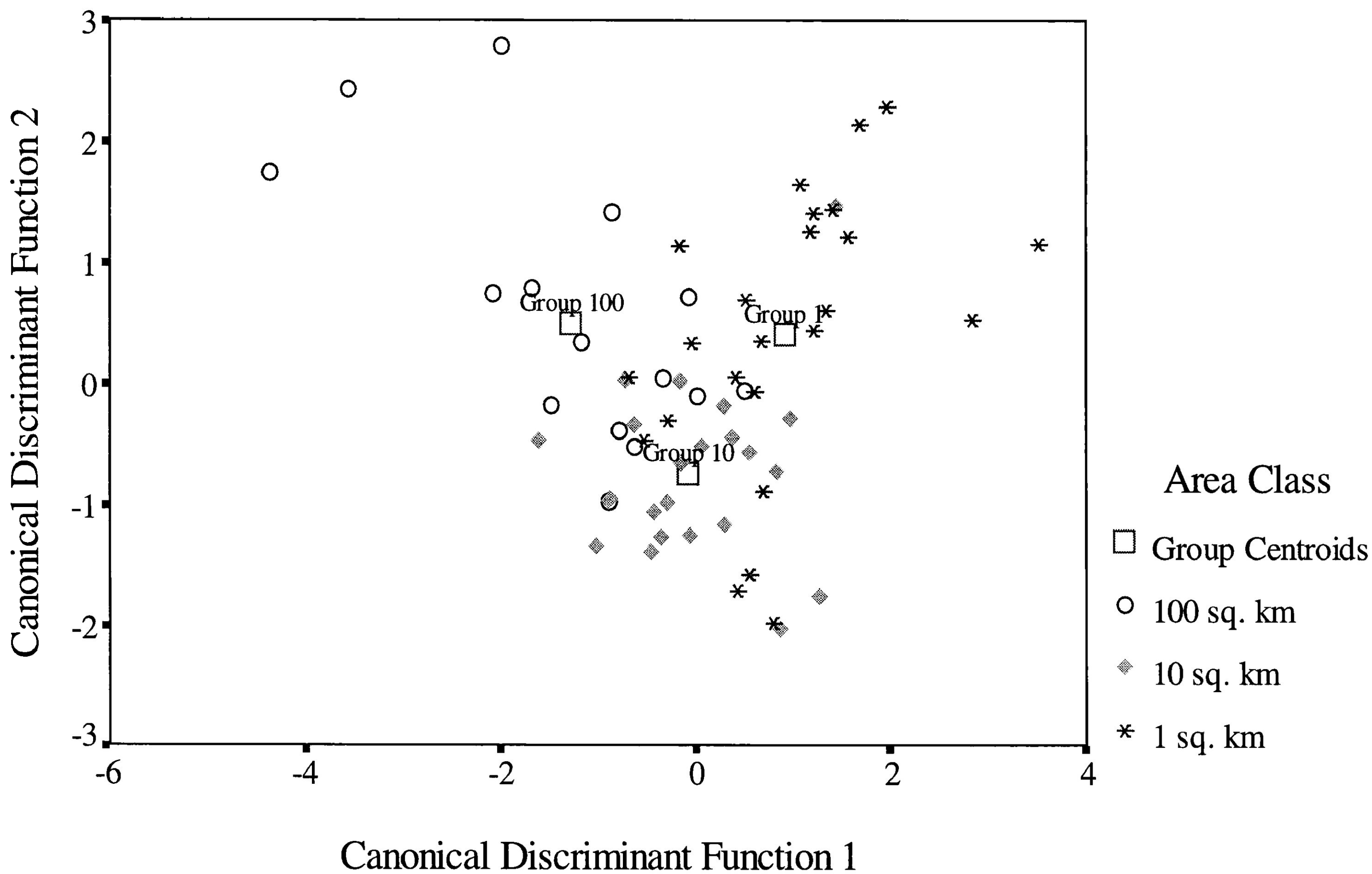

Figure 3.16. Discriminant Function Analysis results of riparian species grouped by watershed area class. Note: Both Function 1 and 2 were significant ($P < 0.05$).

Ten km^2 watershed riparian zones were separated from 1 and 100 km^2 sites along function 2 due to decreasing amounts of Speckled Alder (CDFC = 0.753) and increasing amounts of grasses (CDFC = -.270).

3.3 Physical and Hydrological Drainage Basin Characteristics

As predicted, there were clear differences among physical and hydrological drainage basin characteristics in different watershed area classes. A DFA indicated that physical and hydrological drainage basin characteristics could be used to differentiate among watershed area classes. One significant function, having a canonical correlation coefficient of 0.88, was used in the analysis to separate among watershed area classes (Table 3.9). The separation of watershed area class groupings was accomplished linearly along function one, as neither of the other two functions were significant (Figure 3.17). Function 2 was used for graphical purposes only, as it contributes only 5.4 percent of the variation explained by the model, which was not significant in separating among watershed area classes ($P = 0.39$). Increasing indices of surface roughness and width/depth ratios and decreasing stream channel slopes separated larger (40 - 100 km^2) drainage basins from smaller (1 - 10 km^2) drainage basins (Table 3.10). Classification results ranged from 75 to 100 percent efficiency in each of the watershed area classes, with an overall classification efficiency of 85 percent (Table 3.11). Box's M test of equality revealed a significant difference in group covariance matrices ($F = 1.40$, $P = 0.042$), though, as this analyses was not used as an hypothesis testing tool, this result was assumed not to invalidate the analysis.

To examine the differences among different variables and watershed area further, several univariate analyses were done. There was a negative relationship found between watershed area class and basin slope (Figure 3.18), with 1 km^2 watersheds having a

Table 3.9. Discriminant Function Analysis results of physical and hydrological drainage basin characteristics grouped by watershed area class. Only one significant function ($P < 0.05$) was used in the analysis, function 1, which accounted for 92.9 percent of the variation, and had a high canonical correlation of 0.88.

Fcn	Eigenvalue	Percent of Variation	Canonical Correlation	Wilks' Lambda	Chi-square	df	Significance
1	3.4999	92.9	0.8819	0.1738	60.378	15	< 0.0001
2	0.2044	5.4	0.4119	0.7819	8.488	8	0.3873
3	0.0619	1.6	0.2415	0.9417	2.073	3	0.5574

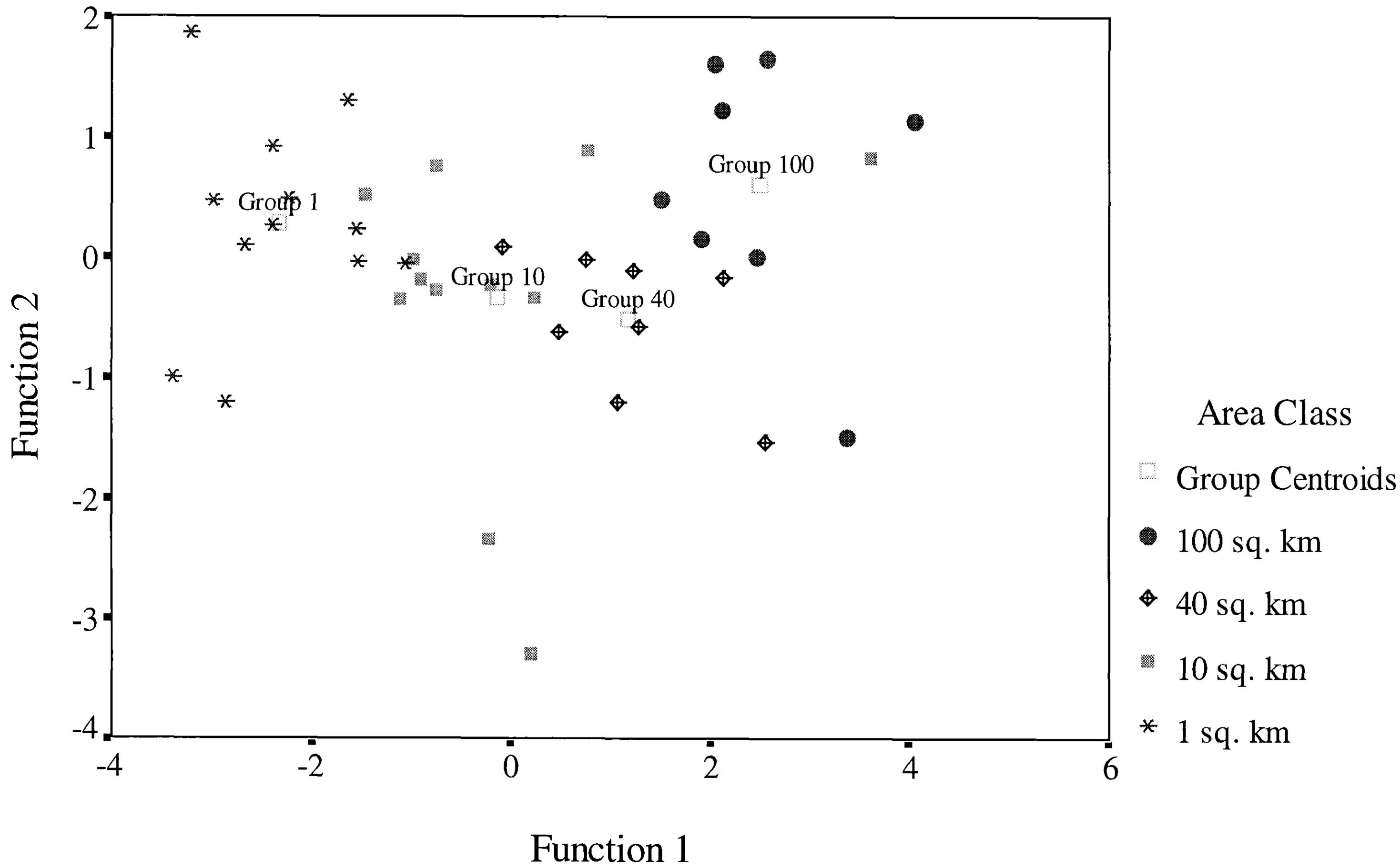

Figure 3.17. Discriminant Function Analysis results of physical and hydrological drainage basin characteristics grouped by watershed area class. Note: Only Function 1 was significant ($P < 0.05$).

Table 3.10 Standardized Canonical Discriminant Function coefficients and pooled within-group correlations for Discriminant Function Analysis results of physical and hydrological drainage basin characteristics grouped by watershed area class. As indicated by the group centroids, drainage basin characteristics with high negative standardized CDF coefficients and pooled within-group correlations separated smaller watersheds along function 1 from larger watersheds which had high positive coefficients and correlations. For example, increasing surface roughness was indicative of larger watershed area classes, while an increasing stream channel slope was more indicative of smaller watersheds.

Variables	Function #1 Standardized CDF Coefficients	 Pooled Within-Group Correlations
Surface Roughness	0.9142	0.3361
Width/Depth Ratio	0.4948	0.4086
Lake and Wetland Area	0.1727	0.3505
Stream Channel Sinuosity	0.1258	0.2959
Stream Channel Slope	-0.6814	-0.5765

Group Centroids	Function 1
1 km²	-2.3211
10 km²	-0.1297
40 km²	1.1727
100 km²	2.5036

Table 3.11. Classification results of Discriminant Function Analysis of physical and hydrological drainage basin characteristics grouped by watershed area class. This table compares the actual measured watershed area class with the DFA classification's predicted watershed area class based upon the measured drainage basin characteristics. The DFA resulted in an overall classification efficiency of 85 percent.

Actual Watershed Area Class (km^2)	Predicted Watershed Area Class (km^2)				Total Number of Cases
	1	10	40	100	
1	11 91.7%	1 8.3%	0 0.0%	0 0.0%	12
10	1 8.3%	9 75.0%	1 8.3%	1 8.3%	12
40	0 0.0%	1 12.5%	6 75.0%	1 12.5%	8
100	0 0.0%	0 0.0%	0 0.0%	8 100.0%	8
					40
			Overall Classification Efficiency =		85.0%

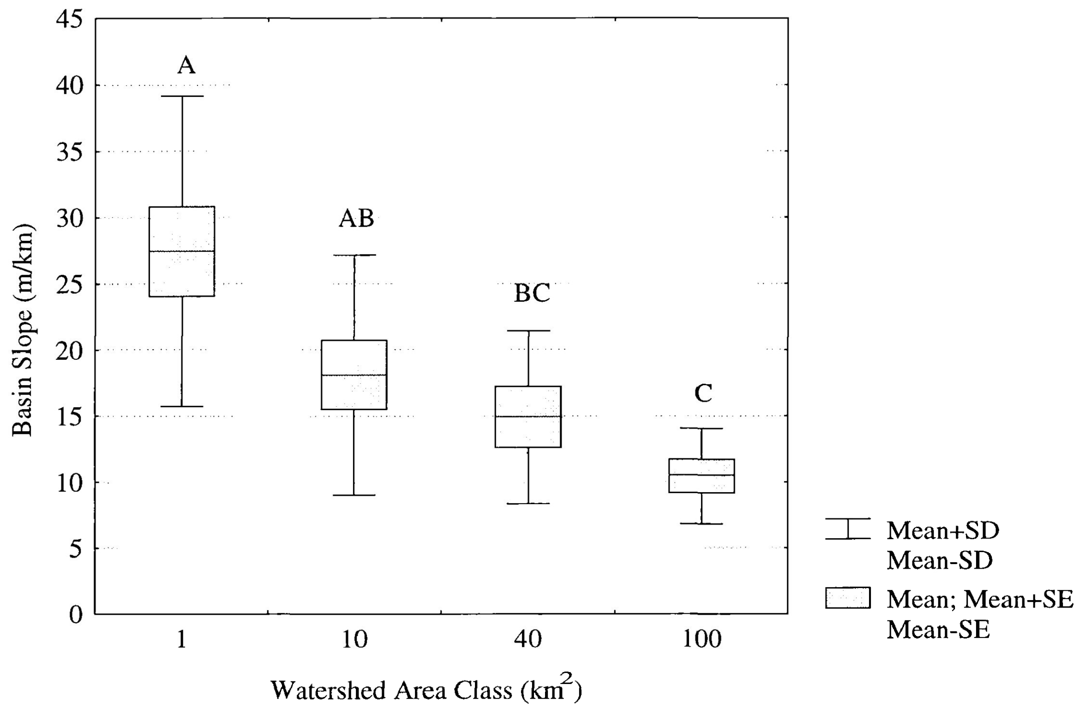

Figure 3.18. Basin slope by watershed area class.

significantly greater mean basin slope than 40 and 100 km^2 watersheds, and 10 km^2 watersheds having a significantly greater mean basin slope than 100 km^2 watersheds (ANOVA, $F = 9.52$, $P = 0.0001$, Tukey-HSD, $\alpha = 0.05$).

There were no significant differences found in the mean indices of basin shape among watershed area classes (Figure 3.19) (ANOVA, $F = 0.67$, $P = 0.57$). This indicates that the two-dimensional shape of watersheds is not related to watershed area. However, there was a positive relationship found between watershed area and width/depth ratio (ANOVA, $F = 11.56$, $P < 0.001$, Figure 3.20). Forty and 100 km^2 watersheds had a significantly higher mean width/depth ratio than 1 km^2 watersheds, and 100 km^2 watersheds had a significantly higher mean width/depth ratio than 10 km^2 watersheds (Tukey-HSD test with $\alpha = 0.05$). This indicated that smaller drainage basins (1 - 10 km^2) are relatively narrower and deeper, and appear less variable, than larger drainage basins (40 - 100 km^2).

The index of surface roughness showed a significant positive relationship with watershed area class (ANOVA, $F = 5.04$, $P = 0.005$) as 100 km^2 watersheds had significantly greater mean surface roughness indices than 1 km^2 watersheds (Tukey-HSD, $\alpha = 0.05$). There was also a general trend of increasing surface roughness with watershed area increases throughout the watershed area classes (Figure 3.21).

Mean channel slope decreased significantly in larger watershed area classes (ANOVA, $F = 12.24$, $P < 0.001$), which was expected because stream channel slope was highly

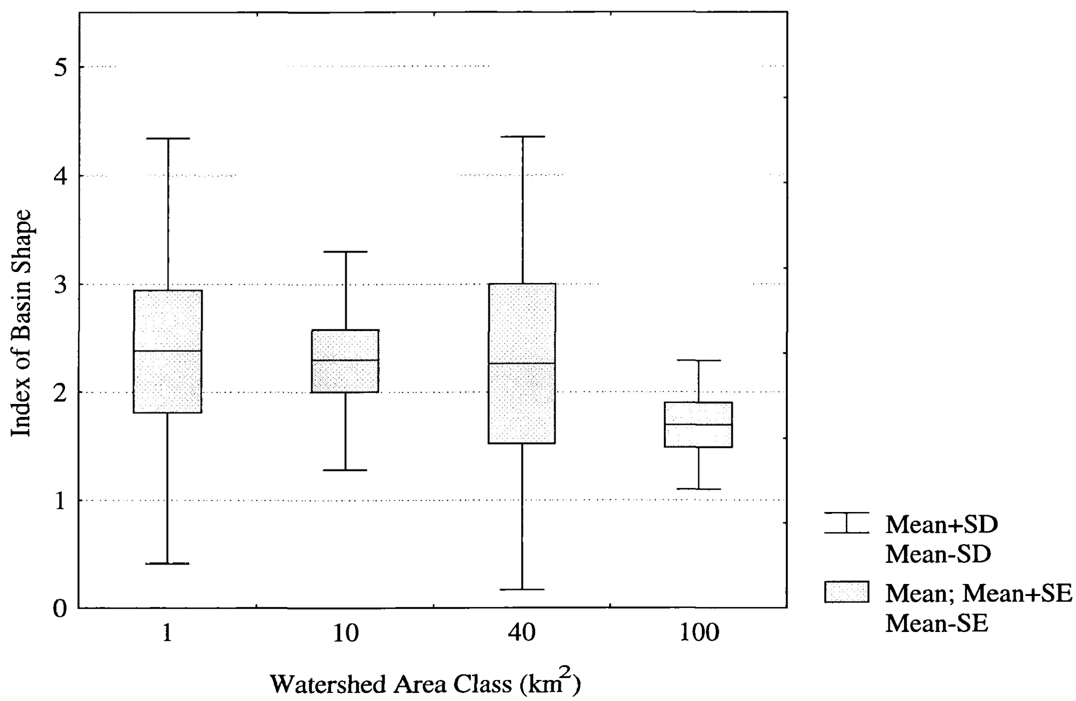

Figure 3.19. Basin shape by watershed area class.

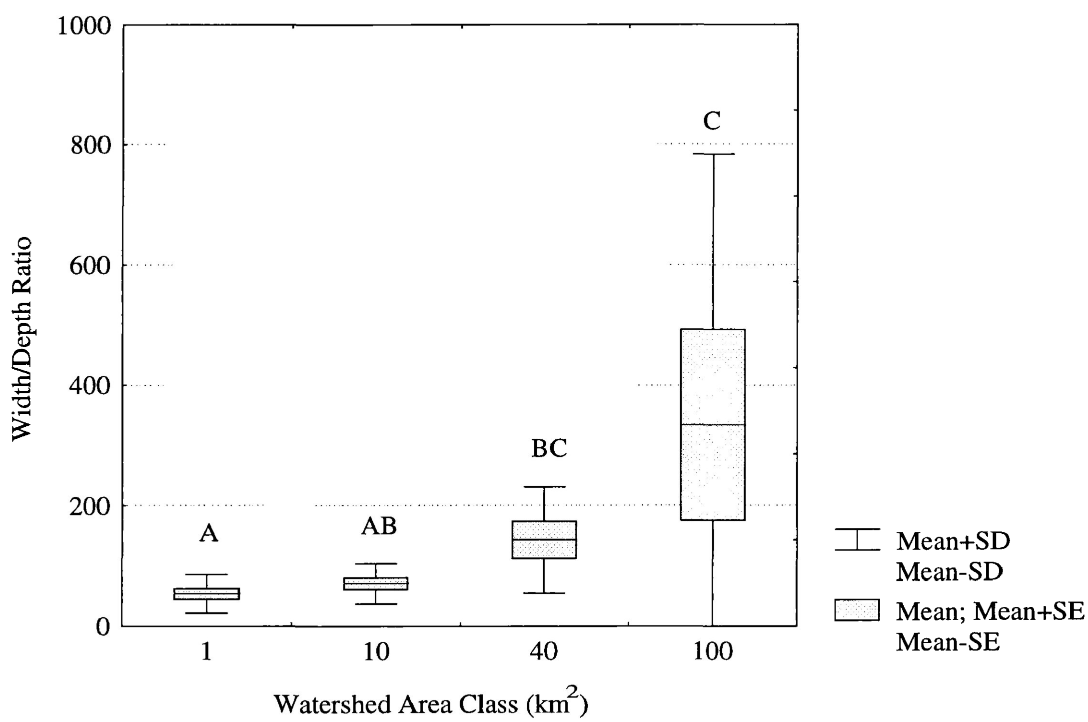

Figure 3.20. Width/depth ratio by watershed area class.

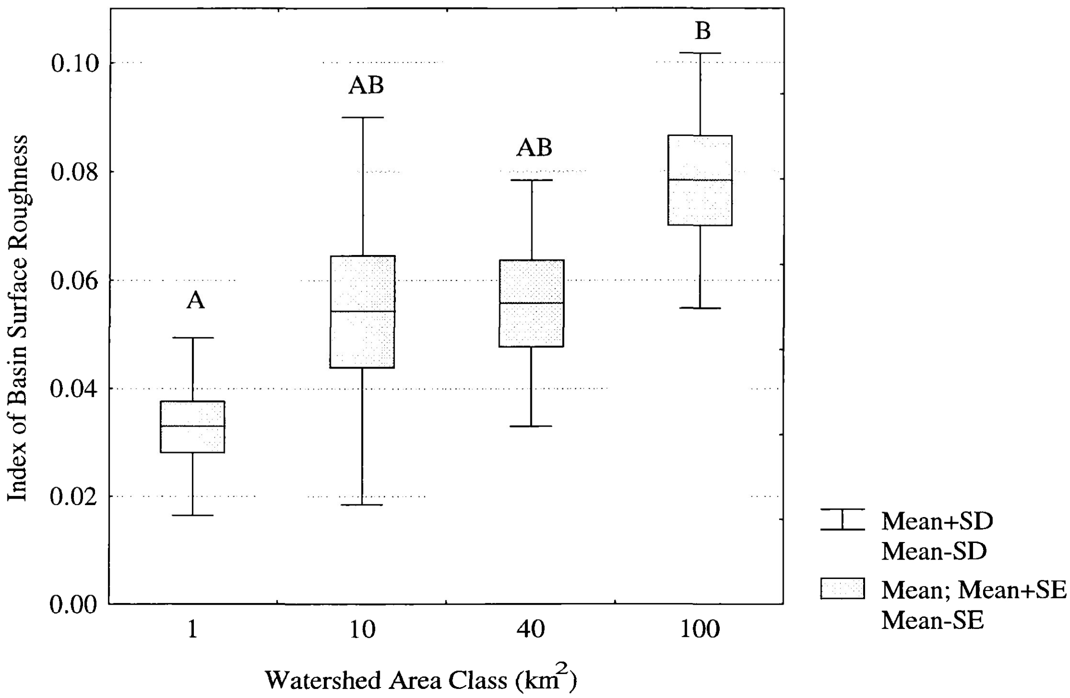

Figure 3.21. Index of surface roughness by watershed area class.

correlated with basin slope (correlation coefficient = 0.89). One km^2 watersheds had significantly steeper channels than those in 10, 40, and 100 km^2 watersheds (Tukey-HSD, $\alpha = 0.05$, Figure 3.22). Streams also had greater channel sinuosity in larger watershed area classes (ANOVA, $F = 7.77$, $P = 0.0002$). Sinuosity was significantly greater in 40 and 100 km^2 watersheds than streams in 1 km^2 watersheds (Tukey-HSD, $\alpha = 0.05$, Figure 3.23).

Mean percent lake and wetland area did not differ among watershed area classes (ANOVA, $F = 1.40$, $P = 0.25$, Figure 3.24). However, when grouping watersheds by primary watershed surficial geology types, there was a significantly higher mean percentage of lake and wetland area in watersheds with bedrock as the dominant landform as compared to watersheds dominated by morainal deposits (ANOVA, $F = 10.57$, $P = 0.0002$). The area of lakes and wetlands in morainal-dominated watersheds ranged from 0 to 5.8 percent, while bedrock-dominated watersheds ranged from 1.5 to 22.8 percent (Figure 3.25). This relationship remained true within the 1 km^2 drainage basins, as the mean percent lake and wetland area was 3.84, and the standard deviation 1.62 in bedrock-dominated 1 km^2 watersheds, as compared to a mean of 1.02 and standard deviation of 0.99 in morainal-dominated 1 km^2 watersheds (ANOVA, $F = 11.95$, $P = 0.009$). No other significant differences in physical or hydrological watershed characteristics were found between watersheds with bedrock compared to morainal-dominant surficial geology.

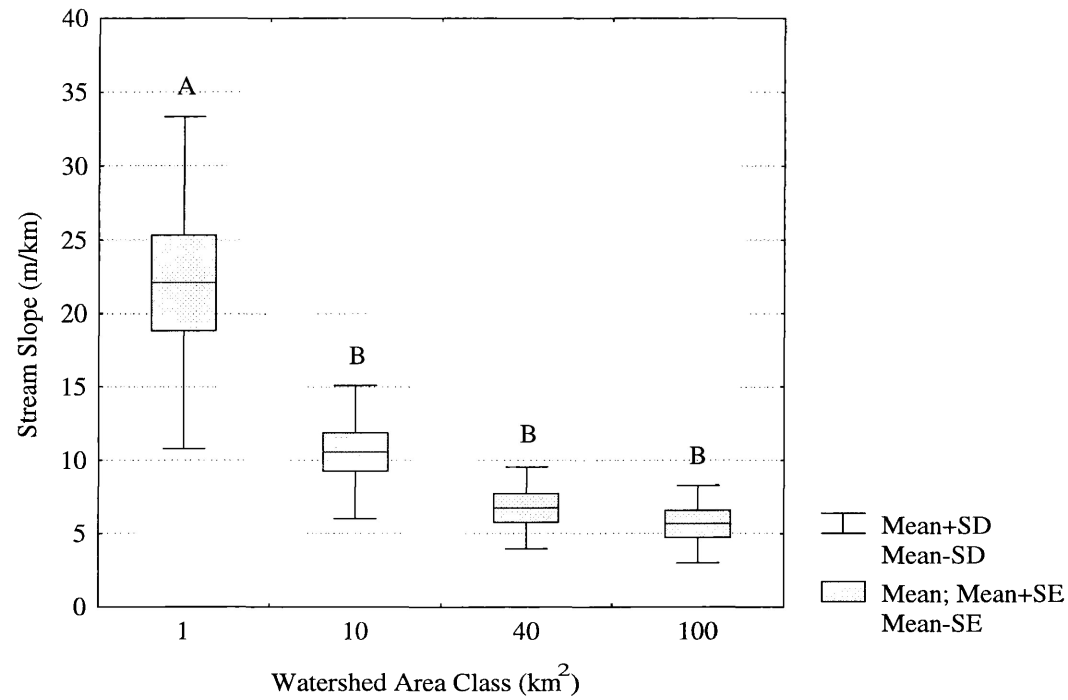

Figure 3.22. Stream channel slope by watershed area class.

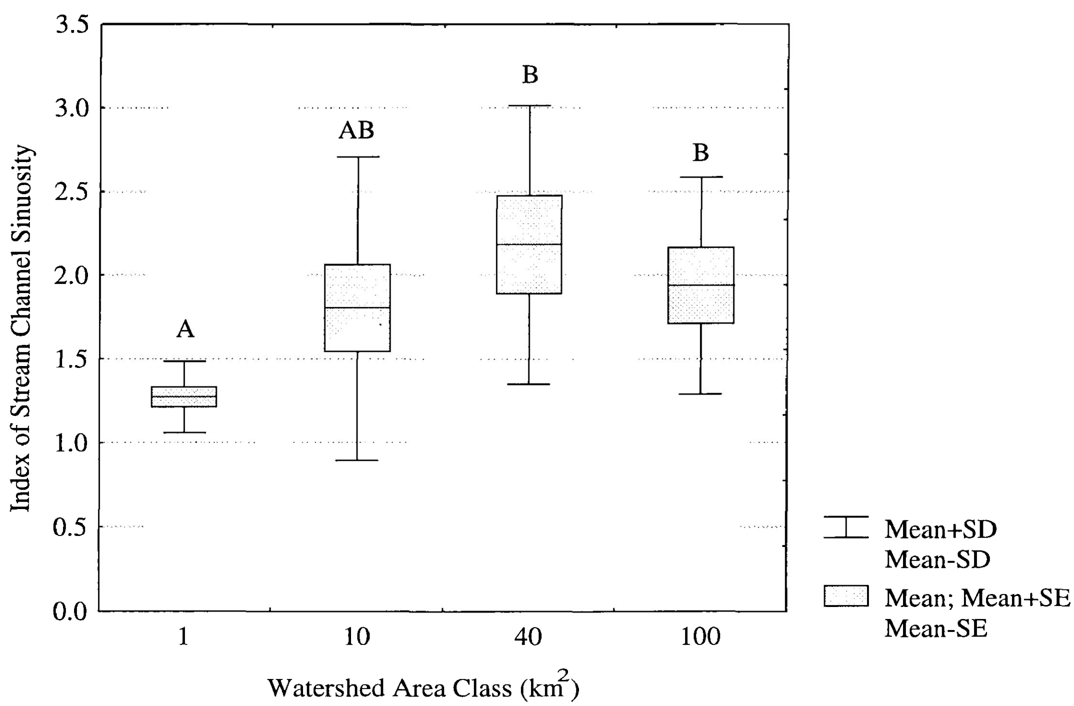

Figure 3.23. Index of stream channel sinuosity by watershed area class.

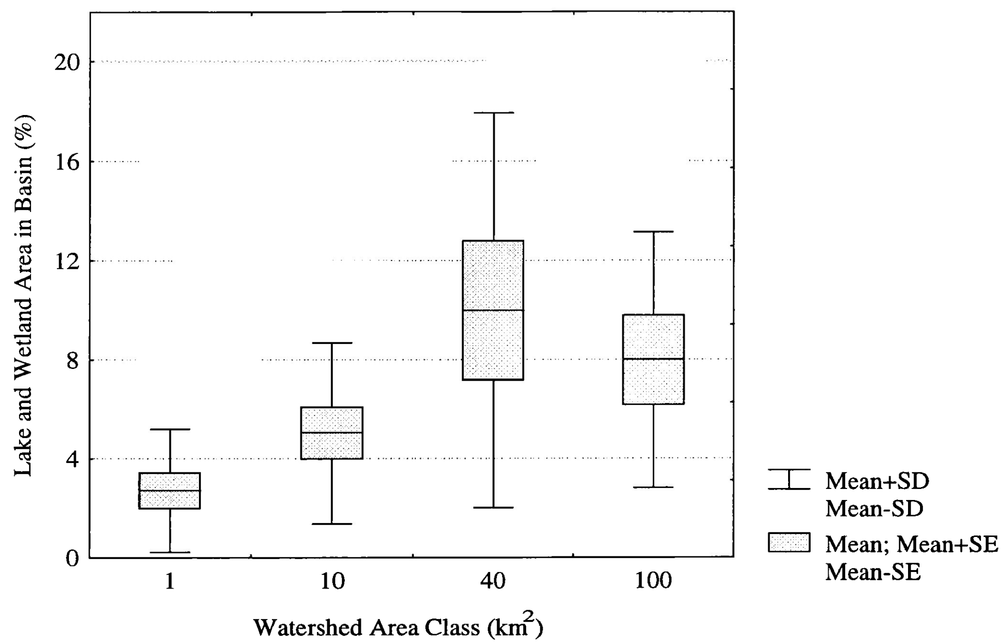

Figure 3.24. Percent lake and wetland area by watershed area class.

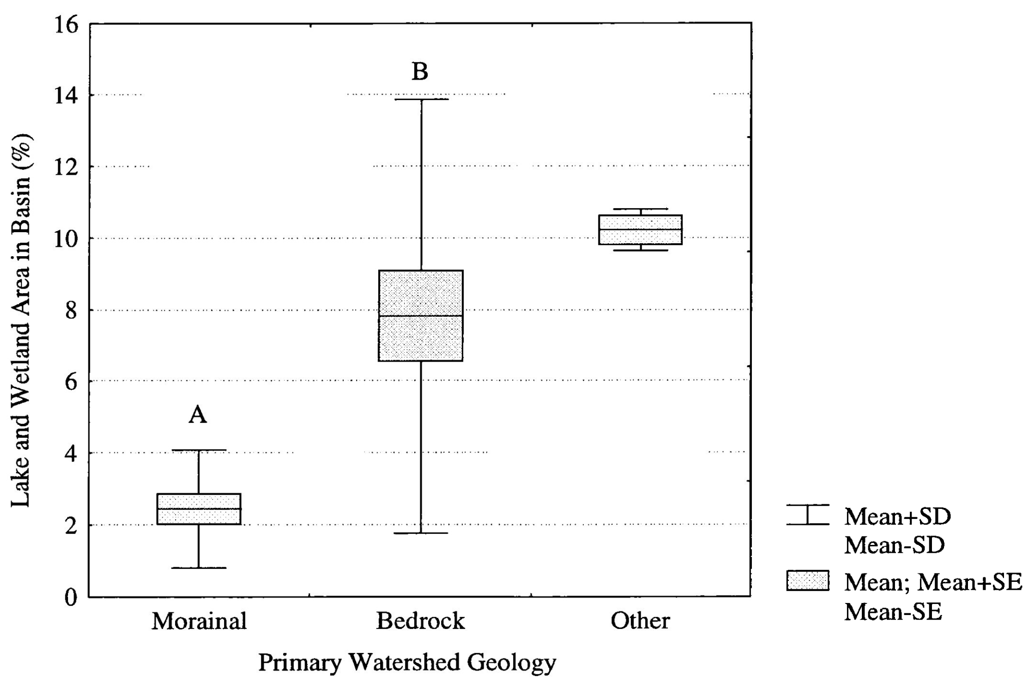

Figure 3.25. Percent lake and wetland area by primary watershed surficial geology types.

Physical and hydrological watershed characteristics showed clear differences among riparian areas of differing WEC types. A significantly higher mean percentage of lakes and wetlands were found within the drainage basins of streams having conifer swamp compared with hardwood or meadow marsh wetland classifications (ANOVA, F = 8.76, P = 0.001, Figure 3.26). Conifer swamps were also found around streams in drainage basins with significantly greater mean indices of surface roughness than meadow marsh wetlands (ANOVA, F = 5.15, P = 0.01, Figure 3.27). However, this may be confounded by the positive relationship found between the mean indices of surface roughness among watershed area classes, as there were more conifer swamp riparian zones found in larger drainage basins (40 - 100 km^2) than meadow marsh riparian zones, which were found only in smaller (1 - 10 km^2) drainage basins (Table 3.1). No relationships were revealed when analyzing surface roughness by WEC types within 1 km^2 drainage basins.

There was no clear overall relationship between WEC groups and dominant watershed or site surficial geology types (Table 3.12). However, there did appear to be a higher number of meadow marsh classifications (6 of 7) where there was morainal-dominated site surficial geology, as well as a higher number of conifer swamp classifications (5 of 7) at sites with bedrock-dominated site or watershed surficial geology.

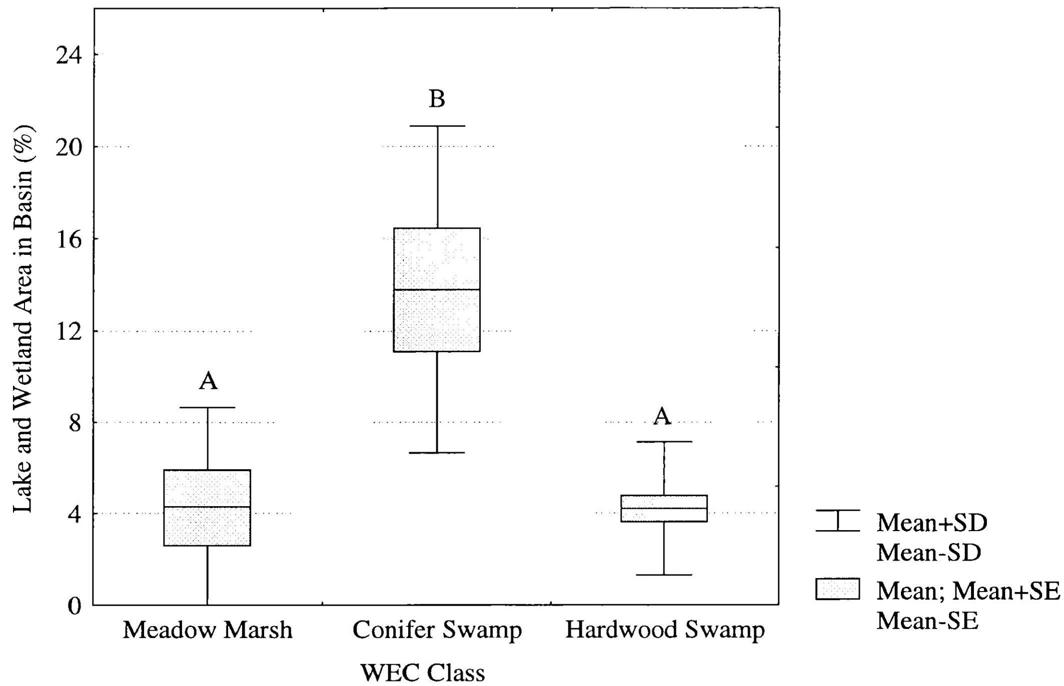

Figure 3.26. Percent area of lakes and wetlands in drainage basin by Wetland Ecosystem Classification types.

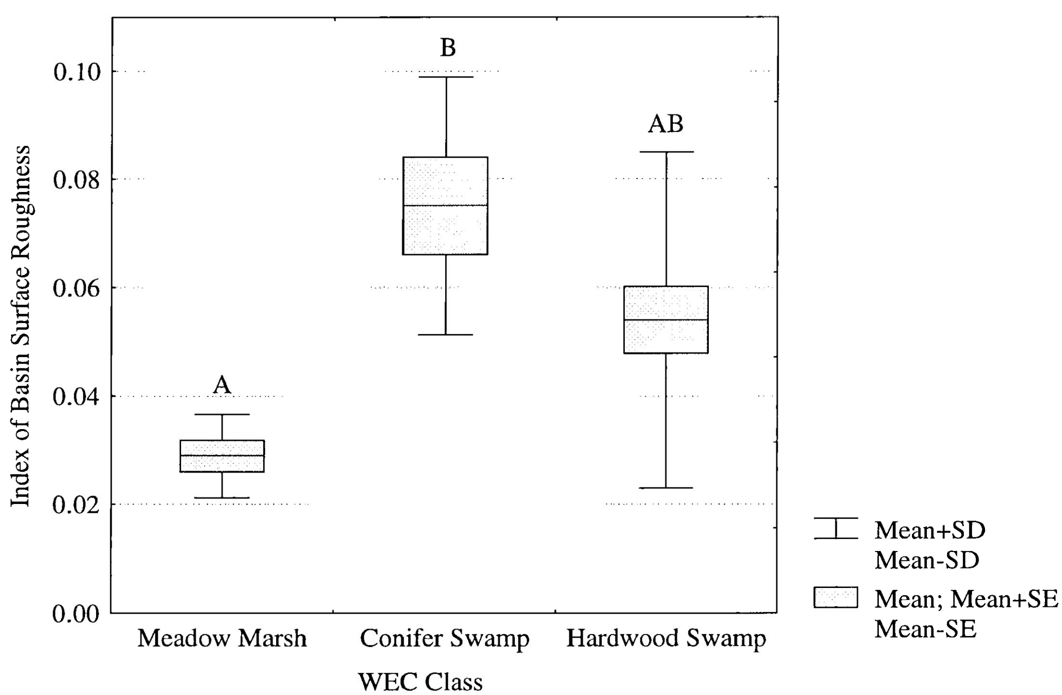

Figure 3.27. Index of surface roughness of watershed by Wetland Ecosystem Classification types.

Table 3.12. Count of Wetland Ecosystem Classification groups surveyed within dominant watershed and site surficial geology types.

Dominant Surficial Geology		Wetland Ecosystem Classification Group: Meadow Marsh	Conifer Swamp	Hardwood Swamp	non-classified
Alluvial	Site	0	0	1	0
	Watershed	0	0	0	0
Morainal	Site	6	1	7	0
	Watershed	4	1	10	0
Glaciofluvial	Site	0	1	2	0
	Watershed	0	1	0	0
Glaciolacustrine	Site	0	0	1	0
	Watershed	0	0	1	0
Bedrock	Site	1	5	14	1
	Watershed	3	5	14	1

4.0 DISCUSSION

This study examined relationships both within and among stream, riparian zone, and watershed characteristics to characterize better the complexity of riparian vegetation structure along a river continuum. A clear relationship was found between the structure and composition of riparian zones and stream and watershed characteristics. Stream discharge, temperature, and gradient were related to riparian vegetation, surficial geology and watershed characteristics. Riparian zones, which had significantly different vegetation communities than upland zones, were also related to watershed characteristics such as area, surficial geology and roughness.

Analysis of stream discharge measurements confirmed the positive relationship between drainage area and stream discharge (Décamps, 1984). Generally, as the drainage area increases stream size and discharge also increases. The energy levels of the aquatic ecosystem also increase with drainage area, and therefore with increases in discharge, which are associated with structural and compositional changes in the ecosystem from headwaters to high order streams (Vannote *et al.*, 1980).

A positive relationship was found between stream temperature and watershed area class. As greater amounts of surface and subsurface flows accumulate in stream channels the temperature of the stream increases (Vannote *et al.*, 1980). This may be due to increased accumulation of solar energy in stream waters from headwaters to mouth, as well as the increased solar radiation reaching the stream channel in streams with larger drainage areas, as riparian canopies tend to be more open on larger streams (Naiman *et al.*, 1987). Also, baseflow in the headwaters of these coldwater systems is primarily groundwater derived, and therefore colder.

Stream gradient, measured as the drop in elevation from source to mouth, is one of the main determinants of flow velocity and streamflow energy (Leopold *et al.*, 1964). Examination of the stream gradient within the stream reach among watershed area classes revealed only a marginally negative relationship between area class and stream slope. Streams with 1 km^2 watersheds appeared to have the most variation in slopes, while the other three area classes were similar in variability. Geomorphologists have illustrated this characteristic of stream channels by describing the general relationship of decreasing slope from headwaters to mouth coinciding with the decrease in flow velocity and streamflow energy along a similar gradient (Knighton, 1984; Leopold *et al.*, 1964). However, downstream hydraulic relationships have also shown that flow velocity can increase from headwaters to mouth due to reduced channel roughness in the downstream direction (Knighton, 1984).

As predicted, the results show that physical and hydrological stream characteristics are related to watershed area. However, watershed characteristics mediate flow patterns through water retention, surface and subsurface flows (Knighton, 1984; Brinson *et al.*, 1980). The characteristics of the riparian zone can also affect the local stream characteristics through groundwater flows (Fiebig *et al.*, 1990), inputs of organic matter, coarse wood debris (Macdonald and Keller, 1987; Harmon *et al.*, 1986) and local geology

(Knighton, 1984). Therefore, it was important to examine riparian and watershed characteristics for relations with physical and hydrological stream characteristics.

As meadow marsh riparian zones had little or no overstory canopies, it was expected that these streams, with less canopy cover, would have higher temperatures due to increased solar radiation (Naiman *et al.*, 1987). Streams with meadow marsh riparian zones also had the least gradient and, therefore, the least stream flow and energy (Leopold *et al.*, 1964). However, as meadow marsh riparian zones were found more often on morainal deposits, which are more conducive to groundwater flows, this may have greatly influenced the stream temperature, as stream temperatures are highly correlated with riparian soil temperatures (Brosofske *et al.*, 1997).

Riparian and upland vegetation communities were significantly different in diversity and composition. However, riparian zone species diversity was not generally greater than upland areas as predicted. In fact, in the 1 and 10 km^2 sites riparian diversity was lower than upland sites. Diversity was about equal between riparian and upland zones in the 40 and 100 km^2 sites. This could have been due to the greater proportion of meadow marsh WEC types found around streams with 1 to 10 km^2 watersheds as compared with 40 to 100 km^2 watersheds, as riparian species diversity was revealed to be lower in meadow marshes than conifer or hardwood swamps. The lower diversity in the meadow marsh riparian zones is related to the high percentage of grass and sedge species out-competing other herbs, and dominating the wetland. Riparian zones where plant species richness is not high may also be an indication that flood disturbances are at intermediate levels of intensity and duration (Décamps and Tabacchi, 1994). This is typical of smaller streams, as the lower the discharge, the lower the levels of streamflow variation (Leopold *et al.*, 1964). Flooding may also be the result of beaver activity which is common in the smaller streams in the area.

In the sites studied, the riparian community was best characterized by the presence of Speckled Alder, Violets, and grasses. Baldwin and Sims (1993) describe Speckled Alder as frequenting moist to wet, poorly drained sites, especially along the margins of streams, rivers, and lakes. This nitrogen fixing species is an important component of the riparian zone due to its ability to provide nutrients and carbon to the natural cycle, which are essential to the health of the aquatic ecosystem (Vannote *et al.*, 1980). Violets, however, occur in a variety of habitats across northwestern Ontario having a wide range of soil and site conditions (Baldwin and Sims, 1993), but preferring cool, moist, shady sites, and commonly found along streams (Legasy *et al.*, 1995) and in swamp wetlands (Newmaster *et al.*, 1997). Perhaps these generalist plants were found more frequently in the riparian zone due to its better growing conditions, having more moist, rich soils than the upland zone.

Grasses, being extremely abundant in meadow marsh riparian zones, were also good indicators of riparian habitat. Grass cover ranged from 23 to 80 percent in meadow marsh riparian zones, which is characteristic of moist, rich organic soils (Baldwin and Sims, 1993). High amounts of grass cover are also considered very good in filtering non-organic sediments from surface runoff (Magette *et al.*, 1989), indicating that meadow marsh riparian zones may be very effective at protecting aquatic ecosystems from eroded sediments carried by surface runoff.

Black Spruce, Balsam Fir and Twinflower were excellent indicators of upland forest habitat in the sites studied. These species were common in upland forest areas, and are typical components of Boreal forest ecosystems (Sims *et al.*, 1989). Trembling Aspen was found in abundance in upland areas, and is generally found on most soil types, growing best on well-drained, moist, sandy to gravelly loams (Hosie, 1990). These trees found in close proximity to the riparian zone generally exhibit better than average growth rates and form (Bren, 1993), which can make them more valuable to forest harvesting companies. Buffer strips that are too wide may leave much of this valuable timber behind, potentially resulting in future economic losses.

The Timber Management Guidelines for the Protection of Fish Habitat (OMNR, 1988) appeared to protect larger streams (40-100 km^2 watersheds) better than smaller streams (1-10 km^2 watersheds), as 1 and 10 km^2 sites had the greatest potential (*i.e.* at least one of the six transects with a riparian width greater than the prescribed buffer width) to be under-protected. In these smaller streams, four of the seven sites with the potential to be under-protected had meadow marsh riparian zones, which tend to be wide and flat, and are an excellent natural buffer due to their high percentage of grasses (Magette *et al.*, 1989). None of these 1 - 10 km^2 sites had conifer swamp classifications which had the most narrow and sloped riparian zones, providing the lowest potential for filtering surface runoff and protecting stream habitat (Schlosser and Karr, 1981).

The remaining sites, where the prescribed buffer width would have been less than the riparian zone width, were found in hardwood swamp riparian zones. These hardwood wetlands were intermediate in both riparian width and slope and had a low potential for disturbance (*i.e.* only one of six transects with riparian width greater than the prescribed buffer width). However, hardwood swamp riparian zones are dominated by Speckled Alder, a nitrogen fixing shrub, which is important in providing allochthonous inputs to low productivity, headwater streams (Vannote *et al.*, 1980). With few commercially valuable species found in these wetland types, there would be a very small loss of potential revenue if buffers were extended on all sites to include the entire natural riparian zone, ensuring the protection of this important vegetation community. However, the results of this study suggest that the current guidelines (OMNR, 1988) are generally adequate in protecting the natural riparian vegetation.

It appears that the riparian zones around smaller streams (1 - 10 km^2 catchments) are more vulnerable to under-protection than the riparian zones of larger streams (40 - 100 km^2 catchments). One of the initial hypotheses was that riparian width would increase with drainage area. The opposite of this hypothesis was found as there was generally a negative relationship between drainage area and riparian zone width. Part of the reason for this result may have been the positive relationship found between drainage area and riparian slope, as there appeared to be a negative relationship between riparian slope and width. The smaller streams (1 - 10 km^2 watersheds) also appeared to have more variable riparian widths and less variable riparian slopes than the larger streams (40 - 100 km^2 watersheds).

Generally, as the stream became larger, the slope of the riparian zone increased, and the width of the riparian zone decreased. It may be that the larger streams have had time to become more entrenched, creating a more sloped riparian habitat (Knighton, 1984). The greater riparian slope narrowed the width of the natural floodplain, by increasing the rate of change in elevation above the stream and causing changes in the relative dominance of vegetation species from wetter riparian habitat to a drier, more upland habitat (Nakamura *et al.*, 1997).

Although there appeared to be differences in the variability of riparian structure among watershed area classes, differences in the local variability of riparian width and slope measurements were not evident. Examining measurements of riparian width and slope within a site among watershed area classes showed no significant differences. Therefore, it was concluded that riparian structure at the site scale was relatively homogeneous among watershed area classes.

Within riverine systems, the complexity of the aquatic ecosystem increases from headwaters to mouth (Vannote *et al.*, 1980), while the variability in physical riparian characteristics does not seem to change along with aquatic ecosystem changes. However, the riparian vegetation community does change in both composition and diversity along with changes in watershed area. Analysis of the vegetation structure showed significant changes in riparian vegetation characteristics among watershed area classes. In the sites studied, Speckled Alder, Aspen, and Beaked Hazel predominated the riparian zone of streams with 1 km^2 watersheds. These low productivity headwater streams rely on the allochthonous energy inputs of the surrounding vegetation (Décamps, 1984), particularly nitrogen fixing plants such as Speckled Alder, to provide nutrients and carbon to the aquatic ecosystem (Vannote *et al.*, 1980).

Streams with 10 km^2 watersheds were characterized by the presence of very high amounts of grasses within the riparian zone. This was due particularly to the large number of meadow marsh riparian zones found around streams with 10 km^2 watersheds. These streams may rely less upon allochthonous inputs than streams with 1 km^2 watersheds as they have less nitrogen fixing species in their riparian zones. Being further along the stream continuum, autochthonous production may have increased enough to make up for the absence of additional nutrient and carbon inputs from species such as Speckled Alder (Naiman, 1983).

Riparian zones around streams with 100 km^2 watersheds generally had high amounts of Cedar, Honeysuckle and Currants, and low amounts of Speckled Alder, Aspen, and Beaked Hazel. Cedar, Honeysuckle and Currants are commonly found in rich conifer or hardwood sites, with moist organic soils (Legasy *et al.*, 1995). This indicates that riparian zones around larger streams (100 km^2 catchments) may have more nutrient and organic rich soils, which is why these species were found more often around the larger streams studied.

Analysis of drainage basin characteristics revealed a positive relationship between watershed area and surface roughness, width/depth ratio, and stream channel sinuosity, as well as a negative relationship between watershed area and stream channel and basin slope. Only the percent lake and wetland area of the drainage basin remained relatively constant throughout the watershed area classes. This illustrates the increasing complexity of watersheds from 1 to 100 km^2 in area. As a stream becomes larger and more complex, its watershed becomes relatively much wider, flatter and more variable in surface elevations. This reinforces the arguments for a watershed perspective on stream research (Frissell *et al.*, 1986; Knopf and Samson, 1994), as not only are there changes in the complexity of the aquatic ecosystem from headwaters to mouth (Vannote *et al.*, 1980), but in the watershed as well.

It was predicted that watersheds differing in dominant surficial geology would also differ in drainage basin characteristics. However, only the percent lake and wetland area of the basin showed a relationship to surficial geology, as there was a significantly higher percent of lakes and wetlands in bedrock dominated watersheds than in morainal dominated watersheds. This relationship was also significant within each of the watershed area classes.

Riparian wetland ecosystem classifications were also examined for relationships with physical and hydrological drainage basin characteristics. Streams with conifer swamp riparian zones had drainage basins with a greater percent area of lakes and wetlands than streams with either meadow marsh or hardwood swamp riparian zones. Conifer swamp riparian zones were also found around streams having drainage basins with higher surface roughness than streams with meadow marsh riparian zones. Since six of seven conifer swamp riparian zones were found in 40 to 100 km^2 watersheds, it was unclear whether they were related to surface roughness. However, conifer swamp riparian zones were not related to any of the other drainage basin characteristics having positive relationships with watershed area. Thus, it may be concluded that, in the sites studied, there was a significant positive relationship between streams with conifer swamp riparian zones and the surface roughness of its drainage basin.

While there were not any clear relationships between surficial geology and riparian vegetation structure, there did appear to be some trends. Six of seven meadow marsh riparian zones were found where there was morainal dominated site surficial geology, and in five of seven cases conifer swamp riparian zones were found where bedrock was the dominant watershed and site surficial geology. However, riparian vegetation structure is more likely related to a broad range of environmental variables rather than a single variable as coarse as surficial geology.

The results of this study have shown that there are relationships among physical and hydrological stream and drainage basin characteristics and riparian vegetation structure. As drainage area increased, stream discharge and temperature increased and stream gradient decreased. Stream discharge in 1 km^2 watersheds was shown to be the most variable where there was bedrock dominated watershed and site surficial geology. Stream temperature and gradient were found to be lowest in streams with meadow marsh riparian zones.

Riparian vegetation structure also showed relationships with drainage area. Riparian width decreased while riparian slope increased with increases in drainage area. Riparian width was greatest, and riparian slope least in meadow marsh riparian zones, while the width was narrowest and slope greatest in conifer swamp riparian zones. Riparian vegetation composition also changed with watershed area class. Smaller streams (1 km^2 watershed) had riparian zones with large amounts of Speckled Alder, Aspen, and Beaked Hazel and appear more vulnerable to under-protection during forest harvesting than larger streams, while having little commercially valuable timber within. Intermediate sized streams (10 km^2 watershed) were more likely to have riparian zones with large amounts of grasses and sedges, while riparian zones around large streams (100 km^2 watersheds) were best characterized by the presence of Cedar, Honeysuckle and Currants. Streams with both 1 and 10 km^2 watersheds also had riparian zones which had lower vegetation species diversity than the surrounding upland timber zone.

Physical and hydrological drainage basin characteristics also showed relationships with watershed area. There was a positive relationship between drainage area and the drainage basin's surface roughness, width/depth ratio, and stream channel sinuosity, while there was a negative relationship between drainage area and the drainage basin's stream channel and basin slopes. This indicates the change in complexity from small to large drainage basins along a continuous gradient.

This study has illustrated the relationships among physical and hydrological stream and drainage basin characteristics and riparian vegetation structure. It has also characterized riparian vegetation structure along a stream continuum to understand better the structure and function of riparian communities. To ensure sustainable forest management practices, forest managers will use this information to protect better riparian zones which contain a valuable and unique community of vegetation and provide a necessary function as part of stream and forest ecosystems.

5.0 Summary of Findings

This study revealed the relationships among physical and hydrological stream and drainage basin characteristics and riparian vegetation structure. Streams with smaller watersheds (1-10 km^2) were colder, steeper and less sinuous than streams with larger watersheds. However, instream characteristics were also related to riparian vegetation structure. Streams with meadow marsh riparian zones had the lowest and most variable stream temperatures and the least stream gradient, while the opposite was true for streams with conifer swamp riparian zones. The riparian zone was related to both wetland ecosystem classification and watershed characteristics in that:

1. Meadow marsh riparian zones were the widest, least sloped, and had the lowest species diversity, while conifer swamp riparian zones were the narrowest, most sloped, and had the highest species diversity;
2. Riparian zones around smaller streams (1-10 km^2 watersheds) were wider, flatter and more vulnerable to under-protection during timber harvesting than riparian zones around larger streams (40-100 km^2 watersheds); and
3. The vegetation community changes with along with watershed area from more nitrogen fixing, flood tolerant species in smaller streams to less flood tolerant species which are adapted to more nutrient rich soils around larger streams.

This information will be used as part of a first step towards assessing the possible effects of timber harvesting on aquatic ecosystems, and to ensure the effective management of riparian forest ecosystems.

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7.0 APPENDICES

7.1 APPENDIX I

Field Methods

Equipment: GPS unit, compass, map, 50 metre measuring tape, metre stick, Suunto clinometer, flow meter and rod, clipboard, data sheets (site description, vegetation sampling, soils, and discharge), pencils, permanent marker, calculator, flagging tape, hip waders, hand axe, soil probe, trowel, Ziploc plastic bags, plant identification guide, Forest (FEC) and Wetland (WEC) Ecosystem Classification guides, and soil classification manual.

Site Description Procedures:

1. After traveling to a chosen stream, the UTM location, date, stream name, name of the road the stream crosses, site code, tally person, and surveyor were recorded on the data sheet.
2. The crew started at the road crossing and traveled upstream a distance of at least greater than the area of disturbance (>50 m) of the right of way of the road (for sites near road crossings).
3. Once beyond any disturbance, the next thalweg of the stream channel was chosen as a representative starting point and was flagged as the downstream transect (or transect one of the stream sampling procedure).
4. At this point the surveyor walked into the left riparian zone (chosen while facing upstream) at 90 degrees to the stream with one end of the tape while the tally person stood on the bank full edge. Upon the surveyor reaching the edge of the riparian zone the tally person recorded the distance and slope change.

5. Procedure 4 is repeated for the right bank.
6. The crew then measured 20 m upstream (or to the middle of the stream sampling reach) and flagged both sides of the stream at this point.
7. The riparian vegetation plot (5 m by 5 m square) for the left bank was laid out on the upstream side of the transect.
8. A 30 m transect at 90 degrees to the stream was put in next on both sides of the stream. Starting on the left bank, the surveyor walked out from the bank full edge with the measuring tape until a significant change in slope was found or before the surveyor went out of site. The tally person stood at the bank full edge and used the clinometer to sight on the surveyor at eye height (tally persons eye height) and recorded the percent slope change on the tally sheet as well as the distance of the first section of gradient.
9. The tally person then walked to the surveyor's position, and the surveyor moved forward with the measuring tape along the transect until a slope change took place or before s/he went out of site. As before, the tally person used the clinometer to sight on the surveyor (where s/he stops) at eye height (tally persons eye height) and read and recorded the percent slope change on the tally sheet. This continued until the transect crossed the edge of the riparian zone, at which point the riparian width was recorded by the tally person and the point flagged. Note: The transect always extended at least 10 m beyond the edge of the riparian zone even if it was already 30 m in length and the end of the transect flagged.

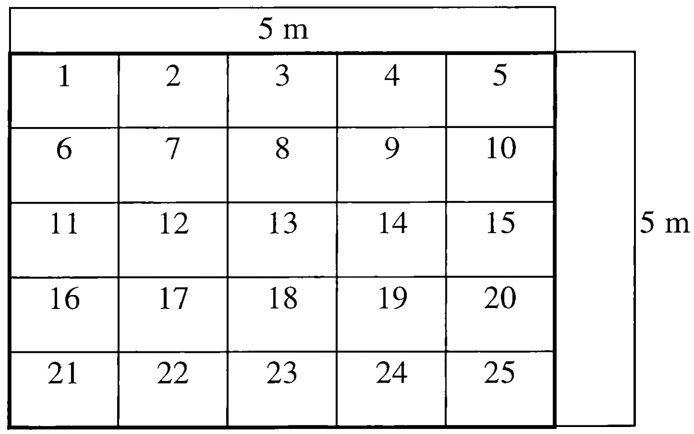
10. While in the upland zone, the 10 m by 10 m square vegetation plot was measured out using the end of the transect as a corner point, and following the same procedure as the 5 m by 5 m riparian sample plot.
11. Steps 7 through 10 were then repeated for the right bank transect.
12. To measure the stream gradient and the upstream riparian width and slope the crew moved 20 meters upstream of the middle transect and flagged the point (or to the last transect of the stream sampling reach).
13. Steps 4 and 5 were repeated for the upstream transect.
14. To measure the stream gradient the tally person held the end of the 50 m tape at the flagged upstream point and the surveyor walked downstream with the tape as far as the tally person could easily see (or to the downstream transect). The tally person used the clinometer to sight at their eye level on the surveyor and read and recorded the slope change and distance (i.e. down slope = a negative slope change, up slope = a positive slope change) in the corresponding section of the tally sheet.
15. The tally person then moved to where the surveyor measured to (if less than 40 m) and step 14 was repeated again. This process continued until 40 m of stream gradient (or the length of the reach) was measured and recorded.
16. General comments describing the site were recorded in the comments section of the tally sheets (*e.g.* upland vegetation plot was located in a cutover).

Vegetation Assessment Procedures:

FEC (Sims *et al.*, 1989) and WEC (Harris *et al.*, 1996) procedures of identifying and assessing the percent cover of all herbs, shrubs and trees in the plots, as well as soils information were used. However, sub-sampling of the vegetation plots was performed for the assessment of the percent cover of herbs. Three 1 metre by 1 metre plots were used within each vegetation plot, and the % herb cover was assessed for each sub-plot, to give an average for the entire vegetation plot. Selection of the three vegetation sub-plots was completed on site using a generated random number table and located using a diagram with numbered plot locations for the possible 25 (riparian) or 100 (upland) sub-plot locations. As each sub-plot was selected (in order from 1 - ∞) they were removed from the list, providing a new random number for each sub-plot location. The herb sub-plot location was measured from the nearest corner of the vegetation plot.

Example of the riparian plot with herb sub-plot layout and random number table.

<<<< Streamflow Direction (Right Bank)



<<<< Streamflow Direction (Left Bank)

1	22	28	11	55	4
2	8	29	7	56	15
3	21	30	11	57	9
4	9	31	1	58	18
5	23	32	16	59	14
6	8	33	11	60	21
7	2	34	11	61	13
8	3	35	15	62	11
9	8	36	8	63	10
10	9	37	8	64	3
11	8	38	11	65	18
12	9	39	3	66	3
13	22	40	8	67	17
14	4	41	23	68	20
15	8	42	4	69	17
16	19	43	10	70	23
17	21	44	15	71	17
18	15	45	15	72	13
19	1	46	6	73	21
20	15	47	24	74	23
21	4	48	20	75	5
22	25	49	13	76	9
23	25	50	21	77	8
24	7	51	6	78	25
25	23	52	13	79	3
26	16	53	19	80	17
27	15	54	17	81	6

7.2 **APPENDIX II**

Site Description Sheet

Stream name: ______________________ Date: ______________________

Site Code: ______________ Road: ______________________

Water Temperature: ______________ UTM location: ______________________

Left Bank Transect		(m)	(%)	**Right Bank Transect**		(m)	(%)
Riparian Width -	At transect:			Riparian Width -	At transect:		
and % slope	Upstream width:			and % slope	Upstream width:		
	Downstream width:				Downstream width:		

Transect Gradient			**Stream Gradient**		
Sections	Distance (m)	Slope (%)	Section	Distance (m)	Slope (%)
L.B. 1 - 2			1 - 2		
2 - 3			2 - 3		
3 - 4			3 - 4		
4 - 5			4 - 5		
5 - 6			5 - 6		
R.B. 1 - 2			6 - 7		
2 - 3			7 - 8		
3 - 4			8 - 9		
4 - 5					
5 - 6					

Soil Plots

	Left Bank		Right Bank	
Soil Samples	Riparian	Upland	Riparian	Upland
Surface Layer Type				
Depth of Surface Layer (cm)				
OM Horizons				
Depth of OM horizons (cm)				
A Horizon				
Mottles present (y/n)				
Depth to Mottles (cm)				
Depth to Restricting Layer (cm)				
Restricting Layer Type				
Percent Overstory Cover (%)				

Tally person: ______________________

Surveyor: ______________________

Comments: ____

____