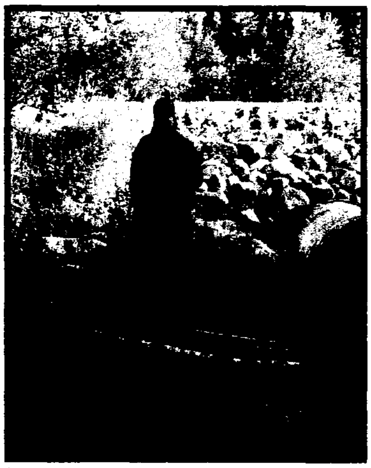
INTRODUCTION TO THE LEGACY FOREST SMALL STREAMS STUDY: RUNOFF PATTERNS AND RELATED BIOGEOCHEMISTRY ON THE WESTERN PORTION OF THE BOREAL SHIELD



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BY
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INTRODUCTION TO THE LEGACY FOREST SMALL STREAMS STUDY: RUNOFF PATTERNS AND RELATED BIOGEOCHEMISTRY IN THE WESTERN PORTION OF THE BOREAL SHIELD.

by

Elyse Mussell

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ABSTRACT

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Key Words: boreal forest, watershed disturbance, runoff, forest harvest, bioindicators, macroinvertebrates, leaf packs

The Forest Watershed and Riparian Disturbance (FORWARD) Project is an ongoing study initiated on the western Boreal Plain (northwestern Alberta) in 2001 to incorporate hydrologic processes into industrial forest management. Data collection and modelling focused on streamflow during the growing season (01 May to 31 October) in eight recently disturbed (>50% by total area) and six reference first- to fourth-order watersheds. In 2003, the Legacy Forest Small Streams (LFSS) study was launched in the western Boreal Shield (northwestern Ontario) to extend the geographical scope of the FORWARD Project. The objectives of my study were to provide a comparable baseline data set on stream flow dynamics for the modelling process within industrial forest management and in the context of a comparative study of storm driven patterns. Long-term intention is to apply controlled disturbance (ie. forest harvest) to a subset of the study watersheds. My study focused on five first- to third-order designated reference streams characterized between the 01 April to 31 October 2004 period. Mean total runoff in the small streams in the western Boreal Shield were >3 times higher than similarly sized reference watersheds in the western Boreal Plain

($P<0.01$). Long-term data from federally monitored rivers (Environment Canada 2006*b*) indicate that the timing and magnitude of peak flows differ between the Boreal Shield and Boreal Plain. During the long-term (25 yr) 01 April to 31 October period, an average of 30% of the runoff from Boreal Shield reference watersheds (Whitefish and Current rivers) occurred during snowmelt in April, compared to 16% in the Boreal Plain watershed (Sakwatamau River). Long-term mean total runoff (25 year) for the same period was twice as high in reference watersheds on the Boreal Shield (overall average 258 ± 4 mm; mean ± standard error) than the reference watershed on the Boreal Plain (129 ± 10 mm). During the 01 April to 31 October 2004 period, an average of 65% of the runoff from LFSS watersheds occurred during snowmelt in April, compared to only 21% in FORWARD study streams on the Boreal Plain. Precipitation patterns were estimated to account for <30% of the disparity in snowmelt volume between the two study areas; the remainder was attributed to physiographic features that promote retention of the snowpack and limit infiltration. It is projected that forest disturbances (e.g. harvest) in LFSS watersheds will enhance sublimation of the snowpack, cause earlier snowmelt in cleared areas and reduce interaction of snowmelt water with soils. The focus on these western Boreal Shield streams will be primarily on response variables related to snowpack in contrast to runoff during the growing season.

A pilot project (Appendix A) was initiated to provide introductory baseline data on the presence and abundance of aquatic macroinvertebrates and to determine rates of leaf pack (alder) decomposition prior to watershed disturbance. Leaf litter breakdown and associated invertebrate communities are sensitive to and ecologically-relevant measurements of land use impacts on stream ecological integrity (Gessner and Chauvet 2002). In four streams in the western Boreal Shield study, leaf pack loss was 3-fold higher and there was an indication that macroinvertebrate densities were higher in June compared to September deployment. One of the four streams, East Dog, had the fewest Plecoptera and Trichoptera among all four streams and the water had the highest color in June (306 and 356 TCU) and September (254 and 267 TCU) in both 2004 and 2005, respectively. Water in East Dog also had the tendency to have the lowest pH (min. 5.5) in both 2004 and 2005 while the other three streams had a minimum ranging from 5.9 to 6.0. Seasonal deployment (June vs. Sept.) and water quality characteristics (e.g. color, pH) likely influence leaf pack colonization by macroinvertebrates.

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CHAPTER I: GENERAL INTRODUCTION

Within North America, the boreal forest is recognized as the single largest land based ecosystem and stretches from Alaska to Newfoundland, bordered by tundra to the north and reaching the Great Lakes – St. Lawrence Lowlands to the south (http://www.borealforest.org). Spanning across most of Canada, the boreal forest consists of a variety of coniferous and deciduous trees, and aquatic environments. Anthropogenic and natural processes (e.g. harvesting, surface and subsurface mining, road construction and fire), impose a variety of biogeochemical changes on the watershed and downstream water quality. To link these changes with landscape projection models (e.g. forest disturbance simulations), specific watershed parameters must be monitored prior to and post-disturbance.

In the western portion of the Canadian boreal forest, the Forest Watershed and Riparian Disturbance (FORWARD) project was initiated to evaluate the varying effects of forest disturbance at the terrestrial level on streams on the Boreal Plain, with the intention of extending the project onto the Boreal Shield (Smith et al. 2003). The Legacy Forest Small Streams (LFSS) study was initiated in 2003 on the Boreal Shield to compliment the western component of the FORWARD project. It includes streams within the Legacy Forest in northwestern Ontario (Fig. 2.3, Table 2.2). The focus of this study is on streamflow and water quality prior to disturbance to provide baseline/reference measures of disturbance through similarities and differences as input into the modelling process. I will present baseline flow data on five streams within the LFSS study, and compare them with watersheds on the western Boreal Plain. The dynamic modelling process developed in a pilot scale for a managed area on the Boreal Plain requires considerable modification to be extended across the forested land base (Putz et al. 2003). The LFSS study offered an opportunity to collect comparable and complimentary data sets to extend the generality of the approach. Even though both study sites have paired designs, my study was to focus on a subset of watersheds in undisturbed conditions.

Further, I initiated a pilot project to provide introductory baseline data on the presence and abundance of aquatic macroinvertebrates and leaf pack decomposition rates prior to watershed disturbance. My pilot study focused on researching aquatic macroinvertebrates using leaf packs within four stream sites in the Legacy Forest (Appendix A). The leaf packs were used to provide two measures of stream integrity at the same time: 1) leafpack associated aquatic macroinvertebrate communities and 2) leafpack decomposition rates as a functional measure of stream health.

CHAPTER II: INTRODUCTION TO THE LEGACY FOREST SMALL STREAMS STUDY: RUNOFF PATTERNS AND RELATED FEATURES IN THE WESTERN PORTION OF THE BOREAL SHIELD[1]

INTRODUCTION

Recent initiatives in North America have examined the impacts of watershed disturbance on surface waters, and shown how research findings can be incorporated into forest management planning. In the United States, well-established studies such as that of Hubbard Brook in New Hampshire (Likens et al. 1978; Likens 2004) and the Marcell Experimental Forest in Minnesota (Stone and Elioff 1998; Verry et al. 2000) have emphasized the need for practices and tools for land management and planning that minimize these impacts. Traditionally, aquatic research and operational foresters have few opportunities to work on coordinated projects. Tools have emerged that incorporate terrestrial biodiversity considerations (e.g. Van Damme et al. 2003) and aquatic bioindicators through the government (e.g. Environment Canada's Environmental Effects Monitoring, http://www.ec.gc.ca/eem/English/default.cfm) into timber supply analysis. Very little industrial forest planning currently incorporates the

[1] A version of this chapter; Introduction to the Legacy Forest Small Streams study: Runoff patterns and related biogeochemistry in the western portion of the Boreal Shield, co-authored with W.P. Dinsmore, J.M. Burke and E.E. Prepas, has been submitted to the *Journal of Environmental Engineering and Science* for publication.

progress to date. However, long-term experimental stream studies, such as the Turkey Lakes Watershed in the province of Ontario (e.g. Foster et al. 2005) and the Malcolm Knapp Research Forest in British Columbia (e.g. McArthur and Richardson 2002), have produced extensive datasets, but have generally not been incorporated in the industrial planning process. The Stand-Level Adaptive Management case study in northeastern Ontario brings together government, industry, non-profit and academic partners, but focuses on stand-level experimental units and terrestrial vegetation and economic indicators with little consideration on impacts on aquatic ecosystems (MacDonald and Rice 2004).

Investigations in conifer-dominated watersheds on the central Canadian Boreal Shield ecozone and deciduous-dominated watersheds on the western Canadian Boreal Plain ecozone have indicated that the export of nutrients and other ions to streams and lakes is related to watershed-scale variables, primarily geomorphology, wetland cover and intensity of natural and anthropogenic disturbance (i.e., percent of watershed area impacted; Pinel-Alloul et al. 2002; Paterson et al. 2006). However, forest planning in Canada is organized around forest cover. More, well-designed long-term studies are essential to assist managers in identifying appropriate constraints for spatial patterns for forest harvesting within the operational boundaries of watersheds that will ensure healthy freshwater ecosystems.

The Forest Watershed and Riparian Disturbance (FORWARD) Project was initiated in 2001 and originally centered on Boreal Plain forests in the Swan Hills of Alberta (Smith et al. 2003) (Fig. 2.1). Scientists and forest industry practitioners collaborated on the design and implementation of watershed-scale experiments in 12 first- and second-order (≤15 km^2 in area) watersheds, with treatment (forest harvest of >50% of watershed area) versus reference, and pre- versus post-treatment comparisons. The extensive database has been incorporated in process-based models that enable the major industry partner to predict changes into the industrial planning process so as to balance forest harvest changes with other planning considerations. The hydrologic response variable being used in the FORWARD Project is runoff, measured as streamflow at the watershed outlet and corrected to the watershed area. Therefore, the term "runoff" here refers to the integration of surface and subsurface flow, and direct interception of precipitation by the stream channel (Brooks et al. 2003). In 2003, the FORWARD Project initiated the Legacy Forest Small Streams (LFSS) study on the Boreal Shield of northwestern Ontario, to broaden the generalization that might be made based on previous regionally-centered patterns and processes (Fig. 2.1). Four years of baseline data are being collected from first- to third-order (<10 km^2 in area) LFSS watersheds, prior to experimental harvesting (>50% of total area) in two of the watersheds that will occur in winter 2007-2008 or 2008-2009.

My introduction to the LFSS component of the FORWARD Project describes the study area, which has not been described in the peer-reviewed literature to date. Physiographic features in LFSS watersheds were the focus of this baseline study. Runoff patterns observed in the LFSS and Swan Hills study

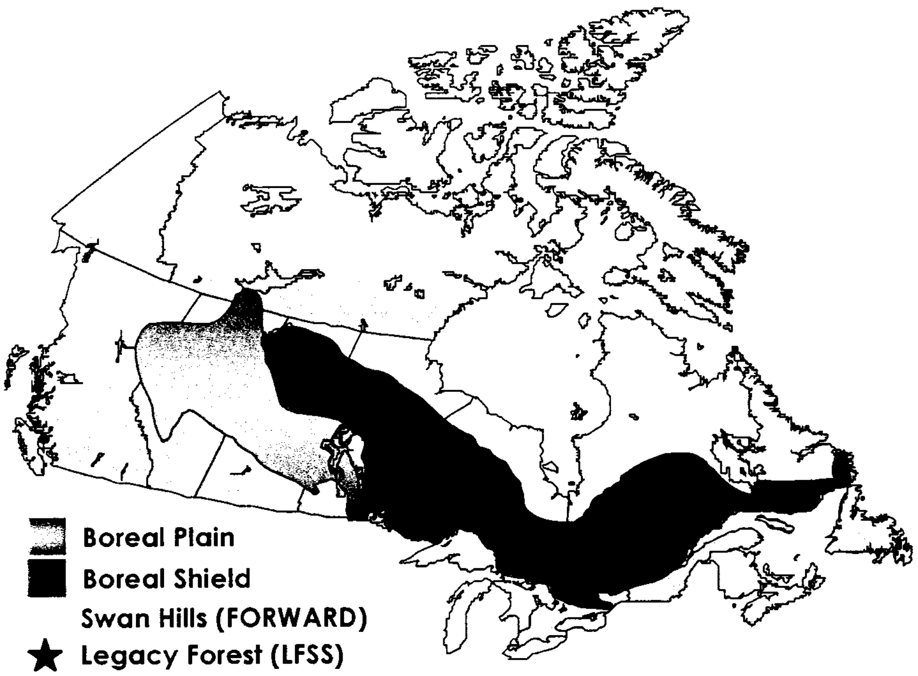

Figure 2.1. Location of the FORWARD Project and LFSS study on the Boreal Plain and Boreal Shield of Canada.

areas will be compared, to facilitate development of projections regarding disturbance impacts on the hydrological regimes of the LFSS watersheds. Long-term regional runoff patterns will be characterized using data from high-order stream watersheds in northwestern Ontario (Whitefish River at Nolalu and Current River at Stepstone) and the Swan Hills (Sakwatamau River near Whitecourt) (Environment Canada 2006*b*). The first field season (01 April to 31 October 2004) of pre-disturbance precipitation and runoff data from five LFSS watersheds will be presented and compared with published data from five reference watersheds in the Swan Hills of Alberta. This will help to identify the appropriate response variable(s) for the LFSS study area that will help focus post-harvest data collection and modelling efforts on time periods that appear to be most sensitive to watershed disturbance.

Legacy Forest Small Streams (LFSS) Study Area

The LFSS study area is within the Legacy Forest, an experimental forest, whose eastern boundary lies approximately 50 km northwest of Thunder Bay, Ontario (Fig. 2.2). The Legacy Forest was established in 2002 by several partners, including Lakehead University, the Ontario and Federal Governments and forestry-based industries operating in northwestern Ontario. It provides a land base for long-term research into relationships between intensive forest management, site biodiversity, forest ecosystem function, and non-timber values at the landscape level (Legacy Forest 2007). This 14,000 km^2 forest includes: 1) the Dog River-Matawin Forest (DRMF) Management Area, administered by the Ontario Ministry of Natural Resources (OMNR) where intensive silvicultural activity occurs and 2) the adjacent Quetico Provincial Park, an Ontario Parks wilderness preserve with minimal human land use (Fig. 2.2). The DRMF is well suited for watershed-scale experiments of the LFSS study because it contains hundreds of small streams and watersheds with reliable flow that can readily be compared. The DRMF also permits different forest harvesting treatments and therefore, contains all the streams in the LFSS study. Also, long-term aquatic studies at Dorset (Dillon and Molot 2005), Turkey Lakes (Beall et al. 2001), and the Experimental Lakes Area (Schindler et al. 1985) provide data for other central

Canadian boreal forests that may allow useful comparisons as the LFSS study evolves.

The DRMF is 9,450 km^2 in area and is located approximately 20 km north of the Ontario-Minnesota border between 48°16' and 49°28' latitude north and 89°30' and 91°50' longitude west (OMNR 2005) (Fig. 2.2). Approximately 12% of the DRMF is open water, while another 9% is currently classified as wetland. The southeast and central regions (35% by area) drain into Lake Superior, whereas the remainder is part of the Arctic (Hudson Bay) drainage basin. The landscape

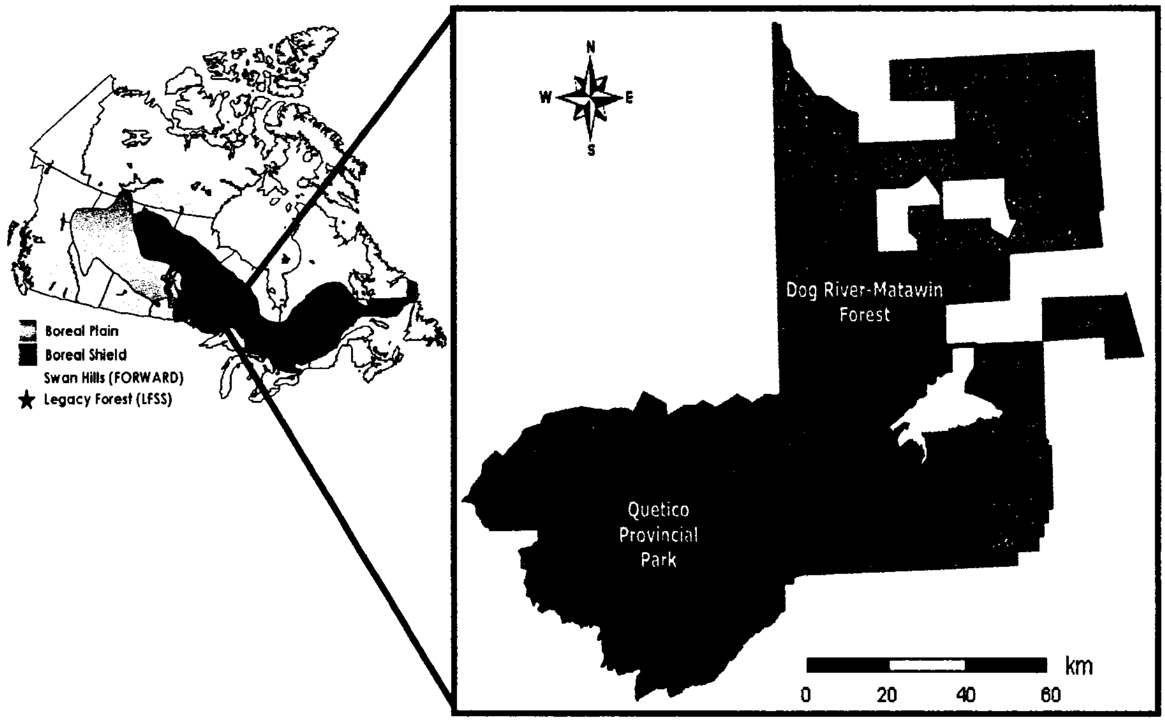

Figure 2.2. Locations of the FORWARD Project study sites within the Boreal Plain (Swan Hills) and Boreal Shield (LFSS) ecozones of Canada (inset); the Dog River-Matawin Forest (DRMF), northwestern Ontario.

is typical of the Boreal Shield ecozone, with low to moderate relief, thin layers of Podzol/Spodosol soils over discontinuous till, glaciofluvial or aeolian deposits, numerous outcrops of igneous bedrock, and many hundreds of lakes and streams (Environment Canada 2000, Singer and Cheng 2002, OMNR 2005). The topography follows a general gradient of low to high relief running northwest to southeast, such that the southeast corner records both the highest (680 m above mean sea level (amsl)) and lowest (370 m amsl) elevations within the DRMF (Natural Resources Canada 2007). Soils range generally from sandy to coarse loamy/silty textures in the north, to silty and sandy tills in the south. However, poorly drained depressions are found throughout the DRMF, especially in the central and northwest areas, resulting in extensive organic deposits and wetlands (OMNR 2005). The southeast corner of the DRMF is further distinguished by predominant red, calcareous clay deposits (OMNR 2005). The bedrock geology of the DRMF is the Precambrian Shield of the Wabigoon, Quetico and Wawa subprovinces (running north to south) (Ontario Ministry of Northern Development and Mines 2003).

In comparison, elevations in the FORWARD Swan Hills study area range from 775 to 1225 m amsl (Prepas et al. 2006), which is higher than the typical Boreal Plain elevations (300 to 600 m amsl) (Natural Resources Canada 2007). The Swan Hills landscape is formed largely of rolling moraines which consist of glacial till ranging from 15 to 30 m in thickness, with lacustrine deposits in the lowlands, underlain by Cretaceous and Tertiary sandstones and shales (Allen et al. 2003; Smith et al. 2003). The dominant soils in the Swan Hills are forest

Luvisols, Brunisols and organic soils and less frequently, Gleysols and Regosols (Ecological Stratification Working Group 1996).

Approximately 77% of the total DRMF area is forested (OMNR 2005). The northern two-thirds are dominated by boreal forest, while the southern third is transitional between the Boreal Shield and Great Lakes – St. Lawrence Lowlands ecozones. Predominant species are black spruce (*Picea mariana* (Mill) BSP; 35% of DRMF total area), trembling aspen (*Populus tremuloides* Michx; 25%), jack pine (*Pinus banksiana* Lamb; 19%), white birch (*Betula papyrifera* Marsh; 12%), balsam fir (*Abies balsamea* (L.) P. Mill; 5%), and white spruce (*Picea glauca* (Moench) Voss; 1%) (OMNR 2005). Mixedwood stands form the majority of forest cover in upland areas, but stands approaching pure conifer are prevalent on drier, sandy soils (jack pine) and in low-lying, poorly drained areas (black spruce). In contrast to the finer soils which dominate the western Boreal region, soils in the central Boreal region are generally coarser.

Commercial Forest Management is the dominant land use within the DRMF, although management provisions are made for non-industrial resources such as wildlife, recreation opportunities, and commodities important to indigenous culture (OMNR 2005). Also, 6% of the DRMF area is protected within three provincial parks and five conservation reserves. Forest harvesting on a commercial scale first appeared within the Lake Superior drainage basin of the DRMF during the mid-19th century, and expanded into the Hudson Bay drainage basin with the introduction of rail and bush road infrastructures in the 1880s and 1930s, respectively. Harvesting operations in the region reached their peak during the 1980s (OMNR 2005). During 1995 to 2000, a total of almost 390 km^2 of forests were harvested, yielding 4.4 million m^3 of timber. In the past, replanting in the DRMF was in the form of monocultures of jack pine or black spruce, but current forest renewal policy is designed to encourage replacement of original stand diversity. Historical records are scarce, but percent composition of forest cover has generally remained constant during the past 35 years at the LFSS study sites. Other sources of disturbance such as fire, insect infestations, and blowdown have had only minor impacts within the ten years prior to this study relative to commercial forest harvesting since fire suppression and other management protocols became widely established in the mid-20th century (OMNR 2005). Although mine sites and private land holdings lie outside the DRMF management plan, they occur in pockets scattered throughout the DRMF and conceivably have impacts on the surrounding landscape. Mineral extraction, primarily open-pit mining of base and precious metals, is concentrated in the south-central and northeastern regions of the DRMF. There are five hamlets within the DRMF management area and seasonal residences are scattered throughout; most of the latter are concentrated on the shores of larger lakes and are intended for recreation.

The Boreal Shield ecozone is characterized by long, cold winters and short, warm summers, but the Great Lakes have a moderating effect on the climate of adjacent regions (Environment Canada 2000). Few reliable meteorological data exist for the area within the DRMF, but 30-year (1971-2000) climate normals exist for two stations approximately 180 km apart, between which the DRMF lies roughly equidistant: Thunder Bay to the southeast, on the shore of Lake Superior, and Atikokan to the northwest (Table 2.1, Fig. 2.3). Thermal, elevation, and moisture gradients along this southeast to northwest plane are important in this region in terms of residual moisture for runoff and habitat considerations. Compared to Atikokan, mean annual and mean January air temperature 30-year normals were warmer in Thunder Bay, but mean July temperatures were slightly cooler (Table 2.1). While these differences in temperature normals suggest a moderating influence from Lake Superior on Thunder Bay air temperatures, Atikokan is almost 200 m higher in elevation than Thunder Bay, which would be expected to depress mean annual air temperatures there. The 30-year normal "degree days above 5°C" (an estimate of the growing season for native boreal vegetation) is higher for Atikokan than for Thunder Bay (Table 2.1), which indicates that spring daily temperatures increase more rapidly at inland sites than at shoreline sites. The greater elevation of the inland Atikokan site may also explain why mean annual rainfall, snowfall and total precipitation normals were higher relative to the shoreline Thunder Bay normals. The impact of elevation on weather is supported by a limited dataset from Upsala, located in the north-central DRMF at almost 100 m higher elevation than Atikokan (Table 2.1, Fig. 2.3). Degree-day data were not available for Upsala, but anecdotal evidence suggests that the growing season for boreal tree species is 20 days shorter at Upsala than at Atikokan (OMNR 2005). In addition to being cooler, Upsala is relatively wet, with mean annual precipitation in 2004 that was 12% and 49% higher, respectively, than Atikokan and Thunder Bay (Table 2.1). Climate in the northern portion of the DRMF may be influenced more by elevation than its location relative to Lake Superior. The thermal, elevation, and moisture gradients along this southeast to northwest plane are consistent with studies which are based on strategically placed local weather stations.

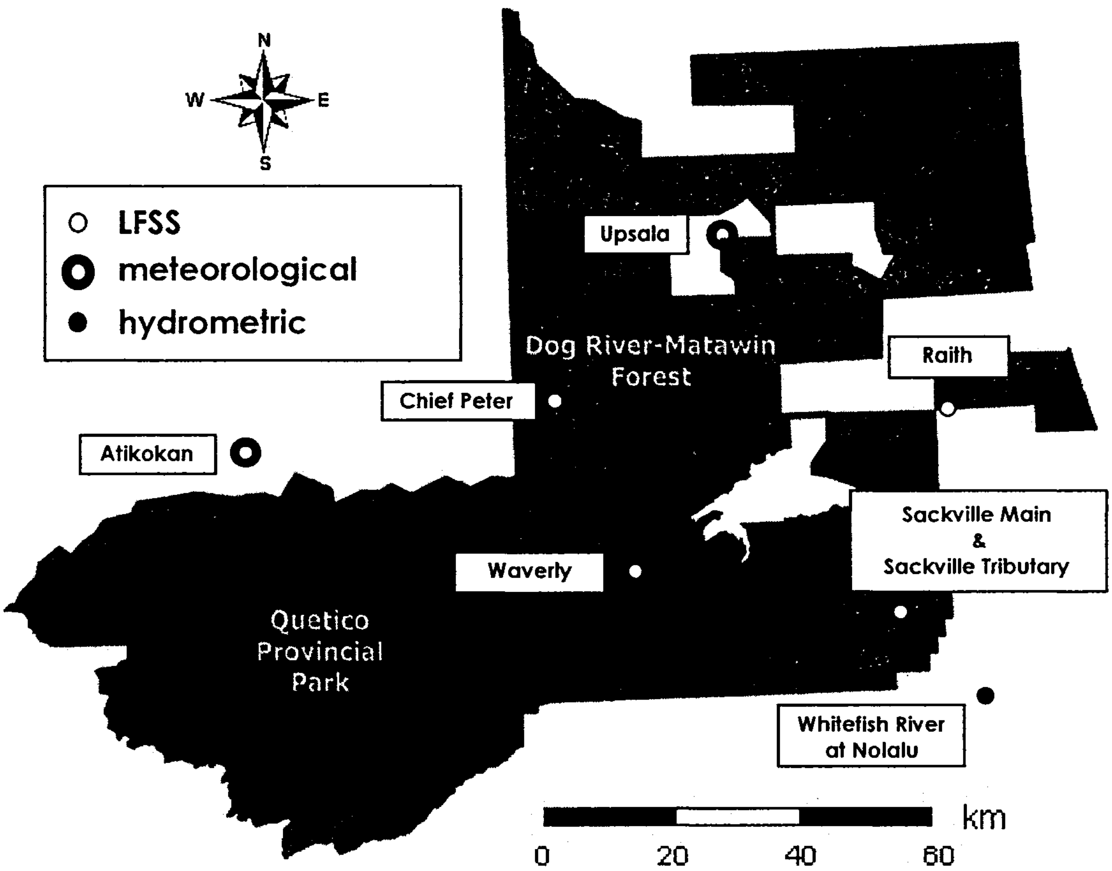

Figure 2.3. Locations of the LFSS watersheds, the Environment Canada (2006*a*) meteorological stations at Atikokan and Upsala, and the Environment Canada (2006*b*) hydrometric station on the Whitefish River at Nolalu. Not shown on the map are the meteorological station at Thunder Bay and the hydrometric station on the Current River at Stepstone which are approximately 50 km southeast and 85 km east of the eastern boundary of the DRMF, respectively.

By comparison, the climate on the Boreal Plain is generally dry continental, with a prolonged (November through March) winter season. Whitecourt, located approximately 30 km southeast of the Swan Hills study area, receives approximately 80% of the annual precipitation that falls on Thunder Bay and Atikokan, as indicated by 30-year climate normal data (Table 2.1). Although mean annual temperature is similar at Whitecourt and Thunder Bay, the Whitecourt mean July temperature normal was 2°C cooler than Thunder Bay or Atikokan (Table 2.1). As well, the normal for mean degree days above 5°C normal was low at Whitecourt relative to the Boreal Shield stations, which indicates a shorter growing season for the Swan Hills region. Mean annual air temperature at Whitecourt during 2004 was slightly warmer than the 30-year normal (Table 2.1). During 2004, total precipitation recorded at Whitecourt was similar to the 30-year normal, and 66% and 87% of that recorded at Atikokan and Thunder Bay, respectively (Table 2.1). Mean annual air temperature at Upsala during 2004 was more than two degrees lower than at Whitecourt for the same year. Most significantly, Upsala received almost twice as much precipitation during 2004 compared to Whitecourt (Table 2.1).

Table 2.1. Climate data for locations within or close to (≤50 km) the Boreal Plain and Boreal Shield study sites. Data courtesy of Environment Canada (2006*a*).

Characteristic	**Boreal Plain**	**Boreal Shield**		
	Whitecourt	Thunder Bay	Atikokan	Upsala
Latitude (N)	54°8'	48°22'	48°45'	49°1'
Longitude (W)	115°47'	89°9'	91°37'	90°28'
Elevation (m amsl)	782	199	395	489
1971-2000 Normals				
Mean Air Temperature (°C)				
Annual	2.6	2.5	1.6	ND
January	-12.1	-14.8	-18.1	ND
July	15.7	17.6	17.7	ND
Degree Days > 5°C	1286	1434	1467	ND
Precipitation				
April Rainfall (mm)	12.6	29.5	27.1	ND
Annual Rainfall (mm)	440	559	568	ND
Annual Snowfall (mm	138	153	172	ND
Annual Precipitation (mm)	578	712	740	ND
2004 Data				
Mean Air Temperature (°C)				
Annual	3.2	2.4	2.0	1.0
January	-14.8	-18.5	-20.3	-21.2
July	16.5	16.5	17.7	16.4
Precipitation				
April Rainfall (mm)	10.7	ND	35.8	ND
Annual Rainfall (mm)	440	ND	707	ND
Annual Snowfall (mm	133	ND	161	ND
Annual Precipitation (mm)	573	655	868	973

Thirty-year climate normals were obtained from meteorological stations Whitecourt A, Atikokan, and Thunder Bay A. Air temperature and precipitation data for 2004 were obtained from stations Whitecourt A, Atikokan (AUT) (temperature), Atikokan Marmion (precipitation), and Upsala (AUT); 2004 air temperature and precipitation data for Thunder Bay were compiled from stations Thunder Bay A, Thunder Bay AWOS, and Thunder Bay CS. 'ND' = no data.

METHODS

LFSS Site Selection

Streams were chosen as study sites rather than lakes, because they could provide essential short-term (1-2 yrs) and long-term (5-10 yrs) inputs to the modelling process while lakes, particularly in the semi-arid Boreal Plain, tend to be better indicators of long-term change. Headwater streams were chosen because the modelling process had identified first order streams as the primary unit for organization and linkages with their watersheds were stronger than streams draining networks in higher order watersheds (Gomi et al. 2002). They were therefore expected to respond swiftly to perturbation, as demonstrated by the Hubbard Brook experiment in New Hampshire (Likens et al. 1978). Headwater stream watersheds selected for long-term monitoring were small enough to permit high-intensity (>50% by area) harvesting treatments, yet large enough to support year-round stream flow, and possessed stands of merchantable coniferous or deciduous timber aged 40 years or older. For my study sites, I selected reaches with well-defined channels and as close as possible to the LFSS monitoring sites. Reaches with low channel slope, "braided" channeling, soft, silty substrate and alder-sedge dominated riparian communities indicated that a significant proportion of the flow from the watershed was subsurface at that point in the channel, and thus was impossible to quantify with my methodology.

Five first- to third-order headwater streams were selected during summer 2003 for the LFSS study, following ground truthing of potential sites identified from 1:50 000 topographic and 1:63 360 GIS-generated maps (Table 2.2). Watersheds were delineated and channel slope was estimated using 1:50 000 topographic maps. The stream sampling sites lie within a 75-km radius inside the DRMF.

Sackville Main, Sackville Tributary and Raith are located within the Lake Superior drainage basin, whereas Waverly and Chief Peter are part of the Hudson Bay drainage basin. With the exception of Waverly, channel substrate is igneous boulder and cobble rubble, with interstitial fine-particle accumulation in pools. This rubble layer is of indeterminate depth except at the Chief Peter site, where it is 30-50 cm thick overlying granitic bedrock. Stream banks are boulder rubble overlain by approximately 20-30 cm of soil, leaf litter and coarse woody debris. At the Waverly site, the channel substrate is predominately sand/silt with scattered pebbles and cobbles; on the banks, a similar thickness of topsoil overlies a predominately sandy B horizon. The five study reaches are located above established weirs and were used to collect water quality data for the duration of the LFSS study. The study reaches flow under forest canopy, with narrow riparian zones of 10 m or less. In-channel beaver ponds and other small (<1 ha) standing waters made up 2% or less by area of all watersheds. All watersheds have experienced some harvest perturbation within the past 20 years (Table 2.2). More potential study sites have been assessed by other investigators and five more watersheds have been recently added to the LFSS study design.

Table 2.2. Physical characteristics of the five LFSS watersheds and five reference watersheds in the Swan Hills, Alberta.

Watershed	Watershed Area (ha)	Stream Order	Study Site Elevation (m amsl)	Wetland Cover* (% area)	Recent Harvest** (% area)	Channel Slope (%)	Max. Bankful Width (cm)****
LFSS							
Sackville Main	945	3	396	7.1	9	1.0	525
Sackville Tributary	100	1	411	3.4	5	3.2	71
Raith	412	3	450	13.7	28	1.6	175
Waverly	399	2	457	3.7	14	0.5	203
Chief Peter	181	1	457	0.0	7	1.6	223
Mean ± SE	407 ± 147	-	434 ± 13	5.6 ± 2.3	12.6 ± 4.1	1.6 ± 0.5	239 ± 76
Swan Hills* **	765 ± 217	-	894 ± 19	12.8 ± 3.9	0	2.7 ± 0.5	188 ± 48

* Values were estimated for LFSS watersheds from aerial photographs by Bowater Canadian Forest Products (Thunder Bay, ON).

** Percent watershed area harvested within the past 20 years.

*** Means and standard errors of five watersheds (1A, Cassidy, Mosquito, Thistle and Willow) in the Swan Hills were obtained from Couling et al. (In press) and Pelster et al. (In press).

**** Bankful width was measured as the maximum width without exceeding stream bank for the 01 April to 31 October 2004 period.

Stream Discharge

Discharge was measured to determine the fraction of precipitation reaching the stream channel and my approach is to relate any patterns to watershed features. Mean daily discharge (Q) data were obtained from Environment Canada (2006*b*) for two large rivers near the LFSS study area and for the large river near the Swan Hills study area. The Whitefish River at Nolalu, Ontario (station ID 02AB017), located approx. 11 km southeast of the DRMF, has a gross drainage area of 210 km^2 and the gauging station is at an elevation of 330 m amsl. The Current River at Stepstone, Ontario (station ID 02AB021), located approx. 85 km east of the DRMF, has a gross drainage area of 392 km^2 and the gauging station is at 343 m amsl. The Sakwatamau River (station ID 07AH003), located 8 km northeast of the town of Whitecourt, Alberta, has a gross drainage area of 1140 km^2 and is at 730 m amsl. Long-term data were available for the Whitefish and Sakwatamau rivers for 1980 to 2004, and for the Current River from 1989 to 2004. Therefore, 25-yr data sets were used for Whitefish and Sakwatamau rivers and a 15-yr data set was used for Current River.

In the LFSS study watersheds, V-notch weirs were installed at Sackville Main (Fig. 2.4), Sackville Tributary and Waverly sampling sites during late February and early March 2004. A weir was not installed at Raith because of OMNR concerns regarding accessibility by brook trout (*Salvelinus fontinalis* Mitch.) to upstream habitat. A weir was installed at Chief Peter after this study (September 2005). Weirs consisted of a frame of ACQ pressure-treated 4”×4” lumber overlain on the upstream side with EBDM 60-gauge rubber membrane to ensure structure impermeability and prevent hyporheic flow, the region below and lateral to the streambed where mixing of both shallow ground water and surface water occurs, from passing beneath the structure. Each weir notch was fitted with a 90°-angle, beveled steel plate. A stilling well was set at the edge of each stilling

Figure 2.4. Sackville Main monitoring site, V-notch weir and stilling well. Photo by W.P. Dinsmore.

pool (Fig. 2.4) to facilitate monitoring water table fluctuations. Weir design specifications included the capacity to carry flow from a storm event of a 10-year return period, and structures were designed for a projected life expectancy of 20 years.

Stream Q was measured weekly at the LFSS stream sites during the ice-free period (01 May to 31 October), with the exception of Raith, which was added to the project in September 2004. Water depth and current velocity at 40% depth were measured at a minimum of 10 intervals along a transect perpendicular to the current with a Gurley 625D Pygmy current meter (Fig. 2.5). Staff height was recorded weekly using a staff gauge installed in either the stilling pool or a natural pool at each site (Fig. 2.6). The relationship (n = 11, r^2 = 0.94, P < 0.001) between Q and staff height was used to calculate Q on 27 July and 22 September 2004 at Waverly, when debris in the channel interfered with gauging. The stilling well at the Sackville Main weir was instrumented with a Global Water Instrument WL15 water-level recorder, programmed to record depth every ten

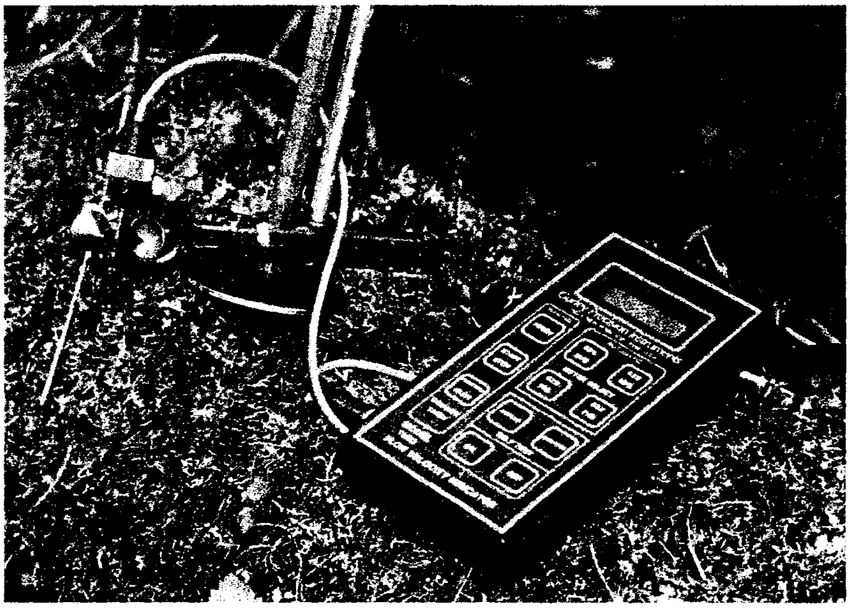

Figure 2.5. Gurley 625D Pygmy current meter. Photo by W.P Dinsmore.

minutes. Water level at the Sackville Main site was recorded from 20 July to 31 October 2004. Water level data were used to calculate Q using the relationship between water level and instantaneous Q, as in Burke et al. (2005) and Prepas et al. (2006).

During April, accurate flow gauging was not possible with our methodology because of the presence of ice in the stream channels. Therefore, mean daily Q in April was estimated from a linear relationship between log-transformed gauged Q measured at Sackville Main and log-transformed mean daily Q from the Whitefish River at Nolalu (n = 21, r^2 = 0.92, P < 0.001). The same method was

Figure 2.6. Staff gauge installed in a natural pool. Photo by W.P. Dinsmore.

used to estimate mean daily Q for the four other streams between gauging dates, using gauged Q from Sackville Main as the independent variable for Sackville Tributary (n = 17, r^2 = 0.86, P < 0.001), Raith (n = 9, r^2 = 0.78, P = 0.002, untransformed data) and Waverly (n = 20, r^2 = 0.82, P < 0.001), and Q from the Current River at Stepstone for Chief Peter (n = 24, r^2 = 0.88, P < 0.001). Note that Raith Q was estimated with this method from 01 May to 09 September 2004. Estimating mean daily Q from a linear relationship between log-transformed gauged Q measured at a stream and log-transformed mean daily Q from a larger reference stream was successfully used as in Prepas et al. (2006). April runoff was not directly measured in the study watersheds and therefore the magnitude of the peaks should be considered with caution.

Rain Measurement

Rain gauges were installed within 500 m of each site on 15 July 2004 (Sackville Main, Sackville Tributary, and Waverly), 22 July 2004 (Chief Peter) or 23 September 2004 (Raith). Rain data were collected until 31 October 2004. For the period prior to gauge installation, mean daily rainfall was calculated using data from the Thunder Bay (AWOS), Atikokan (Marmion) and Upsala stations (Fig. 2.3) (Environment Canada 2006*a*). The precipitation data collected from my study sites were compared to the surrounding Environment Canada monitoring sites. My data and the Environment Canada data were comparable for dates where LFSS had data. However, as the Environment Canada data were more complete and comparable, they were used throughout.

Data Analysis

Total runoff (mm) for a given time period was calculated for the three Environment Canada (2006*b*) rivers and the five LFSS watersheds by dividing the total streamflow volume measured at the stream sampling site by the watershed area above the sampling site. Therefore, 'runoff' refers to the sum of overland flow, interflow, groundwater flow and channel interception of precipitation that contributes to streamflow at the outlet of the watershed (Brooks et al. 2003). Runoff coefficients (the proportion of precipitation that becomes runoff) were calculated by dividing the total runoff by the total precipitation (mm) for the 01 May to 31 October period. The April period was excluded here, because snowmelt contributes to runoff in April (Singer and Cheng 2002); therefore runoff coefficients for the April period would be erroneously high. Using published values for the Swan Hills (Pelster et al. In press), mean LFSS (n = 5) and Swan Hills (n = 5) precipitation, runoff and runoff coefficients were compared with two-tailed t-tests after checking for equality of variance (Zar 1996). Relationships between elevation (independent variable) and precipitation and runoff (dependent variables) were determined with simple linear regression analysis. Alpha was set at 0.05.

RESULTS

Long-term data from large rivers (Environment Canada 2006*b*) indicate that the timing and magnitude of peak flows differ between the Boreal Shield and Boreal Plain. Long-term mean total runoff for the 01 April to 31 October period was 2 times higher from Whitefish and Current river watersheds on the Boreal Shield (253 ± 16 mm and 262 ± 20 mm respectively, overall average 258 ± 4 mm; mean ± *SE*) than from the Sakwatamau River watershed on the Boreal Plain (129 ± 10 mm) (Fig. 2.7). This can be attributed largely to dramatically higher peak flows in April during the snowmelt period and to a lesser extent, slightly higher flows in October at the Boreal Shield sites (Fig. 2.7). Among years, total runoff varied by approximately 3-fold in the Boreal Shield rivers, compared to more than 6-fold for the Boreal Plain river. It should also be noted that the Boreal Shield rivers flowed year-round, though winter runoff (November to March) only constituted 15 ± 1% and 17 ± 1% of total annual (November to October water year) runoff from the Whitefish and Current rivers, respectively. The Boreal Plain river was only monitored from March to October. Although the contribution of winter runoff to annual runoff is not known, long-term mean March runoff was only 2.2 mm. The 2004 year was relatively wet in both the LFSS watersheds and in the FORWARD watersheds on the Boreal Plain, having a 12% above long-term average for the 01 April to 31 October period in both cases.

In 2004, high peak flows during the snowmelt period were also evident in the LFSS watersheds. Among the five streams, the peak runoff event in April ranged from 22 mm to 96 mm (Fig. 2.8*a*). It must be noted that these peaks were

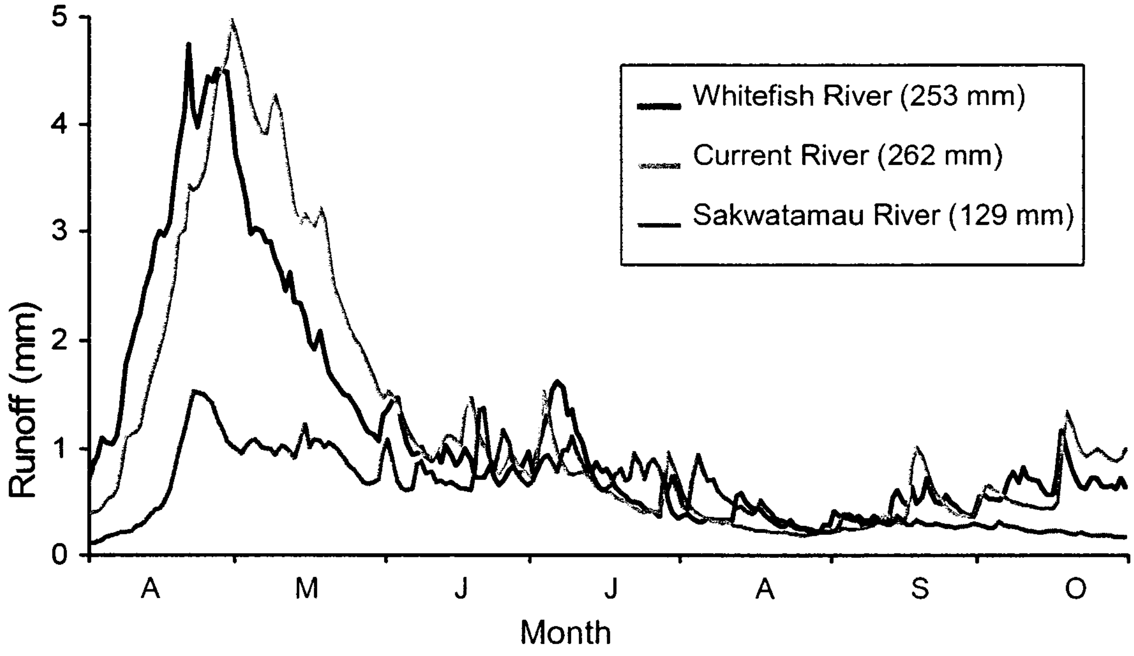

Figure 2.7. Long-term mean daily runoff during the ice-free period for representative large watersheds on the Boreal Shield (Whitefish River at Nolalu, 1980-2004; Current River at Stepstone, 1989-2004) and Boreal Plain (Sakwatamau River near Whitecourt, 1980-2004). Total runoff for the 01 April to 31 October period is indicated after the river name. Data are from Environment Canada (2006*b*).

not calculated from gauged values and should therefore be considered estimates. Snowmelt peaks were dramatically higher in the LFSS watersheds in 2004 than the long-term mean snowmelt peaks (~ 5 mm) in the large rivers in the region (Fig. 2.7). However, snowmelt peaks in the Whitefish and Current rivers historically (1980 to 2004) ranged from 4 to 27 mm and from 5 to 15 mm, respectively, and in 2004, they were 15 and 12 mm, respectively (Environment Canada 2006*b*). Smaller flow events associated with rain occurred in four of the

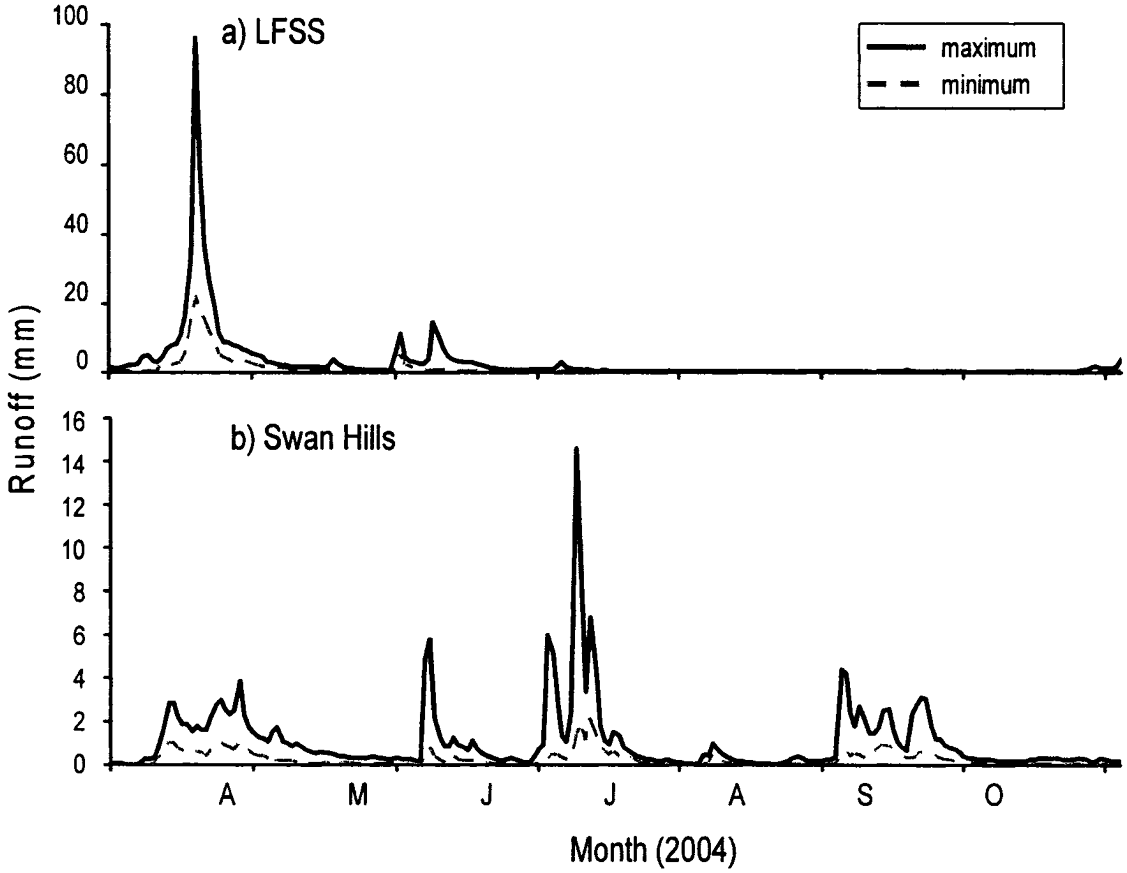

Figure 2.8. Minimum and maximum daily runoff among a) five LFSS watersheds and b) five Swan Hills watersheds (1A, Cassidy, Mosquito, Thistle and Willow) during April to October 2004. Note change in scale.

five LFSS watersheds on 01 and 08 June 2004, with peak runoff ranging from 5 mm (Waverly) to 14 mm (Raith) among watersheds (Fig. 2.8*a*, 2.9*a*). The exception was Chief Peter, which had a single small (4 mm) runoff event on 02

June 2004. The LFSS streams exhibited baseflow throughout the remainder of the April to October 2004 period. There was no comparable spring runoff peak in any of the Swan Hills watersheds in 2004 (Fig. 2.8*b*). Instead, peak runoff events occurred after protracted rain storms in July (Fig. 2.9*b*).

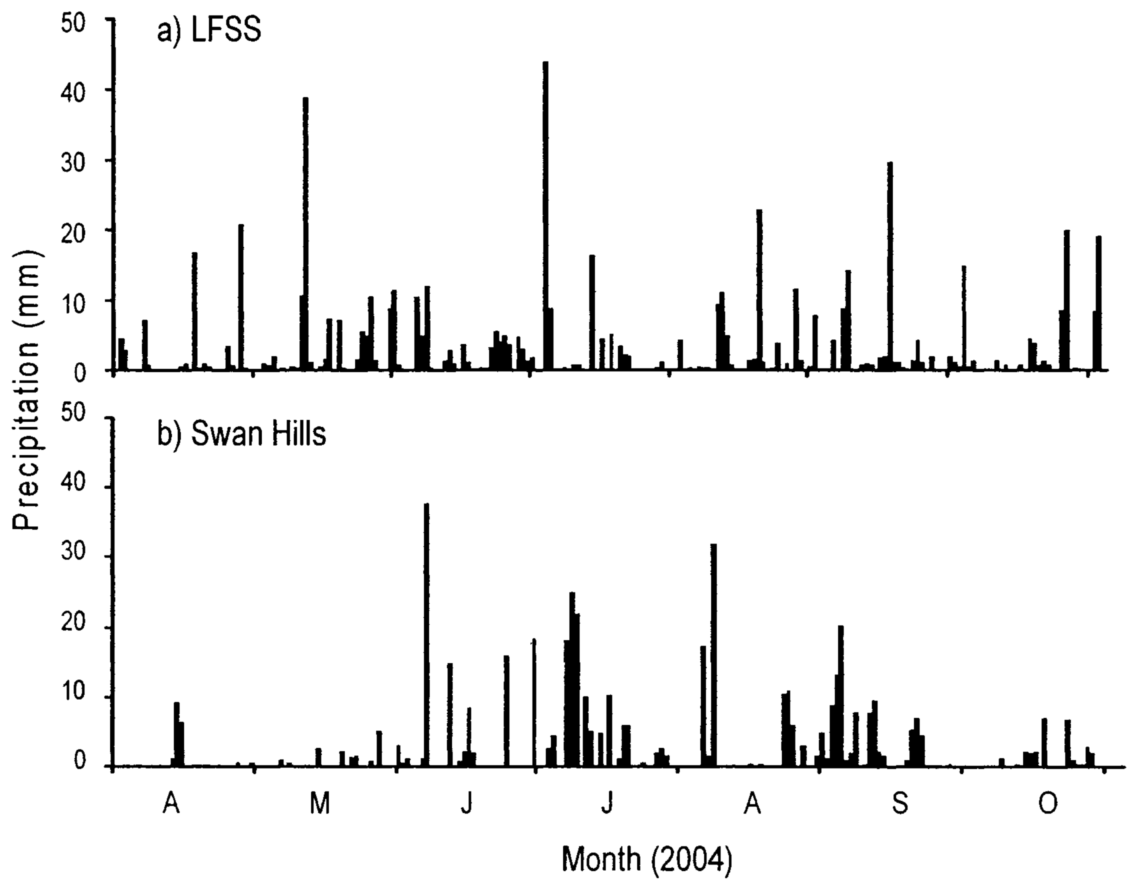

Figure 2.9. Mean daily precipitation among a) five LFSS watersheds and b) five Swan Hills watersheds (1A, Cassidy, Mosquito, Thistle and Willow) during April to October 2004.

As was the case for the large rivers, high spring peaks in 2004 in the small LFSS study watersheds appeared to drive high seasonal runoff in this study area compared to the Swan Hills. Mean April runoff was 11 times higher in the LFSS watersheds than in the Swan Hills watersheds (*P* = 0.005), and accounted for 65 ± 3% of the seasonal runoff, compared to only 21 ± 2% in the Swan Hills watersheds (Table 2.3). Whereas the total April to October runoff was more than three times higher in LFSS (392 ± 56 mm) than Swan Hills watersheds (115 ± 28 mm) (*P* = 0.004). Runoff for the May to October period was similar (*P* = 0.21, ns)

Table 2.3. Rainfall, runoff and runoff coefficients for the five LFSS watersheds and reference Swan Hills watersheds.

Watershed	**Rainfall (mm)**	**Runoff (mm)**		**Runoff Coefficient**
	May – Oct.	April	May – Oct.	May – Oct.
LFSS				
Sackville Main	477	281	155	0.32
Sackville Trib.	472	149	110	0.23
Raith*	590	323	218	0.37
Waverly	571	174	92	0.16
Chief Peter	610	352	105	0.17
Mean ± *SE*	544 ± 29	256 ± 40	136 ± 23	0.25 ± 0.04
Swan Hills**	464 ± 2	23 ± 6	92 ± 23	0.20 ± 0.05

* Runoff was estimated from 01 May to 09 September 2004.

** Means and standard errors for five watersheds (1A, Cassidy, Mosquito, Thistle and Willow) in the Swan Hills were obtained from Pelster et al. (In press).

(Table 2.3). Total April to October runoff varied by a factor of 2 in both study areas, ranging from 259 to 541 mm among the LFSS watersheds (Table 2.3) and from 90 to 222 mm among the Swan Hills watersheds. Total runoff for the same period from the LFSS watersheds was approximately four times higher than the Swan Hills watersheds ($P = 0.004$).

Rainfall data for the May through October period from the LFSS sampling sites support the regional trend for an increase in precipitation moving from the southeast (Sackville sites) to the northwest (Chief Peter) of the DRMF (Table 2.3, Fig. 2.3). This gradient was positively related to elevation ($df = 4$, $r^2 = 0.90$, $P = 0.01$). Total May through October rainfall was 17% higher among the LFSS watersheds than the Swan Hills watersheds all though given the small sample size and variation the difference was not detectable ($P = 0.05$, ns) (Table 2.3). During the May through October period, 16% to 37% of the total rain falling on the LFSS watersheds generated runoff that was measured at the stream sampling sites, as indicated by runoff coefficients (Table 2.3). No relationship existed between runoff from the LFSS watersheds and elevation at the study site ($P = 0.89$, ns). Runoff coefficients were similar between the LFSS and Swan Hills study areas ($P = 0.41$, ns) (Table 2.3).

DISCUSSION

Runoff patterns observed in the five LFSS watersheds in 2004 matched the long-term seasonal patterns for larger river watersheds in the region. Notably, snowmelt in April was the dominant runoff event, accounting for an average of 65% of the total April to October runoff among the LFSS watersheds. The hydrographs for the large rivers demonstrate relatively diminished and drawn out peak flows, in part because they are long-term means, but also because there is a lag in streamflow response as event water moves long distances to the stream channel and the potential exists for more spatial variation in a number of variables that affect water movement along the flow paths to the river channel (e.g. slope, drainage density, vegetation cover, soils, and precipitation cells; Brooks et al. 2003).

Working with the estimated spring snowmelt peak flows for the LFSS watersheds, precipitation patterns can explain at best 30% (73 mm) of the ~230 mm disparity in total April runoff between the LFSS and Swan Hills study areas. Since antecedent soil moisture conditions influence snowmelt runoff (Whitson et al. 2004), rainfall data for the preceding fall were examined. During November 2003, 6 to 20 mm more rain fell in the LFSS study area (at Atikokan and Thunder Bay, respectively, no data at Upsala) than the Swan Hills (0 mm at Whitecourt: Environment Canada 2006*a*). Atikokan received 25 mm more rainfall in April 2004, and 28 mm more snow (water equivalents) on an annual basis than the

Boreal Plain station (Table 2.1). Even assuming that all of the November 2003 rainfall and April 2004 rainfall and snowfall became runoff in April 2004, precipitation alone does not appear to account for high spring flows at the LFSS sites.

Other factors could have interacted to preserve the snowpack, such that there was more snow at the LFSS sites available for snowmelt runoff in April. Indeed, April 2004 began with 22 and 47 cm of snowpack at Thunder Bay and Upsala, respectively (no data for Atikokan), whereas only trace amounts (<1 cm) of snow were measured at Whitecourt (Environment Canada 2006*a*). All three stations reported no snowpack by the end of April. Cooler winter air temperatures at the LFSS sites (Table 2.1) would be associated with lower sublimation rates (Law and van Dijk 1994). In addition, the LFSS study area is situated at the boundary between the sub-humid and humid zones of the Canadian boreal region, in contrast to the Swan Hills, which are situated in the sub-humid zone (Zoltai et al. 1998). Sublimation rates are higher in more arid sites (Law and van Dijk 1994). Finally, differences in vegetation cover between the two study areas could have affected sublimation rates. Although snow accumulates preferentially in clear versus vegetated areas (due to snow interception by vegetation), vegetation cover – particularly conifer cover - protects existing snowpack from solar radiation and wind (Metcalfe and Buttle 1998; Bhatti et al. 2000). The Boreal Plain supports more mixed-wood forests than the Boreal Shield which is generally dominated by conifers.

Differences in soil characteristics also could have contributed to higher spring runoff in the LFSS watersheds. The LFSS study area is blanketed in thin soil layers and glacial and aeolian deposits, with areas of exposed bedrock (Environment Canada 2000; Singer and Cheng 2002; OMNR 2005). Infiltration of precipitation and surface runoff into the soils is inhibited in this kind of landscape by impermeable basal till layers and bedrock (Peters et al. 1995; Hazlett et al. 2001). At the LFSS sites during winters with low snowfall and thin snow cover, the potential may also exist for the presence of concrete frost, defined as the impermeable layer formed when water enters frozen litter and upper soil horizons and refreezes (Jones and Pomeroy 2001). For example, concrete frost was associated with highly efficient (≤100%) conversion of rain-on-snow events to runoff in the Lac Laflamme watershed in Québec (Jones and Pomeroy 2001). By comparison, the Swan Hills basin has a well-developed soil layer and mantle of thick (15 to 150 m) glacial till deposits over sedimentary bedrock (Green 1972, Pawlowicz and Fenton 1995). Boreal Plain soils to the east of the Swan Hills study area exhibited high infiltration and water storage capacity during snowmelt, even when mineral soils were frozen (Whitson et al. 2004). This was attributed to low antecedent (autumn) soil moisture conditions, a condition that could also be inferred from the lack of rainfall recorded at Whitecourt in November 2003 (Environment Canada 2006*a*). Shallow soils, concrete frost and wetter soils in spring in the LFSS study area could have enhanced snowmelt runoff to streams relative to the Swan Hills basin, where a deeper and drier soil and till substrate retained snowmelt.

Among the reference watersheds in the Swan Hills, wetland cover was the most important watershed variable in terms of explaining total May through October runoff and runoff coefficients over at least four seasons (Prepas et al. 2006, unpubl. data). For this reason, modelling of runoff coefficient for those watersheds included wetland cover as a modifier. The wetland cover estimates for the LFSS watersheds represent only treeless wetlands (i.e. marshes and sedge meadows), therefore they are probably underestimates compared to values from the Swan Hills, which include treed wetlands (see Couling et al. In press). Using these estimates, a positive relationship also existed between wetland cover in the five LFSS watersheds (Table 2.2) and total runoff ($r^2 = 0.88$, $P = 0.02$), as well as runoff coefficients ($r^2 = 0.83$, $P = 0.03$) for the May through October period in 2004 (Table 2.3). However, including April data in runoff estimates eliminated the runoff versus wetland cover relationship ($P = 0.33$, ns). These preliminary data suggest that wetlands interact with runoff moving to the stream channel during the frost-free period, but not during the important spring snowmelt period.

Forest removal has been associated with a higher peak flow magnitude and volume after rain, as well as more rapid streamflow responses to rain events (Brooks et al. 2003). Peak flows associated with rain increased by up to 90% in small experimentally clear cut watersheds in the Pacific Northwest, but only during small flow events (Thomas and Megahan 1998). During very heavy rains, watershed vegetation and soils conditions are of less importance, because water retention mechanisms are quickly saturated (Brooks et al. 2003). Higher annual runoff volumes often have been noted after forest removal and have been attributed to reduced evapotranspiration by vegetation, and reduced infiltration rates in soils compacted by harvesting equipment and roads (see review by Bosch and Hewlett (1982)). In general, runoff volumes during the growing season decline to pre-disturbance levels within 3 years on the Boreal Shield (e.g. Schindler et al. 1980), whereas recovery rates appear to be slower (at least 6 years) on the Boreal Plain, probably due to slower vegetation regrowth in arid conditions (Pelster et al. In press).

The snowmelt response and recovery trajectory after forest removal is less clear. Hydrologic simulations over large landscape areas (> 500 km^2) indicate that less mature forests accumulate more snow, thus potentially have more snowmelt runoff in spring (Matheussen et al. 2000). At smaller scales, snow accumulation patterns vary according to localized variations in landform, vegetation cover and air flow (Pomeroy et al. 2002). For example, less runoff was generated during snowmelt at upper than lower slope positions in the Turkey Lakes Watershed (Hazlett and Foster 2002). Clear cutting of upland aspen forest in Minnesota was associated with higher (up to 143%) spring snowmelt peak discharge, whereas partial cutting (leaving mature trees on site) of <50% of the watershed was followed by lower spring snowmelt peaks (Verry et al. 1983). This observation was attributed to “desynchronization” of snowmelt within a watershed, whereby snowpack in the cleared areas melted before the snowpack in adjacent vegetated areas. Interception of snow by a jack pine canopy in a Boreal Plain forest in Saskatchewan took at least 5 years to return to pre-clearcut conditions (Pomeroy et al. 1999). Recovery of snowmelt perturbations after forest harvest took 9 years after clearcutting in the Minnesota study (Verry et al. 1983).

It is projected that the hydrological impacts of forest harvest in the LFSS watersheds will be manifested most strongly via alterations to the snowpack. Specifically, removal of vegetation cover from LFSS watersheds will:
1) desynchronize snowmelt, such that it occurs earlier in cleared areas;
2) enhance sublimation in clearings in winter by exposing snow to wind and solar radiation; 3) promote freezing of soils and organic layers in clearings due to a reduction in snowpack depth; 4) reduce storage of spring meltwater in soils and reduce interaction of runoff water with soil layers, because early snowmelt flows over frozen substrates; and 5) reduce storage in wetlands by limiting infiltration due to soil compaction caused by harvesting equipment, and lower base flow during the growing season in watersheds with treed wetlands that are harvested. These changes will reduce snowmelt volume and peak flows and soil moisture conditions in April. Nutrient concentrations in meltwater will decrease as well. Sources of variation in snowmelt responses among harvested watersheds will consist of physiographic features (e.g. elevation, topographic relief, aspect), cutblock size and location (upland versus lowland), microsite conditions in

clearings (especially wind exposure), harvest intensity (percent of watershed cut) and post-harvest silvicultural activities. Hydrologic responses during the growing season will be detectable, but are expected to be small relative to snowmelt responses, and should return to preharvest levels within 3 years.

CONCLUSIONS

The response variable used in watershed disturbance modelling in the Swan Hills does not appear to be appropriate for the LFSS watersheds. The May through October runoff coefficient was chosen as the response variable for the Swan Hills, because approximately 80% of the total April to October runoff occurs during this period, and normalizing runoff to precipitation accounts for high spatial variability in precipitation in the study area (Prepas et al. 2006; Pelster et al. In press). In the management plan completed in 2007 by the major industry partner operating in the Swan Hills (see Russell et al. unpublished data), changes to the runoff coefficient for first-order watersheds that exceeded a threshold value triggered another iteration of spatial planning processes, in order to lower the response. In contrast, May through October runoff comprised only 35% of the April through October runoff among LFSS watersheds in 2004. Therefore, runoff during this time period (May through October) may not be a sensitive indicator of disturbance. Rather, snowpack conditions are expected to change after forest harvest and alter the magnitude and timing of spring snowmelt, the dominant hydrological event in the LFSS watersheds. Snowpack depth, coverage and melt rate and timing of melt rate are therefore more likely candidates for response variables for disturbance modelling.

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APPENDICES

APPENDIX A

PILOT PROJECT: MACROINVERTEBRATES AND LEAF PACK DECOMPOSITION WITHIN THE LFSS STUDY

INTRODUCTION

In North America, macroinvertebrates were incorporated into biomonitoring programs during the early 20^{th} Century. During the 1970s, the North American approach shifted from more qualitative methods to more quantitative evaluations. Biological monitoring recognizes the importance of using living organisms and their behavioral responses as a systematic method for measuring the quality of an aquatic environment. Although other aquatic organisms such as algae, plants, fish, protozoans, etc. have been recommended for use in water quality assessments, macroinvertebrates are the group most frequently used for many reasons (Merritt and Cummins 1996). Aquatic insects are the most diverse group of benthic macroinvertebrates which can be described as organisms that inhabit the sediment of a body of water. Accounting for approximately 70% of the known species in North America; more than 4000 species of aquatic insects and water mites are recognized from Canada (Rosenberg et al. 2001). Aquatic invertebrates are good biological indicators of stream health and provide site specific information since they are relatively sedentary; and for at least some part of their life cycle they depend on and therefore reflect the quality of an aquatic environment. Within aquatic environments benthic macroinvertebrates are abundant and have specific habitat and feeding requirements for their survival. Many species have a complex life cycle of approximately one year or more and sensitive life stages that respond quickly to pollution or stressful conditions. Aquatic invertebrates are also ubiquitous and easily sampled using relatively inexpensive equipment and causing very little detrimental effect on the resident biota (Merritt and Cummins 1996). Sampling requires very few people and with proper training and experience the investigator can readily identify aquatic insects. Therefore, monitoring benthic macroinvertebrate species for their presence and abundance within a particular location for a specified time period can provide information on environmental conditions, such as changes in water quality due to disturbance.

Aquatic invertebrates such as Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) (EPTs) are used as biological indicators of stream integrity. Many of the community descriptors (metrics) are based on those EPT taxa with complex life cycles, habitat requirements and pollution/stress sensitivity; and are indicators of ecosystem health (Resh and Jackson 1993). Members of the family Chironomidae, belonging to the Order Diptera (trueflies), are usually more pollution and disturbance tolerant than many other invertebrate taxa and can also be found in abundance allowing their numbers to be easily analyzed.

Stoneflies are primarily associated with clean, cool running water and have specific water temperature, substrate type and stream size requirements that are reflected in their distribution along a stream or river course. Since the life cycle of stoneflies ranges from one to three years depending on the species and generally only one to four weeks is occupied as an adult; stonefly larvae have specific aquatic habitat requirements. The microhabitat requirements of stonefly larvae include boulder surfaces, cobble, and gravel interstices, debris accumulations and leaf packs (Stewart and Harper 1996). Similar to stoneflies, mayflies can be found in a variety of standing and running water habitats. Mayflies can display a varied tolerance to pollution, however, they are also generally considered sensitive to pollution preferring cleaner water, along with stoneflies (U.S. E.P.A. 2006). Caddisflies are known to be one of the largest groups of aquatic insects consisting of more than 1200 species identified in North America (Wiggins 1978). Similar to stoneflies and mayflies, caddisflies can be found in most types of freshwater environments; however, they represent a larger range of pollution tolerance than the other two orders and are considered to be moderately tolerant to pollution (U.S. E.P.A. 2006). Members of the family Chironomidae are usually very abundant in most aquatic environments; densities of 50,000/m^2 are not uncommon and can be exceeded in preferred habitats such as small to medium sized streams with cobble substrate and deep hyporheic habitats (Coffman 1978).

Changes in aquatic environmental conditions (eg. water temperature, dissolved oxygen levels) can affect the survival of aquatic macroinvertebrates. For example, macroinvertebrate responses to changes in the environment (eg. harvesting practices) could be due to changes in substrate as a result of higher erosion or an increase in stream temperature caused by a loss of riparian cover. An increase in water temperatures may reduce the amount of dissolved oxygen in standing water while flowing water within an aquatic environment can have higher concentrations of dissolved oxygen. Water flow and turbulence help to increase the amount of dissolved oxygen by forcing aeration and increasing the water's surface area. Under normal conditions there are approximately 12 to 15 ppm of dissolved oxygen found in cold water compared to more than four fold higher found in the air (Merritt and Cummins 1996).

Disturbance of a forested watershed imposes a variety of effects on the physical and chemical character of a watercourse (Garmen and Moring 1991). For example forest harvesting near a watercourse has shown changes in stream hydrology and higher peak stream flows after a precipitation event (Harr and McCorison 1979, Garman and Moring 1991) as well as increased annual mean discharge (Webster et al. 1983). It is the flow conditions that influence the movement of aquatic larvae by increasing the downstream distance traveled during high discharge (Malmqvist 2002). Further, changes in stream water temperatures have been noted (Webster et al. 1983, Likens et al. 1970); post watershed disturbances may increase water temperature due to increased light exposure caused by the removal of forest cover and canopy. Shading from the forest canopy or riparian vegetation can maintain cooler water temperatures than those along cleared stream shorelines (Webster et al. 1983). Riparian canopy closure influences the amount of direct solar radiation reaching the stream's surface and affects both short and long wave radiation exchange processes as well as wind and microclimate conditions above the stream, all contributing to net heat exchange in small streams (MacDonald et al. 2003). Both water temperature and light input can change with the removal of riparian vegetation and both factors can profoundly affect stream communities (Hill et al. 1995).

Organic matter input and subsequent nutrient release can also be affected by watershed disturbance (Webster 1990, Garman and Moring 1991). It forms the major energy base of streams and provides important structural elements that help regulate biotic habitat quality (Kreutzweiser et al. 2004). Inputs of terrestrial organic matter such as speckled alder (*Alnus incana* ssp. *rugosa* (Du Roi)) leaves support in-stream productivity (Wallace et al. 1997) and are especially important for northern headwater streams where productivity can be low due to dense canopy cover and cool stream temperatures. Specifically, riparian detritus contributes a large portion of organic matter inputs to streams and is often a major source of energy for heterotrophic organisms (Meyer et al. 1998) and a dominant source of habitat for aquatic invertebrates (Murphy and Giller 2000). Microbial and invertebrate decomposition of detritus enables energy to move through the aquatic food webs (Suberkropp 1998), therefore, leaf decomposition rates and invertebrate assemblages are measures for assessing the ecological integrity of forested watersheds (Davis et al. 2001). Leaf litter breakdown and associated invertebrate communities are sensitive to and ecologically-relevant measurements of land use impacts on stream ecological integrity (Gessner and Chauvet 2002)

METHODS

LFSS Site Selection

Within the LFSS study, four small (<10 km^2 in area) first- to third-order headwater streams were selected for leaf pack deployment (June and September) in 2005 to measure mass loss attributed to aquatic invertebrate and microbial decomposition as well as macroinvertebrate presence and abundance. The stream sampling sites were chosen by substrate similarities, percent of surrounding watershed forest that had been harvested within the past 20 yrs and stream order. Sackville Main, Sackville Tributary, Raith and East Dog were determined to be four suitable LFSS sites (Table 3.1). Channel substrate at all four sites is relatively similar, consisting of igneous boulder and cobble rubble with fine particulate accumulation in pools. Each site was determined to have the preferred level (< 30%) of recent harvest within the past 20 yrs. However, after a more thorough review of the percentage disturbance in the East dog watershed, it was determined to have more than the preferred $\leq$30% disturbance by total area (East Dog had >50% recent harvest). However, leaf packs were already deployed at this time, therefore, this information was taken into account during data analysis. Stream side vegetation was dominated by alder species and sedges, therefore, alder leaves were chosen for processing and leaf pack assembly. See Chapter II LFSS Site Selection for further site description.

Table 3.1. LFSS study watersheds monitored in 2005.

Study Area	Watershed Area (ha)	Stream Order	Wetland Cover* (% area)	Recent Harvest** (% area)	Channel Length (km)	Channel Slope (%)
Sack. Main	945	3	7.1	9	5.1	1.0
Sack. Trib.	100	1	3.4	5	1.9	3.2
Raith	412	3	13.7	28	3.2	1.6
East Dog	571	2	3.5	51	2.3	0.6

* estimate includes treeless wetlands and open water only
** areas harvested within the past 20 years

Leaf Pack Preparation

Alder leaves and leaf pack preparation and processing protocols were provided by Dave Kreutzweiser (Canadian Forest Service, Sault St. Marie. Ont. Pers. comm.) (Appendix B) and were followed closely with few exceptions. In order to represent natural leaf fall, alder leaves were collected at senescence

Figure 3.1. Alder leaves collected in 2004, used for macroinvertebrate study. Photo by E. Mussell.

during the fall of the previous year (2004) and dried and stored until future use (Fig.3.1). Current summer leaves are not suitable for use since green leaves do not normally enter stream channels and can have different nutrient qualities from leaves at senescence (Gan and Amasino 1997). The alder leaves used in this study were sent to the Centre for Northern Forest Ecosystem Research (CNFER) in Thunder Bay, Ontario. At the CNFER facilities the alder leaves were pre-leached with slow flowing water overnight. The leaves were laid out the following day on perforated aluminum trays and placed in an incubator at 30C°, overnight, and in a drying oven at 50C° for four hours the following morning until they reached constant mass. Once removed from the drying oven, the leaves were allowed to cool for at least one hour to allow for re-adsorption of atmospheric moisture before being weighed.

Individual plastic containers were placed on a digital scale and tared, leaves were then added to be approximately 10g per container. Aluminum labeling tags consisting of corresponding stream information were placed in each container (Fig. 3.2) and recorded along with the label information. The leaf masses were recorded as initial pre-mass (g) and can be seen in Table 3.2. Prior to the day of deployment, water was added to the containers (overnight) to make the leaves more pliable for handling. Coarse mesh bags with wire frames were used to hold the leaves and labels in place and prior to stream deployment, each leaf pack was attached to a brick to ensure channel placement and to make certain each leaf pack remained under water especially during periods of low water (Fig. 3.3, Fig. 3.4).

Figure 3.2. Treatment process for leaf packs. Photo by H. Veldhoen.

Figures 3.3 and 3.4. Leaf packs attached to bricks to ensure channel placement and remain under water. Photos by T. Russell and E. Mussell.

Four leaf packs per stream were deployed in both early summer (June) and early fall (September) and left *in situ* for three weeks to be colonized by aquatic invertebrates. Leaf packs were retrieved with a 'D' frame net exactly three weeks post-deployment to gain a comparative measure of decomposition and macroinvertebrate abundance between sites over a given time. To stop any further post-experimental microbial decomposition, wire frames were removed and leaf packs were immediately placed in their original containers with 85% ethanol.

Leaf Pack Processing

Once retrieved, leaf packs were brought to the Lakehead University Nutrient Ecology (LUNE) Lab where they were processed individually for leaf decomposition and macroinvertebrates. As a visual aid, phloxine B dye was added to each sample container prior to processing (24 h) to help locate macroinvertebrates for preservation. The contents of each container were rinsed in a sink through a USA standard 425-μm testing sieve to remove the mesh bag, sediment and ethanol and then placed in an elutriation tub. The elutriation tub helped to separate the macroinvertebrates and leaves by providing air turbulence to the water using an air outlet and flowing water. Each large leaf or leaf particle was rinsed clean and inspected individually and placed on a labeled aluminum weighing tray to be later dried in a drying oven. Macroinvertebrates from each leaf pack were removed and placed in labeled glass vials with 85% ethanol to be later identified, sorted, and counted. The remaining smaller leaf particles and invertebrates were poured through a set of three USA standard testing sieves (3.35 mm, 1.7 mm, 425-µm) with the remaining tub water. Macroinvertebrates and leaf particles caught in the sieves were placed in corresponding glass vials and aluminum trays to be further processed. A dissecting microscope (Leica 2000 model # Z45 L) was used to examine the leaf pack remains from the 425-µm sieve for macroinvertebrates.

The aluminum trays holding the alder leaves from each leaf pack were placed in a drying oven at 60C° for two days. Prior to weighing, the leaves were allowed to cool for at least 1 hour to allow for re-adsorption of atmospheric moisture and reach constant mass. The tray contents were weighed using a digital scale and recorded as dry-masses (Table 3.2). Loss of leaf biomass due to microbial and macroinvertebrate decomposition was calculated and recorded as Leaf Loss (g) (Table 3.2). A complete list of streams, leaf pack masses, deployment and retrieval dates can be found in Appendix C.

Macroinvertebrates preserved in glass vials were later identified and sorted by Order, specifically, Ephemeroptera (Mayflies), Plecoptera (Stoneflies), Trichoptera (Caddisflies) (EPTs) and Diptera (True flies); family Chironomidae (Table 3.3) with dissecting and compound microscopes (WILD Heerbrugg model # M5-98146 and # 404207, respectively) and identification keys (Pennak 1978, Clifford 1991, Merritt and Cummins 1978, Merritt and Cummins 1996).

Table 3.2. Leaf pack masses

Deployment Month	Stream	Leaf Pack	Pre-mass (g)	Dry-mass (g)	Leaf loss (g)	**Leaf loss mean (g)**	***SE***
June	Sack Main	a	10.08	4.62	5.46	***5.82***	***0.96***
		b	10.05	6.76	3.28		
		c	10.00	3.14	6.86		
		d	10.06	2.38	7.68		
	Sack Trib	a	10.00	5.23	4.78	***3.84***	***0.42***
		b	10.01	6.05	3.96		
		c	10.02	6.10	3.93		
		d	10.04	7.32	2.72		
	East Dog	a	10.02	6.20	3.82	***3.33***	***0.22***
		b	10.07	6.49	3.58		
		c	10.11	7.19	2.91		
		d	10.00	7.01	2.99		
	Raith	a	10.11	5.91	4.21	***3.67***	***0.29***
		b	10.03	5.90	4.13		
		c	10.08	7.01	3.07		
		d	10.14	6.86	3.28		
September	Sack Main	a	10.03	8.56	1.47	***1.22***	***0.12***
		b	10.08	9.01	1.08		
		c	10.09	9.11	0.97		
		d	10.09	8.72	1.37		
	Sack Trib	a	10.09	8.55	1.55	***1.59***	***0.04***
		b	10.04	8.47	1.57		
		c	9.99	8.45	1.54		
		d	10.11	8.40	1.71		
	East Dog	a	10.02	8.36	1.67	***1.69***	***0.05***
		b	10.08	8.32	1.77		
		c	10.07	8.51	1.56		
		d	10.00	8.25	1.75		
	Raith	a	10.04	8.26	1.78	***1.76***	***0.04***
		b	10.02	8.16	1.86		
		c	10.05	8.38	1.67		
		d	9.99	8.27	1.72		

A summary of all dates, streams, and macroinvertebrates found during this study can be found in Appendix D. The EPTs and Chironomidae were counted without sub-sampling and recorded as the direct invertebrate count.

Table 3.3. Macroinvertebrate Orders

Deployment Month	Stream	Leaf Pack	Ephemeroptera Mayflies	Plecoptera Stoneflies	Trichoptera Caddisflies	Diptera Chironomidae
June	Sack Main	a	20	70	10	209
		b	40	110	1	476
		c	0	179	8	23
		d	8	57	7	32
	mean		***17***	***104***	***6.5***	***185***
	SE		**8.7**	**54.9**	**3.9**	**212**
	Sack Trib	a	1	71	7	962
		b	8	10	3	945
		c	28	76	7	1384
		d	54	44	4	606
	mean		***23***	***50***	***5.2***	***974***
	SE		**12**	**15**	**1.0**	**159**
	East Dog	a	51	35	0	1527
		b	20	0	0	279
		c	35	0	1	926
		d	36	0	2	414
	mean		***36***	***8.8***	***0.8***	***786***
	SE		**6.3**	**8.8**	**0.5**	**283**
	Raith	a	210	76	15	1026
		b	39	281	9	1006
		c	137	66	5	787
		d	101	80	8	590
	mean		***122***	***126***	***9.2***	***852***
	SE		**36**	**528**	**2.1**	**103**

Deployment Month	Stream	Leaf Pack	Ephemeroptera Mayflies	Plecoptera Stoneflies	Trichoptera Caddisflies	Diptera Chironomidae
September	Sack Main	a	6	2	19	92
		b	13	15	20	80
		c	19	9	16	52
		d	15	6	1	68
	mean		***13***	***8***	***14***	***73***
	SE		**2.7**	**2.7**	**4.4**	**8.5**
	Sack Trib	a	0	20	17	12
		b	0	29	39	17
		c	0	13	4	4
		d	0	3	9	14
	mean		***0***	***16***	***17***	***12***
	SE		**0.0**	**5.5**	**7.7**	**2.8**

	East Dog	a	6	14	4	135
		b	2	1	0	76
		c	10	3	0	177
		d	4	2	0	119
	mean		***5.5***	***5***	***1***	***127***
	SE		**1.7**	**3.0**	**1.0**	**21**
	Raith	a	1	8	13	122
		b	1	12	50	129
		c	0	3	25	130
		d	1	11	4	101
	mean		***0.8***	***8.5***	***23***	***120***
	SE		**0.3**	**2.0**	**10**	**6.7**

Water Quality Monitoring

Water sampling was conducted at all four streams on a weekly basis from early May until early December 2005. Water temperature was measured (Table 3.4), along with other water quality characteristic including pH (Table 3.5) and alkalinity levels, specific conductance and turbidity, total phosphorus (TP) and total dissolved phosphorus (TDP) and color. Table 3.6 shows the weighted daily means for the water quality data.

Table 3.4. Maximum and minimum water temperatures for the LFSS study sites

Water Temp	Sack Main		Sack Trib		East Dog		Raith	
2004	Max (C°)	Min (C°)	Max (C°)	Min (C°)	Max (C°)	Min (C°)	Max (C°)	Min (C°)
May	ND	ND	ND	ND	ND	ND	ND	ND
June*	21.3	11.6	13.4	10.3	17.2	10.2	ND	ND
July	23.7	12.7	30.4	9.5	26.7	10.3	ND	ND
August	19.8	10.1	15.5	4.8	19.5	7.4	ND	ND
September	17.9	8.4	14.1	7.1	18.7	6.5	14.1**	6.7**
2005								
May***	19.1	4.1	12.7	2.5	16.0	3.2	12.1	2.5
June	25.0	11.5	16.0	10.9	22.6	10.4	19.0	8.5
July	26.5	13.4	18.0	6.4	26.8	10.7	21.5	10.6
August	21.1	11.6	22.8	5.4	23.2	9.2	20.4	8.6
September	18.4	7.0	19.2	6.8	18.9	5.1	18.3	6.3

*monitoring began June 22, 2004, **Sept. 16, 2004, and *** first week of May 2004.
ND refers to No Data available.

Table 3.5. Maximum and minimum stream water pH (2004 and 2005).

pH	Sack Main		Sack Trib		East Dog		Raith	
2004	Max	Min	Max	Min	Max	Min	Max	Min
May	6.8	5.9	6.5	5.9	6.3	5.5	ND	ND
June	6.6	6.4	6.7	5.9	6.4	5.9	ND	ND
July	7.2	6.6	6.7	6.0	6.4	6.3	ND	ND
August	6.6	5.9	6.8	6.6	6.5	5.5	ND	ND
September	7.0	6.6	7.1	6.6	6.5	5.7	6.6	6.0
2005								
May	6.8	6.1	6.5	5.9	7.0	6.4	7.5	6.6
June	6.7	5.9	6.4	6.3	6.4	5.5	6.7	6.2
July	6.5	6.0	6.9	6.3	6.5	6.0	7.0	6.2
August	6.8	6.1	6.0*	6.0*	6.4	6.0	6.6	6.2
September	7.0	6.2	7.3	6.5	6.6	6.3	7.6	6.6

* one monthly reading
ND refers to No Data available

A YSI (85) meter was used to measure water temperature (C°) for each stream and prior to obtaining any measurements, the YSI meter was calibrated and site elevation levels were entered for each study site. 'Grab' samples collected from the study sites were obtained from the middle of the streams using 2-L amber high density polyethylene bottles pre-washed with phosphate-free detergent and 3% hydrochloric acid. 'Grab' samples were tested on site for pH and alkalinity levels using a portable pH/ATC meter, and turbidity using a Hanna Instruments Microprocessor meter. The remaining 'Grab' sample was returned to the LUNE Lab for further testing consisting of total phosphorus (TP) and total dissolved phosphorus (TDP) concentrations and color.

Table 3.6. Water quality data for 2004 and 2005, time weighted daily means.

2004	Month	TP	TDP	Spec Cond (µS/cm)	Alkalinity (mg/L CaCO3)	Color (TCU)	Turb (NTU)
Sack Main	May	17.8	18.5	46.2	18.0	193	3.3
	June	31.9	19.2	47.5	23.1	239	13.2
	July	46.8	47.0	85.9	41.1	244	16.7
	Aug	31.6	24.3	92.9	47.8	165	20.8
	Sep	26.6	14.9	77.3	58.6	93	13.8
Sack Trib.	May	13.2	11.0	49.1	19.0	162	0.7
	June	23.7	14.7	46.9	22.7	203	5.8
	July	19.2	18.9	62.4	30.0	163	8.6
	Aug	14.9	11.1	73.2	39.8	125	9.5
	Sep	11.5	7.9	55.1	39.1	102	2.7
East Dog	May	35.0	11.7	26.5	11.6	245	2.5
	June	14.1	11.4	31.9	14.8	306	5.7
	July	29.9	29.4	60.6	27.4	464	13.7
	Aug	27.1	18.4	55.7	30.4	357	20.1
	Sep	22.0	11.4	37.3	28.4	254	12.6
Raith	May	ND	ND	ND	ND	ND	ND
	June	ND	ND	ND	ND	ND	ND
	July	ND	ND	ND	ND	ND	ND
	Aug	ND	ND	ND	ND	ND	ND
	Sep	17.9	11.9	56.2	23.9	229	10.3
2005	**Month**	**TP**	**TDP**	**Spec Cond (µS/cm)**	**Alkalinity (mg/L CaCO3)**	**Color (TCU)**	**Turb (NTU)**
Sack Main	May	25.0	11.2	50.1	16.8	227	18.5
	June	37.4	16.2	62.7	24.9	295	21.5
	July	59.2	26.1	88.8	40.6	217	32.3
	Aug	53.2	17.9	121.6	58.7	134	21.4
	Sep	51.4	17.6	109.8	38.8	136	23.7
Sack Trib.	May	16.9	10.8	50.2	15.8	201	8.4
	June	21.3	13.7	59.1	22.1	213	2.4
	July	28.0	18.8	73.6	29.4	189	4.8
	Aug	15.8	12.1	88.6	35.4	98	4.3
	Sep	44.0	23.1	68.9	24.7	151	11.2
East Dog	May	15.4	10.0	31.1	11.4	278	3.4
	June	18.0	9.3	40.2	14.3	356	4.0
	July	36.4	14.8	72.9	32.9	452	26.8
	Aug	45.6	16.7	93.3	41.1	325	19.4
	Sep	30.1	15.7	104.4	49.2	267	15.1
Raith	May	10.5	7.4	29.4	10.4	221	8.8
	June	16.8	10.3	38.4	13.0	220	7.4
	July	27.8	16.6	50.2	21.2	227	8.2
	Aug	25.3	17.2	78.3	29.9	119	11.3
	Sep	18.6	10.8	70.5	29.7	128	6.9

PATTERNS NOTED and PROJECTED

Macroinvertebrate densities and leaf matter loss were higher during the month of June compared to September. Leaf loss in Sackville Main was highest (6 ± 1 g; mean ± standard error) during June and lowest (1 ± 0.1 g) in September among all four streams. The higher densities of Ephemeroptera, Plecoptera and Diptera (family Chironomidae) were observed during June compared to September in all four streams. However, Trichoptera densities tended to be greater in fall compared to June for all four streams. Sackville Tributary had the highest number of Chironomids (974 ± 159) in June and the lowest density of Chironomids (12 ± 3) in September. East Dog had the lowest density of macroinvertebrates, especially Trichoptera, of the four streams. East Dog had the highest stream water color in June and September 2005 (356 and 267 TCU, respectively) compared to the other three streams (mean 258 and 138 TCU, respectively). Further, water in East Dog tended to have a lower pH than the other study sites.

I have no data on the role that invertebrates or vertebrate predation played on these changes. However, in the case of watershed disturbance such as forest harvesting, I project that invertebrate densities (EPTs and Chironomidae) will decline due to increased water temperature and suspended sediments and decreased detrital inputs.

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APPENDIX B:

LEAF PACK PREPARATION AND PROCESSING PROTOCOLS

Leaf Pack Preparation and Processing

Provided by Dave Kreutzweiser, Canadian Forest Service, Sault St. Marie. Ont.

November 2004

Preparation

1. these are leaves in large mesh bags to measure mass loss from invertebrate and microbial decomposition
2. mesh bags are plastic, approximately 30 cm long, 13 cm wide when stretched, the mesh is approximately 5mm X 10 mm diamond shape when stretched, the wire frame is constructed of fence brace wire, or something similar, and is oblong with dimensions of about 20 X 15 cm – when filled, the mesh bags are closed off with metal strapping clips pinched off
3. pre-leach the leaves overnight in slowly flowing water
4. spread leaves on perforated aluminum trays and dry in oven at 30° C to constant weight (usually 2 d) – avoid leaves that are already damaged or full of holes – a few small holes are ok
5. **allow leaves to cool for about 1 hr before weighing to allow for re-adsorption of ambient moisture**
6. take aluminum labeling tag, (or make one) record number on data sheet, then place tag in leaf pack container (e.g. plastic yogurt container or something similar), place container in balance and tare
7. add dry leaves to container until a weight of about 10 g is attained – record this weight with corresponding tag number as the initial mass (leaves only)

8. put lid on container and set aside – this will later (on site) be put into a mesh bag with a wire frame and the corresponding tag to make the leaf pack
9. repeat for all required leaf packs
10. just before deployment, water is added to the leaf pack containers (overnight) to make the leaves pliable for handling
11. leaf packs are deployed by attaching mesh bag containing leaves, wire, and tag to a brick and placing in a depositional spot in or near the thalweg of the creek – the bags are tied off to the brick, the brick tied off to shore in case of high water – the pack is placed with an edge poked under the brick to hold it in place, but with care not to pinch the bag contents or restrict access to the bag, and to avoid burying the bag in detritus or sediment
12. packs are collected by placing a d-frame net downstream of the pack, cutting the tether, and lifting the pack and net out of the water together
13. the leaf pack is opened, wire removed, contents and tag placed in the collection container, the contents of the net added to the container, and enough water is added to preserve the sample in formaldehyde
14. familiarize yourself with MSDS for formaldehyde before using
15. at White River, leaf packs are deployed for 3-week periods, one in early summer (use 50% leaf-out in riparian trees as phonological indicator for

timing for putting leaf packs in; this is usually around the 1st week in June), and one in early fall (put in 1st or 2nd week of September)

Lab Processing

16. at least 24 h prior to processing, add a little phloxine B dye powder to the sample to dye the insects
17. rinse the contents of the container (leaves, mesh, tag, accumulated material) in the sink under the fume hood on a 250 μm sieve to remove the preservative
18. take the tag and place in an aluminum weighing dish – record the tag number and dish number on data sheet and retain for later – keep track of this dish and tag to make sure it stays with corresponding sample
19. prepare a glass vial for the insects – label the vial with **site number** (e.g. WR4), **date**, **sample type and number** (e.g. leafpack#3), and **Direct Count** – add ethanol mixture (70% ethanol, 10% glycerol) and set aside for insects
20. take the contents on the 250 μm sieve to the processing lab and prepare the water elutriation tub (white tub with air/water mix inlet) – fill the tub first with water, place a 4mm, 2mm and a 250 μm sieve under the outlet – add the air/water mix (turn air on first, then water) to cause turbulence in the tub for elutriation, and sufficient outflow to move insects and particles out of the tub
21. wash the contents on the 250 μm sieve into the tub

22. thoroughly rinse off mesh bag (pick particles and insects off with forceps if necessary) and discard
23. stir and move leaves and other material to float off insects and fine particles – pull leaves and larger leaf particles out, visually inspect for insects and place in vial any that are found, then put leaves and larger leaf particles in aluminum weighing dish
24. when all leaves and large leaf particles are removed, turn off the air/water inlet (turn water off first, then air) and pour the remaining materials out of the tub through the set of sieves at the outflow – any non-leaf particles that are easily collected during this process (e.g. sticks, pieces of bark, stones, etc) can be discarded
25. wash the contents of the 4mm and 2mm sieve into a white sorting tray. The 4mm sieve simply aids in rinsing the larger leaf pieces from smaller leaf pieces and bugs.
26. wash the contents of the 250 μm sieve into a separate white sorting tray
27. pick all leaf particles in the 4mm and 2mm tray and add to the aluminum weighing dish – all insects in this tray are placed in the labeled vial – discard all other non-leaf materials
28. pick the insects from the 250 μm sieve tray and add to the vial
29. if all bugs from both trays are picked than vial should be labeled as direct count. If, after all non-chironomid bugs have been picked from the 250 μm tray, there is a substantial number of chironomids or other very small

insects remaining (substantial number meaning several hours of sorting time required) then the sample should be *subsampled.*

30. dry the contents of the aluminum weighing dish at 60° C to constant weight (at least 2 d), then weigh and record as "mass of leaves and tray". **Allow leaves to cool for at least 1 hour before weighing.**
31. remove the leaf material and weigh the dish and the tag and record as "tray mass"

Subsampling Procedure

32. put a small amount of water into the bottom of the 1 L subsampling cone so that the air stone is covered
33. turn on the air so that the water is bubbling vigorously
34. decant the contents of the 250 µm tray into the cone
35. top up the cone with water until the 1000ml mark is reached
36. using a 50 ml beaker, take a minimum 200 ml subsample (4 scoops). If it looks like this will yield a small subsample of bugs/chironomids, more scoops may be needed.
37. ensure that subsample vial is marked with the correct proportion of subsample (eg. 200ml of 1000ml = **1/5** subsample). Both vials (direct count and subsample) for this sample should also be marked as **1 of 2** and **2 of 2** respectively, then taped together.

APPENDIX C:

STREAMS, LEAF PACK MASSES, DEPLOYMENT AND RETRIEVAL DATES

Leaf Pack Data - June Deployment 2005						
Date Deployed	Date Retrieved	Site Name		Pre-mass (g)	Dry-mass (g)	Leaf loss (g)
21-Jun-05	12-Jul-05	Sackville Main	a	10.075	4.617	5.458
21-Jun-05	12-Jul-05	Sackville Main	b	10.046	6.765	3.282
21-Jun-05	12-Jul-05	Sackville Main	c	10.001	3.142	6.859
21-Jun-05	12-Jul-05	Sackville Main	d	10.063	2.383	7.679
21-Jun-05	12-Jul-05	Sackville Trib.	a	10.004	5.227	4.777
21-Jun-05	12-Jul-05	Sackville Trib.	b	10.006	6.049	3.957
21-Jun-05	12-Jul-05	Sackville Trib.	c	10.022	6.096	3.926
21-Jun-05	12-Jul-05	Sackville Trib.	d	10.042	7.324	2.717
23-Jun-05	13-Jul-05	East Dog	a	10.022	6.200	3.822
23-Jun-05	13-Jul-05	East Dog	b	10.074	6.489	3.585
23-Jun-05	13-Jul-05	East Dog	c	10.107	7.193	2.914
23-Jun-05	13-Jul-05	East Dog	d	10.003	7.010	2.993
23-Jun-05	13-Jul-05	Raith	a	10.113	5.907	4.206
23-Jun-05	13-Jul-05	Raith	b	10.035	5.901	4.134
23-Jun-05	13-Jul-05	Raith	c	10.081	7.007	3.074
23-Jun-05	13-Jul-05	Raith	d	10.138	6.862	3.276

Leaf Pack Data - Sept. Deployment 2005						
Date Deployed	Date Retrieved	Site Name		Pre-mass (g)	Dry-mass (g)	Leaf Loss (g)
13-Sep-05	04-Oct-05	Sackville Main	a	10.033	8.562	1.471
13-Sep-05	04-Oct-05	Sackville Main	b	10.083	9.008	1.076
13-Sep-05	04-Oct-05	Sackville Main	c	10.086	9.115	0.972
13-Sep-05	04-Oct-05	Sackville Main	d	10.090	8.716	1.374
13-Sep-05	04-Oct-05	Sackville Trib.	a	10.091	8.545	1.546
13-Sep-05	04-Oct-05	Sackville Trib.	b	10.042	8.469	1.573
13-Sep-05	04-Oct-05	Sackville Trib.	c	9.991	8.453	1.537
13-Sep-05	04-Oct-05	Sackville Trib.	d	10.112	8.404	1.709
14-Sep-05	05-Oct-05	East Dog	a	10.024	8.358	1.666
14-Sep-05	05-Oct-05	East Dog	b	10.083	8.318	1.765
14-Sep-05	05-Oct-05	East Dog	c	10.075	8.513	1.562
14-Sep-05	05-Oct-05	East Dog	d	9.997	8.251	1.747
14-Sep-05	05-Oct-05	Raith	a	10.044	8.262	1.781
14-Sep-05	05-Oct-05	Raith	b	10.017	8.156	1.861
14-Sep-05	05-Oct-05	Raith	c	10.050	8.383	1.667
14-Sep-05	05-Oct-05	Raith	d	9.995	8.274	1.721

APPENDIX D:

MACROINVERTEBRATES

Season	Stream	Leafpack	Ephemeroptera	Plecoptera	Trichoptera	Diptera							
						Chironomidae larvae	Chironomidae pupa	Culicidae pupa	Tipulidae	Ceratopogonidae	Simuliidae	Sciomyzidae
Spring	Sack Main 1	a	20	70	10	209	0	0	0	0	0	0
		b	40	110	1	476	0	0	0	0	0	0
		c	0	179	8	23	0	0	0	0	1	0
		d	8	57	7	32	0	0	0	1	0	0
	Total		**68**	**416**	**26**	**740**	**0**	**0**	**0**	**1**	**1**	**0**
	Average		**17**	**104**	**6.5**	**185**	**0**	**0**	**0**	**0.25**	**0.25**	**0**
Spring	Sack Trib 2	a	1	71	7	962	0	0	2	0	0	2
		b	8	10	3	945	0	0	2	0	0	4
		c	28	76	7	1384	0	0	0	1	0	2
		d	54	44	4	606	0	0	0	0	0	1
	Total		**91**	**201**	**21**	**3897**	**0**	**0**	**4**	**1**	**0**	**9**
	Average		**22.75**	**50.25**	**5.25**	**974.25**	**0**	**0**	**1**	**0.25**	**0**	**2.25**
Spring	East Dog 3	a	51	35	0	1524	3	1	4	15	11	2
		b	20	0	0	279	0	0	0	20	0	0
		c	35	0	1	926	0	0	0	1	0	0
		d	36	0	2	412	2	0	0	0	0	0
	Total		**142**	**35**	**3**	**3141**	**5**	**1**	**4**	**36**	**11**	**2**
	Average		**35.5**	**8.75**	**0.75**	**785.25**	**1.25**	**0.25**	**1**	**9**	**2.75**	**0.5**
Spring	Raith 4	a	210	76	15	1025	1	3	0	0	0	1
		b	39	281	9	1005	1	0	0	0	0	0
		c	137	66	5	784	3	0	0	0	0	0
		d	101	80	8	588	2	0	0	0	0	0
	Total		**487**	**503**	**37**	**3402**	**7**	**3**	**0**	**0**	**0**	**1**
	Average		**121.75**	**125.75**	**9.25**	**850.5**	**1.75**	**0.75**	**0**	**0**	**0**	**0.25**

Season	Stream	Leafpack	Ephemeroptera	Plecoptera	Trichoptera	Diptera						
						Chironomidae larvae	Chironomidae pupa	Culicidae pupa	Tipulidae	Ceratopogonidae	Simuliidae	Sciomyzidae
Fall	**Sack Main**	a	6	2	19	92	0	0	0	3	0	0
	1	b	13	15	20	71	9	0	0	1	0	0
		c	19	9	16	52	0	0	0	0	0	0
		d	15	6	1	67	1	0	0	1	0	0
	Total		**53**	**32**	**56**	**282**	**10**	**0**	**0**	**5**	**0**	**0**
	Average		**13.25**	**8**	**14**	**70.5**	**2.5**	**0**	**0**	**1.25**	**0**	**0**
Fall	**Sack Trib**	a	0	20	17	12	0	0	0	0	0	0
	2	b	0	29	39	17	0	0	0	0	0	0
		c	0	13	4	4	0	0	0	0	0	0
		d	0	3	9	13	1	0	0	0	0	0
	Total		**0**	**65**	**69**	**46**	**1**	**0**	**0**	**0**	**0**	**0**
	Average		**0**	**16.25**	**17.25**	**11.5**	**0.25**	**0**	**0**	**0**	**0**	**0**
Fall	**East Dog**	a	6	14	4	135	0	0	0	2	0	0
	3	b	2	1	0	76	0	0	0	1	0	0
		c	10	3	0	177	0	0	0	2	0	0
		d	4	2	0	119	0	0	1	2	0	0
	Total		**22**	**20**	**4**	**507**	**0**	**0**	**1**	**7**	**0**	**0**
	Average		**5.5**	**5**	**1**	**126.75**	**0**	**0**	**0.25**	**1.75**	**0**	**0**
Fall	**Raith**	a	1	8	13	122	0	0	0	0	0	0
	4	b	1	12	50	129	0	0	0	2	0	0
		c	0	3	25	130	0	0	0	0	0	0
		d	1	11	4	101	0	0	0	0	0	0
	Total		**3**	**34**	**92**	**482**	**0**	**0**	**0**	**2**	**0**	**0**
	Average		**0.75**	**8.5**	**23**	**120.5**	**0**	**0**	**0**	**0.5**	**0**	**0**

Season	Stream	Odonata larvae	Coleoptera adult	Coleoptera larvae	Coleoptera water penny	Pelecypoda	Gastropoda	Oligochaeta	Hydrachnidia	Hirundinea	Collembola	Amphipoda
Spring	Sack Main	1	2	4	4	0	3	0	5	2	0	0
	1	1	2	5	0	7	1	0	2	29	0	4
		1	7	0	0	0	0	0	2	0	0	1
		0	2	1	1	0	0	0	4	1	0	0
	Total	**3**	**13**	**10**	**5**	**7**	**4**	**0**	**13**	**32**	**0**	**5**
	Average	**0.75**	**3.25**	**2.5**	**1.25**	**1.75**	**1**	**0**	**3.25**	**8**	**0**	**1.25**
Spring	Sack Trib	0	1	5	0	1	11	0	5	0	0	0
	2	0	0	3	0	11	2	8	7	0	0	0
		0	0	4	0	5	8	8	3	0	0	0
		0	0	2	0	0	10	0	0	0	0	0
	Total	**0**	**1**	**14**	**0**	**17**	**31**	**16**	**15**	**0**	**0**	**0**
	Average	**0**	**0.25**	**3.5**	**0**	**4.25**	**7.75**	**4**	**3.75**	**0**	**0**	**0**
Spring	East Dog	0	0	1	0	24	0	0	1	15	0	0
	3	0	0	0	0	9	0	3	0	4	0	0
		4	0	4	0	8	1	3	0	6	0	0
		4	0	0	0	21	3	1	0	9	0	0
	Total	**8**	**0**	**5**	**0**	**62**	**4**	**7**	**1**	**34**	**0**	**0**
	Average	**2**	**0**	**1.25**	**0**	**15.5**	**1**	**1.75**	**0.25**	**8.5**	**0**	**0**
Spring	Raith	4	0	0	0	0	7	0	1	0	0	0
	4	2	0	1	0	10	3	0	8	0	0	0
		4	0	0	0	2	0	0	0	2	0	0
		2	0	0	0	1	1	0	0	24	0	0
	Total	**12**	**0**	**1**	**0**	**13**	**11**	**0**	**9**	**26**	**0**	**0**
	Average	**3**	**0**	**0.25**	**0**	**3.25**	**2.75**	**0**	**2.25**	**6.5**	**0**	**0**

Season	Stream	Odonata	Coleoptera			Pelecypoda	Gastropoda	Oligochaeta	Hydrachnidia	Hirundinea	Collembola	Amphipoda
		larvae	adult	larvae	water penny							
Fall	Sack Main	0	3	2	0	7	0	4	0	4	0	1
	1	0	1	0	0	0	1	0	4	0	0	0
		0	1	7	0	0	0	1	0	0	0	0
		0		3	0	11	0	0	0	0	3	0
	Total	0	5	12	0	18	1	5	4	4	3	1
	Average	0	1.667	3	0	4.5	0.25	1.25	1	1	0.75	0.25
Fall	Sack Trib	0	0	0	0	4	3	9	3	4	0	0
	2	0	0	0	0	2	5	10	3	2	2	0
		0	0	0	0	3	1	6	1	0	0	0
		1	0	0	0	3	1	12	0	0	2	0
	Total	1	0	0	0	12	10	37	7	6	4	0
	Average	0.25	0	0	0	3	2.5	9.25	1.75	1.5	1	0
Fall	East Dog	1	0	0	0	30	0	0	6	0	0	0
	3	1	0	0	0	4	0	0	0	0	0	0
		0	0	0	0	23	0	0	6	1	0	0
		2	0	0	0	5	0	0	2	1	0	0
	Total	4	0	0	0	62	0	0	14	2	0	0
	Average	1	0	0	0	15.5	0	0	3.5	0.5	0	0
Fall	Raith	1	1	2	0	0	9	0	6	0	0	0
	4	4	0	3	0	4	15	0	1	0	0	0
		2	0	0	0	1	3	1	1	0	0	0
		1	0	0	0	2	8	0	3	0	0	0
	Total	8	1	5	0	7	35	1	11	0	0	0
	Average	2	0.25	1.25	0	1.75	8.75	0.25	2.75	0	0	0