Fundy Model Forest

~Partners in Sustainability~

Report Title: The Hydrogeochemical responses associated with Forestry Practices in the Hayward-Holmes Watershed Study in NB's FMF

Author: J. Pomeroy, J. Kerekes, T. Pollack

Year of project: 1997

Principal contact information: Environment Canada
Moncton N.B.
P.O. Box 20005
E1A 6S8

File Name:
Biodiversity_1997_Pomeroy_The_Hydrogeochemical_responses_associated_with_Forestry_Practices_in_the_Hayward_Holmes_Watershed_study_in_NB_FMF

The Fundy Model Forest…
…Partners in Sustainability

"The Fundy Model Forest (FMF) is a partnership of 38 organizations that are promoting sustainable forest management practices in the Acadian Forest region."

Atlantic Society of Fish and Wildlife Biologists
Canadian Institute of Forestry
Canadian Forest Service
City of Moncton
Conservation Council of New Brunswick
Fisheries and Oceans Canada
Indian and Northern Affairs Canada
Eel Ground First Nation
Elgin Eco Association
Elmhurst Outdoors
Environment Canada
Fawcett Lumber Company
Fundy Environmental Action Group
Fundy National Park
Greater Fundy Ecosystem Research Group
INFOR, Inc.
J.D. Irving, Limited
KC Irving Chair for Sustainable Development
Maritime College of Forest Technology
NB Department of the Environment and Local Government
NB Department of Natural Resources
NB Federation of Naturalists
New Brunswick Federation of Woodlot Owners
NB Premier's Round Table on the Environment & Economy
New Brunswick School District 2
New Brunswick School District 6
Nova Forest Alliance
Petitcodiac Sportsman's Club
Red Bank First Nation
Remsoft Inc.
Southern New Brunswick Wood Cooperative Limited
Sussex and District Chamber of Commerce
Sussex Fish and Game Association
Town of Sussex
Université de Moncton
University of NB, Fredericton - Faculty of Forestry
University of NB - Saint John Campus
Village of Petitcodiac
Washademoak Environmentalists

Natural Resources Canada   Ressources naturelles Canada

Canada

THE HYDROGEOCHEMICAL RESPONSES ASSOCIATED WITH FORESTRY PRACTICES IN THE HAYWARD-HOLMES WATERSHED STUDY

C19A

THE HYDROGEOCHEMICAL RESPONSES ASSOCIATED WITH FORESTRY PRACTICES IN THE HAYWARD - HOLMES WATERSHED STUDY IN NEW BRUNSWICK'S FUNDY MODEL FOREST

1993- 1997

FUNDY MODEL FOREST AND ENVIRONMENT CANADA

J. POMEROY[1], J. KEREKES[2], T. POLLOCK[1]

[1]Environment Canada, Environmental Conservation Branch, Moncton, New Brunswick, P.O. Box 23005 E1A 6S8
[2]Environment Canada, Environmental Conservation Branch, 45 Alderney Drive, Dartmouth, Nova Scotia B3Y 2N6

Abstract:

The hydrogeochemical response of three forest management practices were assessed over a four year period in the Hayward Brook Watershed Study of the Fundy Model Forest. The Fundy Model Forest is located in the Acadian forest of south-east New Brunswick, Canada. The study area includes the watersheds of Hayward and Holmes Brooks. Data collection involved five automated water monitoring stations, surface water sampling and in-situ stream measurements.

The comparison of one year of pre-harvest data to two years of post-harvest data found the hydrogeochemical responses to be minimal in the watersheds. Results indicate that multiple criteria must be considered when designing a harvest plan for stream protection. Criteria include the area of watershed to be harvested, the width of the buffer, age and density of understorey growth, soil conditions, type of harvest equipment and road construction. Results found that the seventeen percent of the watershed clear cut adjacent to a 30 metre stream buffer caused minimal response in two watersheds which had moderate to heavy density of undergrowth. The twelve percent clear cut adjacent to a 60 metre stream buffer detected no response. This indicates that the percentage of a watershed which can be harvested when using a 60 metre buffer can be greater. The twelve percent clear cut harvest adjacent to the selection harvest within the stream buffer caused no nutrient flux increase in the stream water but, runoff did increase. The increase in runoff is attributed to the lack of understorey growth, slow regrowth of vegetation and, the sandy soil type. The selection harvest within the riparian area was not found to contribute to the stream response. The most significant impacts to the streams were due to erosion from culverts, soil rupture due to equipment and, the use of corrosive metal culverts not suited for the soft waters of the Hayward Brook Watershed Study.

Introduction:

Sustainable forestry is based on the premise of removing essential nutrient at a rate less than or equal to that which can be replenished by natural processes (Dahlgren and Driscoll, 1994). If harvesting only removed timber and disturbed nothing else this concept could be achieved but, the harvesting operation reduces interception and transpiration. These processes increases soil moisture which recharges the groundwater and result in a greater stream-flow (Bari et al. 1996). The greater discharge is often associated with a greater export of suspended sediments and associated nutrients (Naslas et al. 1994). Other nutrient losses occurs during harvesting when the soil is ruptured and this results in a leaching of organic matter, nutrients and metals (Ahtiainen, 1992). Combinations of these effects can lead to a depletion of forest nutrient and productivity and, can interfere with water quality when exports exceed the systems threshold (Martin et al. 1984).

To investigate how terrestrial and aquatic systems of the Acadian forest of Atlantic Canada respond to current forest management practices the Hayward Brook Watershed Study (HBWS) was established in 1994. The project considered six research components: bryophytes, vascular plants, fisheries and stream morphology, forest birds, selection harvesting and hydrogeochemistry (Pomeroy et al. 1996). The site is located in southeast New Brunswick, Canada, within the boundaries of the Fundy Model Forest. The forest is an 80 year old mixed Acadian stand within the Atlantic Maritime ecozone. The site covers 30 km^2 and includes the catchment areas of Hayward and Holmes Brooks. Eight research plots perpendicular to the stream were located within the site. The plot size is 150 metre on both sides of the stream and up to one kilometre in length (Map 1). Four sampling sites on the Hayward and one site on Holmes Brooks were monitored using automated instrumentation. The station number used to identify the stream, sample station, and study plot are given in Table 1.

Table 1: Station identifiers, type, locations, basin sizes and initial collection date at Hayward and Holmes Brook

Station # (study plot)	Treatment	Latitude	Longitude	Area (km^2)	Data collection
station 1 NB01BU0072*	selection	45 51 57	65 09 27	4.8	March 1994 automated
station 2 NB01BU0077*	selection	45 51 54	65 09 50	1.2	March 1994
station 3 NB01BU0078*	no-harvest	45 52 10	65 11 37	1.8	March 1994 manual discharge
station 4 NB01BU0073*	no-harvest	45 52 30	65 11 16	1.6	March 1994 automated
station 5 NB01BU0074*	30-metre	45 52 18	65 11 05	7.2	March 1994 automated
station 6 NB01BU0075*	30-metre buffer	45 52 22	65 11 16	2.34	March 1994
station 9 NB01BU0081*	60-metre buffer	45 53 17	65 08 46	6.0	April 1995 automated

- (National water quality station identification number)

In May-June 1995 road construction and treatments began. Treatments consisted of clear cutting up to the designated buffer width on both sides of the stream (Table 1). At study plot 1 a selection harvest occurred within the buffer according to a pre-determined harvest plan (Krause, 1997).

Methodology:

Field sample data and, laboratory analyses were processed in accordance to standard procedures (Pomeroy et al.1996). Approximately 850 surface water grab samples were collected. The ion exports were calculated from surface water ion concentrations and the associated hourly specific conductance and discharge. A regression of ion concentration data (mg/L) and discharge data were used to constructed a dataset of daily ion exports (Keq.day/surface unit area). Regressions were not used in study plot 3 or for correlations less than r = 0.7 (Table 2).

Table 2: The correlation for regressions used to calculate the daily mean concentrations

(correlation greater or equal to r = 0.7 were used: bold correlations were not used)

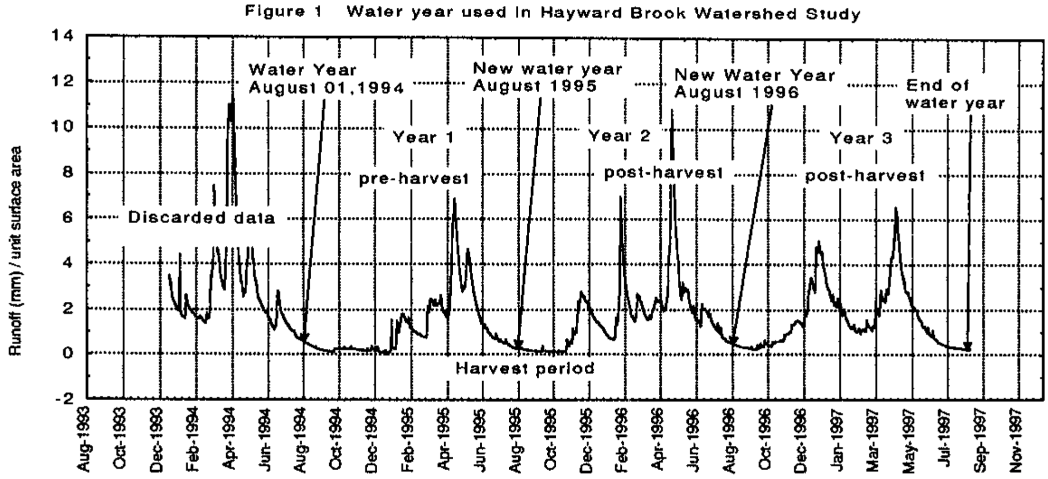
	Plot 1	Plot 4	Plot 5	Plot 6	Plot 9
Calcium	0.9	0.9	0.9	0.9	0.9
Bicarbonate	0.9	0.9	0.9	0.9	0.9
Sodium	0.9	**0.5**	0.9	0.9	0.8
Magnesium	0.9	0.9	0.9	0.9	0.9
Sulphate	0.7	**0.5**	0.9	0.9	0.8
Potassium	**0.1**	0.9	0.7	**0.5**	0.7
Chloride	**0.4**	**0.5**	0.7	0.9	0.8
Total Inorganic Carbon	0.9	0.9	0.9	0.9	0.9

Daily mean exports using regressions were not calculated for conductivity, nitrate-nitrogen, total phosphorus and metals due to low correlations. These exports were calculated from the smaller dataset of grab samples. Outliers and extremes values shown in the boxplots represent data points which are outside the; [75th percentile (mean + standard deviation) + 1.5 (an outlier coefficient) *(75th-25th value)]. Extremes are data points which are greater than the [75th percentile + 3.0 (outlier coefficient) *(75th-25th)] (Statistica, 1995).

Results:

The years of comparison are based on a "water year" of August 01 to July 31. This period is not the standard October - September water-year for Atlantic Canada but, the earlier date provides a larger data set. The movement of the 'standard' water-year still meets the guideline of beginning a water year when the water storage is at or near the yearly low values (Brimley, 1997). The August 01, 1994 - July 31, 1995 data represents pre-harvest data. The forest treatment occurred in late 1995. The second and third years of the study represent post-harvest data (August 1995 - July 31, 1997) (Figure 1).

Figure 1 Water year used in Hayward Brook Watershed Study



The harvest treatment occurred over a seven month period and was completed by December 1995 (Table 3).

Table 3 : The dates of treatment for each watershed within the Hayward Brook Watershed Study

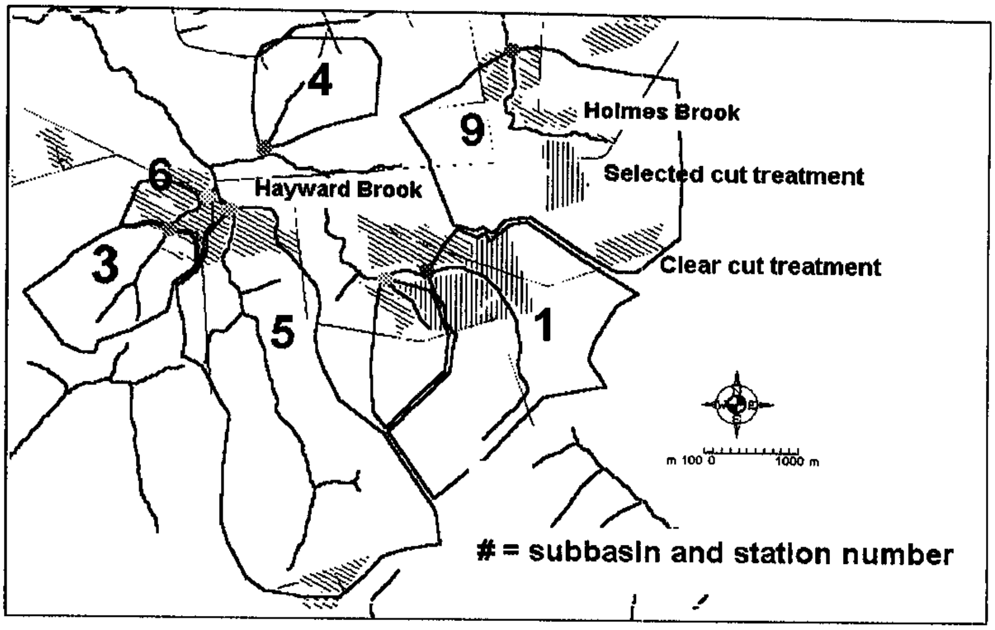
Study Plot	Start Date	Finish Date
Plot 1	June 01, 1995	September 01, 1995
Plot 3	no treatment	no treatment
Plot 4	no treatment	no treatment
Plot 5 (eastern block)	June 01, 1995	September 1995
Plot 5 (western block)	May 15, 1995	July 15, 1995
Plot 6	July 01, 1995	September 01, 1995
Plot 9 (eastern block)	June 01, 1995	December 01, 1995
Plot 9 (western block)	July 01, 1995	September 30, 1995
Plot 9 (southern block)	June 01, 1995	September 1995

Using geographical software (SPANS) the percentage of watershed area harvested and area of selected land uses were calculated (Table 4, Map 1).

Table 4: Area (Km^2) and Area Percent of Attributes of each land-use within the seven sub-basins in the Hayward Brook Watershed Study

Study Plot		clear cut	natural state	roads	select cut	wood road	Total
1	Area (km2)	0.10	3.9	0.04	0.8		4.9
	Area %	**2.3**	80.8	0.8	**16.0**		
3	Area (km2)	0.06	1.8			0.002	1.8
	Area (%)	**3.0**	96.6			0.13	
4	Area (km2)		1.3	0.03			1.7
	Area (%)		76.0	1.6			
5	Area (km2)	0.50	7.0	0.03			7.6
	Area (%)	**7.0**	92.4	0.4			
6	Area (km2)	0.4	2.0	0.01		0.003	2.3
	Area (%)	**17.0**	82.0	0.4		0.09	
9	Area (km2)	0.70	4.9	0.06	0.3		6.0
	Area (%)	**12.0**	81.0	1.0	**5.7**		
Total (km2)		1.78	21.1	0.2	1.1	0.005	24.3

Map 1: Subbasins and treatments in Hayward Brook Watershed Study



Clear cut harvesting was by a tracked feller buncher. The trees were cut whole and laid in piles adjacent to the cut trail. The trees were limbed, cut to length and, sorted by a tracked processor. The limbs remained on site as slash and were used as a road bed. Field observation of the tracked equipment found minor soil disturbance. The logs were transported from the cut site by a wheeled porter. The weight of the logs in this vehicle caused a large amount of rutting in all plots. A significant runoff was observed at study plot 9, Holmes Brook due to soil rutting. The ruts created ditches which directed water flow down the slope of the clear cut. Here the water pooled and pushed through a 60 metre stream buffer. In study plot 1 a selection harvest occurred. Selected trees were cut by chainsaw and winched through the riparian zone by a skidder located in the clear cut area (Krause, 1997).

Discharge:

The discharge in each plot showed similar yearly events. Noted differences were attributed to the watershed size, soil type and forest cover. The watersheds range in size from 1.7 to 7.6 km^2 (Table 4). The data was normalized for basin size and is discussed as runoff per unit surface area (Figures 2,3). Gaps in the data for study plot 3 were calculated using a regression with study plot 6 which is located one kilometre downstream.

Figure 2 Mean monthly runoff (mm) per unit surface area at study plots 5,6,3 of Hayward BrookWatershed Study between August 01, 1994 to July 31, 1997

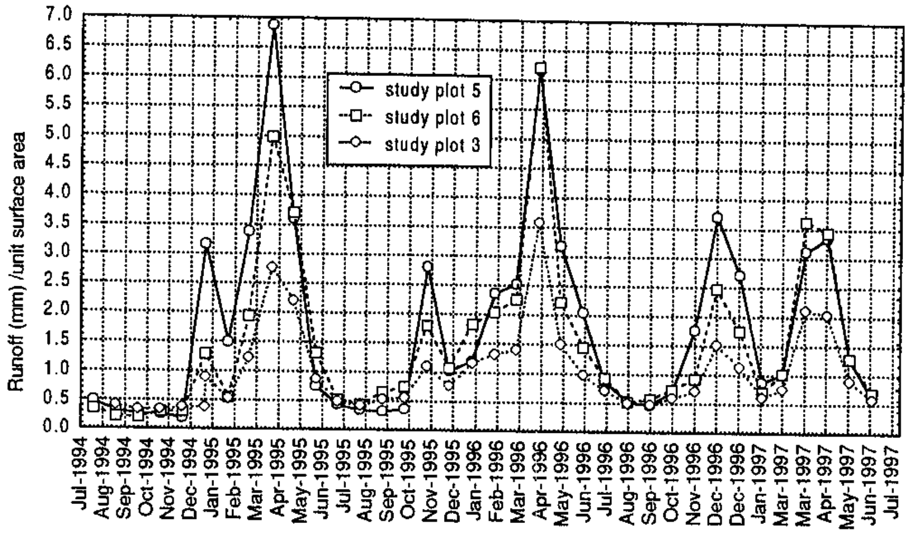
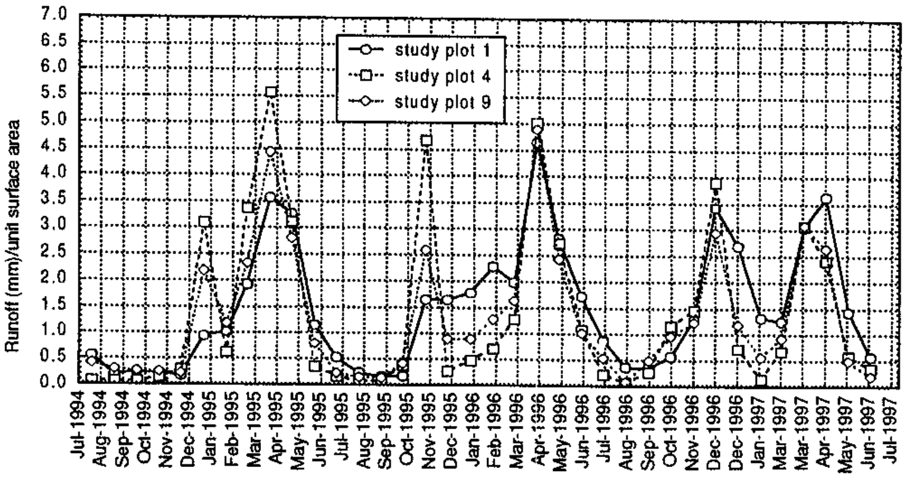
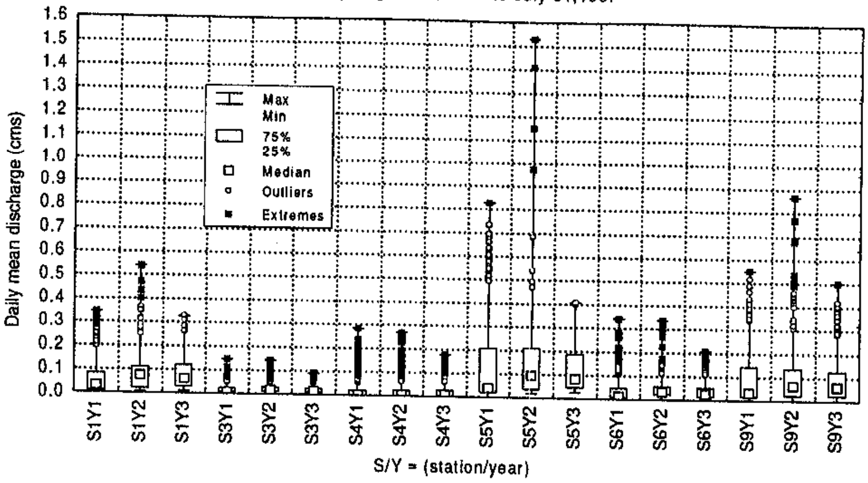


Figure 3 Mean monthly runoff (mm) per unit surface area at study plots 1,4,9 in the Hayward Watershed Study between August 02, 1994 and July 31, 1997



The runoff range shows similar patterns for all streams which suggest similar precipitation amounts over the study site. Although the first year of precipitation contained five dry months the last seven months had sufficient precipitation to make the yearly mean discharge similar to the following two years (Figure 4).

Figure 4: Boxplots of the daily mean discharge (cms) per year at each study plot within the Hayward Brook Watershed Study during August 01, 1994 to July 31,1997



The yearly mean discharge was analyzed using an Anova . This analyses using a post hoc LSD mean comparison test indicated a difference at study plots 1, 5, and 6 (Table 5).

Table 5 : p-value results (marked differences are significant at p< 0.050) for one way ANOVA for daily mean discharge (m^3) during Pre-harvest -year 1 versus Post Harvest Years 2 and Year 3 for each Study Plot in the Hayward Brook Watershed Study. Period of study is August 01, 1994 to July 31, 1997 (water-year is From August 01 to July 31 of each year)

Study Plot	Compare Years	ANOVA for study plot and Year of Discharge	Study Plot	Compare Years	ANOVA for study plot and Year of Discharge
1	1-2	*.000*	5	1-2	*.041*
1	1-3	*.000*	5	1-3	.420
1	2-3	.965	5	2-3	*.004*
3	1-2	.352	6	1-2	*.029*
3	1-3	.723	6	1-3	.399
3	2-3	.564	6	2-3	.184
4	1-2	.982	9	1-2	.192
4	1-3	.693	9	1-3	.616
4	2-3	.709	9	2-3	.071

Chemistry:

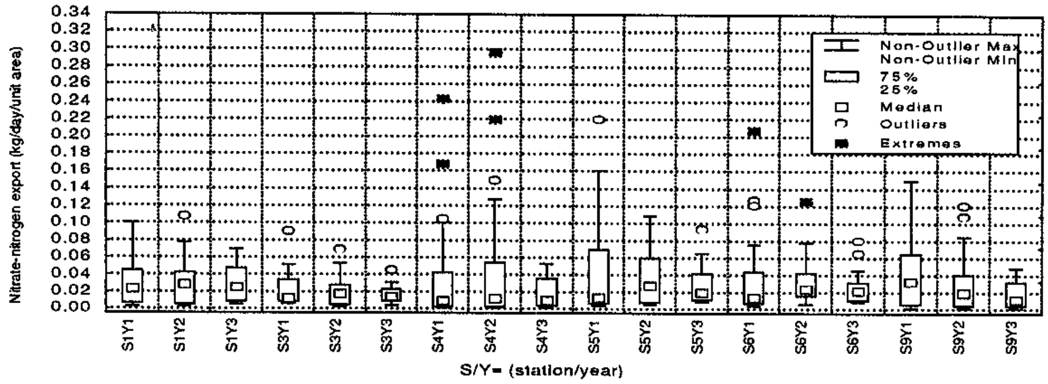
A difference in the yearly mean export of ions was detected using an Anova. The year of activity was used as the independent variable. Within the eighteen sets of data means of five ions did not differ (Table 6).

Table 6 : Analyses of variance for the export of water chemistry variables

Variable	F-ratio	p-value	Variable	F-ratio	p-value
Nitrate	**1.46**	**0.103**	**Sulphate**	53.02	0.000
T. Nitrogen	3.14	0.000	**Potassium**	6.02	0.000
Bicarbonate	144.39	0.000	**Calcium**	144.26	0.000
H+	2.32	0.002	**Manganese**	**1.57**	**0.066**
Sodium	15.32	0.000	**Iron**	**1.64**	**0.050**
Magnesium	39.46	0.000	**Zinc**	**1.64**	**0.050**
Aluminum	2.86	0.001	**TOC**	4.40	0.000
Silica	2.06	0.007	**TIC**	109.40	0.000
T. Phosphor.	**0.99**	**0.461**	**Chloride**	5.06	0.000

Exports of the essential nutrients, nitrate-nitrogen and total phosphorus did not change during the study. An export of ions after a treatment is usually detected in the second to third year during high discharge events as is seen in the export of nitrate-nitrogen (Figure 5). Studies have found that the essential nutrients such as nitrogen and phosphorus are often transported mainly during high discharge events (Hill, 1986).

Figure 5: Boxplot of nitrate-nitrogen export (Kg.day/unit area) for each study plot in the Hayward Brook Watershed Study during August 01, 1994 to July 31, 1997



A post-hoc LSD comparison test was used to determine in which years the mean exports of ions occurred. Year 1 (pre-harvest) was compared to the post harvest years and, the post harvest years were compared (Tables 7).

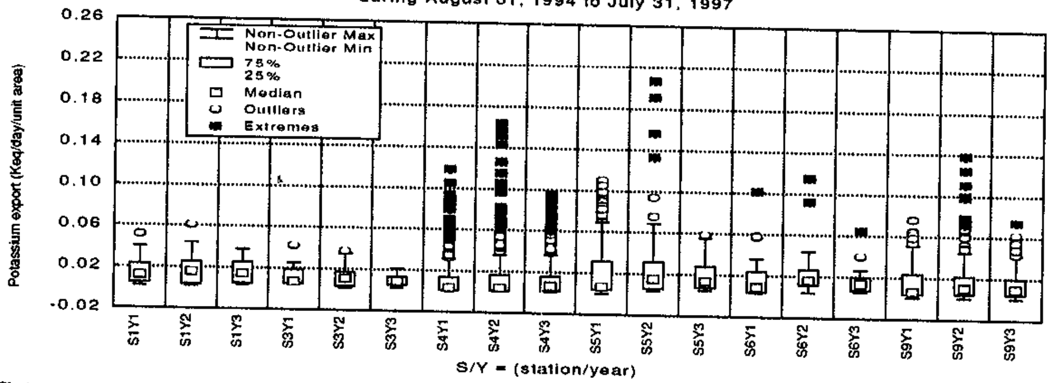
Table 7 : p-value results (marked differences are significant at p< 0.050) for one way ANOVA for chemical variables during pre-harvest -year 1 verses post harvest years 2 and year 3 for each study plot in the Hayward Brook watershed study. Period of study is August 01, 1994 to July 31, 1997 (water-year is from August 01 to July 31 of each year)

Study Plot	Compare Years	Mg	Ca	K	Na	HCO3	Cl	H+	Total Nitrogen	TI-carbon	TO-Carbon	SO4
1	1-2	***.000***	***.026***	.809	***.000***	***.000***	.965	.887	.976	***.005***	.969	***.001***
1	1-3	***.000***	***.001***	.871	***.000***	***.000***	.929	.663	.552	***.000***	.585	***.000***
1	2-3	.277	.334	.955	.703	.204	.957	.742	.544	.297	.585	.537

3	1-2	.984	.999	.948	.852	.978	.866	.779	.899	.835	.884	.770
3	1-3	.817	.700	.584	.489	.637	.590	.598	.931	.378	.530	.422
3	2-3	.824	.687	.611	.588	.641	.690	.780	.972	.472	.607	.579
4	1-2	.109	.231	.288	.499	***.000***	.202	.311	*.056*	***.003***	.987	.725
4	1-3	.839	.967	.745	*.084*	.282	*.089*	***.055***	.321	.430	.914	***.004***
4	2-3	*.071*	.247	.165	***.017***	***.011***	***.003***	***.004***	***.005***	***.036***	.924	***.001***
5	1-2	.623	.175	.185	.291	***.000***	.259	.689	.903	.222	.797	.320
5	1-3	.982	.881	.749	.877	***.000***	.808	.459	.745	.976	.498	.845
5	2-3	.607	.228	.099	.227	.947	.171	.703	.827	.211	.351	.234
6	1-2	***.000***	***.000***	.192	***.000***	***.000***	***.000***	.947	.380	***.000***	.150	***.000***
6	1-3	***.000***	***.000***	.894	***.000***	***.000***	***.008***	.612	.660	***.000***	.451	***.000***
6	2-3	***.000***	***.000***	.183	***.002***	***.049***	***.005***	.566	.711	***.000***	***.035***	***.000***
9	1-2	.580	.997	.237	.818	.500	.567	.582	.959	.601	.392	.775
9	1-3	.487	.562	.798	.124	.202	.320	***.050***	.182	.269	***.014***	.431
9	2-3	.212	.564	.150	.191	.549	.117	***.007***	.159	.560	***.000***	.283

The mean export of potassium was not found to differ from year to year. Potassium is quickly utilized by vegetation and, if leaching occurs it usually happens in the year following the treatment during high discharge events (Figure 6).

Figure 6: Boxplots of potassium exports (keq/day/unit area) for each study plot in Hayward Brook Watershed Study during August 01, 1994 to July 31, 1997



Calcium and magnesium exports were found to differ at study plots 1 and 6. Calcium exports in study plot 1 appear to increase in proportion to discharge which suggest that the export is not a function of increased nutrient loss (Figure 7). Exports at study plot 6 show less dependence on the discharge.

Figure 7: Boxplots of calcium exports (Keq/day/unit area) for each study plot in the Hayward Brook Watershed Study during August 01, 1994 to July 31, 1997

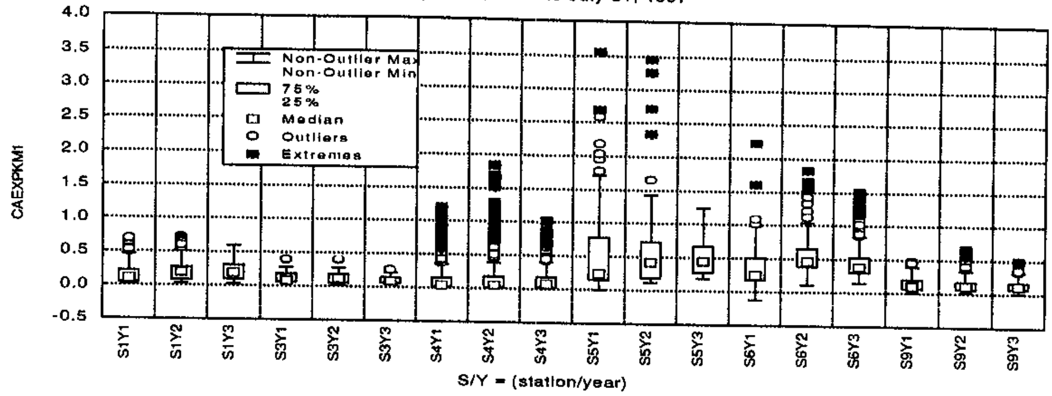
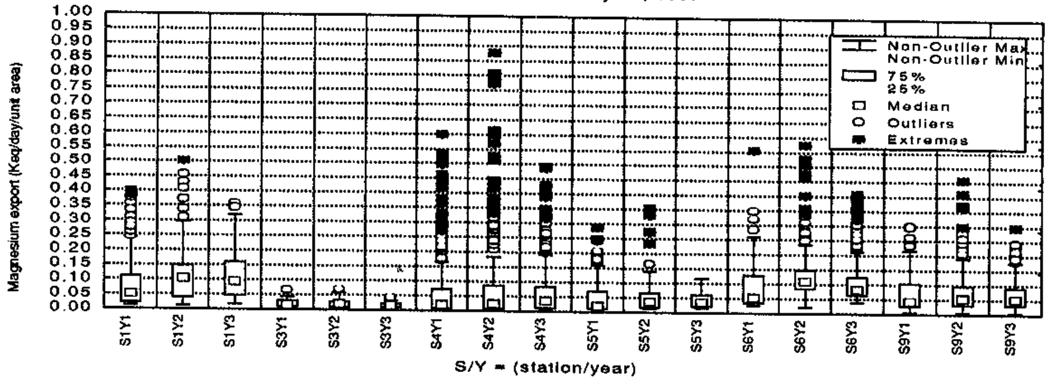


Figure 8: Boxplots of magnesium exports (Keq/day/unit area) for each study plot in the Hayward Brook Watershed Study during August 01, 1994 to July 31, 1997



At treated study plots the exports of sodium, bicarbonate, chloride and sulphate were identified as having yearly means which differed.

Figure 9: Boxplots of sodium exports (keq/day/unit area) for each study plot in the Haywrd Brook Watershed Study during August 01, 1994 to July 31, 1997

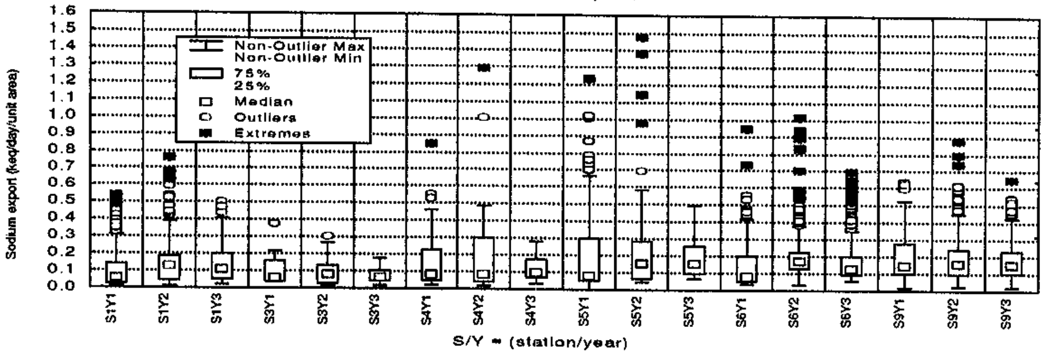


Figure 10: Boxplots of bicarbonate export (keq/day/unit area) for each study plot in the Hayward Brook Watershed Study during August 01, 1994 to July 31, 1997

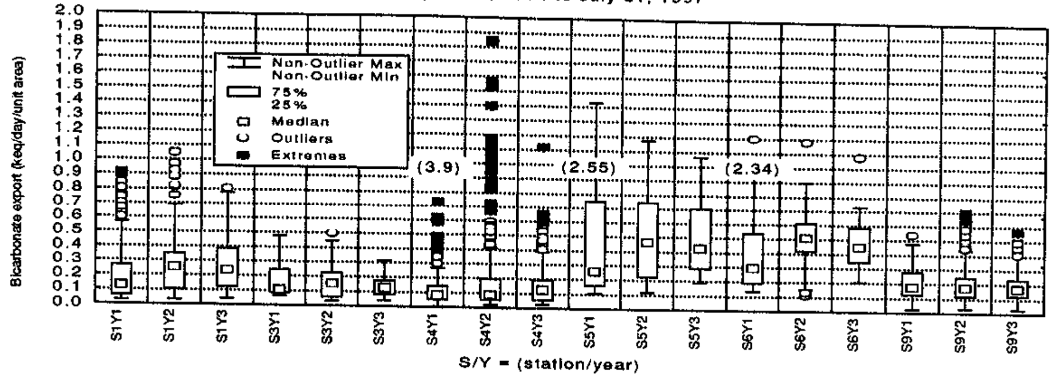


Figure 11: Boxplots of sulphate export (keq/day/unit area) for each study plot in the Hayward Brook Watershed Study during August 01, 1994 to July 31, 1997

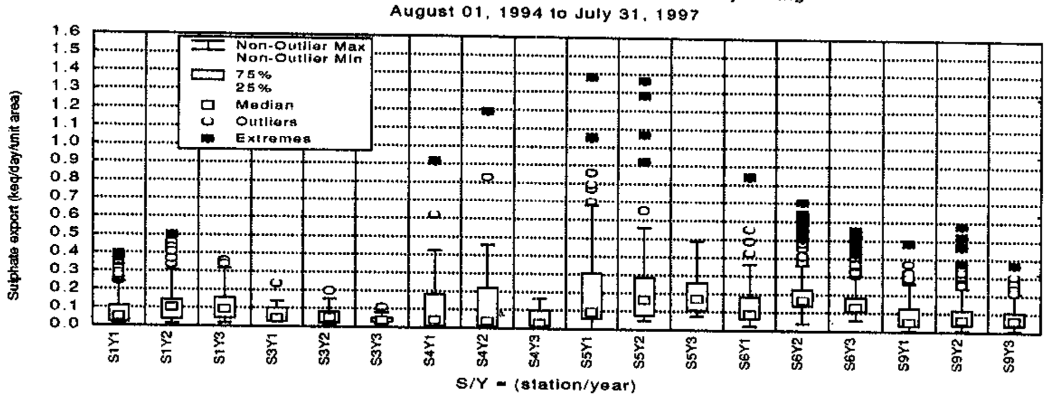
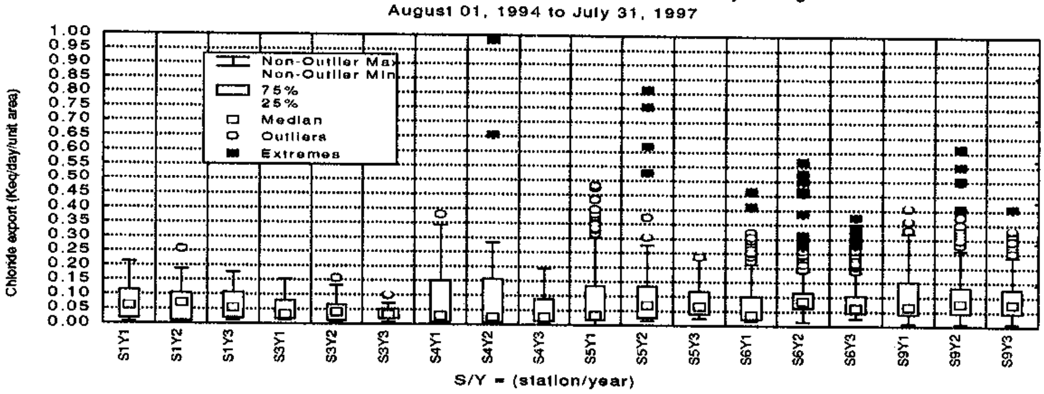
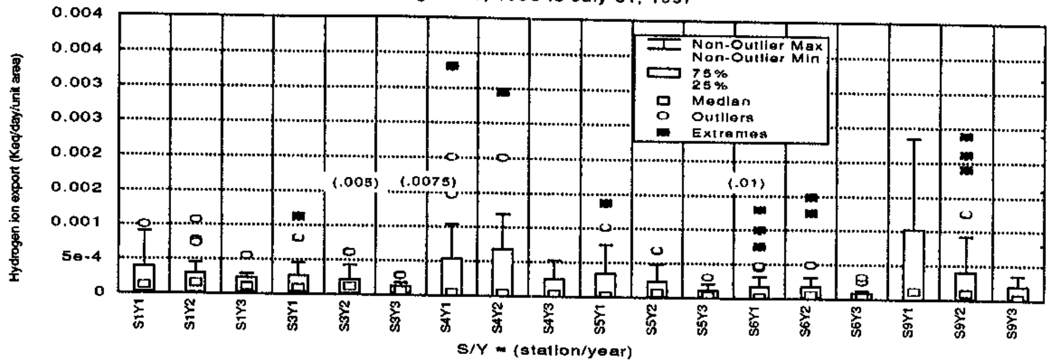


Figure 12: Boxplots of chloride export (keq/day/unit area) for each study plot in the Hayward Brook Watershed Study during August 01, 1994 to July 31, 1997



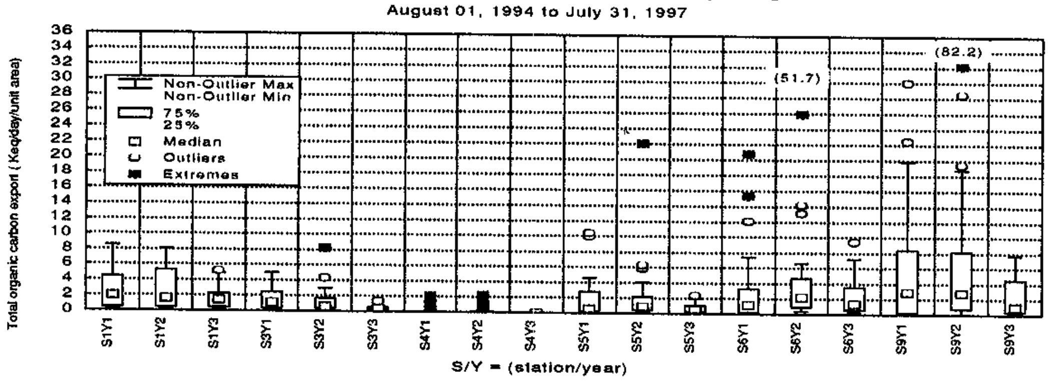
Study plot 9 had a higher export of hydrogen ions due to elevated discharge events and associated organic carbon.

Figure 13: Boxplots of hydrogen ion exports (keq/day/unit area) for each study plot in the Hayward Brook Watershed Study during August 01, 1998 to July 31, 1997



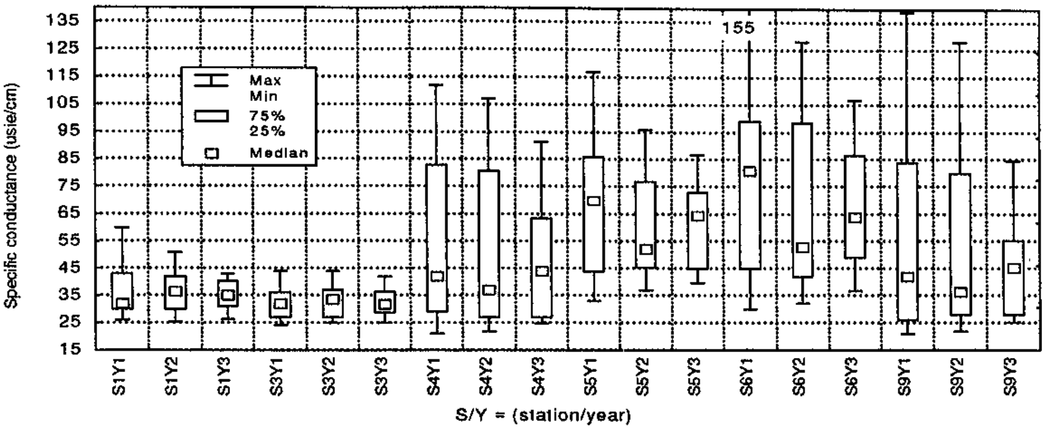
Organic carbon exports are generally low in forested ecosystems. Higher fluxes of dissolved organic carbon are associated with high discharge events when accumulated soluble carbon is flushed from the leaf layer and soil. At low discharge a large percentage of the soluble carbon is adsorb by mineral soils (David et al, 1992)

Figure 14: Boxplots of total organic carbon exports (keq/day/unit area) for eac study plot in the Hayward Brook Watershed Study during August 01, 1994 to July 31, 1997



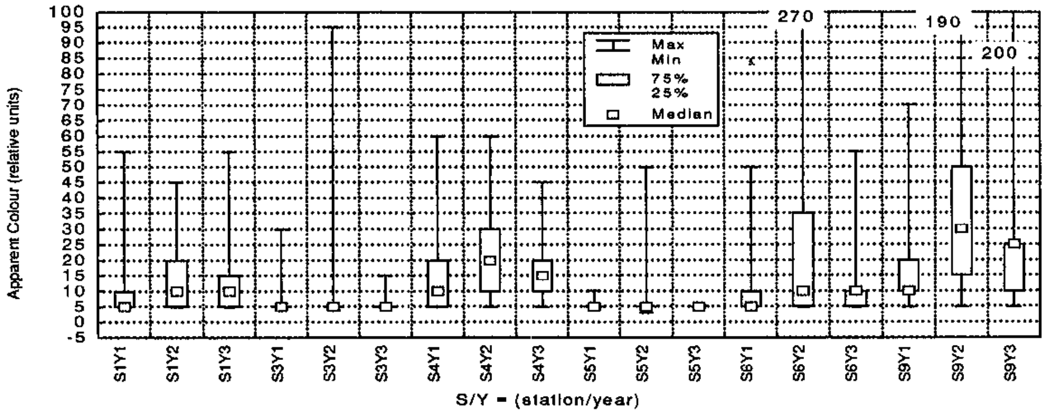
The range of specific conductance (usie/cm) is attributed to forest soil units and cover type (Pomeroy et al. 1997). The low ranges at study plots 1 and 3 occur in the Sunbury soils to the south. The higher range found in study plots 5 and 6 are associated with the central Parry soils. To the north the Salisbury soils produce mid range values (Figure 15).

Figure 15: Boxplots of specific conductance (usie/cm) for each study plot in the Hayward Brook Watershed Study during August 01, 1994 to July 31, 1997



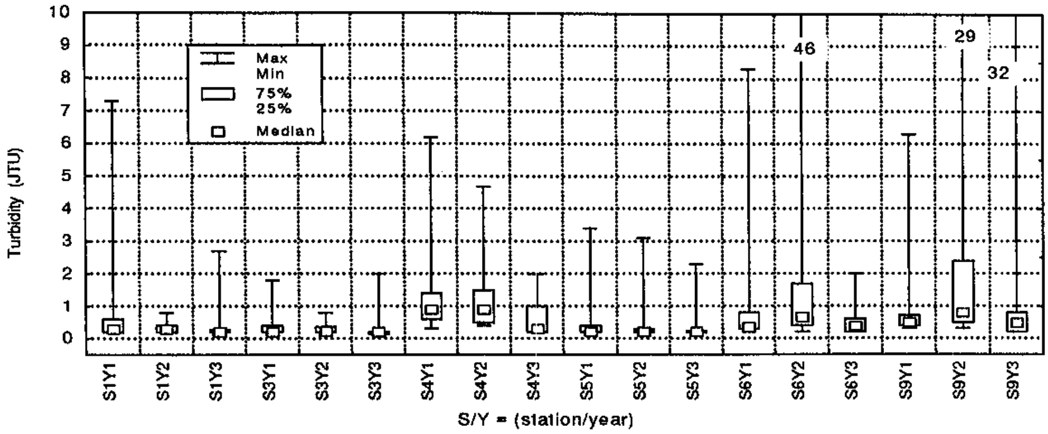
Apparent or of true colour is generally below 30 relative units. During rain events the suspension of sediment and input of erosion caused values to peak in areas of road building (Figure 16).

Figure 16: Boxplots of apparent colour (relative units) for each study plot in the Hayward Brook Watershed Study during August 01, 1994 to July 31, 1997



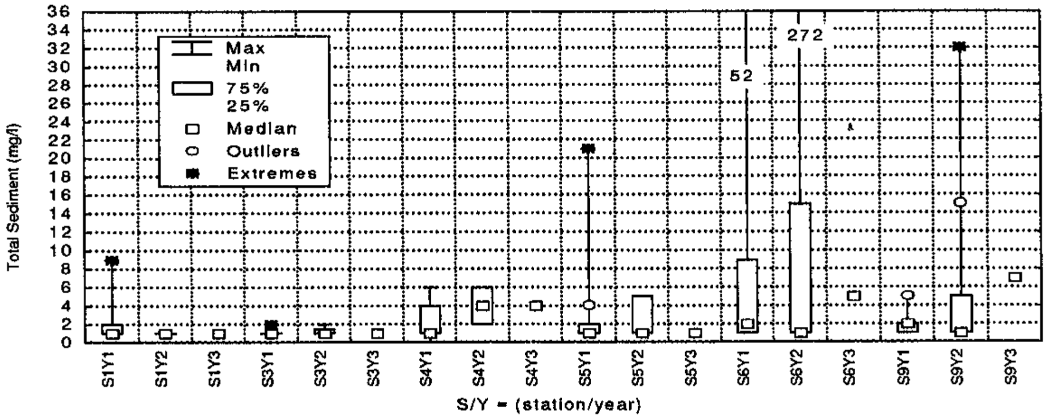
Median turbidity values were generally below 1 JTU with elevated values occurring during storm events and associated high suspended sediment concentrations (Figure 17).

Figure 17: Boxplots of turbidity (JTU) for each study plot in the Hayward Brook Watershed Study during August 01, 1994 to July 31, 1997



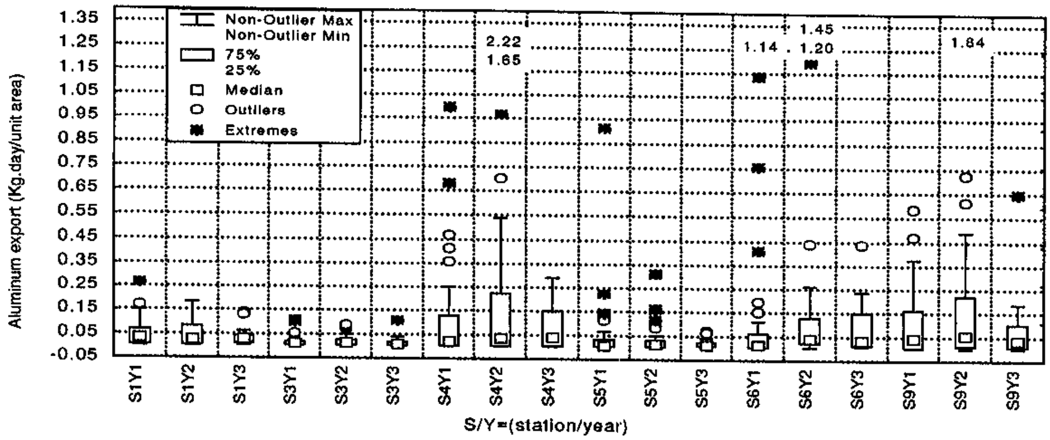
Total sediment concentrations are based on manually collected samples. A sample was collected when the water column appeared to have a high turbidity (Figure 18).

Figure 18: Boxplots of total concentration of sediment (mg/L) for each study plot in the Hayward Brook Watershed Study during August 01, 1994 to July 31, 1997



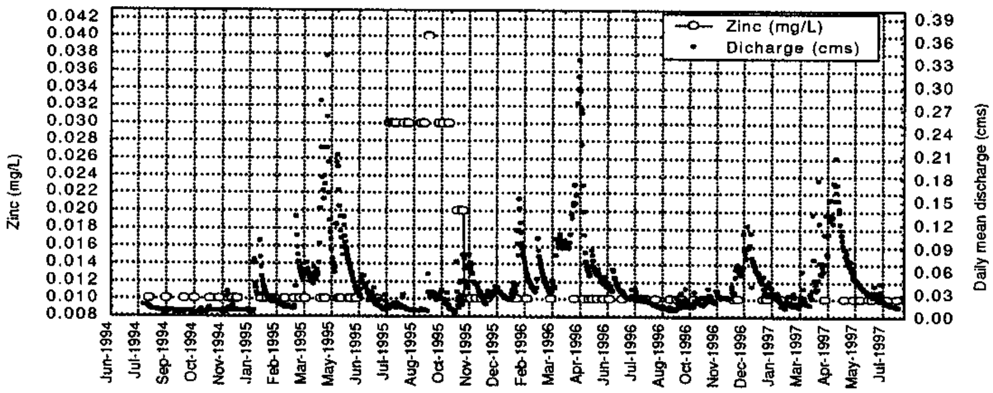
The export of extractable metals (kg.day/unit surface area) were calculated from spatial surface water grab samples. A difference in the mean was detected for only aluminum (Figure 19).

Figure 19: Boxplots of aluminum export (kg.day/unit area) for each plot for each study plot in the Hayward Brook Watershed Study during August 01, 1994 to July 31, 1997



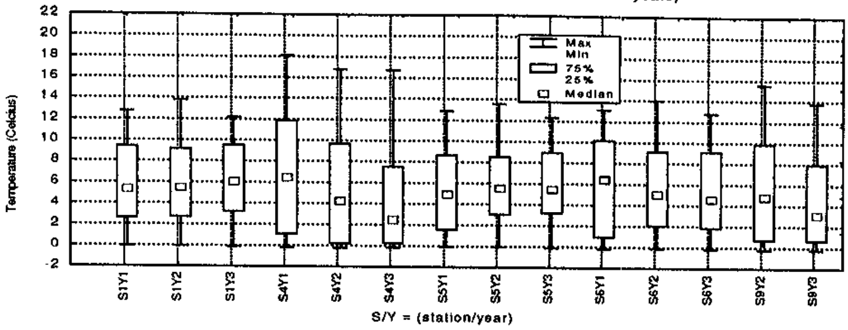
Zinc concentrations (mg/L) were elevated above the Canadian Water Quality Guidelines for a five month period after the placement of a galvanized culvert at study plot 6 (CCREM, 1997). Corrosion has been identified as the cause of zinc removal from culverts (Figure 20).

Figure 20: Concentration of zinc (mg/L) and the daily mean discharge (cms) at study plot 6 in the Hayward Brook Watershed Study during August 01, 1994 to July 31, 1997



Stream temperature data was collected every hour at five study plots. The temperature ranged between -2.0 to 18 degrees with a mean of +5.0 and medians between 2 and 7 degrees (Figure 21).

Figure 21 Boxplots of temperature (degrees Celsius) at automated monitoring stations in study plots 1,4,5,6,9 in the Hayward Brook Watershed Study during August 1994 to July 1997 (study plot 9 based on two years)



Discussion:

The Hayward Brook Watershed Study was funded by the Fundy Model Forest as a local research project which would investigate the ecosystem response to various forest management practices. Because of the Model Forests' time frame the HBWS study period covered a four year period (Figure 1). The period is unusually short when compared to studies which collected six to eight years of pre-harvest data prior to forest treatment (Ahtiainen, 1992; Hornbeck 1973, Bari et al. 1993, Jewett et al. 1995, Hicks et al, 1991) but, other studies have been based on a similar time periods (Stevens et al. 1995, Lawrence et al., 1987). The data collection period was based on a August 01 to July 31 wateryear. This wateryear is not the accepted October to September Atlantic Canada wateryear but, the movement allows for a larger data set which begins during a low water storage period (Brimley,1997). Wateryears differ according to the study location. In the Hubbard Brook Experimental Forest in New Hampshire the wateryear runs between June 01 to May 31 (Hornbeck et al. 1970).

The watersheds sizes range from 180 to 760 hectares (Table 4). The mean monthly runoff (mm) ranges between 0.5 mm to 7.0 mm per unit area (Figures 2,3) and the daily mean discharge between 0.001 cms to 1.53 cms (Figure 4). The runoff values in relation to time provide a comparison of the seasonal variation of each watershed (Figures 2,3). The peaks or 'quick flows" as used by Hornbeck (1973) and Bari et al (1996) to describe direct runoff from overland flow occur in the HBWS streams at the same time. This similarity suggest that the precipitation is uniform over the study area and the major influence on runoff is the physiographic variables (forest soil units, forest cover type and basin size) more so than the climatic ones (Gan et al. 1990). The influence of physiographic variables are found in study plot 5 which has the largest watershed size and largest runoff (Figure 2) and, in study plot 4 which has the second smallest watershed yet has the second highest runoff (Figure 3). The runoff curves for all the streams show a ranking of watersheds in relation to one another up to November- December of 1995. In the winter of the second harvest year the relationships appear to change.

The relationships of the runoff between study plots 5,6 and 3 show minimum changes during the low flow periods (Figure 2). According to a study in Hubbards Brook Experimental Forest the relative flow increases which occur in dry periods show water yield changes more clearly than the larger absolute increases in wet months (Hornbeck et al. 1970). One noted change is the increase in the peak runoff during the April snow melts. The runoff in study plot 6 increased to similar values as seen in study plot 5 during 1996 and 1997. In the pre-harvest year 1995 the runoff at study plot 6 was lower. These changes were not observed in the no-treatment study plot 3. To determine if a change had occurred an Anova of the daily mean discharge compared the pre-harvest data with each post harvest year (Table 5). Results indicate that the mean daily discharges for the water-years did differ for various years at study plots 5 and 6.

The analyses detected a difference at study plot 5 when the daily mean discharge during the pre-harvest year (u1= 0.132 m^3/second) was compared to the first post-harvest year (u2 = 0.144 m^3/second), and when the two post harvest years were compared (u3=0.126 m^3/second) (Figure 4). No difference was found between the pre-harvest year (u1) and the second post harvest year (u3). This indicates that the mean discharge at study plot 5 increased in the first post-harvest year but returned by the following year. The large discharge events which occurred in the second year resulted in the higher mean; u2 (Figure 4).

In study plot 6 a difference was detected between the pre-harvest year (u1 = 0.035 m^3/second) and the first post harvest year (u2 = 0.048 m^3/second). No difference was detected between other years (u3 = 0.040 m^3/second). This indicates that the discharge increased after treatment and was beginning to decrease to pre-harvest levels in the second post-harvest year. The discharge in the second post-harvest period was at a point where it was not different from the pre-harvest or first post harvest years.

The runoff at study plots 1,4,9 also indicated a change (Figure 3). In the pre-harvest season study plot 4 has the highest runoff and study plot 1 had the lowest. The runoff of study plot 9 lies between these curves. This runoff order changes after the winter of 1995 when study plot 1 produces the highest runoff for the remainder of the study. The runoff is the highest during the low and mid months and all the plots have similar runoff during the spring snow melt events. The analyses detected a difference in only study plot 1 which indicates the runoff increased in relation to the other two streams (Figure 5). A difference was found between the pre-harvest year (u1= 0.057 m^3/second) and both the first and second post-harvest years (u2 = 0.082 m^3/second, u3 = 0.083 m^3/second). A difference was not found between the two post-harvest seasons which indicates that the discharge increased after treatment and remained elevated in the second post-harvest year.

The similar yearly runoff at study plot 9 is attributed to the low percent of the watershed cut adjacent to 60 metre riparian zone and, the harvest block locations. In each watershed a similar amount of area was harvested but, at study plot 9 the harvest was divided into several smaller blocks (Map 1) which would lessen any response.

In study plots 1, 5 and 6 the similar percentages of harvested watershed would accumulate similar amounts of snow which would melt at the same time each during the post harvest years. Other studies have found that increased flow during the spring melt is attributed to a increase in snow pack in the harvested areas. One study in a lodgepole pine forest found the increase in peak water equivalents averaged 34 percent with 100 percent of the trees removed. The larger amount of snow accumulation was found to be due to the reduction of snow evaporation in tree crowns and a redistribution of snow into the harvest blocks by wind (Schmidt and Troendle, 1988). In Hubbards Brook, Hornbeck (1970) concluded that because the snow-melt is rapidly occurring over a few weeks the presence or absence of a hardwood canopy has little effect on snow-melt rate. The canopy of the Hayward project was a mixed which would shelter the ground snow causing a slower melt. After harvesting the accumulated snow would melt earlier and quicker (Hornbeck, 1975).

Changes in the low to mid-range runoff was observed at plots 1,5,6. If the discharge measurement estimate error of 5-10 percent (Gray, 1970) is considered plus the error associated with determining the catchment area in low relief the certainty of change is reduced. These variances when applied to the study plots would change the increase less in study plot 1. The change in study plot 1 is larger than the 10 percent error during the summer-fall of 1996 and 1997 than in the other curves (Figure 3). Studies have show that when the forest canopy is reduced the amount of transpiration is decreased and the amount of evaporation does not make up for the difference. Up to 40 percent of precipitation may be removed from a watershed by evapotranspiration (Hornbeck, 1973, 1975, Likens et al. 1977). The amount of change in the basins is attributed to the forest cover type, soil units and the degree of harvest within the buffer.

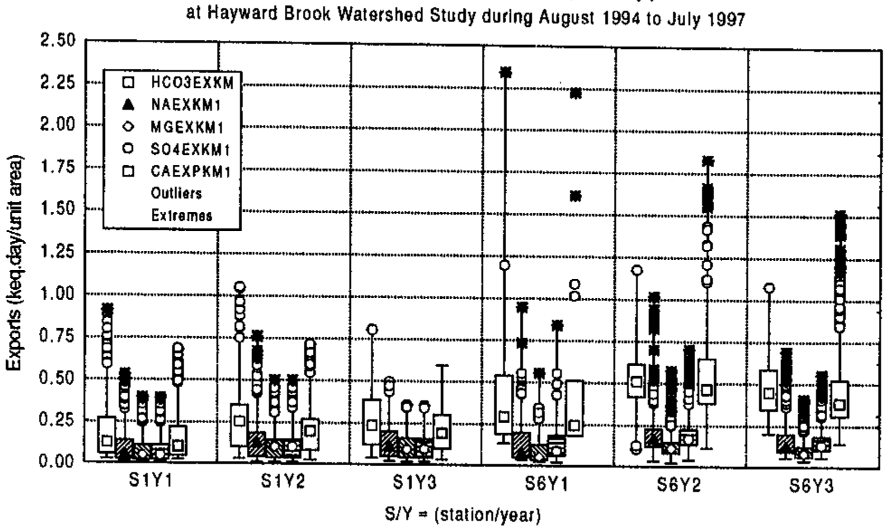
In study plot 1 the forest type was predominately mature red and white pine with little understorey. In plots 5 and 6 the forest was mixed with large pine distributed within and a semi-heavy understorey. When the mature pine were harvested from study plot 1 the evapotranspiration and canopy interception was removed causing an increase in stream discharge (Hornbeck et al. 1970). The absence of understorey growth and sandy soils allowed surface water to move with minor resistant. In study plots 5 and 6 the understorey provided a degree of canopy interception, water uptake and evapotranspiration. Young trees often use water stored in the upper soil profile which cause a decrease in the through-flow component (Bari et al., 1996). The differences in time for the runoff to decrease is attributed to the amount and time of re-vegetation. In study plot 5 and 6 the aspen sucklings re-established quickly in large numbers (Krause, 1997), whereas in study plot 1 re-vegetation was slow reaching only a percentage of re-growth found in the other plots. The importance of vegetation has been documented in other studies which found the absence of vegetation to cause sizable streamflow increases and, regrowth of vegetation rapidly eliminated the summer increases in stream flow (Hornbeck, 1975, Bari et al. 1996).

The effect of a selection harvesting within the buffer is difficult to assess. Because the understorey was left intact, soil rupture was minimal and size of the selection was minor compared to the adjacent clear cut the response is considered to be minor (Krause , personal communication). The selection harvest removed approximately 28 percent of the timber volume and left many healthy trees. Studies have shown that the transpiration rates are higher in trees on the border of clear cuts due to the fact that their root extend into wetter cut strips (Hornbeck, 1975). This increased uptake would also make the remaining buffer more effective in absorbing nutrients and water.

The Anova of yearly mean exports of water chemistry ions (kg.day/unit area) using the water-years as the dependent factor did not detect a difference in nitrate-nitrogen, total phosphorus, manganese, iron or zinc (Table 6). Other ions were identified as having a differing variances but, several of these contained small variances between and within the group mean producing a F-ratio close to 1.0 (Table 7). This group included total nitrogen, hydrogen, aluminum, silica, potassium, total organic carbon an chloride. Although these ions can be highly mobile in the first year following harvesting they can also be conserved through biological retention or immobility (Dahlgren and Driscoll). Studies have also shown that if leaching occurs the concentrations usually peak in the first post harvest year after the forest floor nutrient and associated microbial population decrease. This period is required for decomposition of vegetation to reach a level where leaching may occur (Steven et al. 1995, Dahlgren and Driscoll , 1994). Naslas et al. (1994) found that greater nitrification occurs in open areas than in wooded areas and the associated uptake of nutrients and microbial utilization is also greater in wooded areas. The 12 to 17 percent of the harvested watershed plus the rapid regrowth in most study plots would reduce the amount of nitrification and increase the amount of nutrient uptake. The post-hoc LSD test identified consistent differences between years in study plots 1 and 6 (Table 7). Sporadic differences were detected at the other study plots but, the inconsistencies suggest an event disturbance. The post-hoc test on individual years identified magnesium, calcium, sodium, bicarbonate, sulphate and total inorganic carbon as having a detectable difference in mean export.

At study plot 1 the analysis indicates that the exports increased in year two and maintained the higher exports into year three. At study plot 6 differences in mean exports were detected in all three comparisons indicating that the export increased in the second year but, began to return during the third year. The total export of the ions at study plot 1 increased in proportion to discharge. The runoff (Figure 4) shows a slight increase in year two and a similar increase is seen in the specific conductance (Figure 15). The specific conductance also shows that study plot 1 reacted difference from the other plots in that the maximum values decrease over the three years but, the mean increased indicating that more ions moved into the watercolumn with the increased runoff. This increase is attributed to the movement of ion through the sandy soil and low nutrient uptake of vegetation of the harvest area. The opposite pattern occurred at study plot 6 where the runoff (Figure 4) increased slightly in year two but, this caused a decrease in the mean specific conductance through a dilution factor. Figure 22 shows the export of ions in kiloequivents per day per unit surface area for study plots 1 and 6. In both study plots the main cation is calcium and the main anion is bicarbonate with higher concentrations of sulphate at study plot 6 (Figure 22).

Figure 22 The exports of ions (keq.day /unit area) at study plots 1 and 6 at Hayward Brook Watershed Study during August 1994 to July 1997



As the nutrient export from the treated areas did not change after harvesting and the slash remained in the harvest blocks the accumulation of nutrient in the HBWS area should maintain a balance for future growth. The Hubbard's Brook Study concluded that the major input of basic cations into an ecosystem are from bulk precipitation and weathering, but a balance is maintained due to biomass accumulation and stream outflow (Driscoll 1989).

Road building is always identified as the major impact to aquatic systems from landuse changes. A study by Anderson and Potts (1987) found soil additions during road building and surface erosion adjacent to culverts accounted for most of the increase in sediment yield. During road construction two 21 foot bridges were constructed below the water monitoring stations and one galvanized road culvert was installed in study plot 6. During installation of the main bridges there was no visual impacts to the streams. Equipment traveled across the streams on floats and excavation was set back from the stream. Over the three years there did not appear to be erosion problems associated with these structures. The culvert installed at study plot 6 was sufficiently large enough to allow large atypical flows to pass and the banks were stabilized with hay and rock. Although the culvert was installation correctly, high sediment loading from an old woods road occurred with each rain event. The road is postioned down the ridge to the west of the stream and directs the runoff through the 30 metre buffer below the monitoring station of study plot 3. The turbidity measurements show high values at study plots 6 and 9 in year two and three (Figure 17). One elevated reading is associated with a November, 1995 storm. During the same storm a culvert adjacent to the buffer of Holmes Brook was not properly channeled and directed surface water down a slope and through the 60 metre buffer. The discharge from this culvert was redirected and the problem was corrected. Another event occurred at study plot 9 on June 19, 1997. The turbidity reading was 34 NTU's , colour was 200 rel units and aluminum was 2.9 mg/L. The circumstance surrounding this event is assumed to be from a road culvert upstream which received road repairs.

High turbidity is usually associated with elevated colour, suspended solids and aluminum (Figures 16, 17, 18, 19). Studies have found turbidity values to have an excellent to poor correlation with suspended solids depending on the particular system of study (Anderson and Potts, 1987). The correlation of turbidity to suspended sediment for the HBWS does not provide a accurate relationship because suspended sediment samples were collected only during high turbidity. A correlation between aluminum and other variables indicates that concentration of aluminum is closely explained by turbidity (r =0.63) and total organic carbon (r =0.25. Studies show that the suspended sediment is the major source of aluminum (Johnson et al. 1969) which is released through erosion. Other studies have found that aluminum concentrations are more related to a decrease in acidity (Browne and Driscoll, 1993). Elevated colour during low turbidity were found to be in response to elevated organic acids (Figures 16, 14). Selected water samples show the relationship of various water quality variables (Table 8).

Table 8: Selected water quality variables for five precipitation events at study plot 6 in the Hayward Brook Watershed Study

Study Plot	Date	Turbidity (NTU)	Aluminum (mg/L)	Apparent Colour (Relative Units)	TOC/TIC (mg/L)	Suspended Sediment (mg/L)
6	Jan17/ 95	2.7	0.4	35	5.4/ 3.2	52
6	Nov 08/95	46	0.40	270	17.3/ 1.7	272.0
6	Sept 14/96	2	0.19	55	10.6/ 7.2	5.0
9	Dec 06/94	6.3	0.14	70	9.8/ 3.3	5.0
9	Nov 08/95	29	0.34	190	15.2/ 0.7	32.0
9	Sept 14/96	2.0	0.24	100	15.4 /2.5	7.0
9	Jun 19/97	32	2.9	200	3.4/ 3.2	not collected

Another response to road building occurred in July 1995 when a galvanized culvert was installed at study plot 6. The concentration of zinc increased in surface water over a four month period (Figure 20). The concentration on July 24 was 0.03 mg/L, the maximum concentration for the protection of aquatic life (Canadian Water Quality Guideline). The turbidity was twice the mean (3.0 JTU) and the organic carbon concentration was 3.5 mg/L (mean of TOC = 2.1 mg/L). Zinc continued to leach and produce high concentrations for seven additional samplings (3.0 mg/l). The low turbidity values indicate that abrasion which is one of the two noted processes which contribute to galvanized pipe durability was not the major factor (Bednar, 1989, Noyce et al. 1975). The most significant process is corrosion of the pipe in waters not suited for galvanized metals. In waters which have a certain combination of pH, conductivity, resistivity, hardness and alkalinity corrosion, a reaction of steel, zinc and water occurs. In the HBWS corrosion increases and the protective scaling process (CaCo3, MgCO3) from hardness and alkalinity is reduced. The HBWS has moderately soft waters, high alkalinity and sulphate, and, a high specific conductance which enhances the conduction of an electrical current and promotes corrosion (Hicks et al. 1997 -unpublished report). Zinc being a heavy metal is ubiquitous and is readily dissolved and transported in water (Barak and Mason 1989). When leached into the water column heavy metals will exist as a free ion or complex with an organic ligand (fulvic, humic organic acids), and inorganic ligands (-OH anion, charged soil particles) (Evans 1989, Forstner 1982). Studies have shown that the major carriers of metal compounds is the fine silt and clay fractions, as found in the study area (Forstner, 1982). The large molecules containing the complex metal settle on the stream bed and are suspended during high discharge. An example of the suspension occurred on September, 19 , 1995 when the concentration of zinc measured 4.0 mg/L and the associated carriers increased (TOC = 5.2 mg/L, turbidity = 2.4 JTU and colour = 40 relative units). Five months after the culvert was installed the concentrations of zinc measured 0.02 mg/L during a November 8 storm. The low concentration of zinc was associated with an increase of colour from

6 to 270 relative units, turbidity to 46 JTU, TOC to 17.3 mg/L and suspended sediment to 272 mg/L. On November 9 zinc concentration were found at 0.01 mg/L and remained at the detection level of 0.01mg/L. The lower concentration of zinc indicates the coating had completely been corroded. The availability of metals to biota is influenced by chemical form, water chemistry and relative distribution between soluble and particulate fractions (Barak and Mason, 1989). Studies have found that the streams receiving heavy metals show major alterations to the macroinvertebrate community. In one study a ten day experiment showed the abundance of a number of macroinvertebrate taxa and dominant groups subject to various concentrations of zinc and copper was reduced by 57% (Clements et al. 1988). Several other studies have documented the bioavailibility of zinc in macrophytes, invertebrates and various species of fish (Sprenger and McIntosh, 1989, Hattum et al. 1991). In the trophic level of fish results generally show that larger fish tend to concentrate higher concentrations of metals (Barak and Mason 1990) and data tend to show a net mineral loss, retarted skeletal calcification, inhibited yolk resorption and an overall physiological imbalance due to combinations of trace metals (Sayer et al. 1991, Christopher etal, 1990, Anadu et al. 1989).

The temperature in the streams range from - 2.0 celsius to a high of 18 celsius. The higher values in study plot 4 were due to the low water level during the 1994 summer. The shade of the forest maintained a mean of 5 degrees. In each treatment study plot the temperature in second year contained higher maximum values. In study plots 5 and 6 the median temperature decreased in the third year. The decrease was not observed in study plot 1. The difference in the forest regrowth rates in the plots could be attributed to the difference. Studies have shown that forest harvesting increases incoming radiation and disturbs the soil to an extent that an increase in water temperature and biomass occurs (Holopainen and Huttunen, 1992).

Conclusion:

The three years of data for the Hayward Brook Watershed Study suggest that the harvest management planning for this area must consider the width of the stream buffer, the density and age of understorey and the percent of watershed cut when setting out a harvest plan. Results indicate that if a watershed has a heavy understory then a least 17 percent of the watershed can be clear cut adjacent to a 30 metre stream buffer without causing an increase in runoff or nutrient export. If the same conditions exist and a 60 metre stream buffer is used a larger percentage of harvest is possible although the maximum area is not known at this time. In areas where the understorey is low a clear cut is not suggested and the harvest method should be such that the understorey is allowed to establish itself prior to more intensive harvesting. Data indicates that a selection harvest within the stream buffers will not impact a stream if conducted with minimum disturbance to the soils and understorey. The selection cut must allow sufficient timber to remain to utilize possible enhanced nutrient flux from the adjacent clear cut. Erosion was a main impact in the project. The heavy weight of a wheeled porter caused deep soil ruts in most clear cuts whereas the tracked harvesters appeared to operate with minor soil rupture. The movement of porters within harvest blocks and in the direction of the slope created a ditch for surface runoff which directed water flow through 60 metre stream buffers. The lack of proper culvert channeling, the use of geofibre and seeding also provides a ditch for surface runoff which could not be slowed by stream buffers. An impact of erosion from a old haul road adjacent to the landowners property caused heavy sediment load down stream at one of the monitoring stations. A management plan should be implemented to address this issue for had a diversion been in place the sediment loading would be minor at the water sampling station and the public perception would had been improved. Another noted impact from road building is the corrosion of galvanized culverts in various streams throughout the province. Due to the water quality type in many areas like the project a galvanized product is quickly corroded and frees dangerous amounts of zinc to the environment. Zinc is a heavy metal and can cause body deformities or can be lethal to the aquatic life and others as it biomagnifies. Other products should be used in areas which promote erosion.

The result of this study are based on a short period of data and general conclusions for runoff based on yearly mean are drawn. A more intensive analyses is occurring in a master thesis by Brent Stanley , UNB Forestry and will be released in the spring of 1999.

References:

-Ahtiainen, M., 1992. The effects of forest clear-cutting and scarification on the water quality of small brooks. Hydrobiologia 243/244:465-473.

-Anadu, D.I., Chapman, G.A., Curtis, L.R. and Tubb, R.A., 1989. Effect of zinc exposure on subsequent acute tolerance to heavy metals in rainbow trout. Bull. Environ. Contam. Toxicol. 43:329-336.

-Anderson, B. and Potts, D.F. 1987. Suspended sediment and turbidity following road construction and logging in Western Montana. Water Resources Bulletin, American Water Resources Association, Vol. 23, No. 4.

-Barak, N.A.E. and Mason, C.F., 1989. Heavy metals in water, sediment and invertebrates from rivers in eastern England. Chemosphere, Vol. 19, Nos. 10/11, pp. 1709-1714.

-Barak, N.A.E. and Mason, C.F., 1990. Mercury, cadmium and lead concentrations in five species of freshwater fish from eastern England. The Science of the Total Environment.

-Bari, M., Smith, N., Ruprecht, J. and Boyd, B., 1993. Changes in streamflow components following logging and regeneration in the southern forest of western Australia, Leederville, Australia

-Bednar, L.. 1989. Plain galvanized steel drainage pipe durability estimation with a modified California chart. Transportation Research Record 1231, Transportation Research Board, National Research Council, Washington, D.C.

-Brown,B.A. and Driscoll, C.F. 1993. pH-dependent binding of aluminum by a fulvic acid. Environ. Sci. Technol. 1993, 27, 915-922.

-Brimley, B. 1997, Personal communication. Environment Canada, Atmospheric Environmental Branch, Halifax, Nova Scotia.

-Canadian Council of Resource and Environment Ministers (CCREM), 1987. Canadian Water Quality Guidelines. Ottawa, Ontario.

-Clements, W.H., Cherry, D.S. and Cairns, J., 1988. Impact of heavy metals on insect communities in streams: A comparison of observational and experimental results. Can. J. Fish. Aquatic Sci., Vol. 45.

-Dahlgren R., and Driscoll C., 1994. The effects of whole-tree clear-cutting on soil processes at the Hubbard Brook Experimental Forest, New Hampshire, USA.

-David, M.B., Vance, G.F. and Kahl, J.S., 1992. Chemistry of dissolved organic carbon and organic acids in two streams draining forested watersheds. Water Resources Research, Vol. 28, No. 2, pp. 389-396.

-Driscoll, C.T., Likens, G.E., Hedin, L.O., Eaton, J.S. and Bormann, F.H., 1989. Changes in the chemistry of surface waters. Environ. Sci. Technol., Vol. 23, No. 2.

-Evans, L.J., 1989. Chemistry of metal retention by soils. Environ. Sci. Technol., Vol. 23, No. 9.

-Fahmy, S., Colpitts, M., 1995. Soils of the Fundy Model Forest. Fundy Model Forest -Agriculture and Agri-Food Canada Research Branch. CLBRR Contribution NO. 95-96

-Forstner, U., 1982. Accumulative phases for heavy metals in limnic sediments. Hydrobiologia 91, 269-284.

-Gan, K., McMahon, T., O'Neill, I..1990. Errors in estimated streamflow parameters and storage for ungauged catchments. Water Resources Bulletin. American Water Resources Association. Vol. 26, No.3.

-Gray, D., 1970. Handbook on the Principles of Hydrology. Department of Hydrology, Department of Agricultural Engineering. University of Saskatoon, Saskatchewan, Canada.

-Hicks, B., Beschta, R., Harr, R.. 1991. Long term changes in streamflow following logging in Western Oregon an associated fisheries implications. Water Resource Bulletin, American Water Resources Association. Vol. 27, No. 2.

-Hicks, T., Hansen, P. and Lockerbie, D., 1997. An investigation into the durability of galvanized corrugated steel culverts and bridges in New Brunswick, Canada. (unpublished manuscript) Environment Canada and the New Brunswick Department of Transportation

-Hill, A.R. 1986. Stream-nitrate-N loads in relation to variations in annual and seasonal runoff regimes. Water Resources Bulletin, American Water Resources Association, Vol. 22, No. 5.

-Holopainen, A.L. and Huttunen, P. 1992. Effects of Forest Clear-Cutting and Soil Disturbance on the Biology of Small Forest Brooks. Hydrobiologia 243/244: 457-464.

-Hornbeck, J., Pierce, R., Federer, A.. 1970. Streamflow changes after forest clearing in New England. USDA Northeastern Forest Experimental Station, Durham, New Hampshire 03824. Water Resources Research, Volume 9, No. 2.

-Hornbeck, J.. 1973. Storm flow from hardwood-forest and cleared watersheds in New Hampshire. USDA Northeastern Forest Experimental Station, Durham, New Hampshire 03824. Water Resources Research, Volume 6, No. 4.

-Hornbeck, J., 1975. Streamflow ressponse to forest cutting and revegetation. USDA Northeastern Forest Experimental Station, Durham, New Hampshire 03824. Water Resource Bulletin, American Water Resources Association. Vol. 11, No. 6.

-Jewett, K., Daugharty, D., Krause, H., Arp, P.. 1995. Watershed response to clear-cutting: Effects on soil solutions and stream water discharge in central New Brunswick. Faculty of Forestry, University of New Brunswick, Fredericton, New Brunswick, Canada E3B 6C2.

-Johnson, N.M., Likens, G.E., Bormann, F.H., Fisher, D.W. and Pierce, R.S., 1969. A working model for the variation in stream water chemistry at the Hubbard Brook Experimental Forest, New Hampshire. Water Resources Research, Vol. 5, No. 6.

-Kerekes, J. 1980. Preliminary characterization of three lake basins sensitive to acid precipitation in Nova Scotia, Canada. In: Drablos D. Tollan (eds) Impacts of Acid Precipitation. SNSF Project. Oslo Norway. Pp 232-234.

-Krause, H., 1997 Buffer Zone Management. A component study of the Hayward Brook Watershed Project in the Fundy Model Forest, New Brunswick, Canada..

-Lawrence G., Fuller, R., Driscoll, 1987. Release of aluminum following whole-tree harvesting at the Hubbard Brook Experimental Forest, New Hampshire. Journal of Environmental Quality. Vol. 16, No 4.

-Likens, G., Bormann, H., Eaton, J.. 1977. Variations in precipitation and streamwater chemisty at the Hubbards Brook Experimental Forest during 1964 to 1977. Effects of Acid Precipitation on Terrestrial Ecosystems. NATO Conference, NATO Scientific Affairs Division.

-Lawrence, G.B., Fuller, R.D., and Driscoll, C.T. 1987. Release of aluminum following whole-tree harvesting at the Hubbard Brook Experimental Forest, New Hampshire. J. Environ. Qual., Vol. 16, No. 4.

-Martin, C.W., Noel, D.S. and Federer, C. A. 1984. Effects of forest clearcutting in New England on Stream Chemistry. J. Environ. Qual., Vol. 13, No. 2.

-Naslas, G.D., Miller, W.W., Blank, R.R. and Gifford, G.F. 1994. Sediment, nitrate, and ammonium in surface runoff from two Tahoe Basin soil types. Water Resources Bulletin, American Water Resources Association, Vol. 30, No. 3.

- Noyce, R., Ostrowski,R.,Ritchie,M..1975. Corrosion of galvanized metal culverts. Geotechnical Services Unit, Michigan Department of State Highways and Transportation. Transportation Research Board #539 National Research Council. Washington, D.C., 1975, Dr70572.

-Pomeroy J., Kerekes J. and Pollock T. 1996. Pre-harvest characterizations of seven streams in the Hayward-Holmes watershed study of New Brunswick's Fundy Model Forest, New Brunswick.

-Sayer, M.D.J., Reader, J.P. and Morris, R., 1991. Embryonic and larval development of brown trout, *Salmo trutta* L.: Exposure to trace metal mixtures in soft water. Journal of Fish Biology (1991) 38, 773-787.

-Schmidt R., Troendle, A.. 1989. Snowfall into a forest and clearing. U.S. Department of Agriculture, Forest Service, rocky Mountain Forest and Range Experiment Station, 240 W. Prospect Street, Fort Collins, CO 80526-2098 (U.S.A.). Journal of Hydrology, 110 (1989) Pp 335-348.

-Schmitt, C.J. and Brumbaugh, W.G., 1990. National Contaminant Biomonitoring Program: Concentrations of arsenic, cadmium, copper, lead, mercury, selenium, and zinc in U.S. freshwater fish, 1976-1984. Arch. Environ. Contam. Toxicol. 19, 731-747.

-Sprenger, M. and McIntosh, A., 1989. Relationship between concentrations of aluminum, cadmium, lead and zinc in water, sediments, and aquatic macrophytes in six acidic lakes. Arch. Environ. Contam. Toxicol. 18:225-231.

-Statistica, statsoft II, and Edition. Copyright 1984-1995 by StatSoft , Inc..

-Stevens, P., Norris, D., Williams, T., Hughes, S., Durrant, D., Anderson, M., Weatherley, N., Hornung, M., Woods, C.. 1995. Nutrient losses after clearfelling in Beddgelert Forest: a comparison of the effects of conventional and whole-tree harvest on soil water chemistry. Forestry, Vol. 68, No.2.

-Van Hattum, B., Timmermans, K.R., and Governs, H.A., 1991. Abiotic and Biotic Factors Influencing in situ Trace Metal Levels in Macroinvertebrates in Freshwater Ecosystems. Environmental Toxicology and Chemistry, Vol. 10, pp. 275-292.