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Effects of Regeneration on Hydrology and Water Quality of a Managed Pine Forest

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Abstract. *Intensive forest management practices such as drainage, harvesting, site preparation, regeneration, and fertilization have been frequently blamed for problems related to excessive nitrogen, phosphorus, and sediment in receiving waters. Two 25 ha experimental watersheds (D1 – control; D2 – treatment) on a pine plantation in eastern North Carolina have been monitored since 1988 to study the hydrologic and water quality effects of various silvicultural and water management treatments using a paired watershed approach. Data from a two-year calibration period (1988-90) and a four-year regeneration period (2000-03) were used for the analysis. This study period recorded both the highest (2330 mm in 2003) and lowest (850 mm in 2001) rainfall of the 16-years (1988-2003) of record at this site. Nearly seven years after planting, water table elevations returned back to pre-treatment conditions. However, peak flow rates and consequently annual outflows were generally higher on the treatment watershed D2 compared to the control watershed (D1), indicating that the outflows on the treatment watershed may not have completely returned back to base line conditions. Average outflow nutrient (NO_3-N, TKN, and Total-P) concentrations for the treatment (D2) watershed for the period from 2000 to 2003 were, however, similar or somewhat lower than their expected values. Although sediment concentration seems to have slightly increased compared to the calibration period, regeneration did not seem to have any effect by the third year after planting, The water quality concentrations were also much lower than the data reported for agricultural lands in the same region. These results will be evaluated and reported soon in the context of prior data after harvesting in 1995 and planting in 1997 to detect the actual effects of regeneration.*

Keywords. Pine plantation, Harvesting, Drainage Outflow, Water Table, Nutrients, Sediment.

Introduction

Hydrologic and water quality impacts of sustainable forest management practices (e.g. harvesting, site preparation, bedding, regeneration, and thinning of pine forests) on receiving water bodies continue to be important environmental issues. Timber harvests in the South are expected to increase over the next 20 years, and it is likely that impacts to forested wetlands as a result of increasing and intensified forestry will continue (SOFRA, 2002). Land use pressures and environmental set asides tend to decrease the industrial forest base, leading to more areas of more intensive silvicultural practices including access, drainage, harvesting, site preparation, fertilization, herbicides and artificial regeneration. A large number of studies on effects of timber harvesting on the hydrology and water quality are found in the literature (Grace et al., 2003; Xu et al., 2002; Sun et al., 2000; 2001; Swank et al., 2001; Lebo and Herrmann, 1998; Dube and Plamondon, 1995; Crawford et al., 1992; Riekerk, 1989; Swindel et al., 1982; Bosch and Hewlett, 1982). Studies show that removing the forest canopy reduces evapotranspiration (ET), increasing the water yield from a forested site until the canopy is regenerated. Elevated ground water tables, increased peak flows, and higher outflows result, also increasing nutrient and sediment movement. However, most of the previous studies have been limited to either upland forest hydrologic conditions or only a short period immediately after harvesting.

A few studies have recently documented some of the impacts on soil properties, hydrology and water quality as a result of harvesting and subsequent regeneration of pine forests in the poorly drained lowlands of Atlantic Coastal Plain (Grace et al., 2003; Xu et al., 2002; Sun et al., 2001; Blanton et al., 1998; Lebo and Herrmann, 1998; Amatya et al., 1997; Crawford et al., 1992; Ursic, 1991; Riekerk, 1989; Swindel et al., 1982). Shepard (1994) reviewed results of effects of silvicultural practices on water quality from nine wetland forest sites and found that harvesting timber raised nutrient concentrations, with concentrations decreasing to “natural” levels after one to four years. Lebo and Martin (1998) observed increased outflow and small increases in nutrient concentrations following tree harvest on drained pine forests in eastern North Carolina, with outflow and concentrations returning to base line levels within two to three years. Grace et al. (2003) also reported increase in event outflows, peak flows and number of days with outflows as a result of harvesting a 23-ha drained mature hardwood forest stand in the same region. Xu et al. (2002) found a sharp decrease in difference in water table depths between harvested and a mature tree stand during the first two years after tree planting in South Carolina. Sun et al. (2001) in their synthesis study on effects of timber management on wetland forests reported that the hydrologic impacts of various forest management practices across the southern US are variable, but generally minor, especially when forest best management practices (BMPs) are adopted. Using a conceptual model, the authors suggested that in addition to soils, wetland types, and management options, climate is an important factor in controlling hydrology and magnitude of disturbance.

A long-term forest hydrology and water management study was initiated at three experimental pine forests at Carteret County, North Carolina in early 1988 to quantify the potential impacts of both silvicultural and water management practices on downstream hydrology and water quality. Continuous hydrologic monitoring on these watersheds has provided a database for quantifying the water and nutrient budgets and evaluating impacts of various management practices (McCarthy et al., 1991; Amatya et al., 1996; 1998; 2000; 2003). It has also provided a data base for developing simulation models. McCarthy et al. (1992) used limited data to develop and test a forest hydrologic model, DRAINLOB, which was a modification of the agricultural water management model DRAINMOD (Skaggs, 1978). DRAINLOB was later used to simulate the effects of forest management practices including harvesting and regeneration for the same North Carolina site (McCarthy and Skaggs, 1992; Richardson and Mccarthy, 1994). The model was further tested with long-term data from the same pine plantation site (Amatya and Skaggs, 2001).

Blanton et al. (1998) studied the changes in soil hydraulic properties including the hydrology of one of the three drained forested watersheds at Carteret County site during harvest and regeneration periods. The authors reported that harvesting operations including site preparation reduced drainable porosity in the top 60 cm of the profile by approximately 50%, resulting in a significant change in storm outflow hydrographs. The main objective of this study is to extend the Carteret research to evaluate the effects of regeneration after plantation establishment in 1997 using four years (2000-2003) of data from the same watersheds at Carteret County in North Carolina.

Methods

Site Description:

The study site (Fig. 1) is located at approximately 34° 48' N latitude and 76° 42' W longitude in Carteret County, North Carolina, and is owned and managed by Weyerhaeuser Company. The research site consists of three artificially drained experimental watersheds, each about 25 ha in size. Topography of the site is flat and soils have shallow water tables. The soil is a hydric series, Deloss fine sandy loam (fine-loamy mixed, Thermic Typic Umbraquult). Each watershed is drained by four 1.4 to 1.8 m deep parallel lateral ditches spaced 100 m apart (Fig. 1). Data on hydrology, soil and vegetation parameters were collected from three experimental plots (each about 0.13 ha in area) in each watershed (Fig. 1).

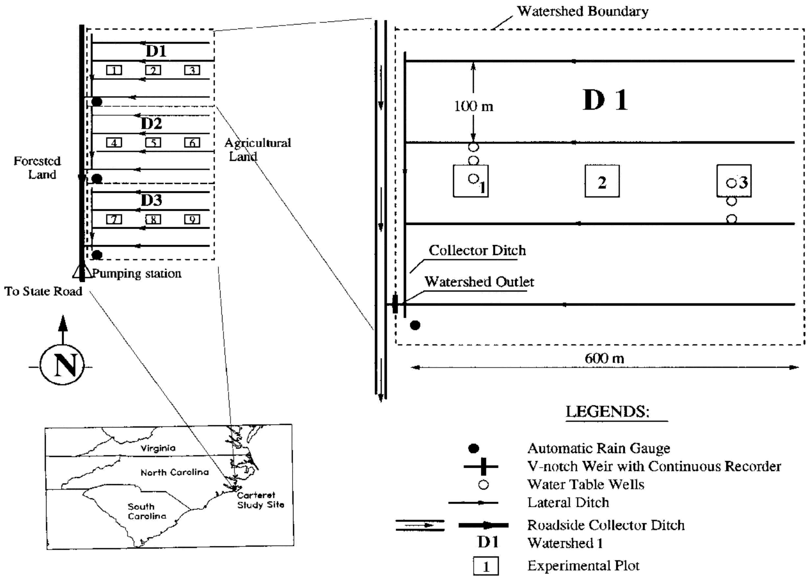

Figure 1. Location map and layout of experimental watersheds (D1 – control and D2 – treatment with plantation for regeneration) at Carteret County, North Carolina.

Rainfall was measured with a Qualimetric tipping bucket rain gauge with a datalogger in an open area on the western side of each watershed (Fig. 1). Air temperature, relative humidity, wind speed and net radiation were continuously measured by an automatic weather station located at the center of the treatment watershed (D2). An adjustable height 120° V-notched weir, located in a water level control structure at a depth nearly equal to the bottom of outlet ditch (Fig. 1), was used to measure drainage outflow in each watershed. Upstream of each weir, water levels were measured at six-minute intervals by a water level recorder and an automatic datalogger. An additional recorder was placed downstream from the weirs (not shown) to determine if weir submergence occurred and to correct flows in that event. In 1990, a pump was installed downstream from all three watersheds in the roadside collector ditch to prevent weir submergence during larger events. Water table elevations were measured by a continuous water level recorder at two locations midway between the field ditches for each watershed (Fig. 1). The reader is referred to McCarthy et al. (1991) and Amatya et al. (2003; 2000; 1996) for a detailed description of the site and other measurements, including the history of the loblolly pine stand planted in 1974.

Two methods of water sampling (composite using Automatic water samplers ISCO-2700 and grab sampling) have been used since late 1989. For composite sampling during an event, 250 mL of water was collected every two hours; four consecutive samples were composited making three samples per day. All samples were frozen and taken to the soil-chemistry laboratory of the Soil Science Department at North Carolina State University in Raleigh, NC. Grab samples were collected weekly during the flow events of the study period. Water samples were analyzed for NO_3+NO_2-N, NH_4-N, total Kjeldahl nitrogen (TKN), total phosphorus (TP), and total suspended solids (TSS). Details of procedures of sample analysis in the laboratory have been documented by Amatya et al. (1998; 2003).

Study design and treatments:

A paired watershed approach (EPA, 1993) was used to assess the comparability of hydrologic characteristics of these watersheds during the pre-treatment calibration period. Hydrologic calibration of the watersheds took place between February 1988 and March 1990 when all three watersheds were treated identically in terms of weir level in the outlet ditch (McCarthy et al., 1991; Amatya et al., 1996). In this study, watershed D1 with a 30-year old mature pine forest was a control and watershed D2, harvested in July 1995 at stand age of 21 years with a site preparation and bedding in October 1996 followed by planting for regeneration in February 1997, was the treatment watershed. So nine years of hydrologic data have been collected since harvesting in July 1995. This study will examine data only for the regeneration period from years 2000 to 2003. Thus the comparisons are for a pine plantation during years 26 to 29 and a plantation undergoing regeneration in years 3 to 6.

Hydrologic data and pre-treatment calibration relationships for daily water table depths and drainage outflows for these two watersheds for the period 1988-90 have been recently reported by Amatya et al. (2000). The effects of regeneration on hydrology were evaluated using both the graphical and statistical comparisons of (a) the measured daily water table elevations, (b) annual drainage outflows, (c) daily hydrographs between the control (D1) and treatment (D2) watersheds. For water quality parameters, annual mean concentrations and annual expected concentrations for each of the years were used to determine the effects of regeneration.

Regression relationships developed from the daily outflow data from two watersheds (D1 and D2) for the calibration period (1988-90) were used with measured daily data from the control watershed D1 for the treatment period to predict the expected daily outflows from the treatment watershed D2. Both the measured data and its regression line for each of the four treatment years and expected regression line based on the calibration period were plotted individually. A test for statistical significance ($\alpha = 0.05$) was conducted using SAS (1994) to examine the overall model significance and the difference between the slopes of regression lines for each of the regeneration treatment years and the pre-treatment period using EPA (1993) approach. This test was conducted for both the daily water table depths and daily outflows.

In order to assess the effects of regeneration on the annual hydrology and water quality during the treatment period, the characteristic differences observed in the annual rainfall, outflows and concentrations between the two watersheds during the pre-treatment period were taken into account as was done by Amatya et al. (1998; 2000). This was done by multiplying the measured annual values from D1 by an average correction factor determined from the 1989-90 pre-treatment data. This gives an expected annual value for D2. Thus the factor of 0.96 observed as the average ratio of annual outflow of D2 and D1 during the pre-treatment period was used to estimate the expected outflow from D2 for each of the years of the treatment period, which was then compared with the expected outflow for the evaluation. Similarly, the factors from pre-treatment characteristic differences observed in NO_3-N, TKN, and sediment concentrations were used to estimate the expected annual values for the study period. PROC REG and PROC GLM procedures available in SAS (1994) were used for regression and for significance tests for the slopes of regression between calibration and treatment periods, respectively.

Results and Discussion

Rainfall:

Annual data on measured rainfall, outflow and estimated runoff coefficients and potential evapotranspiration (PET) for the 1988-90 calibration and 2000-2003 regeneration treatment period are presented in Table 1. This period covered a wide range of variation in annual rainfall. The rainfall of 2330 mm (on D1) in year 2003 was the highest of the 16-years (1988-2003) of record at this site (Figure 1). Rainfall amounts were similar in 2000 and 2002. Gauges on both D1 and D2 watersheds occasionally malfunctioned until new gauges were installed at the end of the year 2000, and data from the weather station at D2 watershed were used for the missing and/or bad data. The lowest annual rainfall of around 850 mm (less than half observed in 2000 and 2002) was recorded in 2001, the driest year of the 16-year period. Annual rainfall was somewhat lower on watershed D2 compared to D1 during the 1988-90 calibration but was reversed in 2000-2003 treatment years, except in 2001.

Table 1. Measured annual rainfall, outflow, temperature and estimated annual runoff ratio and potential evapotranspiration for two watersheds for the calibration and treatment periods.

	Annual Rainfall, mm		Annual Outflow, mm		Runoff Ratio, %		Expected Outflow On D2, mm	Annual P-M PET mm
Year	D1	D2	D1	D2	D1	D2		
1988	1235	1207	168	162	13.6	13.4	-	1041
1989	1876	1829	658	642	35.1	35.1	-	945
1990	163	159	101	87	61.9	54.7	-	1031
2000	1718	1786	857	792	49.9	44.3	824	1023
2001	852	851	45	51	5.3	6.0	43	1024
2002	1718	1776	426	430	24.8	24.2	409	940
2003	2331	2388	1404	1469	60.2	61.5	1350	1097

Measured monthly rainfall for the four-year treatment period is shown in Figure 3. It is evident that all months in 2003, except in January, exceeded the long-term average rain measured at nearby Morehead City. To the contrary, all months in 2001 had lower than normal rainfall, except for June. Most of the months in 2000 and 2002 were also wetter than normal. The highest monthly rainfall of 355 mm was recorded in September 2003 as a result of Hurricane Isabelle. Lowest monthly rainfall of 13 mm was recorded in November 2001; maximum monthly rainfall in 2001 was only 145 mm. The months of June through September usually had 150 mm or more rain due to summer storms, typical of the region.

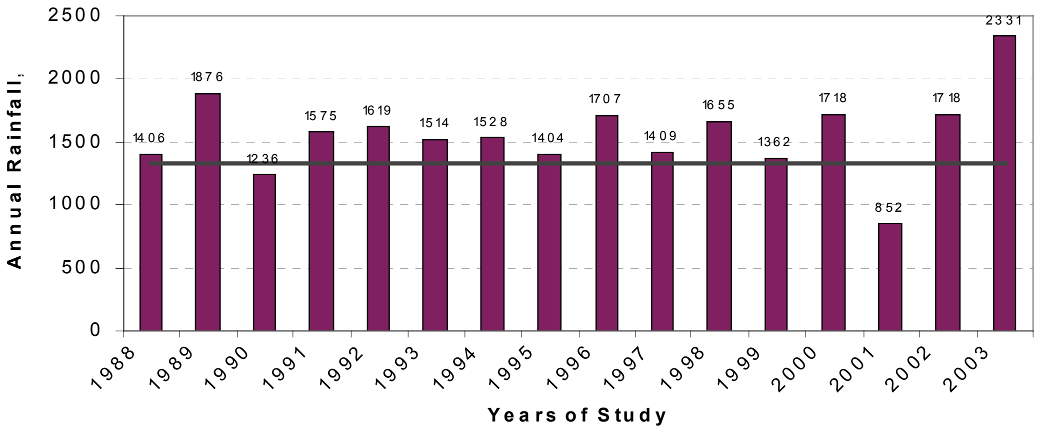

Figure 2. Measured annual rainfall from 1988 (start of study) to 2003 on control watershed D1 at Carteret site, NC. The horizontal line is long-term rainfall of 1330 mm at Morehead City, NC.

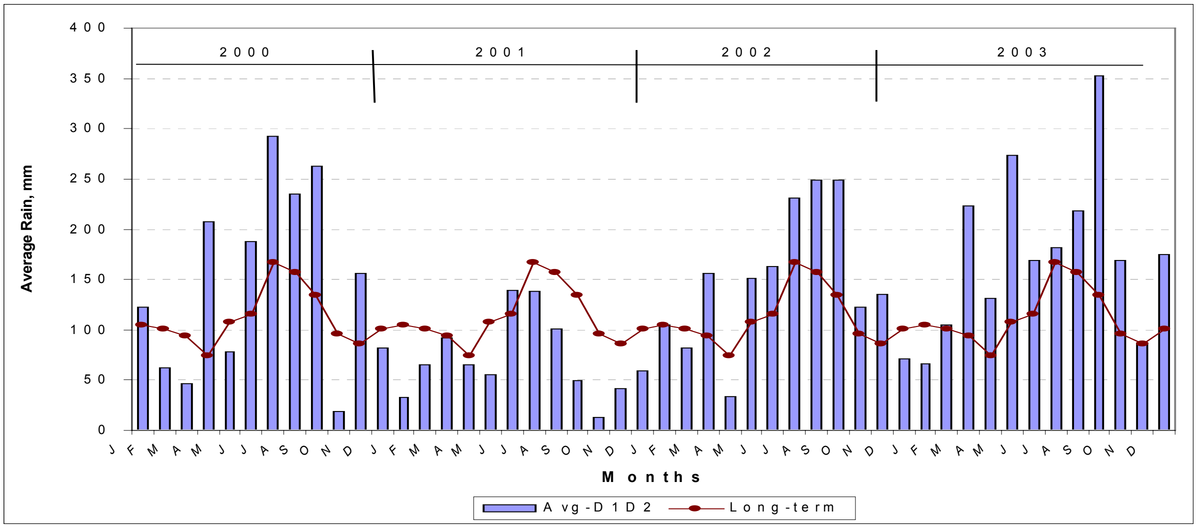

Figure 3. Measured monthly rainfall (average of rain from D1 and D2) for the 2000-03 regeneration period. The connected points are long-term monthly rainfall at Morehead City, NC.

Water Table Elevations:

Daily average water table elevations for watersheds D1 (control) and D2 (treatment) are presented in Figure 4 for the 2000-03 treatment period. Some data were not available in 2000 (Fig. 4, top) for both the watersheds and for October (Day 285-305) in 2002 on watershed D2 (3rd plot). Measured water table elevation responded as expected to rainfall in all four years. Rainfall plotted in Figure 4 is the daily average for D1 and D2 for 2000 and hourly for other three years. Data from 2000 to 2002 showed that water table in the harvested and regenerating watershed (D2) responded quicker to rainfall events with higher elevations than the control watershed D1 when the elevations were below 2.0 m. However, the observed pattern seemed to be different in the year 2003 when the elevations on treatment watershed D2 were consistently lower than the control, except for the large events that brought the water table near the surface. This could have been due to reduced ET losses from the watershed D2 with shorter effective root depths and smaller canopy for the stands planted in 1997. However, differences in water table depths were small by 2002 and 2003.

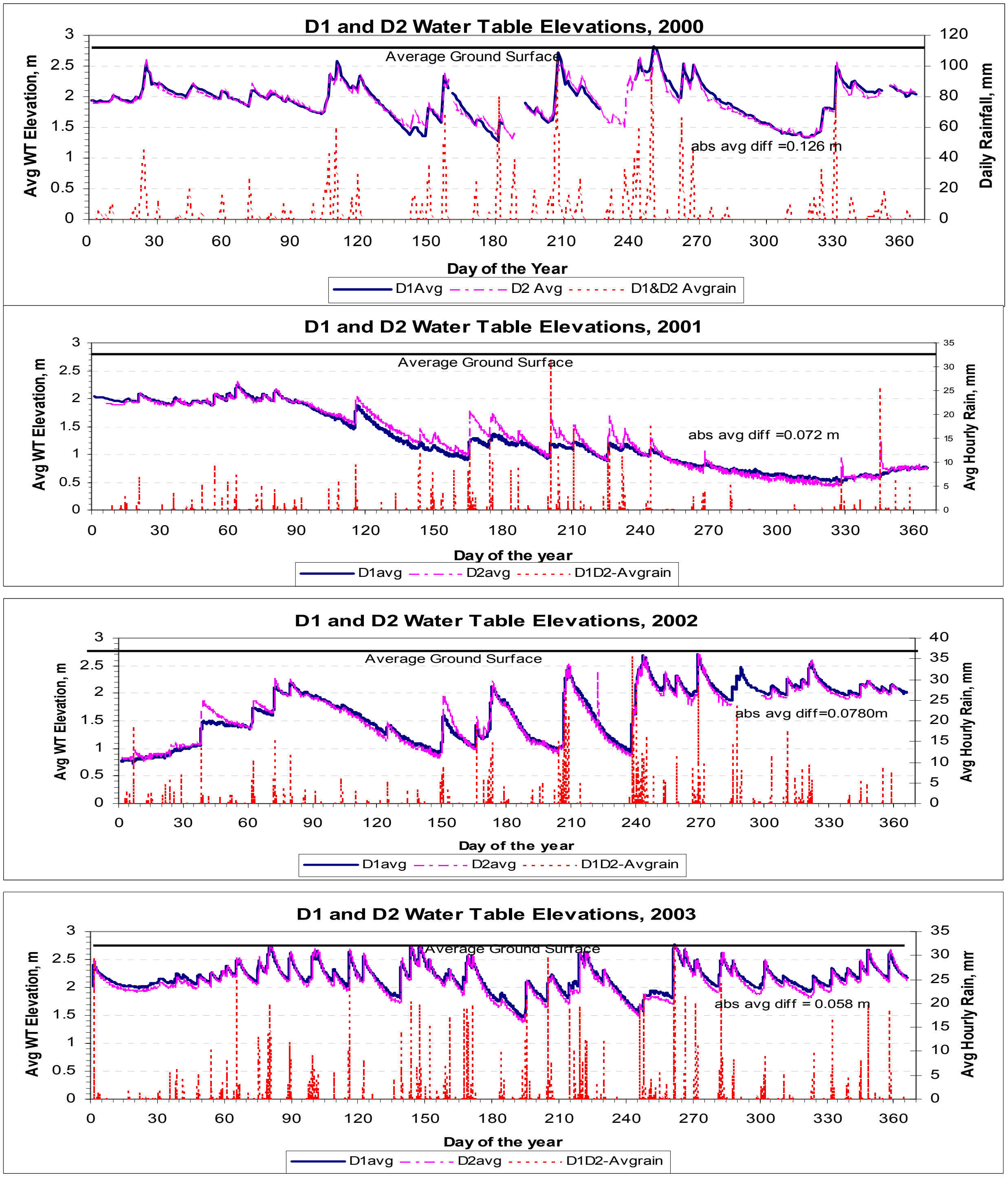

Figure 4. Daily average water table elevations for control (D1, solid) and treatment (D2, dashed) watersheds for four treatment years. Dotted vertical lines are average rainfall for D1 and D2.

At shallower water tables, ET losses may not be limited by soil moisture in the root zone. The calculated value of average absolute difference in elevations between D1 and D2 was getting smaller from 0.126 m in 2000 to 0.058 m in 2003, indicating that by 2003 the water table elevations were returning back to the baseline calibration conditions when the difference was only 0.057 m.

The annual average water table elevations and their deviations for 2000-03 period are presented in Table 2. Although the average deviation in elevations between D1 and D2 in 2000 was near zero, it was negative in 2001 and 2002, indicating that average elevation on treatment watershed was higher than on the control. Intermittent loss of nearly three months of data from the wells both on watershed D1 and D2 may have affected the computed statistics for the year 2000. This was especially true for the summer, when large differences may occur due to high ET losses. The average deviations were computed to be positive for the year 2003 as well as a short period of data through March 20, 2004 (not shown). This was further supported by the decreasing calculated slope of regression between water table elevations of D2 and D1 watersheds. The slopes were 0.99, 1.03, 1.02, and 0.98 for 2000, 2001, 2002, and 2003, respectively. Again the value of 0.99 in 2000 may be questionable. The value for near 3-month data in 2004 also stayed about 0.98. This slope (0.98) was the same as the one obtained for the calibration period (Amatya et al., 2000). This indicates that the water table elevations on watershed D2 have returned to base line conditions, eight years after harvesting and six years after plantating for regeneration. Although the effective root depth and canopy cover for the seven year old stand are probably not as large as that of the mature pine stand (Baldwin, 1987), the under-story vegetation on the watershed D2 may have also contributed to total ET. However, these effects are probably more important for the period immediately after harvest (1996 to 1999, data not shown) than for this regeneration period.

Table 2. Average annual water table elevations (WTE) and difference in annual average WTE between control (D1) and treatment (D2) watersheds

Water shed	2000		2001		2002		2003		2004 (thru March)	
	Avg Water Table Elev	Avg Dev D1 - D2 WTE	Avg Water Table Elev	Avg Dev D1 – D2 WTE	Avg Water Table Elev	Avg Dev D1 – D2 WTE	Avg Water Table Elev	Avg Dev D1 – D2 WTE	Avg Water Table Elev	Avg Dev D1 – D2 WTE
	cm	Cm	Cm	cm	cm	Cm	Cm	cm	cm	cm
D1	1.91		1.22		1.66		2.16		2.16	
D2	1.92	0.01	1.27	-4.3	1.67	-1.0	2.11	5.0	2.11	5.4

Drainage Outflows:

Measured daily drainage outflows from the treatment watershed (D2) are compared with flows from the control (D1) for four years (2000-03) in Figure 5. Most of the measured daily drainage outflows were limited to 30 mm, except for two large events in 2002 and 2003. One of them exceeded 50 mm day^{-1} as a result of 176 mm of rain with a maximum intensity of 33 mm hr^{-1} brought by Hurricane Isabelle on September 18, 2003. On the other extreme, all daily outflows were lower than 5 mm for the driest year, 2001, with an annual rainfall of only 850 mm (Table 1). Although the daily drainage outflows from the treatment watershed closely followed the control, the peak flow rates on the treatment were consistently higher for most of the periods. Otherwise, the measured daily outflows for treatment watershed D2 were closely associated ($R^2 > 0.92$) with that from the control (D1) for all years, except for the year 2003 when there was a wide variation in outflows. DRAINMOD extrapolated data were used for Days 78-157 and 260 - 273 on watershed D1 and Days 78-157 and 260-365 for D2 because of large and prolonged weir submergence in year 2003.

The regression slopes of daily outflow from watershed D2 (y) on watershed D1 (x) for each of the treatment years are also plotted in Figure 5. Except for the year 2000, the slope as high as 1.28 in the year 2001 continued to decrease to near unity in 2003.

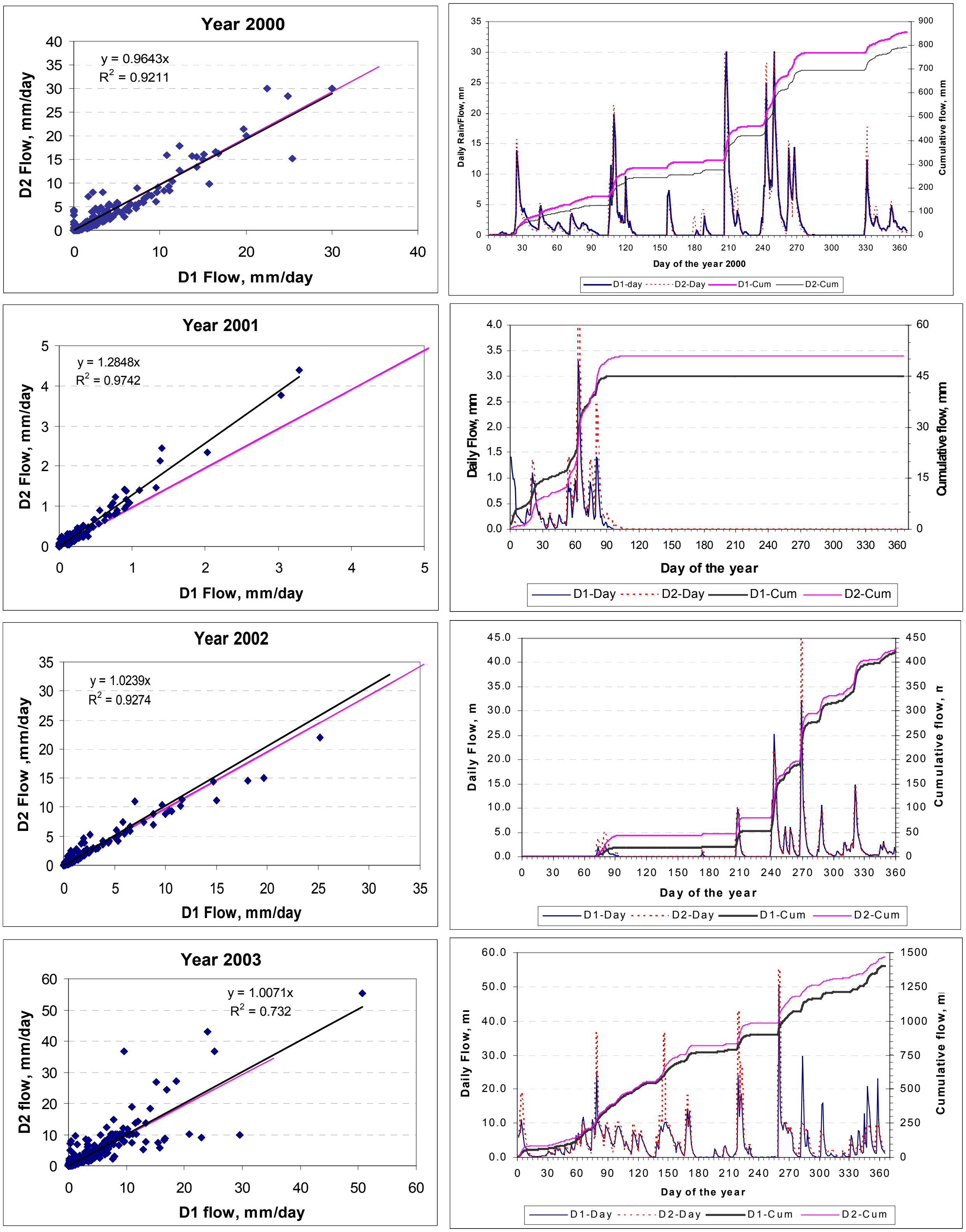

Figure 5. Left side plots are comparison of regression lines between treatment (D2) and control (D1) watersheds for four treatment years (solid dark) and 1988-90 calibration period (solid light). Plots on the right side show daily and cumulative outflows for corresponding treatment years.

Like with the water table elevations, there were some missing periods in flow data mostly on watershed D1 and some on D2 for the year 2000 due to aging stage recorders and data loggers. These data were replaced using data from the third watershed D3 (Figure 1), which had a similar treatment as the control. So in general, the daily flow rates from the treatment watershed (D2) tend to be decreasing from the year 2001 to 2003. This is also evident from the slope for the 1988-90 calibration period plotted together with each of the slopes from the treatment years in the same Figure 5. However, the calculated slope of 1.00 in 2003 was still slightly higher than the slope of 0.98 calculated for the calibration period (Amatya et al., 2000). The results of SAS (1994) GLM procedure for significance test indicated no difference ($\alpha = 0.05$) in slopes between the calibration and treatment periods in 2000 and 2003, but there were differences ($\alpha = 0.05$) in both 2001 and 2002. Again, a similar analysis for a short period of data through March 25 of 2004 with exclusion of a few days of weir submergence on D2 indicates a significant difference between the slopes. This indicates that unlike the water table depths, the daily flow regime on treatment watershed (D2) may not have yet returned to base line conditions. The analysis with the flow data especially in 2000, 2003 and partly in 2004 were complicated by extrapolated data from nearby watershed and also frequent large weir submergences, especially on watershed D2.

The annual drainage outflows for the two watersheds for the 1988-90 calibration period and four years of regeneration treatment period are presented in Table 1. The expected annual outflows for the treatment watershed (D2) computed using measured flow data from control watershed (D1) and a calibration factor were compared with its measured data in Figure 6. Data for the control watershed (D1) are also shown in the same figure.

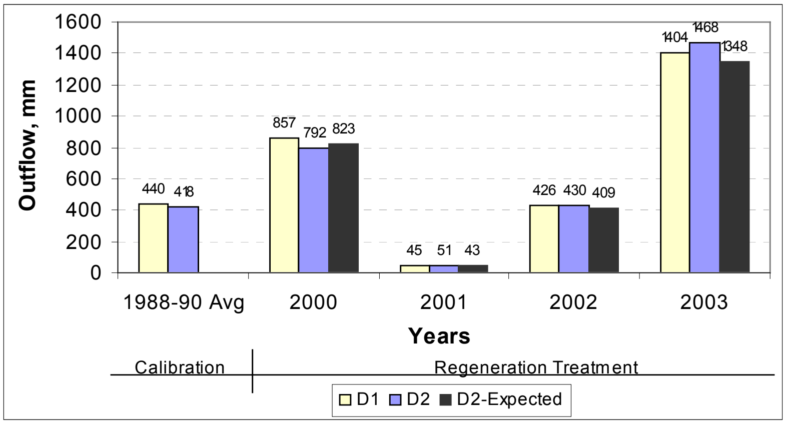

Figure 6. Measured drainage outflows for control (D1) and treatment (D2) watersheds for four treatment years. Plot also shows expected D2 annual and 1988-90 calibration period outflows.

The measured annual outflows on these two watersheds varied from as low as 45 mm in the driest year with 851 mm of rain to as high as 1469 mm with annual rainfall of 2388 mm for treatment watershed D2. Because of very drier antecedent conditions with deeper water tables in late 2001 continuing through the beginning of 2002 (Figures 4 and 5), for the similar amount of annual rainfall, outflows on both watersheds in 2002 were nearly half of the outflows that occurred in 2000 (Table 1). Plot of daily outflow data for 2002 showed no outflow occurring on the watersheds until Day 70, because of very dry conditions at the end of 2001. The annual outflows on the treatment watershed (D2) were higher than the expected values in all years, except for 2000. While this difference may be due to treatment, other factors including the rainfall may have had an effect. Weir submergence probably caused errors in measured outflows, especially in 2003. Annual rainfall for the treatment years was consistently higher on D2 compared to the control, except for 2001 (Table 1). The annual rainfall pattern was opposite during the calibration period. When the measured annual outflows from D2 for the treatment years were adjusted for the effects of rainfall with computed expected runoff ratio for D2 using the ratio for the calibration period and the computed ratio for D1 in treatment years, the annual increases were very small (not shown).

Although the pine trees planted in 1997 on the treatment watershed (D2) are just about 7 to 8 m tall with shorter effective rooting depth than the mature 25-26 m tall forest on the control (D1), the difference in water table elevations between the treatment and control seemed to close by early 2004. On these flat, poorly drained watersheds drainage outflow is generally dependent upon the position of the water table as affected by rainfall and ET, indicating that the drainage outflow from the treatment watershed also should perhaps behaving similar to the control. Most of the other studies on pine plantations and pine flatwoods (Xu et al., 2002; Lebo and Herrmann; 1998; Shepard,1994; Swindel et al., 1982;) reported the hydrology returning back to base line levels within one to four years. Factors such as deviations in rainfall between the watersheds, outlet weir submergence and some instrument malfunction in this study have complicated the conclusive results on effects of regeneration six years after planting the trees on drainage outflows. It is, therefore, important to analyze these results in the context of prior data after harvesting in 1995 and planting in 1997 as well as the data from 2004 without problems of weir submergence to detect the actual trend and effects of regeneration.

Nutrients and Sediment:

Concentrations of nutrients (TP, NO_3, and TKN) and sediment measured both by grab and automatic composite sampling during flow events at the drainage outlets of watersheds D1 and D2 for the period from 2000 to 2003 were averaged to obtain annual mean values. The annual means, standard deviations and maximum values along with number of composite and grab samples are presented in Table 3. Measurement for TKN and sediment were not available in 2003. As expected, the largest number (31) of samples was collected during the wettest year of 2003. Samples in other three years varied from 9 on D2 in 2002 to 16 on D1 in 2000. Measured data from the third year (2000) after planting on watershed D2 show the annual mean nitrate (NO_3) concentrations much lower than that on the control watershed (D1) for all four years. The four-year average value of NO_3 concentration (0.05 ± 0.06) mg L^{-1} observed on treatment watershed D2 was within the ranges of values published for other drained pine forests in the same region that also underwent harvesting (Lebo and Herrmann, 1998). Average TP (0.03 ± 0.01) mg L^{-1} for the four-year period was less than half of those found by Lebo and Herrmann study. The pattern found between the two watersheds during the calibration period (Amatya et al., 1998) seemed to be valid for all four years on treatment watershed (D2). Both the annual mean values of TKN and sediment were lower than those observed on control watershed (D1) and also reported by Lebo and Herrmann (1998). There was a decreasing trend in TKN concentrations from 2000 to 2002 as the pine trees on watershed D2 grew. This may be due to decrease in organic nitrogen (TKN - NH_4), as under-story vegetation continued to decrease with the growth of pine trees. The lower 4-year average sediment concentration (8.2 ± 7.8) mg L^{-1} on treatment watershed (D2) compared to (19.8 ± 6.9) mg L^{-1} on the control (D1) was opposite of what was found during the calibration period. There is an increasing trend of sediment on watershed D1 since the pre-treatment period (Amatya et al., 2003) (Figure 7). However, all these annual concentrations are well below the values for agricultural lands in the region (Amatya et al., 1998).

Table 3. Mean annual concentrations (mg L^{-1}) of nutrients and sediment based on given number of samples measured at control (D1) and treatment (D2) watersheds. For sample numbers "C" means composite and "G" is grab sample.

Parameters	2000		2001		2002		2003	
	D1	D2	D1	D2	D1	D2	D1	D2
Sample #	16C	12C	10C	11C	9C, 3G	8C, 1G	18C,13G	18C,13G
Months	2-4, 7-12	1, 8-12	1-4	1-4	4, 8-12	4, 9-12	1-9	1-9
Mean NO_3	0.48	0.05	0.08	0.00	0.39	0.06	0.26	0.06
S.D. NO_3	0.50	0.03	0.05	0.04	0.40	0.14	0.22	0.03
Max NO_3	0.89	0.11	0.19	0.04	1.34	0.43	1.08	0.15
Mean TKN	1.09	0.53	0.43	0.37	1.61	0.26	N/A	N/A
S.D. TKN	0.68	0.23	0.28	0.18	1.57	0.27	N/A	N/A
Max TKN	2.50	1.00	0.90	0.80	4.78	0.65	N/A	N/A
Mean TP	0.02	0.02	0.01	0.01	0.03	0.03	0.03	0.03
S.D. TP	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Max TP	0.05	0.03	0.03	0.02	0.04	0.05	0.05	0.04
Mean Sedim	22.1	6.8	12	3.2	25.1	20.2	N/A	N/A
S.D. Sedim.	3.1	2.4	6.8	1.3	4.9	9.7	N/A	N/A
Max Sedim.	28.0	12	20	6	33	35	N/A	N/A

The effects of regeneration were evaluated by comparing the measured annual mean concentration values (with S.D.) on D2 with the expected data (Figure 7) based on the control watershed D1 and the factors to account for characteristic differences (only in NO_3, TKN and sediment) from the calibration period (Amatya et al., 1998) as described earlier in the methodology section. Using those calibration factors, the measured NO_3 concentrations on D2 were consistently lower than the expected, indicating no more effects of the treatment and even lower than that from the calibration period. Similarly, expected TKN concentration on watershed D2 was lower than the measured in two out of three years. A high mean TKN concentration on control watershed (D1) in 2002 was a result of a peak value of 4.8 mg L^{-1} (Table 3) observed on August 11 after a fairly long dry period causing build up of ammonia (3.7 mg L^{-1}). The reason for a slight increase in TKN in 2001 was perhaps due to very little nitrification caused by low flows. Data for 2003 were not available. Measured sediment concentrations from watershed D2 were also lower than the expected value in all three years, although these values in all years were higher than that observed during the calibration period. Although the trend should have been decreasing as the trees grow older, the increase in D2 may be due to the remaining impacts of soil disturbance after harvesting. But the reason for increase on the control watershed D1 was not clear. The higher sediments in 2003 are most likely the results of large number of high flow events in that year (Figure 5). Mean NO_3 concentrations in all years were lower than that from the calibration period (Figure 7). Same was nearly true for sediment and TKN. The reason for higher values during the (1988-90) calibration period was due to the effects of fertilization after the commercial thinning of these watersheds in October 1988 (Amatya et al., 1998).

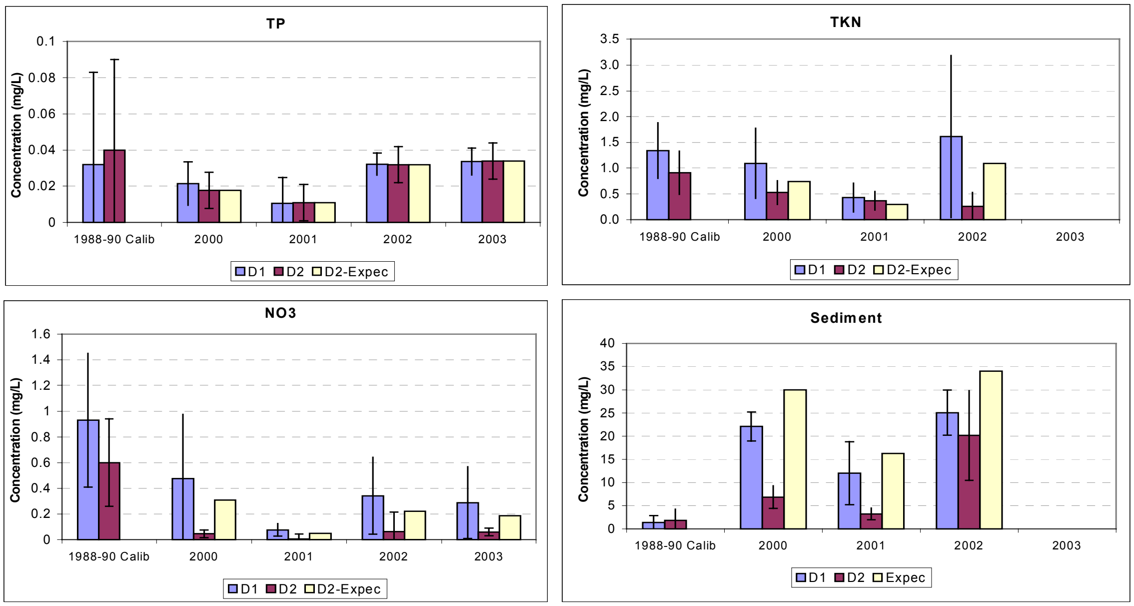

Figure 7. Measured annual mean concentrations of nutrient and sediment for control (D1) and treatment (D2) watersheds for 1988-90 calibration and treatment years. Expected annual values for treatment watershed (D2) are also shown.

These results indicate that the effects of regeneration treatment on water quality were not observed even in the third year (2000) after planting in 1997, consistent with data from other studies (Shepard, 1994; Lebo and Herrmann, 1998). The mean annual nutrient concentrations were below the calibration values and also the data by Chescheir et al., (2003), except for sediment, which was found to be somewhat increasing for both the watersheds. The outflow nutrient parameters on treatment watershed (D2) have returned to base line conditions. However, further analysis using the watershed export of nutrients and sediment together with post-harvesting and plantation data will give an accurate insight of the effects.

Summary and Conclusion

A study using a paired watershed approach was conducted on two experimental watersheds on a drained pine plantation in Carteret County, eastern North Carolina to evaluate the effects of pine regeneration after harvesting in 1995 and subsequent planting of trees in 1997. The evaluation was conducted using only four years (2000-03) of hydro-meteorologic and water quality data measured on a control (D1) and a treatment (D2) watershed. Data were analyzed for years three to six after planting on D2 in 1997. This study period recorded both the highest (2330 mm in 2003) and lowest (850 mm in 2001) annual rainfall of the 16-years (1988-2003) of record at this site. Seasonal monthly rainfall was usually higher during the months of June to September. Measured water table elevations were found to be higher on the treatment watershed (D2) until 2002 after which the pattern was reversed as shown by data through March of 2004. This indicated that the water table elevations on the control watershed returned back to base line conditions in the sixth year after planting the trees, consistent with or somewhat longer than other findings in the same region.

Although the daily drainage outflows from the treatment watershed closely followed that from the control, the peak flow rates on the treatment were consistently higher for most of the period. As a result the annual outflow (yield) from the treatment watershed was higher than that from the control in all years, except in 2000. The higher annual outflows in 2001 and 2002 were consistent with higher observed water table elevations. However, the higher outflow on D2 in 2003 may be an artifact of both the higher rainfall than on D1 and potential errors in flow measurements due to weir submergence. Although rainfall was similar in 2000 and 2002, annual outflow in 2002 was almost half of that observed in 2000 as a result of very dry antecedent conditions caused by drought at the end of 2001. Lower outflow from D2 compared to D1 in 2000 tend to indicate the return of base line conditions although with some extrapolated data due to instrument malfunction, the result may have to be carefully interpreted. However, statistical tests of slopes of regression lines for calibration and treatment periods indicated differences in 2001 and 2002 with a return of daily outflows to baseline conditions possibly by the end of 2003.

Analysis of nutrients and sediment data indicated that the concentrations measured on the treatment watershed were consistently lower than the expected estimates based on the calibration, indicating no more effects of the treatment from the year 2000. The mean annual concentrations of all nutrients (NO_3-N, TKN, TP) and sediment were lower than, or comparable to, those from the calibration period, as well as measured data from nearby sites. At least the nutrient levels on regeneration watershed were already near or below the base line conditions. However, sediment concentrations on both the control and treatment watersheds tended to be elevated compared to the calibration period.

Although the results indicate the treatment level water table elevations and nutrients and sediment concentrations have essentially returned to base line conditions, the data on outflows are not yet conclusive. We believe that with a ditch cleanup and a recently installed new pump downstream of these watersheds will prevent submergence providing good data for the rest of 2004 flow season and allow a reevaluation of effects of regeneration on outflows. A further analysis of water quality data using the nutrient and sediment mass balance will help determine the actual effects in terms of their export downstream. Furthermore, the complete picture of effects of regeneration will be clearer when data collected for the four-year period immediately following harvest in 1995 are analyzed. This analysis will be conducted and reported soon.

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