10-2003

Runoff and Sediment Losses from Annual and Unusual Storm Events from the Alto Experimental Watersheds, Texas: 23 Years After Silvicultural Treatments

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Abstract

Evaluating the potential impacts of intensive silvicultural practices on water quality is critical for establishing the long-term sustainability of contemporary forest management practices. From 1979 to 1985, a study involving nine small (~2.5 ha) forested watersheds was conducted near Alto, Texas in the upper western Gulf-Coastal Plain to evaluate the impacts then-current silvicultural practices on water quality. In the years following the study, silvicultural Best Management Practices (BMPs) including Streamside Management Zones (SMZs) and other erosion control practices evolved and questions arose about the applicability of earlier results to current practices. In 1999, these same watersheds were re-instrumented to evaluate the water quality effects of intensive silviculture using modern BMPs. Three years of pre-treatment data were collected to calibrate the watersheds. During the calibration phase, in June 2001, Tropical Storm Allison struck southeastern Texas, dumping almost 11.8 cm of rainfall on saturated soils in about 3 hours. This single storm event resulted in over 73% of the annual flow and over 95% of the annual sediment for 2001. In a little over three hours, the watersheds clearcut and chopped in 1980 generated over 2.5 times more sediment that the entire year following harvest and site-preparation. Comparisons of data from the 1979 Alto Watershed study with pre-treatment data from the current study suggest that these watersheds have a high potential for geologic erosion even with mature forest cover. Large natural variation in runoff and sediment makes it difficult to detect treatment effects for these forested watersheds.

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Keywords: stream flow, water quality, sediment, silviculture, non-point source pollution, best management practices

Introduction

Concerns exist in the public policy arena about the potential effects of silvicultural non-point source pollution on water quality (USEPA 2000). Forested watersheds are generally associated with better water quality than waters draining watersheds of other major land uses (USEPA 1995). However, forest practices such as harvesting may temporarily increase sediment losses from harvested areas (Beasley et al. 2000). Detecting the impacts of forest practices on water quality is complicated by great spatial and temporal variability in runoff from forested watersheds. For example, stream sediment losses from undisturbed forested watersheds in the South are reported to range from a trace up to 717 kg/ha/yr (Yoho 1980).

During the 1970s and 1980s, a series of watershed studies were conduced to measure the effects of forest practices in the mid-South on non-point source pollution (Beasley 1979, Blackburn et al. 1986, Miller et al. 1988, Ursic 1986). A common forest practice at that time involved clearcutting naturally regenerated, mature, mixed pine-hardwood stands and replanting with genetically improved loblolly pine (*Pinus taeda*). Harvest efficiency (wood utilization) was not as high as today, with less topwood and poorer species utilization. As a consequence, management of large quantities of residual logging slash required mechanically intensive site preparation methods such as shearing, windrowing, and burning or roller-chopping and burning to prepare sites for replanting. Furthermore, BMPs at that time did not call for SMZs on many smaller headwater streams, so sites were prepared and planted across these streams.

Stands regenerated in the 1970s and early 1980s are now being harvested. Clearcutting of these stands results in very little residual logging slash due to better harvest efficiency and stand homogeneity. Therefore, mechanical treatments such as shearing and windrowing are used less extensively. Contemporary practices involve increased use of herbicides and fertilizers. BMPs now include SMZs on intermittent and many ephemeral streams, and these types of BMPs have been shown to effectively reduce silvicultural impacts on water quality (Lynch and Corbett 1990, Arthur et al. 1988). Williams et al. (1999) reported a ten-fold decrease in sediment from logging with BMPs when compared to logging without BMPs. According to Carraway et al. (2002), BMPs were voluntarily implemented on about 91.5% of silvicultural operations in Texas.

The Texas Intensive Silviculture Study (TexIS) was initiated in 1999 to evaluate the effects of contemporary silvicultural practices on water quality in small headwater catchments. Nine small (~2.5 ha) watersheds that were studied by Blackburn et al. (1986) were re-instrumented. This affords a unique opportunity to contrast water quality effects of contemporary intensive forest practices with practices from two decades ago.

This paper will examine the water yields and sediment losses measured from 1999 through 2001 on these forested watersheds. Comparisons will be made with data collected from 1980 through 1985 on these watersheds following clearcut harvesting and site preparation. An extreme hydrologic event, Tropical Storm Allison, will also be examined and an overall comparison with pre-and post-harvest conditions will be conducted.

The Alto Experimental Watersheds

Nine small watersheds (2.57 to 2.72 ha) in the Neches River Watershed, about 16 km west of Alto in southwest Cherokee County in East Texas, are used in this study. This area has a humid, sub-tropical climate with hot summers and cool winters. The average annual rainfall of 117 cm is fairly evenly distributed throughout the year, with April and May receiving a little more rainfall than other months. Topography is dominated by rolling hills, with watershed elevations ranging from 90 to 131 m and watershed slopes ranging from 4 to 25%. Mean channel slopes are about 19%, indicative of ephemeral or intermittent headwater reaches. Soils developed under mixed loblolly pine and hardwood forests from marine sediments of the Queen City Sand of the Eocene Epoch. Soils tend to be light-colored, well-drained, erodible, and generally have low fertility. Cuthbert and Kirvin soils (clayey, mixed, thermic typic Hapludults) compose about 78% of the watersheds.

Fully-stocked, unthinned loblolly pine plantations planted in 1981 dominated 6 of the 9 watersheds. The other 3 had younger plantations. Watersheds had full canopy closure with almost 100% soil coverage by forest vegetation and forest litter layers.

The original study reported by Blackburn et al. (1986) employed a randomized block design, with three watersheds being clearcut with shear, windrow and burn site-preparation (SW1, 2, 3), three being clearcut with roller-chop and burn site-preparation (SW5, 7, 9), and three serving as controls (SW4, 6, 8). The six treatment watersheds were clearcut in the summer of 1980, with site-preparation and planting occurring that same year. Measurement of stream flow and sediment continued until 1985, after which these watersheds were decommissioned.

In 1998, these same watersheds were re-instrumented. The concrete approach sections that were constructed on these watersheds in 1979 were refitted with 3-foot H-flumes. Stage recorders were installed, along with Coshocton wheel samplers. Stage is measured with a potentiometric float and pulley level recorder in the stilling well at the sidewall of the flume. A datalogger stores stage measurements in 5-minute intervals and initiates an ISCO autosampler during storm-runoff events. Water samples are collected with a 3-foot float arm, with the sampler intake at its midpoint. This allows for sample collection at 0.5 stream depth regardless of stage. Samples are taken at approximately a 30-minute interval during runoff events to represent the phases of the storm hydrograph. Samples are pumped into 1-L polypropylene bottles.

Samples are collected and taken to the laboratory immediately after each event for analysis of suspended solids using the gravimetric method. Immediately upstream of the concrete approach section is a sediment trap. Bed-load deposited in the sediment trap is collected and dry-weight determinations of bed-load are made after storm events as well. Total sediment loss is suspended sediment concentration from each ISCO sample bottle or composite (mg/L) times total flow for the representative time interval (L) plus bed-load (kg). This value is then divided by watershed area (ha) to get kg/ha of sediment loss. Sediment data were not available for part of one event on 01/29/1999, so sediment concentrations were estimated using regression with streamflow. Total rainfall is measured with a series of National Weather Service standard 8-inch non-recording rain gauges at each watershed, and tipping-bucket recording rain gauges are used for determining storm intensity and duration.

Annual Runoff

Precipitation

In the original Alto Watershed study, the pre-treatment year (1980) was an abnormally dry with only 79.1 cm of precipitation, almost 38 cm less than average (Blackburn et al. 1986). The first post-treatment year was wetter than average, with 129.8 cm, almost 13 cm greater than average. The next 3 years annual precipitation was close to average.

In the current watershed study, during the first year of the pre-treatment period, 1999, only 82.6 cm of rainfall were recorded, or 34.4 cm less that the long-term average (Table 1). The year 2000 was wetter; though most of the storms were low-intensity, long-duration events, resulting in little runoff. The year 2001 was very wet, with 170.6 cm of precipitation, or 53.6 cm greater than average.

Water yield

Water yield in these headwater streams is dominated by storm runoff, with baseflow making only a minor contribution to total annual water yield. Most runoff tends to occur during the winter and spring, when antecedent soil moisture is highest due to low evapotranspiration demand. Watershed runoff efficiencies tend to be low, with most precipitation being retained by vegetation and soils.

Prior to treatment in 1980, Blackburn et al. (1986) reported about 2.2 to 6.1 cm of runoff from these watersheds. 1980 was an abnormally dry year, with annual runoff efficiencies ranging from 4.1 to 5.6%. After treatment, first-year stormflow was greater from sheared (14.6 cm, or 11.2% of rainfall) than chopped (8.3 cm, or 6.4% of rainfall) or control (2.6 cm, or 2.0% of rainfall) watersheds. Streamflow returned to pretreatment levels by the third year after harvest.

Annual water yields measured in 1999 to 2001 tended to be comparable to those measured in 1980 (Table 1). Highest water yields were recorded in 2001, the year with the greatest annual rainfall. Rainfall efficiency was below 1% in 1999 and 2000, and between 3 and 5% in 2001. This higher efficiency was due to the effects of an extreme storm event as discussed below.

Table 1. Mean pretreatment rainfall, runoff, sediment loss, and flow-weighted sediment concentration by year and for Tropical Storm Allison by watershed treatment block* for the Alto Watersheds.

Block	Year	Rainfall (cm)	Runoff (cm)	Sed Loss (kg/ha)	Flow-weight conc. (mg/L)
Shear Block	1980	79.12	3.31	115.33	348.4
	1999	82.60	3.28	85.2	161.4
	2000	126.29	0.99	3.5	32.1
	2001	170.64	9.24	293.0	257.9
	Allison	11.81	6.44	277.7	349.3
Chop Block	1980	79.12	4.42	28.66	64.8
	1999	82.60	2.49	26.4	40.6
	2000	126.29	0.53	0.2	4.5
	2001	170.64	6.46	67.3	72.8
	Allison	11.81	4.66	66.4	98.4
Cntrl Block	1980	79.12	3.45	62.19	180.3
	1999	82.60	2.95	52.2	92.7
	2000	126.29	0.64	1.0	14.9
	2001	170.64	7.10	241.8	260.5
	Allison	11.81	5.81	227.0	288.4

* Watersheds are blocked by Blackburn et al. (1986) treatments; shear/pile windrow burn = SW1, 2, 3; roller chop and burn = SW5, 7, 9; control = SW4, 6, 8.

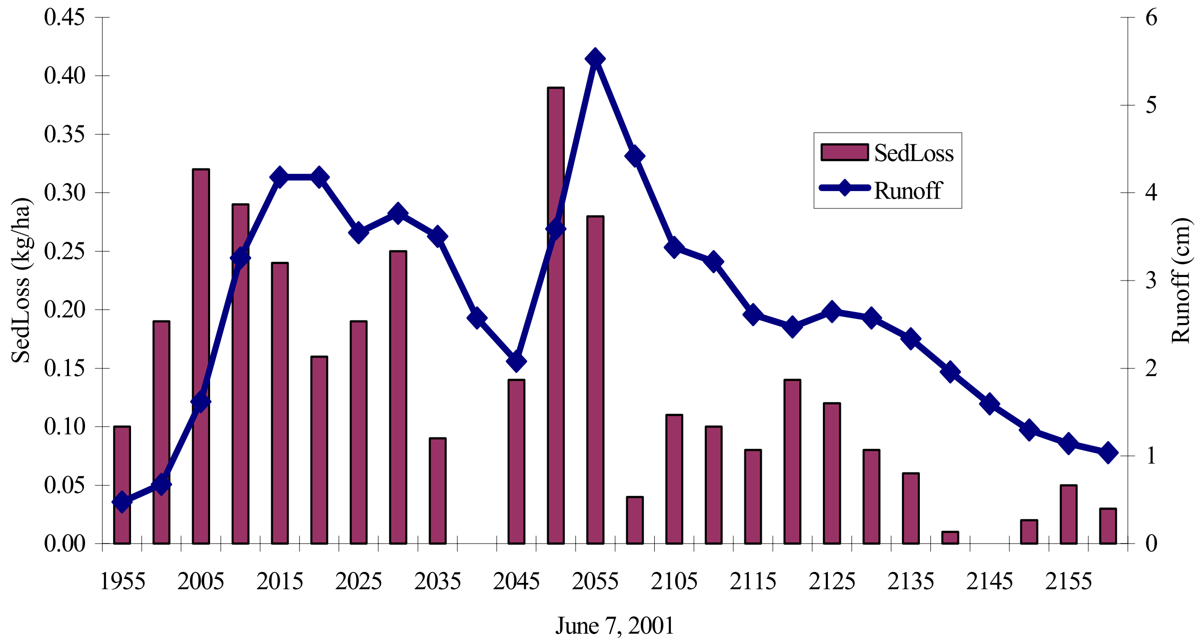

Figure 1. Runoff and sediment losses for small watershed 2 for Tropical Storm Allison for the period of most intense rainfall on 06/07/2001 (total rainfall = 16.3 cm) for the Alto Watersheds.

Sediment losses

Total sediment loss

Prior to the first commercial clearcut of these watersheds in 1980, sediment losses ranged from 55 to 530 kg/ha/yr. Pre-treatment sediment loss rates at Alto are higher than those measured in some other studies in the southeast following harvest. For example, Miller et al. (1988) reported mean first-year sediment losses of 237 kg/ha after clearcutting and site preparation in the Ouachita Mountains. In the Gulf Coastal Plain, streambeds and banks are comprised mostly of deposited sediments causing stream channels to be more susceptible to erosion.

After treatment, Blackburn et al. (1986) measured the highest first-year sediment loss rates yet reported in the western Gulf Coastal Plain, with 2,937 kg/ha/yr on the sheared and windrowed watersheds, 25 kg/ha/yr on the roller-chopped, and 33 kg/ha/yr on control watersheds. Clearcutting followed by shearing, windrowing, and burning resulted in 56.8% bare soil, thus increasing overland flow and erosion potential. For comparison, roller chop site-preparation resulted in only 15.7% bare soil while the control watersheds had 3.3% bare soil.

In the current study, annual sediment losses varied during the three pre-treatment years depending on precipitation (Table 1). As discussed below, extreme storm events were the controlling factor for total annual sediment yield. Pre-treatment sediment losses measured in the current study were comparable to those reported by Blackburn et al. (1986). Pre-treatment loss rates were nonetheless higher in 1980 on watersheds 2 (514 kg/ha) and 3 (313 kg/ha) than those reported by Miller et al. (1988) with 237 kg/ha and Beasley and Granillo (1988) with 264 kg/ha after clearcutting and site-preparation.

Sediment loss timing

Blackburn et al. (1986) measured the greatest sediment concentrations during the peak phase of the hydrograph, and the same was generally true for this study. For larger events, when more bottles were analyzed along the hydrograph, the greatest sediment loss rates were observed at or just prior to the peak of the hydrograph (Figure 1). During periods of higher flow, as streams approach bank-full, more water is in contact with the erodible channel cross-section, resulting in greater sediment loss rates even in undisturbed forested watersheds. Also, stream velocities are highest during this phase of the storm event, increasing the energy available for sediment detachment and transport from channels.

Unusual Storm Events

In the first Alto study, one relatively large storm event on 05/15/1980 produced most of the sediment loss and stream flow for the pre-treatment year. This single event (8.2 cm rainfall) resulted in 96 to 99% of the total annual pre-treatment sediment loss and 59 to 79% of the total annual streamflow. About 7.3 cm of rain fell during the 3 days prior to this event, saturating soils. Based on the 94-year precipitation record at Nacogdoches, Texas, located approximately 64 km east of the study site, this 1-day event would have about a 2-year return period (Chang et al. 1996).

The largest pre-treatment storm event for the current study was Tropical Storm Allison, which produced almost 30 cm of rain over a 3-day period from 06/05/2001 through 06/07/2001. Almost 10 cm of rain fell up to 06/07/2001, saturating soils, and during late afternoon of 06/07, 11.8 cm of rainfall fell over a 4-hour period with a maximum 1-hour intensity of 6.55 cm. This 3-day storm event had over a 100-year return period, with a maximum 1-day return period of about 20 years.

Tropical Storm Allison resulted in 71 to 76% of the annual streamflow and 92 to 98% of the total annual sediment loss for 2001 (Table 2). Allison resulted in more sediment loss than occurred in the entire post-treatment year for the clearcut and roller-chopped watersheds in 1981 and for the second-year losses for the sheared watersheds in 1982. Other studies in the Southeast have found that single storms often account for the majority of total annual sediment loss (Beasley 1979, Beasley 1984). Similarly, for the current study, a single storm on 01/28/1999 with about a 10-year 1-day return period resulted in over 95% of the total annual sediment loss (Table 2). In 2000, precipitation was more evenly distributed, yet about one-quarter to one-half of the annual sediment loss occurred as a result of a runoff event on 05/04/2000. This rainfall event had less than a 2-year 1-day return interval.

Discussion and Conclusions

The reactivated Texas Alto Watershed Study provides a unique opportunity to evaluate effects of contemporary silvicultural practices on water quality. Results from the calibration phase of the current study are consistent with pre-treatment results from the original Alto study in 1980, indicating that these watersheds have recovered from harvesting and site-preparation. Blackburn et al. (1986) found that treatment effects were greatly diminished by the second post-harvest year. Vegetative regrowth is rapid in the southeastern United States due to warm temperatures and evenly distributed annual rainfall, resulting in shorter recovery times than are observed in cooler, dryer regions. Storm flows and sediment losses from undisturbed watersheds were low, though losses at Alto were higher than those reported in other studies following harvest and site-preparation. Overland flow is rarely observed in these watersheds, with flow responses most likely dominated by subsurface macro-channel flow and variable source areas (Beasley 1976).

Table 2. Percentage of annual flow and sediment loss accounted for by the largest storm event in each pretreatment year by watershed treatment block* for the Alto Watersheds.

Watershed	Year	% Annual Rainfall	% Annual Runoff	% Annual Sed Loss
	1999	15.2	97.1	98.2
Shear	2000	7.9	27.0	56.9
Block	2001	6.9	70.8	94.1
	1999	11.9	92.4	95.3
Chop	2000	3.5	49.1	38.9
Block	2001	6.9	75.5	98.5
	1999	15.2	96.9	98.8
Cntrl	2000	4.8	37.2	26.9
Block	2001	6.9	73.4	92.0

* Watersheds are blocked by Blackburn et al. (1986) treatments; shear/pile windrow burn = SW1, 2, 3; roller chop and burn = SW5, 7, 9; control = SW4, 6, 8.

Most annual runoff and sediment loss results from a few larger events that occur during periods when soils are near saturation. Such storms may have a fairly high probability of occurrence, as was the case on May 15, 1980 when a 2-year 1-day storm generated 96 to 99% of the annual runoff on these watersheds. For the current study, a 10-year 1-day storm on January 28, 1999 resulted in over 90% of the annual sediment loss. Tropical Storm Allison had about a 20-year 1-day return period, and resulted in more sediment loss than was observed for the entire year after clearcutting and roller-chop site preparation on these same watersheds in 1981.

Since there is no evidence of sheet-flow, head-cutting, or gullying in these watersheds, it is reasonable to conclude that elevated sediment loss rates for forested watersheds results from erosion of channels that are incised into erodible marine sediments. Little rock- armoring is present, leaving channels exposed to erosive forces. Rock cover in streams can be a factor that reduces sediment loss rates in streams draining forested watersheds (Beasley et al. 2000). Increased flow rates result in increased channel erosion and thus higher sediment concentrations in stormflow.

Great variability is observed in runoff and sediment loss rates in these forested watersheds. These data from undisturbed watersheds highlights the need for non-point source pollution assessment and management strategies that reflect the temporal and spatial variability inherent in nature.

Acknowledgments

The authors appreciate the reviews of Don Turton and Jami Nettles. This research was funded in part by Temple-Inland Inc. and National Council for Air and Stream Improvement. Special appreciation is given to Temple-Inland for location of the study site and assistance with watershed instrumentation and treatments.

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