


EVALUATING THE EFFECTIVENESS OF TEXAS FORESTRY BEST MANAGEMENT PRACTICES

Results from the Texas Silvicultural
BMP Effectiveness Monitoring Project
2003-2007

TEXAS FOREST SERVICE
A Member of the Texas A&M University System

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By

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EXECUTIVE SUMMARY

Four perennial streams on intensively managed silvicultural sites in East Texas were monitored from September 2003 until September 2007 to evaluate the effectiveness of Texas forestry Best Management Practices (BMPs) in protecting water quality. This was done to test the hypothesis that forestry operations, using properly applied BMPs, would not have a significant impact on water quality.

This project followed the BACI study design. Reference and test sections were established upstream and downstream of the treatment area, respectively. Biological (benthic macroinvertebrates, fish, and habitat) and physiochemical (grab and stormwater) monitoring was conducted on these sections for one year prior to the treatment (regeneration harvest, site preparation, and reforestation) to obtain a baseline. Data collection continued for three years after the initial treatment. Treatments were conducted in accordance with the state recommended BMP guidelines.

Weather conditions varied over the course of the project from extremely wet to extremely dry. Average rainfall for this area is approximately 46 inches. In 2004, the project sites received almost 70 inches of rain, while only 32 inches of rain fell in 2005.

Statistical analyses (ANOVA) were conducted to test for significant differences among the project results at each section (upstream vs. downstream), time period (pre- vs. post-treatment), and their interaction (section vs. time period). The interaction analysis was used to determine if a treatment effect had occurred at $\alpha = 0.05$. The physiochemical data showed no significant differences in the interaction analysis. The biological data showed significant differences in habitat results at two sites (Cherokee and San Augustine) and in fish results at one site (Houston). In all three cases, the post-treatment section/period interaction was higher than its pre-treatment counterpart, indicating the treatment had no negative effect on these parameters. Therefore, this project showed that BMPs, when applied properly, are effective in protecting water quality during forestry operations.

INTRODUCTION

Forestry BMPs have been developed and implemented for almost 20 years in Texas. Texas Forest Service promotes these practices and monitors their implementation. Published reports have shown that these guidelines have been embraced by the forestry community, noting significant improvement in BMP implementation rates over the years to the current all time high of 91.7% (Simpson et al., 2005). However, this approach only addresses the presence and functionality of BMPs, not their actual effectiveness in protecting water quality. A controlled, holistic stream biological and physiochemical monitoring approach would be critical to determine the effectiveness of Texas forestry BMPs.

Numerous studies have been conducted in the South to determine the effects of specific forest practices on water quality, both with and without the use of BMPs (Jackson et al., 2004). Similar studies designed to look at more of a holistic approach of the entire operation are not as common. There has only been one project to take the latter approach (Vowell, 2000). However, it was not conducted under the conditions found in the Western Gulf region, and only included a biological monitoring component.

Monitoring BMP effectiveness is also mandated by federal law. The reauthorization of the Clean Water Act (CWA) of 1987 required that "states develop methods for determining BMP effectiveness," something Texas has not done for its forestry BMP guidelines.

The Texas BMP Effectiveness Monitoring Project, funded by a FY03 CWA Section 319(h) grant from the Environmental Protection Agency (EPA) through the Texas State Soil and Water Conservation Board (TSSWCB), was designed to determine the effectiveness of BMPs in reducing nonpoint source (NPS) pollution from silvicultural activities. This report documents the findings of this monitoring project.

SELECTION OF PROJECT SITES

The site selection criteria that were used for this project were extremely restrictive. Project sites had to be under intensive, operational forest management and adjacent to perennial streams. These streams had to originate on and flow through commercial timberlands, as well as have comparable fluvial conditions above and below the proposed treatment area. This limited the effects any non-silvicultural activities (poultry, cattle, agriculture, construction, urban, etc.) could have on the project, facilitated a clearer analysis of the project results, and provided additional quality assurance/control.

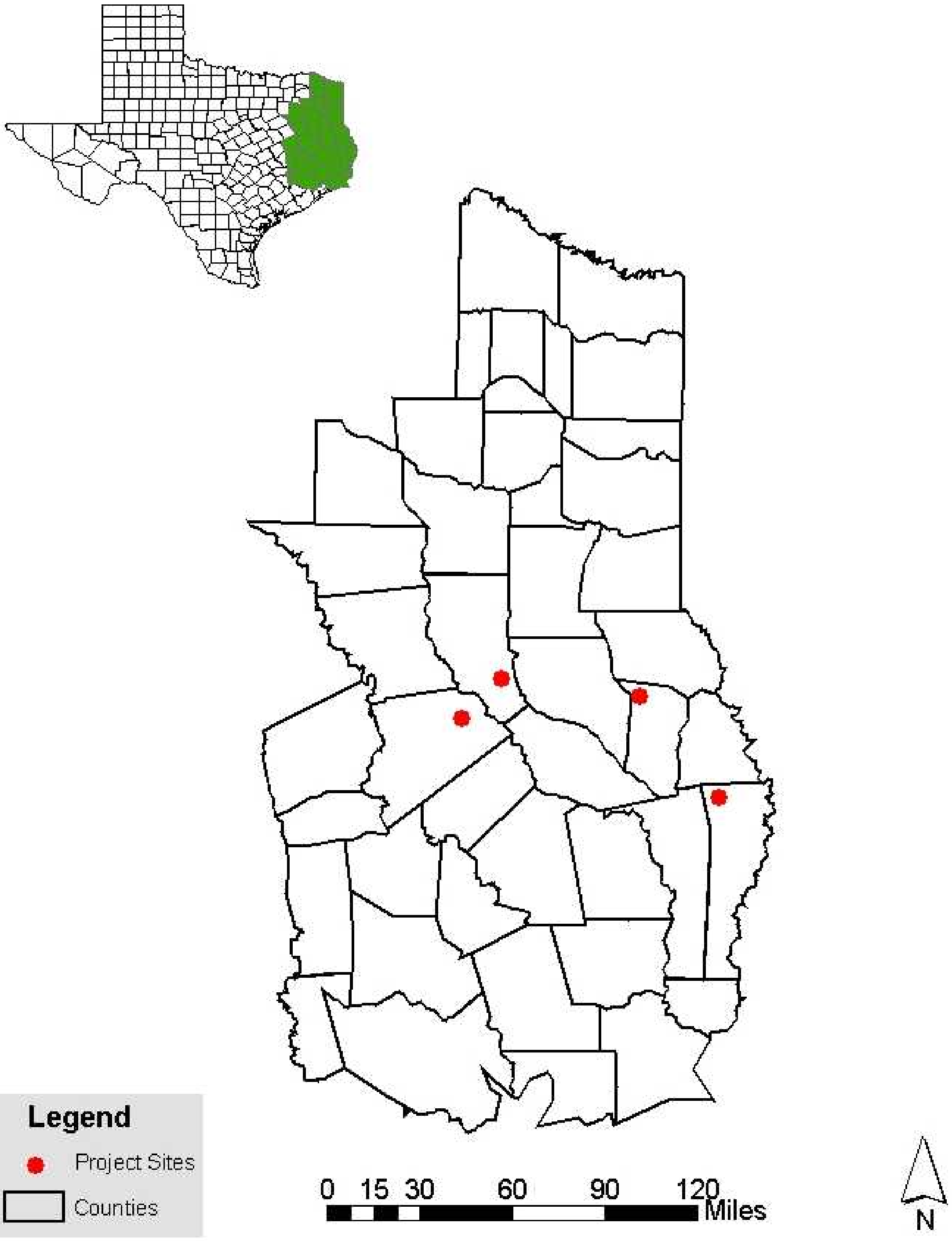
Sites were also selected to include significant topography and erodibility. These conditions were chosen on the basis that if BMPs can protect water quality on these “worst case scenario” tracts, then they should be able to protect water quality on other East Texas tracts with less severe topography and erodibility. Finally, to facilitate data collection, the sites had to be located within an hour’s drive of Lufkin, Texas, and scheduled for harvest in 2004 through 2005.

STREAMS

Second and third order perennial streams were selected for this project in order to facilitate biological monitoring, mainly fish assemblages. Watersheds ranged in size from 500 to 2300 acres.

Four sites were selected: Walker Creek in Cherokee County, Johnson Creek in Houston County, East Prong of McKim Creek in Newton County, and an unnamed creek in San Augustine County. See Figure 1.

Figure 1. Location of project sites.



SITE LAYOUT

Project sites were divided into two sections. The reference was located upstream of the treatment area and the test was located downstream of the treatment area. Five, evenly spaced stream transects, 125 feet apart, were established at each section, and constituted the monitoring reach (500 feet) for the biological assessment. Monitoring stations, consisting of an automatic water sampler and flow meter housed in a metal box, were installed at each section along the monitoring reach of the project sites. A standard National Weather Service rain gauge and a tipping bucket rain gauge were installed at each site to obtain precipitation data. The standard gauge measured the total precipitation, while the tipping bucket recorded start/stop time and intensity. The treatment area encompassed up to 25% of the watershed. See Figures 2 and 3.

Figure 2. Typical project site layout.

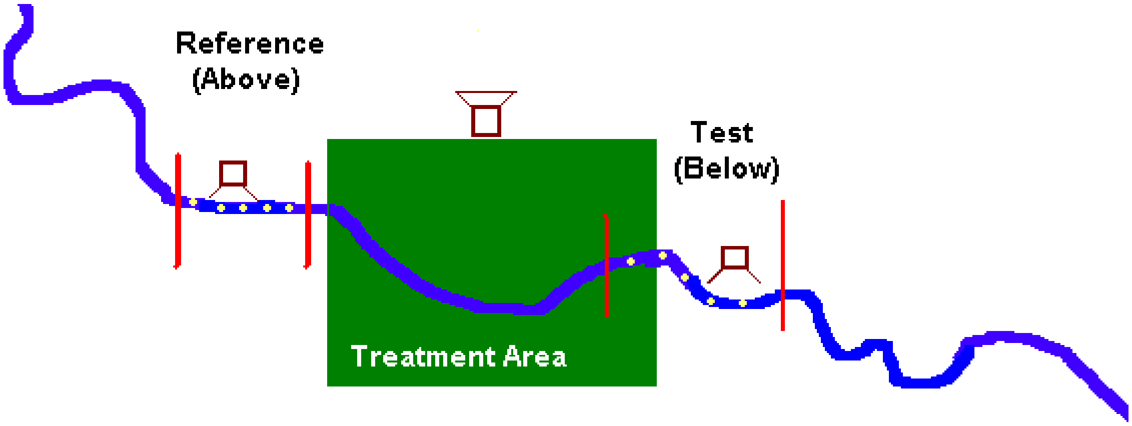
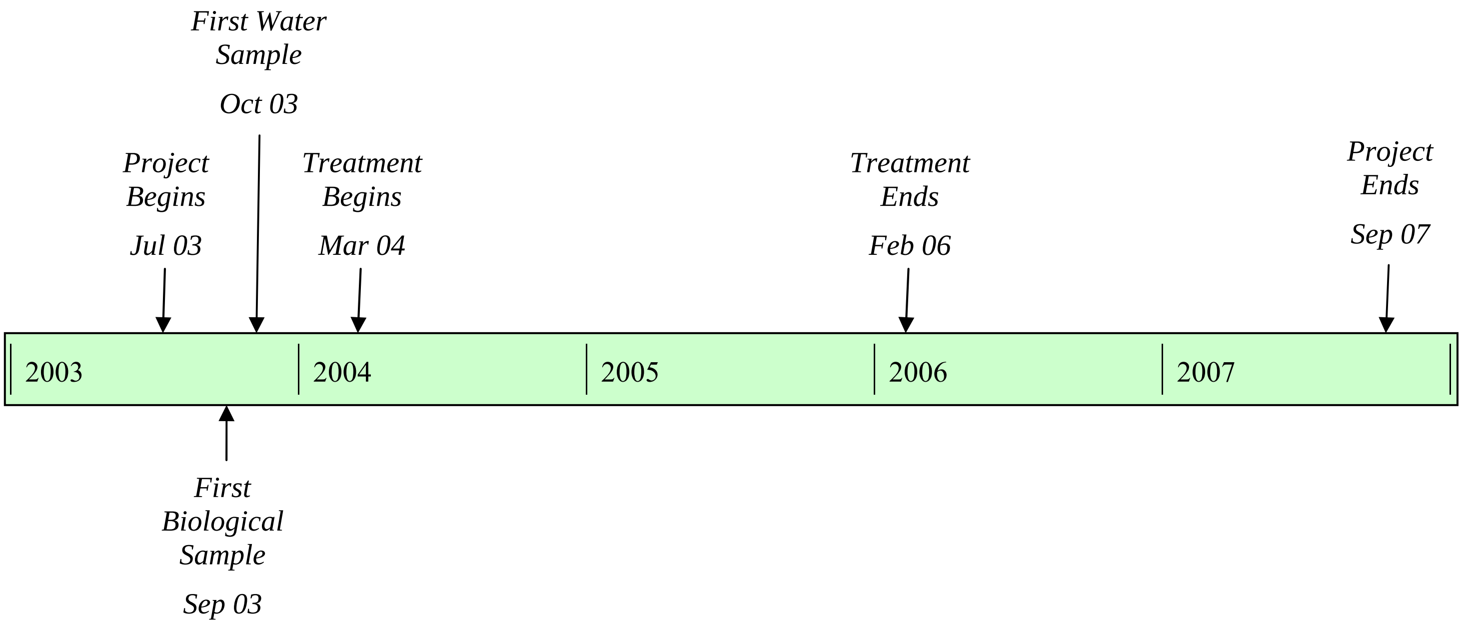


Figure 3. Monitoring station and rain gauges.

SCHEDULE

The project began in July 2003 and was completed in September 2007. Biological sampling was conducted twice a year, during spring (April – May) and late summer (August – September). Grab samples were collected monthly, while stormwater samples were collected based on weather (approximately 40 times per year). Treatments began in March 2004 and concluded in February 2006. See Figure 4.

Figure 4. Project timeline.



TREATMENTS

Operational treatments were conducted at all sites in accordance with state recommended BMPs. Project sites underwent a commercial timber harvest, site preparation, and machine planting of loblolly pine. All harvest contractors were trained in BMPs and had a current “Pro Logger” certificate.

SAMPLING PARAMETERS

Grab samples were monitored for the following parameters: dissolved oxygen (DO), potential hydrogen (pH), specific conductance, total nitrogen (TN), total phosphorous (TP), total suspended solids (TSS), turbidity, water temperature, and stream flow. Stormwater samples were monitored for the following parameters: TN, TP, TSS, and turbidity. Biological monitoring consisted of a habitat assessment, benthic macroinvertebrate sampling, and fish sample collection. See Table 1.

Table 1. Summary of biological and physiochemical sampling parameters.

Parameter	Biological	Grab	Stormwater
Dissolved Oxygen		X	
pH		X	
Specific Conductivity		X	
Temperature		X	
Stream Flow		X	
Total Nitrogen		X	X
Total Phosphorous		X	X
Total Suspended Solids		X	X
Turbidity		X	X
Rainfall Amount			X
Rainfall Intensity			X
Benthic Macroinvertebrates	X		
Fish	X		
Habitat	X		

SAMPLING METHODS / DATA COLLECTION

Sampling methods were conducted in accordance with the protocols established by the Texas Commission on Environmental Quality (TCEQ) in *Surface Water Quality Monitoring Procedures*, Volumes 1 and 2. Test sections were always monitored before reference sections to prevent contamination of downstream water quality samples. Appropriate scientific collection permits from Texas Parks and Wildlife Department (TPWD) were obtained prior to biological sampling. Data from the monitoring stations and rain gauges were downloaded monthly to a laptop.

Biological Monitoring – Benthic Macroinvertebrates

A D-frame kick net was used to collect benthic macroinvertebrates along the monitoring reach. This net was swept across the stream bed along riffles, runs, and glides to dislodge organisms. After "sweeping" for five minutes, the contents of the net were emptied into a dishpan. Benthic macroinvertebrates were then removed using forceps and placed in a collection jar with 70% isopropyl alcohol. Sampling continued, keeping record of the number of "sweeps" that were made, until 100 individual macroinvertebrates were collected. Organisms were also collected from submerged leaf and twig samples. Crawfish were counted and released. Samples were then labeled and sent to a taxonomist for identification and enumeration. See Figure 5.

Figure 5. Sampling for benthic macroinvertebrates.

Biological Monitoring – Fish

A backpack electrofisher, operated by a TPWD fisheries biologist, was used to sample fish species. This equipment emits an electrical current in the water, temporarily stunning fish and causing them to float to the surface so they can be collected. This was done for a minimum of 15 minutes, or longer if new species were still being collected, starting from the bottom of the monitoring reach and working upstream.

A seine was also used because of its effectiveness in collecting smaller fish in riffles and deep pools that may have been missed by the electrofisher. This large net was stretched across the water and pulled upstream parallel to the bank, ensuring that the lead line remained firmly on the stream bottom. This process was continued until a minimum of six effective hauls were completed along the monitoring reach, covering a minimum of 60 meters. See Figure 6.

Fish samples were separated based on the collection method employed. The TPWD fisheries biologist field identified the samples, releasing any known specimens into the stream after monitoring was completed. Results were reported on the appropriate biological monitoring form.

Two representative samples of each species per site and monitoring period were reserved for reference. Digital photographs were taken as reference vouchers in some cases. Any samples that were not easily field identified, along with reference samples, were preserved in a 90% formalin solution and returned to the lab for identification.

Figure 6. Collecting fish specimens.

Biological Monitoring – Habitat Assessment

General physical characteristics of the stream along the entire monitoring reach were determined from field observations. Direct measurements were also taken at each of the five stream transects and in the area extending three meters on either side of the transect line. Data collected from these observations and measurements were reported on the habitat assessment form to calculate the Habitat Quality Index. See Figure 7.

Figure 7. Conducting habitat assessment.

Physiochemical Monitoring – Grab Water Samples

Grab samples were collected immediately upstream of monitoring stations at each section on a monthly basis. Water was collected from the stream and placed in pre-preserved sample bottles for analysis of TN, TP, and TSS. A duplicate sample was collected at a different site each month for quality control purposes. Bottles were labeled and placed on ice until delivered to the contract lab, ensuring all holding times were met.

Turbidity was measured using a portable turbidity meter. Water was collected from the stream and allowed to reach ambient air temperature before placing it in the meter for analysis. Water temperature, pH, specific conductivity, and dissolved oxygen were measured *in-situ* with a Hydrolab multiprobe datasonde.

Stream flow was measured using a Marsh-McBirney portable flowmeter at designated areas located near the monitoring station for each section. Velocity and depth measurements were taken at regular intervals across the stream cross section. Average velocity and cross sectional area were then used to calculate stream flow. All physiochemical data was recorded on the water quality monitoring data sheet.

Physiochemical Monitoring – Stormwater Samples

Flow-weighted composite stormwater samples were collected from monitoring stations. An ISCO 4230 bubbler flowmeter was used to measure stage (flow depth) continuously at 15-minute intervals. A stage-discharge relationship was established at each site by measuring flow rate (discharge) using the Marsh-McBirney flowmeter at a variety of stages. This information was programmed into the bubbler flowmeter, allowing constant flow rate and volume measurements to be taken on the project streams. Upon detecting a 0.3 foot rise in stream level, the bubbler flowmeter activated the ISCO 3700 water sampler. Samples were automatically collected at one millimeter intervals (volumetric depth based on runoff from the watershed) while the bubbler flowmeter was enabled.

Water was retrieved from the sampler, measured, and placed in pre-preserved sample bottles for analysis of TN, TP, and TSS. First priority was given to TSS, TP, and then TN when minimum sample analysis volumes were not met. Turbidity was measured on any remaining sample volume. Bottles were labeled and placed on ice until delivered to the contract lab, ensuring all holding times were met.

DATA ANALYSIS

Biological metrics (see Table 2) were used to calculate the Aquatic Life Use (ALU) and Habitat Quality Index (HQI) for each section based on the protocols established by TCEQ in *Surface Water Quality Monitoring Procedures*, Volume 2. Metrics were assigned a numerical value based on where they scored in a given range. The individual values were summed to obtain a total score for each section, which related to a general ALU or HQI (Exceptional, High, Intermediate, or Limited).

Physiochemical parameters measured *in-situ*, along with grab sample concentrations, were analyzed to establish baseflow conditions before and after silvicultural treatments. Non-detectable laboratory results were assigned a value equal to one half of the method detection limit. Precipitation and streamflow relationships were also developed to determine possible treatment effects. Stormwater sample concentrations were converted to loads (kg/ha) for analysis. This was done by multiplying the storm event flow volume by the sample concentration and dividing by the watershed area. Correlations between TSS and turbidity were also analyzed. Annual sediment and nutrient losses for the project sites were computed.

Statistical analyses (ANOVA) were conducted to test for significant differences among the project results at each section (upstream vs. downstream), time period (pre- vs. post-treatment), and their interaction (section vs. time period) at $\alpha = 0.05$. The interaction analysis was used to determine if a treatment effect had occurred.

Table 2. Summary of biological metrics.

Benthic Macroinvertebrates	Fish	Habitat
Taxa richness	Total # of species	Available instream cover
EPT taxa abundance	# of Native cyprinid species	Bottom substrate stability
Biotic Index (HBI)	# of Benthic invertivore species	# of Riffles
% Chironomidae	# of Sunfish species	Dimensions of largest pool
% Dominant taxon	# of Intolerant species	Channel flow status
% Dominant FFG	% of Individuals as tolerant	Bank stability
% Predators	% of Individuals as omnivores	Channel sinuosity
Ratio of intolerant to tolerant taxa	% of Individuals as invertivores	Riparian buffer vegetation
% of Trichoptera as Hydropsychidae	% of Individuals as piscivores	Aesthetics of reach
# of Non-insect taxa	# of Individuals in sample	
% Collector/Gatherers	# of Individuals/seine haul	
% of Total as Elmidae	# of Individuals/min. electrofishing	
	% Individuals non-native	
	% Individuals with disease	

RESULTS AND DISCUSSION

Over the course of the project, nine biological assessments were conducted at each section (three pre-treatment, six post-treatment); grab samples were taken once a month at each section for 47 months; and stormwater samples were collected on 139 dates where needed.

Biological Monitoring – Benthic Macroinvertebrates

Project streams proved to be extremely diverse in benthic macroinvertebrate populations, with 115 different species being collected, 31 of which were found at all sites. Common species included damsel/dragonflies, mayflies, caddisflies, water beetles, midges, and crawfish. The majority of organisms collected were in the Ephemeroptera and Odonata orders, while the predominant functional feeding group (FFG) was predator. The least common order and functional feeding group was Diptera and shredder, respectively.

ALU scores ranged from 18 (Limited) to 36 (High), with most falling in the Intermediate to High classification. Mean post-treatment results decreased at all but one section (San Augustine upstream). Statistical analysis showed these section/period interaction declines were not significant. A potential cause may be linked to the weather. In 2004 (pre-treatment), East Texas experienced one of the wettest years on record, while 2005 (post-treatment) was one of the driest, even with Hurricane Rita dropping 10 inches of rain on some of the project sites. This weather pattern began in March 2005 and at some sites lasted until field data collection ended in September 2007. Droughty, low flow stream conditions are not conducive to benthic macroinvertebrate survival and reproduction (Wiseman and Matthews, 2000).

Several individual metrics played integral roles in determining the resulting ALU score. The percent of predators and percent of Trichoptera as Hydropsychidae consistently provided lower scores than other metrics, while the percent of Elmidae scored higher. Trends associated with seasonal and sectional differences were not found. See Tables 3 and 6 and Figures 8 and 9.

Table 3. Benthic macroinvertebrate Aquatic Life Use scores across all project sites.

Season	Cherokee		Houston		Newton		San Augustine	
	Above	Below	Above	Below	Above	Below	Above	Below
Fall 03	*28*	*28*	*27*	*33*	*27*	*27*	*28*	*30*
Spring 04	*36*	*28*	*25*	*31*	*29*	*30*	*26*	*24*
Fall 04	*32*	*31*	*28*	*27*	*31*	*27*	*30*	*30*
Spring 05	*33*	*32*	*26*	*23*	*28*	*31*	*25*	*29*
Fall 05	*34*	*25*	*27*	*29*	*27*	*25*	*26*	*28*
Spring 06	*29*	*23*	*24*	*32*	*28*	*28*	*31*	*27*
Fall 06	*28*	*18*	*21*	*30*	*20*	*23*	*26*	*26*
Spring 07	*31*	*34*	*23*	*28*	*23*	*20*	*33*	*31*
Fall 07	*27*	*25*	*27*	*25*	*25*	*24*	*33*	*24*

Ratings (per TCEQ): > 36 = Exceptional
29 – 36 = High
22 – 28 = Intermediate
< 22 = Limited

Figure 8. Mean benthic macroinvertebrate Aquatic Life Use scores across all sites.

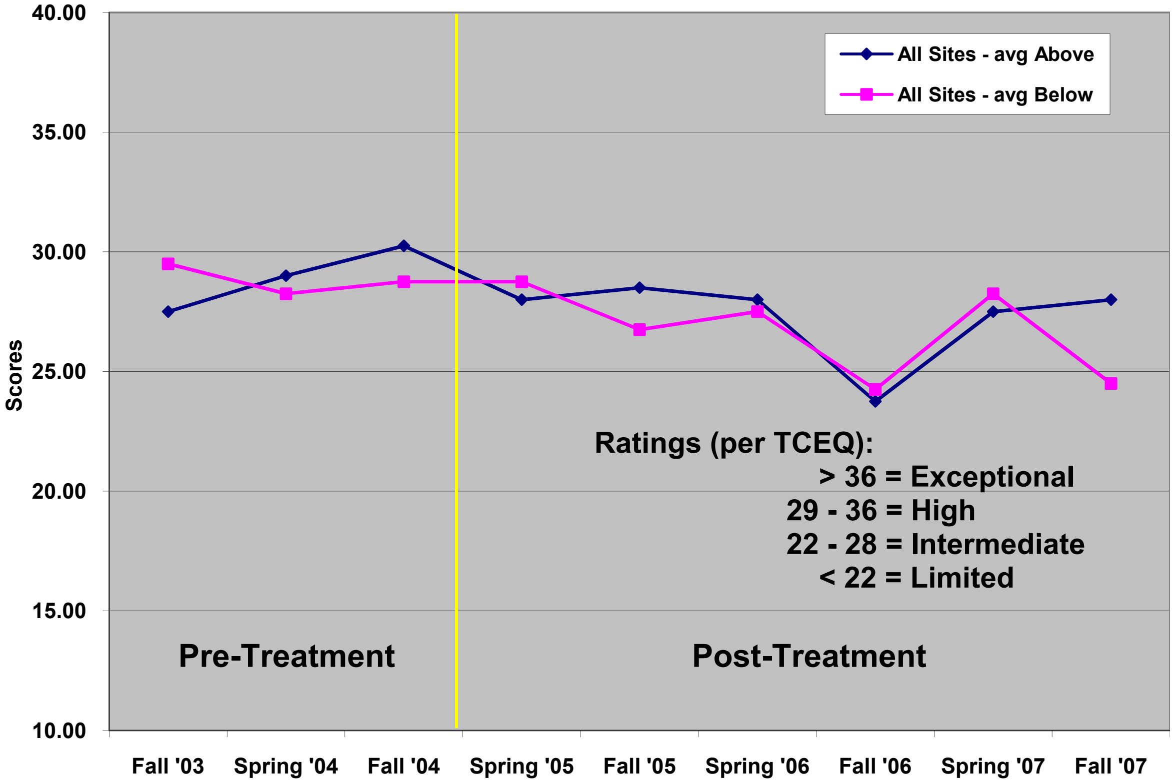


Figure 9. Common benthic macroinvertebrates collected during the project.

Dragonfly larva

Stonefly larva

Mayfly larva

Biological Monitoring – Fish

Project streams also proved to be very diverse in fish populations, with 38 different fish species being sampled, 14 of which were found at all sites. Common species included shiners, chubs, topminnows, darters, sunfish, and lampreys, with the majority being classified as cyprinids (shiners, chubs). The predominant functional feeding group was invertivore (shiners, sunfish, darters), while the least common was omnivore (catfish). Only one percent of all fish sampled were considered tolerant of pollution, most of which (73%) were found in the reference sections of the project sites.

ALU scores ranged from 33 (Limited) to 58 (Exceptional), with most falling in the High classification. Mean post-treatment results increased at all test sections, while decreasing at all but one reference section (Cherokee), indicating that the treatment had no negative effect on fish species. One explanation could be the transient nature of fish over the course of this project. Downstream sections were expected to have higher fish populations due to draining larger watersheds. Statistical analysis indicated the post-treatment section/period interaction was significantly different (higher) than the pre-treatment section/period interaction at the Houston County project site.

Several individual metrics played integral roles in determining the resulting ALU score. The percent of individuals as non-native species and percent of individuals as tolerant species were consistently low, providing a higher score than the other metrics, while the number of sunfish species was usually low, contributing a lower score. There was a slight seasonal trend in fish ALU scores. Five of the eight sections had higher average scores during the late summer sampling period than the spring. See Tables 4 and 6 and Figures 10 and 11.

Table 4. Fish Aquatic Life Use scores across all sites.

Season	**Cherokee**		**Houston**		**Newton**		**San Augustine**	
	Above	**Below**	**Above**	**Below**	**Above**	**Below**	**Above**	**Below**
Fall 03	*44*	*48*	*44*	*48*	*58*	*55*	*45*	*45*
Spring 04	*45*	*49*	*44*	*39*	*51*	*46*	*46*	*49*
Fall 04	*43*	*51*	*41*	*39*	*58*	*54*	*40*	*45*
Spring 05	*46*	*50*	*39*	*51*	*52*	*55*	*47*	*43*
Fall 05	*47*	*51*	*42*	*42*	*49*	*51*	*42*	*48*
Spring 06	*50*	*51*	*40*	*48*	*51*	*55*	*41*	*45*
Fall 06	*47*	*53*	*44*	*48*	*55*	*55*	*43*	*51*
Spring 07	*49*	*47*	*33*	*43*	*50*	*54*	*42*	*43*
Fall 07	*47*	*49*	*40*	*48*	*54*	*52*	*48*	*48*

Ratings (per TCEQ):
≥ 52 = Exceptional
42 – 51 = High
36 – 41 = Intermediate
< 36 = Limited

Figure 10. Mean fish Aquatic Life Use scores across all sites.

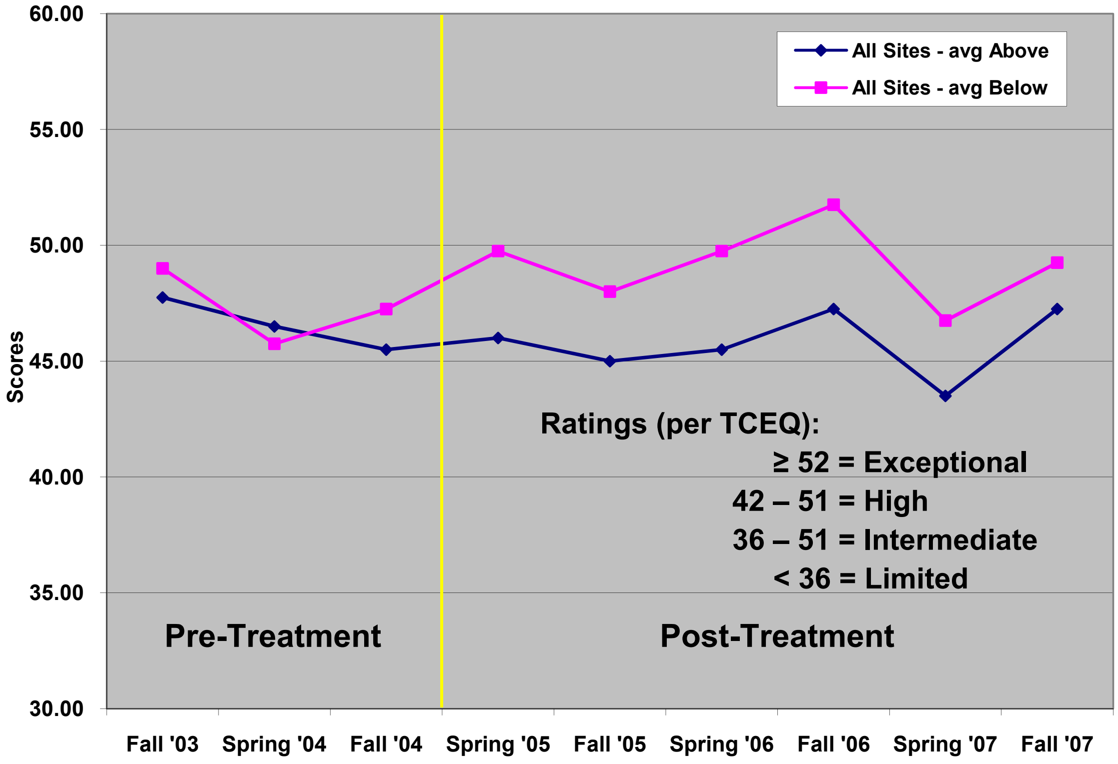


Figure 11. Examples of fish specimens collected.

Longear sunfish

Grass pickerel

Spotted bass

Redfin darter

Biological Monitoring – Habitat Assessment

Project streams generally provided good habitat for biological communities. HQI scores ranged from 16.5 (Intermediate) to 23.5 (High), with most falling in the High classification. Mean post-treatment results increased or remained the same at all sections but one reference (Cherokee), indicating the treatment had no negative effect. Statistical analysis indicated the post-treatment section/period interaction was significantly different (higher) than the pre-treatment section/period interaction at the Cherokee and San Augustine project sites.

Several individual metrics played integral roles in determining the resulting HQI score. The available instream cover consistently scored higher than the other metrics, while bank stability and bottom substrate stability scored lower. A seasonal trend was detected in HQI scores. The spring sampling periods produced higher habitat scores than those in the late summer, primarily because of low flow conditions found during the latter time period. See Tables 5 and 6 and Figure 12.

Table 5. Habitat Quality Index scores across all sites.

Season	**Cherokee**		**Houston**		**Newton**		**San Augustine**	
	Above	**Below**	**Above**	**Below**	**Above**	**Below**	**Above**	**Below**
Fall 03	*21.5*	*19*	*20*	*22*	*20.25*	*20*	*20*	*18.5*
Spring 04	*21.5*	*20.5*	*21*	*24*	*18*	*18.5*	*21.5*	*20.5*
Fall 04	*20.5*	*20*	*21.5*	*22*	*21.5*	*16.5*	*20.5*	*19.5*
Spring 05	*22*	*22*	*21.5*	*23.5*	*21.5*	*20*	*21.5*	*19*
Fall 05	*18.5*	*21*	*21*	*22.5*	*23*	*19.5*	*21.5*	*20.5*
Spring 06	*21*	*22*	*21.5*	*23.5*	*23*	*22.5*	*22*	*20*
Fall 06	*21.5*	*21.5*	*21*	*21.5*	*22.5*	*22*	*22*	*21*
Spring 07	*19.5*	*21*	*23*	*23.5*	*23.5*	*21.5*	*22.5*	*19.5*
Fall 07	*19.5*	*20*	*21.5*	*23*	*22*	*22*	*22*	*18*

Ratings (per TCEQ):
26 – 31 = Exceptional
20 – 25 = High
14 – 19 = Intermediate
≤ 13 = Limited

Figure 12. Mean Habitat Quality Index scores across all project sites.

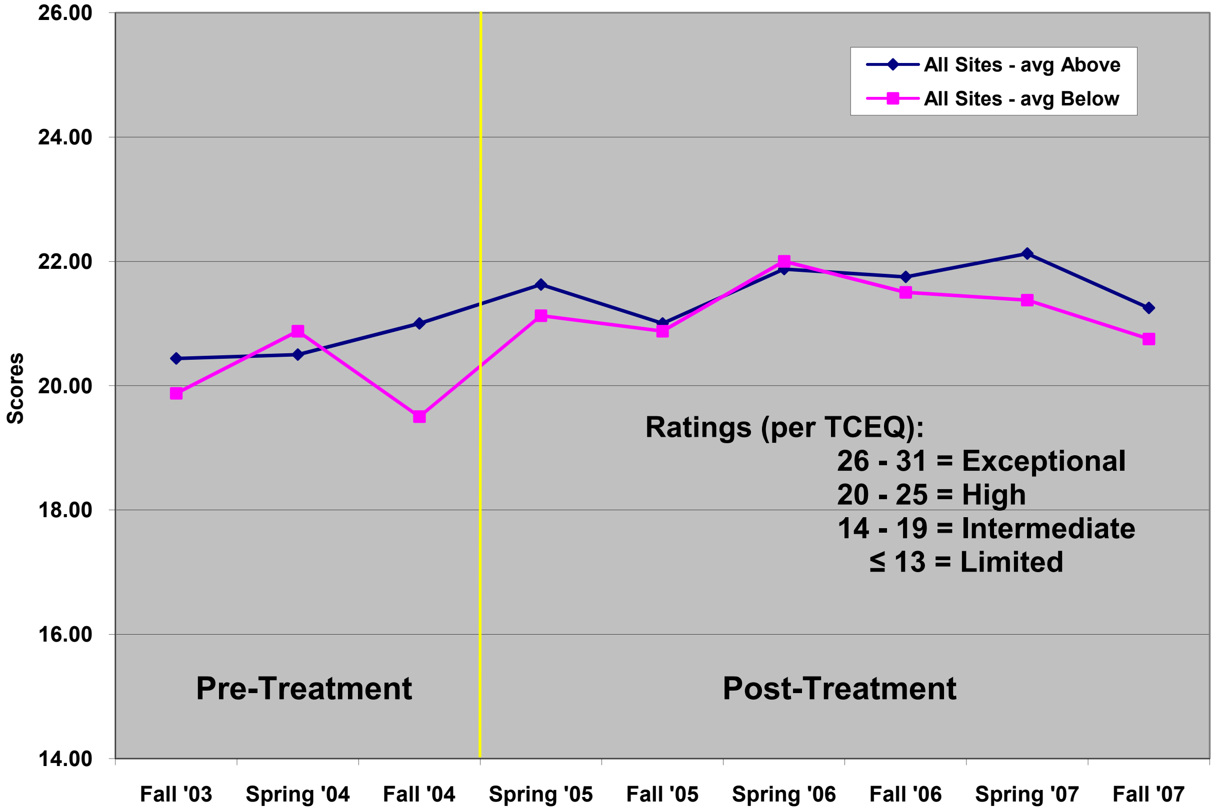


Table 6. Mean Habitat Quality Index and Aquatic Life Use scores of biological samples across all project sites (pre = pre-harvest; post = post-harvest).

Site	Section	Habitat			Benthics			Fish		
		HQI			ALU					
		Pre	Post	Sig[1]	Pre	Post	Sig[1]	Pre	Post[1]	Sig[1]
Cherokee	Upstream	21.17	20.33	A	32.00	30.33	A	44.00	47.67	A
	Downstream	19.83	21.25	**B**	29.00	26.17	A	49.33	50.17	A
Houston	Upstream	20.83	21.58	A	26.67	24.67	A	43.00	39.67	A
	Downstream	22.67	22.92	A	30.33	27.83	A	42.00	46.67	**B**
Newton	Upstream	19.92	22.58	A	29.00	25.17	A	55.67	51.83	A
	Downstream	18.33	21.25	A	28.00	25.17	A	51.67	53.67	A
San Augustine	Upstream	20.00	21.69	A	28.00	28.75	A	45.00	43.63	A
	Downstream	18.5	19.75	**B**	30.00	27.38	A	45.00	46.5	A

[1] Mean section/period interactions with the same letter are not significantly different at $\alpha = 0.05$.

Physiochemical Monitoring – Grab Water Samples

Results from grab samples collected indicated high water quality across all project sites (see Table 7). Parameters measured *in-situ* (conductivity, DO, pH, temperature, and turbidity) at each section closely paralleled each other, showing no treatment effect. DO ranged from 3.1 to 12.2 mg/l across all sites, exceeding the minimum criteria set by the 2000 Texas Surface Water Quality Standards for unclassified perennial streams (3.0 mg/l). The lowest reading occurred when stream flow fell below the seven-day, two-year low flow. Only eight out of 376 (2%) DO samples were below 5.0 mg/l. Conductivity ranged from 0.0003 to 0.0873 mS/cm, pH ranged from 4.67 to 10.56, and turbidity ranged from 2.5 to 37.0 NTU. As expected, DO and temperature were strongly correlated ($r^2 = 0.95$).

Laboratory analysis of grab samples (TN, TP, and TSS) also resulted in no significant treatment effect. TSS values ranged from non-detectable (assigned value 0.5) to 38.7 mg/l. TN and TP had much lower ranges, with results between 0.073 and 5.430 mg/l and non-detectable (assigned value 0.005) and 3.310, respectively. Over 86% of grab samples analyzed for TP were non-detectable, and only 1% (4 out of 376 samples) exceeded the TCEQ screening criteria for TP (0.69 mg/l). Less than 0.5% (1 out of 376) of TN samples exceeded the screening criteria for nitrate nitrogen (1.95 mg/l). Natural variability in lab parameters was noticeable. A comparison between grab and duplicate samples collected showed TSS values varying by 24%, TN by 18% and TP by 11%. See Table 8.

Table 7. Number of grab samples taken across all project sites.

Project Site	Pre-Treatment Samples	Post-Treatment Samples	Total Samples
Cherokee	13	34	47
Houston	14	33	47
Newton	17	30	47
San Augustine	5	42	47

Table 8. Mean sediment and nutrient (Total Nitrogen, Total Phosphorous) concentrations of grab samples across all project sites (pre = pre-harvest; post=post-harvest).

Site	Section	Total Nitrogen			Total Phosphorous			Sediment		
		mg / l								
		Pre	Post	Sig[1]	Pre	Post	Sig[1]	Pre	Post[1]	Sig[1]
Cherokee	Upstream	0.67	0.89	A	0.05	0.07	A	8.80	6.92	A
	Downstream	0.66	0.89	A	0.05	0.06	A	4.76	6.22	A
Houston	Upstream	0.44	0.83	A	0.05	0.06	A	7.13	10.63	A
	Downstream	0.80	0.78	A	0.05	0.06	A	7.04	8.70	A
Newton	Upstream	0.55	0.85	A	0.05	0.12	A	5.62	5.36	A
	Downstream	0.56	0.83	A	0.05	0.10	A	5.88	5.52	A
San Augustine	Upstream	0.34	0.64	A	0.05	0.14	A	5.50	6.02	A
	Downstream	0.28	0.65	A	0.05	0.06	A	6.16	6.45	A

[1] Mean section/period interactions with the same letter are not significantly different at α = 0.05.

Physiochemical Monitoring – Stormwater Samples

Results from stormwater samples collected varied greatly among sites. Concentrations varied with storm event conditions and watershed physiographic characteristics. A total of 550 samples were collected throughout the course of this project. Approximately 60% of these samples represented a matched pair (data collected from both the upstream and downstream section during the same storm event), on which statistical analyses were conducted. See Table 9.

Turbidity, measured *in-situ* from collected storm samples, ranged from 6.3 to 950.0 NTU. While this variance is high, no statistical difference was observed between the sections that could be attributed to the treatment. Laboratory analysis of stormwater samples (TN, TP, and TSS) also resulted in no significant treatment effect. TSS values ranged from 2.0 to 4,540.0 mg/l. TN and TP had much lower ranges, with results between 0.13 and 6.03 mg/l and non-detectable (assigned value 0.025) and 0.612 mg/l, respectively. It is important to note that no TP or TN samples exceeded their respective TCEQ screening criteria. Strong correlations between turbidity and TSS were established ($r^2 = 0.75$) at most sites. Seventy-five percent of the annual sediment and nutrient losses from each site were accounted for from five storm events. See Tables 10, 11, and 12.

Table 9. Number of stormwater samples collected, by parameter.

Project Site	**# of Samples**		**Matched TSS**		**Matched TP**		**Matched TN**	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Cherokee	21	79	20	41	19	33	19	35
Houston	17	49	14	31	10	23	10	24
Newton	25	48	23	32	20	25	20	32
San Augustine	7	67	7	38	5	34	7	32

Table 10. Mean stream flow and turbidity results of paired stormwater samples across all project sites (pre = pre-harvest, post = post-harvest).

Site	Section	Stream Flow			Turbidity		
		——— cm ———			——— NTU ———		
		Pre	Post	Sig[1]	Pre	Post	Sig[1]
Cherokee	Upstream	0.36	0.32	A	61.14	40.93	A
	Downstream	0.69	0.54	A	49.13	58.10	A
Houston	Upstream	0.56	0.79	A	79	51.03	A
	Downstream	0.36	1.07	A	81.14	98.77	A
Newton	Upstream	0.83	0.97	A	70.42	107.33	A
	Downstream	1.37	1.40	A	115	132.63	A
San Augustine	Upstream	1.51	1.20	A	53.8	182.88	A
	Downstream	1.08	1.77	A	41.6	221.08	A

[1] Mean section/period interactions with the same letter are not significantly different at $\alpha = 0.05$.

Table 11. Mean sediment and nutrient (Total Nitrogen, Total Phosphorous) losses of paired stormwater samples across all project sites (pre = pre-harvest; post = post-harvest).

Site	Section	Total Nitrogen			Total Phosphorous			Sediment		
		kg ha^{-1}								
		Pre	Post	Sig[1]	Pre	Post	Sig[1]	Pre	Post[1]	Sig[1]
Cherokee	Upstream	0.04	0.06	A	0.00	0.00	A	4.23	3.19	A
	Downstream	0.08	0.12	A	0.00	0.01	A	9.07	9.71	A
Houston	Upstream	0.08	0.11	A	0.00	0.01	A	7.85	4.22	A
	Downstream	0.07	0.14	A	0.00	0.01	A	8.65	11.08	A
Newton	Upstream	0.10	0.14	A	0.01	0.02	A	11.08	14.41	A
	Downstream	0.18	0.23	A	0.01	0.03	A	41.98	38.83	A
San Augustine	Upstream	0.09	0.20	A	0.01	0.02	A	40.59	67.92	A
	Downstream	0.06	0.29	A	0.02	0.03	A	13.76	74.57	A

[1] Mean section/period interactions with the same letter are not significantly different at $\alpha = 0.05$.

Table 12. Total annual rainfall, stream flow, sediment, and nutrient (Total Nitrogen, Total Phosphorous) losses of stormwater samples across all project sites.

Site	Upstream (reference)				Downstream (test)			
	2004	2005	2006	2007[1]	2004	2005	2006	2007[1]
				Rainfall (cm)				
Cherokee	179.07	81.79	126.75	91.69	179.07	81.79	126.75	91.69
Houston	158.24	78.49	144.27	90.42	158.24	78.49	144.27	90.42
Newton	194.06	119.63	179.58	74.42	194.06	119.63	179.58	74.42
San Augustine	203.71	101.85	136.91	104.39	203.71	101.85	136.91	104.39
				Flow (cm)				
Cherokee	11.22	7.05	4.60	5.99	21.92	9.96	6.51	10.71
Houston	8.91	8.19	11.67	10.00	7.56	11.94	15.03	11.97
Newton	14.46	13.31	19.44	9.03	23.58	17.07	32.83	20.13
San Augustine	26.23	16.41	19.80	14.25	29.55	18.26	28.32	24.08
				Total Sediment (kg ha^{-1} yr^{-1})				
Cherokee	133.11	46.78	48.95	19.78	385.84	119.15	46.47	73.98
Houston	118.69	77.09	74.13	52.83	134.37	117.85	120.43	111.11
Newton	234.63	143.39	281.82	87.07	879.69	175.45	940.54	494.26
San Augustine	2337.80	237.77	214.83	357.29	1453.31	282.28	467.06	919.58
				Total Nitrogen (kg ha^{-1} yr^{-1})				
Cherokee	1.30	0.79	0.60	0.76	2.56	1.45	0.94	1.45
Houston	0.97	0.99	1.27	1.19	1.09	1.00	2.01	1.31
Newton	1.40	1.72	3.00	1.06	2.93	2.03	5.29	3.14
San Augustine	2.99	1.52	1.31	2.37	3.24	1.57	3.65	3.34
				Total Phosphorus (kg ha^{-1} yr^{-1})				
Cherokee	0.06	0.04	0.05	0.04	0.13	0.07	0.05	0.07
Houston	0.05	0.05	0.08	0.05	0.05	0.09	0.26	0.14
Newton	0.10	0.06	0.31	0.11	0.25	0.09	0.45	0.26
San Augustine	0.27	0.15	0.21	0.22	0.32	0.15	0.44	0.26

[1] Data through August 2007

Precipitation

Precipitation varied greatly over the course of the project. Average rainfall across the project area historically ranges from 44.5 to 54.6 inches annually. These averages were determined from 50 years of records at NOAA weather stations in close proximity to the project sites. In 2004, the project sites experienced one of the wettest years on record, receiving over 70 inches of rain. However, only 35 inches fell in 2005, even with Hurricane Rita dumping 10 inches on some of the project sites. This drought began in March 2005. Rainfall deficits peaked in December at 13 inches below normal, and did not start to recover until October 2006. The drought continued at some sites until July 2007. See Table 13.

Table 13. Total annual rainfall across all project sites.

Project Site	2004 Rain Gauge (in)	2005 Rain Gauge (in)	2006 Rain Gauge (in)	2007[1] Rain Gauge (in)	Historical NOAA (in)
Cherokee	70.5	32.2	49.9	36.1	44.5
Houston	62.3	30.9	56.8	35.6	44.5
Newton	76.4	47.1	70.7	29.3	54.6
San Augustine	80.2	40.1	53.9	41.1	53.8

[1] Data only through August 2007.

CONCLUSION

The results from this project indicated that Texas forestry BMPs, when implemented properly, are effective in protecting water quality and aquatic biological communities. The analysis of physiochemical and biological parameters resulted in no significant treatment differences between forest stands harvested and regenerated using BMPs and undisturbed forests. This demonstrates the value of and provides empirical justification for the continued use and implementation of forestry BMPs in Texas. These results further establish that forestry BMPs are the optimum means for minimizing silvicultural nonpoint source pollution.

APPENDIX

Benthic Macroinvertebrate Taxa List

Fish Taxa List

References

Benthic Macroinvertebrate Taxa List

Ablabesmyia sp.

Aedes sp.

Aeshna sp.

Anax sp.

Ancyronyx sp.

Anopheles sp.

Antocha sp.

Argia sp.

Argiogomphus sp.

Asellus sp.

Belostoma sp.

Bezzia sp.

Bittacomorpha sp.

Boyeria sp.

Caenis sp.

Calopteryx sp.

Cambarellus sp.

Cambaridae

Cambarus sp.

Cernotina sp.

Centroptilum sp.

Chauliodes sp.

Cheumatopsyche sp.

Dubiraphia sp.

Enallagma sp.

Ephemerella sp.

Erythrodiplax sp.

Estigmene sp.

Eurylophella sp.

Gelastocoris sp.

Gerris sp.

Gomphus sp.

Gyretes sp.

Gyrinus sp.

Hagenius sp.

Haliplus sp.

Hapoperla sp.

Helius sp.

Helleniella sp.

Helocordulia sp.

Hetaerina sp.

Hexagenia limbata

Hexagenia sp.

Hirundinea

Hyalella azteca

Hydaticus sp.

Mooreobdella sp.

Narpus sp.

Nematomorpha

Neureclipsis sp.

Notonecta sp.

Nyctiophylax sp.

Ochterus sp.

Oligochaeta

Orconectes sp.

Parachironomus sp.

Paraleptophlebia sp.

Paraplea sp.

Paratendipes sp.

Perithemis sp.

Perlesta sp.

Phylocentropus sp.

Placobdella sp.

Polypedilum sp.

Procambarus sp.

Procladius sp.

Progomphus sp.

Pseudochironomus sp.

Ranatra sp.

Chironomidae

Chironomus sp.

Chrysops sp.

Cordulegaster sp.

Corixidae

Corydalus cornutus

Corydalus sp.

Crangonyx. sp.

Cryptochironomus sp.

Culex sp.

Didymops sp.

Dimulium sp.

Dineutus sp.

Dixa sp.

Dixella sp.

Dromogomphus sp.

Hydrochus sp.

Hydroporus sp.

Hydropsyche sp.

Hydroptila

Isoperla sp.

Libellula sp.

Lipogomphus sp.

Lirceus sp.

Lumbricus sp.

Lype sp.

Macromia sp.

Macronychus sp.

Macrothemis sp.

Metrobates sp.

Micropsectra sp.

Rhagovelia sp.

Rheumatobates sp.

Sialis sp.

Simulium sp.

Stenacron sp.

Stenelmis sp.

Stenonema sp.

Stictochironomus sp.

Stylurus sp.

Tabanus sp.

Tanypus sp.

Tanytarsus sp.

Tipula sp.

Trepobates sp.

Trichocorixa sp.

Fish Taxa List

Black bullhead	*Ameiurus melas*
Blackspot shiner	*Notropis atrocaudalis*
Blackspotted topminnow	*Fundulus olivaceus*
Blackstripe topminnow	*Fundulus notatus*
Blacktail redhorse	*Moxostoma poecilurum*
Blacktail shiner	*Cyprinella venusta*
Bluegill	*Lepomis machrochirus*
Bluntnose darter	*Etheostoma chlorosomum*
Chestnut lamprey	*Ichthyomyzon castaneus*
Creek chub	*Semotilus atromaculatus*
Dollar sunfish	*Lepomis marginatus*
Dusky darter	*Percina sciera*
Freckled madtom	*Noturus nocturnus*
Golden shiner	*Notimegonus chrysoleucas*
Goldstripe darter	*Etheostoma parvipinne*
Grass pickerel	*Esox americanus vermiculatus*
Green sunfish	*Lepomis cyanellus*
Hybrid sunfish	
Lake chubsucker	*Erimyzon sucetta*
Largemouth bass	*Micropterus salmoides*
Longear sunfish	*Lepomis megalotis*
Mud darter	*Etheostoma asprigene*
Pirate perch	*Aphredoderus sayanus*

Pugnose minnow	*Opsopoedus emilae*
Redfin darter	*Etheostoma whipplei*
Redfin shiner	*Lythrurus umbratilis*
Ribbon shiner	*Lythrurus fumeus*
Sabine shiner	*Notropis sabinae*
Slough darter	*Etheostoma gracile*
Southern brook lamprey	*Ichthyomyzon gagei*
Spotted bass	*Micropterus punctulatus*
Spotted sucker	*Minytrema melanops*
Spotted sunfish	*Lepomis punctatus*
Tadpole madtom	*Noturus gyrinus*
Warmouth	*Lepomis gulosus*
Weed shiner	*Notropis texanus*
Western mosquitofish	*Gambusia affinis*
Yellow bullhead	*Ameiurus natalis*

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