Assessment and Mitigation of Agricultural and Other Nonpoint Source Activities in the Cypress Creek Basin

TSSWCB Project 04-14

Final Report

Northeast Texas Municipal Water District, HDR Engineering, Inc.
Texas Registered Engineering Firm No. F-754 and Center for Research in Water Resources, University of Texas-Austin

Funding provided through a Clean Water Act §319(h) Nonpoint Source Grant
from the Texas State Soil and Water Conservation Board and
the U.S. Environmental Protection Agency

Table of Contents

List of Figures

List of Tables

List of Acronyms

BOD	Biological Oxygen Demand
BMP	Best Management Practice
CFS	Cubic Feet per Second
CRP	Clean Rivers Program
CRWR	Center for Research in Water Resources, University of Texas-Austin
CWA	Clean Water Act
DO	Dissolved Oxygen
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information Systems
GPS	Global Positioning System
HDR	HDR Engineering, Inc.
I-Plan	Implementation Plan
NELAC	National Environmental Laboratory Accreditation Conference
NETMWD	Northeast Texas Municipal Water District
NMP	Nutrient Management Plan
NOAA	National Oceanic Atmospheric Administration
NPS	Nonpoint Source
NRCS	Natural Resources Conservation Service
OSSF	On-Site Sewage Facility
PDSI	Palmer Hydrological Drought Index
PI	Phosphorus Index
PPAI	Paul Price Associates, Inc.
PPM	Parts per Million
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
RTD	Rapid Transfer Device
SEP	Supplemental Environmental Project
SH	State Highway
SSURGO	Soil Survey Geographic Database
SWAT	Soil and Water Assessment Tool
SWCD	Soil and Water Conservation District
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
TSSWCB	Texas State Soil and Water Conservation Board
USACE	U.S. Army Corps of Engineers
USDA-ARS	U.S. Department of Agriculture-Agricultural Research Service

USGS	United States Geological Survey
WQMP	Water Quality Management Plan
WWTF	Wastewater Treatment Facility

Executive Summary

Big Cypress Creek (Segment 0404) between Lake Bob Sandlin and Lake O' the Pines was placed on the 1998 303(d) List based on water quality testing because intermittent but chronic low dissolved oxygen (DO) levels impaired aquatic life use and was of concern to regional interests. Pollutant loading to Lake O' the Pines, Big Cypress Creek and their tributaries were thought to originate from both point and nonpoint sources of pollution including municipal wastewater treatment facilities (WWTF), natural occurrence, leaking on-site sewage facilities (OSSFs) and agricultural operations. Intensive monitoring and several special studies were initiated within Segments 0403 and 0404 in 1998 and 1999 by the Texas Commission of Environmental Quality (TCEQ) and the Cypress Creek Basin Clean Rivers Program (CRP). The sampling results confirmed the lake was not meeting its assigned DO criteria and provided the detailed water quality information necessary to develop a TMDL.

The results of the intensive surveys indicated that Tankersley Creek was the largest source of nitrogen and phosphorus entering Segment 0404. The Southside WWTF in Mount Pleasant, which also processes wastewater from the Pilgrim's Pride Corporation poultry processing facility, was identified as the main point source of a large proportion of the nitrogen and phosphorus load entering Tankersley Creek and Segment 0404 of Big Cypress Creek. The monitoring data summarized in the 2004 Cypress Creek Basin Summary Report indicated Tankersley Creek and other tributaries of Segment 0404 (e.g., Hart Creek) are the largest nutrient sources entering Lake O' The Pines.

The development of a Total Maximum Daily Load (TMDL) for the Lake O' the Pines Watershed was coordinated through the TCEQ and directed by Northeast Texas Municipal Water District (NETMWD). The goal of the TMDL process was to identify the source of pollutants responsible for the low DO and determine the amount of pollutant load reduction needed to raise DO concentrations in order to meet state water quality standards. Several studies were conducted to investigate the correlation between nonpoint source loading from storm runoff and lake water quality. Analysis of water quality data from the lake and the parallel analysis and modeling of Big Cypress Creek showed that external nutrient loading of the reservoir does not correspond in time to the occurrence of low DO episodes (Ward, 2001a).

Water quality analysis and model development for Lake O' the Pines was calibrated and verified from the water quality data collected. The Soil and Water Assessment Tool (SWAT) model was adopted for application to the simulation of runoff and associated watershed loads into Lake O' the Pines as part of the TMDL. Analysis of monitoring data and operation of models of the hydraulic and kinetic behavior of the watershed, stream network, and reservoir system indicated that Lake O’ the Pines is being adversely affected by phosphorus loading. The TMDL document developed for Lake O’ the Pines with the guidance of the TCEQ and the U.S. Environmental Protection Agency (EPA) was approved on June 7, 2006.

Measures to reduce pollutant loads through an implementation plan (I-Plan) were then developed. The Lake O’ the Pines TMDL I-Plan was developed through the Cypress Creek Basin CRP/Lake O’ the Pines TMDL Combined Steering Committee and was approved on July 9, 2008. This I-Plan (TCEQ, 2008) describes the actions necessary to reduce the excessive phosphorous inputs from both point and nonpoint sources into Lake O’ the Pines.

An edge-of-field demonstration was conducted by NETMWD to characterize the effects of agricultural activities on the nutrient composition of the surface runoff characteristics of defined areas (i.e., a single field) each representing a major land use in the upper Big Cypress Creek Watershed. This project was part of a larger effort to extend and improve the technical basis of nonpoint source pollution management in the basin, particularly TMDL determination for Lake O’ the Pines, which was based in part upon application of the SWAT model.

Edge-of-field measurements of overland flow quantity and of nutrient concentrations in overland flow were conducted using automated samplers during runoff events. The constructed automated sampling sites were established at 12 locations that focused on the integrated effect of agricultural land use for subwatershed-scale areas ranging in size from 0.54 to 10.85 acres within several small agricultural fields located in Camp, Titus, and Morris Counties. This network of sampling stations was operated from September 2005 through January 2008, a time period longer than envisioned at the outset of the project. The greatest obstacles to success of the project were availability of suitable sites provided by a willing landowner, uncompromising weather patterns, and the harmonious operation of electronic data capture devices. Project challenges included the collection of water samples during a 16-month period of drought, managing and processing large volumes of data, integration of heterogeneous data (i.e., precipitation), and model integration.

In each location, soil samples were collected to identify the dominant soil types in each of the sample sub-watersheds and the nutrient level status in pastureland used for cattle grazing and hay production. Storm event flow water samples were collected using a flow-proportional technique (Harmel et al., 2003) and stored in the automated sampling equipment until pickup.

They were then transported to a National Environmental Laboratory Accreditation Conference (NELAC) certified laboratory for analysis of nutrients and sediments. All data collected involving land use, soil and hydrologic conditions were essential in the development and calibration of 12 small-scale SWAT models.

1.0 Introduction

Water quality monitoring, storm runoff studies, and modeling results, which were part of the Lake O' the Pines TMDL, have shown that WWTFs, OSSFs, poultry production, processing, and fertilizers are a source of significant contribution to the nutrient load currently entering Big Cypress Creek from both point and nonpoint sources, and the cause of low DO in Lake O' the Pines (Segment 0403). Local effects on water quality have been shown to be related to poultry production activity under low flow conditions, while storm-generated surface runoff is the primary route through which nitrogen and phosphorus (and other pollutants) enter Lake O' the Pines at the bottom of this impaired watershed (PPAI, 2003).

The Lake O' the Pines Watershed encompasses Segment 0403 and drainage areas upstream from Lake O' the Pines designated as Segments 0404, 0405, and 0408. It includes four major impoundments (Lake Cypress Springs, Lake Monticello, Lake Bob Sandlin, and Lake O' the Pines), about 50 miles of Big Cypress Creek (Segment 0404), and numerous tributary streams including Tankersley Creek, Boggy Creek, Hart Creek, Meddlin Creek, Prairie Creek, Walkers Creek and Swauano Creek (Figure 1-1). It is part of the 2,812 square mile Cypress Creek Basin, which is located in Northeast Texas bounded on the north by the Sulphur River basin and the Sabine River basin to the west and south. Lake O' the Pines is a major tributary to Caddo Lake on the Texas-Louisiana border. The watershed contains the majority of the Big Cypress Creek Basin's urban concentrations, industry, and recreational waters. The dominant land use is crop and pastureland, which is primarily rangeland for cattle grazing, fertilized pasture used for hay production or some combination of the two (PPAI, 1998, 2001; Ward, 2003). The primary uses of Lake O' Pines are recreation and public water supply, and demand for both uses is expected to continue to grow.

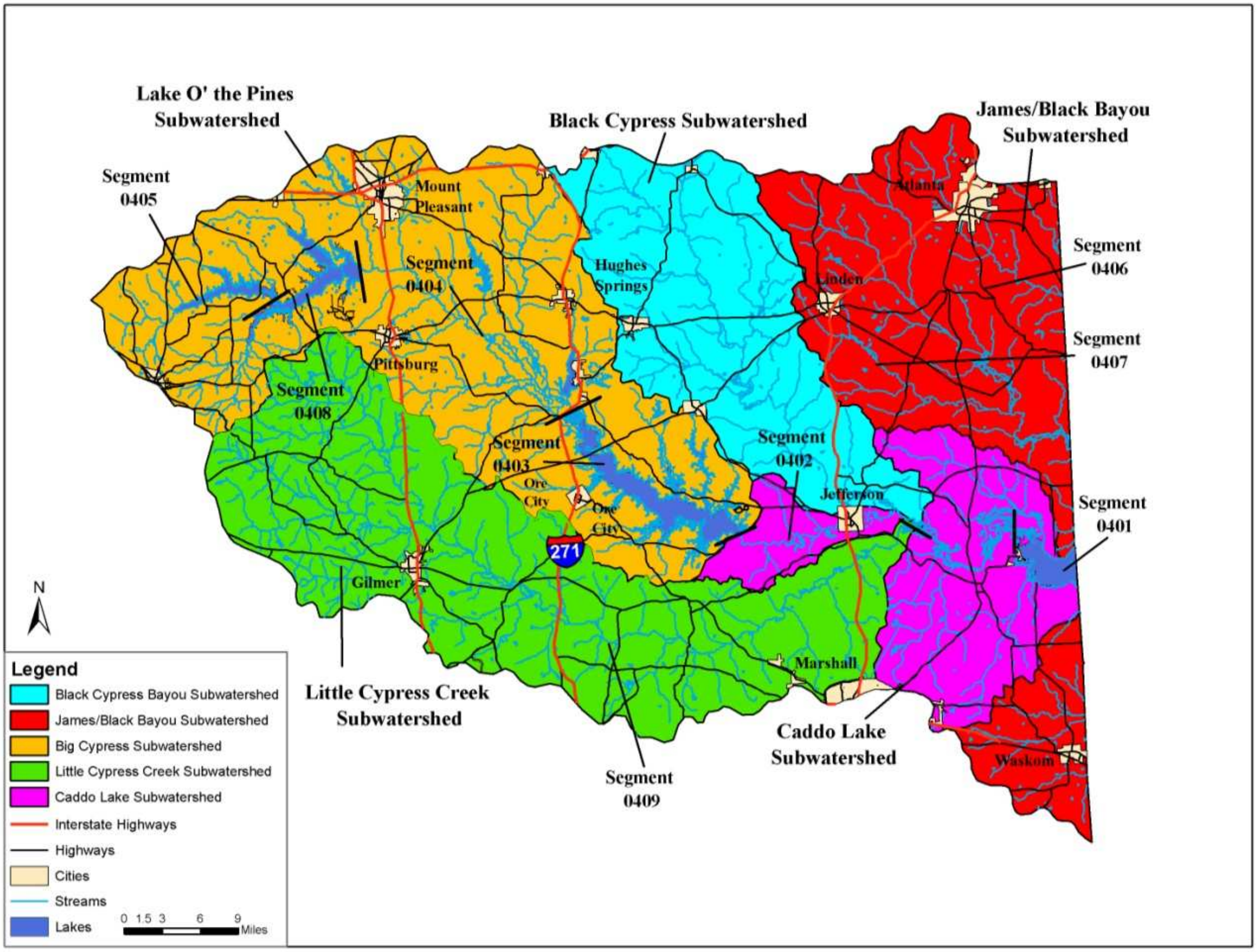

Figure 1-1. Cypress Creek Basin Subwatersheds

The Lake O' the Pines (Segment 0403) was included on the 2000 303(d) List for low DO levels at the upper end of the lake. Corresponding to that portion of the reservoir above the State Highway (SH) 155 causeway, this approximately 2,000 acre area is a transition zone between the lotic (flowing) conditions prevailing in Big Cypress Creek and the more typically lentic (non-flowing) environment of the lower lake basin. Continued concern for depressed DO concentrations extended after the 2002 assessment to include a total of 3,700 acres including the upper main basin in the vicinity of the NETMWD raw water intake. This area was also listed for low DO on the 2004 303(d) List but was subsequently removed from the 2006 303(d) List after the TMDL concluded that low DO concentrations in Lake O' the Pines result from photosynthesis and respiration of aquatic plants in the reservoir, rather than from inflowing, oxygen-demanding materials (TCEQ, 2006).

Historical data for Segment 0404 has also shown a trend for increasing nutrient concentrations upstream of Lake O' the Pines on Big Cypress Creek at SH 11 and US Highway 259. The introduction of these nutrient enriched inflows have resulted in an increase in algal growth and a significant increase of chlorophyll-a in the middle and lower portions of the reservoir (NETMWD, 2009a).

The TSSWCB provided NETMWD funding through a Clean Water Act (CWA) Section 319(h) nonpoint source grant for the edge-of-field monitoring and the SWAT modeling portions of this project (TSSWCB Project 04-14). Data collection, laboratory analyses, and model development was conducted in accordance with the final sampling plan and modeling guidelines specified in two separate and final TSSWCB and EPA approved Quality Assurance Project Plans (QAPPs) created by NETMWD.

In addition, a total of $200,000 was allocated to NETMWD for the replacement of OSSFs located within the Lake O' the Pines Watershed to help reduce the contribution of malfunctioning OSSFs on in-stream nutrient loadings and bacteria concentrations. With the use of this available financial assistance, a total of 42 new systems were installed, to replace identified failing systems and/or make repairs to existing systems.

While the current SWAT model implies that the use of poultry litter as a source of nitrogen, phosphorus and organic material on crops and pastures is a major source of excessive phosphorus loading in the Lake O' the Pines watershed, two issues remained. First, no distinction between poultry litter and other nutrient sources is made in the SWAT model, and no direct comparisons of runoff loading from alternative land use types, fertilization levels and Best Management Practice (BMP) implementation in the Lake O' the Pines watershed are available. Second, the litter application levels and most of the monitoring data used in the model development were obtained prior to the significant implementation of BMPs by the poultry production industry in this area.

Storm water and modeling studies conducted as part of the Lake O' the Pines TMDL have suggested that the presence of poultry litter application sites in a subwatershed are associated with increased nitrogen and phosphorus loads in the receiving streams. However, the relationships among poultry litter and conventional fertilizer application rates, soil types, soil nutrient levels, vegetation cover, the presence of BMPs, and field runoff loads of nutrient and sediment is known only generally for the Cypress Creek Basin. Demonstration of varying efficiencies of nutrient retention in the agricultural system, or positive delineation of the extent to which agricultural activities affect the retention of nutrients in the soil or their loss downstream, will lead to better public understanding of the problem and support for water quality protection measures, and will be beneficial to securing voluntary participation in the Water Quality Management Plan (WQMP) program.

The primary goal of this report is to evaluate the effectiveness of selected BMPs in reducing nutrient inputs to Big Cypress Creek and Lake O' the Pines by documenting runoff quality from sites representing dominant soil and land use types, with and without implemented BMPs initiating a nutrient reduction program by mitigating overflowing sewage from OSSFs in the rural areas. In addition, the effectiveness of applied WQMPs in reducing the runoff of nutrients from fields that receive applications of poultry litter has been evaluated. BMPs within the Lake O' the Pines watershed include farming methods that assure optimum plant growth and minimize adverse environmental effects, primarily by minimizing environmental damage from excess nitrogen and phosphorus in runoff. Examples of BMPs include practices for the management of pests, nutrients and waste; vegetative and tillage practices, such as contour farming, cropping sequence and windbreaks; and structural practices, such as terraces, grade stabilization and sediment control basins.

The effectiveness of these BMPs was evaluated through a series of small-scale comparative runoff demonstrations which were integrated with the water quality data collected. This analysis will supplement and complement monitoring in Lake O' the Pines and its watershed currently being conducted through the CRP.

2.0 Background

The Lake O' the Pines is an important municipal, cultural, recreational, ecological, and aesthetic asset. Working to preserve and maintain water quality will ensure prosperity, productivity, and quality of life for the entire Big Cypress Creek watershed. Water quality in the headwater segment of this watershed is vital in maintaining the functionality of the downstream reaches of the Cypress Creek Basin.

The 887 square mile Lake O' the Pines Watershed extends upstream from Ferrells Bridge Dam, constructed on Big Cypress Creek in 1957, to impound the 16,919 acre (68,471,193 m^2) Lake O' the Pines (Segment 0403), to the westernmost extreme of the Cypress Creek Basin. Figure 1-1 shows this watershed to encompass Lake O' the Pines (Segment 0403) and its immediate tributaries, the reach of Big Cypress Creek upstream to Fort Sherman Dam (Segment

0404), Lake Bob Sandlin (Segment 0408), and Lake Cypress Springs (Segment 0405), and their tributaries. Four major tributary reservoirs, Lake Monticello, Welsh Reservoir, Ellison Creek Reservoir, and Johnson Creek Reservoir, have been constructed in this watershed to provide cooling water for steam-electric generating stations. Lake Monticello, Welsh Reservoir and Tankersley Lake are located on tributaries to Big Cypress Creek (Segment 0403). Ellison Creek Reservoir, Lake Daingerfield, and Johnson Creek reservoir are located on tributaries whose watersheds tend to be more wooded and drain directly to the Lake O' the Pines. Major streams of the watershed include Tankersley Creek, Boggy Creek, Hart Creek, Meddlin Creek, Prairie Creek, Walkers Creek and Swauano Creek. Large areas of the upper portion of Lake O' the Pines and the floodplains surrounding Big Cypress Creek and its major tributaries contain extensive forested wetlands. Woodland vegetation in the watershed is typified by oaks, hickory and pines.

The vegetation of the watershed is marked by a transition from the extensive agricultural clearing of the western portion of the basin to the more densely forested eastern portion. Big Cypress Creek's extensive floodplain is marked by numerous sloughs and depressions that tend to retain water following flood events. This floodplain is heavily wooded and undisturbed relative to the adjacent uplands that are extensively employed for livestock grazing and hay production. Soils of this floodplain are predominated by poorly to somewhat poorly drained clay loam soils. Upland soils of the watershed are typically well drained sandy and loamy soils.

2.1 One Total Maximum Daily Load for Dissolved Oxygen in Lake O' the Pines

A considerable amount of data has been collected for Lake O' the Pines and its watershed. Roughly 10 years of monitoring and short-term sampling programs by TCEQ Region 5 personnel, the Cypress Creek Basin CRP, and other studies have been conducted to support the TMDL development for Lake O' the Pines.

In response to historical measurements of low DO levels in Lake O' the Pines, a TMDL was initiated to determine the measures necessary to restore water quality in the reservoir. The TMDL monitoring program consisted of base flow and wet weather stream flow monitoring within the Lake O' the Pines Watershed (Ward, 2000).

The SWAT model was used to the simulate runoff and associated watershed loads into Lake O' the Pines as part of the TMDL. Its application in the Lake O' the Pines TMDL is summarized in three project technical memoranda (Ward, 2001b, 2002, 2003). Analysis of monitoring data and operation of models of the hydraulic and kinetic behavior of the watershed-stream network-reservoir system indicated that Lake O' the Pines is being adversely affected by phosphorus loading. Contributions of OSSFs to the nutrient loads from the Lake O' the Pines watershed are included in the SWAT model as a consequence of watershed land uses, and are part of the calculated landscape loads. The Lake O' the Pines cove stations, which monitor runoff from small, generally forested watersheds that support low density residential uses near the reservoir exhibit significantly better water quality than the main basin. This indicates that OSSFs do not presently exert a major impact on Lake O' the Pines water quality, at least relative to other nonpoint and point sources located on tributaries to Big Cypress Creek.

The TMDL concluded that phosphorus was the material most responsible for the low DO and a reduction in the total phosphorus load to Lake O' the Pines of 56% was estimated to be needed to allow Segment 0404 to meet its DO standard. The *One Total Maximum Daily Load for Dissolved Oxygen in Lake O' the Pines (For Segment 0403)* was developed and approved by the TCEQ on April 6, 2006, TSSWCB on March 23, 2006 and submitted to the EPA and approved on June 7, 2006. Dissolved oxygen, total phosphorous, and chlorophyll-a are the three parameters of concern included in the Lake O' the Pines Basin TMDL (TCEQ, 2006).

2.2 Implementation Plan for One Total Maximum Daily Load for Dissolved Oxygen in Lake O' the Pines

The findings of the Lake O' the Pines TMDL showed that excessive loadings of phosphorus enter Lake O' the Pines in Big Cypress Creek inflows and result in intense summer biological activity in the shallow, upper portion of the reservoir that causes large daily changes in DO concentration. Big Cypress Creek was estimated to contribute about 80% of the total annual inflow to Lake O' the Pines, and about 88% of the total phosphorus load. This estimate of the importance of Big Cypress Creek contributions is consistent with the water quality conditions found to prevail in the upper and main reservoir basins, compared with the cove environments into which the minor tributaries flow.

The TMDL I-Plan describes the actions necessary to reduce the excessive phosphorous inputs from both point and nonpoint sources into Lake O' the Pines (TCEQ, 2008). The I-Plan was developed through the Cypress Creek Basin CRP/Lake O' the Pines TMDL Combined Steering Committee and was approved on July 9, 2008. The I-Plan provides a detailed description of the regulatory and voluntary management actions that will be undertaken in order to help restore and protect water quality. This includes a list of pollutants of concern and their sources, proposed treatment strategies, a timeline for implementation activities, and proposed methods for monitoring effectiveness of the implementation activities. The I-Plan also discusses the Tracking Strategy that identifies the actions necessary to (1) determine phosphorus loading into Lake O' the Pines, (2) monitor diel DO levels in Lake O' the Pines, (3) establish appropriate criteria and milestones by which to assess progress towards reducing phosphorous load in Lake O' the Pines by 56% and the incidence of DO standards violations, (4) provide tools for evaluating future land use and population changes on water quality, and (5) develop a range of longer range adaptive management alternatives for tracking and watershed management.

2.3 Sources of Phosphorous in the Upper Cypress Creek Basin

Excessive phosphorous input from both point and nonpoint sources has been identified as the primary cause of failures to meet Segment 0403 DO standards in the upper portion of Lake O' the Pines. This watershed exhibits the most intensive agricultural and urban development in the Cypress Creek Basin. Of the 568,447 acres within the Cypress Creek Basin, agricultural land uses occupy 226,108 acres and urban areas occupy 22,563 acres. At 39.8% and 4.0%, respectively, these land uses are substantially more common in the Lake The majority of poultry operations are located in the upper sub-watersheds drained by Tankersley Creek, Walker Creek, Dry Creek, and Prairie Creek near the Cities of Pittsburg and Mount Pleasant.

A U.S. Geological Survey (USGS) streamflow gauge is located on Big Cypress Creek at the SH 11 crossing near the city of Pittsburg (USGS 07344500). During most of the 1990s this gauge recorded only peak flood flows (>2,500 cfs) for U.S. Army Corps of Engineers (USACE) use in operating Lake O' the Pines. The 366 square mile drainage area of the gauge near Pittsburg exhibited a daily average flow of 297 cfs, and minimum and maximum flows of 0 and 48,900 cfs, respectively (April, 1943 through September, 2002). NETWMD supplied the funding for full range reports on water quality data collected from this gage during the TMDL project. Big Cypress Creek (Segment 0404) is the source of about 80% of the inflow to Lake O' the Pines. Big Cypress Creek flows are partially controlled by releases from Fort Sherman Dam, which impounds Lake Bob Sandlin (Segment 0408). Water quality in Big Cypress Creek immediately below Lake Bob Sandlin is the best in Segment 0404, as substantial loads of sediments and nutrients from the upper watershed (Segments 0408 and 0405) are trapped in Lake Bob Sandlin and Lake Cypress Springs.

Industrial facilities are present in and near the Cities of Mount Pleasant, Lone Star, Pittsburg and Daingerfield. Electric power production facilities are located on Lake Monticello (0408A) and Welsh Reservoir (0404D) in the upper watershed and Ellison Creek Reservoir (0404A) and Johnson Creek Reservoir in the lower watershed. Shoreline residential development is present on Lake Cypress Springs and substantial low-density retirement and recreational residential development surrounds Lake O' the Pines. Significant urban concentrations occur at Mount Pleasant, Pittsburg, Daingerfield, Lone Star, and Ore City. There are two permitted hazardous waste sites located in the watershed within 4 miles northeast of Lake O' the Pines. Of the 15 landfills located in the Lake O' the Pines watershed, eight are located near Lake O' the Pines.

Population growth in the Lake O' the Pines watershed is higher than that of the other watersheds in the basin with over half of all discharge permits in the Cypress Basin. Excluding cooling water use and discharge, the largest point sources in the watershed are the WWTFs on Tankersley and Hart Creeks in Mount Pleasant operated by Pilgrims' Pride Corporation and the City of Mount Pleasant.

Storm water studies conducted as part of the Lake O' the Pines TMDL have shown that the presence of poultry litter application sites in an agricultural subwatershed is associated with increased nitrogen and phosphorus loads in the receiving streams. Other unidentified nonpoint source pollutants may also be transported in solution with runoff water, suspended in water, or absorbed on eroded soil particles. However, the relationships among poultry litter and conventional fertilizer application rates, soil types, soil nutrient levels, vegetation cover, presence of BMPs, and field runoff loads of nutrient and sediment is known only generally for the Cypress Creek Basin. Demonstration of varying efficiencies of nutrient retention in the agricultural system, or positive delineation of the extent to which agricultural activities affect the retention of nutrients in the soil or their loss downstream, will lead to better understanding of the problem and support for water quality protection measures, and will be beneficial to securing voluntary participation in the WQMP program.

3.0 Project Description

The intensive monitoring surveys conducted in the Lake O' the Pines Watershed were critical to TMDL development, providing data sets for model calibration and verification, and to characterize DO and nutrient concentrations in receiving waters and in point source discharges, and associated use impairments during summer low flow conditions.

The litter used in the production of poultry (broiler chickens) in the Lake O' the Pines watershed is commonly applied as fertilizer to fields used in the production of grasses used as forage for cattle. An important component of the WQMPs being implemented in the Lake O' the Pines watershed (and, more broadly in the Cypress Creek Basin) are BMPs. One of the goals of BMPs is to reduce nonpoint source pollution. The effectiveness of these BMPs were evaluated through a series of small-scale comparative runoff plots from 12 locations which will be integrated with existing water quality data collected and compiled in the CRP and TMDL. This analysis will supplement and complement monitoring in Lake O' the Pines and its watershed currently conducted under the CRP, or as part of the TMDL I-Plan.

Private landowners willing to participate in the project were sought in 2004 with the help of a Watershed Advisory Committee consisting of invited representatives of NETMWD, TSSWCB, Sulphur-Cypress Soil and Water Conservation District (SWCD), TCEQ, Pilgrims Pride Corporation, interested agricultural operators, local independent contractors, local commercial fertilization companies, and Texas AgriLife Extension Service.

Demonstration sites were selected using a set of criteria that includes land use, soil type and vegetation cover characteristics, history of poultry litter or other fertilizer application, suitability for efficiently capturing runoff from a defined area from a 10-year rainfall event, and accessibility during inclement weather.

3.1 Project Goals and Objectives

The primary goal of this project is to explore the potential utility of applying SWAT, or a combination of SWAT and data analysis, to evaluate the effectiveness of selected BMPs in reducing nutrient inputs to Big Cypress Creek and Lake O' the Pines. The project will help support determination of the steps that could be taken to implement the current Lake O' the Pines TMDL as it relates to nonpoint source nutrient input.

The project also involved the establishment of a public outreach program to educate the public about nonpoint source water quality issues, particularly the role of agricultural activities in basin-wide nutrient loading. Using the Supplemental Environmental Project (SEP) Fund, NETMWD identified and replaced or made repairs to 42 failing OSSFs in the SEP Project boundary.

Another project task is to focus data analysis using the results of the individual field studies together with the land use and soil sampling information in the GIS database together with runs of the updated SWAT model to extrapolate the nonpoint source nutrient contributions of the agricultural or silvicultural land uses/activities throughout the Cypress Creek Basin. This analysis will also use the results of water quality monitoring in Segments 0403 and 0404 to provide continuing validation of SWAT model updates.

Additionally, the nutrient information obtained from the demonstration sites selected for this project will be made available to the TSSWCB Phosphorus Index (PI) project that is aimed at developing and implementing a PI tool for Texas. This PI tool is intended for field personnel, crop advisors, watershed planners and farmers to identify agricultural areas or practices that have the greatest potential to lose phosphorous to adjacent streams. Comparison of the results of this project will provide direct evaluation of the relationship between the PI and nutrient loadings to area streams and to Lake O' the Pines, and will likely be useful to this project in providing insight to the relationship between nutrient runoff and antecedent conditions, information that is difficult to obtain with storm event monitoring only.

3.2 Measures of Success

This project will support determination of the steps that can be taken to implement the current Lake O' the Pines TMDL as it relates to nonpoint source nutrient input. The overall goal of this project consists of the development and application of small scale mathematical models (SWAT modeling) to strategically selected catchments. The SWAT model was used to quantify the effects of applying BMPs on phosphorous loadings to streams, rivers, and lakes (as appropriate) in each watershed.

The following are the measures of success associated with the project:

(1) Obtain actual nutrient and sediment loading data from agricultural fields that represent the major soil types, land use, fertilization levels and BMP implementations used to develop the SWAT model for the Lake O' the Pines watershed.

(2) Update the Lake O' the Pines SWAT subwatershed models with locally obtained data to identify and quantify the agricultural practices resulting in the largest proportion of nutrient and sediment loading in the watershed.

(3) Use basin-specific data and models to quantify the reductions in nutrient loading already achieved by BMP implementation in the poultry industry, and what additional steps will be needed to achieve the goals of the Lake O' the Pines

TMDL (e.g., roughly a reduction of 60% in 1998-2000 total phosphorus loading levels).

(4) Replaced 42 failing OSSFs thus reducing the amount of raw sewage being released on the surface of the ground (approximately 9,967 gallons/day).

3.3 Methods and Materials

A total of 12 sites were selected using a set of criteria that includes land use, soil type and vegetation cover characteristics, history of poultry litter or other fertilizer application, suitability for efficiently capturing runoff from a defined area from a 10-year rainfall event, and accessibility during inclement weather. Information concerning land uses, litter or fertilizer application history, and BMP strategies was compiled for each of the 12 sites (Table 3-1).

Overland flow from local rainfall events were directed down the slope of the field into a weir system installed at the edge of a field to measure water levels, allowing calculation of discharge volumes, and collect water quality samples. Sampling collection involved the use of automated sampling equipment, which include programmable operation and memory, water level recorder, sample collection pump, and sample bottles. The automatic sampler timers were programmed with a sampling regime provided by the U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS). This sampling regime relied upon automated monitoring for data collection (e.g., Harmel et al., 2003) which included measurement of runoff flow (employing calibrated weirs and water-level sensors) and integrated water sampling triggered by a specified threshold of water level and keyed to cumulative flow, so that the sample represents the "event-mean" of the storm event. A weather station consisting of a tipping bucket rain gage and event datalogger was also used at each monitoring location. All gages were setup and calibrated according to the manufacturers' specifications and were maintained on a two week rotation by NETMWD staff.

Table 3-1.
Land Management History of the Demonstration Sites

Station Number	County	Sub-Watershed	Land Use (Last 5 Yrs)	Land Use During Study	WQMP	Time Period	Fertilizer Type	Application Rate	Comments
NT1	Camp	Dry Creek	Cattle; hay production	Pasture	No	2000-2008	None	N/A	No application since 2000
NT2	Camp	Big Cypress Creek	Cattle; hay production	Pasture	No	2000-2008	None	N/A	No indication of application
NT3	Camp	Lake Bob Sandlin	Cattle; hay production	Pasture	Yes	Pre-2000 2001-2005 2006-2008	Poultry litter 21-0-21 commercial None	N/A	BMP since 2000; nutrient limitation
NT4	Camp	Dry Creek	Cattle; hay production	Pasture	No	2004	Poultry litter	3 tons/acre	Single application only
NT5	Titus	Williamson Creek	Hay production	Pasture	No	2000-2008	None	N/A	No application in recent years
NT6	Camp	Prairie Creek	Hay production	Pasture	No	2000-2002 2003-2005 2006-2008	None Poultry litter None	N/A 3.5 tons/acre/yr None	Residential yard
NT7	Titus	Little Boggy Creek	Hay production	Pasture	Yes	2001 2002 2003 2004 2005 2006-2008	Poultry litter Commercial fertilizer Poultry litter Commercial fertilizer Poultry litter None	N/A N/A N/A N/A N/A None	Assume 21-0-21 commercial fertilizer; no application during study period
NT8	Morris	Boggy Creek	Cattle; hay production	Pasture	No	2000-2001 2002-2004 2005 2006-2008	None Poultry litter 21-0-21 None	N/A 3.2 tons/acre 0.15 tons/acre None	No application during study
NT9	Titus	Boggy Creek	Cattle; hay meadow	Pasture	No	2000-2004 2005-2008	Broiler litter None	1.6 tons/acre/yr None	No application during study
NT10	Morris	Boggy Creek	Cattle; hay production	Pasture	Yes	2001-2005 2006-2008	Broiler litter None	1.8 tons/acre/yr None	No application since 2000
NT11	Titus	Tankersley Creek	Hay production	Pasture	Yes	2004 2005 2006-2008	Commercial fertilizer Commercial fertilizer None	0.175 tons/acre 0.275 tons/acre None	Assume 21-0-21 commercial fertilizer
NT12	Titus	Tankersley Creek	Hay production	Pasture	No	2000-2008	None	N/A	No application in recent years

3.3.1 Criteria for Selecting Sites

The final identification and selection of the 12 demonstration sites was completed by March 30, 2005. The Global Positioning System (GPS) latitude-longitude coordinates taken from each site visited were plotted to determine drainage area and to determine extent and location of soil types that are present within the drainage area boundary. Digital photographs were also taken at each location. The initial landowner designated as Station NT-6 decided to withdraw from the project so another site was selected as its replacement. The locations of the sites in the watershed are shown in Figure 3-1.

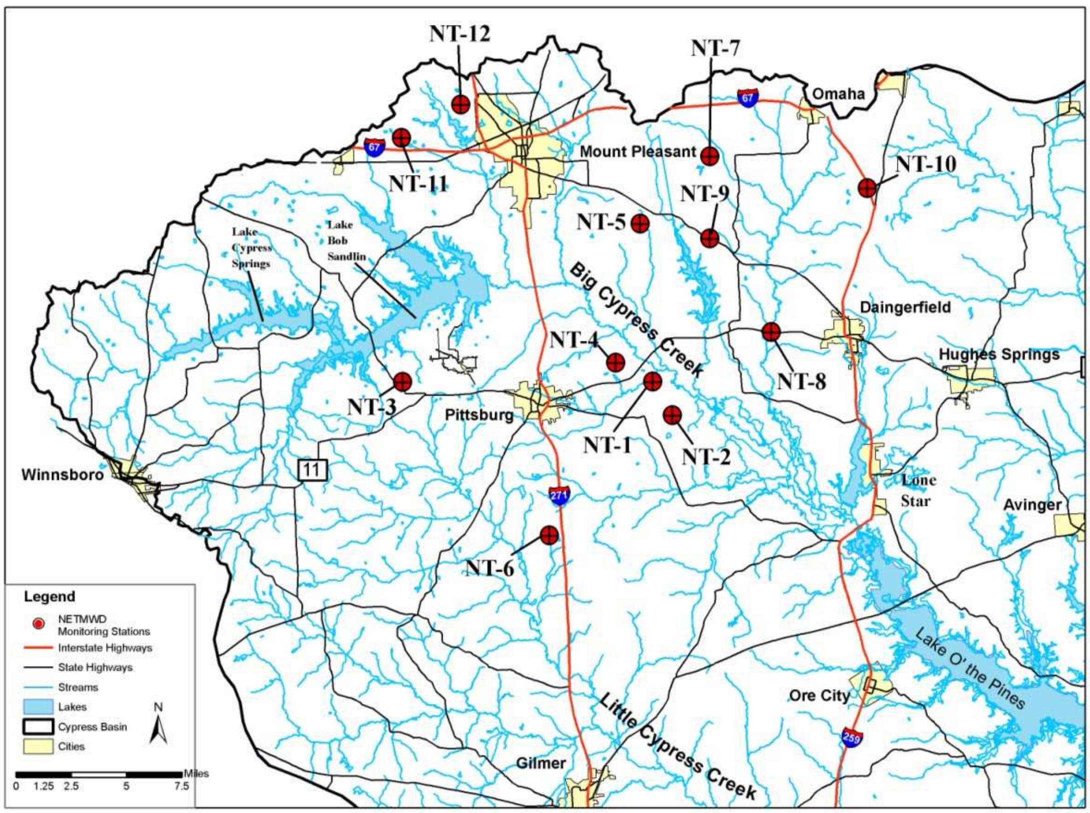

Figure 3-1. Location of the Twelve Demonstration Sites

3.3.2 Field Sampling Methods

Field sampling was conducted according to the sampling handling procedures in the project QAPP and briefly described in the following subsections.

3.3.2.1 Sampling Procedures for Baseline Soil and Water Monitoring Collections

The measurement performance specifications to support the project objectives for a minimum data set for soil and water samples are specified in Table A7.1 of the project's QAPP.

Composite soil sampling procedures were consistent with the accepted soil science techniques for achieving representative and analytical results. Analytes that were analyzed included baseline soil-water pH, soluble salts/electrical conductivity, Mehlich-3 extractable phosphorous (P), potassium (K), nitrate-nitrogen (NO_3-N), sodium (Na), magnesium (Mg), and calcium (Ca) nutrients.

Water samples were collected from field sampling sites only during rainfall events with sufficient runoff to trigger automated samplers. The water samples were not filtered in the field due to the high concentrations of solids and nutrients in the storm samples. Laboratory analysis was performed for orthophosphate phosphorus, total phosphorus, total suspended solids (TSS), TDS, ammonia nitrogen, total Kjeldahl nitrogen, nitrite nitrogen, nitrate nitrogen, and total organic carbon.

The Texas AgriLife Extension Service Soil, Water and Forage Testing Laboratory in College Station, Texas provided analyses for soil samples collected for this project. Ana-Lab Corporation of Kilgore, Texas conducted the water sample analyses.

3.3.2.1.1 Soil Sample Collection

Soil sampling and testing is an important tool for crop production and field management. Soil samples are most commonly collected throughout a field to obtain a collective representation of soil characteristics on which to base recommendations for fertilizer and lime application rates.

During the reconnaissance phase in March and April 2005, each location selected for monitoring was visited to delineate the field boundaries based on slope and drainage. A portable hand-held GPS unit was used to record the latitude-longitude coordinates to help determine total site acreage and the representative soil type(s) for each location. For each location, a set of maps were developed including site boundary location transposed on USGS topographic maps, an infrared aerial photo of each area taken in 2004 with the field boundary line plotted based on the initial GPS coordinates, and a map based on the aerial photo showing the soil subunit boundaries.

Soil samples were collected in July 2005 and February 2007 to measure existing soil conditions. Soil samples were analyzed within the estimated accuracy and precision limits of measured parameters to insure data quality.

A review of the 2005 data showed that composited samples at 6 fields were represented by a mixture of two or more soil types. It was determined that 5 of the 6 locations would require retesting. For the February 2007 investigation, sampling points within each soil type at Stations NT-3, NT-4, NT-6, NT-7, NT-8, and NT-9 were pre-determined across each field at fixed GPS coordinates. All core samples were collected near each georeferenced point provided to ensure that each sample composited for each depth was composed of the same type of soil. Collection, preparation and delivery for analysis followed the aforementioned protocol.

3.3.2.1.2 Water Sample Collection

Quantification of nonpoint source inputs of nutrient and oxygen-demanding materials to the Lake O' the Pines watershed required information concerning rainfall-runoff relationships in sub-watersheds throughout the basin, and information about the water quality characteristics of runoff accompanying rainfall events onto major vegetational cover and land use types in the watershed.

The initial water monitoring objective was to collect a total of 5 monitored storm event samples per site over the course of the project period to provide estimates of seasonal and inter-annual variation in runoff loading.

The storm water sampling was initiated with the construction and installation of hydraulic structures (i.e., 90° V-notch weirs), automated, battery operated samplers, bubble-type flow meters, telephones, and rain gauges at 12 sites in the Lake O' the Pines watershed during the summer of 2005. Each sampling station was monitored on a regular basis to assure the instruments maintained proper working order.

3.3.2.1.3 Weir Design and Fabrication

V-notch weirs are often used for measuring runoff from small plots. They have been accurately rated in the laboratory regarding crest characteristics, their placement in the channel or waterway, the approach waterway, flow conditions, and the relation expressed in the form of discharge formulae. Generally, a weir crest consists of a metal blade with a sharp edge. The distinct advantage of the triangular weir is its suitability for measuring high as well as low flows with a high degree of accuracy. The most commonly used triangular weirs have 90° and 120° V-notches.

A Technical Memorandum (PPAI, 2005a) regarding the design of V-notch weirs for the sites was distributed to NETMWD and USDA-ARS for review and comments and finalized (PPAI, 2005b). The design for the project site V-notch weirs were consistent to the criteria found in ASTM International's ASTM D 5242-92 Standard Test Method for Open-Channel Flow Measurement of Water with Thin-Plate Weirs (ASTM, 2001). Calculations were made using the Rational Method equation to estimate the maximum flows the sites, ranging from 0.5 to 10 acres, are likely to experience during the multi-year sample period. The basic equation used for the small rural drainage basins is given by: $Q = kCiA$

where:

Q = the peak flow expressed in cfs or m3/s

k = the conversion factor equal to 1.008 (SI) or .00278 (metric)

C = the dimensionless runoff coefficient

i = the rainfall intensity (in/hr, mm/hr)

A = the catchment area (acres, ha)

Additionally, this memorandum provided construction and installation instructions for the 90° V-notch weir and approach channel dimensions with a diagram to help simplify calibration of the bubbler and for setting the enable and sample trigger levels.

3.3.2.1.4 Weir Structures

Two sets of V-notch weirs (large and small dimension) were pre-cut based on expected peak flows from the different sized sites. The specifications for each of the two 90° V-notch sizes are found in Table 3-2. The large weir dimensions were used at sites NT1, NT-3, NT-4, NT-5, NT-6, NT-7, and NT-8. The small weir dimensions were used at sites NT-2, NT-9, NT-10, NT-11, and NT-12. The main objective of these barriers was to divert sheet flow into the approach channel for water collection and water level measurements.

Table 3-2.
Large and Small 90°V-Notch Weir Dimensions

Specifications	*Large*	*Small*
Weir Plate	78 ¾" wide x 45" deep	41" wide x 30 ½" deep
Box Structure	78 ¾" wide x 45" deep x 144" long	41" wide x 30 ½" deep x 96" long

3.3.2.1.5 Construction and Installation

NETMWD staff began the construction process for the primary flow measurement device (Figure 3-2). At each site, the weir face was attached to the approach box constructed of ¾" plywood and positioned below the natural ground surface (Figures 3-3 and 3-4). Landscape fabric material was placed on the ground in front of each approach channel to encourage the growth of bermudagrass seed applied in this area to help protect against sheet erosion.

An ISCO automated, battery operated sampling system consisting of a bubbler-type flow meter, automatic sampler and necessary accessories, were installed in secure enclosures at each location by NETMWD staff (Figure 3-5).

A shelter cabinet constructed of either sheet metal or fiberglass was placed near each weir structure. Telemetry equipment activated by the water level sensor was installed to initiate water level monitoring and automated water sampling, and to alert NETMWD field staff that a sample event was initiated. Rechargeable batteries and/or solar panels were deployed to supply enough energy to keep the units powered. Additionally, the installation of a perimeter fence with a gate at each location ensured protection from grazing livestock.

Figure 3-2. Installation of Metal Shelter Cabinet

Figure 3-3. Completed Installation at Station NT-4

Figure 3-4 Completed Installation at Station NT-11

Figure 3-5. Automated, Battery Operated Sampling System

3.3.2.1.6 *Programming Automatic Samplers*

For this project, the ISCO Model 3700 and Model 6712 portable water samplers were programmed to collect flow-composite water samples as described by Harmel et al. (2003) from the field periodically over the course of each runoff event (Figure 3-6.). Samples were collected at 2 mm volumetric depth intervals. Each sub-sample was taken in 300 ml amounts, thus allowing 107 mm runoff events to be entirely captured in each 16 liter bottle.

Figure 3-6. Programming Automatic Sampler

Sampler enable levels (corresponding to flow rates of 0.001 - 0.04 m3/s depending on field size) was programmed to capture the "first flush" of runoff, which is expected to account for a large portion of the total nutrient and sediment loading in a runoff event and continue sampling throughout the duration of the runoff event.

3.3.2.1.7 Flow Meter Initialization and Calibration

Bubble flow meter systems detect changes in the level of the flow stream by measuring the amount of air pressure required to force an air bubble from the end of a submerged tube. As the liquid level in the flow stream increases, the amount of air pressure required to force the bubble from the tube also increases.

The bubble rate was set and the flow meter calibration was achieved at each location prior to sample collection. The flow meter was attached to a power source and turned on. The valve knob was tightened in a clockwise direction to prevent the escape of air. The valve was then turned counterclockwise until air bubbles appeared. The knob was carefully adjusted until a rate of one bubble per second was achieved.

To obtain the level status, a length of string was placed in the center of the 90° V-notch weir with a weight positioned on the exit end. After leveling the string, the distance from the bottom of the 90° V-notch weir to the bottom of the weir was marked and measured. This measurement became the level to be programmed in the sampler.

A Secchi tube, marked with the level obtained, was placed on the floor of the weir. Vinyl tubing from the flow meter was inserted into the Secchi tube at the top opening and slowly filled with distilled water. When the programmed level of > 0.05-inches was reached, the sampler became enabled (Figure 3-7.).

Figure 3-7. Flow Meter Calibration

3.3.2.1.8 Rain Gauge Monitoring

Rain gauges were installed at every site to collect data to correlate rainfall patterns with runoff conditions. When connected to a flow meter, the rain gauge enables the flow meter to print rainfall data on its chart or store rainfall data in memory. An ISCO Model 674 tipping bucket rain gauge was mounted to a steel pipe driven into the ground, programmed, set-up, and calibrated at every station. They were located in open areas so nearby structures did not affect the collection data.

3.3.2.1.9 Site Inspection

The construction, installation, and calibration of all field monitoring equipment was completed by June 9, 2005. A site inspection was conducted on June 21-22, 2005 to visually observe any apparent deficiencies involving the final weir structure construction and on-site automated equipment installation. A list of items requiring modification by specific location was identified and corrected by July 15, 2005 and prior to initiation of sampling (PPAI, 2005c).

The final as-built diagram plans that included a description of construction including final changes along with the characteristics and specifications for each of the 12 sites were submitted to the TSSWCB (NETMWD, 2005) on August 9, 2005.

NETMWD supplied a vehicle and the field staff to retrieve samples, delivery of samples to Ana-Lab for analysis, routine calibration and maintenance of all equipment, and recurrent data retrieval from each location.

3.3.2.1.10 Field Protocols

The key aspects of quality control associated with sample collection included the proper use of sample collection gear and the ability to distinguish acceptable versus unacceptable water samples in accordance with the sampling criteria specified in the QAPP; the recognition and avoidance of potential sources of contamination, appropriate sample containers that have been pre-cleaned and are free of contaminants; and the conditions set aside for sample collection, preservation and holding times.

Sample Retrieval

Water samples were collected from the sites only during rainfall events with sufficient overland water runoff to trigger automated samplers. After each rainfall event, the ISCO samplers were inspected within 24 hours by NETMWD field staff to retrieve all water samples that have been collected. The field staff mobilized when weather and flow conditions were considered to be safe and occurring during daylight hours when possible. Properly collected water samples were mixed thoroughly to ensure homogeneity of the water, subdivided on-site into three separate containers provided by Ana-Lab Corporation with the appropriated preservative, stored on ice, and immediately delivered to the laboratory in Kilgore, Texas to meet the required parameter holding times. The site name, collection date, collection time and collector name were written in waterproof ink on each sample container, all samples logged on chain of custody forms and immediately transported to the laboratory under direct custody or custody-sealed delivery for chemical analysis.

Water samples were analyzed only if they met preservation requirements and holding times. Datalogger printouts were checked routinely to ensure that samples came from a rainfall event rather than from some anomaly.

Data Retrieval

Field notes were maintained for all field activities, including the collection of samples and the gathering of field equipment data. The information recorded and stored in the ISCO flow meters was downloaded in the field by NETMWD field staff onto a field laptop computer to obtain sample collection times and corresponding flow data by the ISCO 581 Rapid Transfer Device (RTD). The RTD data was evaluated using ISCO Flowlink 4 software to allow for complete review of the hydrograph, sampling event, and flow measurements.

Equipment Maintenance

General maintenance of the equipment and data handling occurred every two weeks beginning on July 20, 2005 and ended on December 31, 2007. NETMWD field staff recorded all maintenance, repair, or troubleshooting activities on the General Maintenance and Storm Water Sample Collection form. In addition, each rain gauge was serviced every two to three weeks by NETMWD field staff to offload data and re-launch the unit. A general maintenance procedure was followed and a maintenance log sheet was filled out for each rain gauge during every trip. Data sheets were maintained in a bound notebook kept by the NETMWD field staff.

Uploading Data Shuttle Information to the Computer

Information was transferred to a laptop computer using a PC interface cable. Stored data was retrieved from each gauge and saved to the file for that specific location.

3.3.2.2 SWAT Model

The SWAT model is a watershed-scale loading model developed by the USDA-ARS and Texas AgriLife Blackland Research and Extension Center to compute nonpoint source pollutant loads to stream and river systems. The model uses GIS technology, topography, soils, precipitation, plant growth, and crop management information to form a complete deterministic definition of the hydrology and water quality of a watershed. It has evolved through continued review and expansion of capabilities over the past 30 years from a model originally designed to simulate crop dynamics on agricultural catchments to its present version that includes the surface hydrological cycle, runoff and channel routing, storage content in the surface and subsurface, and associated transport and reactions of a variety of waterborne parameters. The model therefore provides a capability for treating general landscape and hydrological processes on large watersheds, and includes the effects of topography, soils, precipitation, plant growth, crop management, and urbanization.

The SWAT model was selected for nutrient loading determinations from the Lake O' the Pines watershed, and its application in the Lake O' the Pines TMDL is detailed in Ward (2001a, 2002, and 2003). For the TMDL application, the Lake O' the Pines watershed was comprised of 25 sub-basins. Fifteen subbasins were used to depict the complex watershed of the Big Cypress Creek, the main riverine input into the reservoir, and 10 subbasins to depict the other tributaries that flow into the Lake O' the Pines (Ward, 2003).

For this project, the SWAT model was used to quantify the effects of applying BMPs on phosphorous loadings to streams, rivers, and lakes (as appropriate) in each watershed. The effectiveness of these BMPs was evaluated through 12 separate and independent small-scale comparative runoff plots which were integrated with the water quality data collected and compiled through CRP and the TMDL. This analysis will supplement and complement monitoring in Lake O' the Pines and its watershed currently conducted through CRP and the TMDL I-Plan.

Water quality samples and flow data were used to develop edge-of-field sources to the model. The data was collected and compiled by NETMWD field staff prior to the initiation of the modeling project. The information was placed in electronic form for use in model development to HDR. HDR reviewed the sufficiency of the data and coordinated with the Center for Research in Water Resources, University of Texas-Austin (CRWR) for any deficiencies. Watershed data are the primary input drivers of nonpoint source loadings to the SWAT model. HDR provided electronic copies of the relevant information containing the flow and water quality constituents via CD and email to CRWR. GIS and water quality data required for SWAT model setup and calibration include, but are not limited to those identified below. All GIS data has a single common projection.

- Digital Elevation
- Digital Ortho Quads
- Soils
- Land use and land cover
- Fire coverage
- Hydrography
- Stream Gauge Locations
- Weather Stations
- Water features
- Point sources
- Climate
- Basins
- Geology
- Cities
- Infrastructure
- Transportation

Several technical memoranda were prepared by CRWR during the project to track progress, decisions, and assumptions and to form the basis for this report that summarizes the model development and calibration. The objective was to contain the necessary detail to complete SWAT model setup and calibration for each sub-watershed, and accurately reproduce modeling results.

3.3.2.2.1 Sample Verification and Validation

The HDR Project Manager reviewed all data collected by NETMWD staff from the ISCO dataloggers during the project to determine if the data met holding times, appropriate preservation, handling, and lab quality assurance (QA) procedures.

3.3.2.2.2 Acceptance Criteria for Accepting Existing Data

The process of reviewing the submitted data began June 2008 to determine the need for supplemental information from HDR Engineering, Inc. A request was prepared by CRWR for HDR to provide GIS-based output for use in the development of the SWAT models. This additional effort included large-area aerial maps showing each site including delineation of the subwatershed areas for each; computed measurement of each subwatershed area; land use/vegetation for each subwatershed; and location of wastewater discharges or returns in relation to each site location.

A three-tiered approach was used for the processing and reduction of raw digitized data sets recovered from each of the 12 ISCO automated samplers in order to apply an appropriate QA level with the confidence needed in modeling results. The fundamental requirements that define the QA level critical for format consistency involved intensive data QA protocols to detect and either repair or expunge errant records.

3.3.2.2.3 Three-Tier Data Screening

Tier 1: Processing of the raw field data into database files facilitated by special-purpose software and limited post-processing, effected by NETMWD staff and HDR, the data-collection contractor;

Tier 2: Manual inspection of data files verifying/correcting all conversions, and screening for aberrant values (spurious zeroes, spikes, and numbers out of the physical range), carried out by CRWR in the modeling phase of the project;

Tier 3: Data screening based upon cross comparison of variables (e.g., flow versus rainfall), cross comparison with other stations, and assessment of the physical plausibility of the data, performed by CRWR in the modeling phase project.

In the Tier 1 process, invalid data are expunged from the record. Tiers 2 and 3 are screening processes, in which data are eliminated from consideration in the analysis and modeling tasks, but retained for archival purposes in the master data base. Tier 2 is based upon the continuity, magnitude, and general temporal behavior of the data streams for each parameter. In this level of QA improbable values are identified and removed from the database to be used in analysis and modeling. Suspicious data were flagged for closer review later. The Tier 3 process, based upon the comparison of rainfall magnitudes and the measured runoff at the site in question and contemporaneously at other sites. Where suspicious data had been flagged in Tier 2 they can be quantitatively compared in Tier 3 for consistency at the station and with other stations.

3.3.2.3 On-Site Sewage Facility Regulation and Inspection

Replacement of failed OSSFs improve the quality of water in receiving basins and aquifers because the effluent travels through soils that effectively remove bacteria and other pollutants from the water. All new systems installed were required to be checked and certified for operation by the county health departments.

NETMWD received a total of 43 applications for system replacement and expended approximately $192,880 of the project match dollars on these replacement projects.

3.3.2.3.1 Installations

A total of 42 systems were installed at no cost to the landowner. These included 7 conventional and one alternative system. The alternatives included one drip system adjusted to non-standard site and layout specifications; five low pressure dosing systems, and 27 aerobic systems with surface spray application.

3.4 General Project Area Descriptions

The edge-of-field project area is situated in the upper, western portion of the Cypress Creek Basin in a transitional zone between the South and East Central Texas Plains Ecoregions (Ecoregions 33 and 35) (Omernik, 1987). The two major vegetational areas corresponding to the South and East Central Texas Plains Ecoregions are the post oak savanna and pine forests. The post oak savannah is a north-south strip in the central part of eastern Texas encompassing the western portion of the Cypress Creek basin. Although post oak and blackjack oak constitute the dominant climax overstory vegetation, loblolly and shortleaf pine are also common. The post oak savanna consists of a mosaic of woodland and native prairie which has experienced substantial clearing and agricultural development.

Annual rainfall ranges from 35 inches per year at the western extreme of the basin to near 50 inches annually at Ferrels Bridge Dam, which was closed to impound Big Cypress Creek, forming Lake O' the Pines in 1958. Temperatures average near 90° Fahrenheit in the summer and winter freezes can be expected each year, but temperatures as low as 0° Fahrenheit are rare. The abundant rainfall and low regional slope result in frequent floods that overflow onto floodplains for lengthy periods, leaving water-filled oxbow lakes, sloughs and other water-filled depressions behind when they recede. These floodplain habitats associated with the waterways are used as important dispersal highways by eastern forest dwelling animals to move beyond the forest limits, into areas such as the Blackland prairies, where upland vegetation types present a barrier to them. Regionally, the predominate soil textures in the upland soils tend to be acid sandy loams or sands, while bottomland soils are typically brown to dark gray, acid sandy loams to clays. The regional landscape consists of rolling wooded hills with regional elevations of 200 to 800 feet above sea level, but with limited local relief, gentle slopes, and broad, frequently flooded, densely vegetated stream bottoms.

3.4.1 General Weather and Sampling Conditions

The weather conditions in the Northeast Texas area at the time of sample collection initiation were dryer than normal. As of September 2005, this region was approximately 11 inches below the average for rainfall for the year. In late September, Hurricane Rita made landfall in southeastern Louisiana and steadily weakened as the storm advanced northward providing beneficial rainfall over portions of the drought-stricken region. The Palmer Hydrological Drought Index (PDSI), primarily an indicator of meteorological drought revealed Northeast Texas as being in severe drought conditions in December 2005. During 2006, Northeast Texas was experiencing exceptional drought ranging from moderate to severe conditions. Dry weather prevailed in the Big Cypress Creek Basin until late December 2006 when a major winter storm and associated strong cold front moved across the central and eastern United States. The frequent and widespread rainfall observed during the latter half of December 2006 and severe weather through much of January 2007 associated with a series of snow and ice storms allowed for the improvement of drought conditions with January monthly rainfall totals of 4 to 8 inches across portions of Northeast Texas.

In 2007, the area experienced an extremely wet first half and a proportionally even drier second half. Due to the combination of excessive rain, cloudiness, and cool temperatures during

May 2007, the area was removed from drought status ending more than two years of drought in East Texas. Twelve-month precipitation exceeded 100% of normal at the end of May 2007, marking the last of the drought markers to fall. Area lakes and streams were all either full or in flood for most of July 2007. The major river systems and smaller streams of the area including Big Cypress Creek were in flood stage throughout the entire month. Turbulent weather conditions persisted in August and September with the development of Tropical Storm Erin, Hurricane Dean, and Hurricane Humber to produced localized cool temperatures and considerable shower activity. Although significant rainfall fell in the area toward the end of the year, December 2007 continued a trend, beginning in mid-July, of below normal rainfall amounts.

3.4.2 General Study Area Soil Characteristics

The Soil Survey Geographic (SSURGO) databases were available for Camp, Titus, and Morris Counties. SSURGO is the most detailed level of soil mapping done by the NRCS. These soil databases were downloaded and merged together to create the soils database for the 12 sites. A total of 12 major soils are distributed throughout the project area. The dominant soil series identified were Besner, Bowie, Cuthbert, Derly, Estes, Freestone, Grayrock, Kirvin, Kullit, Lilbert, Raino, and Talco.

3.4.3 Physical Descriptions of Sampling Stations

The identity of individual landowner participants in this project have been kept confidential to encourage cooperation in addressing the project objectives. The volunteers were assigned a site number to protect their privacy. Figure 3-1 shows the general location of each sample area in the Basin. A brief description of each collection station is presented in the following subsections. Table 3-3 presents background information regarding the 12 experimental monitoring station locations selected for the edge-of-field study program. Typically, all monitoring sites were found on a landscape dominated by pastureland and rural residential areas.

Table 3-3.
Characteristics of the 12 Watersheds Monitored in the Upper Cypress Creek Basin

Station Number	County	Sub-Watershed	Total Site Drainage Area (ac)	Watershed Slope (average)	WQMP Strategy	Number of Water Samples Collected	Soil Types and Percent Composition	Reconnaissance Date	Installation Date	Calibration Date
NT1	Camp	Dry Creek	10.8	2.0×10^{-2}	No	7	Bowie - 95% Kullit - 5%	13 April 2005	19 May 2005	9 June 2005
NT2	Camp	Big Cypress Creek	0.73	3.0×10^{-2}	No	9	Bowie - 100%	31 March 2005	18 May 2005	9 June 2005
NT3	Camp	Lake Bob Sandlin	6.2	1.8×10^{-2}	Yes Nutrient Limitation	4	Bowie - 74% Lilbert - 26%	31 March 2005	19 May 2005	9 June 2005
NT4	Camp	Dry Creek	6.9	2.1×10^{-2}	No	11	Bowie - 60% Lilbert - 1% Kullit - 14% Kirvin - 19% Cuthbert - 6%	31 March 2005	18 May 2005	7 June 2005
NT5	Titus	Williamson Creek	10.6	2.2×10^{-2}	No	0	Bowie - 100%	1 April 2005	20 May 2005	7June 2005
NT6	Camp	Prairie Creek	1.9	3.0×10^{-2}	No	4	Bowie - 58% Talco Raino - 42%	24 May 2005	24 May 2005	7 June 2005
NT7	Titus	Little Boggy Creek	4.4	6.6×10^{-2}	Yes Commercial Fertilizer	4	Bowie - 44% Cuthbert - 52% Kirvin - 4%	1 April 2005	23 May 2005	7 June 2005
NT8	Morris	Boggy Creek	9.6	1.9×10^{-2}	No	5	Besner-Talco - 55% Cuthbert - 25% Estes - 20%	14 April 2005	17 May 2005	9 June 2005
NT9	Titus	Boggy Creek	1.3	3.4×10^{-2}	No	0	Cuthbert - 90% Kullit - 10%	1 April 2005	23 May 2005	7 June 2005
NT10	Morris	Boggy Creek	3.0	3.4×10^{-2}	Yes Nutrient Limitation	3	Lilbert - 100%	14 April 2005	24 May 2005	7 June 2005
NT11	Titus	Tankersley Creek	1.8	2×10^{-2}	Yes Commercial Fertilizer	8	Grayrock - 100%	13 April 2005	19 May 2005	6 June 2005
NT12	Titus	Tankersley Creek	0.54	2.5×10^{-2}	No	8	Derly-Raino - 39% Freestone - 61%	13 April 2005	20 May 2005	6 June 2005

3.4.3.1 Station NT-1

Station NT1 was located in Camp County (Figure 3-8). The site consisted of a large pasture area that gently slopes to the north into a small, unnamed ephemeral drainage that ultimately empties into Dry Creek. The total site area upstream of the weir structure was approximately 10.8 acres and was the largest site. Land use practices over the last 5 years consisted of cattle grazing and hay production. The land use during the project period was pasture with no BMPs. Soil types included Bowie fine sandy loam, 2 to 5% slopes and Kullit very fine sandy loam, 1 to 3% slopes.

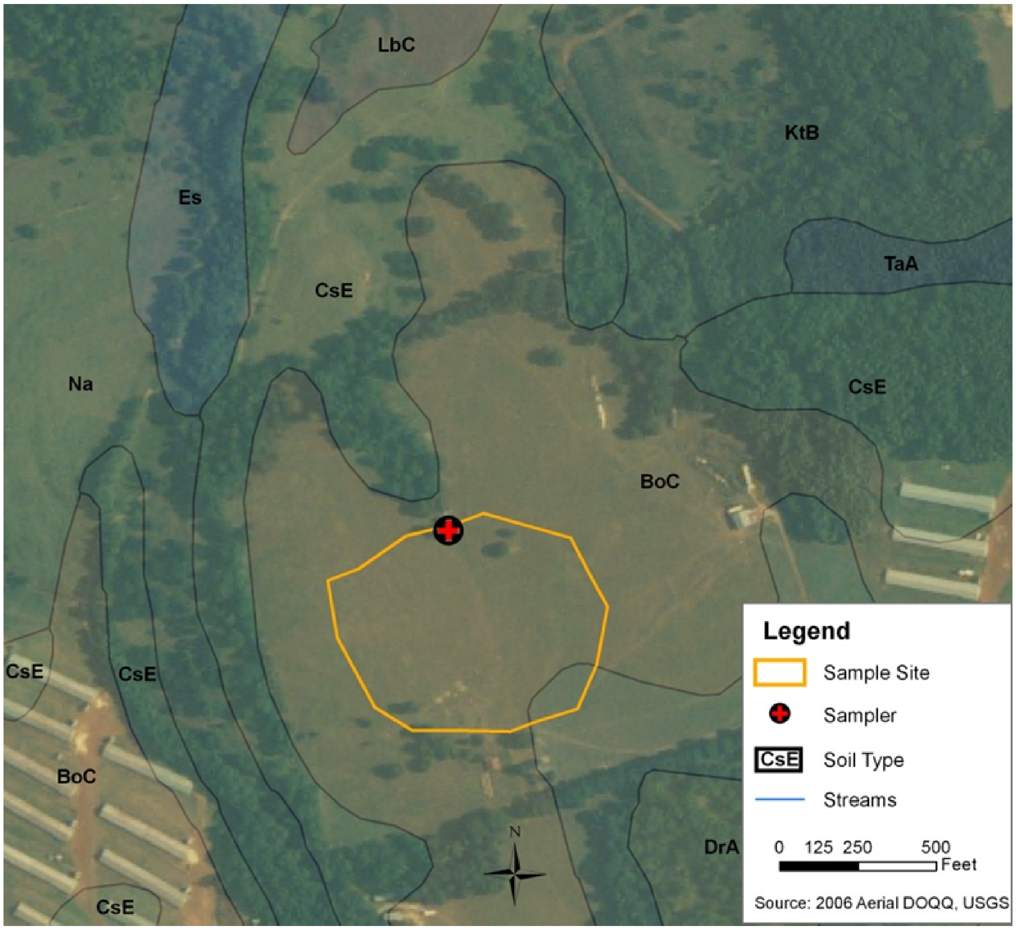

Figure 3-8. Station NT1

3.4.3.2 Station NT-2

Station NT-2 was located in Camp County (Figure 3-9). This field was a small pasture area that slopes to the east into a narrow channel that connects with a stock pond and eventually drains into an unnamed minor tributary that contributes surface runoff directly to Big Cypress Creek. Total area of the field above the weir structure is approximately 0.73 acres. Land use practices over the last 5 years consisted of cattle grazing and hay production. This area was being used as pasture during the project period with no BMPs. The soil type was entirely composed of the Bowie fine sandy loam, 2 to 5% slopes.

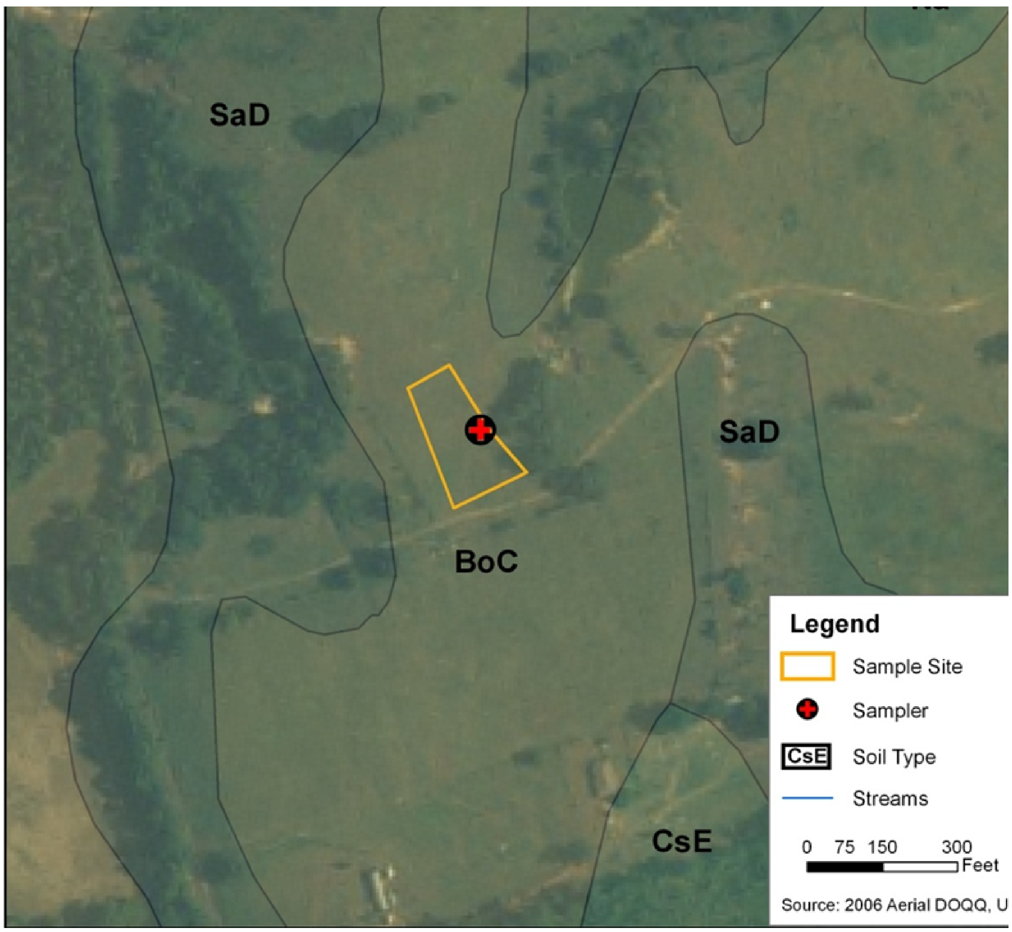

Figure 3-9. Station NT-2

3.4.3.3 Station NT-3

Station NT-3 was located in Camp County (Figure 3-10). The land area upstream of the weir structure was approximately 6.2 acres that gently slopes to the west into a small channel that connects to a stock pond. This was the westernmost site of the project and was located on an unnamed tributary that connected directly with Lake Bob Sandlin. Land use practices over the last 5 years consisted of cattle grazing and hay production. Current use of the land during the project was hay production using commercial fertilizer (21-0-21) only; no broiler litter has been applied over the last 5 years. Two major soil types within the drainage area included Bowie fine sandy loam, 2 to 5% slopes and Lilbert loamy fine sand, 2 to 5% slopes.

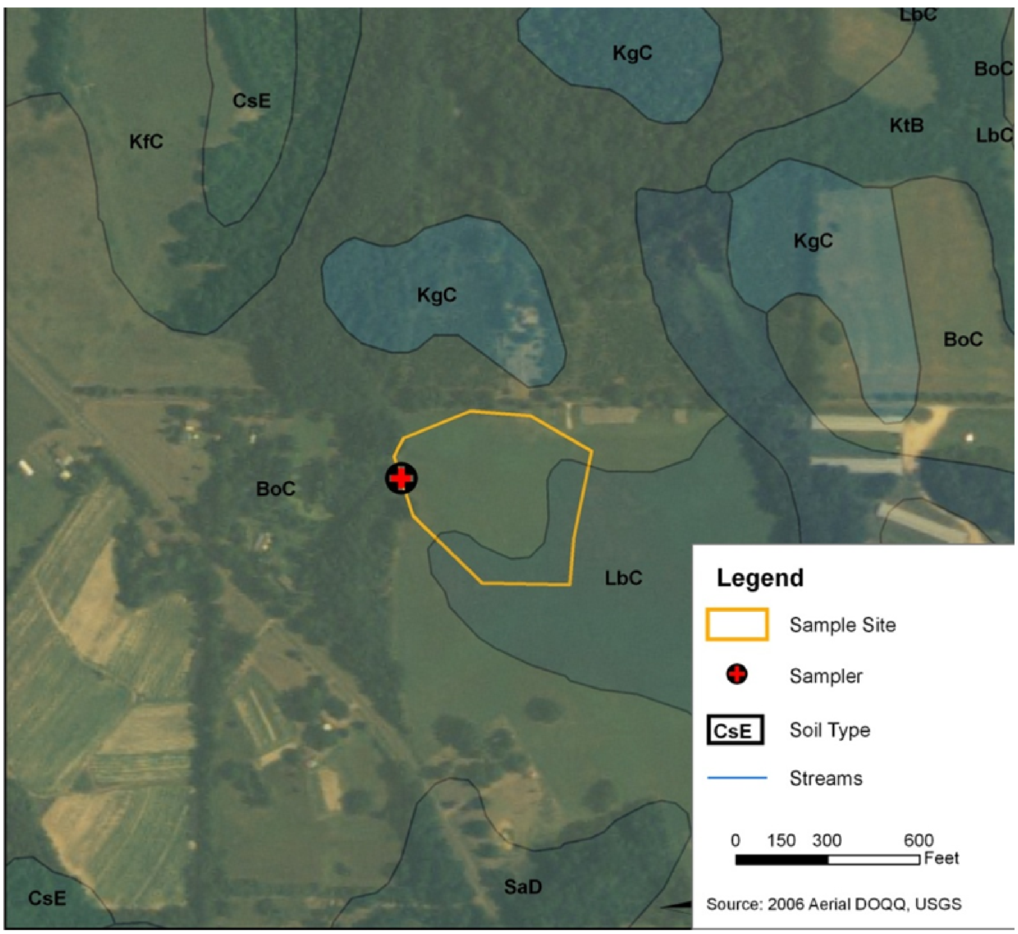

Figure 3-10. Station NT-3

3.4.3.4 Station NT-4

Station NT-4 was located in Camp County (Figure 3-11). The total land area upstream of the weir structure was approximately 6.9 acres. This site was a large pasture area that gently slopes to the east into a small, unnamed ephemeral channel that connects with a stock pond in the Dry Creek subwatershed. Land use practices over the last 5 years consisted of cattle production and hay meadow. This area was being used as pasture during the project period with no BMPs. Five soil types within the site included Bowie fine sandy loam, 2 to 5% slopes, Lilbert loamy fine sand, 2 to 5% slopes, Kullit very fine sandy loam, 1 to 3% slopes, Kirvin very fine sandy loam, 3 to 8% slopes, and Cuthbert fine sandy loam, 8 to 25% slopes.

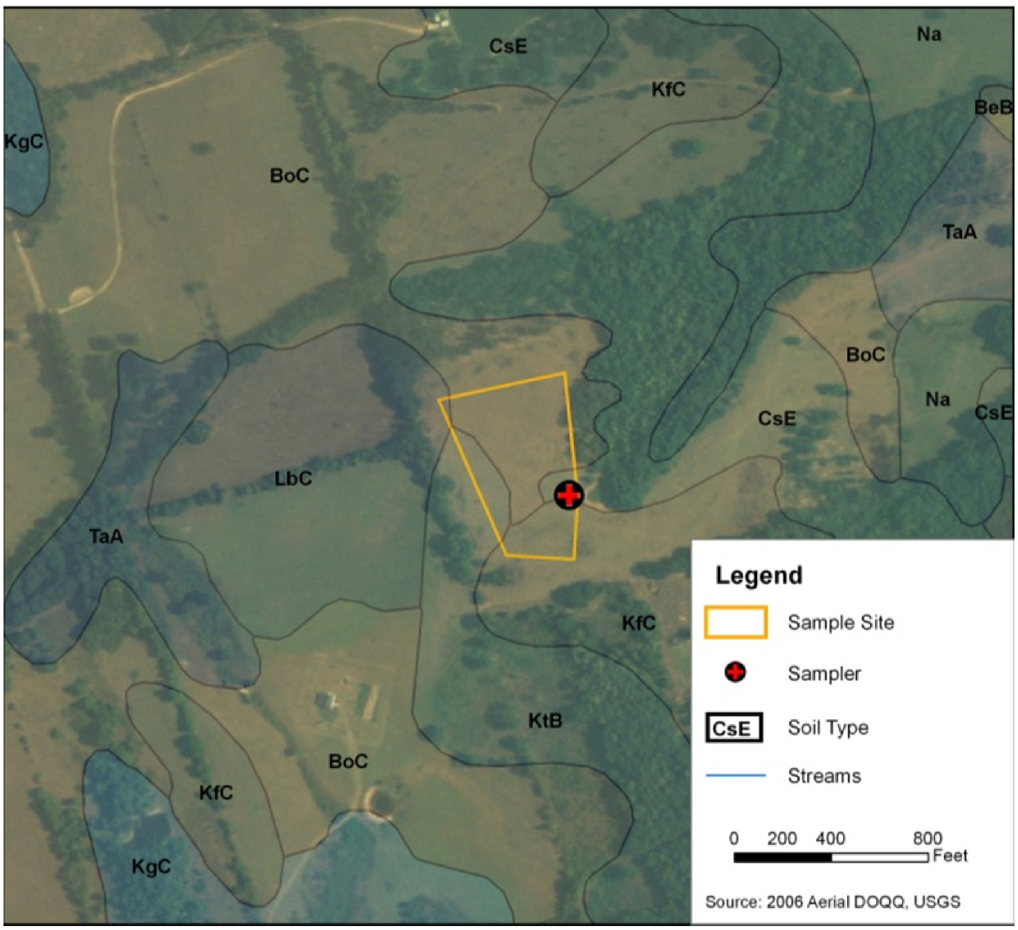

Figure 3-11. Station NT-4

3.4.3.5 Station NT-5

Station NT-5 was located in Titus County (Figure 3-12). The total site area upstream of the weir structure was approximately 10.6 acres. This site was the second largest area surveyed and was being used as pasture during the collection period. Past land use has been as a hay meadow with no BMPs. This field slopes gently in a north-northeast direction into a low-lying grassy swale near a gated fenceline in the Williamson Creek subwatershed which drains directly into Big Cypress Creek. The area was characterized by one major soil type: Bowie fine sandy loam, 2 to 5% slopes.

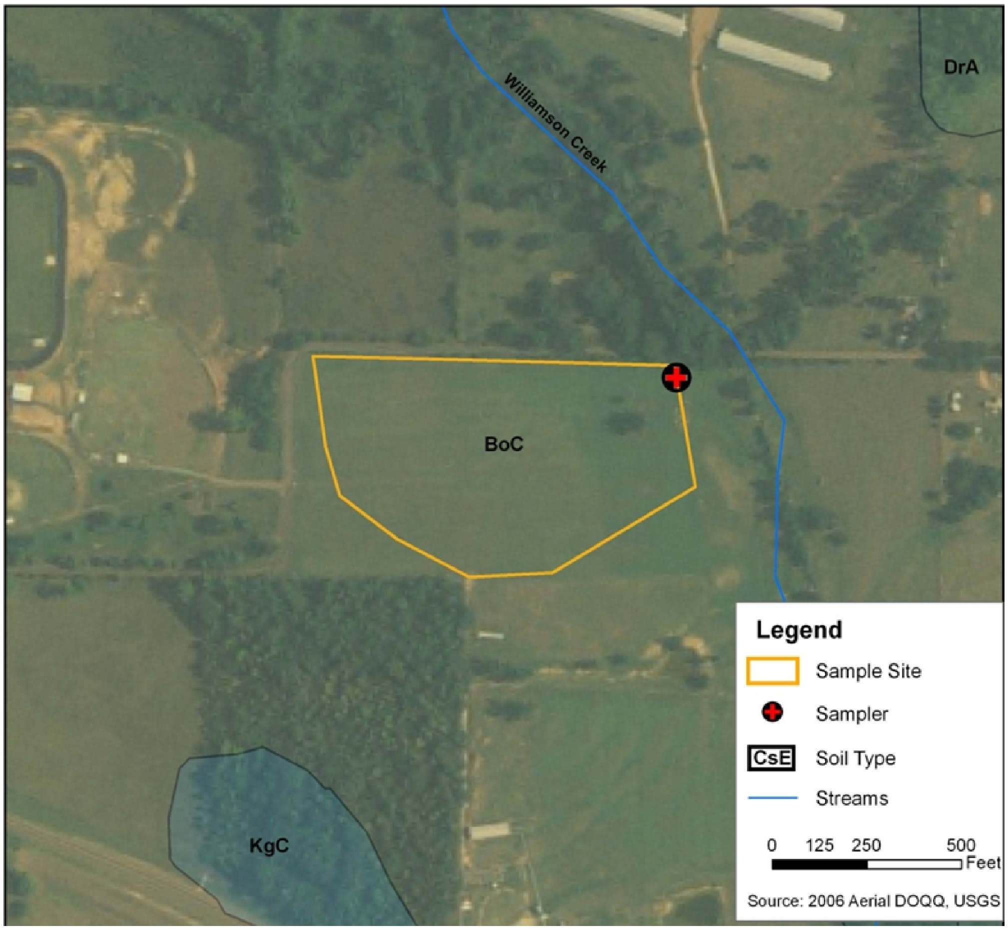

Figure 3-12. Station NT-5

3.4.3.6 Station NT-6

Station NT-6 was located in Camp County (Figure 3-13). The total land area upstream of the weir structure was approximately 1.9 acres. This field had been historically used as a hay meadow and was being used as pasture during the collection period with no BMPs. This area was found on the headwaters of an unnamed tributary of Coopwood Branch in the Lilly Creek subwatershed near the drainage divide with Darby Creek. This location is the only site located in the southwest section of the Big Cypress basin. The soils found at this location include Bowie fine sandy loam, 2 to 5% slopes and the Talco-Raino complex, 0 to 1% slopes.

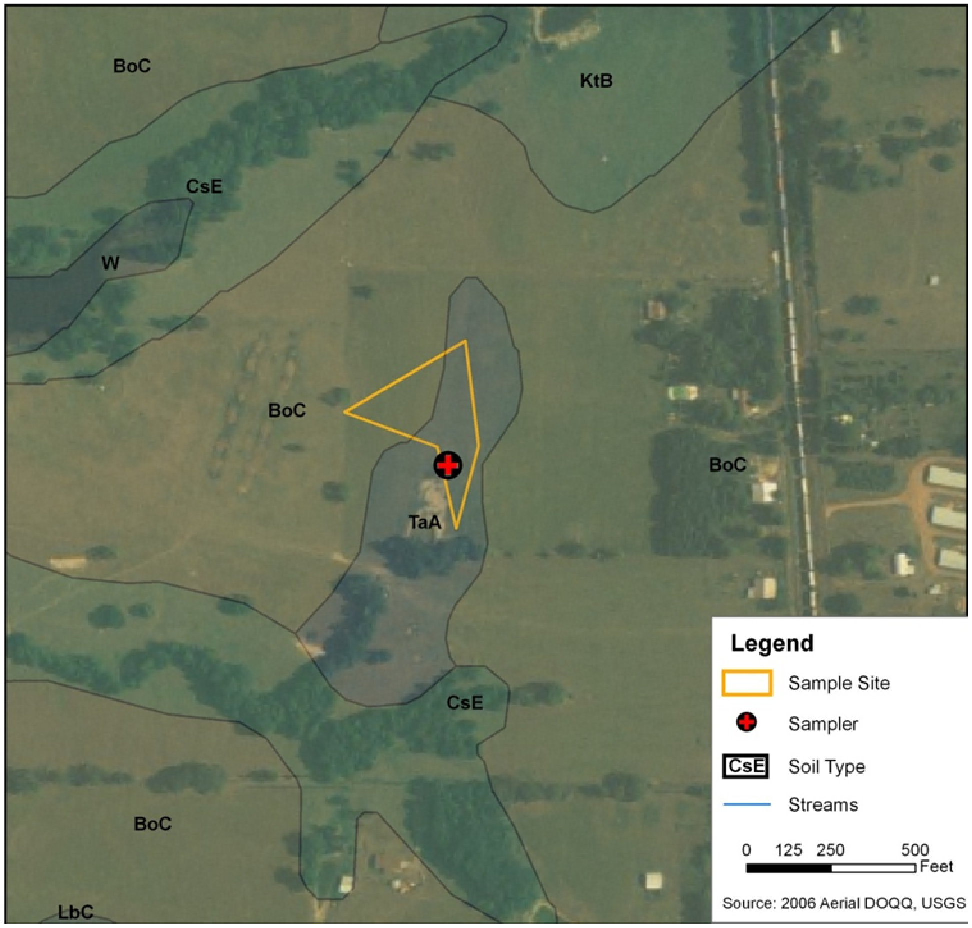

Figure 3-13. Station NT-6

3.4.3.7 Station NT-7

Station NT-7 was situated in Titus County (Figure 3-14). The total land area upstream of the weir structure was approximately 4.4 acres. This field is a hay meadow that was being used as pasture during the project period that was operating under a WQMP. This land tract is fairly steep and slopes to the west and southwest toward a small, unnamed headwater channel in the upper reach of Little Boggy Creek in the Boggy Creek subwatershed. The area was characterized by three major soil types: Bowie fine sandy loam, 2 to 5% slopes, Cuthbert fine sandy loam, 8 to 25% slopes, and Kirvin gravelly fine sandy loam, 3 to 8% slopes.

Figure 3-14. Station NT-7

3.4.3.8 Station NT-8

Station NT-8 was located in Morris County (Figure 3-15). The total land area upstream of the weir structure was approximately 9.6 acres. This site was a large pasture area with no BMPs that gently slopes to the west across a fenceline into an adjacent pasture. A low wet depression approximately 0.45 acres was present along a 150 feet length of fence that separated the two fields. A closer inspection of surface slope was made by NETMWD staff to evaluate water movement prior to weir installation. This property drained into an unnamed tributary in the Boggy Creek subwatershed west of Daingerfield. Land use over the last 5 years consisted of cattle grazing and hay production. Major soil types include Besner-Talco complex, 1 to 2% slopes, Cuthbert fine sandy loam, 8 to 25% slopes, and Estes clay loam, frequently flooded.

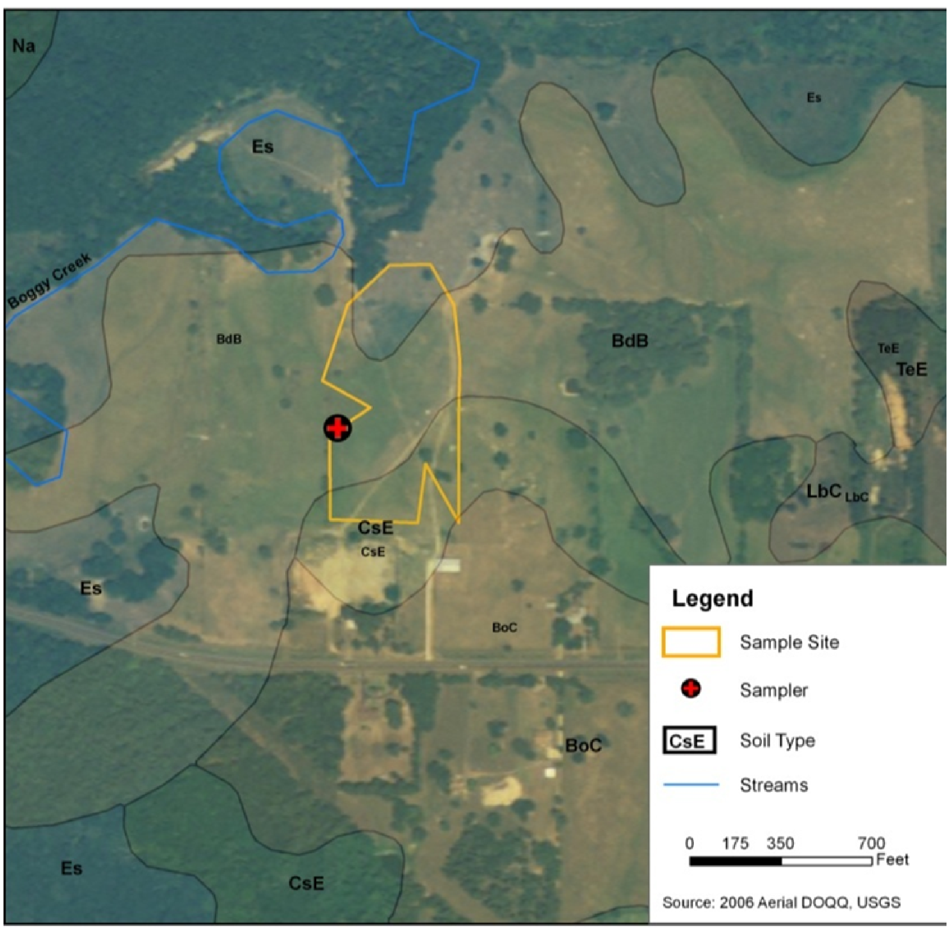

Figure 3-15. Station NT-8

3.4.3.9 Station NT-9

Station NT-9 was located in Titus County (Figure 3-16). The total land area upstream of the weir structure was approximately 1.3 acres. This site was a small pasture area with no BMPs that slopes to the southeast into a narrow ravine that interconnects with an unnamed tributary found in the Boggy Creek subwatershed. The land use during the project period was cattle grazing. The soils found at this location include Cuthbert fine sandy loam, 8 to 25% slopes and Kullit very fine sandy loam, 1 to 3% slopes.

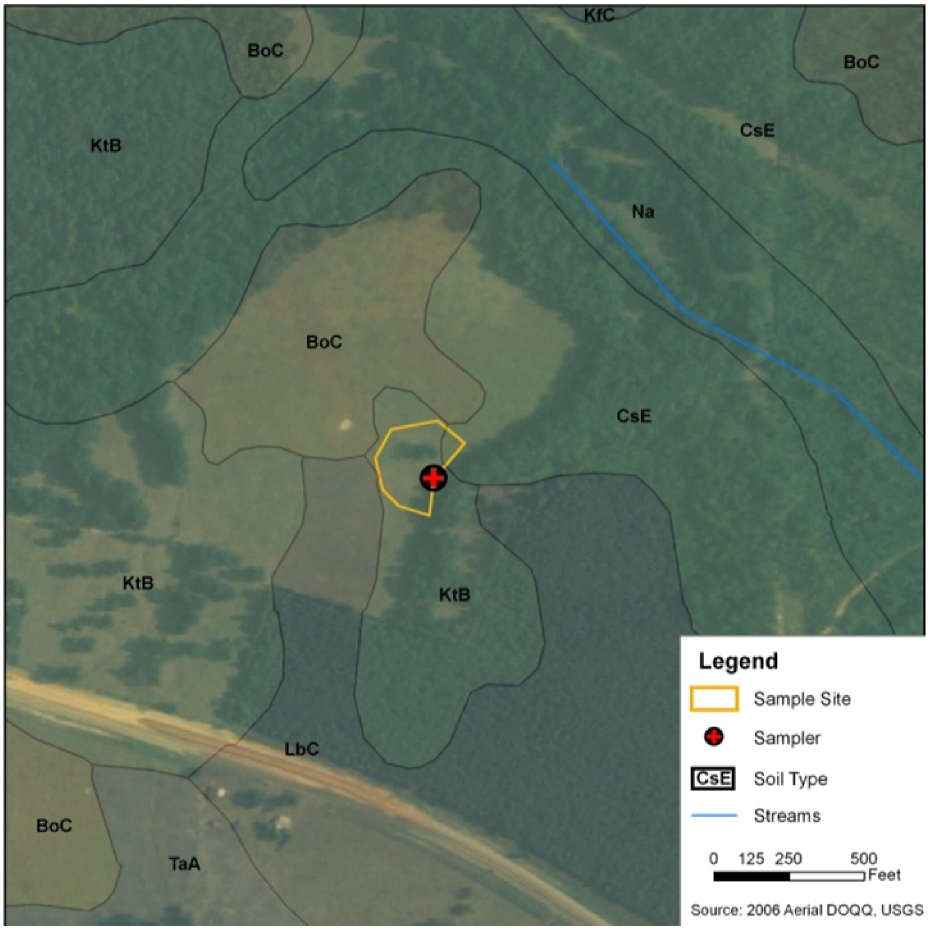

Figure 3-16. Station NT-9

3.4.3.10 Station NT-10

Station NT-10 was located in Morris County (Figure 3-17). The total land area upstream of the weir structure was approximately 3.0 acres. This hay meadow field was being used as pasture during the project period and operating under a WQMP. The landscape gently slopes along a low-lying depression to the southwest that contributes runoff to an unnamed tributary of Okry Creek found in the upper portion of the Boggy Creek subwatershed. The area was characterized by one major soil type: Lilbert loamy fine sand, 2 to 5% slopes.

Figure 3-17. Station NT-10

3.4.3.11 Station NT-11

Station NT-11 was located in Titus County (Figure 3-18). The total site area upstream of the weir structure was approximately 1.8 acres. This site was located on reclaimed mine property adjacent a small constructed stock tank in the upper portion of Dragoo Creek which ultimately drains into the Tankersley Creek subwatershed west of Mount Pleasant. This field is a pasture that was being used for hay production during the project period. Available records show this field received commercial fertilizer treatment, assumed to be 21-0-21, in 2004 and 2005 at application rates of 0.175 tons/ac and 0.275 tons/ac, respectively. The soil type was entirely composed of the Grayrock silty clay loam, 2 to 5% slopes.

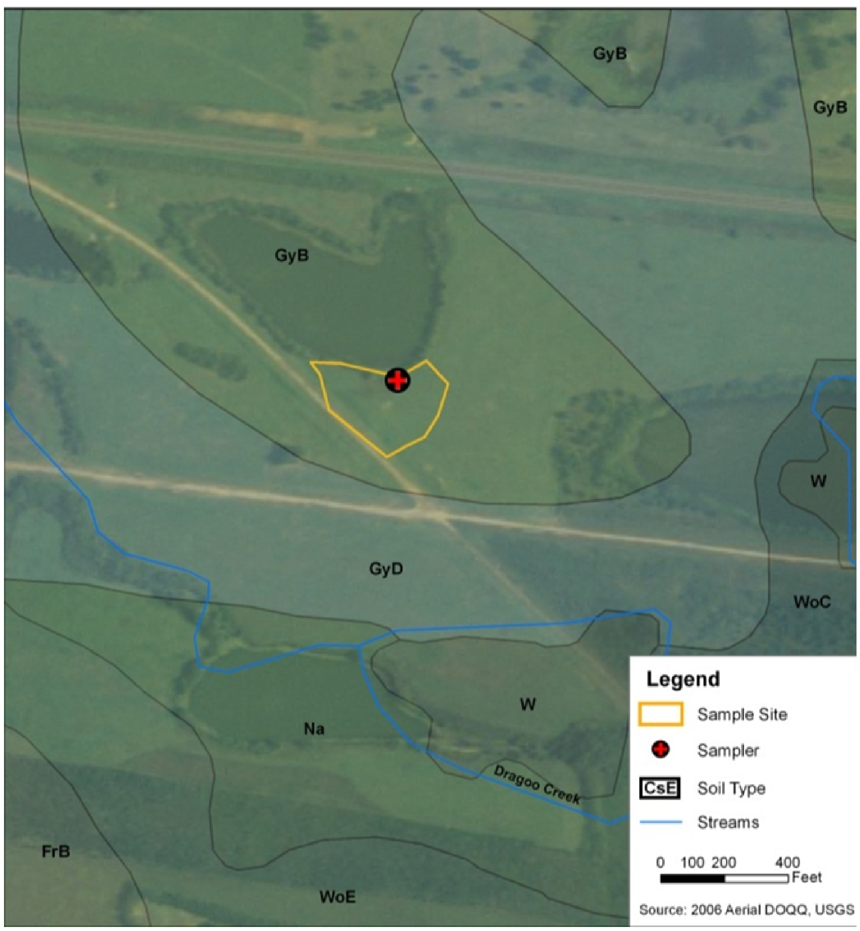

Figure 3-18. Station NT-11

3.4.3.12 Station NT-12

Station NT-12 was located in Titus County (Figure 3-19.). The total land area upstream of the weir structure was approximately 0.54 acres, the smallest area sampled during this project. This pasture has and was being used for hay production during the project period with no BMPs. This field was found in the headwater segment of Tankersley Creek in an area disturbed by past mining activity. The surface slope of the field sample terrain was much greater than the description of the soil units mapped for this location. The two major soil units documented for this area consisted of the Derly-Raino complex, 0 to 1% slopes and Freestone fine sandy loam, 1 to 3% slopes.

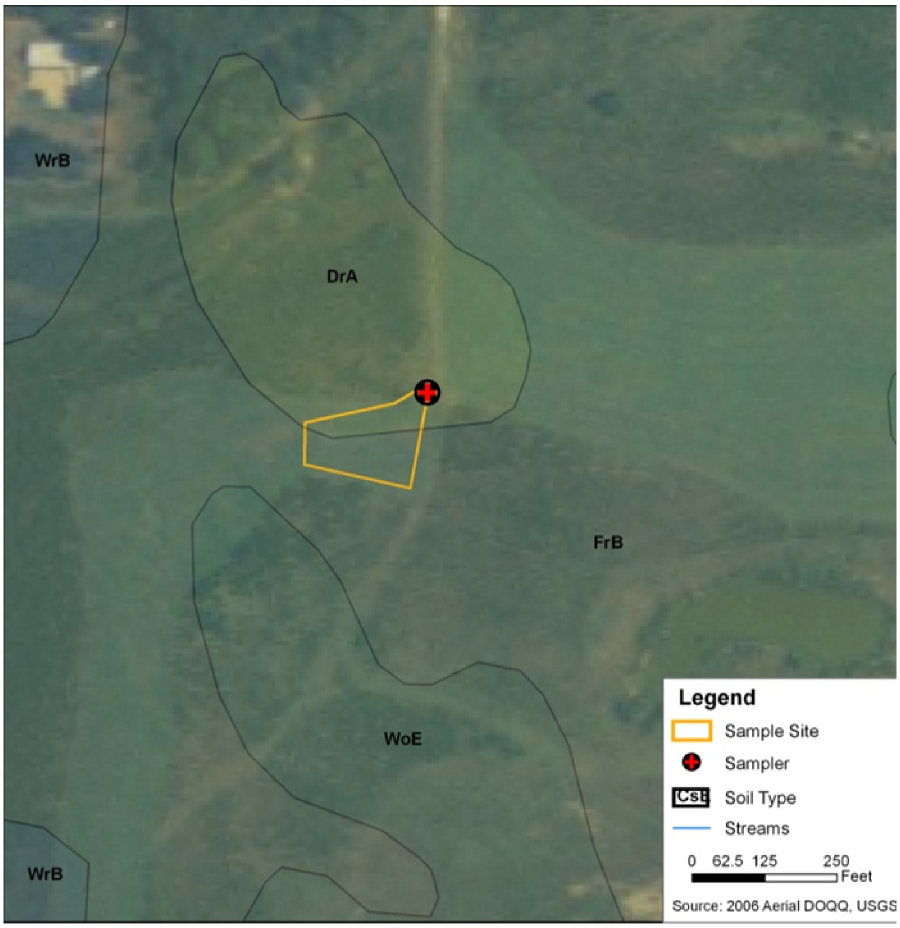

Figure 3-19. Station NT-12

4.0 Monitoring Survey Results

4.1 Soil Sample Collections

Each soil type within the boundary of each location was identified, sampled at two depth intervals, and tested to determine which soils have the greatest potential to supply phosphorus to runoff.

All sampling sites were characteristic of pastureland. Key sources of environmental variability involve differences between several factors including edaphic (i.e., soil depth and fertility), biological (disease, insect pests, and weeds), and climatic (rainfall and temperature). Farm management inputs play an important role on pasture composition over time. Many of the study pastures were left ungrazed in order to cut for hay or silage while others were intended for livestock production. The objective of maintaining a productive pasture may require the planting of different species that vary in their adaption to soils and requirement for nutrients.

Awareness of possible agricultural contributions to nonpoint source runoff requires that these small sub-watershed systems be considered for their mitigation of contaminants from field runoff. An important intent of the project was inclusion of several watersheds with WQMPs in place, ideally exemplifying different BMP strategies. Implementation of BMPs is the most effective and practical means available to reduce or prevent nonpoint source pollution from agricultural operations. The data and modeling of these watersheds were to enable evaluation of the efficacy of WQMP's by comparing to similar watershed lacking such adaptive strategies. As matters developed, the overwhelming criterion for site selection was the willingness of the landowner to grant access for operation of the sampling equipment. At the time of final site selection and during monitoring, only four of the project landowner participants (Stations NT-3, NT-7, NT-10, and NT-11) were utilizing nutrient management plans (NMPs) to better manage field inputs that sustain crop production and protect the environment (Table 3-1).

Table 4-1 presents the numeric value of each soil type for the 0-6 inch and 6-24 inch depth levels and an interpretation of the soil test values based on the relative amounts of each constituent in the soil. Fertility recommendations are made based on amounts of actual nutrients in the soil, not on the amount of any particular fertilizer or mixture.

Figures 3-8 through 3-19 show the soil types at each site. As Table 3-1 indicates, the 12 sites were all composed of pasture/hayfields on fine-grained, loamy soils; primarily fine sandy loams (seven series), but also silty loams (Talco, Derly), silty clay (Grayrock) and clay loams (Estes). The most commonly occurring soil types were of the Bowie (BoC) found at seven sites and Cuthbert (CsE) series found at four sites. While Station NT-12 is shown to be composed of the Derly-Raino complex (DrA) and Freestone (FrB) soils, it is actually reclaimed mine land mixed, reserved topsoil has been replaced and the landscape contoured prior to planting pasture grasses. Together, the 12 sites included soils that occupy at least a third of the Lake O' the Pines drainage area (NRCS Soil Series Extent Map, http://www.cei.psu.edu/soiltool).

Soils at all sites were acidic, with slight to moderately acid pH values (5.5-6.8) predominant. More strongly acid soils (pH 4.4-5.4) were present in portions of sites NT-6, NT-7, NT-8, and NT-9 (Table 4-1). The least acid soils were present at NT-1 and NT-2, which also exhibited, by far, the highest concentrations of the divalent cations, calcium and magnesium, which suggests a substantially lower solubility of phosphorus at these sites relative to the remaining sites.

Calcium, with one exception, was the dominant cation in individual soil samples. Considering whole sites, the divalent cations were more abundant (generally 2-4 times) than the monovalent potassium and sodium ions, although only slightly so at site NT-9. Stations NT-1 and NT-2 stand out relative to the others, exhibiting divalent:monovalent concentration ratios of about 10:1 and 8:1, respectively.

Nitrogen in the nitrate form (NO_3) is the main threat to groundwater quality because it can leach deeply into the soil and contaminate well water. Like elemental nitrogen (N), nitrate is water soluble and not held by the soil. With respect to nutrients, nitrate was present in concentrations ranging from 1 to about 26 parts per million (ppm) [milligrams per kilograms (mg/kg)] in individual soil samples. Considering only the surface sample collections (0-6 inches), since nutrients in the upper soil levels are the most likely to be mobilized in runoff from these small watersheds, NT-2, NT-4, NT-6, NT-8, NT-9, and NT 11 exhibited the lowest nitrate concentrations (~2-5 ppm), while the highest concentrations were present at NT-10 (Table 4-1). Average nitrate concentration across all sample locations was 6.8 ppm. With regard to the two most frequent soil types sampled, nitrate concentrations in the surface layer ranged from 3 to 13 ppm in the Bowie soils (average 7.9 ppm) and 2 to 7 ppm (average 3.5 ppm) in the Cuthbert soils.

Table 4-1.
Soil Constituents Measured in the Surface and Subsurface Layer Samples
July 2005 and February 2007

Station Number	Collection Date	Soil Type	Soil Depth (inches)	Soil Analysis								
				pH (log l/[H=+]	Conductivity μmhos/cm	Nitrate-N (ppm)	Phosphorous (ppm)	Potassium (ppm)	Calcium (ppm)	Magnesium (ppm)	Sulfur (ppm)	Sodium (ppm)
NT1-A	14 July 2005	Bowie	0-6	5.5	95	12.83	92	108	371	86	--	141
NT1-B	14 July 2005	Bowie	6-24	5.7	74	7.12	76	136	469	117	--	135
NT2-A	13 July 2005	Bowie	0-6	6.0	121	13.57	53	102	500	37	--	198
NT2-B	13 July 2005	Bowie	6-24	5.8	73	10.21	24	87	284	23	--	138
NT3-A	7 February 2007	Bowie	0-6	6.0	90	8	275	30	670	33	12	144
NT3-A	7 February 2007	Lilbert	0-6	6.6	123	8	136	84	795	34	10	109
NT-3B	7 February 2007	Bowie	6-24	6.1	41	2	86	92	463	60	10	119
NT3-B	7 February 2007	Lilbert	6-24	5.8	61	2	77	55	597	95	9	128
NT4-A	7 February 2007	Bowie	0-6	5.5	28	3	32	92	407	57	11	120
NT4-A	7 February 2007	Cuthbert	0-6	5.4	44	2	14	95	574	99	12	127
NT4-A	7 February 2007	Kirvin	0-6	5.9	38	1	117	153	642	59	10	114
NT4-A	7 February 2007	Kullit	0-6	5.4	37	4	115	77	364	43	12	144
NT4-B	7 February 2007	Bowie	6-24	5.7	59	4	10	82	743	137	13	91
NT4-B	7 February 2007	Cuthbert	6-24	5.9	108	1	2	98	899	267	25	112
NT4-B	7 February 2007	Kirvin	6-24	6.2	50	1	29	149	671	79	9	122
NT4-B	7 February 2007	Kullit	6-24	6.0	46	1	40	63	299	31	7	105

Table 4-1.
Soil Constituents Measured in the Surface and Subsurface Layer Samples
July 2005 and February 2007
(Continued)

Station Number	Collection Date	Soil Type	Soil Depth (inches)	Soil Analysis								
				pH (log l/[H=+]	Conductivity µmhos/cm	Nitrate-N (ppm)	Phosphorous (ppm)	Potassium (ppm)	Calcium (ppm)	Magnesium (ppm)	Sulfur (ppm)	Sodium (ppm)
NT5-A	12 July 2005	Bowie	0-6	5.8	97	11.02	26	49	478	27	--	164
NT5-B	12 July 2005	Bowie	6-24	5.7	101	8.36	12	40	354	41	--	128
NT6-A	19 February 2007	Bowie	0-6	5.1	48	3	21	38	192	15	9	129
NT6-A	19 February 2007	Talco Raino	0-6	5.3	40	3	12	36	228	13	12	145
NT6-B	19 February 2007	Bowie	6-24	5.9	24	3	3	19	239	12	7	106
NT6-B	19 February 2007	Talco Raino	6-24	4.7	44	3	3	17	194	44	13	138
NT7-A	20 February 2007	Bowie	0-6	5.2	52	4	21	79	212	40	16	123
NT7-A	20 February 2007	Cuthbert	0-6	5.5	66	7	41	101	183	27	8	106
NT7-A	20 February 2007	Kirvin	0-6	4.5	63	17	18	49	176	37	14	114
NT7-B	20 February 2007	Bowie	6-24	5.0	53	1	4	60	229	49	19	118
NT7-B	20 February 2007	Cuthbert	6-24	5.6	29	2	14	65	155	26	7	131
NT7-B	20 February 2007	Kirvin	6-24	4.7	62	1	3	128	669	116	29	149
NT8-A	7 February 2007	Besner Talco	0-6	4.9	59	3	38	63	196	29	19	135
NT8-A	7 February 2007	Cuthbert	0-6	6.1	62	3	21	125	506	56	10	139
NT8-A	7 February 2007	Estes	0-6	5.8	37	4	65	86	242	37	9	128
NT8-B	7 February 2007	Besner Talco	6-24	4.4	30	1	6	69	240	26	29	335
NT8-B	7 February 2007	Cuthbert	6-24	6.3	36	3	3	169	657	86	13	144

Table 4-1.
Soil Constituents Measured in the Surface and Subsurface Layer Samples
July 2005 and February 2007
(Concluded)

Station Number	Collection Date	Soil Type	Soil Depth (inches)	Soil Analysis								
				pH (log l/[H=+]	Conductivity µmhos/cm	Nitrate-N (ppm)	Phosphorous (ppm)	Potassium (ppm)	Calcium (ppm)	Magnesium (ppm)	Sulfur (ppm)	Sodium (ppm)
NT8-B	7 February 2007	Estes	6-24	5.5	26	2	38	66	165	31	8	112
NT9-A	27 February 2007	Cuthbert	0-6	4.9	31	2	101	66	170	35	14	130
NT9-B	27 February 2007	Cuthbert	6-24	5.0	48	2	50	44	142	35	11	125
NT10-A	11 July 2005	Lilbert	0-6	5.8	231	25.38	143	102	499	83	--	176
NT10-B	11 July 2005	Lilbert	6-24	5.5	84	13.05	66	81	278	66	--	150
NT11-A	12 July 2005	Grayrock	0-6	6.3	112	4.9	5	60	1794	504	--	168
NT11-B	12 July 2005	Grayrock	6-24	6.7	190	3.46	4	52	1902	456	--	180
NT12-A	13 July 2005	Derly Raino	0-6	6.7	48	3.06	8	81	1291	498	--	151
NT12-B	7 February 2007	Derly Raino	6-24	6.8	33	2.62	7	62	1408	580	--	158
Mean Value by Soil Depth												
0-6 Inches				5.6	72	6.8	66	80	500	88	12	138
6-24 Inches				5.7	61	3.5	27	78	527	113	14	139

Total phosphorus, the primary focus of this project, was generally present in substantially higher concentrations in surface soils than was nitrogen, the reverse of the generally observed condition in surface waters. Phosphorus concentrations in individual samples averaged 66 ppm and ranged from 5 ppm at Station NT-1 to 275 ppm at Station NT-3 (Table 4-1). These soil phosphorus levels, and the observed spatial and temporal variability, are similar to those reported for crop and pasture soils at USDA-ARS Riesel Research Center in Riesel, Texas that had received varying rates and combinations of poultry litter and inorganic fertilizer application (Harmel et al, 2009). The phosphorus content of the Bowie and Cuthbert surface soil samples showed a pattern similar to that exhibited in the nitrate results; averaging 74 ppm and 44 ppm, respectively, and ranging from 21 ppm to 275 ppm in the Bowie soil samples and 14 ppm to 101 ppm in the Cuthbert soil samples.

When comparing surface (0-6 inch) and subsurface (6-24 inch) sample results, both nitrate and total phosphorus concentrations are consistently higher in the surface samples, and is reflected in the mean concentrations of those nutrients in the surface and subsurface samples (Table 4-1). The results suggest that soil nitrogen and phosphorus levels at the sites were being affected by fertilization and cropping practices. The evident lack of relationship between the concentrations of the two nutrients (Figure 4-1) is explained by differing application rates, differences in utilization by plants and soil microorganisms, and the relative solubility of nitrate and phosphorus within and among the various soils sampled.

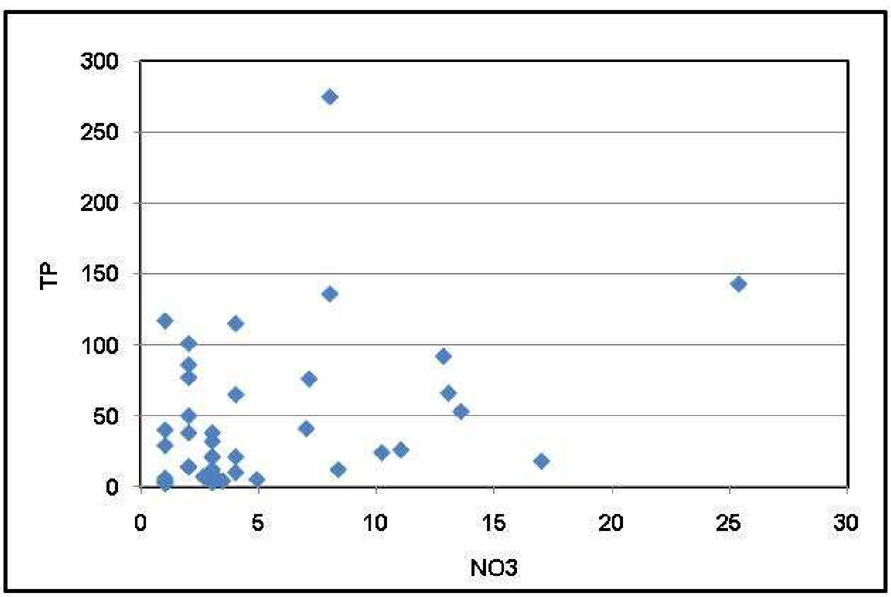

Figure 4-1. Nitrate vs. Total Phosphorus Concentration (ppm) in Soil Samples

4.2 Water Sample Collections

Table 4-2 presents a list of water sample collections by date and station. The amount of rain sufficient to generate runoff and allow for sampling did not occur until November 28, 2005 for Stations NT1 and NT-2. Not all storm events during the sample collection period produced enough runoff to engage the storm trigger at each or all locations although rainfall was recorded (i.e., water depth in the flume was not sufficient to initiate discharge through the weir). For example, all locations were checked immediately after a rainfall event passed through the area on August 7, 2005. No samples were collected. Another occurrence of rainfall associated with Hurricane Rita in late September 2005 also resulted in no water collections. Additional rainfall events not furnishing water for sample analysis occurred on March 18, 2006, April 20-21, 2006, July 2, 2006, and October 27, 2006. Eight wet weather events recorded during the first half of 2007 resulted in several water collections. Drier conditions prevailed after the last sample collection on July 31, 2007, as no water samples were taken during August through the end of December 2007.

Table 4-2.
Composite Water Samples Collected by Date and Station
28 November 2005 - 31 July 2007

Collection Date	***Station***											
	NT1	***NT2***	***NT3***	***NT4***	***NT5***	***NT6***	***NT7***	***NT8***	***NT9***	***NT10***	***NT11***	***NT12***
28 November 2005	X	X										
24 January 2006	X	X		X		X					X	X
30 January 2006	X	X	X	X							X	X
9 March 2006		X		X				X				
13 March 2006				X								
20 March 2006							X			X		
29 April 2006				X							X	X
6 May 2006				X				X				
27 July 2006	X	X		X		X						
6 November 2006	X	X	X	X		X					X	X
11 December 2006		X										
30 December 2006				X							X	X
4 January 2007	X	X	X	X		X		X			X	
13 January 2007	X	X	X	X								
31 March 2007							X	X				
10 May 2007								X				
3 July 2007							X				X	X
6 July 2007										X	X	X
10 July 2007							X					
31 July 2007										X		X
Total Collections	***7***	***9***	***4***	***11***	***0***	***4***	***4***	***5***	***0***	***3***	***8***	***8***

A total of 63 individual, composite water chemistry samples meeting the holding time, storage and lab QA criteria were collected during the period July 15, 2005 through December 31, 2007. Each composite sample represented the event mean concentrations of nine monitoring parameters in site runoff resulting from rainfall events sufficient to initiate operation of the automated water samplers. The nine parameters monitored by NETMWD and analyzed by Ana-Lab Corporation are summarized by sample event date and station in Table 4-3. No water samples were ever collected from Stations NT-5 or NT-9.

It is evident from this table that sampling events were erratically distributed among stations and over time. While some of this variability is explained by factors including climatic conditions, uneven distribution of rainfall across the Lake O' the Pines watershed, and varying antecedent soil moisture conditions among the sites, the failure of complex, automated equipment operated at remote locations where surveillance and monitoring could be accomplished only periodically played some role.

Nutrient concentrations, particularly total phosphorus, tended to exhibit higher event mean concentrations in the runoff samples than are ordinarily encountered in surface waters, although there is substantial overlap with values recorded from the reach of Big Cypress Creek between Tankersley Creek and Lake O' the Pines (PPAI, 2003). Nitrate (plus nitrite) concentrations exhibited a range of concentrations similar to the levels in runoff from the Blackland Prairie study pastures treated with poultry litter (Harmel et al, 2009). However, that study did not report runoff concentrations of other nitrogen species that were very significant in this project. Table 4-2 indicates that ammonia nitrogen was present in runoff in concentrations similar to that of nitrate, while substantially greater concentrations appeared as organic nitrogen.

Dissolved (ortho) phosphorus concentrations, often undetectable in surface waters, exhibited site averages and ranges of event mean concentrations generally overlapping those observed in Blackland Prairie study pastures receiving litter applications at rates of about six tons/acre, substantially above the rates reported for the sites employed in this project (Harmel, et al, 2009). Other studies cited by Harmel reported event mean concentrations of dissolved phosphorus similar to, or lower than those observed in this project in relation to poultry litter

Table 4-3.
Water Constituents Measured in the Composite Samples
28 November 2005 - 31 July 2007

Station Number	Collection Date	Water Analysis								
		TSS (mg/L)	TDS (mg/L)	Ortho-P (mg/L)	Total-P (mg/L)	Nitrite-N (mg/L)	Nitrate-N (mg/L)	Ammonia-N (mg/L)	TKN (mg/L)	TOC (mg/L)
NT1	28 November 2005	177	176	1.84	2.81	ND	6.92	2.08	6.9	68
NT1	24 January 2006	ND	71	1.92	2.19	0.0252	2.16	0.662	2.6	16
NT1	30 January 2006	20	70	1.82	1.88	0.022	0.483	0.483	1.99	19.6
NT1	27 July 2006	18	108	2.48	3.22	0.160	0.903	1.13	4.08	36.6
NT1	6 November 2006	44	47	1.57	1.62	ND	1.04	0.493	3.38*	11.7
NT1	4 January 2007	54	66	2.34	2.51	0.0428	0.389	1.80	6.99	11.4
NT1	13 January 2007	16	89	1.08	1.47	0.0403	0.486	0.0856	0.792	7
NT2	28 November 2005	5	290	5.66	7.54	0.269	9.85	3.56	11.7	85
NT2	24 January 2006	18.2	210	11.6	12.1	0.134	3.79	7.3	15.9	57.6
NT2	30 January 2006	56	140	5.77	6.98	0.146	2.96	2.6	8.08	42
NT2	9 March 2006	20	87	3.99	4.52	0.120	1.28	0.425	6.75	27.4
NT2	27 July 2006	32	478	11.3	15.8	1.29	4.92	3.02	20.8	171
NT2	6 November 2006	21	89	3.39	3.30	0.0272	1.08	0.504	4.22*	26.8
NT2	11 December 2006	23	90	3.37	3.94	0.0244	1.01	0.36	2.2	16.5
NT2	4 January 2007	66	70	1.86	2.02	ND	0.287	0.188	2.64	9.86
NT2	13 January 2007	25	110	2.31	2.38	ND	0.217	0.18	2.2	9.78
NT3	30 January 2006	28	80	0.887	2.20	ND	0.441	0.0951	1.78	52.8
NT3	6 November 2006	872	104	1.91	3.33	ND	0.735	1	5.90*	95.2
NT3	4 January 2007	44	37	1.50	1.57	ND	0.306	0.0696	1.52	6.38
NT3	13 January 2007	13	35	1.89	2.14	ND	0.0352	0.764	1.6	9.26
NT4	24 January 2006	9	70	1.50	1.78	ND	0.911	0.951	3.04	31.7
NT4	30 January 2006	76	57	0.823	1.26	ND	0.326	0.480	2.53	17.2
NT4	9 March 2006	28	102	1.71	2.07	ND	0.496	0.76	4.35	36
NT4	13 March 2006	47.3	98	1.23	1.79	ND	0.399	0.43	4.2	28.2
NT4	29 April 2006	10	54	1.39	1.67	0.0622	0.290	0.533	1.97	18.6

Table 4-3.
Water Constituents Measured in the Composite Samples
28 November 2005 - 31 July 2007
(Continued)

Station Number	Collection Date	Water Analysis								
		TSS (mg/L)	TDS (mg/L)	Ortho-P (mg/L)	Total-P (mg/L)	Nitrite-N (mg/L)	Nitrate-N (mg/L)	Ammonia-N (mg/L)	TKN (mg/L)	TOC (mg/L)
NT4	27 July 2006	64	67	1.19	1.93	ND	0.279	0.67	7.8	29.6
NT4	6 November 2006	20	36	0.487	0.588	ND	0.454	0.361	1.88*	10.9
NT4	30 December 2006	6	50	0.604	0.911	ND	0.0523	0.178	2.63	11.4
NT4	4 January 2007	30	29	0.395	0.644	ND	0.0375	0.122	2	5.09
NT4	13 January 2007	30	26	0.306	0.405	ND	0.0239	0.0419	0.88	4.46
NT5	--	NO			SAMPLES			COLLECTED		
NT6	24 January 2006	7	50	0.636	0.775	ND	0.381	0.479	1.91	23.4
NT6	27 July 2006	12	115	1.48	7.10	ND	0.460	1.36	5.98	45.2
NT6	6 November 2006	18	174	10.8	10.4	ND	11.7	13.1	23.7*	13.5
NT6	4 January 2007	4	23	0.240	0.316	ND	0.0481	0.0969	2.04	6.48
NT7	20 March 2006	12	43	0.188	0.345	ND	0.0937	ND	1.70	14.4
NT7	31 March 2007	20	54	0.267	0.489	ND	0.261	0.338	1.97	14.9
NT7	3 July 2007	3.5	46	0.464	0.889	0.0567	0.103	0.264	1.06	7.38
NT7	10 July 2007	26	81	0.512	0.592	0.0490	0.332	0.220	2.20	16.2
NT8	9 March 2006	56.7	169	0.489	0.891	ND	0.182	0.130	2.1	27.6
NT8	6 May 2006	84	112	0.859	1.11	0.0902	0.342	0.270	2.78	35
NT8	4 January 2007	34	50	0.550	0.786	ND	0.0724	0.119	1.81	7.78
NT8	31 March 2007	24	102	0.691	0.670	ND	0.0778	0.150	2.04	14.8
NT8	10 May 2007	18	59	0.724	0.762	0.0239	0.397	0.0942	1.64	17.4
NT9	--	NO			SAMPLES			COLLECTED		
NT10	20 March 2006	--	--	2.73	3.14	ND	0.217	0.0491	2.57	34.9
NT10	6 July 2007	16	230	19.6**	19.6	1.178	1.75	1.24	10.7	33.0
NT10	31 July 2007	24	400	20	19.8	0.378	12.7	1.15	11.6	42.4
NT11	24 January 2006	5	67	0.668	0.882	ND	0.476	0.220	1.53	25.9

Table 4-3.
Water Constituents Measured in the Composite Samples
28 November 2005 - 31 July 2007
(Concluded)

Station Number	Collection Date	Water Analysis								
		TSS (mg/L)	TDS (mg/L)	Ortho-P (mg/L)	Total-P (mg/L)	Nitrite-N (mg/L)	Nitrate-N (mg/L)	Ammonia-N (mg/L)	TKN (mg/L)	TOC (mg/L)
NT11	30 January 2006	10	60	0.235	0.331	ND	0.309	0.0258	1.15	18.4
NT11	29 April 2006	116	159	0.963	1.75	0.0811	7.10	3.7	8.4	70.8
NT11	6 November 2006	34.3	56	0.916	1.15	0.00796	0.872	0.362	2.7*	17.2
NT11	30 December 2006	20	66	0.079	0.215	ND	0.131	ND	0.799	4.34
NT11	4 January 2007	8	36	0.079	0.137	ND	0.0775	ND	1.15	6.51
NT11	3 July 2007	210	233	0.481	1.94	0.113	2.44	0.640	5.17	15.5
NT11	6 July 2007	140	219	0.760	0.888	0.0763	0.502	0.502	3.64	16.4
NT12	24 January 2006	4	89.1	1.15	1.51	ND	1.28	0.775	2.95	26.4
NT12	30 January 2006	8	60	0.588	0.804	ND	0.912	0.250	1.88	20.2
NT12	29 April 2006	36	104	1.03	1.45	0.061	0.608	0.693	1.96	44.8
NT12	6 November 2006	23	60	0.916	1.12	0.00287	0.281	0.124	1.47	32.8
NT12	30 December 2006	10	54	0.329	0.498	ND	ND	0.034	1.60	13.2
NT12	3 July 2007	9.3	90	0.701	1.11	0.0204	0.576	0.119	2.46	15.7
NT12	6 July 2007	4	107	0.630	0.786	ND	0.0326	0.149	2.30	19.5
NT12	31 July 2007	5.5	43	0.769	0.902	0.0242	0.504	0.185	1.63	13.8

application rates. The sandy loam soils dominating the sites in the Lake O’ the Pines watershed are presumably more susceptible to phosphorus loss than are the clay soils of the Blackland Prairie study sites. Dissolved phosphorus generally accounted for 50 to 90% of total phosphorus, which includes phosphorus bound to organic and inorganic particulate material, in runoff samples. Wang et al. (2006) reported dissolved organic phosphorus, and organic nitrogen (TKN minus ammonia), loss ratios varied widely, both among sites and annually. Loss of organically bound nutrient tended to correspond with sediment loss from Blackland Prairie crop study sites. In this project, there was no relation between TSS and either total phosphorus or organic nitrogen (Correlation Coefficients -0.007, 0.113, respectively). However, both parameters were correlated with total dissolved solids (Total Phosphorous, 0.788; Organic Nitrogen, 0.842).

4.3 SWAT Model

The overall objective of the SWAT modeling for this project was to extend and improve the technical basis of nonpoint source pollution management in the Lake O' the Pines watershed. The improvement of the SWAT model formulation can be achieved through continuous acquisition of field data, formulation and implementation of BMP strategies (i.e., runoff controls), and guide the appropriate adjustments of these strategies for basin-wide nutrient management already outlined in the TMDL I-Plan. The field data acquired during this project will permit extended validation for major combinations of surficial conditions not represented in the earlier work. In addition, various strategies of nutrient and runoff management are included in the land use categories. A total of 43 storm events were identified for detailed analysis and modeling from the data collection period.

4.3.1 Acceptance Criteria for Existing Data

Modeling was reviewed by the CRWR to assess the usability of the model results for the intended purpose of the existing data. In general, model results that are generated such that acceptance criteria are met will be deemed usable for the intended purpose. If data quality indicators (performance criteria) did not meet the project's requirements for data quality objectives , those data were discarded by the modeler.

Validation is the process of verifying the ability of a calibrated model to make predictions outside the calibration period. A portion of the available data is withheld during calibration and later used to validate the model.

4.3.2 Individual Watershed SWAT Models

Due to the complex nature of the modeling procedure and mechanics undertaken for each of the study watersheds, this section provides a highlight of the important aspects of each model and an overview of the findings.

4.3.2.1 Station NT1

Although this watershed has not received fertilizer application since 2000, nutrient concentrations in the Bowie soils are elevated. Precipitation data recovery was moderate as only 39% of the feasible precipitation days yielded data after the first two tiers of QA review and reduced further after the Tier-3 review yielding a net recovery of 28% data recovery. The flow data recovery rate was greater with a total of 45%. The recorded flow values were deemed erratic with a number of zero events despite substantial rainfalls and is therefore regarded with suspicion.

A total of seven water quality samples having linked flow measurements were used to estimate loads. Four of the sample events acquired on-site rainfall for runoff-load evaluation. Of the 25 storms with available discharge data, the model results fall within the 95% confidence limits on 14 storms. The last six storms were regarded with uncertainty (i.e., reported erratic flow values) and when disregarded, the model agreed with measured discharge in 75% of the events. The agreement of model performance concerning loading simulations of suspended solids, nitrogen, and phosphorous with data for the concentrations of constituents indicated the model performance is quite satisfactory. In the absence of fertilization, the solids and nutrients loads from the watershed are dominated by variability in precipitation.

4.3.2.2 Station NT-2

The information received regarding the recent history of no field fertilizer application is inconsistent with the high levels of nutrients found in the soil test results from this site. Data recovery was quite poor resulting in only 31% of the viable precipitation days providing data after the three-tier QA review. A review of the measured values over the whole operating range pointed to unsatisfactory flow meter performance. In a number of cases during operation, the apparent runoff was in excess of the corresponding rainfall amounts.

This faulty behavior (i.e., poor quality of the field data) suggested problems to either the automated equipment or to the monitoring structure. Due to these deficiencies in rainfall and runoff data, model verification was confined to six storms occurring in 2007 having accessible discharge data. Using the measured data, the model results were within the 95% confidence limits, despite the uncertainty in the field data when matched with the model values.

Model performance for loading simulation of suspended solids, nitrogen and phosphorus could not be evaluated due to the scarcity of corresponding measured flows to water samples but water quality were used for comparison of model and measured concentrations. Given the considerable uncertainty in the data, the model performance was assessed as satisfactory.

4.3.2.3 Station NT-3

Current use of the land that flows directly into Lake Bob Sandlin was hay production using commercial fertilizer (21-0-21) only; no broiler litter has been allowed over the last 5 years although no information is available on dates or amounts of application. Though a nutrient management program has been initiated, the relatively high buildup of phosphorous found in the two different soil types (Bowie and Lilbert) suggest past applications using manure.

Initially thought to offer one of the best sets of data to be acquired in the project with no evident flow or rainfall anomalies, the dataset showed small runoff production at this location. A close examination of the rainfall data disclosed a major rainfall measurement discrepancy problem. Screening of the data suggested a disagreement by a factor of two in the cumulative rainfall amounts recorded during the same time period of operation between the site gauge and the NOAA weather surveillance stations at Mt. Pleasant and Pittsburg. All precipitation measurements were therefore rejected making it necessary to introduce a major source of uncertainty by importing rainfall data of higher magnitude from the nearby gauges, thus making the problem of small measured runoff more complex. The reluctance to reject data was evident owing to the uncertainties based on zero runoff values after one-inch storms during drought and wetter conditions; but the data was kept within the modeling framework.

Of the 30 storms offering available discharge data is available, all model results fall within the 95% confidence limits. This was not so much a measure of the precision of the model, but rather the imprecision in the data (i.e., the model agrees within the uncertainty of the field data). Two separate evaluations of model performance were assessed as acceptable: a comparison of modeled to measured constituent loads and concentrations in storm events.

4.3.2.4 Station NT-4

The pasture in which Site NT-4 is located received a single application of poultry litter in 2004, at a rate of 3.0 tons/acre. Generally, the five soil types (Bowie, Kervin, Kullit, Cuthbert, and Lilbert) nutrient concentrations are modest, though phosphorus is elevated in the southern third of the watershed. Data recovery for rainfall was very poor resulting in only 16% of the possible precipitation days providing data after the three-tier QA review. Flow data recovery was 39% after Tier-2 review, of which 92% of the data were zero values and the remaining 8% represented runoff events. The water quality characteristics of storm water constituents at this location is the best represented of the project database. A total of eleven storm events produced water samples with nine of these having associated discharge data permitting an estimate of nutrient loadings.

The general lack of on-site rainfall introduced excessive modeling uncertainty that led to yield spurious results. Through January 2007, the measured runoff significantly surpassed the modeled runoff with no available on-site precipitation data until December 2006. During this time period, the huge uncertainty in the input precipitation is great enough to account for the numerical disparity of the model results although the model results still achieve the 95% confidence level. Overall, of the 23 storms for which runoff data were obtained, 18 are within the limits of the 95% confidence interval, and two of the remaining five events are within 90% confidence, a performance judged as satisfactory.

Eight storms were evaluated for model simulation of suspended solids, nitrogen, and phosphorus using the available water quality samples and measured flows and a separate model evaluation was conducted with the collected water quality data for the concentrations of constituents. The model performance in both cases was satisfactory.

4.3.2.5 Station NT-5

This location was the second largest watershed of this project (10.6 acres.) and was characteristic of nearly uniform land use (hay production) and soil type (Bowie). The site has received no fertilization in recent years, consistent with the modest soil nutrients reported. The combination of no collected water quality data and the low number of recorded storm events made the SWAT model performance assessment difficult. Data recovery resulted in 63% of the eligible precipitation days yielding rainfall and runoff data. However, of the six storms monitored, only the last event produced runoff. The lack of runoff from the previous storm events characterized by modest rainfall amounts may have been driven by the prevailing drought conditions at the time.

Only two of the six storms in the database had appreciable rainfall amounts but inspection of both proved problematic. The first yielded zero runoff after a 1.8-inch measurement of rainfall, while the second produced substantial runoff from half that amount of rainfall. When SWAT was matched with the measured flows of each, the numerical disagreement between measurement and model for the second storm is an order of magnitude. The remaining four storms produced low runoff (zero in the field data), on which both the model and the measurements are in accord. The model-predicted nutrient loads are quite low, averaging 0.4 total N kg/ha and 0.02 total P kg/ha, consistent with the lack of fertilization at this site.

4.3.2.6 Station NT-6

This site was replaced at the end of the station selection process deadline and is actually found within the Little Cypress Creek basin near the watershed divide with Big Cypress Creek. This site occupies the yard of a rural residence with soil distribution evenly divided between Talco-Raino complex and Bowie. Application information provided shows this area received poultry litter fertilization in each of the years 2003-2005, at rate of 3.5 tons/ac for 2003-2004, which was assumed for 2005 as well. It was noted that the relatively low nutrient levels tested in the two soils appeared inconsistent with this level of fertilization.

Precipitation data recovery was very low with only 6% of the data taken from the available rainfall days surviving the first two tiers of QA review; net data recovery was zero after Tier-3 QA review. Flow data recorded was just as disappointing as only 15% of the rainfall events had corresponding discharge data after the first two levels of QA review. Data corruption became apparent during the Tier-3 review suggesting the equipment was operating incorrectly and abnormal counts reported were inaccurate and not representative of field conditions. Large rainfall events produced zero runoff and conversely recorded flow measurements exceeded the rainfall rate. The source of the deviations was suspected to be caused by either debris blockage at the weir plate or the susceptibility of sediment contamination to this highly sensitive instrument. After rejection of all faulty data, the net recovery rate was only 5%.

Only four water samples were pulled from this station during the project period, of which three had associated discharge data permitting an estimate of loadings. The data was collected prior to the observed erratic readings taken by the equipment but the lack of associated rainfall data impaired the ability for model validation.

Of the ten (10) storm events with usable data, all SWAT simulated flows fell within the 95% confidence limits about the measurement. While the numerical agreement is satisfactory for most of the storm events, a few examples illustrated the uncertainty introduced by importing rainfall data from off-site. Model agreement was satisfactory for simulating loads of suspended solids, nitrogen and phosphorus using the eight storms having water quality and flow measurements and also the separate evaluation using the concentrations of constituents measured during all ten storms. The model was simulated without field data validation and there was no obvious correlation between the high phosphorus levels and previous litter applications.

4.3.2.7 Station NT-7

The most distinguishing feature of Station NT-7 watershed, in comparison to the other sites, is its relative steepness of land-surface slope. The sample area is fairly uniform in land use (hay production) and its soils are nearly evenly divided between Cuthbert and Bowie, both similar in their hydrological attributes. The information regarding the landowners' fertilization application history is incomplete but there evidently is a BMP in place, in the form of nutrient management. The field crew determined that commercial fertilizer and poultry litter have been applied in alternate years for the period 2001-05, starting with poultry litter, but no information is available on application rates.

Because the soil nutrient concentrations appear to be modest, the following assumptions were made; application rates of 4 tons/ac for poultry litter and 0.2 tons/ac for commercial fertilizer (21-0-21), and no applied fertilization during the project.

Rainfall data recovery from this station was very poor and was attributed to monitor failure. After the Tier-2 QA level, only 8.5% of the possible precipitation data was recovered, however these data were rejected at the Tier-3 QA level as their magnitudes were so large as to be clearly invalid, so the net on-site rainfall data available was zero. Recovery of the flow data fared somewhat better as approximately 37% of the possible data was kept at the Tier-2 QA level.

Four storms were available for the evaluation of the model performance in load simulations of suspended solids, nitrogen, and phosphorus. For all constituents and all storms, the model results fall within the 95% confidence bounds of the data. The model performed satisfactory based on the agreement of the model within the uncertainty of the concentrations of the constituent data.

4.3.2.8 Station NT-8

The information provided for Station NT-8 indicates the property operates with no BMPs. Fertilization records show the pasture received poultry litter each year for 2002-2004 at a rate of 3.2 tons/ac, and commercial (21-0-21) fertilizer in 2005 at a rate of 0.15 tons/ac. These rates of application seem inconsistent with the relatively modest concentrations of nutrients in the soils.

Precipitation data recovery was only 20% of the feasible precipitation days after the first two tiers of QA review, and an additional 4% were rejected in the Tier-3 review, yielding a net of 16% data recovery. The flow data recovery was 47% after Tier-2 review of which 92% were zero values. The remaining 8% represented runoff events, with only half having accompanying on-site rainfall data. The flow meter has consistently reported much less flow values than would be expected for this area given the rainfall rates. The high rate of zero values during rainfall events indicates this proclivity to low measurements. The very low values of runoff/rainfall at this location were noted and regarded with great suspicion.

The monitoring information collected from this location represents a basic dilemma in the estimation of performance data through model calibration. Throughout the monitoring period, the modeled runoff consistently exceeded the measurements. Thus calibrating a model by varying its input parameters to decrease model runoff can be problematic. With this in mind, adjustments to the model were minimal. Despite the numerical bias between measurement and model, 22 of the 27 storms listed fall within the 95% uncertainty bounds. Similar for the dozen storms having on-site rainfall data, a total of 60% of the unadjusted model results are within the 95% uncertainty bounds of the data.

Model agreement was satisfactory for evaluating load simulation of suspended solids, nitrogen and phosphorus using the three storms having water quality and flow measurements and also in the separate evaluation using the concentrations of constituents measured during all five storms having representative water quality samples.

4.3.2.9 Station NT-9

This watershed was represented by a nearly complete surficial homogeneity consisting entirely of pastureland and 90% Kullit very fine sandy loam soil. According to the landowner, the entire pasture received broiler litter each year throughout the period 2000-2004 at a rate of 1.6 tons/ac (3560 kg/ha), and none thereafter.

Rainfall data recovery at this station was poor as only 33% of the feasible precipitation days yielding data after the three-tier QA review. None of the flow data was determined to be usable. Similar to the recording apparatus observations at Station NT-6, large rainfall events produced zero runoff and in some cases recorded flow measurements 2-3 times greater than the rainfall rate. This anomaly was again attributed to either brush accumulation within the weir structure or an electrical sensing malfunction. Additionally, no water samples were collected for analysis. With no flow data or water sample data, there were no data available to validate the model. Although no data was available for model validation, a SWAT model was setup similar to the other watersheds for estimation of key parameters needed in the model.

4.3.2.10 Station NT-10

As a relatively small watershed (3 acres) with homogeneous soils (Lilbert loamy, fine sand), in many respects Station NT-10 was closer to ideal than many of the sites for the project objectives. According to information provided by the landowner, the pasture has received broiler litter in each of the years from 2001-2005 at a rate of 1.8 tons/acre. According to information provided, the landowner has a WQMP.

The degree of rainfall data recovery was poor with only 16% of the feasible precipitation days yielding data after the three tiers of QA review. Although most of the flow data passed the QA review, these discharge measurements were regarded as suspicious. The measured runoff recorded through June 2007, was much smaller than expected and often zero despite some occasional substantial rains. After June 2007, the runoff was generally excessive, given the amount of rainfall, though still not beyond the bounds of possibility. The ability to evaluate model simulation of loadings was considered biased as of the possible 30 storm events with discharge data, only three had concomitant water samples, each with corresponding but suspicious discharge data.

Given the uncertainty measurements of discharge and rainfall, a total of 26 of 30 storms exhibited agreement between model and measurement with a 95% confidence level. A limited evaluation of only two storms was conducted for model simulation of suspended solids, nitrogen, and phosphorus using the available water quality samples and measured flows. A separate model evaluation was conducted for three storms with available water quality data for the concentrations of constituents. The model performance was assessed as acceptable in both cases.

4.3.2.11 Station NT-11

Station NT-11 was situated in the headwaters of the Tankersley Creek drainage on a swale that drains into a small man-made stock tank, constructed as part of a local mine reclamation project in the far northwest reach of the Big Cypress basin. The landuse during the project was hay production. The area, used for hay production, received commercial fertilizer application (presumably 21-0-21) in 2004 and 2005, at rates of 0.175 tons/ac and 0.275 tons/ac, respectively.

The profound changes in surface topography, hydrological patterns and soil structure after reclamation shows the surface slope has been completely reversed, from its previous slope of north-to-south to its present slope of south-to-north and the homogeneous mixture of surface and subsurface soil layers during mine activity and restoration. The lack of watershed surface slope, a fundamental hydraulic function of SWAT, presented another source of input error.

Precipitation data recovery was low with only 32% of the data taken from the available rainfall days surviving the first two tiers of QA review; net data recovery was 26% after a closer examination during the Tier-3 QA review. Most of the surviving data is for the period 2005-06 when there were relatively few storm events. Flow data recovery totaled 56%; as only 10% are represented by nonzero values with less than 50% of the events; have corresponding rainfall data after the first two levels of QA review. Concerns about the data became apparent during the Tier-3 review where rather substantial rainfalls produced zero or miniscule runoff amounts. It was noted that the measured runoff data notably in 2007 approaches half of the rainfall. From the seven water quality samples collected here, five having linked flow measurements were used to estimate loads; only one of these sampled events also had on-site rainfall.

Model performance in simulating the hydrological features and estimation of runoff loads and concentrations of the storm events was more than satisfactory. Agreement between the model and rainfall/runoff data achieved a 95% probability in 26 of the recorded 35 storms. Additionally, over 90% of the model-computed loads fell within the 95% confidence limits of the data, and over 95% of the model-computed concentrations.

4.3.2.12 Station NT-12

Station NT-12 is also located within a mine reclamation area near Station NT-11. Representative soils for the area dedicated to hay production has experienced considerable disturbance of the topsoil layer through past excavation and backfilling activities. Very little information is available regarding land rehabilitation and fertilizer management practices. It was assumed the watershed had received no prior fertilizer applications and this postulation was consistent with the relatively low measured values of soil nutrients.

It was noted by the field staff that the present topography and soil units for this area conflicted with the most current USGS topographic map and NRCS soil surveys. As was the case at Station NT-11, an estimate of the watershed surface slope represented an additional source of input error for proper validation of the SWAT model. Station NT-12 was the smallest of the study watersheds.

Only 25% of the feasible precipitation days yielded rainfall data after the three-tier QA review. Most of the storm flow data recorded prior to 2007, were taken out in the Tier-1 data processing phase although almost all of these events had linked on-site precipitation data. Since equipment operation error was not obvious, very little of this data was eliminated in the Tier-3 review but still resulted in a net recovery of only 32%.

There were a total of 24 storm events with discharge data, and seven with related water samples, of which five corresponded to available discharge data permitting an estimate of loadings. The modeling performance in simulating the hydrological features and estimation of runoff loads and concentrations of the storm events was evaluated as being more than satisfactory. Agreement between the model and rainfall/runoff data achieved a 95% probability in 21 of the recorded 24 storms. In addition, nearly two-thirds of these have associated on-site rainfall data and represent a more robust test of the model performance than using rainfall data imported from nearby weather stations. The agreement of model and discharge data was seen in 88% of the storms in the absence of sufficient topographic data.

Of the three storms for which nutrient loads could be computed, 8 out of the 9 model results fell within the 95% uncertainty limits. Of the model-computed concentrations more than 85% agree with data within the uncertainty of measurement.

5.0 Discussion and Conclusion

5.1 Summary of Project Results

Storm-generated surface runoff was shown to be the primary route through which nitrogen and phosphorus (and other pollutants) enter Lake O' the Pines at the bottom of this impaired watershed (PPAI, 2003). The amounts of overland flow and the phosphorous concentrations in overland flow varied considerably during events, and among sites and events.

A key goal of this project was to acquire a better understanding of the physical and chemical characteristics of runoff particles being delivered to the edge-of-field plots of various sizes to determine existing soil nutrient conditions represented in the upper watershed. The objective of the project was to use the collected field data to improve the basis for validation of the SWAT model originally employed in the Lake O' the Pines TMDL.

Overall, data recovery at the study sites was disappointing. An average of only 18% of the potential rainfall data was recovered. This includes three of the stations (NT-3, NT-6, and NT-7) for which there was zero recovery of rainfall data. The recovery of runoff flow data might appear to be somewhat better, averaging 36% over the twelve stations, but the majority of these "measurements" are zero values. Of the nonzero valid flow measurements, only a small minority have associated on-site rainfall data.

Over the course of the project, a total of 60 water samples were pulled, an average of five per station. However, the accompanying flow data for 13 of these, nearly a fourth of the water samples, failed to register or were found to be invalid in the QA process, so the associated runoff loads could not be computed. Because of the logistics of retrieving water samples from such a widely dispersed network of remotely located stations, water samples could be obtained only for a minority of the storm events that occurred. No water samples were collected during September, October, November and December 2007. No water samples were ever collected from Station NT-5 and NT-9.

As noted above, the original design strategy had sought the selection of watersheds with a variety of management strategies in place, so that comparative studies could be performed, both with field data results and with modeling. As the site selection process developed, only four of the participating sites had WQMP's in place (Table 3-3). All WQMP's involved some level of nutrient management. For project purposes, the landowners agreed to avoid fertilizer applications during the period of data collection. This action, in effect, temporarily added four sites with a past history of fertilization; therefore resulting in a total of eight sites demonstrating some type of nutrient management (four during the 2005-2008 period of data collection), and four locations with no nutrient application (reportedly) allowing a comparison of the strategies.

Failing OSSFs are a known source of pollution of groundwater and surface water. Replacement of failed OSSFs improve the quality of water in receiving streams and aquifers because the effluent travels through soils that effectively remove bacteria and other pollutants from the water. Although no pre-and post-sampling data was taken, the change from a failing OSSF to a certified new system is an obvious improvement.

5.2 Conclusion

The site visits and storm event measurements appear to validate the conclusions reached in the preparation of the Lake O' the Pines TMDL that sites having exposed soil in densely developed agricultural areas can contribute significant amounts of nonpoint source pollution to local streams and eventually the reservoir. The areas where these conditions exist can be addressed through the implementation of BMPs and further analysis or modeling of such sites for prioritization is not required.

The project results provide a scientifically sound basis for proceeding to the next step in the process (i.e., identifying specific projects within these drainage areas and conducting feasibility studies and, in the case of structural BMPs, preliminary design and cost studies). Some of these projects may be necessary to satisfy the requirements of new stormwater management regulations. Additional projects may be required to meet future water quality standards as directed by the Lake O' the Pines TMDL I-Plan for TMDL specification for the Big Cypress Creek and Lake O' the Pines watersheds.

The overall SWAT model performance was acceptable in simulating runoff, concentrations and loads of nutrients and solids carried by runoff. Unfortunately, due to difficulties with data recovery from the project sites, the resultant data quality impairment weakened the statistical strength of this conclusion, because of the increased uncertainty in the measurements. Overall, the agreement between model and measurement is within the uncertainty of the measurements, so we regard the model performance as satisfactory, especially in light of the minimal (in fact, zero) adjustment made to the terms in the model that would affect runoff concentration and load.

Because most of Texas is composed of privately owned lands and the amount of fertilizer application on agricultural and pasturelands of the Upper Cypress Creek Basin can affect off-site water quality, there has been an increasing interest in the WQMP Program. The impetus of this project is to encourage agricultural landowners to install BMPs in the Upper Big Cypress Creek Watershed with the goal of improving water quality through the reduction of sediment, nutrients and pesticides.

5.3 Recommendations

Additional research needs were identified during model execution for the twelve project sites. The models do not seem to exhibit rational responses to extended dry surface (interstorm) periods as the response of modeled runoff is occasionally erratic, with large runoff volumes for smaller storms, and minimal runoff for larger storms. While the runoff response to rainfall is erratic, it does not seem to be correlated with dessication or saturation of the watershed. Therefore, an analyses to focus on the redistribution of subsurface water within the soil profile between the top of the ground surface and the deeper aquifer zones is recommended.

Unexpected and unintuitive model responses in runoff quality were also noted during the project. Most prominent are the large spikes in concentration of TSS, nitrogen or phosphorus that are not only uncorrelated among themselves but are apparently uncorrelated with hydrology. Detailed studies of the hydrological sensitivity of modeled runoff to sequences of rainfall and other external inputs are recommended, to better map the cause-and-effect behavior of SWAT, and to identify those combinations of variables that seem to provoke such aberrant behavior.

Since completion of the Lake O' the Pines TMDL modeling work, advancements of SWAT through several modifications have been made, specifically in the release of SWAT2007. Though updates to this older version of the TMDL model would unlikely result in any numeric changes, the historical data together with the data derived from this project should be incorporated into the new modeling system.

Because of input data deficiencies, this project demonstrates the application of detailed hydrologic/water quality models is highly dependant on more comprehensive data needed for additional model input data collection to improve model parameter calibration and simulation results. To avoid the logistic difficulties with atypical weather conditions and indiscriminate mechanized equipment operation experienced during this project, a different strategy to reduce sampling constraints for future monitoring studies is reccomended.

The maximum benefit would be the centralization of sample collections, data retrieval and transportation in that the spatial extent of the automated equipment will be concentrated in fewer small watersheds (2-3) to allow quicker field crew response time for sample retrieval and correction of imminent instrument failure. The watersheds should be carefully selected to (1) exhibit relatively homogeneous surficial characteristics, similar to the present project, (2) occupy soils typical of the largest stream segments of the Lake O' the Pines basin, and (3) be amenable to various experimental BMP strategies. Selected watersheds should be thoroughly surveyed using horizontal and vertical topographical elevation units to delineate drainage boundaries. High quality terrain data is critical to SWAT with respect to consistent coverage, scale, quality, and vertical accuracy. During a storm event, a preliminary reconnaissance of each area should be conducted to observe the natural movement of drainage to enable the accurate delineation of watershed boundaries and hydrologic flow representation for precise placement of the automated sampling equipment.

6.0 References

ASTM International (ASTM). 2001. Standard Test Method for Open-Channel Flow Measurement of Water with Thin-Plate Weirs. Designation: D 5242 (Reapproved 2001). ASTM International, West Conshohocken, PA.

Harmel, R.D.,K.W. King, and R.M. Slade. 2003. Automated Storm Water Sampling on Small Watersheds. Applied Engineering in Agriculture Vol. 19(6): 667-674.

Harmel, R.D., D.R. Smith, R.L. Haney, and M. Dozier. 2009. Nitrogen and phosphorus runoff from cropland and pasture fields fertilized with poultry litter. Journal of Soil and Water Conservation Vol. 64(6):400-412

Northeast Texas Municipal Water District (NETMWD). 2005. Task 4 Deliverable: Sample Station Construction and Calibration: As built diagrams of 12 automated sampler installations. Prepared by HDR Engineering, Inc., August 9, 2005.

_____. 2009a. 2009 Cypress Creek Basin Summary Report - DRAFT. Prepared by Water Monitoring Solutions for the Northeast Texas Municipal Water District. In cooperation with the Texas Commission on Environmental Quality, Texas Clean River Program.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Annuals of the Association of American Geographers. 77: 118-125.

Paul Price Associates, Inc. (PPAI). 1998. Poultry operations water-quality impact study. Final Report to North East Texas Municipal Water District, PPAI, Austin, Texas. (Appendix to TNRCC, 1999).

____. 2003. Lake O' the Pines Watershed TMDL Project Documentation Report FINAL Deliverable 14B. Submitted to TCEQ on behalf of Northeast Texas Municipal Water District, PPAI, Austin, Texas.

____. 2005a. Design of V-Notch Weirs-Draft for Comment. Technical Memorandum, April 24, 2005.

____. 2005b. Design of V-Notch Weirs. Technical Memorandum, May 9, 2005.

____. 2005c. Site Inspection of Weir Structure Sites. Project Memorandum, June 24, 2005.

Texas Commission on Environmental Quality (TCEQ). 2006. One Total Maximum Daily Load for Dissolved Oxygen in Lake O' the Pines, Segment 0403. Chief's Engineer Office, Water Programs, TMDL Section, Texas Commission on Environmental Quality, Austin, Texas.

____. 2008. Implementation Plan for One TMDL for Dissolved Oxygen in Lake O' the Pines, Segment 0403. Chief's Engineer Office, Water Programs, TMDL Section, Texas Commission on Environmental Quality, Austin, Texas.

Wang, X., R. D. Harmel, J. R. Williams, W. L. Harman. 2006. Evaluation of EPIC for assessing crop yield, runoff, sediment and nutrient losses from agricultural watersheds with poultry litter fertilization. Transactions of the American Society of Agricultural and Biological Engineers Vol. 49(1): 47−59.

Ward, G.H. 2000. Dissolved oxygen structure and trends in Lake o' the Pines. Lake O’ the Pines TMDL Project Memorandum submitted to TNRCC August, 2002.

_____. 2001a. Seasonal and hydrological controls on dissolved oxygen in Lake O' the Pines. Lake O’ the Pines TMDL Project Technical Memorandum. Submitted to TNRCC February, 2001.

_____. 2001b. Rationale for selection of watershed model. Technical Memorandum, Big Cypress/Lake o' the Pines TMDL Project, Center for Research in Water Resources, University of Texas at Austin.

_____. 2002. Validation of watershed loading model. Technical Memorandum, Big Cypress/Lake O' the Pines TMDL Project, Center for Research in Water Resources, University of Texas at Austin.

_____. 2003. Application of SWAT to Basin Scale Simulation of Lake O’ the Pines Watershed. Technical Memorandum submitted to TCEQ, Lake O’ the Pines TMDL Project, February 2003. Center for Research in Water Resources, University of Texas at Austin.