Clean Water Act Section 319(h) Nonpoint Source Pollution Control Program Project

Assessment and Mitigation of Agricultural and Other Nonpoint Source Activities in the Cypress Creek Basin
TSSWCB Project Number 04-14
Revision #0

Quality Assurance Project Plan

Texas State Soil and Water Conservation Board

prepared by

Northeast Texas Municipal Water District

Effective Period: Upon EPA Approval through July 2007

Questions concerning this quality assurance project plan should be directed to:

David Thomas
Technical Coordinator
HDR Engineering, Inc.
4401 West Gate, Suite 400
Austin, Texas 76745
david.thomas2@hdrinc.com
(512) 912-5100

A1 APPROVAL SHEET

Quality Assurance Project Plan for TSSWCB project # 04-14, Assessment and Mitigation of Agricultural and Other Nonpoint Source Activities in the Cypress Creek Basin, Modeling.

United States Environmental Protection Agency (USEPA), Region VI

Name: Donna Miller
Title: Chief; State/Tribal Programs Section
Signature: Donna R. Miller Date: 3-1-07

Name: Ellen Caldwell
Title: USEPA Texas Nonpoint Source Project Manager
Signature: Ellen Caldwell Date: 2-28-07

Texas Soil and Water Conservation Board (TSSWCB)

Name: T.J. Helton
Title: TSSWCB Project Manager
Signature: TJ Helton Date: 1-10-07

Name: Donna Long
Title: TSSWCB Quality Assurance Officer (QAO)
Signature: Donna K. Long Date: 01-05-07

Northeast Texas Municipal Water District (NETMWD)

Name: Walt Sears, Jr.
Title: General Manager
Signature: Walt Sears Jr. Date: 12-11-06

Name: Ric Blevins
Title: Project Manager, Field Operation Supervisor
Signature: Ric Blevins Date: 12-11-06

HDR Engineering, Inc. (HDR)

Name: Paul Price
Title: Project Manager

Signature: Paul Price Date: 12/01/06

Name: Peggy Jones
Title: Quality Assurance Officer (QAO), Data Manager (Entire Project)
Signature: Peggy Jones Date: 1 Dec 2006

Name: David Thomas
Title: Technical Coordinator

Signature: David Thomas Date: 1 Dec 2006

Center for Research in Water Resources (CRWR), The University of Texas at Austin

Name: George Ward
Title: Principal Investigator

Signature: George Ward Date: 30 Nov 2006

The Northeast Texas Municipal Water District (NETMWD) will secure written documentation from each sub-tier project participant (e.g., subcontractors, other units of government, laboratories) stating the organization's awareness of and commitment to requirements contained in this quality assurance project plan and any amendments or revisions of this plan. NETMWD will maintain this documentation as part of the project's quality assurance records, and will be available for review. (See sample letter in Attachment 1 of this document)

This Quality Assurance Project Plan (QAPP) has been written to support Soil Water Assessment Tool (SWAT) modeling activities within the Lake O' the Pines Watershed, Texas State Soils and Water Conservation Board (TSSWCB) Project Number 04-14 between Northeast Texas Municipal Water District (NETMWD) and HDR Engineering, Inc. (HDR)/Center for Research in Water Resources (CRWR), Assessment and Mitigation of Agricultural and other Nonpoint Source Activities in the Cypress Creek Basin (Assessment and Mitigation Project, hereafter). It has been prepared to outline the quality assurance and control procedures that will be implemented during Sub-tasks 9.1 and 9.2 of Task 9: SWAT Modeling.

The QAPP has been completed under the direction of, and for use by TSSWCB and the U.S. Environmental Protection Agency (EPA) to ensure that (1) modeling input data are valid and defensible, (2) model setup and calibration protocols are followed and documented, and (3) model application and output data are reviewed and evaluated in a consistent manner.

A2 TABLE OF CONTENTS

A2 LIST OF ACRONYMS

BASINS	**Better Assessment Science Integrating Point and Nonpoint Sources**
BMP	**Best Management Practices**
CBMS	**Computer Based Mapping System**
CAR	**Corrective Action Report**
CRWR	**Center for Research in Water Resources**
CWA	**Clean Water Act**
DEM	**Digital Elevation Model**
DM	**Data Manager**
DOC	**Demonstration of Capability**
DO	**Dissolved Oxygen**
DQO	**Data Quality Objectives**
EOF	**Edge-of-field**
EPA	**Environmental Protection Agency**
FY	**Fiscal Year**
GIS	**Geographic Information System**
GPS	**Global Positioning System**
HDR	**HDR Engineering, Inc**
HUMUS	**Hydrologic Modeling of the United States Project**
LMU	**Land Management Unit**
LULC	**Land Use/Land Cover**
MDMA	**Monitoring Data Management & Analysis**
MG/L	**Milligrams per liter**
MUID	**Map Unit Identification**
NA	**Not Applicable**
NCR	**Non-conformance Report**
NETMWD	**Northeast Texas Municipal Water District**
NPS	**Nonpoint Source**
NRCS	**Natural Resources Conservation Service**
OSSS	**On-Site Sewage System**
PI	**Phosphorous Index**
PM	**Project Manager**
QA	**Quality Assurance**
QAM	**Quality Assurance Manual**
QAO	**Quality Assurance Officer**
QAPP	**Quality Assurance Project Plan**
QAS	**Quality Assurance Specialist**
QC	**Quality Control**
QMP	**Quality Management Plan**
SOP	**Standard Operating Procedure**
SSURGO	**Soil Survey Geographic**
SWAT	**Soil and Water Assessment Tool**
SWCD	**Soil and Water Conservation District**

A2 LIST OF ACRONYMS (Concluded)

SWQM	**Surface Water Quality Monitoring**
TC	**Technical Coordinator**
TCE	**Texas Cooperative Extension**
TMDL	**Total Maximum Daily Load**
TDS	**Total Dissolved Solids**
TRACS	**TCEQ Regulatory Activities and Compliance System**
TSS	**Total Suspended Solids**
TSSWCB	**Texas State Soil and Water Conservation Board**
TSWQS	**Texas Surface Water Quality Standards**
USEPA	**United States Environmental Protection Agency**
WMT	**Watershed Management Team**
WQMP	**Water Quality Management Plan**

A3 DISTRIBUTION LIST

Environmental Protection Agency Region 6
1445 Ross Avenue, Suite 1200
Dallas, Texas 75202-2733

Randall Rush
EPA Project Officer
MC-6WQ-AT
(214) 665-7107

Texas State Soil and Water Conservation Board
P.O. Box 658
Temple, Texas 76503

T.J. Helton
NPS Project Manager
(254) 773-2250 ext. 234

Donna Long
Quality Assurance Officer
(254) 773-2250 ext. 228

Northeast Texas Municipal Water District
P.O. Box 955
Hughes Springs, Texas 75656

Walt Sears, Jr., General Manager
Ric Blevins, Project Manager/Field Operations Supervisor
(903) 639-7538

HDR Engineering, Inc.
4401 West Gate, Suite 400
Austin, Texas 78745

Paul Price, Project Manager
Peggy Jones, Data Manager/Quality Assurance Officer
David Thomas, Technical Coordinator
(512) 912-5100

Center for Research in Water Resources
The University of Texas at Austin

U.S. Postal Service
PRC-119 (MC R8000)
Austin, Texas 78712

Other (UPS, DHL, FedEx, courier)
J.J. Pickle Research Campus
10100 Burnet Road, Building 119
Austin, Texas 78758-4497

Dr. George Ward, Principal Investigator
(512) 471-3131

A4 PROJECT/TASK ORGANIZATION

The following is a list of individuals and organizations participating in the project with their specific roles and responsibilities.

USEPA – United States Environmental Protection Agency, Region VI, Dallas. Provides project overview at the Federal level.

Ellen Caldwell, USEPA Texas Nonpoint Source Project Manager

Responsible for overall performance and direction of the project at the Federal level. Ensures that the project assists in achieving the goals of the federal Clean Water Act (CWA). Reviews and approves the quality assurance project plan (QAPP), project progress, and deliverables.

TSSWCB –Texas State Soil and Water Conservation Board, Temple, Texas. Provides project overview at the State level.

T.J. Helton, TSSWCB Project Manager

Responsible for ensuring that the project delivers data of known quality, quantity, and type on schedule to achieve project objectives. Tracks and reviews deliverables to ensure that tasks in the work plan are completed as specified. Reviews and approves QAPP and any amendments or revisions and ensures distribution of approved/revised QAPPs to TSSWCB and USEPA participants. Determines that the project meets the requirements for planning, quality assessment (QA), quality control (QC), and reporting under the CWA Section 319 program.

Donna Long, TSSWCB Quality Assurance Officer

Responsible for determining that the Quality Assurance Project Plan (QAPP) meets the requirements for planning, quality control, quality assessment, and reporting under the CWA Section 319 program. Reviews and approves QAPP and any amendments or revisions. Responsible for verifying that the QAPP is followed by project participants. Monitors implementation of corrective actions. Coordinates or conducts audits of field and laboratory systems and procedures.

NETMWD – Northeast Texas Muncipal Water District, Hughes Springs, Texas. Project Lead, Assessment and Mitigation Project.

Walt Sears, Jr., NETMWD General Manager

Responsible for coordination and cooperation between the Northeast Texas Municipal Water District (NETMWD) Steering Committee members and HDR Engineering, Inc.

Ric Blevins, Project Manager/Project Field Operations Supervisor

Responsible for contact and coordination with HDR Engineering, Inc. (HDR), Texas State Soils and Water Conservation Board (TSSWCB), and other entities participating in the NETMWD TSSWCB activities. Responsible for implementing TSSWCB requirements in contracts, QAPPs, and QAPP amendments and appendices. Coordinates basin planning activities and work of basin partners. Ensures monitoring systems audits are conducted to ensure QAPPs are followed by the NETMWD participants and that projects are producing data of known quality. Ensures that subcontractors are qualified to perform contracted work. Ensures TSSWCB Project Manager and/or Quality Assurance Officer is notified of circumstances which may adversely affect quality of data derived from collection and analysis of samples. Responsible for transmitting all data collected by NETMWD or PPAI staff that meets the data quality objectives of the project to the TSSWCB.

Responsible for performing field sampling and data processing duties in accordance with standard operating procedures (SOP's), data quality objectives (DQO's) and this QAPP, reporting to the Technical Coordinator any deviation from SOP's or DQO's, maintaining proper documentation of sampling events, sample preservation, sample shipment, and field procedures at NPS designated stations. Responsible for data review from all monitoring events and provides data quality comments to the QAO. Responsible for supervising sampling and oversight of project activities. Responsible for field scheduling, staffing, and ensuring that staff are appropriately trained. Responsible for the acquisition of water samples and field data measurements in a timely manner that meet the quality objectives specified in Section A7 (table A.1) as well as the requirements of Sections B1 through B8. Reports status, problems, and progress to Cypress Creek Basin Technical Coordinator.

HDR – HDR Engineering, Inc., Austin, Texas. Project Staff.

Paul Price, HDR Project Manager

Responsible for contact and coordination with NETMWD, TSSWCB, and other entities participating in the Cypress Creek Basin NPS activities. Responsible for implementing NPS requirements in contracts, QAPPs, and QAPP amendments and appendices. Coordinates basin planning activities and work of basin partners. Ensures monitoring systems audits are conducted to ensure QAPPs are followed by planning agency participants and that projects are producing data of known quality. Ensures that subcontractors are qualified to perform contracted work. Ensures NPS project managers and/or QA Specialists are notified of circumstances which may adversely affect quality of data derived from collection and analysis of samples. Responsible for transmitting all data collected by NETMWD that meets the data quality objectives of the project to the TSSWCB.

Peggy Jones, HDR Quality Assurance Officer/Data Manager

Responsible for coordinating the implementations of the Quality Assurance program that includes identifying, receiving, and maintaining project quality assurance records. Responsible for determining if all data collected meet the data quality objectives of the project and are suitable for reporting to the TSSWCB. Coordinates and monitors deficiencies, nonconformances and corrective action, coordinates and maintains records of data verification and validation, and coordinates the research and review of technical QA material and data related of water quality monitoring system design and analytical techniques. Conducts monitoring systems audits on project participants to determine compliance with project and program specifications, issues written reports, and follows through on findings.

Oversees data management plan for the study. Ensures that field data are properly reviewed and verified prior to transfer of data to TSSWCB. Responsible for the acquisition, verification, and transfer of quality-assured data to the TSSWCB. Responsible for transferring data to the TSSWCB in the acceptable format. Ensures that the data review checklist is completed and data are submitted with appropriate codes and data. Documents task progress and track labor and non-labor expenditures to produce the necessary reimbursement forms and progress reports specified in the NPS contract. Provides the point of contact for the TSSWCB Project Manager to resolve issues related to the data and assumes responsibility for the correction of any data errors.

David Thomas, HDR Technical Coordinator

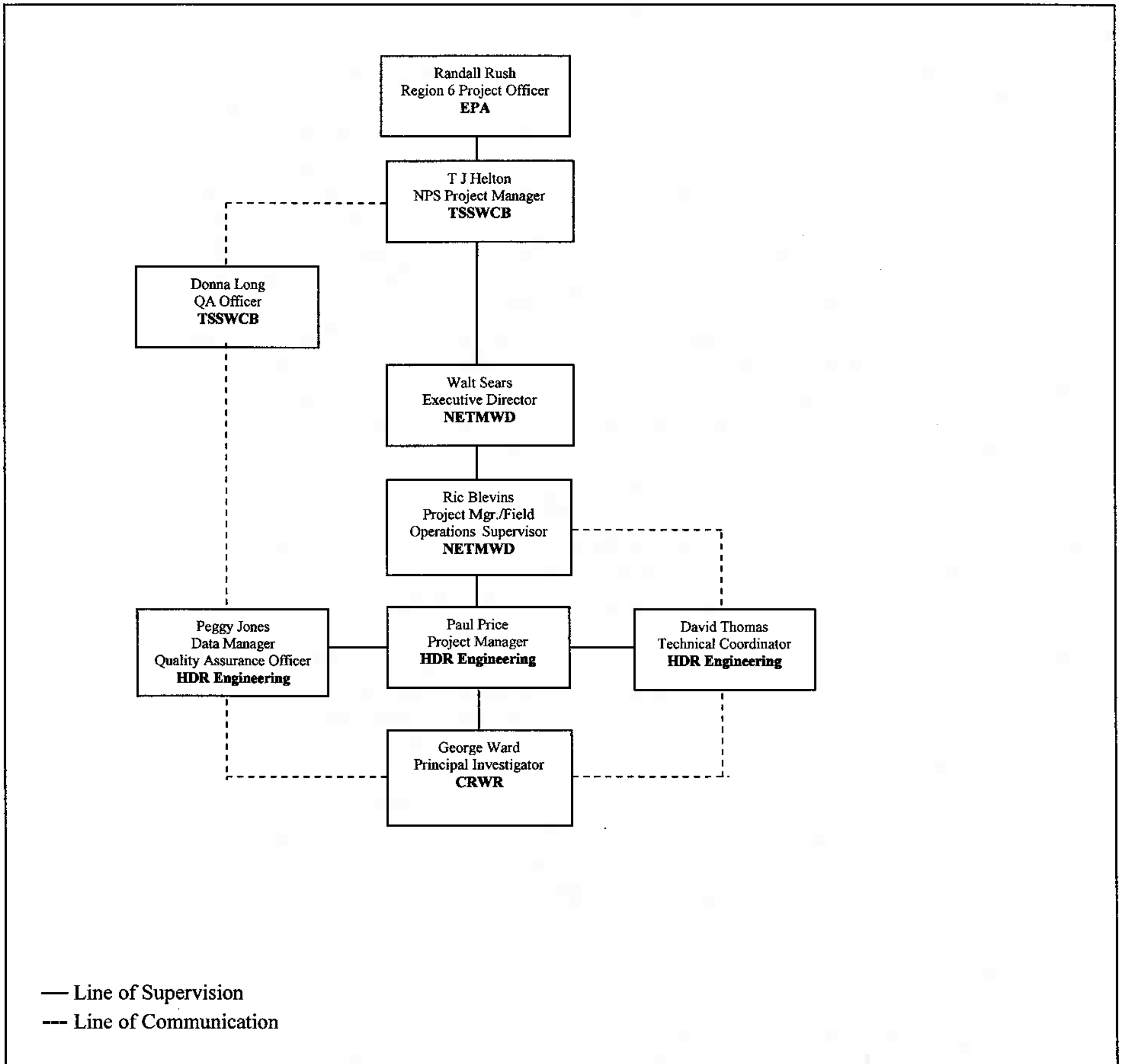
Responsible for writing and maintaining the QAPP and monitoring its implementation that involves maintaining records of QAPP distribution (including appendices and amendments) and maintaining written records of sub-tier commitment to requirements specified in this QAPP. Responsible for the supervision (through direct contact with the Project Field Operations Supervisor) of all NPS field activities, equipment preparation, sampling, sample preservation, fieldwork, sample transport and chain-of-custody maintenance in compliance with the approved QAPP. Ensures that field staff is properly trained (in cooperation with the Project Field Operations Supervisor) and that training records are maintained.

CRWR – Center for Research in Water Resources, University of Texas, Austin, Texas. Project Staff.

George Ward, Principal Investigator

Responsible for water quality modeling, data analyses in support of modeling activities, and reporting for those project tasks associated with SWAT modeling (Task 9) including development of data quality objectives (DQOs) and a quality assurance project plan (QAPP). Responsible for coordination, development, and delivery of Task 9 quarterly reports and the Task 9 final report related to the SWAT modeling effort.

Figure A4.1. PROJECT ORGANIZATION CHART



A5 PROBLEM DEFINITION/BACKGROUND

A Quality Assurance Project Plan (QAPP) entitled *Assessment and Mitigation of Agricultural and Other Nonpoint Source Activities in the Cypress Creek Basin* has been developed and approved by TSSWCB and EPA to ensure the reliability of the monitoring data collected under each task description. During the project QAPP meeting with TSSWCB held in Temple, Texas on February 13, 2005, it was determined that mathematical modeling of nonpoint source loading data derived from this study would require a separate quality assurance project plan (QAPP).

In 1998, water quality testing showed that dissolved oxygen concentrations in the Lake O' the Pines were not optimal for the support of fish and other aquatic life. Lake O' the Pines (Segment 0403) was listed on the state's §§303(d) list as impaired due to low dissolved oxygen levels. As a result of that determination, the TCEQ, in cooperation with NETMWD initiated the *Lake O' the Pines Watershed TMDL (Total Maximum Daily Load) Project* designed to identify the source of pollutants responsible for the low dissolved oxygen and determine the amount of pollutant load reduction needed to raise dissolved oxygen concentrations to the level prescribed in the state water quality standards. This study concluded that phosphorus was the material most responsible for the low dissolved oxygen and that a 56% reduction in phosphorus loadings from the watershed was needed. The TCEQ released the draft TMDL based on this information for public comment in November of 2005. A public meeting was held in Hughes Springs on November 17, 2005 to receive addition public comment on the draft TMDL. The public comment period ended on December 5, 2005. The Texas State Soil and Water Conservation Board (TSSWCB) approved the TMDL at their Board meeting on March 23, 2006. The TCEQ adopted the TMDL at their April 12, 2006 Commission Agenda meeting. The TMDL has been submitted to the USEPA for approval and their review is ongoing. Preliminary plans for the development of an Implementation Plan designed to achieve the load allocations specified in the TMDL have been discussed and the formation of topic-specific workgroups has begun. The development of the Implementation Plan for the TMDL will be overseen by the Big Cypress Creek Basin Steering Committee. The Implementation Plan will require approval by the TSSWCB and the TCEQ.

The Assessment and Mitigation Project will support implementation of agricultural best management practices (BMPs) to reduce nutrient runoff from agricultural operations in the Lake O' the Pines watershed. The Project is an integral and essential part of the implementation plan following the findings and recommendations of the Lake O' the Pines TMDL. Study site monitoring results will be used to validate small scale SWAT models of each edge-of-field monitoring location. As part of that process, the present study is anticipated to identify important variables that generally define nutrient loss rates in the local setting, to quantify loss rates from the study sites, evaluate the effectiveness of BMPs given the land characteristics and uses on the study sites, and to estimate the reductions in nutrient loss with present and projected levels of BMP implementation.

The Implementation Plan for the Lake O' the Pines TMDL, scheduled for completion this spring, will include this project, evaluation of nutrient losses from agricultural operations and on-site wastewater disposal facilities, and projects that will (1) monitor nutrient discharges from permitted point sources, (2) nutrient transport out of selected subwatersheds and down Big Cypress Creek, and (3) monitor nutrient, chlorophyll a and dissolved oxygen concentrations in critical areas of Lake O' the Pines. Selection of nutrient loss study sites, subwatersheds, stream monitoring locations, schedules and parameter sets will be coordinated among the projects to insure that the data collected is adequate to define current conditions and provide input to refine the existing SWAT model of the Lake O' the Pines watershed. The information developed will be used to identify problem areas and opportunities for reducing nutrient losses, explore the relationship over time among application of agricultural BMPs, nutrient loading in Big Cypress Creek and Lake O' the Pines, and the corresponding changes in biological and water quality conditions in the reservoir.

Agencies cooperating in this project include the EPA, TSSWCB, NETMWD, HDR Engineering, Inc. CRWR, the University of Texas at Austin, Ana-Lab Corporation and the Texas Cooperative Extension Soil, Water & Forage Testing Laboratory.

See Appendix A for the Work Plan Tasks that discuss the SWAT Modeling aspect of the project.

A6 PROJECT/TASK DESCRIPTION/SCHEDULE

The overall goal of this project (Task 9) consists of the development and application of small scale mathematical models (SWAT modeling) to strategically selected catchments. The Soil and Water Assessment Tool (SWAT) will be used to quantify the effects of applying BMPs on phosphorous loadings to streams, rivers, and lakes (as appropriate) in each watershed. The Center for Research in Water Resources (CRWR), located at the J.J. Pickle Research Campus of the University of Texas at Austin, will conduct the model simulations.

SWAT is a comprehensive mechanistic numerical model for simulating hydrological, transport and water-quality processes operating on a multi-tributary watershed. The model was developed by the USDA Agricultural Research Service (ARS) and Blackland Research Center of Texas A&M University. It has evolved over the past quarter century 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 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.

Because SWAT has enjoyed successful application to hundreds of watershed projects across the United States, and is a freely disseminated, public model, it has been widely used to support water quality and Total Maximum Daily Load (TMDL) planning throughout the country. Additional technical information regarding the model can be found at the SWAT homepage web address: http://www.brc.tamus.edu/swat.

SWAT was the model of choice for the Lake O' the Pines TMDL program, and has already been applied to the drainage area of the reservoir. In this application, the watershed of Lake O' the Pines, a system of 25 subbasins was employed. Fifteen (15) subbasins were used to depict the complex watershed of the Big Cypress, the main riverine input into the reservoir, and ten (10) to depict the other tributaries that flow into the Lake O' the Pines (Ward, 2003).

Within the Assessment and Mitigation Project, the effectiveness of BMP applications will be evaluated through a series of small-scale comparative runoff studies which will be integrated with the water quality data collected and compiled in the CRP and TMDL programs. This analysis will supplement and complement monitoring in Lake O' the Pines and its watershed currently conducted under the Clean Rivers Program, or as part of the TMDL implementation plan. Landowners willing to participate in the project were selected with the help of an advisory committee consisting of invited representatives of NETMWD, TSSWCB, Sulphur/Cypress Soil and Water Conservation District (SWCD), Pilgrims' Pride Corporation, interested agricultural operators, local independent contractors, local commercial fertilization companies, and Texas Cooperative Extension.

A total of twelve study sites were selected (Figure 1) from among properties offering participation with NETMWD in the project 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.

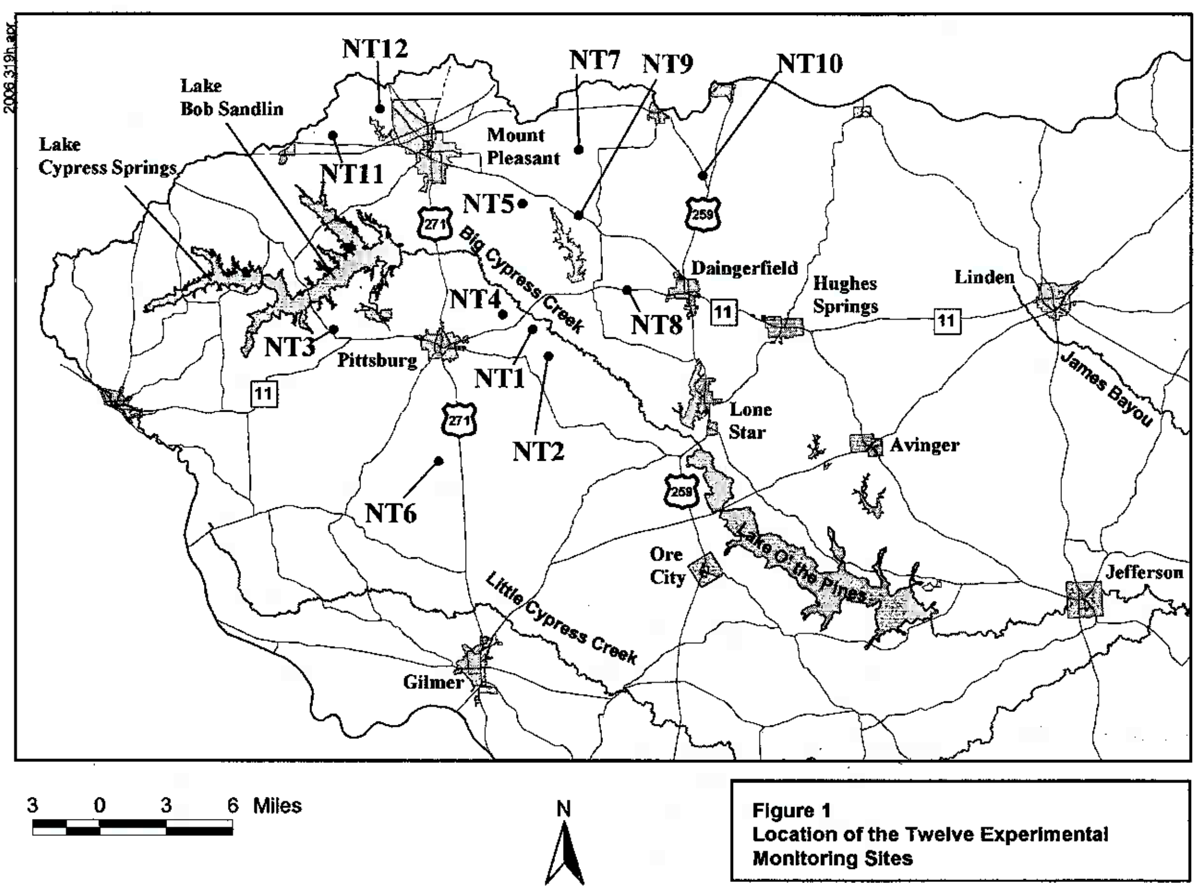


Figure 1
Location of the Twelve Experimental Monitoring Sites

The identity of individual landowners in this study has been kept confidential to encourage cooperation in addressing the study objectives. The volunteers were assigned a site number to protect their privacy. The location map was prepared to show the general area for all study participants without specifying their exact location.

There are two overall objectives of the SWAT modeling within the Assessment and Mitigation Project: (1) improve the validation of the SWAT application to the Lake O' the Pines watershed, (2) make specific evaluations of the effectiveness of runoff controls (BMP's) on the study catchments, and infer the probable effectiveness of these strategies for basin-wide nutrient management. The starting point for the present model validation is the application of SWAT2000 to the subwatersheds documented in the existing TMDL project (Ward, 2003). The model validation exploited excellent storm runoff data and was carried out to a level of detail unusual in basin-scale model studies, addressing six subwatersheds, selected because they represent a range of soils, landuse, and vegetation that typify the variety of properties of watersheds in the Lake O' the Pines basin, from which comprehensive hydrological and water-quality storm data were available for at least two well-defined events on each station. However, the complexity of the watershed and the large number of soils, land-use activities, and vegetation covers, means that field data were not available to that validation for some important combinations. The field data being acquired as part of the present Assessment and Mitigation Project will permit extended validation for major combinations of surficial conditions. Among the land-use categories are included various strategies of nutrient and run-off management. The present project will set-up detailed catchment models for each of the field sites and carry out simulations to calibrate the model for these small watersheds.

The same procedures of model validation documented in the TMDL work (Ward, 2002) presented in Appendix B will be observed in the present project. The key for validation is the storm event, and the associated runoff hydrograph, which is the primary hydrometeorological process for streamflow generation in this climatological area. Associated with this event is a rise and fall in the concentration of a waterborne constituent derived from the watershed, referred to as the storm *fluviograph*. Different parameters exhibit different fluviographs with different relations to the storm hydrograph. (TSS is particularly complicated, in that it can result from sediment mobilization on the watershed or within the stream channel, and be further modified by grain-size dependent scour and settling.)

Data analyses will be carried out in a two-step approach, first analyzing the storm hydrograph then the fluviograph for key waterborne parameters. The quality of how well a storm event is sampled will be based on examination of the rating data, and the relation of the water-sample times to the progress of the storm (i.e., how water samples are distributed over the course of the runoff hydrograph), and whether the data are point grab-samples or flow-weighted integrated samples. To quantify this judgment of data quality, a level of uncertainty, expressed as a standard deviation, will be developed, the higher values corresponding to data of diminished quality, see Appendix B (Ward, 2002). This same two-step procedure will be followed in model validation, in that first the hydrological performance of the model will be subjected to calibration and validation, then the constituent concentration. Analysis of storm fluviographs is essentially the determination of the mass load. We anticipate that three key water-quality variables will be employed in the fluviographical analyses: total suspended solids (TSS), total nitrogen and total phosphorus.

The validation problem of SWAT is compounded by the complexity of model set-up. There are a large number of model parameters whose values must be specified for a given simulation. A model simulation requires a *minimum* of 7 basin-wide input files plus 4 data-base files plus 3 input files per subbasin plus 4 input file per HRU. For a simple uniform catchment, therefore, 18 input files are necessary, and the number proliferates as the complexity of the watershed increases. The number of parameters represented in these input files is overwhelming. The simplest model application, to a single HRU with no special tillage or planting operations, with nutrient simulation only, requires specification of about 200 parameters. When the SWAT default and data-base values are accepted, there still remain over 30 parameters whose values must be specified, values for many of which are unlikely to be known to the modeler, so they are "available" for calibration. Theoretically, model calibration requires as many independent data sets (in the present context, well-sampled storm runoff events) as there are "available" parameters; model verification then requires additional independent data sets. Such a largesse of field data has rarely (if ever) been available to a watershed modeling project. Model validation must *a fortiori* employ judgment and supplementary strategies such as importation of model parameters from nearby catchments and from other modeling projects, and sensitivity analyses. In particular, the experience from application of SWAT to the Lake O' the Pines basin in the TMDL project will be invaluable in the present effort.

Model validation will be documented in a detailed memorandum report, including the supporting data analyses. Model input files for each subwatershed will be provided as well.

One of the important applications of the validated catchment models will be the evaluation of strategies of runoff and nutrient management (i.e., BMP's), as represented in the selection of catchment areas. Additional model runs will be carried out to explore and isolate the effect of these BMP's on loading from the catchment. The results of these evaluations will be documented separately.

The project and task descriptions covered by the SWAT Modeling QAPP are described below. All are part of Task 9: SWAT Modeling between TSSWCB, NETMWD, HDR and CRWR, which includes: Sub-tasks 9.1 and 9.2.

Sub-task 9.1 will involve small scale SWAT models that will be validated for each study site using measured properties (e.g., soils and soil nutrients, vegetative cover and cover types, seasonal effects, antecedent conditions, runoff rates, TSS and nutrient concentrations) instead of the literature values employed in the Lake O' the Pines TMDL modeling.

Deliverables: A validated SWAT model for each of the 12 study sites. Model documentation will include identification of measured variables used in each model together with an evaluation of their respective confidence intervals and major differences, where they occur, with previously employed input variables.

Sub-task 9.2: In this subtask, the validated models will be used to identify the major variables affecting nutrient loss from the study sites and examine the relationships among those variables in order to evaluate the effectiveness of water quality management plans (WQMPs) in limiting nutrient loss.

Deliverables: Model runs necessary to estimate the nutrient reductions achieved through time as WQMPs have been implemented. The results of the SWAT modeling of the study sites will be appropriately presented as part of the Assessment and Mitigation Project final report .

The SWAT Modeling schedule is found in Table A6.1.

TABLE A6.1

NETMWD Agricultural NPS Evaluation: SWAT Modeling
Schedule of Project Plan Milestones

9	SWAT modeling	November 2007	July 2008
9.1	Validated SWAT model for each study site	November 2006	July 2008
9.2	Estimate nutrient reductions to evaluate effectiveness of WQMPs	May 2007	July 2008
10	Data analysis and reporting	December 2007	July 2008
10.1	Perform analyses of data and final project report	December 2007	July 2008
10.2	Present data in final report	December 2007	July 2008

A7 QUALITY OBJECTIVES/CRITERIA FOR MODEL INPUTS AND OUTPUTS

Quality objectives and criteria for model inputs and outputs are qualitative and/or quantitative statements that (1) clarify study objectives, (2) define the appropriate type and acceptance criteria of existing data, (3) establish acceptable model input and calibration criteria, and (4) specify tolerable levels of model performance and potential decision errors. Each is discussed in the following sections.

Study Objectives

The main objective for the SWAT modeling project (Task 9) is to employ the results of nonpoint nutrient loss from specific land use types (edge-of-field results), together with the results of other aquatic monitoring programs where relevant, to examine and refine, as appropriate, the input elements of the SWAT model and to quantify the effectiveness of BMP's.

Secondary objectives that support the main objective include the following:

(1) Compile and analyze storm-event data from the 12 study catchments;
(2) Implement the SWAT model for each of the 12 study catchments;
(3) Specify model parameters based upon data analysis and evaluation of model response, following the general procedures of Ward (2002) found in Appendix B;
(4) For those catchments in which BMPs are in place, determine response of the model to (i) removal of BMP, (ii) present BMP implementation (as reflected in the field data), and (iii) alternate selected feasible BMP strategies (defined for each catchment, as appropriate); and
(5) Document results

Acceptance Criteria for Existing Data

In terms of data compilation and assessment, a substantial base of information on water quality, soils, land use and poultry litter application has been developed under the Cypress Creek Basin Clean Rivers Program (CRP) and the Lake O' the Pines TMDL program. This available data was used to assist NETMWD and its contractors in site selection, study design, approval and implementation.

Data of known and documented quality are essential to the success of the TSSWCB SWAT modeling project. With respect to water-quality and storm runoff monitoring, sample collection, preservation and transportation, chemical analysis, data archiving, and quality assurance is being conducted according to procedures outlined in the *Assessment and Mitigation of Agricultural and Other Nonpoint Source Activities in the Cypress Creek Basin Quality Assurance Project Plan* (*QAPP*) developed for the Northeast Texas Municipal Water District (NETMWD, 2005) and approved by the USEPA on November 25, 2005. The methods are consistent with several other data collection QAPP projects in the Cypress Creek Basin including the *Lake O' the Pines Watershed Total Maximum Daily Load Quality Assurance Project Plan* (NETMWD, 2000).

In addition to field data collected as a part of the Assessment and Mitigation Project, the implementation of the SWAT model requires data from other agencies, including (but not necessarily restricted to) historical data on topography, soils, rainfall (and other meteorological parameters), land use, human road and conveyance infrastructure, and vegetation. Such data will be sought solely from professional sources, collected and compiled by observers trained in the discipline. Therefore, rainfall data, for example, will be obtained from agencies such as the National Weather Service, National Climate Data Center, river authorities, and data sources implemented and reviewed by trained meteorologists or hydrologists. Soils data will be obtained from the extensive data holdings of the Natural Resource Conservation Service, specifically the STATSGO and SSURGO compilations, supplemented by county soil surveys, where additional information or clarification is needed. Topographic data will be obtained from USGS products, and (if available) surveys by registered professional surveyors. Land use and infrastructure data will be obtained from agencies such as Texas Department of Transportation, TSSWCB, TCEQ, as well as from on-site observations of project personnel. Additionally, poultry application rates, soil types, soil nutrient levels vegetation cover, presence of Best Management Practices (BMPs) and field runoff loads of nutrients and sediments will be obtained for the twelve study sites of this Project.

Model Input and Calibration Criteria

In addition to the criteria for acceptance of data for use in the project based upon the integrity of the source and validity of the protocols, the use of various data in model validation studies (encompassing calibration) imposes additional conditions on the field data. These do not relate to the quality of the measurement *per se*, but to whether the data as collected adequately represent events appropriate for model validation. There are two primary criteria. First is whether the monitored storm event is suitable as a model validation case. Especially in the initial calibration runs, it is important that the storm event exhibit features of simplicity, e.g., be characterized by a brief intense rainfall producing a hydrograph with well-defined rising and falling limbs, stable initial (pre-storm) conditions, lack of agricultural activities (plowing, fertilizer application) just prior or during event, etc. Second is whether the monitored data encompass the necessary suite of analytes and are obtained with sufficient time density and over a sufficient duration to satisfactorily sample the entire storm event. These two sets of criteria do not create an "accept/reject" dichotomy for data sets, but rather a logical ordering, so that the noncomplex, better-sampled storms receive the greatest attention and effort in the modeling process. Part of this ordering of the validation data sets is the specification of uncertainty (described above). These uncertainties in field data are carried forward through the analysis and compounded when the data are further processed, e.g. to compute loads, as in Ward (2002) presented in Appendix B. The uncertainty in the validation field data circumscribes the level of uncertainty acceptable in model validation, in that the level of uncertainty of the model prediction logically must at least equal that of the field data. In other words, the accuracy of the validated model cannot be expected to be better than the accuracy of the field data employed in its validation. The model will be considered to be satisfactorily validated if the following criteria are satisfied:

(1) Flow - Model predictions within 95% confidence bounds of the measured value. For average flow prediction versus a long-term record typical of USGS stations, this is on the order of 15% of the mean. For a normally distributed residual, these confidence bounds correspond to two standard deviations about the mean. The model will achieve this difference from the mean in 90% of the modeled values.

(2) Suspended solids - Model predictions within 95% confidence bounds of the measured value. For a normally distributed residual, these confidence bounds correspond to two standard deviations about the mean. The model will achieve this difference from the mean in 90% of the modeled values.

(3) Nutrients (total phosphorus and total nitrogen) - Model predictions within 95% confidence bounds of the measured value. For a normally distributed residual, these confidence bounds correspond to two standard deviations about the mean. The model will achieve this difference from the mean in 90% of the modeled values.

Model Performance and Tolerable Errors In Model-Based Decisions

The ultimate performance test for the TSSWCB SWAT model is whether the output sufficiently represents the natural system that is being simulated. This is a determination by the modeling team based upon their expertise of model formulation and consideration of the amount of available data, and includes model validation. The validation process will utilize the field data to the maximal extent possible, proceeding in the logical order indicated in the previous section, and concluding with a judgment of confidence in the model performance. This judgment will depend upon the nature of the simulation conditions, and will be quantified with the available data. The same philosophy as applied to model calibration, that the accuracy of the data delimits the accuracy of model performance, and the same criteria for satisfactory calibration enumerated above will be applied to the process of model validation.

If a model application fails to meet the criteria of calibration, this will trigger stepwise action, which will be documented in a corrective-action report. First, all model input files will be reviewed for conformity to I/O specifications in the SWAT documentation, and for accuracy of input. If no corrections are necessary, or if the model fails to meet the stated criteria after corrections are implemented, then the possibility will be considered that the model application represents a statistical anomaly. If the number of such cases falls within the 10% acceptable exceedance rate, then no further action will be taken and these events will be simply documented for the file. If the exceedance exceeds the 10% criterion, then the potential sources of error will be enumerated, and whether those sources of error will affect the measured data or the model output. If a model deficiency is identified, the most likely causes will be discussed, which will entail comparison to other model executions, and perhaps case-specific sensitivity studies.

A8 SPECIAL TRAINING/CERTIFICATION

Dr. George Ward will conduct model calibration, validation and development. He has the appropriate education, training and experience required to adequately perform those duties. No special certifications are required.

A9 DOCUMENTS AND RECORDS

All records, including modeler's notebooks and electronic files will be archived by NETMWD for at least 5 years. These records will document model testing, calibration, and evaluation and will include documentation of written rationale for model set-up (i.e., hand calculation checks, formatting), source of field data, any exploratory and/or sensitivity analysis results that might be performed in the course of model validation, and documentation of adjustments to parameter values resulting from the process of calibration.

The NETMWD QA manager will produce an annual QA/QC report, which will be kept at the NETMWD offices with copies made available upon request. Any items or areas identified as potential problems and any variations or supplements to QAPP procedures noted in the QA/QC report will be made known to pertinent project personnel and included in an update or amendment to the QAPP. The Project Manager will ensure distribution of the most recent QAPP to all individual listed in Section A3.

Quarterly progress reports will note activities conducted in connection with the Water Quality modeling work items or areas identified as potential problems, and any variations or supplements to the QAPP. CARs will be utilized when necessary (See Attachment 2). CARs will be maintained in an accessible locations for reference at the NETMWD office. CARs that result in any changes or variations from the QAPP will be made known to pertinent project personnel and documented in an amendment to the QAPP.

The model results will be communicated in one or several memorandum reports to NETMWD, including features of the modeled watershed, aspects of model set-up and operation, comparison to data, and numerical evaluation of model performance, accompanied by figures and tabular material as necessary to communicate the results of the model application. This will comprise the final report for Task 9. In addition, the model team will work with NETMWD and the Assessment and Mitigation Project contractor to incorporate the data analyses and modeling into sections of the Assessment and Mitigation Project final report, as appropriate.

B1 SAMPLING PROCESS DESIGN

Not Relevant

B2 SAMPLING METHODS

Not Relevant

B3 SAMPLE HANDLING AND CUSTODY

Not Relevant

B4 ANALYTICAL METHODS

Not Relevant

B5 QUALITY CONTROL

Not Relevant

B6 INSTRUMENT/EQUIPMENT TESTING, INSPECTION AND MAINTENANCE

Not Relevant

B7 CALIBRATION

As noted earlier, in addition to field data collected as a part of the present project, the implementation of the SWAT model will require data from other agencies, including (but not necessarily restricted to) historical data on topography, soils, rainfall (and other meteorological parameters), land use, human road and conveyance infrastructure, and vegetation. Such data will be sought solely from reliable professional sources.

Set-up and validation of the SWAT model for the individual study watersheds will begin after QAPP approval and after the data-collection effort is underway. The SWAT model will be validated on hydrology and water quality indicators, mainly, sediment and nutrients, as delineated in Section A above. The performance critera are based on the premise that the intrinsic accuracy of the measurements circumscribe the expected accuracy of the model. The model will be considered to be satisfactorily validated if the following criteria are satisfied:

(1) Flow - Model predictions within 95% confidence bounds of the measured value. For average flow prediction versus a long-term record typical of USGS stations, this is on the order of 15% of the mean. (For a normally distributed residual, these confidence bounds correspond to two standard deviations about the mean.) The model will achieve this difference from the mean in 90% of the modeled values.

(2) Suspended solids - Model predictions within 95% confidence bounds of the measured value. (For a normally distributed residual, these confidence bounds correspond to two standard deviations about the mean.) The model will achieve this difference from the mean in 90% of the modeled values.

(3) Nutrients (total phosphorus and total nitrogen) - Model predictions within 95% confidence bounds of the measured value. (For a normally distributed residual, these confidence bounds correspond to two standard deviations about the mean.) The model will achieve this difference from the mean in 90% of the modeled values.

B8 INSPECTION/ACCEPTANCE OF SUPPLIES AND CONSUMABLES

Not Relevant

B9 METHOD OF ACQUIRING INPUT DATA (NON-DIRECT MEASUREMENTS)

The same procedures of model validation documented in the TMDL work (Ward, 2002) included in Appendix B will be observed in the present project. The key for validation is the storm event, and the associated runoff hydrograph, which is the primary hydrometeorological process for streamflow generation in this climatological area. Data analyses will be carried out in a two-step approach, first analyzing the storm hydrograph then the fluviograph for key waterborne parameters. The quality of how well a storm event is sampled will be based on examination of the rating data, and the relation of the water-sample times to the progress of the storm (i.e., how water samples are distributed over the course of the runoff hydrograph), and whether the data are point grab-samples or flow-weighted integrated samples. To quantify this judgment of data quality, a level of uncertainty, expressed as a standard deviation, will be assigned, the higher values corresponding to data of diminished quality, see Ward (2002) in Appendix B. This same two-step procedure will be followed in model validation, in that first the hydrological performance of the model will be subjected to calibration and validation, then the constituent concentration. Analysis of storm fluviographs is essentially the determination of the mass load.

In addition to field data collected as a part of the Assessment and Mitigation Project, the implementation of the SWAT model requires data from other agencies, including (but not necessarily restricted to) historical data on topography, soils, rainfall (and other meteorological parameters), land use, human road and conveyance infrastructure, and vegetation. Such data will be sought solely from professional sources, collected and compiled by observers trained in the discipline. Therefore, rainfall data, for example, will be obtained from agencies such as the National Weather Service, National Climate Data Center, river authorities, and data sources implemented and reviewed by trained meteorologists or hydrologists. Soils data will be obtained from the extensive data holdings of the Natural Resource Conservation Service, specifically the STATSGO and SSURGO compilations, supplemented by county soil surveys, where additional information or clarification is needed. Topographic data will be obtained from USGS products, and (if available and necessary) surveys by registered professional surveyors. Land use and infrastructure data will be obtained from agencies such as Texas Department of Transportation, TSSWCB, TCEQ, as well as from on-site observations of project personnel. Additionally, poultry application rates, soil types, soil nutrient levels vegetation cover, presence of Best Management Practices (BMPs) and field runoff loads of nutrients and sediments will be obtained for the twelve study sites of this Project.

B10 DATA MANAGEMENT

Data to be provided to the modeling effort is described in Section B10 of the Assessment and Mitigation of Agricultural and Other Nonpoint Activities in the Cypress Creek QAPP (NETMWD, 2005). Responsibility for data management during the course of the project is assigned to the prime contractor HDR.

C1 ASSESSMENTS AND RESPONSE ACTIONS

Model assessment and selection was completed prior to the initiation of this SWAT modeling project as part of the Lake O' the Pines TMDL Program in order to identify a successful approach for non-point source modeling in the Cypress Creek Basin. There were no response actions required as part of the model assessment and selection process

As described in Section B9 (Non-direct Measurements), modeling staff will evaluate data from edge-of-field study sites to be used in calibration and as model input according to criteria discussed in Section A7 (Quality Objectives and Criteria for Model Inputs/Outputs Data) and will follow up with the various data sources on any concerns that may arise.

The model calibration procedure and applicable criteria for satisfactory calibration and validation are discussed in Section A7 (Quality Objectives/ for Model Inputs and Outputs). The data employed as part of the modeling results will be evaluated during the validation process specifically for its utility as a standard of model performance evaluation.

The modeling task is intended to rely upon the SWAT2000 modeling code as published by ARS/BRC, and modifications to the code will not be made. The SWAT software that is used to compute model predictions is tested to assess performance relative to specific response times, computer processing usage, run time, convergence to solution, stability of the solution algorithms, the absence of terminal failures, and other quantitative aspects of computer operation, as part of the routine code generation by ARS/BRC. In the event that errors in the code are discovered through the routine model set-up and validation procedures of this project, these errors will be documented to NETMWD, TSSWCB and to the authors of SWAT at ARS/BRC.

C2 REPORTS TO MANAGEMENT

Corrective Action Reports (CAR) will be prepared in the modeling task to document any failures of the model. The procedures and guidelines for data collection QA is addressed separately in the NETMWD project QAPP (NETMWD, 2005). As described in Section A9, memorandum reports will document activities conducted in connection with this water quality modeling project.

If the procedures and guidelines established in this QAPP are not successful, i.e. the success of the modeling activity is impaired in some way, corrective action is required to ensure that conditions adverse to quality performance are identified promptly and corrected as soon as possible. Corrective actions include identification of root causes of problems and correction of identified problem(s). Corrective Action Reports will be filled out to document the problems and the remedial action taken. Copies of Corrective action reports will be included with the NETMWD project final report. The NETMWD project final report will discuss any problems encountered and solutions made.

D1 DATA REVIEW, VERIFICATION, AND VALIDATION

The data review, verification, and validation process identifies whether the final data package for the SWAT Modeling Project conforms to the quality standards of the TSSWCB and EPA, and are separately addressed in the NETMWD project QAPP (NETMWD, 2005). As noted earlier, only those data that are supported by appropriate quality control data will be considered acceptable for use in model validation. Validation and verification criteria for the modeling, as defined by this QAPP, are the standards that are used to determine whether the modeling results are sufficient for drawing conclusions related to the DQOs in Section A7.

The Project Leader of the Assessment and Mitigation Project is responsible for ensuring that data are properly reviewed, verified, and submitted in the required format for the project database.

D2 VALIDATION METHODS

The watershed model, Soil Watershed Assessment Tool (SWAT) is built with state-of-the-art components with an attempt to simulate the processes physically and realistically. Most of the model inputs are physically based (that is, based on readily available information or upon mechanistic relationships). It is important to understand that SWAT is not a simple "one-parameter model" which can be implemented in a formal optimization procedure (as part of the calibration process) to fit any set of data. Instead, there are a number of input variables that are not well defined physically, including the runoff curve number and Universal Soil Loss Equation, N and P generation rates, dependent in turn upon biokinetic parameters of the land-cover vegetation. While these model parameters may be adjusted within literature values so that the results are consistent with knowledge of watershed processes, there is no unique solution to the validation process because there are generally many more free parameters than sets of field data

D3 RECONCILIATION WITH DATA QUALITY OBJECTIVES FOR MODELING

The SWAT modeling framework developed for this project will be used to evaluate water quality issues, as they pertain to sediment and nutrient loading at 12 selected study sites. The information derived from this project together with the results of other aquatic monitoring programs will be consolidated to provide the TSSWCB, TCEQ, SWCDs and local stakeholder groups with best-available information pertaining to watershed characteristics.

References

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Young, J. L., M. Chang, M. C. Cochran, and L. L. Whiteside. 1996. *Poultry Litter Land Application Rate Study* (PILLARS), Final Report, prepared for Texas Natural Resource Conservation Commission by Stephen F. Austin University and Angelina Neches River Authority.

ATTACHMENT 1 Letter to Document Adherence to the Assessment and Mitigation of Agricultural and Other Nonpoint Source Activities in the Cypress Creek Basin SWAT Modeling Quality Assurance Project Plan on Behalf of Northeast Texas Municipal Water District

TO: (name)
(organization)

FROM: (name)
(organization)

Please sign and return this form by (date) to:

(name)
(organization)
(address)

I acknowledge receipt of the referenced document(s). I understand the document(s) describe quality assurance, quality control, data management and reporting, and other technical activities that must be implemented to ensure the results of work performed will satisfy stated performance criteria.

____
Signature Date

Copies of the signed forms should be sent by the Planning Agency to the TSSWCB NPS Project Manager within 60 days of TSSWCB approval of the QAPP.

ATTACHMENT 2 SWAT Model Corrective Action Form

Date:	
Problem:	
Person(s) Involved:	
Cause of Problem:	
Corrective Action:	

Date:	
Follow-up Action:	
Quality Review:	

Reviewed by:

____________________ ____________________
HDR Project Manager Date

Approved by:

____________________ ____________________
Quality Assurance Officer Date

APPENDIX A. Work Plan

Task 9: SWAT Modeling

Objective: Employ the results of non point nutrient loss from specific land use types (this study), together with the results of other aquatic monitoring programs, to examine and refine, as appropriate, elements of the SWAT model which are currently based on literature values or limited local data. Operate the SWAT model to better evaluate land use impacts to nutrient loading to Lake O' the Pines, effectiveness of BMP's, and progress toward achieving the goals of the TMDL.

Task 9.1: Small scale SWAT models will be calibrated and verified for each study site using measured properties (e.g., soils and soil nutrients, vegetative cover and cover types, seasonal effects, antecedent conditions, runoff rates, TSS and nutrient concentrations) instead of the literature values employed in the Lake O' the Pines TMDL modeling.

Task 9.2: The validated models will be used to identify the major variables affecting nutrient loss from the study sites and examine the relationships among those variables in order to evaluate the effectiveness of water quality management plans (WQMPs) in limiting nutrient loss and to estimate basinwide progress in reducing agricultural nutrient loss since the widespread imposition of WQMPs in the Lake O' the Pines watershed began in about 2000.

Deliverables

- A validated SWAT model for each study site. Model documentation including identification of measured variables used in each model together with an evaluation their respective confidence intervals and major differences, where they occur, with previously employed input variables.
- Model runs necessary to estimate the nutrient reductions achieved through time as WQMPs have been implemented. The results of the SWAT modeling of the study sites will be appropriately presented in the final report (Task 9)

APPENDIX B. Validation of Watershed Loading Model

TECHNICAL MEMORANDUM
Big Cypress/Lake o' the Pines TMDL Project

TO: Paul Price Associates, Inc.
COPY: Walt Sears, NETMWD
Arthur Talley, TNRCC

FROM: George H. Ward
Center For Research in Water Resources
University of Texas

DATE: 25 November 2002

VALIDATION OF WATERSHED LOADING MODEL

1. Introduction

Apart from point-source discharges, contaminants in the watercourses of the Lake o' the Pines basin derive from landscape loading (so-called nonpoint source), so the development and application of a model of watershed processes is an important component of the TMDL process. An earlier review of available models (Ward, 2001a) described the formulation and structure of watercourse models and noted the role of landscape processes (Fig. 1) in modeling the Cypress basin. It was observed that there are two distinct hydrological regimes of principal concern to the Lake o' the Pines basin TMDL: the low-flow condition and the storm runoff event. The former is typical of summer conditions, in which the streams and tributaries equilibrate to the high production of summer, and is particularly critical to Lake o' the Pines, because this is the condition under which degraded water quality occurs.

The storm runoff event is typical of the equinoctial seasons, i.e. spring and fall, when the system receives the majority of its runoff. Under this regime, the chief concern is the dynamic loads of contaminants derived from various landuse activities such as agriculture, land waste disposal, urban and suburban development, etc. Central to this regime is the mobilization of contaminants from the watershed surface and their subsequent transport into the waterways of the basin. It is this collection of processes that the watershed model seeks to depict. Ward (2001a) summarizes the nature and

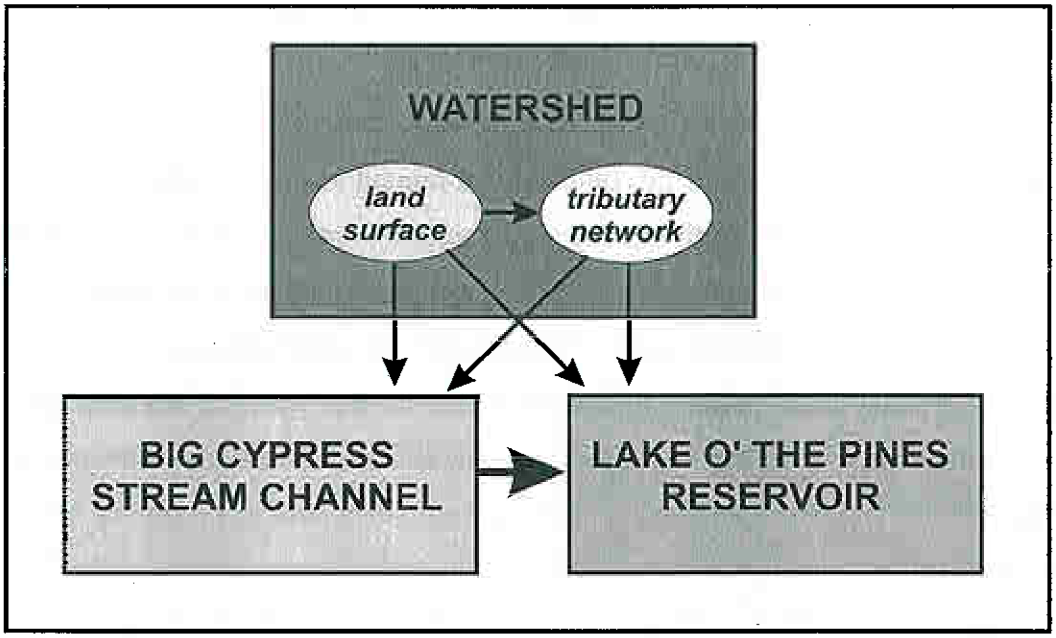

Figure 1 - Schematic of principal components of surface water network of Big Cypress Basin

approaches to watershed modeling, in which the watershed is viewed as a *processor* of rainfall, and two categories of mechanism are distinquished: hydrology and transport. Hydrology characterizes the water budget, composed of *infiltration*, in which a portion of the impingent rainfall penetrates the ground and enters the soil, and *runoff*, in which the remaining rainfall moves by gravity into the surface drainage system. The infiltrated water can be evaporated back to the atmosphere, taken up by plants and transpired to the atmosphere, percolate to deeper layers of soil or aquifers, or move through the subsurface to re-emerge as interflow in a tributary channel. Runoff moves across the watershed surface organizing into rills and furrows, gullies and swales, tributaries and ultimately stream channels.

Transport mechanisms include the processes by which contaminants in particulate or dissolved form are entrained into the runoff. Particles of sediment on the watershed surface are mobilized by the movement of water over the land surface. This process is basic to erosion, and the importance of quantifying soil erosion has been a motivator for the development of watershed models for many years. Whatever is removed by erosion from the land surface is carried into the drainageways as a sediment load, along with many pollutants that sorb to soil particles. In addition, contaminants dissolved in the runoff water represent a solution load to the downstream drainageways.

Models differ in the methods by which they depict these basic processes, by the numerical representation of the watershed, and by the complexity of rainfall and other hydrometeorological variables they accommodate. Application of the model selection rationale in Ward (2001a) resulted in two candidate models, the SCS model *SWAT* (Soil and Water Assessment Tool) or the USGS model *HSPF* (Hydrological Systems Program - Fortran), both of which are surveyed in Ward and Benaman (1999). At the time of issuance of Ward (2001a), no final selection had been made between the two, pending available of storm data from the automated flow and water-sampling system operating in the Big Cypress basin. Analysis of storm data from this sampling network (reported in the following section) and consideration of the specific requirements of the Big Cypress TMDL, especially the large TSS and nutrient loads emanating from several key watersheds, have now led to a choice of SWAT as the model for use in the Big Cypress TMDL. This report describes application of SWAT to key watersheds in the basin, and its calibration and verification.

2. Storm event data analysis

This validation focuses on six watersheds, selected because they represent a range of soils, landuse, and vegetation that typify the variety of properties of watersheds in the Lake o' the Pines basin, and because comprehensive hydrological and water-quality storm data are available for at least two well-defined events on each station. The available storm data for the six watersheds are summarized in Table 1. (In addition to these, monitors were operated at Stations 15836 and 17029 on Prairie Creek, 15894 on Boggy Creek, 17027 on Meddlin Creek, 17032 on Kitchen Creek, and 17034 and 17035 on tributaries in the Hart Creek catchment.)

It will be noted that only data after 2000 are represented in Table 1, moreover, apart from a small storm in January 2001, these data are from the fall and winter of 2001. The sampling stations were in fact installed and operational in time for the spring storm season in 2000. This season proved to

Table 1 - Storm events data inventory

Station	*location*	*event (period)*	*chemistry* number of samples	*flow* period of data	*flow* sampling interval (min)	*watershed properties*	*comments*
10263	Tankersley Creek at FM 127					larger subwatershed,	
		10-13 Jan 01	3	10-13 Jan	5	including light urban,	record terminates 12:10 13 Jan
		11-12 Oct 01	3	11-12 Oct	5	pasture, some litter	new storm 23:55 12 Oct
		13-16 Oct 01	1	12-20 Oct	5	application	
		27 Nov - 5 Dec 01	5	27 Nov-5 Dec	5		WQ samples 28-30 Nov
10266	Hart Creek at SE 12					larger subwatershed,	
		10-13 Jan 01	5	10-13 Jan	5	including light urban,	record terminates 12:25 13 Jan
		11-12 Oct 01	3			pasture, some litter	new storm 23:55 12 Oct
		13-16 Oct 01	2			application	
		27 Nov - 5 Dec 01	5	28 Nov-5 Dec	5		WQ samples 28-30 Nov
16455	Alley Creek at SH 155					small, forested catchment,	
		10-13 Jan 01	no data	10-12 Jan	5	no known fertilizer or	record terminates 10:15 12 Jan
		11-12 Oct 01	2	11-12 Oct	5	litter application	new storm 00:05 13 Oct
		13-16 Oct 01	no data	12-20 Oct	5		
		27 Nov - 5 Dec 01	5	27 Nov-5 Dec	5		WQ samples 28-29 Nov
		24-26 Jan 02	3	24-26 Jan	5		WQ samples on 24 Jan
17030	Prairie Creek Tributary at CR 1264 Crossing					small catchment with	
		10-13 Jan 01	2	10-13 Jan	15	uniform soils and land-	record terminates 13:30 13 Jan
		11-12 Oct 01	4	10-12 Oct	15	use, pasture, no known	new storm 23:45 12 Oct
		13-16 Oct 01	no data	13-16 Oct	15	fertilizer or litter appli-	
		27 Nov - 5 Dec 01	no data	no data		cation	flow record terminated 19 Oct 01

(continued)

Table 1 (continued)

Station	*location*	*event (period)*	*chemistry* number of samples	*flow* period of data	*flow* sampling interval (min)	*comment*	
17031	Prairie Creek Tributary at CR 1140 Crossing					small catchment with	
		10-13 Jan 01	3			uniform soils and land-	
		11-12 Oct 01	5	10-12 Oct	15	use, pasture, heavy	new storm 23:45 12 Oct
		13-16 Oct 01	no data	13-18 Oct	15	litter application	
		27 Nov - 5 Dec 01	5	28 Nov-5 Dec	15		WQ samples 28-29 Nov flow record starts 9:15 28 Nov
17033	Boggy Creek at FM 144 near Omaha-North					moderate catchment,	
		10-13 Jan 01	5	10-13 Jan	5	mainly pasture w/	record terminates 11:25 13 Jan
		11-12 Oct 01	5	10-12 Oct	5	light litter application	new storm 23:25 12 Oct
		13-16 Oct 01	no data	13-20 Oct	5		
		27 Nov - 5 Dec 01	5	27 Nov-5Dec	15		WQ samples 28-30 Nov
17057	Boggy Creek Tributary at CR 3301					moderate catchment,	
		10-13 Jan 01	4	no data	5	similar to 17033 except	data logger failed
		11-12 Oct 01	3	11-12 Oct	15	about 5 x rate of litter	new storm 23:30 12 Oct
		13-16 Oct 01	no data	13-16 Oct		application	
		27 Nov - 5 Dec 01	5	28 Nov-5 Dec	15		WQ samples 28-30 Nov

be excellent, with well-separated, highly peaked storm events, exactly what was needed for the validation process, but the sampling equipment could not be activated because of the QAPP approval process. The project then entered a period of anamolous climatology. Fall of 2000 was basically a drought, with few (and small) events. Winter 2000-2001 produced record rainfalls which occurred in a one-month period and in the process flushed the watershed, so that later storm events were unrepresentative of normal loading. (Data from one small storm event, the 10 January event, were obtained before the watershed was washed away.) Spring 2001 saw a return to drought: the few events that occurred were so small and scattered as to produce no loading. Thus, the storm data available from the monitoring network are concentrated in fall 2001.

In order for a storm event to be usable in the complete validation process it is necessary that both hydrological (i.e. stream flow) and water-quality data be obtained. Stream flow is measured by a water-level sensor, from which flow in determined employing a "rating relation" for that gauge, an empirical curve displaying the relationship between stream flow and water level, see Ward (2001b). The rating relation in turn is established by a series of flow measurements executed by current-meter cross sections, to which the rating relation is fitted statistically. The level sensor operates continuously, measurements being read and recorded automatically by the data logger at a preset time interval, typically a few minutes. Loss of streamflow data can occur due to lack of field measurements of flow from which a rating relation can be determined, failure of the water level sensor, or failure of the data logger. Although the components of the streamflow monitors are quite reliable, it must be recognizes that they are deployed for long periods in untended operation in a hostile environment, so failures are unavoidable.

The water quality data are determined by analysis of water samples drawn by an automatic pumping water sampler, whose sampling is triggered by the data logger based upon water levels, and several pre-programmed options. Operation of the sampler can fail if the data logger or the pump fails. Moreover, water level samples can be lost if they are not retrieved from the sampler within a window of time for starting the chemical analyses. Even if all of these elements work, the selection of sampling strategy based upon thresholds and rates of rise of water level is, in effect, a guess as to the intensity and rate of the next storm event. If that guess proves wide of the mark, then the water samples may be drawn at illogical intervals during the course of the storm.

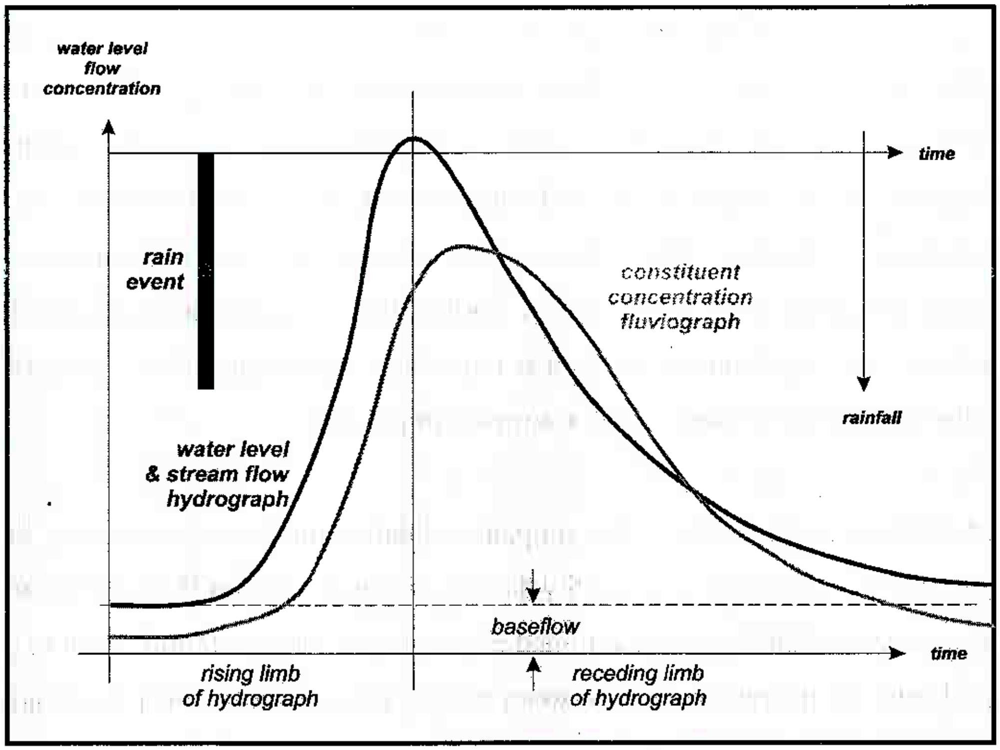

Figure 2 - Qualitative appearance of runoff hydrograph and constituent concentration profile over time during storm event

A runoff hydrograph resulting from a brief intense rainfall event has the general shape shown in Figure 2. Associated with this event is a rise and fall in the concentration of a waterborne constituent derived from the watershed, referred to as the storm *fluviograph* (or *pycnograph*, or more commonly, but with utter disrespect for the language, *pollutograph*). Based upon considerations of water-velocity alone, the peak of the constituent might be expected to coincide with that of flow, but the concentrations are the *integrated* result of a complex of threshold, nonlinear and inertial processes, the net effect of which may be to advance the constituent peak or to retard it with respect to flow. Different parameters exhibit different fluviographs. TSS is particularly complicated, in that it can result from sediment mobilization on the watershed or within the stream channel, and be further modified by grain-size dependent scour and settling.

A network of automatic precipitation gauges was installed throughout the Cypress Basin, see Figure 3. Each of these stations consisted of an "event" recorder and data logger that responded to an

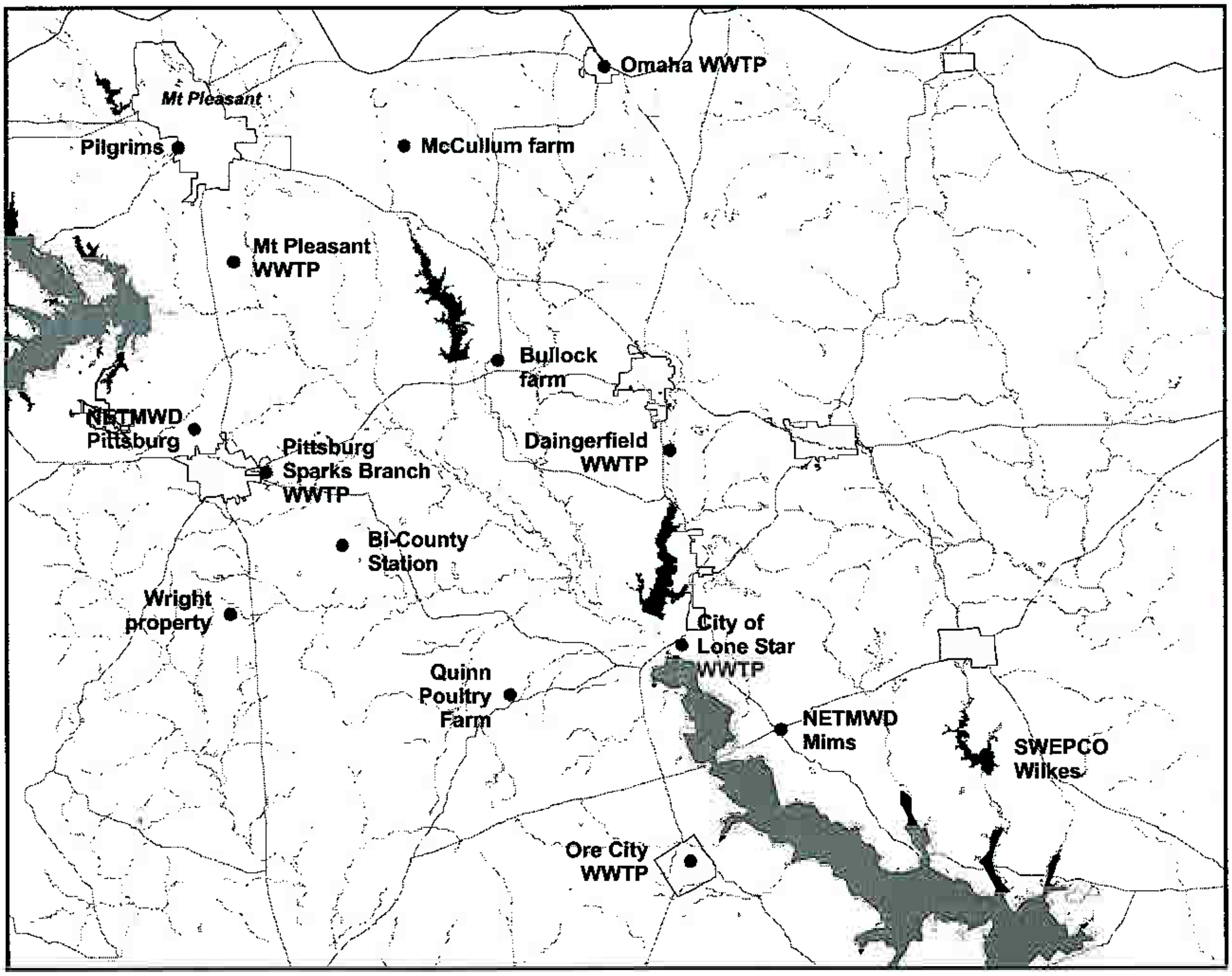

Figure 3 - Precipitation stations operated in Lake o' the Pines watershed

"event" of a cumulated 0.01-inch of precipitation. For each "event occurrence, the logger records date and time. The record of such "events" can be processed an re-expressed as precipitation per unit time. For purposes of this study, these "events" were cumulated by day to yield daily precipitation. In the analyses of storm hydrographs, the gauge (or gauges, appropriately averaged) most representative of the stream station watershed was employed.

Figures 4 *et seq.* display the storm hydrographs for each of the study storms, at each of the validation stations, along with the measured precipitation applicable to that station. The rating for each station has been employed to convert water level to flow. The times at which water samples were drawn are

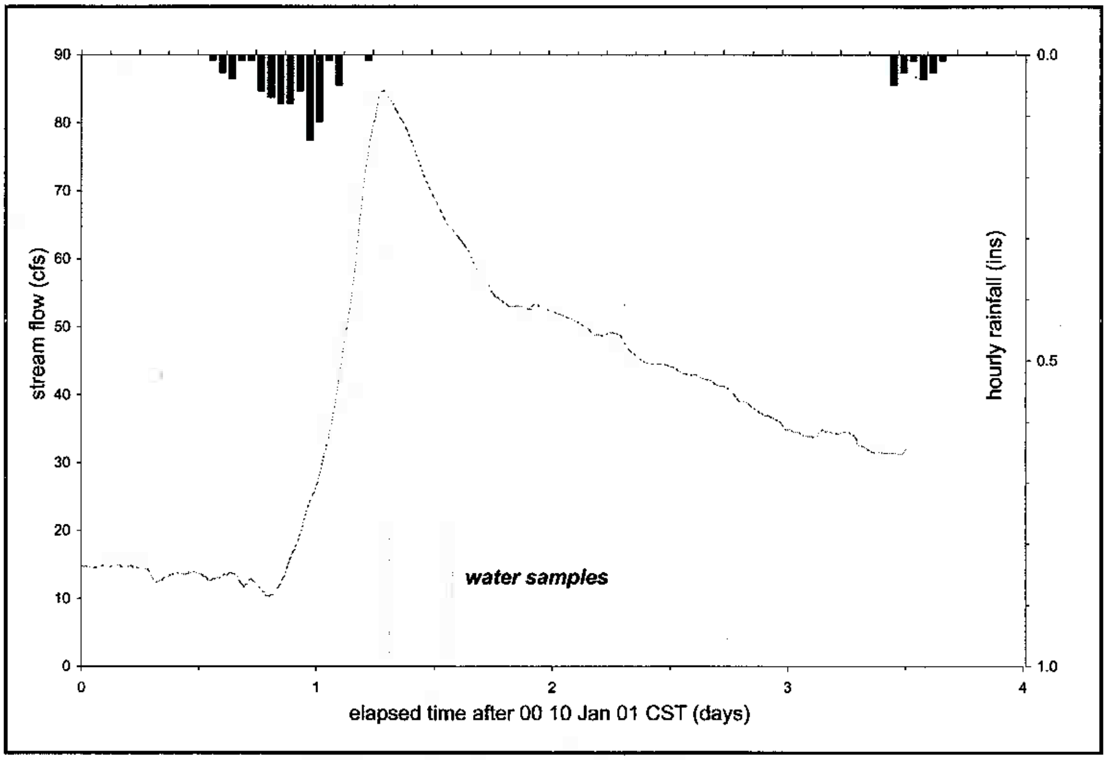

Figure 4 - January 2001 storm event, hydrograph and water sample times, Station 10263 Tankersley Creek

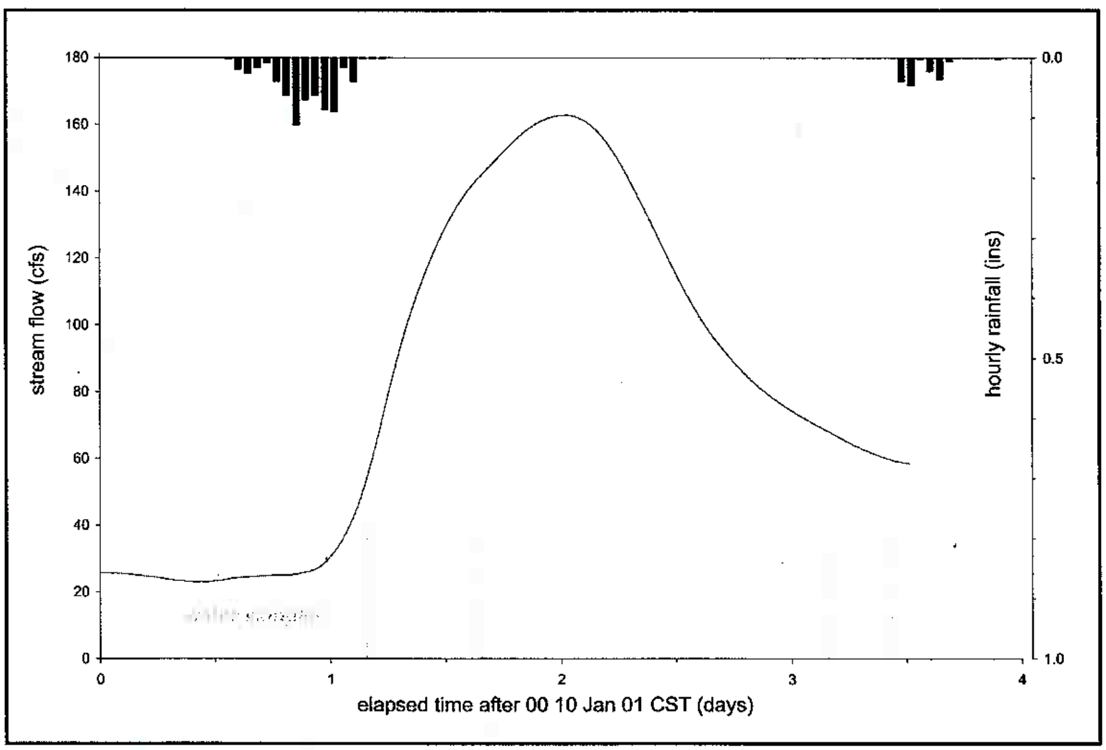

Figure 5 - January 2001 storm event, hydrograph and water sample times, Station 10266 Hart Creek

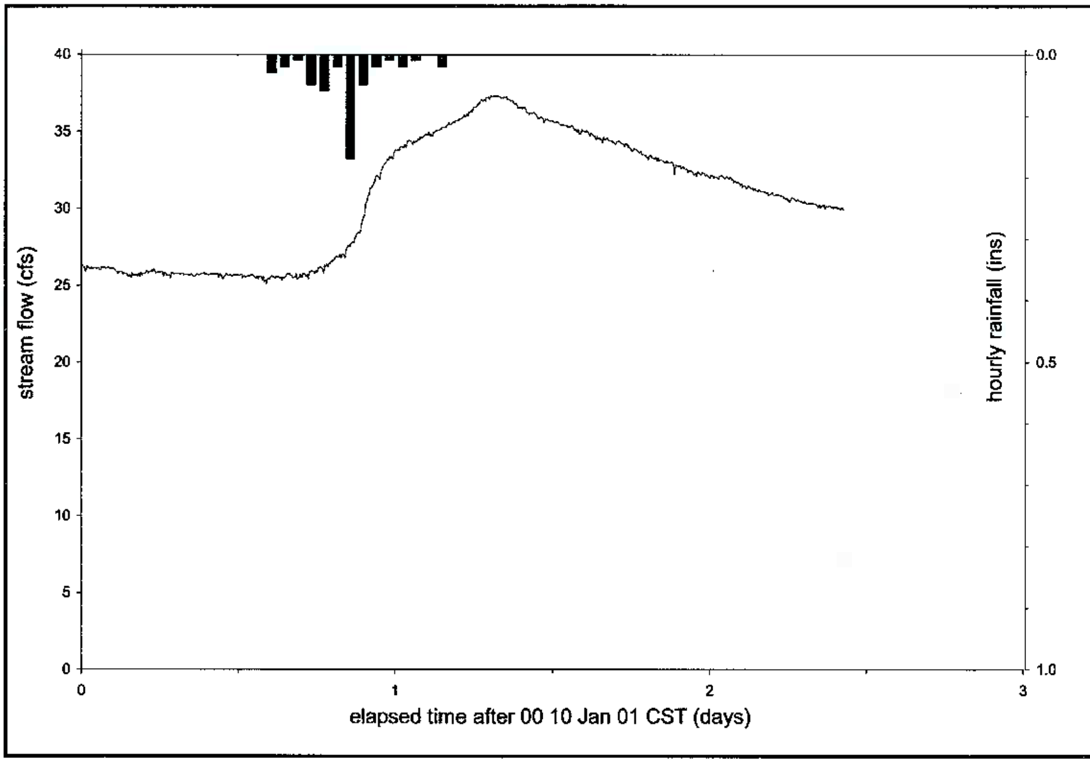

Figure 6 - January 2001 storm event, hydrograph and water sample times, Station 16455 Alley Creek

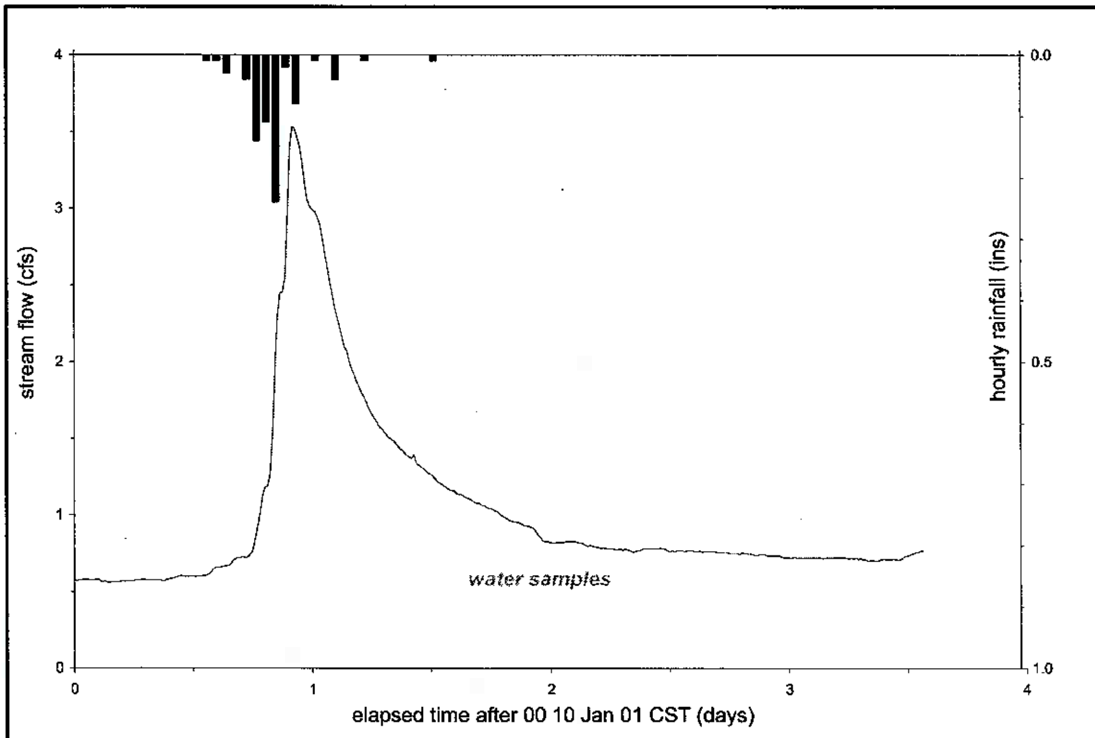

Figure 7 - January 2001 storm event, hydrograph and water sample times, Station 17030 Prairie Creek tributary

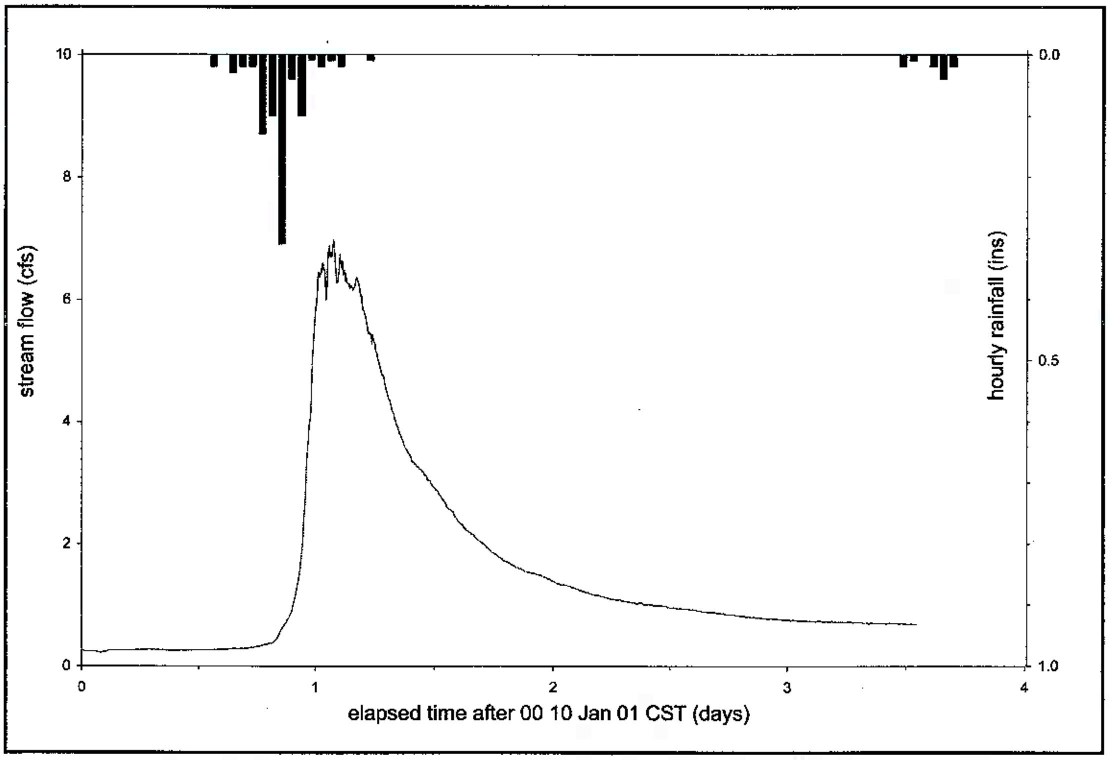

Figure 8 - January 2001 storm event, hydrograph and water sample times, Station 17031 Prairie Creek tributary

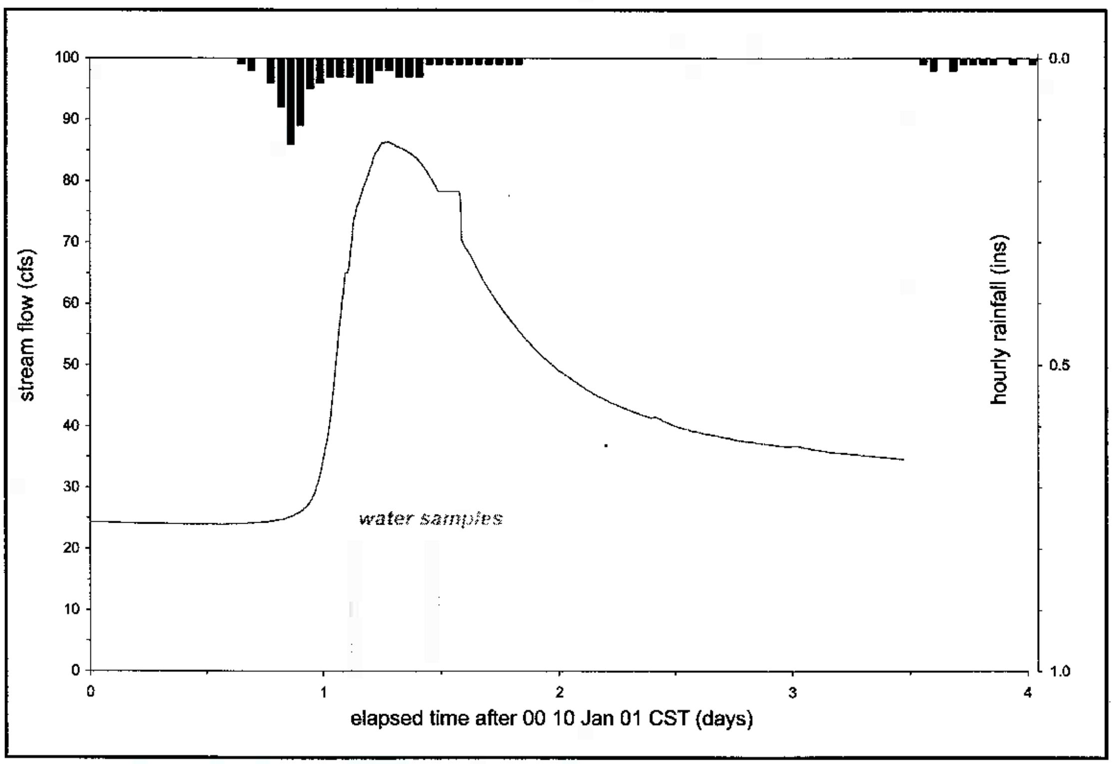

Figure 9 - January 2001 storm event, hydrograph and water sample times, Station 17033 Boggy Creek

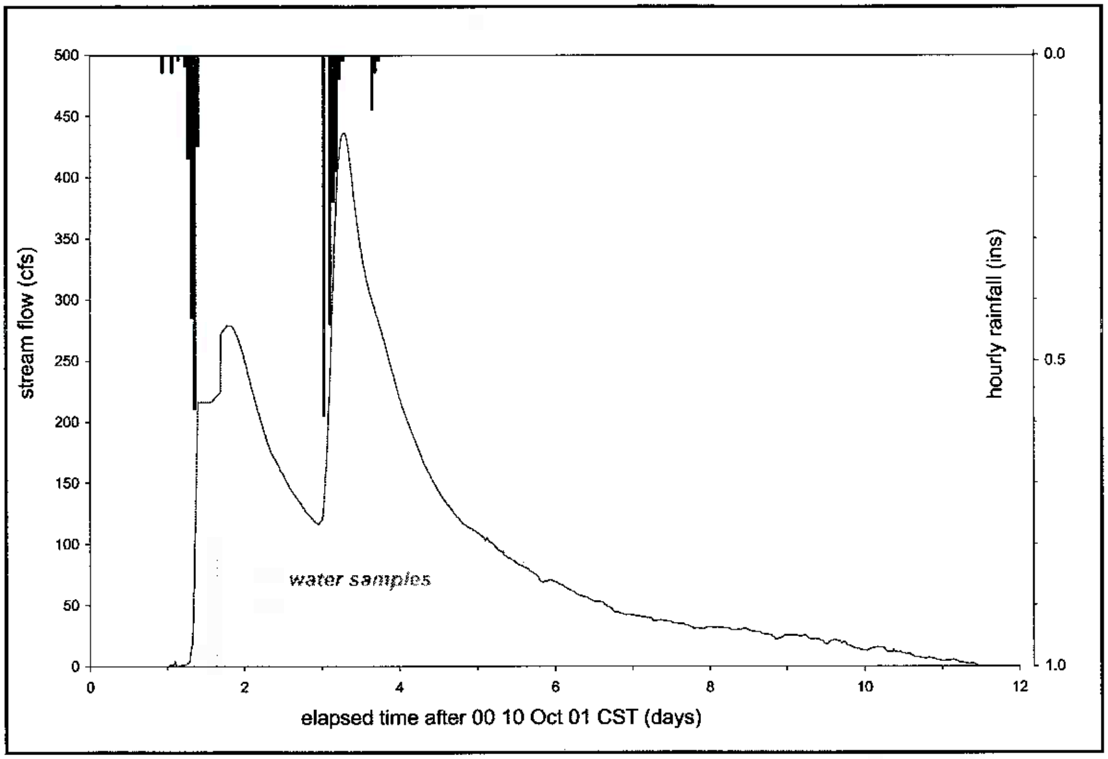

Figure 10 - October 2001 storm events, hydrograph and water sample times, Station 10263 Tankersley Creek

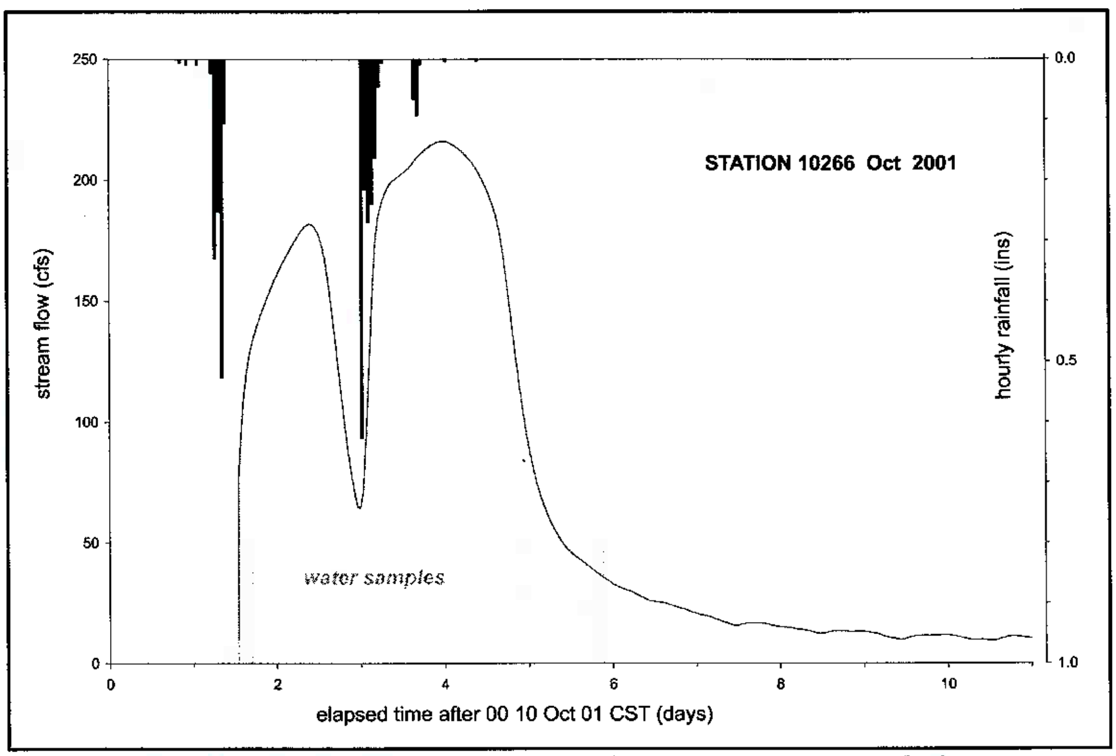

Figure 11 - October 2001 storm events, hydrograph and water sample times, Station 10266 Hart Creek

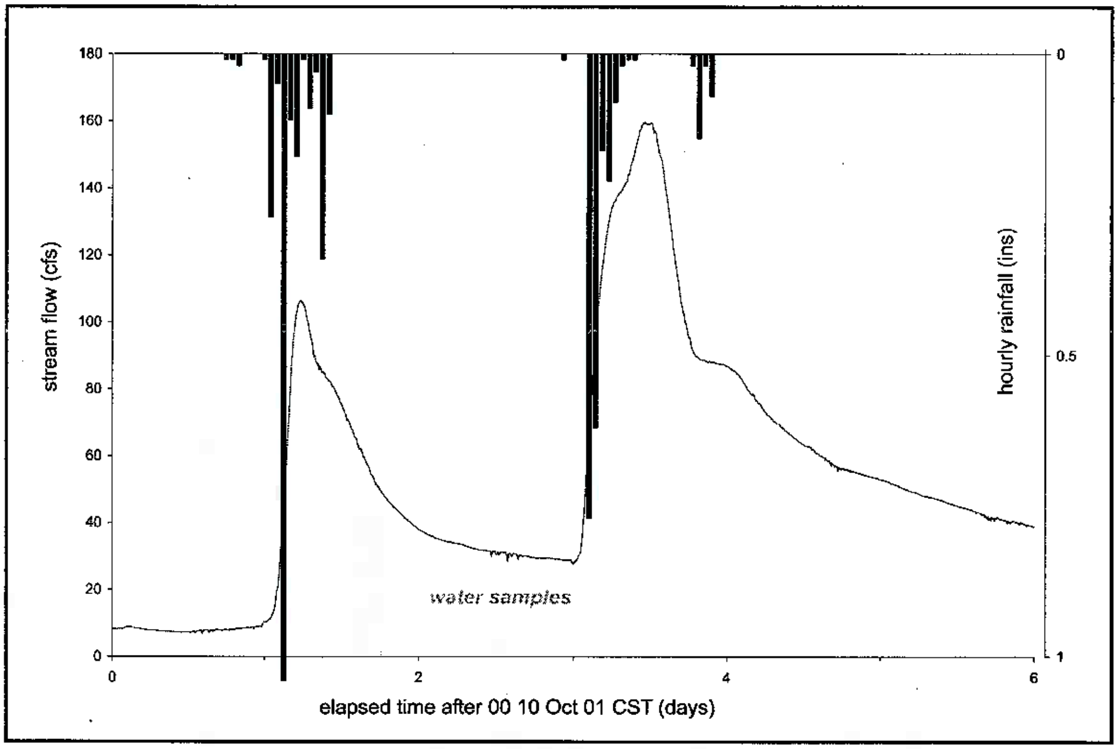

Figure 12 - October 2001 storm events, hydrograph and water sample times, Station 16455 Alley Creek

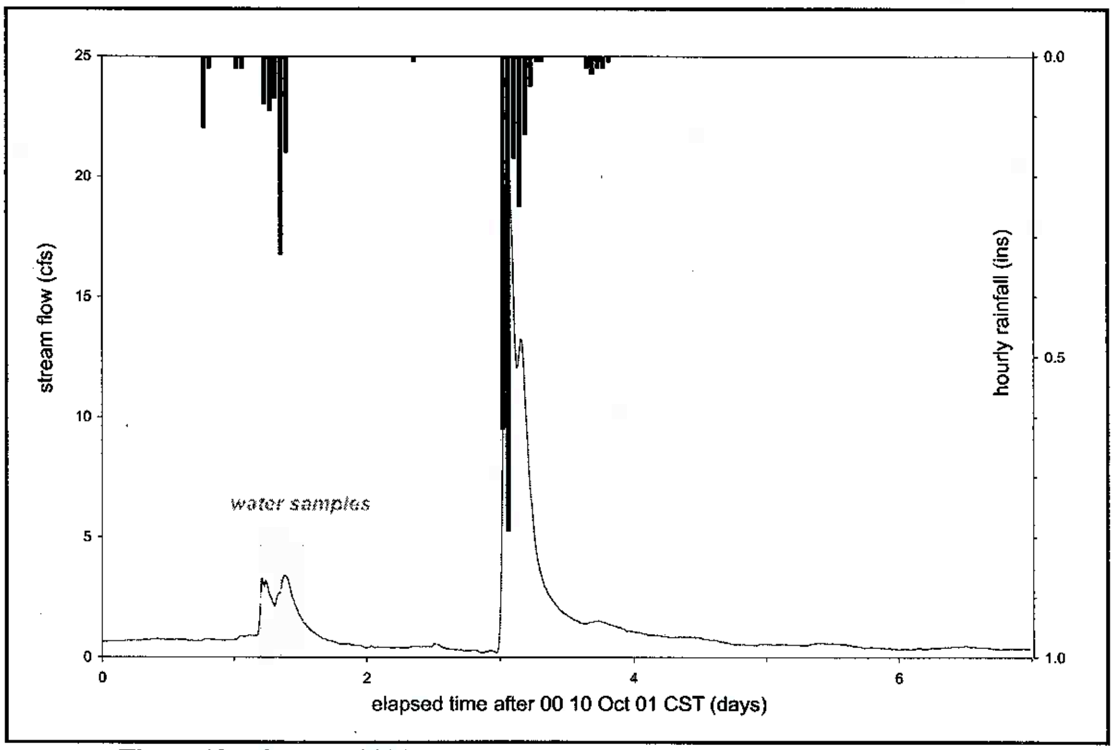

Figure 13 - October 2001 storm events, hydrograph and water sample times, Station 17030 Prairie Creek tributary

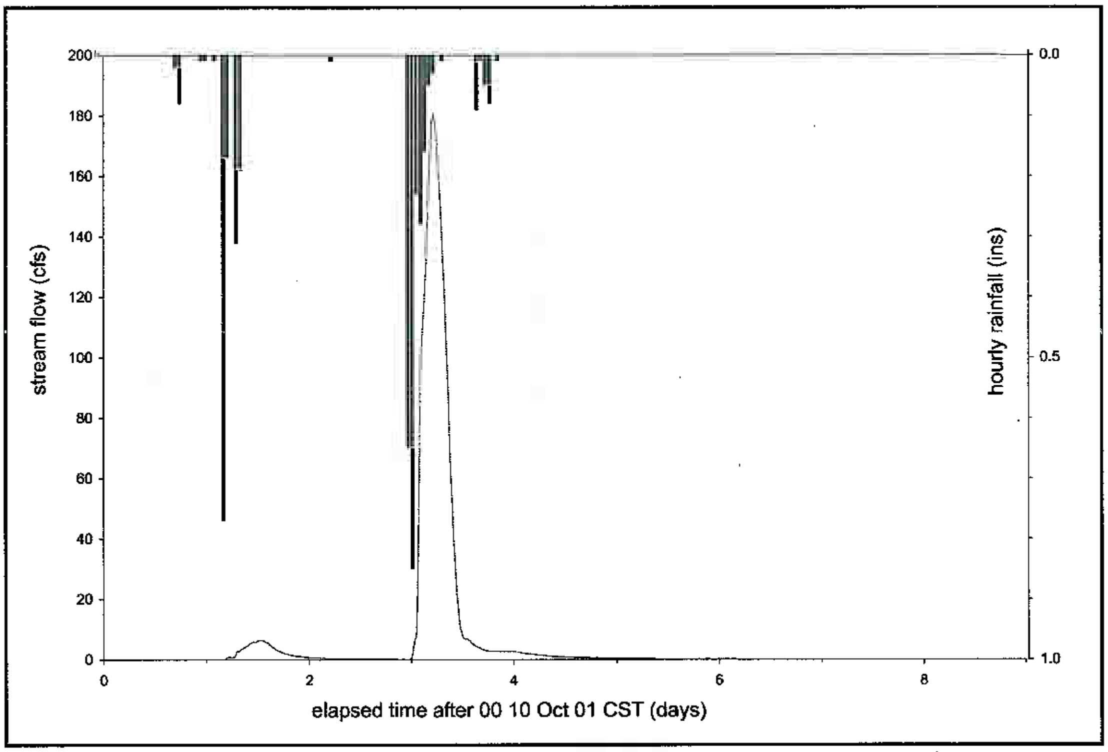

Figure 14 - October 2001 storm events, hydrograph and water sample times, Station 17031 Prairie Creek tributary

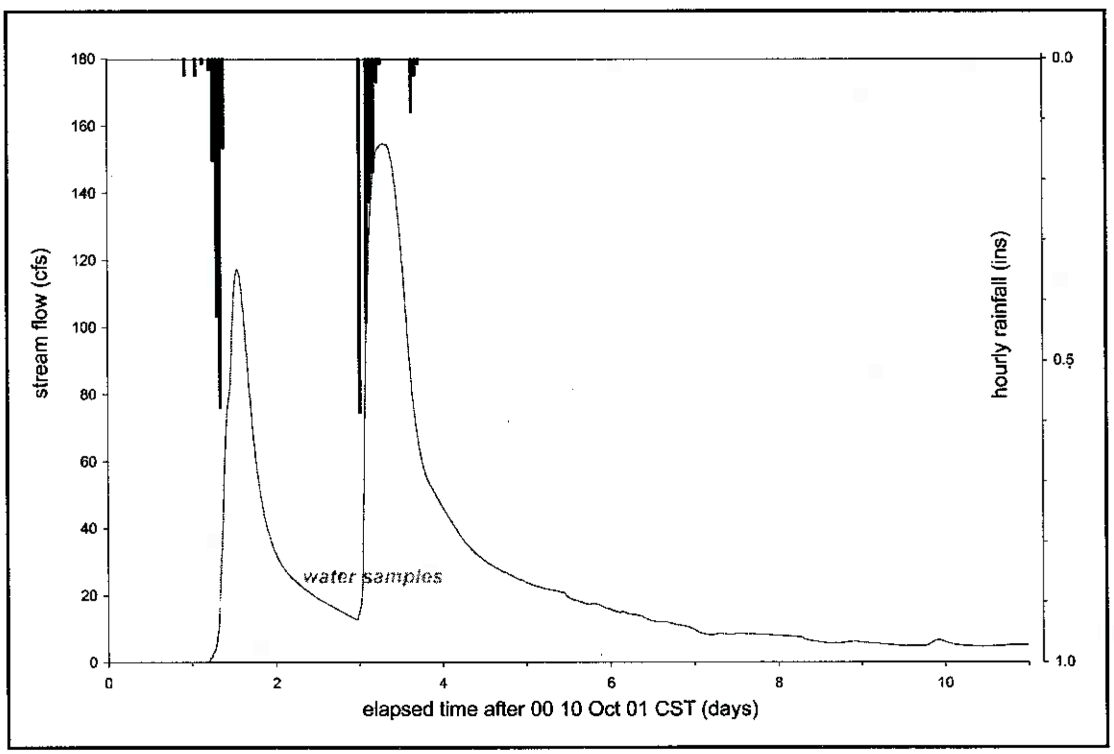

Figure 15 - October 2001 storm events, hydrograph and water sample times, Station 17033 Boggy Creek

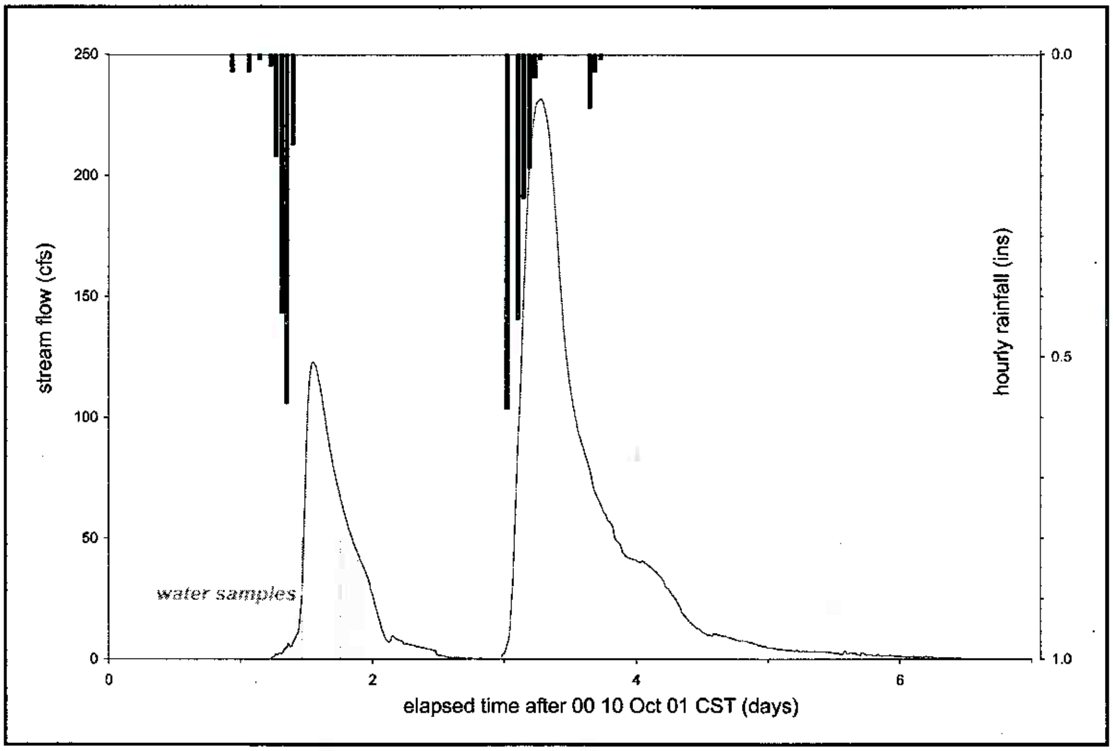

Figure 16 - October 2001 storm events, hydrograph and water sample times, Station 17057 Little Boggy Creek

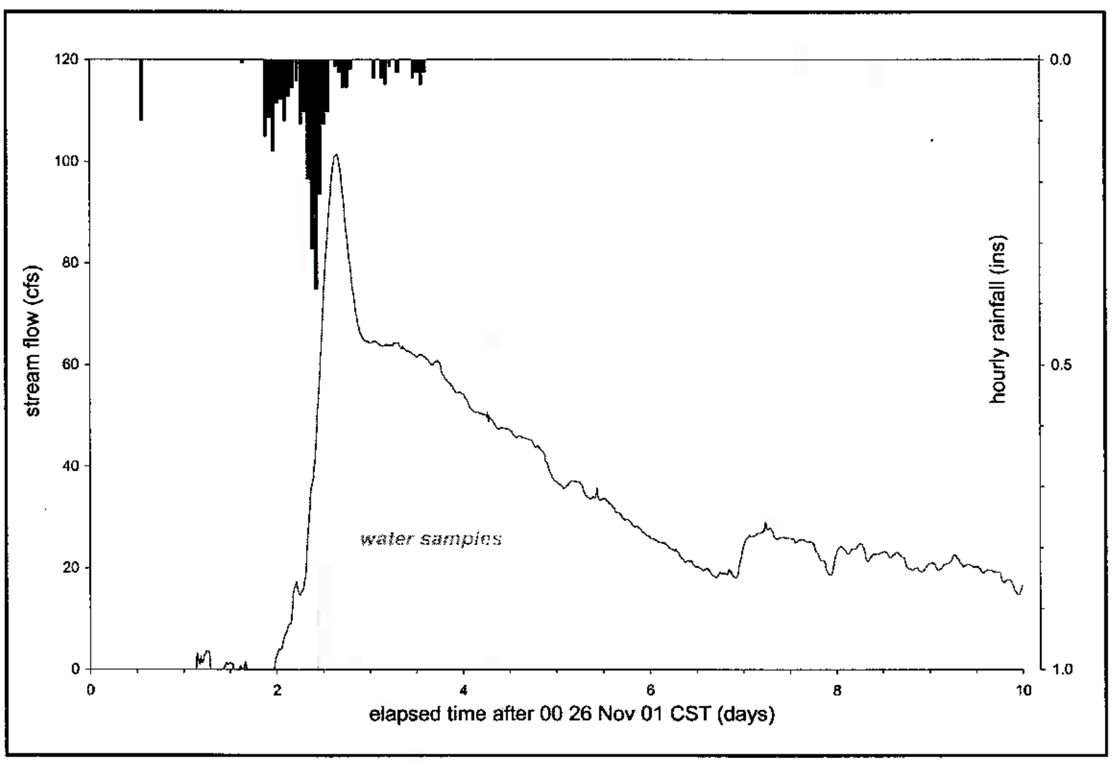

Figure 17 - November-December 2001 storm event, hydrograph and water sample times, Station 10263 Tankersley Creek

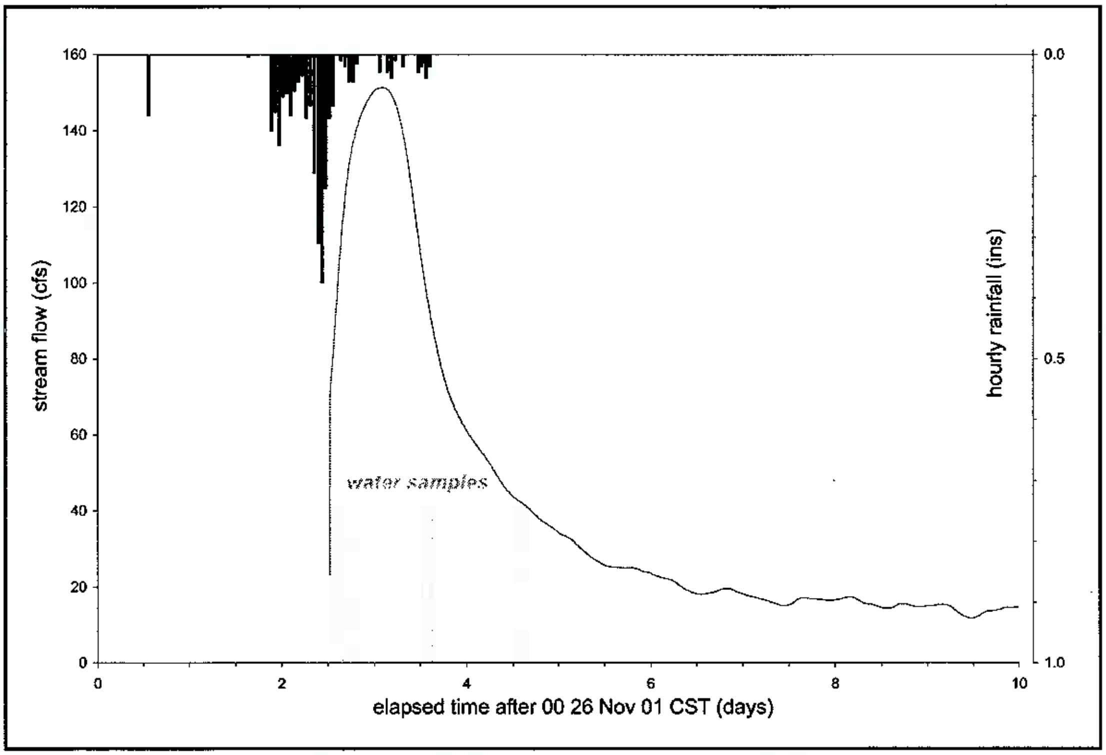

Figure 18 - November-December 2001 storm event, hydrograph and water sample times, Station 10266 Hart Creek

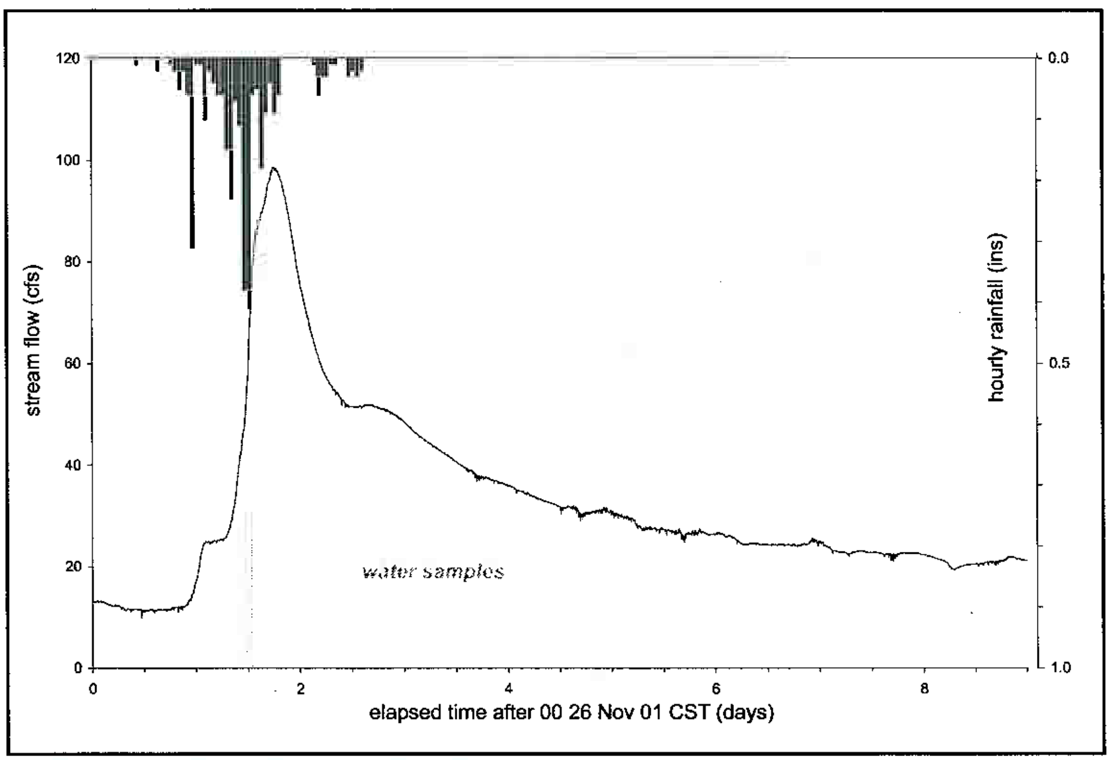

Figure 19 - November-December 2001 storm event, hydrograph and water sample times, Station 16455 Alley Creek

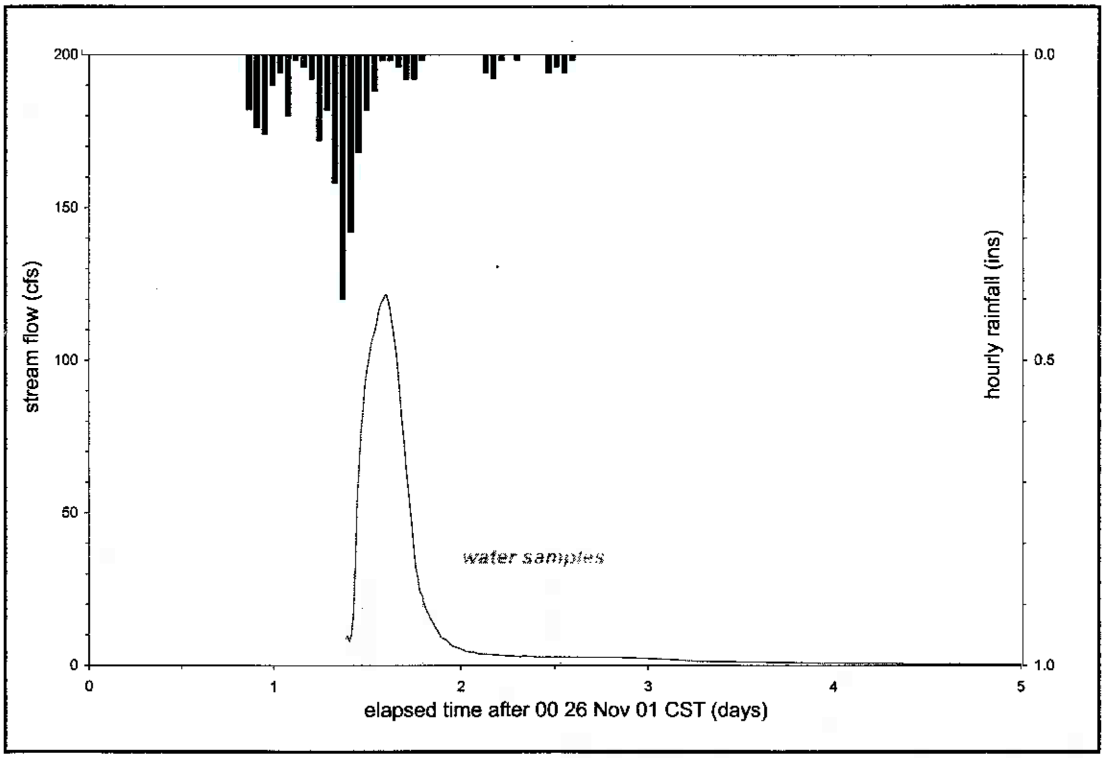

Figure 20 - November-December 2001 storm event, hydrograph and water sample times, Station 17031 Prairie Creek tributary

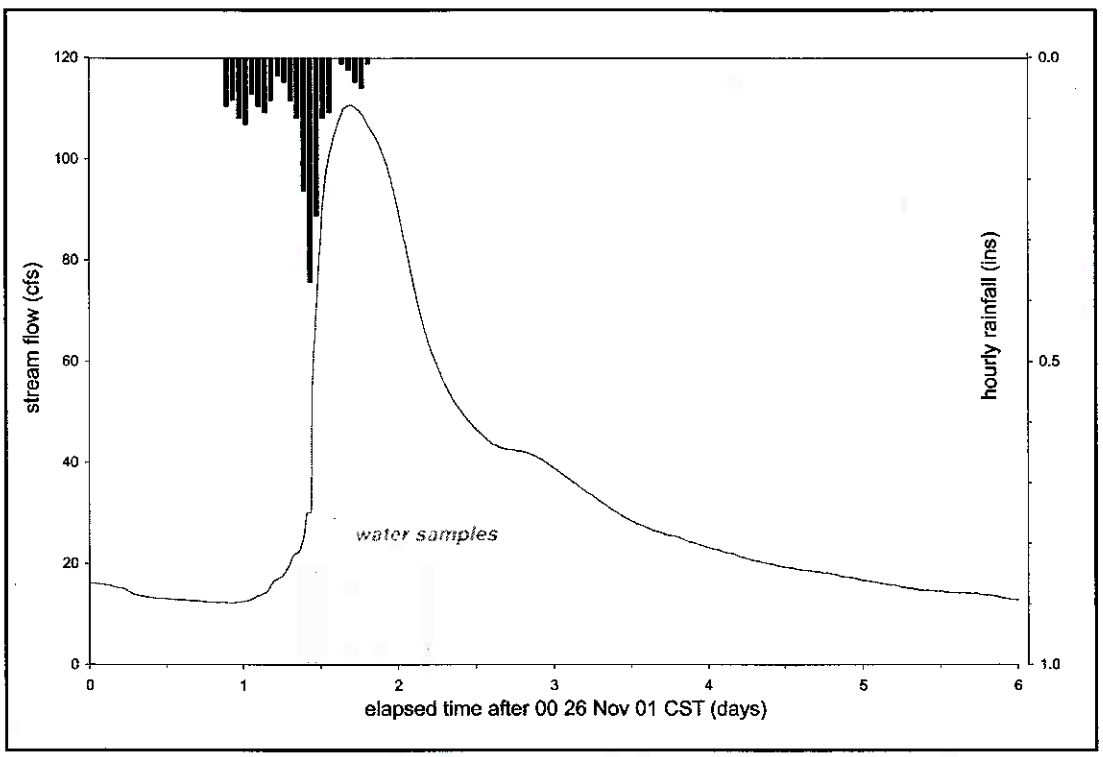

Figure 21 - November-December 2001 storm event, hydrograph and water sample times, Station 17033 Boggy Creek

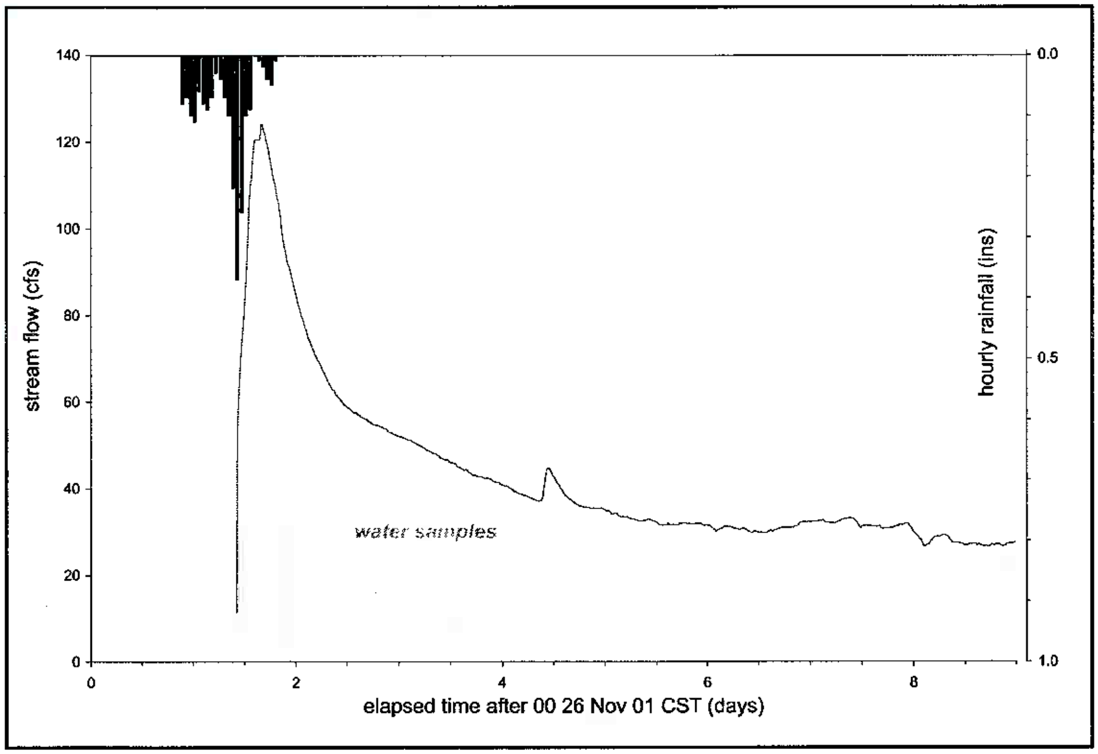

Figure 22 - November-December 2001 storm event, hydrograph and water sample times, Station 17057 Little Boggy Creek

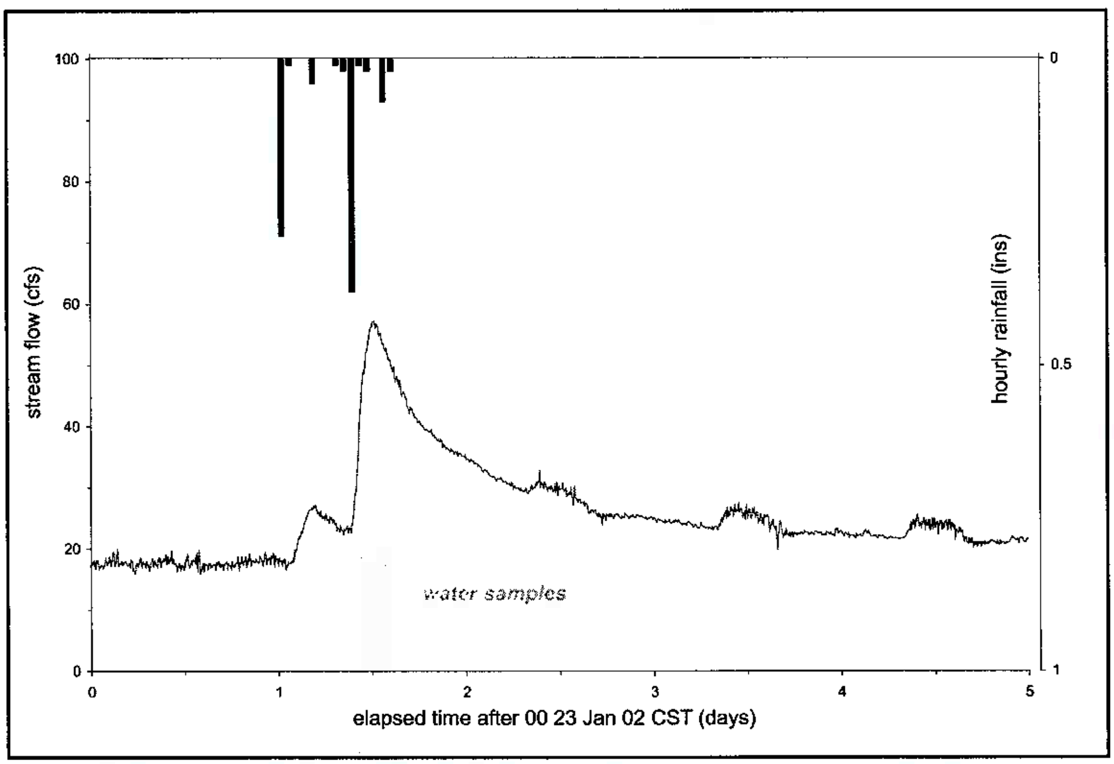

Figure 23 - January 2002 storm event, hydrograph and water sample times, Station 16455 Alley Creek

Table 2 - Watershed areas for automatic monitoring stations

Station	*description*	*km*^{2}	*acres*
10263	Tankersley Creet at FM127	65.4	1.62×10^4
10266	Hart Creek at Titus County Road	119.3	2.95×10^4
15836	Prairie Creek at FM557	79.1	1.95×10^4
15894	Boggy Creek at FM144 (downstream crossing)	245.9	6.08×10^4
16455	Alley Creek at SH155	32.3	7.98×10^3
17027	Meddlin Creek at Snapdragon Road	17.2	4.25×10^3
17028	Prairie Creek tributary at FM993	1.3	3.21×10^2
17029	Prairie Creek tributary (west channel) at FM993	3.2	7.91×10^2
17030	Prairie Creek tributary at Camp CR1264	1.8	4.45×10^2
17031	Prairie Creek tributary at Camp CR1140	5.0	1.24×10^3
17032	Kitchen Branch at FM2254	9.2	2.27×10^3
17033	Boggy Creek at FM144	38.1	9.41×10^3
17034	Hart Creek tributary at 1st Street (Mt Pleasant)	2.6	6.42×10^2
17035	Hart Creek tributary at W. Arizona Street (Mt Pleasant)	1.2	2.97×10^2
17057	Little Boggy Creek at Green Street	31.3	7.73×10^3

shown as vertical lines. By comparing these sampling "event" lines to the storm hydrograph, the adequacy to which each storm was sampled can be immediately judged. The objective of analysis is to quantify the runoff and mass load associated with an entire storm hydrograph. The widespread interest in nonpoint-source runoff over the past three decades has motivated operation of automated sampling systems similar to those used in the Big Cypress, and considerable ingenuity has been invested in extracting data from a few water samples obtained at intervals over the course of the storm. A review of the literature addressing such storm analysis is far beyond the scope of this report. Suffice it to say that the desired theoretical quantity is the integral:

$$\int \rho Q c \, dt \tag{1}$$

in which $Q(t)$ denotes streamflow and $c(t)$ concentration. The methods of estimating this integral involve either (a) fitting of the water-quality data $c(t_i)$ with a time function to allow numerical determination of the above integral, or (b) construction of some sort of average of the sample concentrations that can be multiplied by the storm runoff to estimate load. The bulk of the methods follow (b), in which the flow-weighted event-mean concentration *EQMC* is the conventional quantity. In this work, we seek to delay the imposition of assumptions in the analysis of data as much as possible, and therefore employ linear relations between the measured water quality concentrations, then evaluate (1) by its summand approximation

$$\sum_k \rho Q(k\Delta t)\chi(k\Delta t)\ \Delta t \qquad (2)$$

in which $\chi(t)$ is the depiction of the fluviograph $c(t)$ by piecewise concatenation of linear functions passing through data points $c(t_i)$ and $c(t_{i+1})$, time $t = k\,\Delta t$ and Δt is the time increment, taken to be either 15 mins or 30 mins, depending upon the duration of the hydrograph and the resolution of the water-level data. The quality of this approximation depends upon the accuracy with which Q is measured (especially, the accuracy of the rating relation for the gauge), the accuracy of determination of parameter c, and the distribution of the discrete samples $c(t_i)$ over the storm event.

In the present analyses, the storm data were employed to the maximal extent. The quality of the rating relation was examined (and in a few cases re-derived), and the relation of the water-sample times to the progress of the storm were determined, all of which were used to make a judgment of how well a storm event was sampled. When water samples were available and well-distributed over the course of the runoff hydrograph, the quality of the data were judged to be high. If the storm peak were missed, or if water samples were not drawn before the beginning of the hydrograph rise or sufficiently long after the peak had subsided, or if some of the water quality analyses appeared corrupted, the quality of the data was downgraded, but the data set was still employed in these analyses. To quantify this judgment of data quality, a level of uncertainty, expressed as a standard deviation, was estimated and assigned, the higher values corresponding to data of diminished quality.

Data analyses were carried out in a two-step approach, first analyzing the storm hydrograph then the fluviograph for key waterborne parameters. This same procedure was observed in model validation, in that first the hydrological performance of the model was subjected to calibration and verification, then the constituent concentration. The rainfall events producing the storm runoff are summarized in Table 3. (The hourly rainfalls are plotted in Figures 4 *et seq.*) The time points for each storm are referenced to a specific date, selected for convenience. These reference dates are given in the first column of Table 3. The runoff produced from a storm of given intensity is strongly dependent upon the state of dessication/ saturation of the watershed. Therefore, the antecedent dry period and the magnitude of the previous rainfall are important indices to the processing of that rainstorm by the watershed, and are also given in Table 3 (the former being measured by the time in days after the end of the previous rainy period). The October 2001 event was in fact two storms (see Figures 10-16), the second beginning 48 hours after the first. Moreover, the 11 October event followed a protracted dry period (not reflected by the data of Table 3, which reports only the antecedent period of 6 days after a minor rainfall of 1.3 cm), so the runoff from the first storm of the pair was much diminished in comparison to the second, and the hydrograph of the first was still receding when that of the second began. This greatly complicates the analysis and modeling of this event. Normally, for model validation purposes, such a compound storm would not be employed, but the small number of suitable storms captured by the monitoring program necessitated its use.

The corresponding hydrograph analyses are presented in Table 4. The same reference dates are used as in Table 3. As the principal concern in this analysis is the storm runoff, the storm hydrograph is "scalped" from the baseflow (see Fig. 2). The runoff/rainfall ratio (R/R in Table 4) is a fundamental measure of the production of the watershed per unit precipitation. It is a function of soil infiltration, land use, vegetational ground cover, stream morphology, and the time series of rainfall. In particular, the antecedent dry period has a strong influence on the value of the R/R coefficient: excluding the larger watersheds of Tankersley and Hart, this variable alone accounts for about 25% of the observed variance, see Figure 24. (The linear regression is shown in Fig. 24: the actual dependency is nonlinear, asymptotically tending to zero.) The runoff volume and mean flow values

Table 3 - Storm analyses: rainfall events

reference date 0000 CST	*raingauge*	*rainfall event*			*previous rainfall*		*comments*
		start (days)	*duration (hrs)*	*total (cm)*	*end (days)*	*total (cm)*	
				10263 Tankersley Creek at FM 127			
10-Jan-01	Pilgrims	0.54	16	2.0	9	0.6	
11-Oct-01	Pilgrims	0.00	9	3.6	6	1.5	
12-Oct-01	Pilgrims	1.00	17	4.2	1	3.6	
27-Nov-01	PM*	0.88	41	6.6	3	1.0	gap in Pilgrims record, McCullum terminates 1.79 days
				10266 Hart Creek at SE 12			
10-Jan-01	PMM**	0.58	13	1.7	9	0.5	
11-Oct-01	PMM**	0.21	4	3.2	6	1.3	
12-Oct-01	PMM**	1.00	17	4.4	1	3.2	
27-Nov-01	PM*	0.88	41	6.6	3	1.0	partial record at MCCullum, other raingauges failed
				16455 Alley Creek at SH 155			
10-Jan-01	NETmims	0.58	13	1.2	9	0.6	
11-Oct-01	NETmims	0.00	9	5.7	6	1.4	
12-Oct-01	NETmims	1.04	19	5.4	1	5.7	
27-Nov-01	NETmims	0.63	47	7.5	3	0.6	
24-Jan-02	NETmims	0.00	14	2.2	5	0.5	
				17030 Prairie Creek Tributary at CR 1264 Crossing			
10-Jan-01	Wright	0.54	16	1.9	7	0.4	
10-Oct-01	Wright	0.75	15	2.3	5	0.2	
13-Oct-01	Wright	0.00	19	5.4	2	2.3	

(continued)

Table 3 - Storm analyses: rainfall events (continued)

reference date 0000 CST	*raingauge*	*rainfall event*			*previous rainfall*		*comments*
		start (days)	*duration (hrs)*	*total (cm)*	*end (days)*	*total (cm)*	
				17031 Prairie Creek Tributary at CR 1140 Crossing			
10-Jan-01	Bicounty	0.54	16	2.1	8	0.6	
10-Oct-01	Bicounty	0.75	15	4.0	5	0.4	
12-Oct-01	Bicounty	1.00	21	6.4	1	4.0	
27-Nov-01	Wright	0.88	41	5.9	3	0.9	
				17033 Boggy Creek at FM 144 near Omaha-North			
10-Jan-01	Omaha	0.63	28	2.3	7	0.1	
10-Oct-01	Pilgrims	0.00	9	3.6	5	1.5	Omaha gauge buggy
12-Oct-01	Pilgrims	1.00	17	4.2	1	3.6	Omaha gauge buggy, no clear start/end of rainfall
27-Nov-01	McCullum	0.88	2	5.3	n/a	n/a	McCullum gauge terminates on 28 Nov
	Pittsburg				3	1.0	
				17057 Little Boggy Creek at CR 3301			
10-Oct-01	Pilgrims	0.00	9	3.6	5	1.5	see above
12-Oct-01	Pilgrims	1.00	17	4.2	1	3.6	see above
27-Nov-01	McCullum	0.88	22	5.3	n/a	n/a	see above
	Pittsburg				3	1.0	

*Pittsburg & McCullum mean
** Pilgrims, McCullum, Mt Pleasant mean

Table 4 - Storm analyses: hydrograph events

reference date 0000 CST	*start (days)*	*duration (hrs)*	*volume (m3)*	*mean flow (m3/s)*	*est error (%)*	*R/R*	*comments*
			10263 Tankersley Creek at FM 127				
10-Jan-01	0.81	64.7	2.41×10^5	1.03	20	0.19	flow record terminated
11-Oct-01	0.14	44.5	8.02×10^5	5.01	30	0.34	recession truncated by next storm
12-Oct-01	0.96	45.0	5.62×10^5	3.47	25	0.21	main surge of hydrograph
27-Nov-01	0.96	97.0	4.72×10^5	1.35	40	0.11	recession ragged, clipped at 4 days
			10266 Hart Creek at SE 12				
10-Jan-01	0.96	61.2	4.98×10^5	2.26	20	0.25	
11-Oct-01	0.52	35.3	5.08×10^5	4.01	30	0.13	truncated by next storm
12-Oct-01	1.00	52.0	5.91×10^5	3.16	30	0.11	main surge of hydrograph
27-Nov-01	1.52	59.5	5.29×10^5	2.47	40	0.07	clipped ragged receding limb
			16455 Alley Creek at SH 155				
10-Jan-01	0.75	40.3	3.29×10^4	0.23	25	0.08	flow record terminated
11-Oct-01	0.00	48.0	1.90×10^5	1.10	30	0.10	recession truncated by next storm
12-Oct-01	1.00	72.0	3.44×10^5	1.33	30	0.20	
27-Nov-01	0.96	97.0	3.27×10^5	0.94	40	0.13	recession ragged, clipped at 4 days
24-Jan-02	0.06	70.5	8.65×10^4	0.34	40	0.12	
			17030 Prairie Creek Tributary at CR 1264 Crossing				
10-Jan-01	0.57	71.8	4.48×10^3	0.02	20	0.13	
10-Oct-01	1.17	20.0	2.26×10^3	0.03	15	0.05	recession truncated by next storm
13-Oct-01	0.96	49.0	1.17×10^4	0.07	20	0.12	

(continued)

Table 4 - Storm analyses: hydrograph events (continued)

reference date 0000 CST	*start (days)*	*duration (hrs)*	*volume (m3)*	*mean flow (m3/s)*	*est error (%)*	*R/R*	*comments*
			17031 Prairie Creek Tributary at CR 1140 Crossing				
10-Jan-01	0.71	68.0	1.28×10^4	0.05	20	0.12	flow record terminates
10-Oct-01	1.18	43.0	6.73×10^3	0.04	25	0.03	recession truncated by next storm
12-Oct-01	0.96	73.0	1.20×10^5	0.46	20	0.38	
27-Nov-01	1.39	38.8	8.79×10^4	0.63	40	0.30	flow record missed initial rise
			17033 Boggy Creek at FM 144 near Omaha-North				
10-Jan-01	0.92	61.3	1.57×10^5	0.71	20	0.18	flow record terminated
10-Oct-01	1.19	42.8	1.63×10^5	1.06	20	0.12	recession truncated by next storm R/R based on Pilgrims gauge
12-Oct-01	0.96	73.0	2.73×10^5	1.04	20	0.17	R/R based on Pilgrims gauge
27-Nov-01	1.00	120.0	2.88×10^5	0.67	15	0.14	R/R based on McCullum & Pittsburg gauge
			17057 Little Boggy Creek at CR 3301				
10-Oct-01	1.22	40.7	1.09×10^5	0.74	15	0.10	see above
12-Oct-01	0.96	86.0	3.15×10^5	1.02	15	0.24	see above
27-Nov-01	1.44	85.5	5.03×10^5	1.63	40	0.31	see above

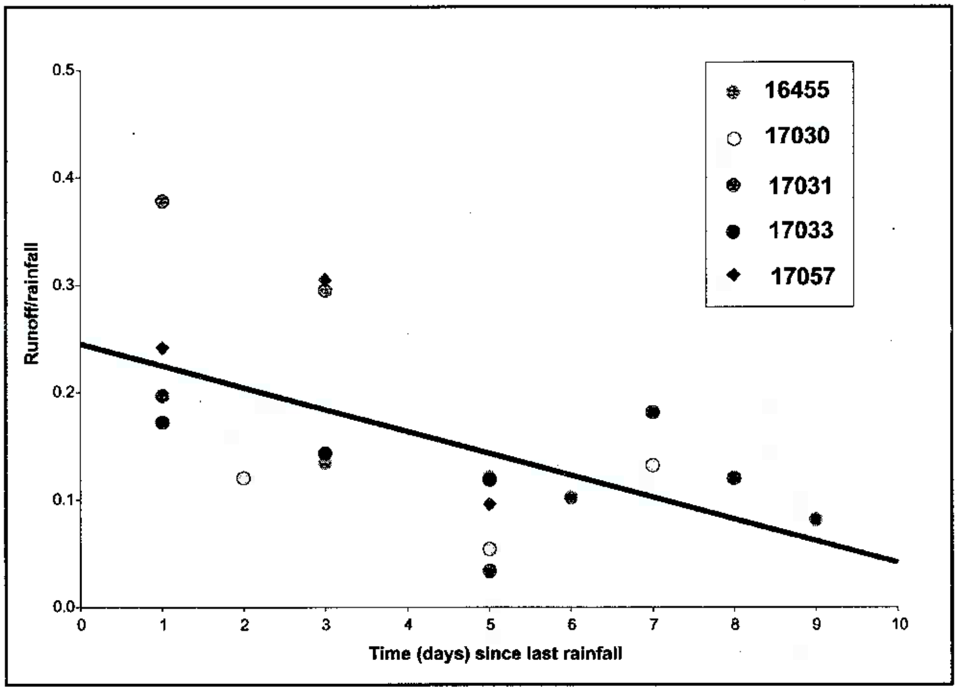

Figure 24 - R/R coefficient (Table 4) versus antecedent dry period (Table 3)

are storm-event values, i.e. applicable to the scalped storm hydrograph and therefore relative to the duration of the runoff event. Because these are scalped values, the mean flow excludes base flow, which at a few of these stations can be substantial.

The estimated standard error is a judgment call, quantifying the general quality of the storm-event data. This error is increased by uncertainty in the gauge rating relation (too few flow data, or too much scatter), by failure to monitor the pre-rise flow or the complete recession limb, or by the superposition of other storm hydrographs on the one sought from the data. Reasons for downgrading the quality of the data (i.e., increasing the estimated error) are given in the "comments" column. The estimate of storm runoff mass load cannot be better than the error in the hydrograph, but will in fact be further compounded by uncertainty in the water-quality sampling, which is addressed next.

As noted above, analysis of storm fluviographs is essentially the determination of the mass load (2). Three key water-quality variables were employed in the fluviographical analyses: total suspended

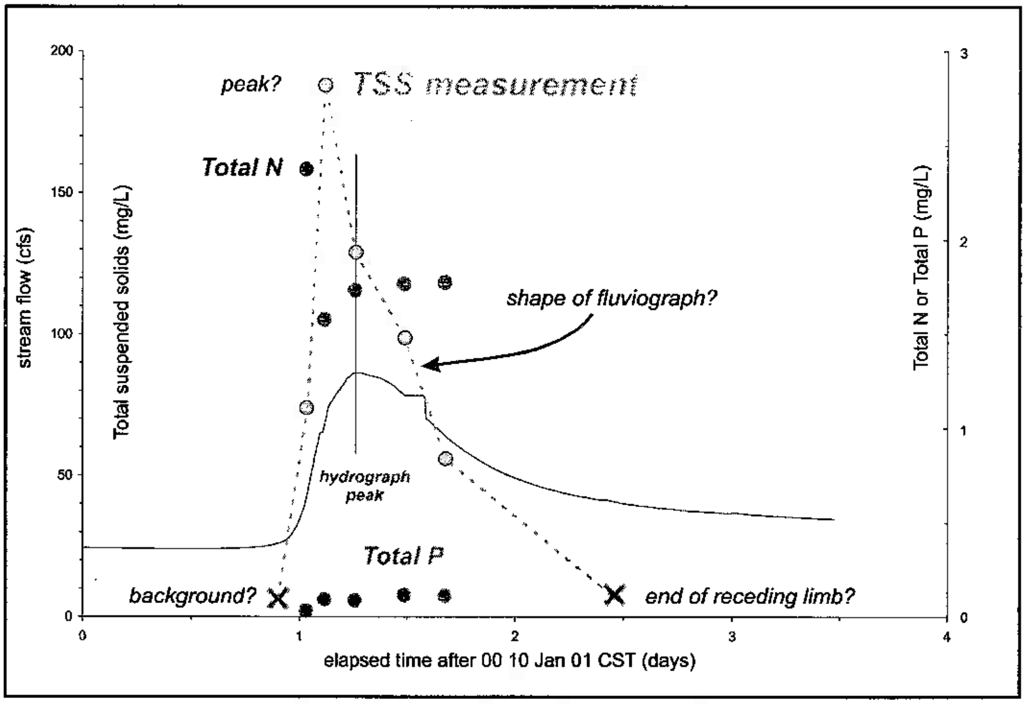

Figure 25 - January 2001 storm event, Station 17033 Boggy Creek, water quality measurements and hydrograph

solids (TSS), total nitrogen and total phosphorus. Total nitrogen is the sum of the organic and inorganic species, e.g. kjeldahl plus (NO_2+NO_3). TSS is an important variable because it is a direct measure of sediment particles mobilized from the watershed, and is a water-quality variable that can be determined inexpensively with a fair degree of precision. The advantage of focusing the analysis on total P and total N, rather than specific compounds, e.g. ammonia, is that the effect of kinetic reactions in interconverting from one form to the other is automatically eliminated.

The procedures and pitfalls of the fluviographic analyses will be illustrated by example. The difficulties arise from the fact that the fluviograph, unlike the fine time resolution of the hydrograph, is sampled sparsely and randomly in time (randomly, that is, with respect to the hydrograph). Consider, for example, the storm of January 2001, monitored at the Boggy Creek station 17033, see Fig. 9. Five water samples were drawn, fairly uniformly distributed around the hydrograph peak, and over the main surge of the runoff event. This is probably as well-sampled a storm event as we

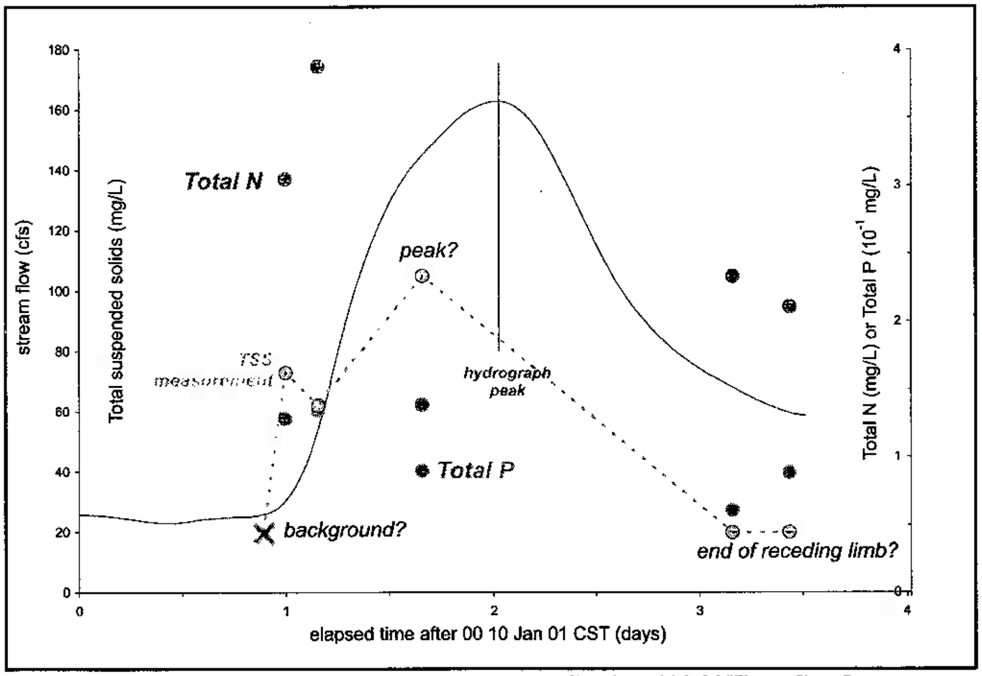

Figure 26 - January 2001 storm event, Station 10266 Hart Creek, water quality measurements and hydrograph

could expect, given the constraints of pre-programming an automatic sampling strategy, and balancing information versus cost. Figure 25 shows the variation of concentration of TSS, total N and total P, plotted on the hydrograph. For TSS the data suggest a fair degree of confidence in estimating the fluviograph, but there is uncertainty in whether the maximum point is truly the peak, what the background (pre-storm) concentration should be (whose value has to be estimated, i.e. guessed), at what point the TSS receded to its pre-storm concentration, and to what extent the linear interpolation approximates the real fluviograph. (Note that, wherever the true TSS peak may have occurred, it did *not* coincide with the hydrograph peak, but in fact led it by several hours.) Despite the good distribution and realistic variation of the measurements, there is still a residual uncertainty in the storm load evaluated from (2), in excess of the uncertainy in the hydrograph. An even greater uncertainty attaches to the N and P loads, whose measurements are less well-behaved than TSS, and whose laboratory determinations are less precise. The corresponding estimates of standard error for the mass loads are therefore even larger than the values given in Table 4.

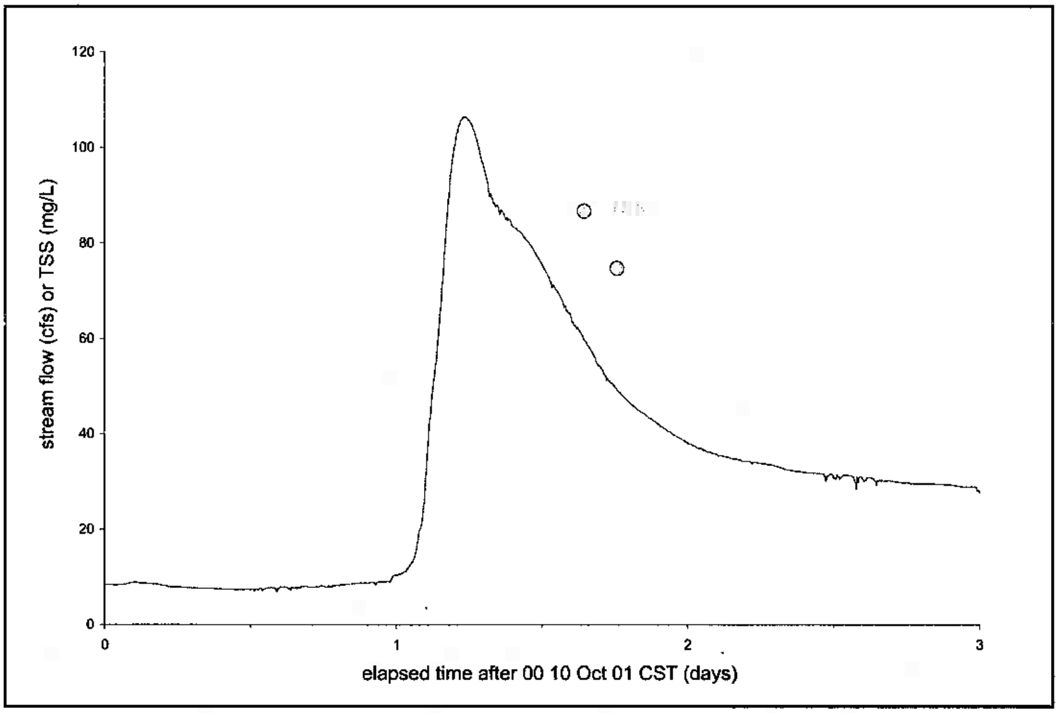

Figure 27 - October 2001 storm event, Station 16455 Alley Creek, water quality measurements and hydrograph

Figure 26 displays the data for the same January 2001 storm at Station 10266. Five samples were also obtained at this station, but their distribution with respect to the hydrograph suggests that the maximum part of the fluviograph (the "crest") was missed. This clearly compromises the accuracy with which (2) can be evaluated, so the assigned uncertainty would be higher than the example of Fig. 25. An even more extreme example is shown in Fig. 27, from the 11 October 2001 storm at Station 16455. (This was a compound storm, see Fig. 12, but only the first hydrograph is shown here.) In this case, only two water quality samples were obtained, both after the hydrograph peak had passed. The concentrations of TSS, N and P, together with the measured flow, allow the load to be quantified to at best order of magnitude. This is, nonetheless, useful information, and should not be disregarded, but clearly carries a level of uncertainty that is much higher than the data of Fig. 25 or Fig. 26.

Yet another problem is exhibited by the data of October 2001 at Station 17031, shown in Table 5. In this case, 5 samples were drawn over the storm hydrograph, but with poor distribution: the first three

Table 5
Water quality data, October 2001 storm Station 17031

date	*time (CST)*	*TSS (mg/L)*	*Total P (mg/L)*	*Total N (mg/L)*
10/11/01	8:27	510	BDL*	3.82
10/11/01	8:41	41	0.167	2.48
10/11/01	8:46	54	0.216	2.08
10/11/01	12:24	1570	0.508	17.01
10/11/01	17:25	56	0.373	5.73

*detection limit 0.01

of these were drawn within a 20-min period. The variation of these three, nearly contemporaneous samples, however, is about an order of magnitude for TSS and total P, which illustrates the potential intrinsic "noise" in storm data, arising from the high natural variability in concentration.

One final exam, Figure 28, demonstrates the complexity—and vagaries—of storm data, from the November storm at Station 17057 on Little Boggy (cf. Fig. 22). This is one of the better data sets taken, in which five water samples were obtained that were well-distributed with respect to the hydrograph. With discrete samples, there is always uncertainty as to whether the maximum concentration was obtained. Assuming that these data are representative of the respective fluviographs for TSS, P and N, the peak in the TSS fluviograph is seen to lead that of the hydrograph, while the peaks of both P and N lag that of the hydrograph.

The storm loading data determined for each of the study storms are summarized in Tables 6 - 8, for TSS, total P and total N, respectively. These are integrated (or averaged) values over the duration of each storm hydrograph, after scalping from the baseflow. EMC is the average concentration over the duration of the event, while EQMC is the flow-weighted average concentration. (EQMC is the quantity that is most frequently identified as "event-mean concentration" in storm loading analyses.) The "mean load" is the most important quantity determined from these analyses, as this quantifies

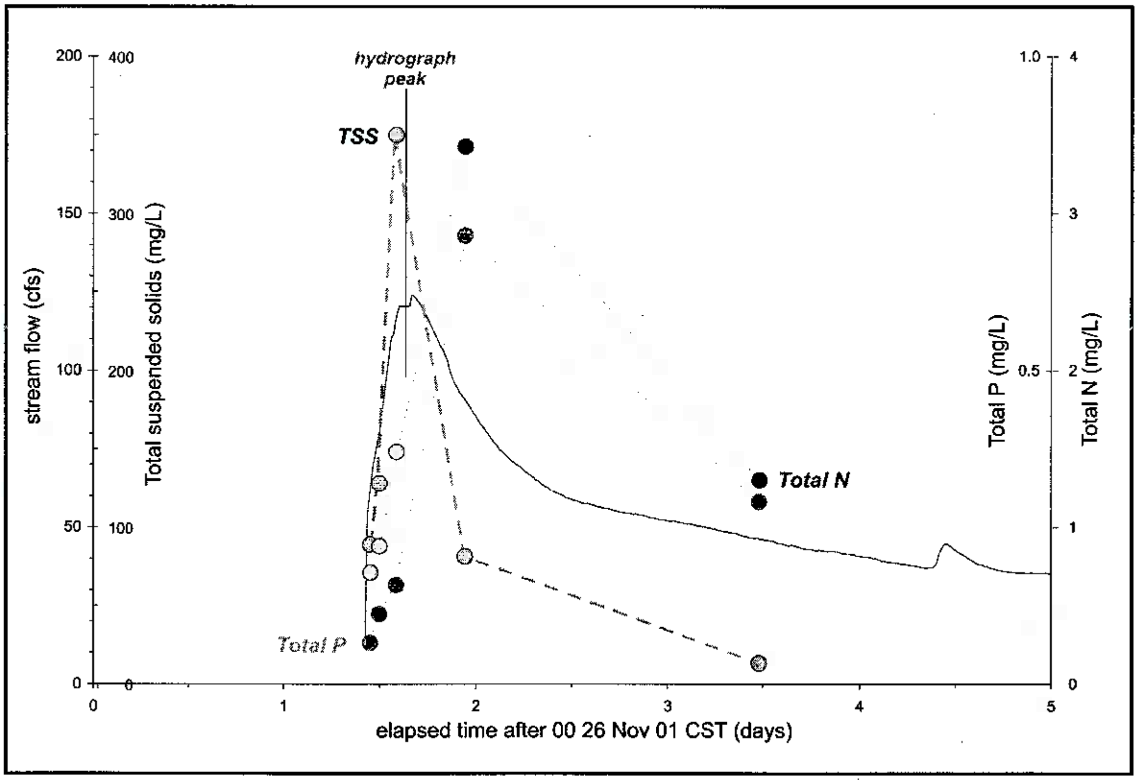

Figure 28 - November 2001 storm event, Station 17057 Little Boggy Creek, water quality measurements and hydrograph. (First three total-N values estimated from measurements of Kjeldahl.)

the rate of mass influx associated with the storm event. The standard error (expressed as a coefficient of variation in per cent) is a judgment of the uncertainty in the load estimate, based upon the considerations examplified above, as well as the uncertainty in determination of runoff volume (Table 4). The error of a load estimate can be no better than the error in runoff volume, but can be rendered worse by poor time distribution of samples, erratic behavior of the data, and analytical imprecision. These considerations are reflected in the assigned standard errors, and are summarized in the "comments" for each storm data set.

Table 6
Total Suspended Solids (TSS) mass loading data for study storms

Station		mass (g)	EMC (g/m^3)	EQMC (g/m^3)	mean load (g/s)	est error (%)	comment
10263	***Tankersley Creek at FM 127***						
	10-13 Jan 01	1.00E+07	35.7	41.6	43.0	40	hydrograph crest only sampled, total mass underestimated due to truncation of event
	11-12 Oct 01	4.56E+08	586.1	569.0	2833.4	50	only 3 samples, total mass underest due to truncation by next storm
	28 Nov - 1 Dec 01	2.64E+07	43.2	55.9	75.2	50	4 samples, good distribn, baseflow conc uncertain
10266	***Hart Creek at SE 12***						
	10-13 Jan 01	4.46E+07	88.8	89.6	201.6	50	peak missed, total mass underestimated due to truncation of event
	11-12 Oct 01	7.34E+07	141.6	144.2	574.3	60	poor distrbn, total mass underest due to truncation by next storm
	28 Nov - 1 Dec 01	4.64E+07	98.7	87.8	215.0	40	5 samples, good distribn, baseflow conc uncertain
16455	***Alley Creek at SH 155***						
	11-12 Oct 01	1.16E+07	59.3	61.0	66.8	80	only 2 samples
	28 Nov - 1 Dec 01	3.37E+07	91.5	102.8	95.9	50	5 samples but on rising & falling limbs, missing main surge of storm, bkgd, duration uncertain
	24-26 Jan 02	1.38E+07	150.2	159.9	54.3	60	only 3 samples, peak obtained but noisy, baseflow conc uncertain
17030	***Prairie Creek Tributary at CR 1264 Crossing***						
	10-13 Jan 01	3.03E+05	43.1	63.7	1.1	50	only 2 samples, may have gotten peak, baseflow conc uncertain
	11-12 Oct 01	4.95E+05	199.2	219.5	6.8	40	u/s& d/s concs uncertain

Table 6 (continued)
Total Suspended Solids (TSS) mass loading data for study storms

Station		*mass* (g)	*EMC* (g/m^3)	*EQMC* (g/m^3)	*mean load* (g/s)	*est error* (%)	*comment*
17031	***Prairie Creek Tributary at CR 1140 Crossing***						
	10-13 Jan 01	6.16E+05	48.3	57.2	2.5	40	total mass underest, EMC & load overest, due to truncation of event, baseflow conc uncertain
	11-12 Oct 01	4.31E+06	211.9	640.2	27.7	50	poor distribn, noisy data, truncated by next storm
	27 - 30 Nov 01	1.29E+07	59.3	146.7	91.8	60	5 samples, but missed main surge, TSS noisy
17033	***Boggy Creek at FM 144 near Omaha-North***						
	10-13 Jan 01	1.97E+07	97.5	125.9	89.4	30	5 samples, good distribn, mass & EMC underest overest due to truncation of event, baseflow conc uncertain
	11-12 Oct 01	2.83E+07	103.6	173.4	183.0	30	5 samples, good distribn
	28 Nov - 2 Dec 01	3.53E+07	41.2	122.9	81.6	20	5 samples, good distribn
17057	***Boggy Creek Tributary at CR 3301***						
	11-12 Oct 01	2.17E+07	103.1	200.1	147.1	40	3 samples only around peak
	28 Nov - 1 Dec 01	4.10E+07	53.5	81.4	132.3	50	5 samples, good distrbn, but may have missed peak

Table 7
Total phosphorus mass loading data for study storms

Station		*mass (g)*	*EMC (g/m^3)*	*EQMC (g/m^3)*	*mean load (g/s)*	*est error (%)*	*comment*
10263	Tankersley Creek at FM 127						
	10-13 Jan 01	2.76E+05	1.01	1.15	1.19	50	only peak of hydrograph sampled, total mass underest due to truncation of event
	11-12 Oct 01	4.71E+05	0.60	0.59	2.92	60	only 3 samples, total mass underest due to truncation by next storm
	28 Nov - 1 Dec 01	7.13E+05	1.44	1.51	2.03	100	good sampl distrbn, but odd P variation, also ortho P> total P
10266	Hart Creek at SE 12						
	10-13 Jan 01	5.50E+04	0.13	0.11	0.25	60	peak missed, mass underest, load overest, due to truncation of event
	11-12 Oct 01	1.21E+05	0.24	0.24	0.95	70	poor distribn, 3 samples, total mass underest due to truncation by next storm
	28 Nov - 1 Dec 01	1.69E+05	0.40	0.32	0.78	60	5 samples, good distribn, u/s uncertain
16455	Alley Creek at SH 155						
	11-12 Oct 01	8.03E+03	0.04	0.04	0.05	80	only 2 samples
	28 Nov - 1 Dec 01	1.45E+04	0.04	0.04	0.04	70	5 samples but on rising & falling limbs, missing crest of storm, baseflow conc uncertain
	24-26 Jan 02	7.20E+03	0.09	0.08	0.03	70	only 3 samples, peak obtained but noisy, baseflow conc uncertain
17030	Prairie Creek Tributary at CR 1264 Crossing						
	10-13 Jan 01	1.32E+03	0.33	0.30	0.01	50	only 2 samples, may have gotten peak, baseflow conc uncertain
	11-12 Oct 01	1.46E+03	0.87	0.65	0.02	50	baseflow conc uncertain

Table 7 (continued)
Total phosphorus mass loading data for study storms

Station		*mass* *(g)*	*EMC* *(g/m³)*	*EQMC* *(g/m³)*	*mean load* *(g/s)*	*est error* *(%)*	*comment*
17031	Prairie Creek Tributary at CR 1140 Crossing						
	10-13 Jan 01	2.35E+03	0.21	0.22	0.01	50	total mass underest, load overest, due to truncation of event, baseflow conc uncertain
	11-12 Oct 01	2.31E+03	0.25	0.34	0.01	50	poor distribn, noisy data, truncated by next storm
	27 Nov - 5 Dec 01	3.60E+04	0.31	0.41	0.26	60	5 samples, but missed main surge, TSS noisy
17033	Boggy Creek at FM 144 near Omaha-North						
	10-13 Jan 01	2.34E+04	0.13	0.15	0.11	40	total mass underest, EMC & load overest, due to truncation of event, baseflow conc uncertain
	11-12 Oct 01	5.36E+04	0.25	0.33	0.35	40	5 samples, good distribn
	28 Nov - 2 Dec 01	9.68E+04	0.15	0.34	0.22	20	5 samples, good distribn
17057	Boggy Creek Tributary at CR 3301						
	11-12 Oct 01	3.58E+04	0.22	0.33	0.24	50	3 samples only, may have missed peak
	28 Nov - 1 Dec 01	1.91E+05	0.35	0.38	0.62	50	5 samples, good distrbn, may have missed peak

Table 8
Total nitrogen mass loading data for study storms

Station		*mass* (g)	*EMC* (g/m^3)	*EQMC* (g/m^3)	*mean load* (g/s)	*est error* (%)	*comment*
10263	Tankersley Creek at FM 127						
	10-13 Jan 01	1.04E+06	3.76	4.31	4.46	50	only peak of hydrograph sampled, mass underest due to truncation of event
	11-12 Oct 01	2.35E+06	3.00	2.92	14.56	60	
	28 Nov - 1 Dec 01	3.91E+06	7.58	8.28	11.14	80	NOx not taken, Kjel rather flat
10266	Hart Creek at SE 12						
	10-13 Jan 01	1.30E+06	3.42	2.60	5.86	60	mass underest, load overest, due to truncation of event
	11-12 Oct 01	7.07E+05	1.42	1.39	5.53	70	poor distribn, 3 samples, mass underest due to truncation by next storm
	28 Nov - 1 Dec 01	1.03E+06	3.26	1.95	4.78	80	only 2 NOx taken, Kjel rather flat
16455	Alley Creek at SH 155						
	11-12 Oct 01	8.42E+04	0.44	0.44	0.48	80	only 2 samples, off the hydrograph peak
	28 Nov - 1 Dec 01	3.22E+05	0.98	0.98	0.92	70	5 samples but on rising & falling limbs, missing crest of storm, baseflow conc uncertain
	24-26 Jan 02	1.07E+05	1.24	1.24	0.42	70	only 3 samples, peak obtained but noisy, baseflow conc uncertain
17030	Prairie Creek Tributary at CR 1264 Crossing						
	10-13 Jan 01	3.24E+04	5.12	5.61	0.10	50	only 2 samples, may have gotten peak, baseflow conc uncertain
	11-12 Oct 01	1.16E+04	6.74	5.12	0.16	50	baseflow conc uncertain

Table 8 (continued)
Total nitrogen mass loading data for study storms

Station		*mass* (g)	*EMC* (g/m^3)	*EQMC* (g/m^3)	*mean load* (g/s)	*est error* (%)	*comment*
17031	Prairie Creek Tributary at CR 1140 Crossing						
	10-13 Jan 01	5.02E+04	4.36	4.66	0.20	50	total mass underest, load overest, due to truncation of event, baseflow conc uncertain
	11-12 Oct 01	5.91E+04	5.00	8.78	0.38	50	poor distribn, jolt of organics in 4th sample, truncated by next storm
	27 - 30 Nov 01	3.35E+05	2.97	3.81	2.39	60	5 samples, but missed crest, TSS noisy
17033	Boggy Creek at FM 144 near Omaha-North						
	10-13 Jan 01	3.98E+05	2.40	2.54	1.80	50	total mass underest, load overest, due to truncation of event, baseflow conc uncertain
	11-12 Oct 01	2.69E+05	1.35	1.64	1.74	40	5 samples, good distribn
	28 Nov - 2 Dec 01	5.97E+05	0.98	2.08	1.38	40	No Nox on 1st 2 samples, est based on Kjel-N
	Kjel-N:	4.42E+05	0.73	1.54	1.02		estimated total N as 135% of kjel
17057	Boggy Creek Tributary at CR 3301						
	11-12 Oct 01	1.77E+05	1.14	1.63	1.20	50	3 samples only, may have missed peak
	28 Nov - 1 Dec 01	9.68E+05	1.71	1.93	3.13	70	5 samples, but NOX only on last 2, probably missed peak
	Kjel-N:	7.45E+05	1.32	1.48	2.41		estimated total N as 130% of kjel

3. SWAT model application

SWAT is the latest in a series of watershed runoff and loading models developed by the ARS, an evolution from the "field-scale" models of CREAMS/GLEAMS that applied to a single small catchment with uniform soils and agriculture, through SWRRB, to culminate in SWAT. The original objective of this model-development enterprise was the management of agricultural practices, e.g. control of soil erosion, fertilizer application, crop selection, planting strategies, etc. In order to effect this, the model must simulate the losses of sediment, nutrients and pesticides from the catchment, and these are in fact the loads of concern to a downstream watercourse. So it became a logical extension to represent the agricultural management model as a surface-water loading model, that has now become SWAT. Technical details of the formulation of SWAT are given in numerous references (e.g., Arnold et al., 1990, Williams and Arnold, 1993, Arnold and Williams, 1995, Arnold et al., 1999, Neitsch et al., 2002). We present here only a rudimentary summary of the model to facilitate explication of the validation results.

There are four primary compartments in the SWAT model, as diagrammed in Figure 29: hydrology, biology, sediment and chemistry, for which basic input data includes physiography, meteorology, soils, vegetation cover, and modifications to the land surface such as tillage, cropping, urbanization, and fertilization. Surface-vegetation biomass is a central variable in the model, and the mathematical expressions for photosynthesis, nutrient & water uptake and storage, growth, senescence and decay are complex. This complexity is a reflection of the ancestry of SWAT as an agricultural management model. The various coefficients and rate parameters governing these processes are quantified in a "crop" data base supplied with the model, with data for 97 vegetation categories. These are comprised chiefly of data for specific crop plants, e.g. sweet corn, bermuda grass, timothy, oats, etc., but with the application of the model to non-crop catchments, categories have been added to include winter wheat, mixed forest, generic rangeland, and so on. The soil data base consists of separate files of soil parameters (horizon depths, grain-size distributions, hydraulic conductivity, etc.) that are derived from the STATSGO soils data base (NRCS, 1994). Additional data bases supplied with the model include chemical composition of numerous fertilizers, including manure and chicken litter of several types, and parameters related to eight categories of urban development.

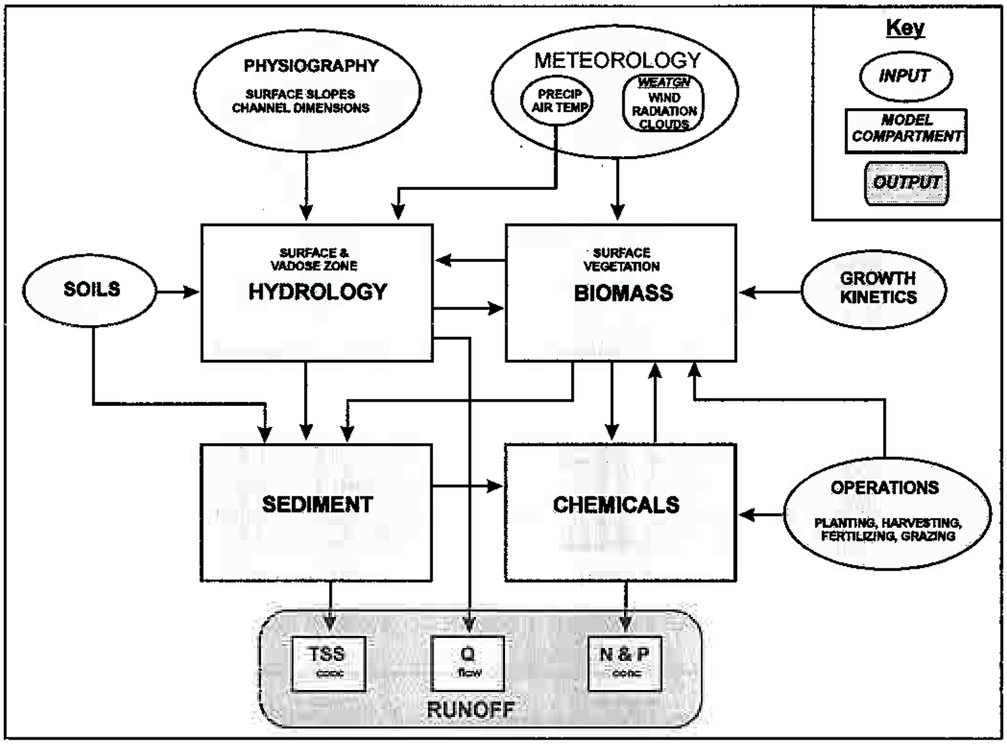

Figure 29 - Structure of SWAT model

In the spatial depiction of the watershed and water conveyances, the basic element of SWAT is the Hydrological Response Unit (HRU), defined to be a specific area with uniform soil, vegetation, surface slope, and landsurface treatment. A subbasin, see Figure 30, is a catchment made up of one or more HRU's, a channel reach and a vadose zone compartment. The internal drainage network of a subbasin is parameterized as a single tributary length. The channel and subbasin network can become quite complex, including ponds, wasteloads and reservoirs, but the structure is essentially as diagrammed in Fig. 30. Emphasis in the SWAT formulation is squarely upon the watershed and its underlying soil structure and vadose zone. The tributary/channel components are essentially routing devices and are too coarsely depicted to effectively simulate biochemical processes that occur as water is conveyed through the channel. For intense storms with swift hydrographs this is a minor limitation. For lower flow scenarios, this can be s substantial weakness.

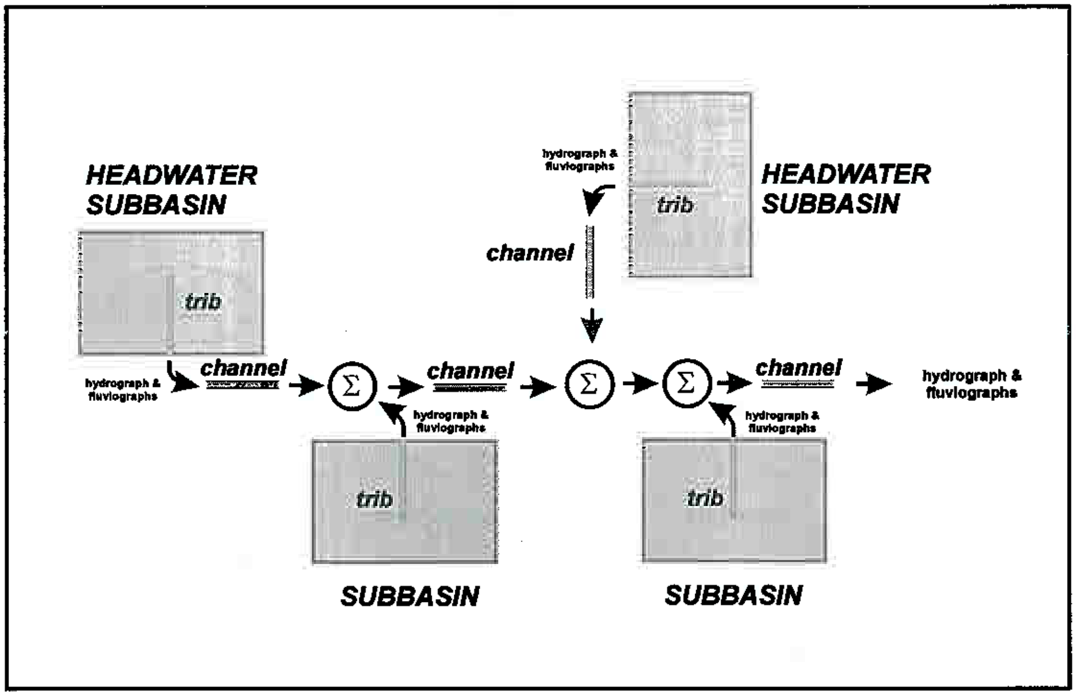

Figure 30 - Schematic of spatial depiction and water budget in SWAT

SWAT is a time-advancing model. The basic time unit is one day, though some of the processes, especially involving biomass, are evaluated intradiurnally. The user can direct the model to aggregate results on a monthly or annual basis to facilitate long-term simulations with generation of many megabytes of output. Any simulation must also be supplied with initial conditions. The user has two basic choices: input values for each of the major model variables (including biomass and soil water content) or start the model from arbitrary conditions and run it with realistic external data until the errors in the initial conditions finally "flush" out of the system. The latter option was followed in this work. Numerical experimentation determined that about a five-year simulation period was sufficient to eliminate the "starting transient" from the model solution, as exemplified by Figure 31.

The hydrological computations of the watershed water budget rely upon the SCS curve-number method, see Ward (2001b). Much of this methodology is empirical and has been criticized for use in watershed water budgets (see Ward and Benaman, 1999). The sediment mobilization processes,

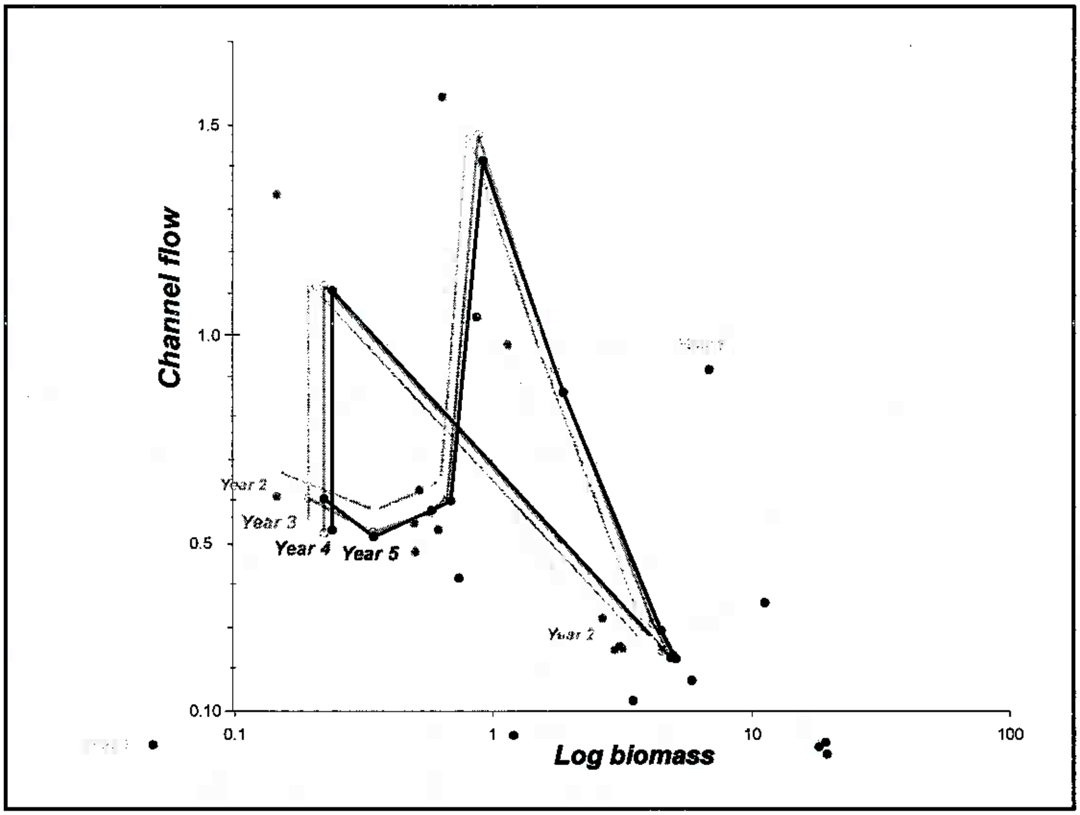

Figure 31 - Acquisition of limit-cycle behavior, monthly SWAT data with repeated 2000 meteorology, Little Boggy Creek 17057 watershed

another major component of SWAT is a computerized version of the Universal Soil Loss Equation, also an empirical procedure that lacks universal acceptance. These weaknesses of the model represent areas for future development and improvement. Despite these weaknesses, SWAT (along with HSPF) is one of the best models currently available for simulation of landscape loading, and its deficiencies need to be considered in interpretting and applying the model.

The driver for hydrology is rainfall. SWAT employs a statistical "weather generator" WEATGN that produces a Monte Carlo time series for each of the major meteorological elements, with seasonally varying climatological mean values that agree with normal data for a given region. One of the products supplied with SWAT is data files with weather generator parameters needed to simulate long-term weather for major regions of Texas. A better course of action would be to drive the model with measured data for the simulation period. Since such meteorological time series are not readily available (radiation and wind data are particularly scarce), the weather generator was used in this work, except for the variables precipitation and air temperature. These are important controls both on the hydrology and the surface vegetation, so were developed from time series of measured data.

The number of model parameters whose values must be specified for a given simulation is overwhelming. A model simulation requires a *minimum* of 7 input files plus 4 data-base files plus 3 input files per subbasin plus 4 input file per HRU. For a simple uniform catchment, therefore, 18 input files are necessary, and the number proliferates as the complexity of the watershed increases. Most of these input files contain numerous parameters whose values might be subject to specification or adjustment by the user. Soils, for example, are identified by MUID associations, characterized by the three dominant soil series. The input file for each soil series requires three structural parameters (maximum rooting depth, porosity measure, and crack volume potential) plus twelve more detailed physicochemical parameters for each of four horizons, for a total of 51 parameters. For each of the 97 land cover/plant growth options in the data base, 29 parameters are necessary, including biomass/radiation-energy efficiency ratio, maximum potential leaf-area index, key points in the growing cycle, maximum root depth and canopy height, N and P uptake parameters, USLE C-factor value (minimum possible), and stomatal conductance variables. Some parameters are computed internally by the model as a default operation, but these may not be accurate for a specific catchment, and the user has the option of overriding this computation with a specified value, e.g. organic P and N enrichment ratios for sediment. Much of the subsurface water budget relies upon parameters, such as soil layer conductivities, baseflow alpha factors for shallow aquifer and bank storage, "revap" and percolation controls, which are not readily available unless substantial groundwater (or baseflow) measurements and/or analyses are available. The simplest model application, to a single HRU with no special tillage or planting operations, with nutrient simulation only, requires specification of about 200 parameters. When the default and data-base values are accepted, there still remain over 30 parameters whose values must be specified, values for many of which are unlikely to be available, so they are available for calibration. (Nietsch et al., 2002, offer suggestions as to some of the variables and their order that might be employed in calibration, but there are others that are equally viable candidates.)

The SWAT development staff recommends against validating SWAT for individual storms, but rather for long-term average loadings from a catchment (e.g., Dugas, pers. comm., 1999). There are two reasons. First, the key climatological inputs are generated stochastically, so it is unlikely that the correct combination of meteorology will obtain for a *specific* storm event, but rather that it will average out over a long period. Second, and more importantly, the response of the model to a specific rainfall event will depend upon the integrated effect of all of the hydrological, sedimentary and biological variables depicted for the watershed. Rarely can it be expected that all of the many parameters and their integrated antecedent results will be exactly right for any specific storm being used for a "cold" validation run. Indeed, the suggested procedure in the SWAT user's manual (Neitsch, et al., 2002) is to begin the validation against annual-mean values, then proceed to monthly (and, if necessary, daily). This is an instance of the "Golf Course" approach to model calibration, in which the first objective is to get the ball on the fairway, next to get it on the green, and finally—maybe, with luck—to get it in the hole.

In the case of the Big Cypress the "Sunday Dinner" approach was followed instead, in which the model is validated at the outset for specific storms on small watersheds. The Sunday Dinner approach seeks to establish validation for the important categories of catchments, so these can then be assembled into a larger, more complex basin model with some assurance of adequacy, as sauces and gravies are combined into dishes, these into the courses that make up the dinner. The relative merits of the two approaches are a matter of debate (the Sunday Dinner being a more "scientific" procedure than the Golf Course, but prone to error if the full range of catchment types is not represented). The reason for this approach for the Big Cypress basin is simple: there are no gauges and/or sampling stations in the stream channels of the basin with long periods of flow and water chemistry data, which are necessary for the Golf Course approach. The basic source of data is the network of wetweather automated sampling stations operated by this project (see Section 2, above). The short period of operation and the small number of storm events available from this network (see Table 1) further constrain their utility in comprehensive landscape modeling. On the other hand, the design of the wetweather sampling strategy anticipated this problem, and the stations were selected to monitor runoff from small, relatively homogeneous catchments, with a range of landuse, soil and vegetation types typical of the Big Cypress.

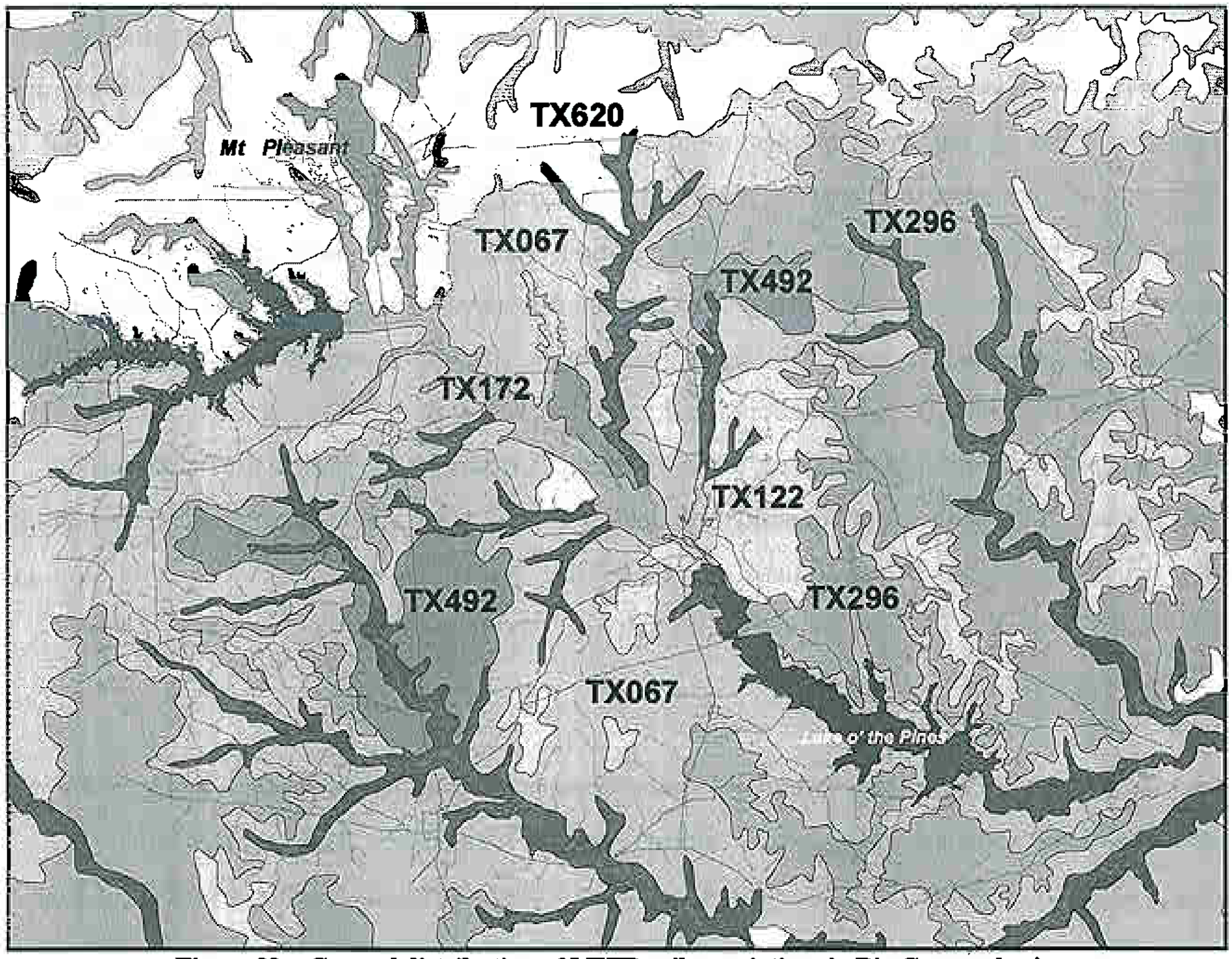

Figure 32 - General distribution of MUID soil associations in Big Cypress basin, from STATSGO data base

Probably the most straightforward model input development is the specification of watershed soils, because of the splendid data bases created by the NRCS, now available in several GIS formats. The STATSGO data base was largely employed for this project (with occasional reference to the much more detailed SSURGO data base, NRCS, 1995). Soils are not highly variable, being predominantly ultisols and alfisols, acid and sandy, having weathered from sandstone, and occasionally shale (Scott, 2000). The general distribution of STATSGO MUID associations in the Big Cypress basin is shown in Figure 32. TX620 is a west-to-east swath of paleudalfs lying across the northern extreme of the basin. The associations to the south are predominantly paleudults. Given the relative

Table 9
Main MUID soil associations for wetweather catchments used in SWAT validation

MUID		*description*	*fraction of watershed*
	10263	***Tankersley Creek at FM127***	
TX620		WOODTELL-FREESTONE-BERNALDO	0.83
TX619		WOLFPEN-PICKTON-WOODTELL	0.08
TX172		ESTES-MANTACHIE-BIENVILLE	0.09
	10266	***Hart Creek at Titus County Road***	
TX620		WOODTELL-FREESTONE-BERNALDO	0.61
TX619		WOLFPEN-PICKTON-WOODTELL	0.21
TX357		NAHATCHE-CROCKETT-WOODTELL	0.16
TX067		BOWIE-CUTHBERT-KIRVIN	0.03
	16455	***Alley Creek approx. 8 KM SW of Avinger at SH155***	
TX296		LILBERT-DARCO-BRILEY	0.50
TX122		CUTHBERT-REDSPRINGS-ELROSE	0.50
	17030	***Unnamed Tributary of Prairie Creek at Camp CR1264***	
TX492		SACUL-BOWIE-KULLIT	1.00
	17031	***Tributary of Prairie Creek at Camp CR1140***	
TX067		BOWIE-CUTHBERT-KIRVIN	1.00
	17033	***Boggy Creek at FM144***	
TX620		WOODTELL-FREESTONE-BERNALDO	0.76
TX316		IUKA-GUYTON-MANTACHIE	0.13
TX067		BOWIE-CUTHBERT-KIRVIN	0.11
	17057	***Little Boggy Creek at Crossing of Morris CR3301 (Green Street Rd.)***	
TX620		WOODTELL-FREESTONE-BERNALDO	0.66
TX067		BOWIE-CUTHBERT-KIRVIN	0.18
TX316		IUKA-GUYTON-MANTACHIE	0.15

similarity of soils in the basin, the predominant series was identified for each MUID, and the properties of that series used to represent the MUID association. The proportions and geography of the MUID's in each watershed were then studied, and the smallest number of MUID's determined that would satisfactorily depict soil variation in the watershed. Table 9 summarizes the principal

MUID's in each of the wetweather watershed, and the proportion of watershed area represented by

Table 10
Dominant land uses in wetweather watersheds (percent)

10263 Tankersley Creek at FM127		***17030 Prairie Creek trib at CR1264***	
Cropland and pasture	72.75	Cropland and pasture	86.23
Forest	9.50	Confined Feeding Operations	8.26
Urban & residential	8.10	Forest	5.51
Strip Mines, Quarries & Gravel Pits	5.81	***17031 Prairie Creek trib at CR 1140***	
10266 Hart Creek at Titus County Road		Cropland and pasture	65.56
Cropland and Pasture	64.20	Forest	34.44
Forest	17.73	***17033 Boggy Creek***	
Urban & residential	15.53	Cropland and pasture	80.11
Confined Feeding Operations	0.71	Forest	15.78
16455 Alley Creek		Urban & residential	3.81
Forest	93.62	***17057 Little Boggy Creek @CR3301***	
Urban & residential	15.53	Cropland and pasture	75.31
Cropland and pasture	4.00	Forest	23.03
Strip Mines, Quarries & Gravel Pits	0.22	Urban & residential	1.29

each. For most of the wetweather watersheds, one carefully selected MUID (with properties represented by the predominant soil series) proved adequate to characterize the soils for modeling purposes.

Landuse in the Cypress basin is predominantly forest and agricultural (a generic category including cropland, pasture and range), more specifically grass pasture (mainly dallis, bahia, common bermuda, and coastal bermuda). The proportions for each of the wetweather station watersheds are tabulated in Table 10. Two categories of agricultural landuse were employed, one a typical pasture with cattle grazing (at the density and manure-generation rates in the SWAT data bases), and the other augmented by an application of chicken litter assumed to occur on 1 January of each year. Paul Price and Associates (1998) compiled data provided by Pilgrims on agricultural chicken litter application in the basin, focusing on 1998 data for the four basins Lilly Creek, Prairie Creek, Boggy Creek and Frazier Creek. An average application rate (per area treated, not the area of the basin) proved to be 2.88 tons(wet)/ac or 6455 kg/ha. This application rate was used in conjunction with the

1998 total area of treatment within each wetweather watershed. We note that areas and amounts vary from year to year, both within and between subwatersheds, so using only 1998 data incurs a degree of error. It is reported, as well, that both pasture and cropland areas in the basin receive occasional application of fertilizer, but we have no data on this and therefore neglect it in the model simulations. Again, this is a potential source of error in the model input that must be borne in mind in interpretting the results. (PPA, 2001, updated the poultry analysis with data from the year 2000, but unfortunately only areas, not weights, are available for the individual litter application events.)

The simplest wetweather watersheds are those on Alley Creek and the tributaries of Prairie Creek, in that each is fairly homogeneous in surface features. Soils and land use for Alley Creek Station 16455 are shown in Figure 33. This is predominantly forested land cover on mainly TX296 soils, of which the Lilbert series, 85% sands down to 0.6 m, is representative. This watershed could be effectively represented as entirely forested, and represents the test case for this landcover category. A curve number of 60 was assigned.

Soils and land use for both Prairie Creek watersheds are shown in Figure 34. The Prairie Creek watersheds are predominantly pasture on the very similar TX492 or TX067 soils, of which the Bowie series, about 60% sand down to 2 m, is representative. Station 17030 was modeled as a single HRU and represents the test case for grass pasture with cattle grazing. According to the Pilgrims data (PPA, 200x), the Station 17031 watershed received the highest rate of litter application in the 1998-2000 period of all of the wetweather watersheds, and therefore was used as the test case for intense litter usage. The areas given by the Pilgrims data base, however, exceed in total the area of the watershed by nearly a factor of 3. This is thought to be erroneous, so for model application it was assumed that one-third (0.33) of the watershed received chicken litter application. This was modeled as a second pasture-with-grazing HRU with 1 January litter application at the average rate (see above). The assigned curve number for both Prairie Creek watersheds was 70.

The Boggy Creek basin wetweather watersheds are larger, more complex examples of rural watersheds. Soils and land use for both Boggy Creek 17033 and Little Boggy 17057 are shown in Figure 35. The uplands soils are MUID 620 or TX067, both greater than 65% sands, while the

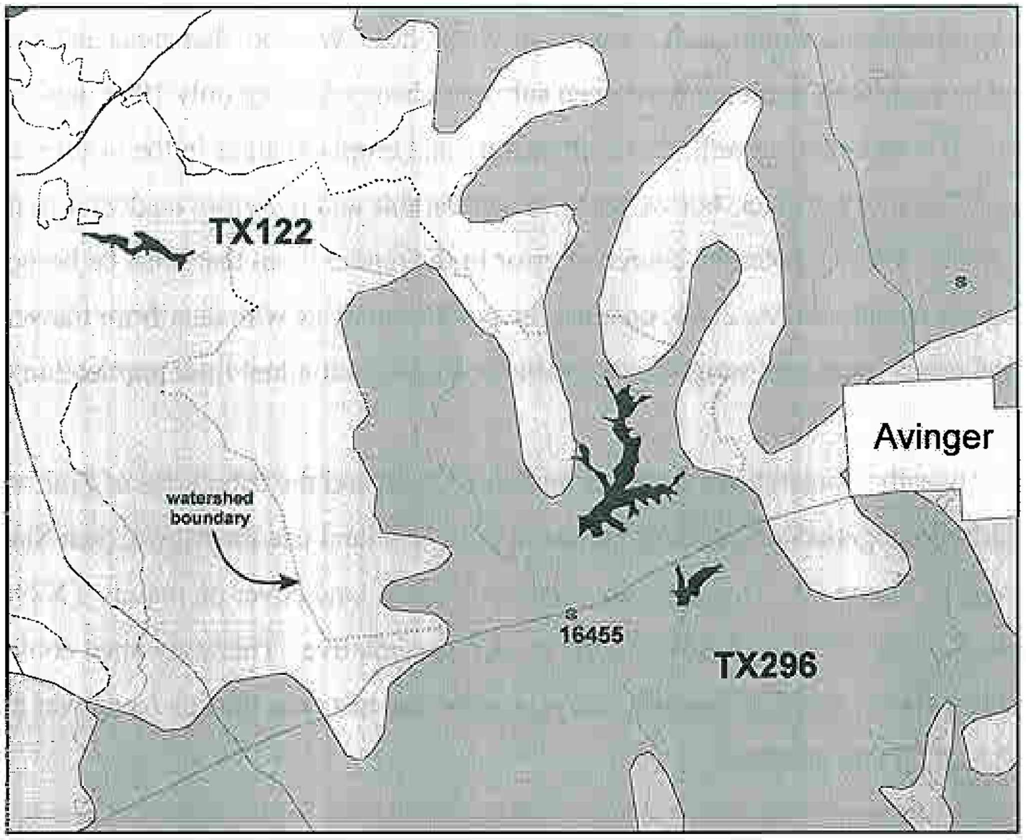

Figure 33a - Soils in Alley Creek Station 16455 watershed

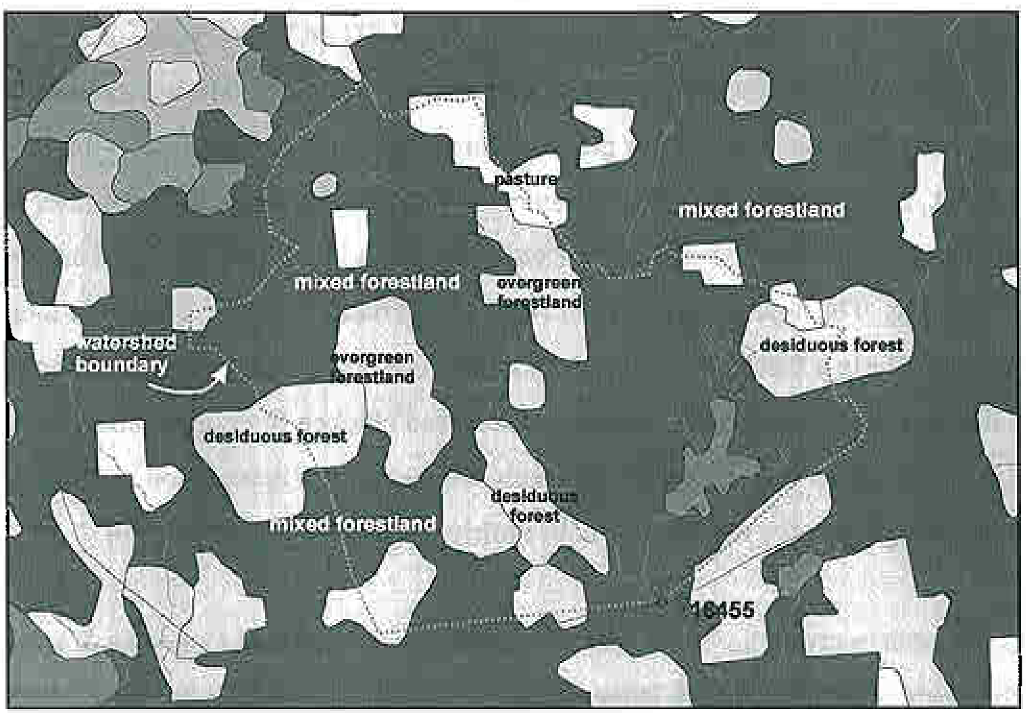

Figure 33b - Landuses in Alley Creek Station 16455 watershed

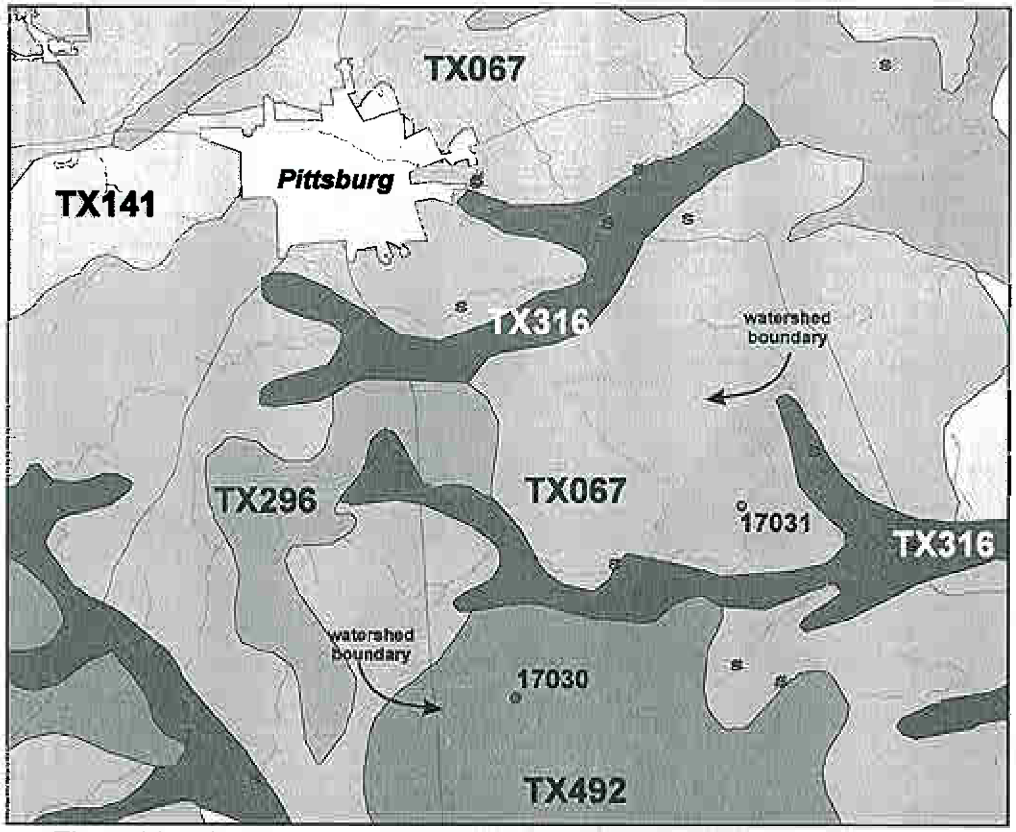

Figure 34a - Soils in watersheds of Prairie Creek trib Stations 17030 and 17031

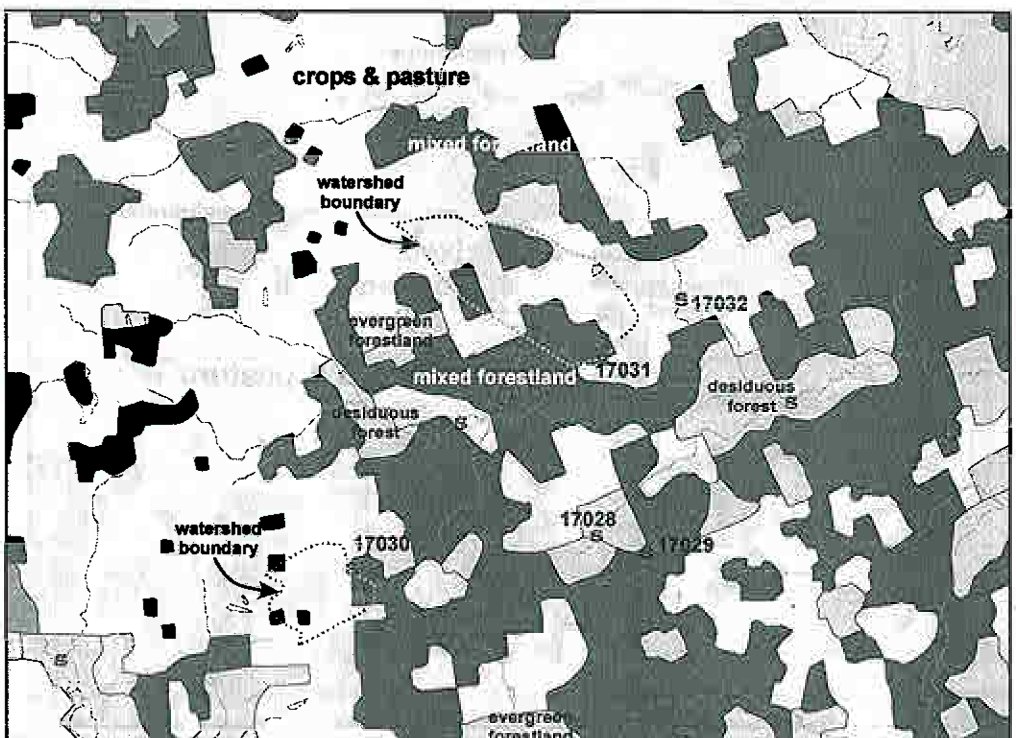

Figure 34b - Landuses in watersheds of Prairie Creek trib Stations 17030 and 17031

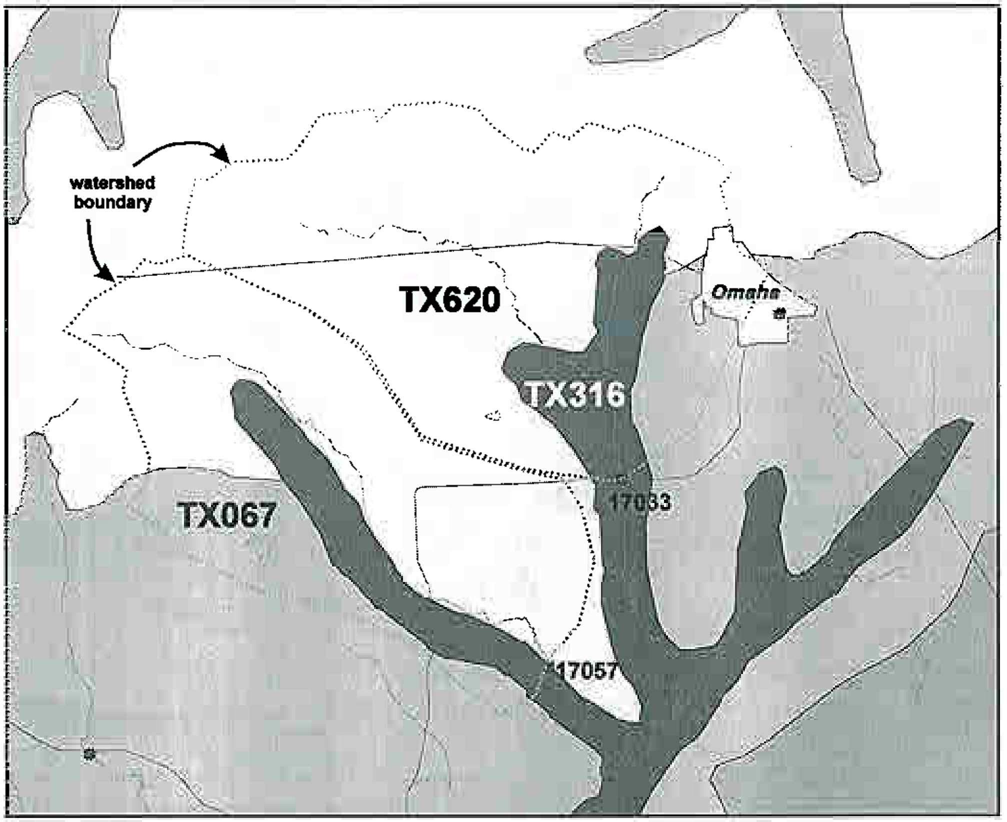

Figure 35a - Soils in watersheds of Boggy Creek Station 17033 and Little Boggy 17057

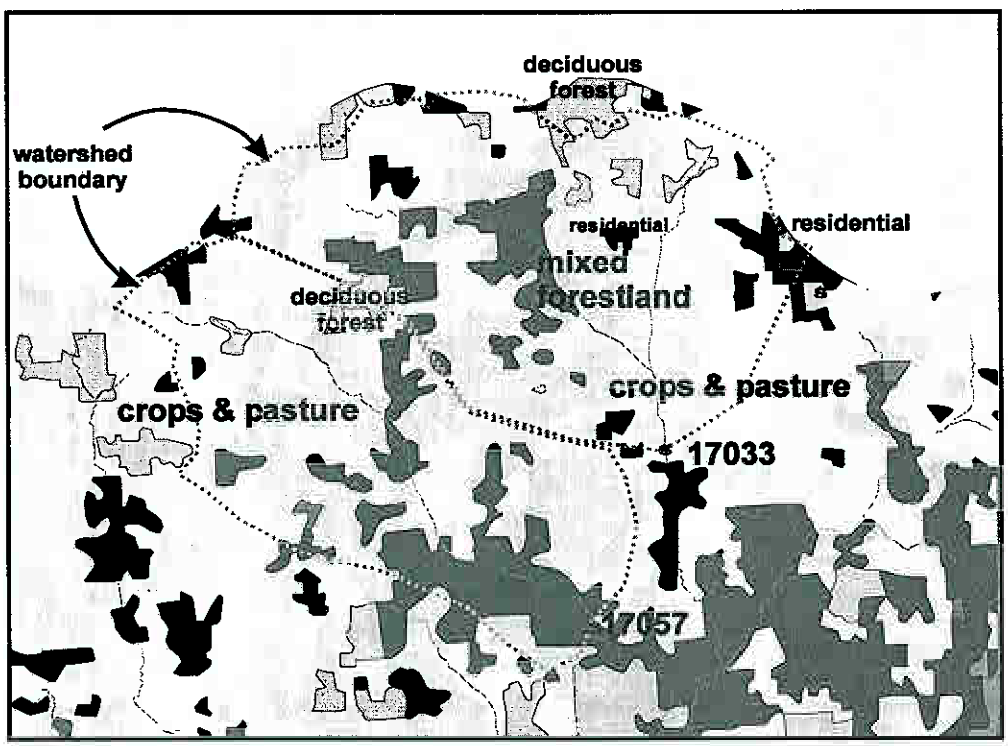

Figure 35b - Landuses in watersheds of Boggy Creek Station 17033 and Little Boggy 17057

floodplain is mainly MUID TX316, about 50% sands. The Bowie series, about 60% sand down to 2 m, was selected to be representative. Both watersheds are predominantly pasture with moderate amounts of chicken litter application, for 17033 about 6% of the watershed, and for 17057 about 26% of the watershed. Both were modeled as 3-HRU catchments, *viz*. pasture, pasture with chicken litter, and forest. The curve numbers were set to 60 for the forest HRU and 70 for the pasture.

Both Tankersley 10263 and Hart Creek 10266 wetweather station watersheds are much larger and much more complex, including urbanized sections, Table 10. Soils and land use for both watersheds are shown in Figure 36. Upland soils in both cases are TX620, predominantly woodtell and freestone, greater than 65% sands. The floodplain soils are finer grained, and somewhat different for the two watercourses. For Hart Creek, it is TX357, equally distributed in sand, silt and clay, with moderately high organics, while for Tankersley it is even finer-grained TX172, about half and half silts and clays. Natache series was finally elected to depict the Hart Creek watershed soils. For Tankersley, Woodtell was used for the urban and pasture HRU's, typically upland, while Estes was used for the forest HRU, typically floodplain. The curve number was assigned a value of 70 except in the forested areas, where it was 60.

Hydrological specification involves the parameters employed in the SCS curve-number method and in the USLE. Land surface slope was determined from topographic maps of the area. An average land slope is used to represent an entire HRU. Channel slopes and dimensions were taken direction from the earlier work in this project (Ward, 2001a). Curve numbers were set based upon terrain and landcover, as described above. SWAT includes a provision for incorporating a reservoir into the channel network of Figure 30. The reservoir is treated in a rather rudimentary fashion, assuming a fixed capacity and a constant discharge through the spillway (with potential for activation of uncontrolled releases, e.g. emergency spillway), but this at least estimates the effect of such a system on storing and lengthening the hydrograph of a flood event, and account for entrapment of solids and sorbed chemicals in the reservoir. Tankersley reservoir was included in the 10263 simulation using this device, which required a separate subbasin corresponding to the reservoir catchment, about 34% of the total watershed.

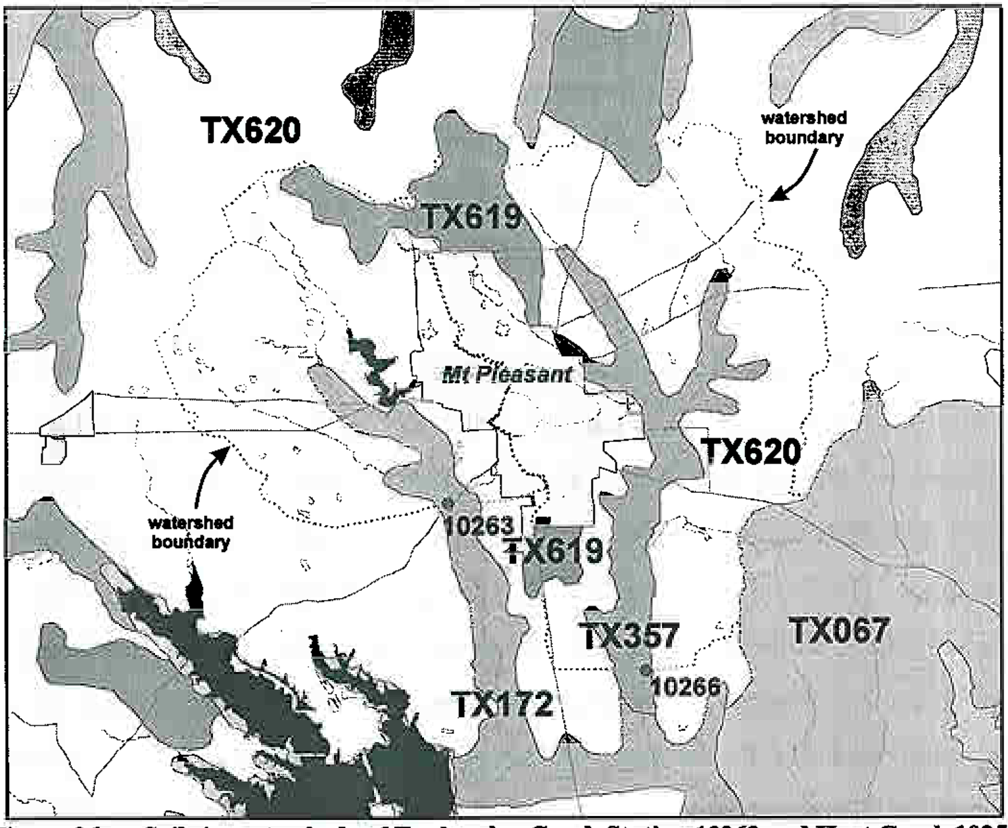

Figure 36a - Soils in watersheds of Tankersley Creek Station 10263 and Hart Creek 10255

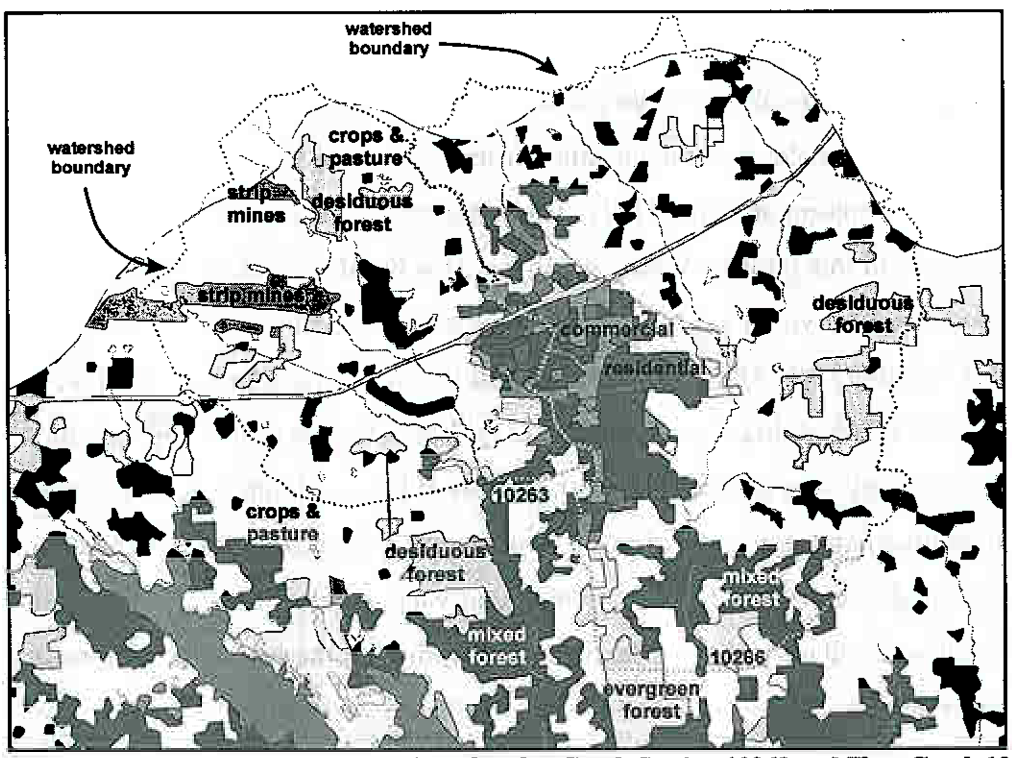

Figure 36b - Landuses in watersheds of Tankersley Creek Station 10263 and Hart Creek 10255

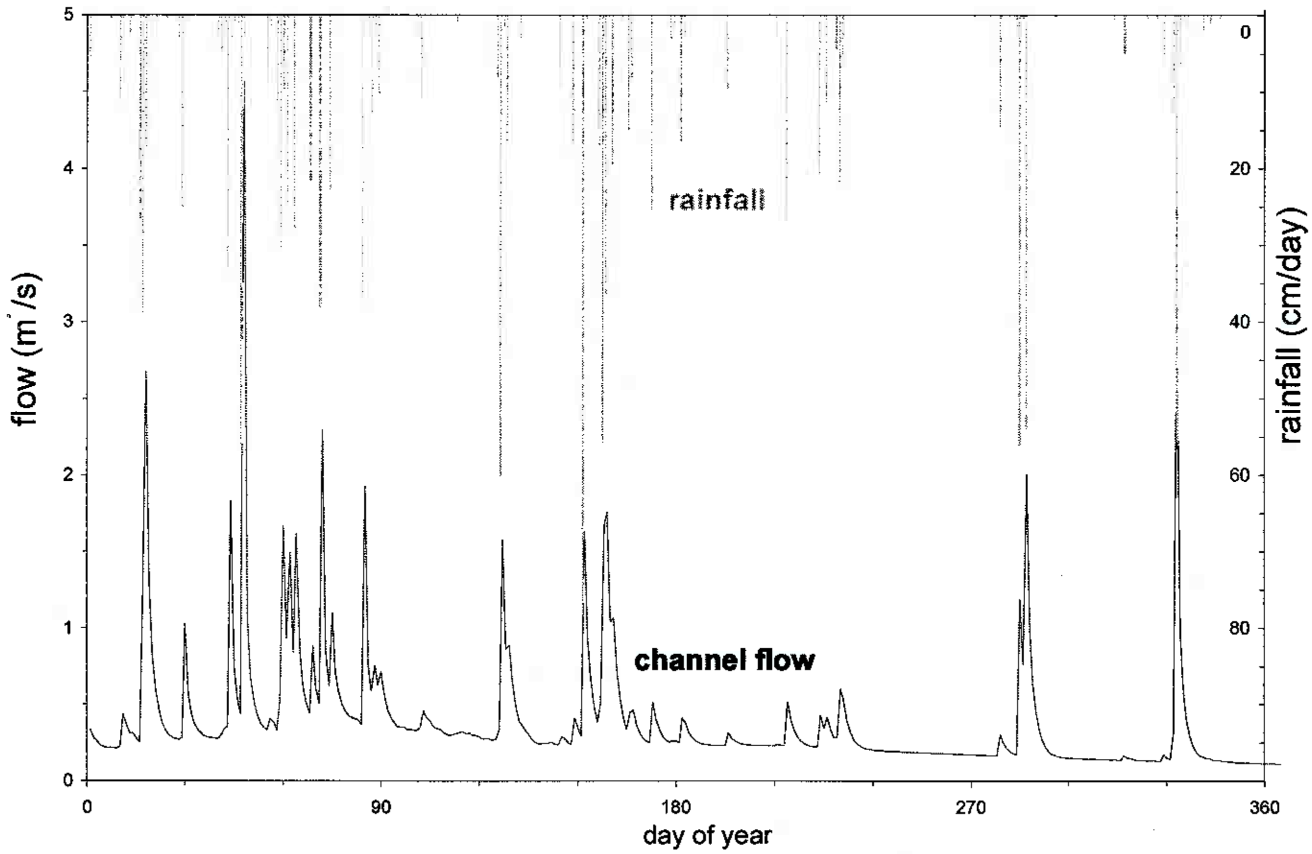

Figure 37 - 2001 hydrograph in channel of Station 16455 predicted by SWAT from daily rainfall

An example SWAT prediction is shown in Figure 37, the 2001 hydrograph of flow in the watershed channel at Station 16455 on Alley Creek, given the input of daily precipitation, also plotted. Substantial infiltration and storage in the shallow soil layers of this sandy, forested watershed result in a baseflow that slowly rises and falls through the year, upon which are superposed the runoff hydrographs from the individual storms. At this level of plotting resolution, the SWAT output looks smooth and realistic. However, SWAT operates on a daily timestep. The observed and computed runoff hydrographs for the October storm are shown in Fig. 38 at this much coarser resolution. While the observations show the fine time response of the event (15-minute water level and flow measurements and hourly precipitation data, cf. Fig 12), the SWAT rendering of the storm is evidently much coarser. Not only is there an imprecision introduced due to the incommensurate resolutions of the flow time signals, but the daily input of precipitation automatically incurs a lag of

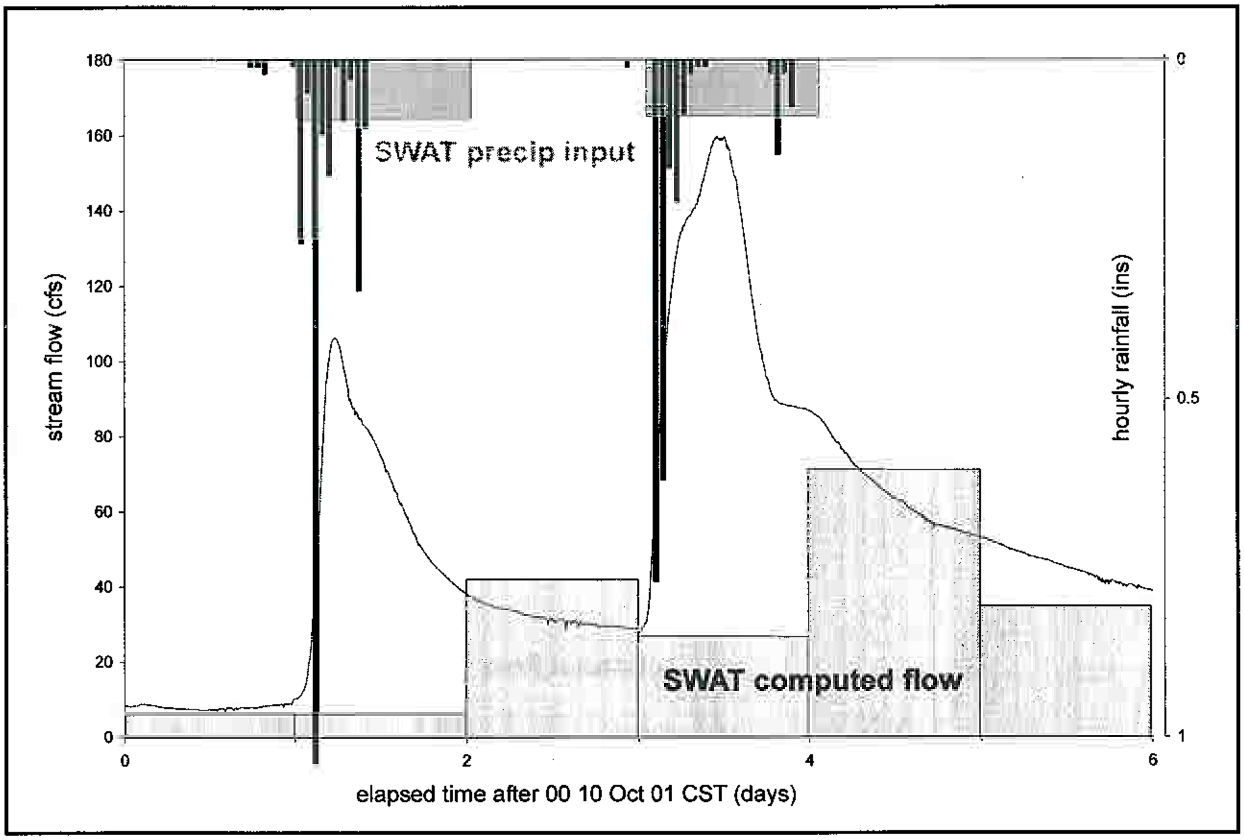

Figure 38 - October 2001 storm events, observed hydrograph and rainfall (cf. Fig. 12) and SWAT model for Station 16455 Alley Creek

one day in the response of the model, which introduces an additional source of error in the model computation.

The one-day time step of the model raises an immediate problem in how to compare the model prediction to observations. There are two options. One is to aggregate the observations on a daily time frame for direct comparison to the model, summing over the days in which runoff from the precipitation was experienced. The second is to integrate the results for both model and observation over the duration of the storm, and compare the "total storm" results without any daily lumping of the observed data. (In both cases, the storm runoff and storm loads are "scalped" from the baseflow.) An argument can be made for either, so both were employed here for evaluation of the hydrological performance.

Table 11 presents the storm runoff comparisons for the first method, in which the same series of days are extracted from the observations as are attributed to the storm in the model results, integrated or averaged (as appropriate) by day, then aggregated in both observation and model for the storm event. In this approach, by definition the storm duration is an integral number of days, and the same number of days are used to determine both the observational features of storm runoff and the model. In Table 11, the uncertainty in the data is expressed as a standard error as a proportion of the mean (i.e., a coefficient of variation), and used to define the 95% confidence limits. The standard errors are those given in Table 4, based upon the quality of the hydrograph data record. (Thus in Table 11 no additional uncertainty is ascribed to accumulating flow over days that included nonstorm data, though clearly this action introduces additional inaccuracy in the observed data.) These 95% confidence bounds are considered to bound the range of the "probable" correct results for the storm, and are used to judge the quality of the model prediction. When the model results lie within these bounds, the model performs just as accurately as the data in estimating the "true" value of the storm runoff, so we judge the model performance to be satisfactory. From inspection of Table 11, it is apparent that 70% of the modeled events are judged to be satisfactorily validated against the data.

This writer favors the storm-duration method slightly, because most of the events studied are quick-rise, short-duration hydrographs, which incur the greatest error when segmented into day increments. (For longer events, there would appear to be little difference in the two approaches.) For this reason, more emphasis was given the storm-duration approach, including complete evaluations for TSS, N and P fluviographs, as well as hydrographs. The results of these analyses are presented in Table 12, following the same convention as Table 11. On the basis of the number of comparisons, approximately 74% of the events are predicted by the model within the applicable 95% confidence limits. By individual parameter, the success of the model is more variable:

volume	68	total P	63	%
TSS	58	total N	95	

Table 11
Comparison of observed runoff integrated over 1-day increments and SWAT model predictions

storm	*observed runoff*			*model*	*performance*	
	volume (m^3)	*coeff of var (%)*	*± 95% conf (m^3)*	*volume (m^3)*	*model/obs*	*within 95% conf*
			10263 Tankersley Creek at FM 127			
10-14 Jan 01	2.62E+05	20	1.05E+05	1.73E+05	0.66	Y
11-16 Oct 01	1.91E+06	30	1.15E+06	1.16E+06	0.61	Y
28 Nov - 2 Dec 01	4.71E+05	40	3.77E+05	1.83E+06	3.89	N
			10266 Hart Creek at SE 12			
10-14 Jan 01	5.92E+05	20	2.37E+05	6.78E+04	0.11	N
11-16 Oct 01	1.52E+06	30	9.14E+05	1.29E+06	0.84	Y
28 Nov - 2 Dec 01	6.29E+05	30	3.77E+05	1.25E+06	1.99	N
			16455 Alley Creek at SH 155			
10-14 Jan 01	3.51E+04	25	1.76E+04	4.54E+04	1.29	Y
11-16 Oct 01	6.76E+05	30	4.06E+05	3.66E+05	0.54	Y
28 Nov - 2 Dec 01	3.42E+05	40	2.74E+05	3.79E+05	1.11	Y
24-26 Jan 02	8.54E+04	40	6.83E+04	6.39E+04	0.75	Y
			17030 Prairie Creek Tributary at CR 1264 Crossing			
10-14 Jan 01	4.20E+03	20	1.68E+03	4.15E+03	0.99	Y
11-16 Oct 01	1.52E+04	20	6.08E+03	4.51E+04	2.97	N

(continued)

Table 11 (continued)
Comparison of observed runoff integrated over 1-day increments and SWAT model predictions

storm	*observed runoff*			*model*	*performance*	
	volume (m^3)	*coeff of var (%)*	*± 95% conf (m^3)*	*volume (m^3)*	*model/obs*	*within 95% conf*
17030 Prairie Creek Tributary at CR 1264 Crossing						
10-14 Jan 01	4.20E+03	20	1.68E+03	4.15E+03	0.99	Y
11-16 Oct 01	1.52E+04	20	6.08E+03	4.51E+04	2.97	N
17031 Prairie Creek Tributary at CR 1140 Crossing						
10-14 Jan 01	1.16E+04	20	4.64E+03	7.51E+03	0.65	Y
11-16 Oct 01	1.27E+05	20	5.07E+04	1.74E+05	1.37	Y
28 Nov - 2 Dec 01	9.16E+04	40	7.33E+04	8.03E+04	0.88	Y
17033 Boggy Creek at FM 144 near Omaha-North						
10-14 Jan 01	1.68E+05	20	6.72E+04	5.46E+04	0.32	N
11-16 Oct 01	5.28E+05	20	2.11E+05	3.08E+05	0.58	N
28 Nov - 2 Dec 01	2.87E+05	15	8.62E+04	3.16E+05	1.10	Y
17057 Little Boggy Creek at CR 3301						
11-16 Oct 01	4.22E+05	15	1.27E+05	3.48E+05	0.82	Y
28 Nov - 2 Dec 01	5.28E+05	40	4.22E+05	3.34E+05	0.63	Y

Table 12
Comparison of observed and modeled storm-event runoff and loads

storm		*runoff volume or load*					
		observed (m³ or kg)	*coeff varn (%)*	*±95% conf*	*model*	*model/ obs*	*within 95% conf*
		10263 Tankersley Creek at FM 127					
10-14 Jan 01	volume	2.41E+05	20	9.63E+04	1.73E+05	0.72	Y
	TSS	1.00E+04	40	8.02E+03	2.18E+04	2.18	N
	total P	2.76E+02	50	2.76E+02	3.89E+01	0.14	Y
	total N	1.04E+03	50	1.04E+03	2.28E+02	0.22	Y
10-12 Oct 01	volume	8.02E+05	30	4.81E+05	3.83E+05	0.48	Y
	TSS	4.56E+05	50	4.56E+05	2.47E+04	0.05	Y
	total P	4.71E+02	60	5.65E+02	7.79E+01	0.17	Y
	total N	2.35E+03	60	2.81E+03	1.96E+02	0.08	Y
28 Nov - 2 Dec 01	volume	4.72E+05	40	3.78E+05	1.83E+06	3.88	N
	TSS	2.64E+04	100	5.28E+04	2.77E+05	10.51	N
	total P	7.13E+02	40	5.71E+02	5.64E+02	0.79	Y
	total N	3.91E+03	80	6.25E+03	1.41E+03	0.36	Y
		10266 Hart Creek at SE 12					
10-14 Jan 01	volume	4.98E+05	20	1.99E+05	6.78E+04	0.14	N
	TSS	4.46E+04	50	4.46E+04	8.43E+03	0.19	Y
	total P	5.50E+01	60	6.60E+01	2.11E+01	0.38	Y
	total N	1.30E+03	60	1.56E+03	8.90E+01	0.07	Y
10-12 Oct 01	volume	5.08E+05	30	3.05E+05	3.34E+05	0.66	Y
	TSS	7.34E+04	60	8.81E+04	4.51E+04	0.61	Y
	total P	1.21E+02	70	1.70E+02	5.92E+01	0.49	Y
	total N	7.07E+02	70	9.90E+02	2.00E+02	0.28	Y
28 Nov - 2 Dec 01	volume	5.29E+05	30	3.17E+05	1.25E+06	2.36	N
	TSS	4.64E+04	40	3.71E+04	1.82E+05	3.92	N
	total P	1.69E+02	60	2.02E+02	4.85E+02	2.88	N
	total N	1.03E+03	80	1.65E+03	1.14E+03	1.11	Y

(continued)

Table 12 (continued)
Comparison of observed and modeled storm-event runoff and loads

storm		*runoff volume or load*					
		observed (m^3 or kg)	*coeff varn (%)*	*±95% conf*	*model*	*model/ obs*	*within 95% conf*
		16455 Alley Creek at SH 155					
10-12 Oct 01	volume	1.90E+05	30	1.14E+05	8.78E+04	0.46	Y
	TSS	1.16E+04	80	1.86E+04	4.17E+03	0.36	Y
	total P	8.03E+00	70	1.12E+01	6.99E-01	0.09	Y
	total N	8.42E+01	80	1.35E+02	7.41E+01	0.88	Y
28 Nov - 2 Dec 01	volume	3.27E+05	40	2.62E+05	3.79E+05	1.16	Y
	TSS	3.37E+04	50	3.37E+04	1.46E+05	4.33	N
	total P	1.45E+01	70	2.04E+01	4.89E+01	3.37	N
	total N	3.22E+02	70	4.50E+02	4.37E+02	1.36	Y
24-26 Jan 02	volume	8.65E+04	40	6.92E+04	6.39E+04	0.74	Y
	TSS	1.38E+04	60	1.66E+04	4.73E+03	0.34	Y
	total P	7.20E+00	70	1.01E+01	1.37E+00	0.19	Y
	total N	1.07E+02	70	1.50E+02	5.43E+01	0.51	Y
		17030 Prairie Creek Tributary at CR 1264 Crossing					
10-14 Jan 01	volume	4.48E+03	20	1.79E+03	4.15E+03	0.93	Y
	TSS	3.03E+02	50	3.03E+02	4.90E+02	1.62	Y
	total P	1.46E+00	50	1.46E+00	5.55E-01	0.38	Y
	total N	1.16E+01	50	1.16E+01	2.96E+00	0.26	Y
10-12 Oct 01	volume	2.26E+03	20	9.02E+02	2.01E+03	0.89	Y
	TSS	4.95E+02	40	3.96E+02	4.90E+02	0.99	Y
	total P	1.46E+00	50	1.46E+00	5.55E-01	0.38	Y
	total N	1.16E+01	50	1.16E+01	4.13E+00	0.36	Y

(continued)

Table 12 (continued)
Comparison of observed and modeled storm-event runoff and loads

storm		*runoff volume or load*					
		observed (m³ or kg)	*coeff varn (%)*	*±95% conf*	*model*	*model/ obs*	*within 95% conf*
		17031 Prairie Creek Tributary at CR 1140 Crossing					
10-14 Jan 01	volume	1.08E+04	20	4.31E+03	7.51E+03	0.70	Y
	TSS	6.16E+02	40	4.93E+02	1.92E+03	3.11	N
	total P	2.35E+00	50	2.35E+00	7.53E+00	3.20	N
	total N	5.02E+01	50	5.02E+01	1.78E+02	3.55	N
10-12 Oct 01	volume	6.73E+03	20	2.69E+03	2.49E+04	3.71	N
	TSS	4.31E+03	50	4.31E+03	5.43E+03	1.26	Y
	total P	2.31E+00	50	2.31E+00	1.84E+01	7.97	N
	total N	5.91E+01	50	5.91E+01	6.11E+01	1.03	Y
28 Nov - 2 Dec 01	volume	8.79E+04	40	7.03E+04	8.03E+04	0.91	Y
	TSS	1.29E+04	60	1.55E+04	1.18E+04	0.91	Y
	total P	3.60E+01	40	2.88E+01	8.28E+01	2.30	N
	total N	3.35E+02	60	4.02E+02	2.08E+02	0.62	Y
		17033 Boggy Creek at FM 144 near Omaha-North					
10-14 Jan 01	volume	1.57E+05	20	6.26E+04	5.46E+04	0.35	N
	TSS	1.97E+04	30	1.18E+04	2.31E+03	0.12	N
	total P	2.34E+01	40	1.87E+01	4.77E+00	0.20	Y
	total N	3.98E+02	50	3.98E+02	2.18E+02	0.55	Y
10-12 Oct 01	volume	1.63E+05	20	6.54E+04	5.31E+04	0.33	N
	TSS	2.83E+04	30	1.70E+04	4.20E+03	0.15	N
	total P	5.36E+01	40	4.29E+01	6.30E+00	0.12	N
	total N	2.69E+02	40	2.15E+02	8.20E+01	0.31	Y
28 Nov - 2 Dec 01	volume	2.88E+05	15	8.63E+04	3.16E+05	1.10	Y
	TSS	3.53E+04	20	1.41E+04	4.53E+04	1.28	Y
	total P	9.68E+01	20	3.87E+01	9.16E+01	0.95	Y
	total N	5.97E+02	40	4.77E+02	5.38E+02	0.90	Y

(continued)

Table 12 (continued)
Comparison of observed and modeled storm-event runoff and loads

storm		*runoff volume or load*					
		observed (m^3 or kg)	*coeff varn (%)*	*±95% conf*	*model*	*model/ obs*	*within 95% conf*
		17057 Little Boggy Creek at CR 3301					
10-12 Oct 01	volume	1.09E+05	15	3.26E+04	8.39E+04	0.77	Y
	TSS	2.17E+04	40	1.74E+04	3.14E+04	1.45	Y
	total P	3.58E+01	50	3.58E+01	4.25E+01	1.19	Y
	total N	1.77E+02	50	1.77E+02	1.18E+02	0.67	Y
28 Nov - 2 Dec 01	volume	5.03E+05	40	4.02E+05	3.34E+05	0.66	Y
	TSS	4.10E+04	50	4.10E+04	1.43E+05	3.48	N
	total P	1.91E+02	50	1.91E+02	4.58E+02	2.40	N
	total N	9.68E+02	70	1.36E+03	9.68E+02	1.00	Y

4. Discussion and conclusions

Given the number of free parameters available, the model could be calibrated to fall dead on the observed results (even if these results are in error). However, in the present project very little "calibration" was indulged, for several reasons. First, with so many parameters at our disposal, such an exercise in curve fitting presents only the illusion of model accuracy, but does not really improve the predictive power of the model. Second, forcing the model to replicate observation can sacrifice solid information that could be inferred from the model's failures. What is most important is the patterns in model errors, since these can indicate deficiencies in the model (or the data) that can be used to distinguish the conditions successfully modeled from those that are not, as well as inform future data-collection and analytical efforts.

The above pronouncements notwithstanding, some adjustments of the model were made. In the pasture management data for all watersheds, the biomass threshold for grazing was reduced to 500, as the default setting was inappropriate for this climatology, preventing grazing until early summer.

The urban HRU's generated far more load than indicated in the data. The SWAT urban loading is dictated by the data base file *urban2000.dat*, supplied with the model, which provides parameter values for eight categories of urbanization. Inspection of *urban2000.dat* disclosed that the only difference among the urban categories is in the impervious cover (and connected impervious cover). Yet, the Mt Pleasant urban area is really "light urban," characterized by more open land, fewer curbs than typical of larger cities, and a greater capacity for retention of contaminants (as well as lower loading rate for these contaminants): Mt. Pleasant is not Philadelphia or even Houston. Therefore, a 9th urban category was created for the Cypress basin in *urban2000.dat* (labelled "Mt Pleasant", but this is intended to be a generic label only for application to other, similar urbanized areas in the basin).

The technical basis for the values assigned parameters in the SWAT crop data base is highly variable (Dugas, pers. comm, 1999). Some of the agricultural crops, such as corn and alfalfa, are supported by years of measurements. Others are presently functioning as "place holders" in the data base, pending availability of better data. It appears that the pasturage types fall into this latter category. Type 12 (generic pasture) was specified for most of the crop/pasture land-use areas in the basin. However, it was determined that Type 15 (range-grasses) works better for the large northwestern basins of Tankersley and Hart Creeks.

Several of the pasture-dominated watersheds evidenced underprediction of N and P loadings. This could be compensated somewhat by increasing the management USLE "C" factor or by increasing the nutrient percolation parameters. However, these parameters were varied only within their "reasonable" ranges, and even at these values, the model continued to underpredict N and P loading. The most likely cause of this underprediction is lack of information on past fertilizer practices (notably chicken litter application) in the subject watersheds.

Perhaps of equal significance are the parameters which were not adjusted. For hydrological operation, these included the curve number (70 for all land-cover categories except forest, for which 60 was used) and the slope length, a key parameter in the USLE (see Ward and Benaman, 1999), which was assigned a value of 40 m and not varied. Both of these are sensitive parameters in model operation and have been used as calibration devices (e.g., Neitsch et al., 2002). Enrichment ratios have been suggested as a calibration device (Hauck and Abraham, pers. comm., 2002) for nutrient loadings. The default operation is for SWAT to compute these internally. Buried in the program code is a hard upper-limit value of 3.5, and it was determined that the model is hitting this hard limit on the Big Cypress simulations. Therefore, any further modification will entail overriding this limit. With so much uncertainty in fertilizer application rates, it seems inappropriate to press the (already spongy) science by inflating enrichment ratios, so the default computation was employed.

The extent to which runoff and loads are overpredicted or underpredicted is erratic for most watersheds. The season of the year in which the event occurs appears to play a large role. Note, for example, the tendency of the model to underpredict events following a period of drought (10 October 2001 storm, November 2001 storm) and the tendency of the model to overpredict winter loadings (January 2001 event). The state of vegetation cover seems to be an important control on this behavior. While the explicit modeling of vegetation landcover growth, maturation, death and decay is a major strength of SWAT, there is much uncertainty about some of the growth kinetics, especially for the non-agricultural crop types. In all of these simulations, for example, the winter die-back seems to occur too abruptly and too completely. Yet, this is an area of model development that is manifestly beyond the scope of the present study.

One immediate conclusion from this work deserves emphasis: that the application of chicken litter can represent a substantial source of solids and nutrient loads to the watercourse, even when the area involved is a small proportion of the watershed. This is due to the high mobilization rates from this land treatment. This is exemplified by Table 13, detailing the annual watershed loads (per unit area) for the four HRU's employed in the Tankersley watershed simulation (Station 10263).

Especially considering the problems entailed by a comparison of the model to individual storm events, and the uncertainty attaching to many of the key model parameters, this is considered to a satisfactory validation of the model. Despite the wealth of data assembled on the Big Cypress basin, especially in the TMDL project, input data remains a significant source of error. It is unfortunate in hindsight that a longer wetweather monitoring program and a richer data base of storm events were

Table 13
Annual landscape loading rates predicted by SWAT for 2001,
Tankersley Creek Station 10263 watershed

model element		*fraction of basin* (%)	*runoff to channel* *(mm/yr)*	*sediment yield* *(tons/ ha-yr)*	*Org nutrient yield* *Org N* *(kg N/ ha-yr)*	*Org P* *(kg P/ ha-yr)*	*Sediment P (sorb) yield* *(kg P/ ha-yr)*	*NO3 in surf runoff* *(kg N/ ha-yr)*
HRU1	pasture	38	375.0	5.36	9.33	1.41	1.27	0.88
HRU2	chicken*	3	351.6	0.76	13.71	3.91	3.46	8.78
HRU3	urban	15	418.4	1.54	3.41	0.59	0.40	1.02
HRU4	forest	10	337.3	0.66	2.03	0.26	0.07	0.74
Subbasin average		66	377.5	3.57	7.08	1.16	0.99	1.25
HRU5	pasture	34	374.8	4.69	8.35	1.25	1.12	0.88

*pasture with one application of chicken litter

not obtained, because this would help resolve some of the residual uncertainties. Neither nature nor the time schedule favored this in the present project. For now, this uncertainty will be incorporated into the margin of safety analyses, so that the TMDL process can continue, but additional data collection in the future would substantially reduce this uncertainty.

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