Book One - Report

Water-Quality Assessment Protocol for Texas River Basins: A Case Study on the Upper Neches River Basin Study Area for the Clean Rivers Program

A research proposal funded by:

Texas Water Development Board
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Austin, Texas 78711-3231

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"Modeling and data collection are not independent processes. Ideally, each drives and directs the other. Better models illuminate the type and quantity of data that are required to test hypotheses. Better data, in turn, permit the development of better and more complete models and new hypotheses."

National Research Council, 1991

Acknowledgments

Special thanks go to several people. Technical assistance was provided principally from the U.S. Geological Survey in the persons of Joy Lizarraga and Marshall Jennings. Harvey Jobson, USGS employee and author of the DAFLOW/BLTM models, provided endless service in the intricacies of unsteady-state deterministic modeling. Charles Marshall and Larry Koenig of the Texas Natural Resources Conservation Commission answered a steady stream of questions about the use of QUALTX, particularly as it was applied with the intensive survey results of 1984 on the Angelina River (Segment 0611).

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Glossary of Terms

ANRA -	Angelina and Neches River Authority
BBLTM -	Build **BLTM**, a FORTRAN program that builds the input for the BLTM model
BDAFLOW -	Build **DAFLOW**, a FORTRAN program that builds the input for the DAFLOW model
BLTM -	Branched Lagrangian Transport Model, a dynamic surface water-quality model
***BLTM.FLW* -**	output file from DAFLOW; Input file for BLTM
***BLTM.IN* -**	an input file needed for BLTM
***BLTM.OUT*-**	output file from BLTM; can be used to determine the effects of different processes on moving parcels
CAMS -	Continuous Automated Monitoring System
CEL -	an ancillary Program for BLTM; uses collected hydraulic data to determine hydraulic parameters for DAFLOW
CTPLT -	a post-processor for DAFLOW/BLTM, plots concentration vs. time at a specified location
CWA -	Clean Water Act
CXPLT -	a post-processor for DAFLOW/BLTM; plots concentration vs. distance at a specified time
DAR -	Drainage Area Ratio; used to estimate flow when flow is not measured.
DAFLOW -	Diffusion Analogy **FLOW** Model, a dynamic flow model for surface water-quality modeling
flnk.f -	a subroutine of the BLTM FORTRAN Program; contains the kinetics equations
***FLOW.IN* -**	an input file for DAFLOW
***FLOW.OUT* -**	an output file from DAFLOW, Input for BLTM
FLWPLT -	a post-processing program for DAFLOW; plots flow vs. time at a specified location
***PARCEL.OUT* -**	an output file of BLTM
PLT -	a post-processing program for DAFLOW; determines accuracy of the DAFLOW simulated results with respect to observed flows
QUAL-2E -	a one-dimensional surface water quality model supported by the USEPA
***QUAL2.IN* -**	an input file for BLTM; contains kinetic coefficients
QUALTX -	the Texas regulatory model for WLA's; a steady-state version of QUAL-2E
TDWR -	old name for TNRCC, Texas Department of Water Resources
TNRCC -	the Texas environmental regulatory agency; the Texas Natural Resource Conservation Commission
TWC -	old name for TNRCC; the Texas Water Commission
UNRB -	the Upper Neches River Basin; study area for model application
USEPA -	the United States Environmental Protection Agency
USGS -	the United States Geological Survey

WLA - Waste Load Allocation

WQS - Water Quality Standards

Executive Summary

This research was intended to develop a protocol for assessment of river basin water quality that would satisfy the hydrologic planning needs for the Texas Clean Rivers Program. Existing water quality data, GIS Arc/INFO mapping coverages and U.S. Geological Survey (USGS) technology was used to the fullest extent possible to characterize the water quality and integrity of monitoring networks on the Upper Angelina and Neches River Basin (UNRB). The methodology used for characterizing the water quality in the UNRB has been defined and is applicable to other river basins in the state.

The current monitoring networks on the UNRB were analyzed and gaps in the monitoring network identified. Deterministic modeling was used to assess the river basin water quality using only currently available data. The modelling tools developed can be used to simulate alternative management strategies for the water quality managers for this study area. Data availability and formatting were limiting factors in this study and will probably be limiting factors in other basins as well. The protocol developed is subject to change depending upon individual basin differences and the availability of data.

Introduction

Typically, to meet the requirements of Section 303(d) of the Clean Water Act and to develop total maximum daily load allocations for every water quality limited segment, the state of Texas monitors and models segments solely in terms of the point source loadings they receive. While this approach has been acceptable in the past, the U.S. Environmental Protection Agency (USEPA) is beginning to emphasize the importance of regarding water quality problems on a watershed basis and with respect to non-point source impacts. This shift requires a major rethinking of the current monitoring and modeling that is performed for water quality analyses in Texas.

Non-point source pollution is both a temporal and spatial phenomena, that revolves principally around the occurrence of rainfall. As point source pollution has largely come under control and regulation, the relative impacts form non-point sources have escalated. This has caused a recent surge in the amount of federal, state and local regulation with regard to such sources and has had important policy and scientific impacts for the state of Texas.

In response to this evolution in thinking about water quality problems and to fill information gaps, the Texas Legislature passed Senate Bill 818 (Texas Clean Rivers Act) in May of 1991. One of the objectives of Senate Bill 818 is to qualify and quantify the problem of non-point source pollution relative to point source pollution. As a result of this legislation, the Angelina & Neches River Authority (ANRA) and other river authorities are required to make biennial reports to the Texas Natural Resource Conservation Commission (TNRCC) on the quality of water in their respective river basin.

Current modeling to set permit levels for discharges around the state is performed using a steady-state model, QUALTX, a modified version of the USEPA model QUAL2. Currently, neither non-point sources nor groundwater impacts are considered when industrial, commercial and municipal discharge limits are set through use of this model. A deterministic modeling approach is needed that will allow for unsteady-state processes to be simulated. One of the most advantageous aspects of deterministic modeling is the ability to test different potential scenarios once a model is calibrated and verified. A modeling approach is needed for the purposes of state permitting needs, the river authorities under the Texas Clean Rivers Act. and for all water quality managers. Although this type of modeling is more sophisticated, the technology is available to meet the task.

The UNRB was selected as a test case for this study due to its relative size and complexity and its seeming applicability as a reasonably typical basin. The UNRB originates in Van Zandt County and extends southeasterly to the confluence of the Neches and Angelina Rivers above B.A. Steinhagen Reservoir. UNRB contains the headwaters of both the Neches and Angelina Rivers with a total drainage area of approximately 7,451 square miles.

The data that was available for analysis of the monitoring network was limited and obviously, the level of monitoring appears to be decreasing rather than increasing. The types of statistical analyses that are recommended in the Texas Clean Rivers Program FY94-95 Program Guidance could not be adequately performed in this basin due to a lack of a sufficient number of overlapping years of data and consistency in the types of parameters monitored.

Due to the lack of overlapping data and consolidation of monitoring data into a more functional database, the only type of analysis that could be performed was the application of a deterministic model. The diffusion analogy flow model (DAFLOW) was chosen as the deterministic hydraulic model for this study, used in conjunction with a water quality transport model known as the Branched Langrangian Transport Model. An intensive study must have been performed to determine channel geometry, water quality and flow data.

Based upon the modeling needs, two portions of the Angelina and Neches Rivers in the UNRB study area were able to be modeled - Segments 0604 and 0611. These two segments covered a significant portion of the UNRB. This research has shown the utility of the DAFLOW model for flow routing on Segment 0604 and the utility of DAFLOW and BLTM with QUAL2 kinetics for modeling flow and water quality on Segment 0611. Based upon the results of this compilation of data and modeling efforts, new monitoring programs for the UNRB have been suggested.

The theory and specific information on the deterministic modeling and water quality transport modeling are provided in the main report.

Results and Recommendations

The DAFLOW and BLTM models run for the UNRB show that the simulated steady-state discharges at certain points in the river system match the observed measurements taken during the intensive survey. There were differences in the results of the BLTM steady-state simulations as compared to the QUALTX simulations. The DAFLOW/BLTM model is proven as a successful steady-state model, that with little additional research could be further modified to provide an accurate simulation of water quality in rivers across Texas.

The DAFLOW and BLTM models run for the UNRB show that the impact from a storm event may vary from one area to another depending on a number of factors, but that the unsteady-state conditions can be effectively modeled to provide valuable information on the movement of contaminants and impacts of flows, and provides information that leads to development of better monitoring networks.

The research has shown that until an adequate number of water quantity and water quality monitoring stations with long histories of records are available, the deterministic modeling framework offers important advantages that statistical analyses cannot offer. One of the most important being the ability to test many alternative control strategies for both point and non-point sources of pollution.

The monitoring that currently exists serves a variety of purposes and is better described as a collection of monitoring sites than as a network. A network implies an interconnectedness between the data being collected. The currently collected data is not synthesized and cooperation between collectors is minimal. Only recently has there been an effort to put all the data into the same database and use the data in a systematic approach.

A watershed approach has become more desirable for both regulatory and practical reasons as related to water quality decision making. Any new monitoring network and information gathering efforts must support a variety of watershed and water modeling tools. Modeling has been shown to provide a valuable tool to illuminate water quality issues and to experiment with different loading scenarios and management techniques.

Two kinds of monitoring operations have been identified as needs for the UNRB, and probably much of the state, - fixed monitoring stations and moveable monitoring stations. Fixed monitoring stations are capable of collecting continuous or partial records of streamflow and water quality data at specific fixed sites for a prolonged period of time. Moveable monitoring stations are instrumentation packages deployed in groups of one to several sites for a short period of time to monitor flow and water quality conditions. At either type of monitoring system, communication to download the data are crucial to the success in storm water monitoring of non-point source events.

Fixed monitoring stations are best used in the UNRB at flow and water quality control points where such sites can serve to determine low-flow conditions or be used as boundary conditions or calibration points for the model applications. The report suggests a network of fixed monitoring stations for the UNRB. Moveable monitoring stations are best used in short river reach situations and on tributary stream locations, perhaps in conjunction with an intensive survey or other special study, such as a rapid bio-assessment program. These moveable stations provide an ideal cost-effective dynamic sampling of storm related events. Groups of moveable station packages can be used on short river reach problems with stations upstream and downstream of a reach exhibiting a problem or needing study. The moveable stations can also be used in conjunction with fixed stations to provide more detail information at specific sites. Several suggestions for implementation of use of moveable stations within the UNRB is given in the report.

The research has shown that the deterministic modeling approach provides a valuable monitoring network evaluation tool for other river basins in Texas. The basis for development and use of the deterministic modeling protocol is to involve as many of the "stakeholders" as possible in the process. The basic protocol is described as follows:

1. Review existing data for each segment.
2. Determine where USGS has continuous flow gages and where steady-state intensive surveys have been performed.
3. Determine the relative scale of non-point to point source discharges using actual flows and pollutant loadings in each basin segment wherever possible. Land use data, local knowledge of problem areas and literature values can provide most valuable information. Define a critical storm event for simulation.
4. Code the existing intensive information into input files for the DAFLOW and BLTM models. In segments where intensive surveys do not exist and there are non-point source impacts, an intensive survey should be planned and executed.
5. Repeat QUALTX model simulations at steady-state with the DAFLOW/BLTM model and check for consistency of results. Superimpose critical non-point source events over the steady-state run.
6. Re-evaluate permit levels and relative impacts based upon model simulation results of the unsteady-state condition.
7. Evaluate the existing flow and water quality monitoring stations. Select boundary condition locations to set off critical locations and choose fixed or moveable monitoring station locations to provide an improved network monitoring plan.

Most water quality criteria focus on protection of biota, and numerical criteria are set for common constituents like dissolved oxygen, temperature, pH most metals, and many organic substances. Bio-monitoring and the performance of bioassessments is probably of more importance than ever, especially since USEPA is now developing biological criteria which will state the level of impacts of pollutants on ecosystems in receiving waters. It is imperative that biomonitoring be integrated into any new monitoring and modeling approach for Texas watersheds.

Abstract

Dynamic and steady-state water quality modeling is an important tool for assessing water quality and the integrity of monitoring networks in a river reach. Monitoring networks should not be designed totally to satisfy the requirements of particular models, neither should they be designed without the ultimate goal of modeling in mind. In the Upper Neches River Basin Study Area of the Angelina and Neches River Basin, an analysis of existing monitoring as well as deterministic modeling on two segments were demonstrated as a methodology in which river quality and monitoring networks could be assessed in light of the needs of the Texas Clean Rivers Program. It was determined that the prior existence of data in the form of intensive surveys and waste load evaluations, particularly on Segment 0611, allowed for the translation of steady-state model input into model input with the potential for unsteady-state impacts to be simulated.

Research Objective

This research was intended to "develop a protocol for assessment of river basin water-quality" that would "satisfy the hydrologic planning needs for the Texas Clean Rivers Act (Senate Bill 818)." Existing time, data, GIS Arc/INFO coverages, and U.S. Geological Survey (USGS) technology, was used to the fullest extent possible to characterize the water quality and integrity of monitoring networks on the Upper Angelina and Neches River Basin (UNRB). The methodology used for characterizing the water quality in the UNRB has been defined and is applicable to other basins in the state where data is available.

An analysis of current monitoring networks on this portion of the basin will be performed. Gaps in the monitoring network will be defined, especially in light of previous monitoring networks that were in existence. Deterministic modeling will be used to assess the river basin water quality where data allows for this type of analysis without additional data collection. The modeling tools developed can be used to simulate alternative management strategies for the water quality managers for this study area. Data availability and formatting may be the limiting factors in this study, which may be the case in other basins as well. Special effort will be made to allow for inclusion of unsteady-state and non-point influences so as to provide a truly versatile and dynamic modeling tool that can be used by any water quality manager in the state. The protocol developed is subject to change depending upon individual basin differences and the availability of data, especially data of a dynamic nature.

A Framework for Water Quality Management - Monitoring and Modeling Needs

Water quality management is the maintenance of necessary levels of water quality to support desired uses of waters. On the surface, this simple definition of water quality management appears to be simple to accomplish, but it is not. "Desired uses", "necessary levels of water quality", and "maintenance" are key parts of the definition that require substantial technical and political-social-economic inputs which are often difficult to attain. Desired uses (e.g., water supply, recreation, sustenance of fish and wildlife, fishing, etc.) are determined through the public hearing process whereby those using the water indicate directly or by default to the water quality regulatory agency what uses are to be made of a body of water, and the regulatory agency evaluates the attainability of those uses and sets those uses deemed feasible. Necessary levels of water quality (water quality criteria) are determined through scientific investigation of what specific levels of water quality (e.g., concentrations of dissolved oxygen, mercury, etc.) are needed or allowed as the case may be for each constituent considered necessary to support the desired use(s). Maintenance of the needed level of water quality is achieved (1) through setting water quality standards (water quality criteria with force of law); (2) through reducing loads of constituents in discharges (e.g., wastewater, tributaries, and runoff) as necessary to sustain the desired level of water quality using various kinds of models as tools to relate constituent load to receiving system water quality and (3) through monitoring the water quality in discharges and in the receiving system to insure that the necessary levels of water quality are sustained in both locations.

Monitoring in the receiving system has the overall objective of determining whether water quality needed to support desired uses is available. What water quality constituents to sample, where to sample, and when to sample then become the key questions to be addressed. What to sample is determined by what constituents are deemed necessary to be monitored to insure necessary levels of water quality, and these constituents generally include temperature, dissolved oxygen, pH, and conductivity, for example, because these measure properties of water or levels of necessary constituents for aerobic life. Beyond this short list, the constituents monitored are oriented towards particular water quality problems to be addressed in a given body of water; for example, BOD may be measured in waters with low dissolved oxygen problems, metals and pesticides in waters with fish kills, and so forth. Obviously, as the constituent list grows, so do the sampling requirements and costs.

Where to sample is normally driven by a variety of things such as: the desire to measure water quality in undisturbed areas; the desire to measure impacts of particular wastewater discharges on receiving waters; or the desire to examine large scale patterns of water quality in a streams drainage basin or a subbasin. Where to sample is probably dictated as much by access to a body of water, particularly shallow bodies of water. When to sample is again driven by the objectives of sampling. For regulatory purposes, sampling is often performed at critical conditions, i.e., when water quality will be at its worst so that impacts of wastewater inputs can be most easily discerned and the most severe impact on uses of the water can be assessed. Historically, this has been during low flow periods (usually defined as the 7Q2, or seven day average flow that occurs with a frequency of once each two years) when wastewater discharge impacts would be most easily seen. Below this flow, some water quality standards no longer apply. With the advent of stormwater runoff permitting in urban areas, a different critical flow will need to be set but on the high flow end of the recurrence frequency curve. Likely this upper flow will be at a level that disruption of the channel's physical and biological nature will begin to occur; its chemical nature will have already been altered at much lower flows. At flows above this critical flow, some water quality standards may also be suspended.

To answer questions about where and when to sample a stream system (assuming the objectives of sampling have been agreed upon), one must determine where critical changes in water quality will occur because of constituent loadings, what loadings will be generated of what constituents, and what will the temporal loading pattern be (e.g., constant load, seasonal, pulse input like runoff, and so forth). To some extent these questions may be addressed through sampling of the system, but, because of the time and expense required to sample, some other way is needed to estimate loads and impacts of those loads on the receiving system. That way is through mathematical modeling. Models now exist that may be used to generate point source and non-point source flows and loads as well as to estimate the changes in flows and water quality in the receiving stream due to those flows and loads. Many of these models are supported and distributed by the U.S. Environmental Protection Agency through its Center for Exposure Assessment Modeling in Athens, GA, or they are available from other federal agencies like the U.S. Geological Survey, the U.S. Army Corps of Engineers, and the National Oceanographic and Atmospheric Administration or from engineering firms that have developed software for water quality applications. These models can be classified principally as watershed models for generating loads or as receiving water models for simulating the impacts of various loads on water quality.

For urban areas, the EPA's SWMM model may be used to estimate time variant contaminant loads while in rural areas the EPA's HSPF will do the same. NOAA's methodology for generating point source loads using monitoring data and typical pollutant concentrations where such data are not available may be applied to constant municipal and industrial loads (Pacheco,P.,et.al, Draft, 1990). In the receiving system, steady state models like EPA's QUAL2E (and, in modified form, the version used by the TNRCC, QUALTX) and unsteady-state models like the USGS model DAFLOW and its associated water quality component BLTM (using QUAL2E kinetics) are available to estimate water quality changes due to constituent loadings in streams and rivers. The EPA's model WASP4 (with specialized versions for eutrophication - EUTRO4 - and toxic materials - TOXI4) may also be used for unsteady-state applications in one-, two-, or three dimensional systems like rivers, lakes, and estuaries.

By using a watershed model, such as SWMM and/or HSPF, to generate runoff flows and loads for any given rainfall event over any part of the watershed and by inputting those flows and loads subsequently into the water quality model so that stream flows and water quality impacts are calculated, it is possible to ascertain the patterns of flow and water quality impact expected to occur in any part of the drainage basin. These patterns of effects then provide the information needed for selecting flow and water quality monitoring locations as well as the temporal nature of the monitoring for whatever monitoring objectives are used. Calibration of the models may be done with existing data if robust enough or through a modest amount of sampling in those areas of the drainage basin deemed critical to the user.

In the long term, what is needed is a more intimate linkage among these loading and receiving water quality models in a geographic context so that it will be possible to represent a single drainage area with the linked models, to generate loadings due to population and/or land use changes, to discern the water quality impacts of those loadings at any point, and to visualize those impacts moments after such changes have been input to the model. Such a system is potentially available using the linked models in association with a Geographic Information System Arc/INFO model. Because GIS is designed to represent geographic features (e.g., stream, lake, and estuarine features as well as topography, land use, soil types, and others that influence runoff flow and quality), it is ideally suited to be the database for such information as well as the means of visualization on a computer screen. By running SWMM and/or HSPF to generate runoff flows and loads for any given rainfall event over any part of the watershed as selected with GIS, and having those flows and loads automatically input into the water quality model so that stream flows and water quality impacts are calculated, it would be possible to ascertain those same patterns of impact mentioned above. It would even be possible to see those patterns represented on the computer monitor and only a few moments after the simulated rainfall event has started.

Use of the various models mentioned here will require a great deal of information about the stream and river system being modeled and the urban and rural areas that drain to it. More and more, this information is being compiled in GIS systems by various federal, state, and local agencies (including river authorities in Texas), and, with the availability of these databases through Internet and other networks, the task of compiling the information is becoming simpler, less time consuming, and less costly. Further, the information is already used by decision makers at various levels in hard copy or electronic form, or its availability would certainly facilitate the work being done by them. Once the information is compiled, updates are required, but again much of those are being made by the originating agency, and for the local user it is a matter of downloading the updated database and incorporating it into the GIS model structure once again.

Ultimately, linking monitoring and modeling results back to the maintenance of the desired uses should be the goal. Numerical criteria and standards are set so that there is an identifiable endpoint in setting permit levels. Unfortunately, sometimes these numbers take on a life of their own, when in fact they should be continually measured against the losses and gains in aquatic ecosystems and attainment of desired uses.

Most water-quality criteria currently available focus on protection of biota, and numerical criteria are set for common constituents like dissolved oxygen and temperature, as well as many of the priority pollutants, notably metals and pesticides and other complex organics. Biomonitoring and the performance of bioassessments is receiving increasing popularity in the United States. In fact, the U.S. EPA is now developing biological criteria which will state the level of impacts of pollutants on ecosystems in receiving waters, so that, where numerical criteria can not protect biota, the biological criteria will do so. Therefore, it is important in developing a new monitoring and modeling approach for Texas watersheds that biomonitoring be integrated in the approach that is recommended.

Introduction to This Study

Non-point pollution is both a temporal and spatial phenomena, that revolves principally around the occurrence of rainfall. As point source impacts have largely come under control and regulation around the nation, the relative impacts from non-point sources have escalated. This has caused a recent surge in the amount of federal, state, and local regulation with regard to such sources. This has had important policy and scientific impacts for the state of Texas.

Section 303(d) of the Clean Water Act (CWA) requires states to develop Total Maximum Daily Load (TMDL) Allocations for every water quality-limited segment (U.S. EPA, 1992). A segment is a defined stretch of surface water (lake, river, or tributary) which must meet certain water quality standards (WQS). To fulfill the requirements of 303(d), and the performance of TMDL's, Texas water quality-limited segments are evaluated (monitored and modeled) solely in terms of the point source loading they receive. There is a well-established monitoring program and associated modeling effort that is used to establish permit levels based upon steady-state low-flow conditions in each specific segment.

While this approach has been acceptable in the past, the U.S. Environmental Protection Agency (U.S. EPA) is beginning to emphasize the importance of regarding water quality problems 1) on a watershed basis, and 2) with respect to non-point source impacts. Tradeoffs between permit levels for point sources and the implementation of non-point source controls are to be considered. This is quite a change from the historical National Pollution Discharge Elimination System (NPDES) command-and-control methods of simply targeting point sources and either performing waste load allocations or directing industries to apply the best available technology. This shift requires a major rethinking of the current monitoring and modeling that Texas performs for NPDES purposes.

Several case studies and workshops have been used to demonstrate the techniques involved in performing a TMDL (Limno-Tech, 1993). The watershed approach involves a screening procedure as well as a more detailed modeling study for each affected segment. There are a number of more widely used flow and transport models that are described in a Compendium of Watershed-Scale Models for TMDL Development (U.S. EPA, 1992). However, there appears to be ample room for creativity in terms of the monitoring and modeling tools a state chooses to employ.

Thus far, neither the state environmental regulatory agency, called the Texas Natural Resources Conservation Commission (TNRCC), nor the U.S. EPA, has performed a TMDL with this new watershed/non-point sources approach for Texas water quality-limited segments. U.S. EPA has been sued by environmental groups in other states for inaction (Limno-Tech, 1993).

In response to this evolution in thinking about water pollution problems, and to fill information gaps in the types of water quality data that has previously been collected in Texas, the Texas Legislature passed Senate Bill 818 in May of 1991. One of the major objectives of Senate Bill 818 is to qualify and quantify the problem of non-point pollution relative to the impacts from point source pollution. The act has been renamed the Texas Clean Rivers Act. Under this act, TNRCC is required to make biannual reports on the water quality in Texas on a watershed basis. This responsibility was then passed on to the respective river authorities throughout Texas, with TNRCC responsible for assessing the water quality in those river basins without river authorities.

The Angelina and Neches River Authority (ANRA) and other river authorities around the state are required to make biannual reports to the Texas Natural Resources Conservation Commission (TNRCC) on the quality of water in their river basin. The reports are intended to provide strategic guidance for developing plans of action for maintaining and improving water quality in their respective basins. One of the major objectives of the Texas Clean Rivers Act is to quantify and qualify the problem of non-point pollution, especially toxicity, relative to the impacts from point source pollution. There have been a series of recommendations that have been forthcoming from the TNRCC on how these basin-wide evaluations should be performed.

In 1993, the TNRCC and the River Authorities formed the Task Force for Data Analysis and Sampling Design under the Texas Clean Rivers Program (Alicia Reinmund, Written Communication, 1993). In September, 1993, the Task Force released written guidance for data analysis (TNRCC, FY94-95 Program Guidance) to be performed by the River Authorities for the 1994 biennial assessment reports mandated by the Texas Clean Rivers Act. Principal tasks of the analysis are the compilation of water-quality data from local, state, and federal sources, screening of data by comparison to water quality standards to identify water-quality concerns, evaluation of relations between water quality, flow and time (trends), and evaluation of water-quality concerns in relation to natural and human factors. No water-quality modeling is proposed in the guidance.

The state currently uses a steady-state model, QUALTX, a modified version of U.S. EPA model QUAL2, to set permit levels for continuous dischargers around the state. During a time period in which TNRCC considers to be low-flow, a crew of TNRCC staff goes out to a particular river reach to characterize the channel geometry, and to take various water quality grab samples. These are called intensive surveys. The data gathered on an intensive survey enables the QUALTX model to be set up and run for various potential permit levels. Based on the results, TNRCC makes recommendations on how or if existing permit levels should be changed. These modeling analyses are called Waste Load Evaluations.

Apparently there has been some consideration of switching from the use of QUALTX to an unsteady-state model (Marshall, 1993). This action has been delayed due to other TNRCC concerns, including numerous agency reorganizations. However, this transition is receiving additional recent attention due to the fact that the U.S. EPA is now stressing a watershed approach to permitting which includes non-point source load allocation.

Currently, neither non-point sources nor groundwater impacts are considered when industrial, commercial, and municipal discharge limits are set through the use of this model. Changes made to calibrate the model, which sometime include the addition or subtraction of flows to maintain the flow balance, are sometimes attributed to non-point sources. But these gains and losses have not been verified with a bonafide gain and loss study. In addition, not all the river segments across the state have been surveyed. In some river segments, the TNRCC has based stream standards and permit limits on various grab samples and conventional permit limits. While over $600,000 was granted to the various river authorities during 1993-1994 to perform non-point pilot projects under the Texas Clean Rivers Act, the results of these projects have not yet been incorporated into dynamic deterministic modeling efforts.

A deterministic modeling approach is needed that will allow for unsteady-state processes to be simulated. Non-point sources of pollutants must be positively identified, particularly in water quality limited segments where the U.S. EPA is requiring evaluation by TMDL analyses. One of the most advantageous aspects of deterministic modeling is the ability to test different potential scenarios once a model is calibrated and verified. A modeling approach is needed for the purposes of state future permitting needs (TMDL modeling), the river authorities under Senate Bill 818 (SB818), and for all water quality managers. Although this type of modeling is more sophisticated, the technology is available to meet the task.

Background Information on the Basin

To meet the Texas Clean Rivers Program objectives, the Angelina-Neches River Basin has been divided into three defined study areas as a temporary agreement with the TNRCC. These include the Upper Neches River Basin Study Area (UNRB), the Lake Palestine Study Area, and the Lower Neches River Basin Study Area. The Angelina and Neches River Authority is responsible for the assessment of the UNRB and the Lake Palestine Study Areas. Please refer to Figure 1.

The Upper Neches River Basin originates in southeast Van Zandt County and extends southeasterly through the piney woods of East Texas to the confluence of the Neches and Angelina Rivers above B.A. Steinhagen Reservoir. UNRB contains the headwaters of both the Neches and the Angelina with a total drainage area of approximately 7,451 square miles.

The UNRB receives an average annual rainfall that varies significantly from north to south; ranging from 36 inches in the northwestern portion of the basin to approximately 50 inches in the southeastern portion. Agricultural activities have historically dominated the region, but some industries that are prevalent in the area include oil and gas, silviculture in the south, and some light and heavy industries such as steel manufacturing and paper processing. Agricultural and industrial runoff and discharges have a lot to do with the water quality scenario, especially in terms of non-point source impacts.

GIS Activities for the Texas Clean Rivers Program

While touted as the tool of choice for the Texas Clean Rivers Act, there is no readily available set of GIS coverages for each basin. Compiling a set of coverages requires that either the coverages are already digitized at the scale desired, or that the system designer plans and creates a set that will serve his or her particular purposes of modeling or problem solving.

Coverages from sources all over the state of Texas (including those available from TNRCC and TNRIS) as well as those generated for the purposes of national studies were compiled into one Arc/Info database. Only coverages containing information on the Upper Neches River Basin were compiled. GIS Arc/Info was used with these coverages to generate the figures in this report. Other river basins could follow the same data gathering procedure. A listing of all the coverages that were gathered for this study can be found in Table 1.

These coverages served primarily a cartographic function for this research. However, some of the coverages were also used to determine drainage areas for the hypothetical storm event. As GIS capabilities expand, and interfaces between GIS and deterministic models are developed, the speed at which data can be structured as input as well as processed for display will

Figure 1: ANGELINA & NECHES RIVER BASIN STUDY AREAS

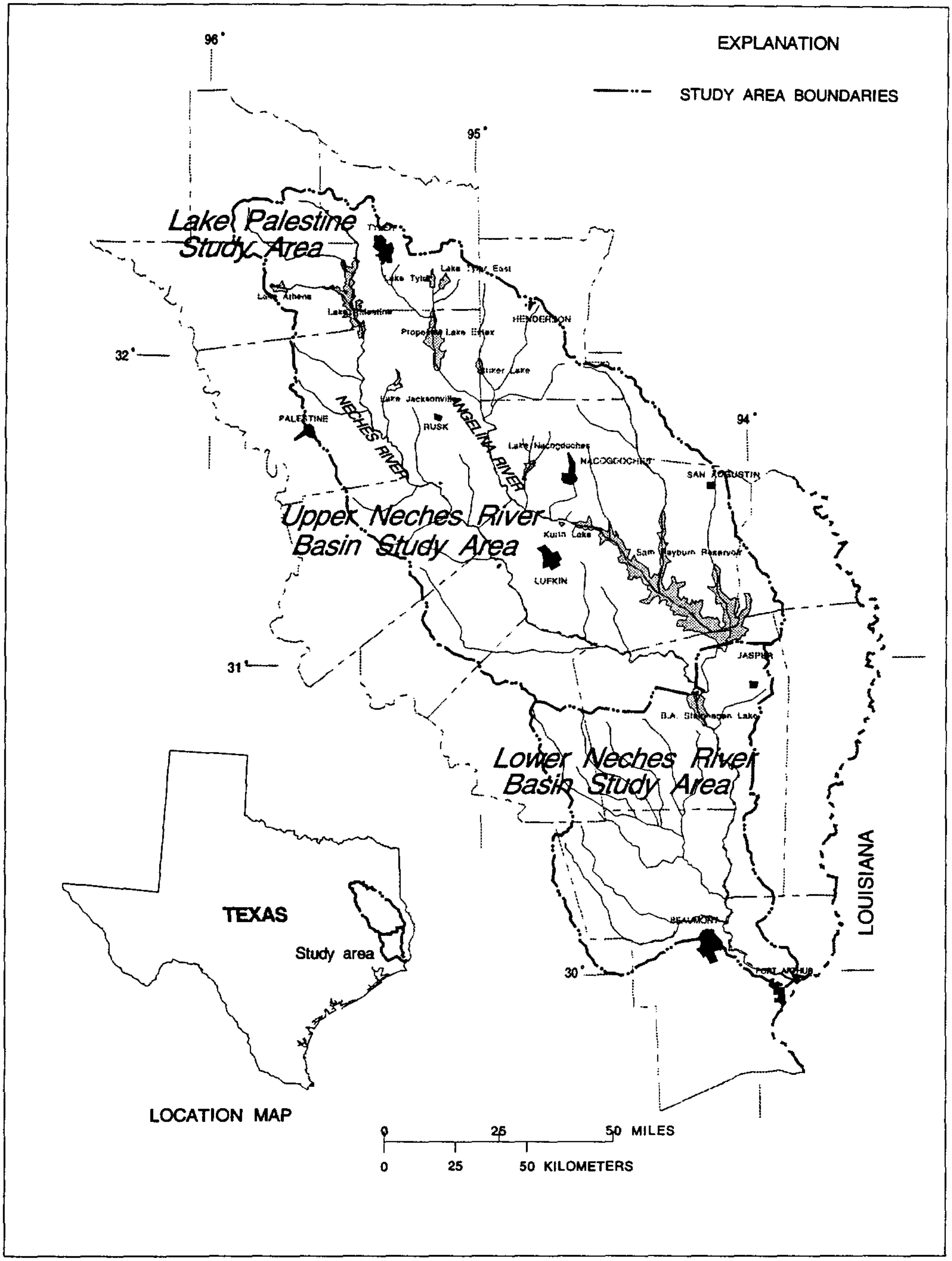


TABLE 1

Compiled Albers Coverages for GIS Arc/INFO work
in the Angelina and Neches River Basin

Coverage	Scale	Source	Explanation
major streams	1:2,000,000	USGS	National Water Summary Work
major lakes	1:2,000,000	USGS	National Water Summary Work
major roads	1:2,000,000	USGS	National Water Summary Work
counties	1:2,000,000	USGS	National Water Summary Work
gage locations	1:2,000,000	TNRCC, USGS	Lat/Longs from USGS, TNRCC Point Coverage Generated at USGS
cities	1:2,000,000	USGS	Digitized or Drawn in ArcEdit at USGS
vegetation	1:2,000,000	TNRIS	from Roger Jaster, TWDB
TIGER	1:2,000,000	TNRIS	from Roger Jaster, TWDB
minor aquifer boundaries	1:500,000	USGS	Hydrologic Unit Map of Texas - 1974
minor streams	1:100,000	TNRCC	Inludes tributaries not on major streams coverage
minor lakes	1:100,000	TNRCC	Inludes lakes not on major lake coverage
railroads	1:2,000,000	USGS	National Water Summary Work
annual average runoff	1:2,000,000	USGS	National Water Summary Work, 1951-1980 Data
annual average precipitation	1:2,000,000	USGS	National Water Summary Work, 1951-1980 Data
surficial geology	1:2,000,000	USGS	Map - King and Beikman 1974
Watershed Boundary	1:2,000,000	USGS	National Water Summary Work
Hydrologic Units	1:250,000	USGS	National Water Summary Work
Henderson Basin	1:250,000	USGS	Digitized at USGS

increase tremendously. These types of interfaces have been developed for some groundwater models (i.e. GMS for MODFLOW) and a limited number of surface water models. It is recommended that such interfaces, especially for the generation and input of unsteady-state processes into models, be strongly supported.

Description of Data Collection in the UNRB

In order to develop a new monitoring network for the UNRB and to determine if data existed for a model application, the existing monitoring in the UNRB and current methods of data analysis were evaluated. Monitoring of flow and water quality is performed by the two major actors described below.

Texas Natural Resources and Conservation Commission (TNRCC) Monitoring Program

TNRCC intensive survey and compliance monitoring is based upon a segment by segment approach. Therefore data is often aggregated on a segment basis. Based upon summary data sheets describing monitoring and water quality by segment that were aggregated in the 1992

Regional Assessment by the ANRA (ANRA, 1993), it was determined that the UNRB area includes eight designated TNRCC Stream Segments: 0604, 0606, 0610, 0611, 0612, 0613, and 0614, and a portion of 0605 outside of the immediate area around Lake Palestine.

TNRCC Surface Water Monitoring (SWM) Program collects water quality data from about 700 sites stationwide each year (Texas Water Commission, 1992). Most of the sites are located on classified segments. The SWM sites are sampled at varying frequencies, with most sites sampled only once a year. The data is stored in STORET, the national computerized water quality data base.

For the eight complete designated stream segments in the UNRB, the TNRCC has SWM and reservoir water quality sites that are to be monitored in the coming year. There is no listing of which sites have been monitored regularly or how often these sites will be monitored in the coming year (Landry, 1994). Raw data reports are available but are cumbersome to analyze for this kind of summary information. Please refer to Figure 2 for the location of the current year monitoring sites to be sampled.

The compiled segment data in the 1992 Regional Assessment report (ANRA, 1993) indicate that, of the water quality segments in the UNRB, six are water quality limited, and two are effluent limited. A segment is classified as water quality limited in Texas if:

1) Stream monitoring data have shown significant violations of the water quality standard established by the Texas Surface Water Quality Standards (July, 1991),

or

2) Advanced waste water treatment for point source waste water discharges is required to meet water quality standards or to protect existing conditions of exceptional water quality,

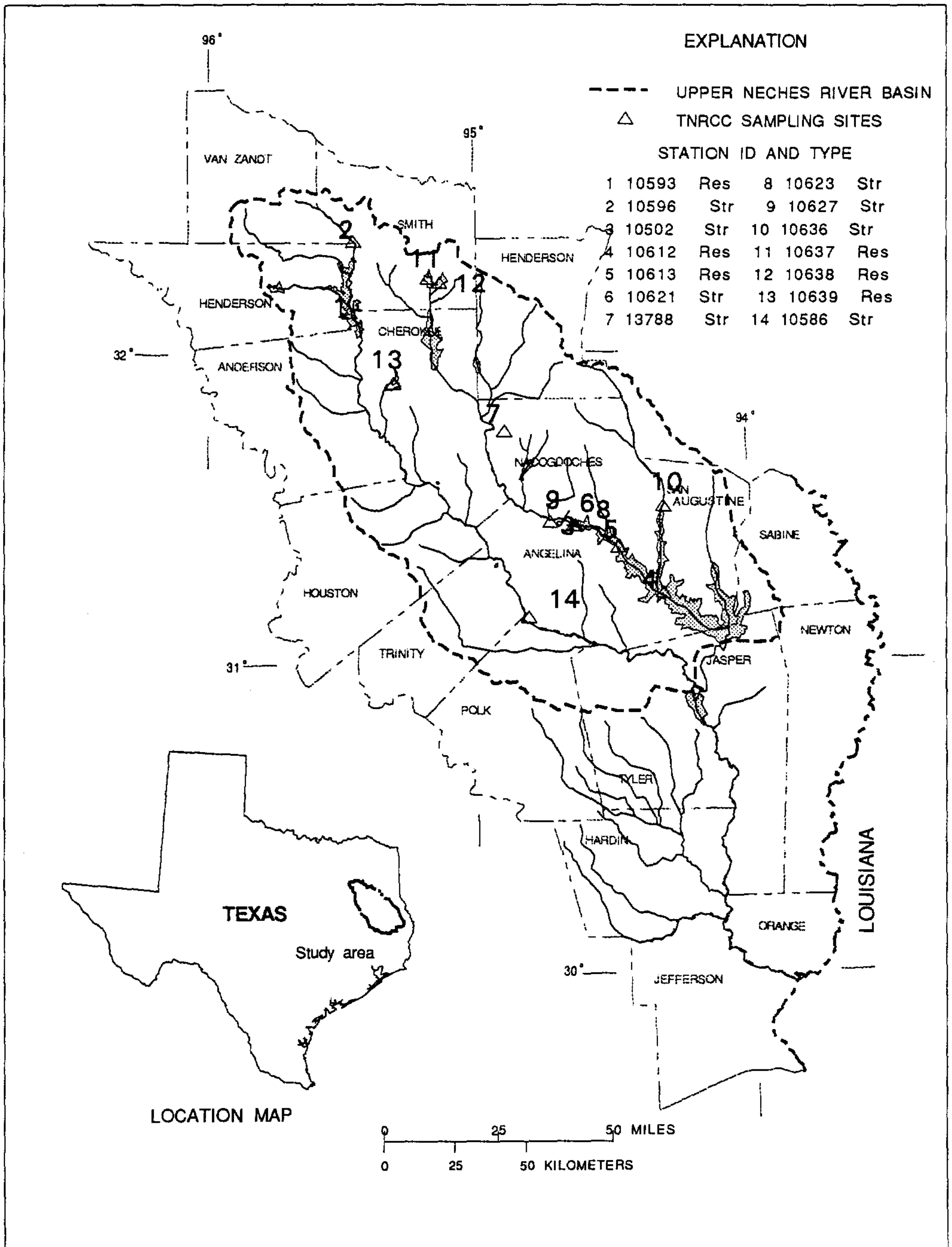
or

3) The segment is a domestic water supply reservoir.

Each of the water quality limited segments is a candidate for intensive survey monitoring by TNRCC. Of the water quality limited segments, only three have been intensively monitored (0606, 0610, 0611). These intensive surveys did not include non-point source evaluations. One segment, 0604, is defined as effluent limited, but may also fit the description of a water quality-limited segment. The water quality standards for dissolved oxygen for this segment are under re-evaluation by TNRCC. No intensive survey or modeling effort has been performed for the entire segment, but intensive surveys and modeling are in process on tributaries that run through the City of Lufkin.

Of additional note is the present discussion between Champion Paper International and TNRCC. Champion Paper International discharges into Paper Mill Creek and has performed a number of internal monitoring and modeling efforts of the tributary. Paper Mill Creek, considered to be part of Segment 0610, a tributary of the Sam Rayburn reservoir, has been under intense scrutiny. A recent intensive survey and modeling effort of only this tributary has been performed by TNRCC for Segment 0604 (Marshall, 1994) and permitted discharges of biochemical oxygen

Figure 2: UNRB, TNRCC ACTIVE AMBIENT RESERVOIR & STREAM SITES, 1994



demand (BOD) may be reduced significantly. With the exception of that tributary, the reservoir segments in UNRB (0605, 0610, 0613, 0614) that are water quality-limited have not been modeled.

TNRCC has the responsibility to coordinate all other monitoring activities in the state (USGS, private industries, river authorities, citizen monitoring). Work on a collective database is progressing, but has yet to be completed. River Authority Monitoring Site Locations (where data is collected by the Upper Neches and the Angelina and Neches River Authorities) are listed.

U.S. Geological Survey Monitoring Program

The U.S. Geological Survey (USGS) has maintained continuous and partial flow monitoring sites within the UNRB at various levels over the past nine decades. Please refer to Table 2. Not included in Table 2 are the USGS reservoir storage gages in UNRB, of which there

TABLE 2
Periods of Record for U.S.G.S. Active and Discontinued Streamflow Gaging Stations
Upper Neches River Basin (in downstream order)
from WSP-1312, Header Files, CD-ROM

Gage Number	Name	Period of Record (Cal. Yr.)	Current Status	Drainage Area (sq.mi.)	Latitude	Longitude
08031200	Kickapoo Creek	1962-1989	Discontinued	232	32:18:34	95:36:19
08031500	Neches River near Reese	1924-1927	Discontinued	851	32:01:30	95:25:40
08032000	Neches River near Neches	1939-	Active Daily	1145	31:53:32	95:25:50
08032500	Neches River near Alto	1944-1978	Discontinued	1945	31:34:45	95:09:55
08033000	Neches River near Diboll	1923-1925 1939-	Partial	2724	31:07:58	94:48:35
08033300	Piney Creek near Groveton	1962-1989	Discontinued	79	31:08:25	95:05:11
08033500	Neches River near Rockland	1903-	Active Daily	3936	31:01:29	94:23:55
08033700	Striker Creek near Summerfield	1941-1949	Discontinued	146	32:00:10	94:59:35
08033900	East Fork Angelina nr Cushing	1964-1989	Discontinued	158	31:51:36	94:49:23
08034500	Mud Creek near Jacksonville	1939-1979	Discontinued	376	31:58:35	95:09:38
08035000	Mud Creek at Ponta	1924-1927	Discontinued	481	31:53:21	95:05:19
08036500	Angelina River near Alto	1941-	Active Daily	1276	31:40:10	94:57:24
08037000	Angelina River near Lufkin	1924-1979	Discontinued	1600	31:27:26	94:43:34
08037050	Bayou Lanana at Nacogdoches	1965-1986 1988-1993	Discontinued	31	31:36:58	94:38:28
08037500	Arenoso Creek nr San Augustine	1938-1940	Discontinued	76	31:35:48	94:16:06
08038000	Attoyac Bayou near Chireno	1924-1985 1985-	Partial	503	31:30:15	94:18:15
08038500	Angelina River near Zavalla	1952-1965	Discontinued	2892	31:12:41	94:17:40
08039000	Ayish Bayou at San Augustine	1924-1925	Discontinued	17.2	31:31:50	94:06:55
08039100	Ayish Bayou near San Augustine	1959-	Partial	89	31:23:46	94:09:03
08039500	Angelina River at Horger	1928-1973	Discontinued	3486	31:02:08	94:07:48

Verified by Houston Sub-District Office (Jim Fisher - 3/4/94) are currently three in operation: at Lake Palestine, Lake Nacogdoches, and Sam Rayburn Reservoir (see Figure 3A). There has also been sporadic water quality sampling by the USGS at these flow and reservoir gage locations and at additional locations. This monitoring was generally in support of various projects that ranged in scale from national to regional level. Ownership of the gaging locations is varied and the gages are not currently operated as a network.

The current level of USGS streamflow monitoring in UNRB has decreased to only six gages, a mixture of three partial and three continuous streamflow gages. The current USGS streamflow gages in the UNRB, some of which also collect limited water-quality information, are represented on Figure 3B.

Of the six gages on Figure 3B, all except for Station 08033500 (Neches River near Rockland) are funded by the Fort Worth District Corps of Engineers for the purposes of water management, flood control, and flood forecasting. Station 08033500 is funded cooperatively by the Lower Neches Valley Authority and the USGS for purposes of flood control, water supply planning, and general water resources appraisals.

Data from both the TNRCC and the USGS monitoring programs was compiled. As of now, both sets of data have not been fully integrated, but each agency performs statistics on a station by station basis. A sample of TNRCC data with statistics can be found in Appendix A. All USGS daily discharge measurements ever taken in the UNRB were compiled and provided to the ANRA by the USGS. This data came from the USGS ADAPS database in 2-3 card format. Also from the USGS, all water quality taken at any gage at any location in the UNRB was summarized in tables. A sample of this data is represented in Appendix B. These tables include all water quality data with the exception of water quality measurements that began and ended before 1963. The water quality data that was summarized came from the USGS QWDATA database. The descriptive statistics performed at each gaging station include the number of samples taken, the maximum, minimum, and mean of the measurements of each water quality constituent. Also included in the descriptive statistics are the 5, 25 50, 75, and 95 percentiles of those measurements. A percentile value represents that value which a certain percentage of the data is equal to or less than.

Deterministic Modeling and Data Availability in the UNRB

The data that was available for an analysis of the monitoring network in the basin was limited, and obviously, the level of monitoring appears to be decreasing rather than increasing. The kinds of statistical analyses that are recommended in the FY94-95 Program Guidance (TNRCC, 1993) could not be performed in this basin due to a lack of a sufficient number of overlapping years of data and consistency in the types of parameters monitored. Trends in water quality can not be established without these kinds of data. The decrease in the level of USGS continuous streamflow monitoring is a concern because such gages are used to determine the 7Q2 low-flow conditions.

Figure 3A: UNRB, USGS ACTIVE RESERVOIR GAGES, 1994

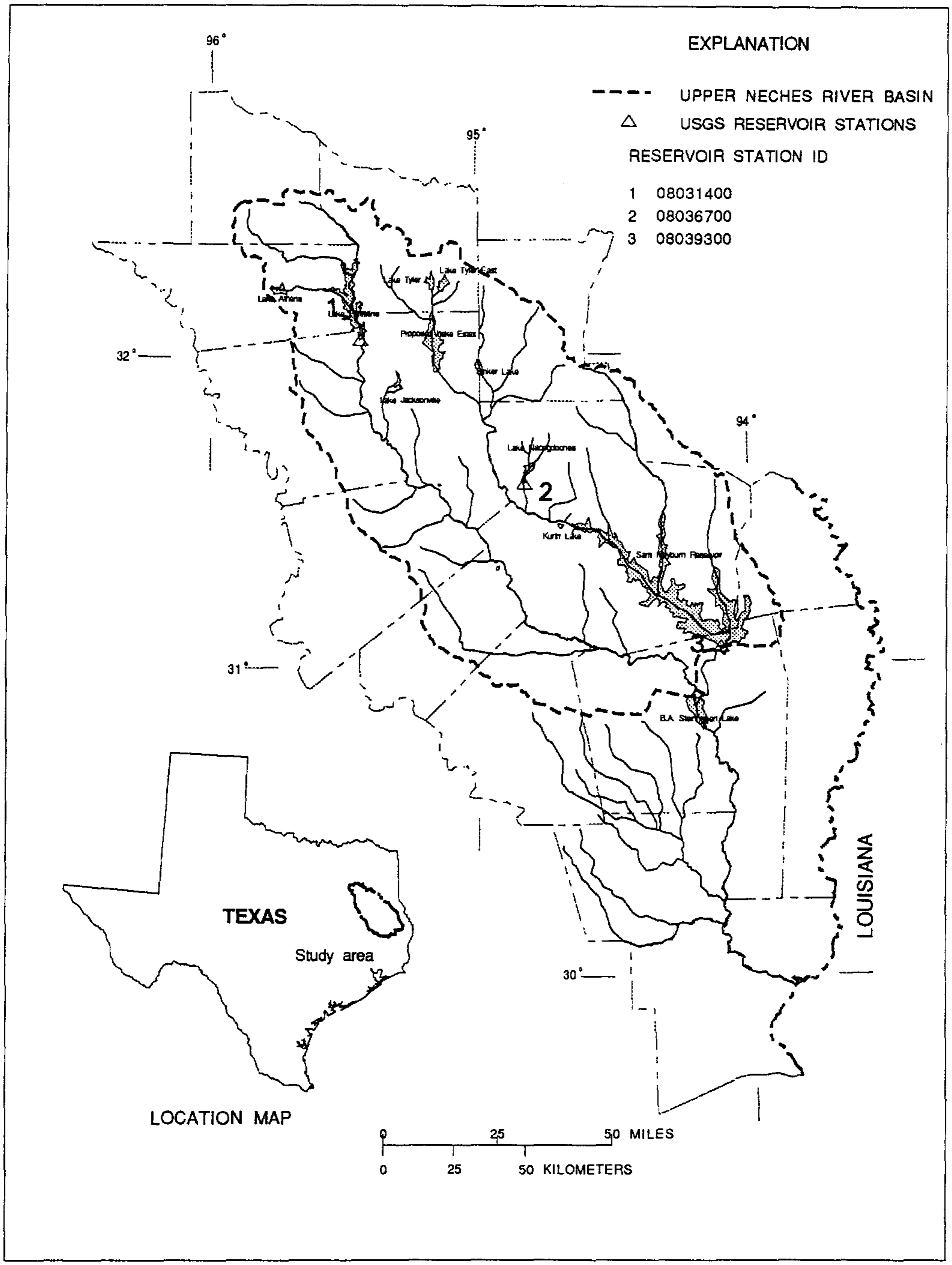
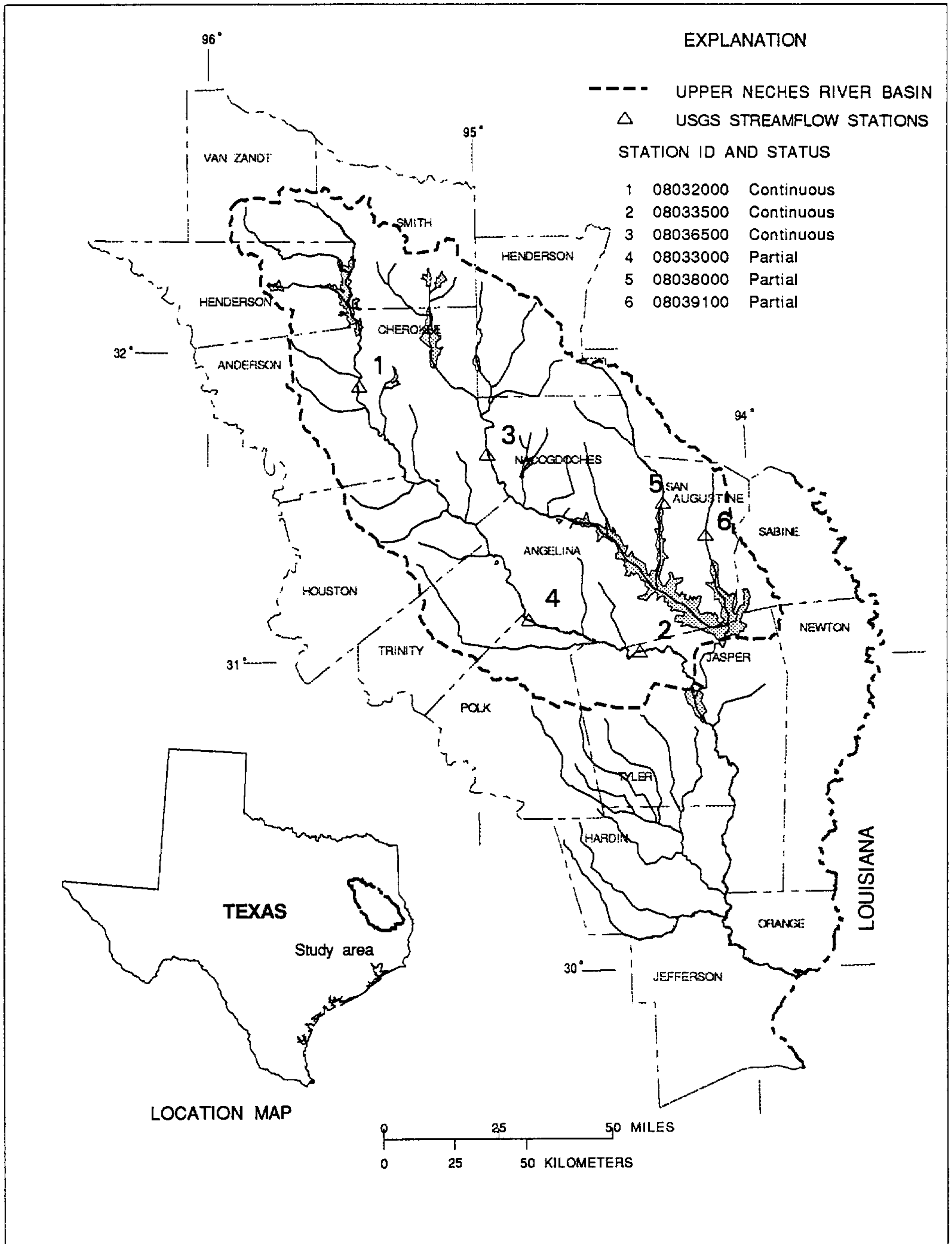


Figure 3: UNRB, USGS ACTIVE STREAMFLOW GAGES, 1994



Without more overlapping data and significant work on the consolidation of the monitoring data into a more functional database, the only type of analysis that could be performed (with the exception of the statistical summary on a gage by gage basis) was the application of a deterministic model. However, data availability is also a controlling factor in the use of a model for water quality assessment of the river segments and a network analysis. The full use of the chosen deterministic hydraulic model, the diffusion analogy flow model (DAFLOW), in combination with a water quality transport model, the Branched Lagrangian Transport Model (BLTM) requires significant data collection or availability. An intensive study must have been performed to determine channel geometry, water quality, and flow data (similar to the TNRCC Intensive Surveys at steady-state conditions). This intensive survey must have occurred at the desired flow levels that would like to be modeled. Some simple flow routing with the use of the deterministic model is also possible where there exists or has existed at least two USGS stream monitoring gages for continuous flow, one of which can be an upstream tributary. This flow routing is limited to the time step of the data and the location of the gages.

Based on these criteria, there were two portions of the Angelina and Neches Rivers in the UNRB study area that were able to be modeled without additional data collection; they were Segments 0604 and 0611. These two segments covered a significant percentage of the river miles in the UNRB. This research will show the utility of the DAFLOW model for flow routing on Segment 0604 and the utility of DAFLOW and BLTM with QUAL2 kinetics for modeling flow and water quality on Segment 0611. Additional kinetics will be incorporated into the transport model for water quality constituents of concern in the UNRB. Based upon the results of this compilation of data and modeling effort, new monitoring programs for the UNRB will be suggested.

Theory of Dynamic Deterministic Modeling Tools

As discussed in the Framework, there are many modeling tools which are available for use. The choice between the models depends largely upon the desired information. For regulatory purposes, due to the large number of possible combinations of physical conditions, the most "critical" condition is simulated and permit levels are based upon those conditions.

In addition to this assumptions regarding the critical period on which to base monitoring and modeling, are the assumptions necessary to solve the governing physical processes of water quality flow and transport, which are represented by differential equations. These equations include the continuity, conservation of momentum, and conservation of mass equations. These equations can be solved in separate models for flow (conservation of momentum) and transport (conservation of mass), or both can be solved simultaneously.

Texas river systems are most often described and modeled as one-dimensional, variable cross-section area water bodies. Such a river system can be segmented into hydraulically homogenuous units based upon the results of an intensive survey. Once this is done, assumptions regarding the local derivatives of flow and water-quality concentration at steady-state greatly simplify the differential equations and allow for a numerical solution to be derived. For more information the reader is referred to the QUAL2E manual (EPA, 1987).

For the conservation of mass equation, which is used to describe the mass transport process and described in more detail later, an analytical solution can not be derived. Numerical solutions must be used. Most models employ a finite-differencing approach that solves a Taylor Series Expansion for the derivative by utilizing the Euler Method. Finite-differencing approximations used in this approach introduce a numerical dispersion error to the solution that is well-documented (Smith, 1965).

The Eulerian reference frame was adopted as standard long before the advent of the digital computer, "probably because of the bookkeeping problems associated with solutions in the more natural Lagrangian reference frame" (Joson, 1980). In a Lagrangian reference frame, the computational nodes move with the flow. This is quite different from the more commonly utilized Eulerian reference frame, in which the conservation of mass principle is applied to a differential control volume that is fixed in space and the convection term complicates the governing differential equation (Jobson, 198).

The Lagrangian form of the conservation of mass equation can be solved numerically more accurately and easily than the Eulerian form; in fact, if the longitudinal dispersion term is zero, the numerical solution is completely accurate. If the longitudinal dispersion is not zero, the numerical dispersion is still much less than that generated by the Euler Method (Jobson, 1980). Although the Eulerian form allows for a unique matrix-like solution at steady-state, interpolation errors are propagated throughout the duration of the model run. For more information on differences between these numerical solutions, the reader is referred to referenced sources.

QUALTX uses the Eulerian framework to solve the continuity and conservation of momentum and mass equations simultaneously. Numerical dispersion has been reduced in QUALTX because dynamic events are not modeled and the dynamic capability has been removed (QUALTX is a steady-state version of the U.S. EPA model QUAL2E); however, if dynamic events were to be modeled, this reference frame has the tendency to produce large numerical dispersion errors.

The reference framework is just one of the many variables that differ between models. When choosing a dynamic water-quality model, decisions regarding the appropriate time step of the model depend largely upon the wording of the regulatory requirements or management decision to be made. If pollutant **loads** are required to be reduced by certain percentages over a larger span of time and area, it may be appropriate to use a daily, or even annual, time step. If achieving and maintaining certain pollutant **concentrations** is the goal, flow dependency and kinetics may require more conservative (smaller) time steps.

Most existing riverine and watershed models, including QUAL2E, WASP, HSPF, and DAFLOW/BLTM allow for variable time steps sizes. However, it must be noted that the appropriate size of the time step is intimately connected with 1) the stability criteria if a finite-differencing approach is utilized and 2) the length of the hydraulically-homogenuous segmentation of the river reach. In addition, it should be noted that, in modeling a particular time period, the computer storage requirements tend to increase as the time step decreases. As stated in the Water

Quality Analysis Simulation Program (WASP) manual, the "choice of proper spatial and temporal grid sizes is still somewhat of an art" (DiToro, et. al., 1982).

For this investigation, the USGS deterministic flow model known as the diffusion analogy flow model (DAFLOW) was selected (Jobson, 1989). The DAFLOW model is accompanied by a companion transport model known as the Branched Lagrangian Transport Model (BLTM). DAFLOW can operate alone for simple flow routing or can be used in conjunction with BLTM to simulate flow and water quality for steady-state or unsteady-state scenarios. It will be demonstrated that these models can be used to repeat steady-state results of QUALTX and to move beyond QUALTX by modeling a storm event.

There are several unique features of the modeling tools used in this research and several interesting possibilities in terms of expansion of these models for use throughout Texas. The structure of the input files and companion programs that help the user to build these input files are very intuitive. In addition, the transport model uses a Lagrangian reference frame and allows for the relatively easy addition of kinetics equations for toxic constituents or other troublesome water quality parameters.

The Branched Lagrangian Transport Model (BLTM) receives hydraulic information directly from DAFLOW output. The model can also receive hydraulic input from other flow models. The BLTM solves the convective-dispersion equation by using a Lagrangian reference frame in which the computational nodes move with the flow. Additional advantages of using BLTM as opposed to QUALTX or another transport model are 1) the model is stable at any time step, 2) the computer code for the algorithm is short and relatively easy to modify, 3) the transport processes are intuitive from the conceptual model, 4) the model is economical to run, 5) model output includes helpful process information not usually available from an Eulerian model.

The BLTM model used in this research and documented by Jobson (1987) is applicable only to one-dimensional, unsteady or steady, non-uniform flow. The model, as it is was received by the USGS Austin office prior to this research, allowed for the transport of up to ten interacting constituents. These included temperature, algae, nitrite, nitrate, ammonia, orthophosphate, carbonaceous biological oxygen demand, dissolved oxygen, and two nonconservative materials. However, this research includes a revised kinetics subroutine which allows for the simulation of organic nitrogen, suspended solids, and a toxic chemical. In addition, the kinetics for BOD have been revised to take nitrogenous BOD into account. Additional work on the kinetics subroutine would be needed to match the kinetics more closely with Texas QUALTX kinetics (i.e. reaeration equation) if this model were to be applied statewide.

Theory of the Diffusion Analogy Flow Model (DAFLOW)

The following section highlights the basic principles of the unsteady flow modeling technique used by the diffusion analogy flow model (DAFLOW). The DAFLOW model has been designed to simulate flows in upland stream systems where flow reversals do not occur and backwater conditions are not severe. If these conditions are met, the diffusion analogy form of the flow equations can be applied with acceptable accuracy even with minimal field data (Jobson,1989). Several successful models have used the diffusion analogy approach.

Jobson (1989) uses the differential equations developed by Barre de Saint-Venant in 1871 as the nucleus of the one-dimensional unsteady flow model. A comprehensive discussion concerning numerical solutions of the Saint-Venant equations is beyond the scope of this report. For more information on the subject the reader is referred to the following references (Chow et al., 1988; Strelkoff, 1970; Saint-Venant, 1871; Lai, 1986).

Assuming no lateral inflow, the conservative forms of the Saint-Venant continuity and momentum equations can be written respectively as:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \tag{1}$$

$$\frac{1}{g}\frac{\partial U}{\partial t} + \frac{U}{g}\frac{\partial U}{\partial x} + \frac{\partial z}{\partial x} + S_f + S_o = 0 \tag{2}$$

where:

A = area of flow (m^2)
g = gravity (m/s^2)
Q = volumetric rate of flow (m^3/s)
S_f = friction slope (m/m)
S_o = bed slope (m/m)
U = velocity (m/s)
t = time (s)
x = longitudinal distance along channel (m)
z = depth of flow (m).

No analytical solution to these equations exists except for cases where the channel geometry is uniform and the nonlinear properties of the equations can be neglected or linearized (Strelkoff, 1970; Jobson, 1989). Therefore, a river is discretized into "grids" with uniform hydraulic properties. Then, to solve for the discharge, width, and cross-sectional area in each grid, a numerical solution to the above equations is required. The complexity of this solution depends upon the number of terms needed in the momentum equation (2) to accurately model the system.

The five terms in the momentum equation from left to right represent the (1) local acceleration, (2) convective acceleration, (3) pressure force, (4) gravity force, and (5) friction force. There are three general classes of solutions to the momentum equation (Chow et al., 1988). A solution which includes all five components is called a dynamic wave model. Neglecting the local and convective acceleration terms and using the remaining three forces results in a diffusion wave model. Models which include only the gravity and friction force terms are called kinematic wave models.

For most river systems not influenced by tidal action or severe backwater effects the first and second terms of the momentum equation can be neglected without impacting the accuracy of the solution (Jobson, 1990). Therefore, the diffusion analogy model developed by Jobson (Jobson, 1989) solves the diffusion wave form of the momentum equation. However, since the model makes several simplifying assumptions, the name diffusion analogy rather than diffusion wave model is used.

Three of the most notable simplifications concern approximations for the cross-sectional area, width, and discharge. (These simplifications are similar to those made in other flow models.) DAFLOW assumes that the parameters listed above can be estimated using the following equations:

$$A = A_1 Q_s^{A_2} + A_0 \tag{3}$$

$$W = W_1 Q_s^{W_2} \tag{4}$$

$$Q = Q_s - DF \frac{\partial A}{\partial x} \tag{5}$$

where:

- A = area of flow (m^2)
- A_0 = average cross-sectional area at zero flow (m^2)
- A_1 = hydraulic geometry coefficient for area
- A_2 = hydraulic geometry exponent for area
- W = width of the flow (m)
- W_1 = hydraulic geometry coefficient for the width
- W_2 = hydraulic geometry exponent for the width
- DF = wave dispersion coefficient
- Q = volumetric rate of flow (m^3/s)
- Q_s = normal discharge defined as the steady-state discharge that corresponds to an area A (m^3/s)
- x = longitudinal distance along channel (m).

Substituting Equation 5 into Equation 1 and simplifying the resulting equation yields:

$$\frac{\partial A}{\partial t} + C \frac{\partial A}{\partial x} - DF \frac{\partial^2 A}{\partial x^2} = 0 \tag{6}$$

where:

$$C = \frac{Q_{s1} - Q_{s2}}{A_2 - A_1} \approx \frac{\partial Q_s}{\partial A} \tag{7}$$

and

$$DF = \frac{Q}{2S_0W} \tag{8}$$

Inserting Equation 3 into Equation 6 and simplifying the derivative terms yields:

$$\frac{\partial Q_s}{\partial t} + C\frac{\partial Q_s}{\partial x} - DF\frac{\partial^2 Q_s}{\partial x^2} = 0 \tag{9}$$

DAFLOW solves for the space-time variation in discharge represented by Equation 9 using a three-step, finite-difference approach. Specific information regarding this process may be found in the program users manual (Jobson, 1989). The hydraulic parameters necessary to run the model include the A1, A2, A0, W1, W2, and DF parameters. These are typically determined through the use of data collected on a dye study. Ancillary programs available for DAFLOW to then use the collected data to determine the hydraulic parameters.

Input and Output of the DAFLOW Program and Associated Programs

The main program and the associated support programs are written in Fortran 77 and can be run on an IBM-PC or compatible, or a DG-UNIX workstation. The size of the river system being modeled is a factor in determining the computer capabilities that are needed.

Associated support programs for DAFLOW include CEL, which can be used to determine hydraulic parameters given some measured values (wave speed, n, etc), and BDAFLOW, which helps the user build the input file for DAFLOW. FLWPLT is a post-processing program which can be used to plot the output of DAFLOW. PLT is a post-processing program which can be used to perform calibration of simulated flows to observed flows.

The input files for the main program of DAFLOW is called *FLOW.IN*. It contains initial conditions, and boundary conditions at each time step. The output includes two files. *FLOW.OUT* gives flow at any time step or location specified by user. *BLTM.FLW*, which can be used directly as input for BLTM, includes values of discharge, cross-sectional area, width, and tributary inflows for each grid.

For more detailed description of the file formats and fortran coding, refer to the program users manual (Jobson, 1989).

Theory of the Branched Lagrangian Transport Model (BLTM)

Dispersive transport in rivers is typically, but not always, modeled using the one-dimensional form of a differential equation that represents the conservation of mass about an element. A simplified form of this equation which just includes advective and dispersive transport is (USEPA, 1985):

$$\frac{\partial C}{\partial t} + U\frac{\partial C}{\partial x} = \frac{\partial}{\partial x}\left(D\frac{\partial C}{\partial x}\right) \qquad (10)$$

where:

C	=	concentration of the water quality constituent (mg/L)
t	=	time (s)
U	=	cross-sectional averaged velocity of flow (m/s)
D	=	longitudinal dispersion coefficient (m^2/s).

In the Lagrangian reference frame of the BLTM model, Equation 10 is written for a particular water quality constituent within a moving fluid particle. In each equation, additional sources and losses of the constituent are considered. The equation takes the following form, in which each of the constituents is numbered. Notice that the convection term on the left side of Equation 10 drops out; the convection term is typically the source of the numerical dispersion in an Eulerian reference frame.

$$\frac{\partial C_m}{\partial t} = \frac{\partial}{\partial \xi}\left(D \frac{\partial C_m}{\partial \xi}\right) + S_m + \Phi_m + \sum_{n=1}^{k} K_{m,n}(C_n - CR_{m,n}) \qquad (11)$$

where:

C_m	=	the concentration of constituent m (mg/L)
ξ	=	Lagrangian distance coordinate
S_m	=	rate of production of constituent m, independent of existing concentration (mg/L/s)
Φm	=	rate of change of constituent m due to tributary inflow (mg/L/s)
$K_{m,n}$	=	rate coefficient for the production of constituent m due to the presence of constituent n (mg/L/s)
C_n	=	the concentration of constituent n (mg/L)
$CR_{m,n}$	=	concentration of constituent n at which production of constituent m due to n ceases (mg/L)
m	=	the number of the water quality constituent that is being modeled
$K_{m,n}$	=	the rate coefficient for the production of constituent m due to the presence of constituent n (mg/L/s)

The Lagrangian distance coordinate, ξ, represents the distance that the particle moves in two coordinate systems - the stationary coordinate system and the moving parcel coordinate system. The equation for ξ is given by:

$$\xi = x - x_0 - \int_{t_o}^{t} U dt' \qquad (12)$$

where:

x	=	Eulerian (stationary) distance coordinate at t (m)
x_0	=	location of the parcel at time t_0 (m)
t_0	=	the time at the beginning of the simulation (s)
t	=	the time passed since the beginning of the simulation (s)
$\int_{t_o}^{t} U dt'$	=	the distance the particle has traveled in real coordinates (m)

Integration of Equation 11 with respect to time interval Δt gives the following reduced equation form, in which each of the P terms represents either the initial concentration of a constituent in the parcel of water (PTI) or the contribution of a specific physical process to the change in concentration of that constituent in the parcel of water:

$$C_m (t + \Delta t) = PTI + PDF + PTR + PDC \qquad (13)$$

where:

PTI	=	initial concentration of constituent m
PDF	=	diffusion effect on concentration of constituent m (mg/L)
PTR	=	tributary effect on concentration of constituent m (mg/L)
PDC	=	other constituents' effects on concentration of constituent m (mg/L)

Each P term is included in the output of the model for the times and locations specified by the user. This information allows the user to determine which processes have the largest effect on a particular water quality constituent as the parcel moves downstream. These P terms can be used to calibrate the model. This is best demonstrated in the model application on the Chattahoochee River (Jobson, 1987).

Input and Output of the BLTM Program and Associated Programs

The main program consists of three fortran codes which are compiled together: the main program, named <u>bltm.f</u>, and two subroutines, named <u>fink.f</u> and <u>dtdds.f</u>. The subroutine <u>fink.f</u> contains the kinetics formulations for the water quality constituents. In this research, <u>fink.f</u> contains kinetics from QUAL2E, 1987. <u>Dtdds.f</u> is used when input from other hydraulic models (besides DAFLOW) is used. The main program and the associated support programs are written in Fortran 77 and can be run on an IBM-PC or compatible, or a DG-UNIX workstation. The size of the river system being modeled is a factor in deciding the terminal that can be used.

Three files are needed to run BLTM. *BLTM.IN* contains the initial conditions, boundary conditions, and some control items (i.e. number of constituents, time step, printout intervals). *QUAL2.IN* contains some of the water quality coefficients that are needed in the kinetics (i.e.

wind speed and solar radiation, decay rates, etc.). *BLTM.FLW*, which is the output from DAFLOW, or another file with the same hydraulic values, is also needed.

An associated support program for BLTM is BBLTM, which helps the user build the main input file (*BLTM.IN*) to run BLTM. CXPLT and CTPLT are post-processing programs which plot either concentration versus time at a particular grid or concentration versus distance for a set of branches at a specific time.

Output files of a BLTM model application include *BLTM.OUT* and *PARCEL.OUT*. *BLTM.OUT* list the P terms at each time step for specified locations that are denoted by the user in *BLTM.IN*. *BLTM.OUT* can be used to track the progression of a particular parcel of water as it flows downstream and can be used as a calibration tool. *PARCEL.OUT* keeps track of the number of parcels and their concentrations in every grid for each time step.

For more detailed description of the file formats and fortran coding, refer to the program users manual (Jobson, 1987).

Modeling Approach - Segment 0604

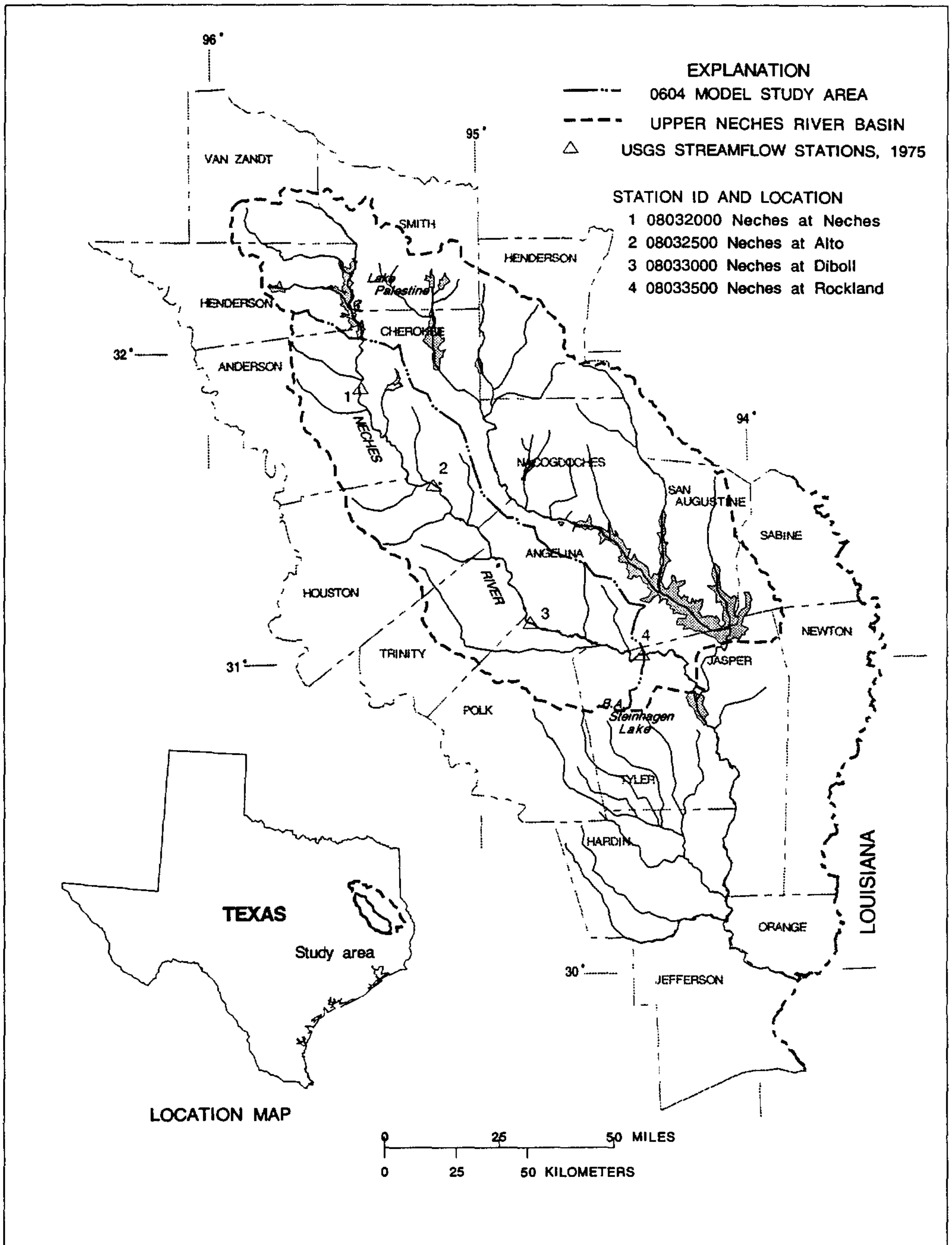
Please refer to the map of the segment in Figure 4. On Segment 0604, the Neches below Lake Palestine, four USGS stream flow gages had been operating simultaneously for a period of time. Presently, only two of those gages are continuously monitoring flow and water quality (08032000 and 08033500). There is one partial record gage for peak flow measurements (08033000).

In order to determine where gages provided the most information on the reach, and where gages were currently most needed, DAFLOW was used to simulate flows at the three downstream gaging locations using only the flow at the upstream gage and a measure of the ungaged inflow. The intensive surveys on this segment are limited to some of the tributaries entering the main Neches River near Lufkin.

Daily flows were simulated from station to station by routing flow down the channel. Using 1975 data, the flow was routed from station to station; beginning with the Neches at Neches station, flow is routed to the Neches at Alto, then to Neches at Diboll, and on to Neches at Rockland. The upstream flow multiplied by a drainage area ratio (DAR) is a measure of the ungaged inflow that is added to the branch. This assumed ungaged inflow is added between the two monitoring stations at a distance equal to the distance traveled in one time step. A disadvantage of the lack of real tributary inflow data and the subsequent use of the DAR to estimate ungaged inflow, is that flow simulated between gages is only an estimate at best.

The accuracy of the flow model is critically dependent on the proper selection of the hydraulic geometry coefficients (A1,A2,W1,W2) and the wave dispersion coefficient (DF). These values are generally computed from estimates of flow resistance and channel width, from the wave speed of flood hydrographs, or from a combination of these approaches. A program called

Figure 4: UPPER NECHES RIVER BASIN, SEGMENT 0604



CEL was developed in conjunction with the DAFLOW model in order to aid in the selection or adjustment of these values.

For each subreach of this segment, where subreaches are defined by the gaging stations, CEL was used with an assumed value of Manning's n at a particular discharge and a representative discharge equal to the annual average flow at the upstream gage. The width and discharge values for each gage was taken from an average of recorded discharge measurements over a period of several years (1971-1973). The slope of the entire river segment was estimated from USGS 1:250,000 topographic maps to be .0000479 ft/ft.

Using 1977 data, the flow routing procedure was repeated. Based on the two runs, the DAR was finalized for each subreach. In order to decide upon an appropriate DAR value, the mean error of the predicted flows compared to the observed flows was calculated using the PLT program. This number was minimized. The root mean square error (RMS) calculated by the PLT program of DAFLOW would not converge to zero by changing the DAR, but was fixed by the hydraulic coefficients. After minimizing the mean error for each subreach by varying the DAR, there was an attempt to verify the model. The time period used to verify the model was chosen specifically to test the limits of the model. A period in which there were significantly higher flows (1972) than the flows used to determine DAR was used. The model was not verified at these higher flows.

Model Input and Results - Segment 0604

Figures 5 and 6 show the daily discharges at the four streamflow gages over the two time periods used in the model to determine DAR. Some local events between gages appears to be contributing to the flows at certain points. These local events could not be captured by the model as they were not related to the flows at the upstream gages. The flows in the time period 2/1/75 - 8/1/76, covered a wider range of values and appeared to be more related from gage to gage (less local events) than those in 1977-1978. For this reason, the '75-'76 time period was considered more important in determining the appropriate DAR, and DAR was varied (to the nearest tenth) to minimize the mean error for those flows.

Channel parameters used for the subreach from Neches at Neches to Neches at Alto included Manning's n = .04 at a Discharge = 862 cfs and Discharge = 541.5 cfs at a Width = 113.4 ft These were used in the CEL program with a representative discharge = 684 cfs. These values generated the following hydraulic coefficients:

A0=100 ft^2	W2 = .21
A1=12.93	DF = 59950 ft^2/s
A2=.61	DL = 101778.85 ft.
W1=30.24	

Figure 5: Daily Discharges at Four Gages, Segment 0604, 1975-1976

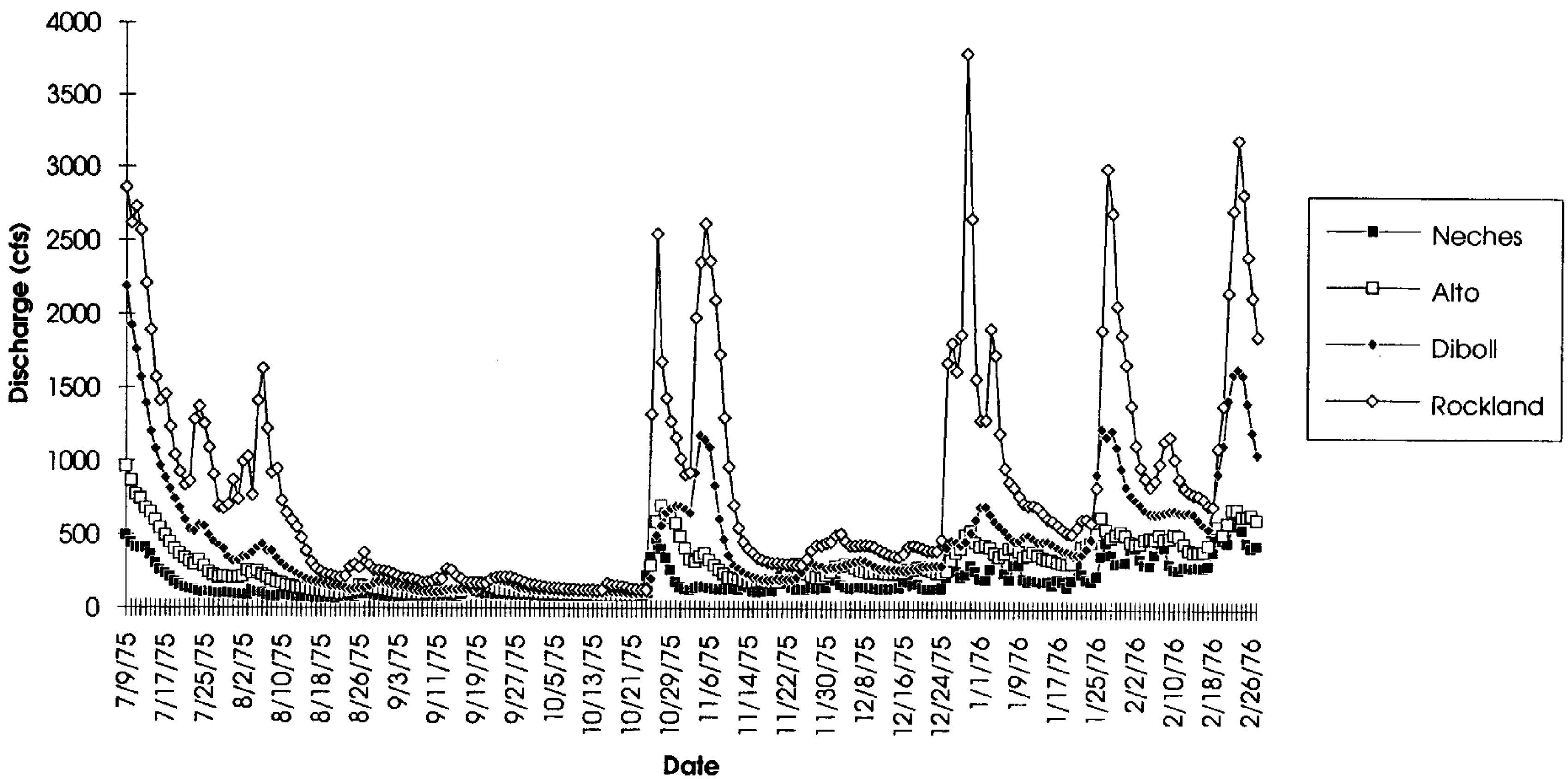
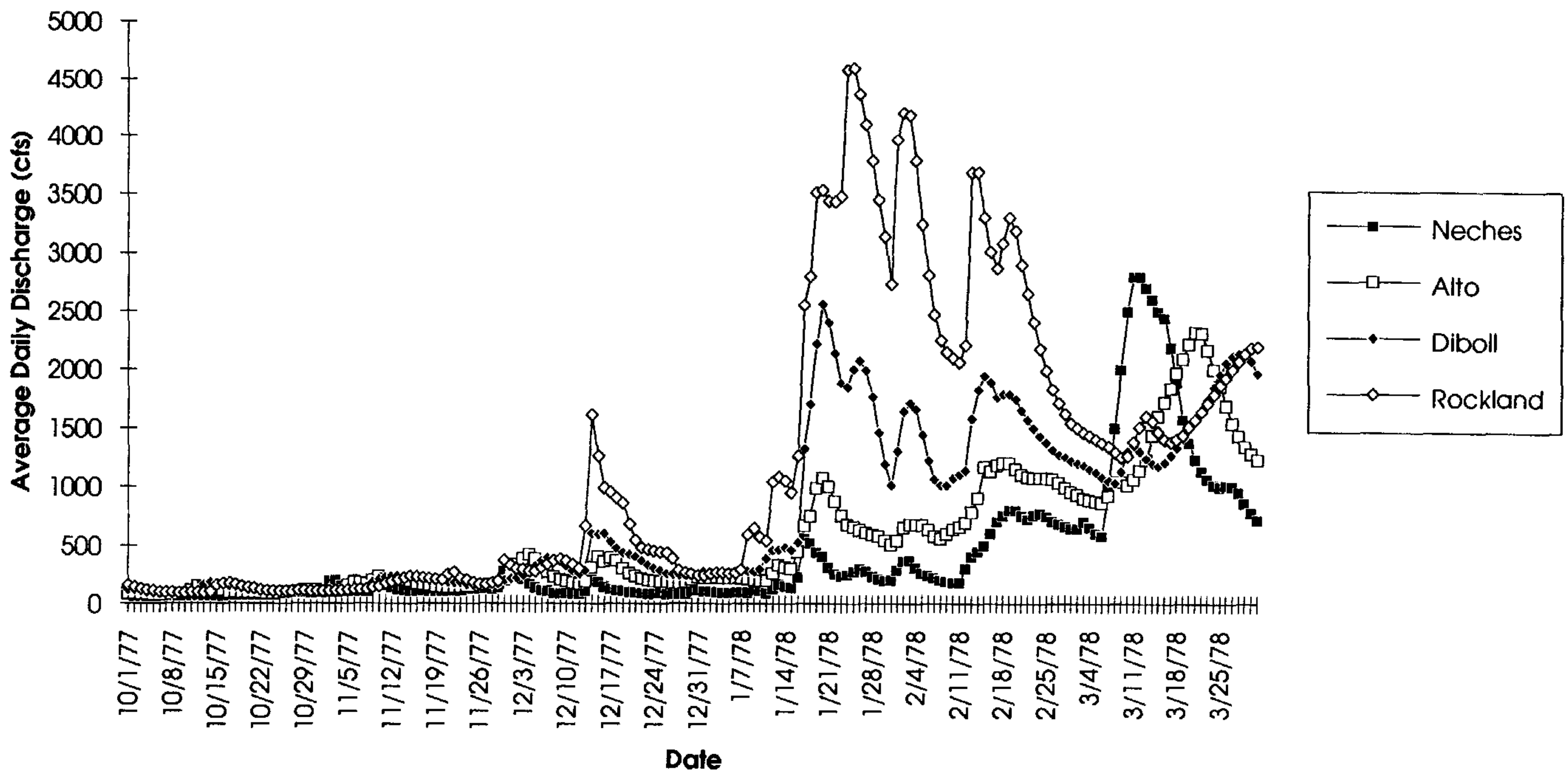


Figure 6: Daily Discharges at Four Gages, Segment 0604, 1977-78



These coefficients, daily flows at Neches at Neches, and inflow equal to the flow at Neches at Neches multiplied by a DAR, were used in the input file (see Appendix C) to generate flows at Neches at Alto for 1975-76. Travel time for the entire reach at the discharge of 684 cfs was 2.24 days. This meant that the ungaged flows were added at a distance of 26.5 miles. DAR's ranging from .5 to .9 were evaluated.

With 1975-76 data (235 days of daily flows), using a DAR=.6 and observed flows at Neches at Neches, flows at Neches at Alto were predicted with a mean error (ME) = -4.57 and a RMS = 67.88. (Refer to Figure 7) Using 1977 data (157 days) with the same parameters in *FLOW.IN* (Appendix D) the model predicted flows at Alto with a ME = 63.22 and RMS = 146.48 (Refer to Figure 8). .

Flow was then routed from Neches at Alto to Neches at Diboll. The same two time periods, flows at Neches at Alto and the measure of ungaged flow were used with the following parameters: n = .04 at a Discharge = 1199 cfs and Discharge = 797 cfs at a Width = 117.77 ft These were used in the CEL program with a representative discharge = 1040 cfs. These values generated the following hydraulic coefficients for use in the input file.(Appendix E)

A0 = 300 ft^2	W2 = .21
A1 = 10.676	DF = 87170 ft^2/s
A2 = .61	DL = 122728 ft
W1 = 28.956	

Based upon the CEL results, one day travel time was equivalent to 37.85 miles from the Neches at Alto station for the representative discharge. DAR's ranging from .3 to .5 were tested and a final DAR=.5 was chosen. With 1975-76 data (235 days of daily flows), flows at Neches at Diboll were predicted with a ME = 3.10 and a RMS = 196.97. (Refer to Figure 9) Using 1977 data (157 days) with the same parameters in *FLOW.IN* (Appendix F), the model predicted flows at the Diboll gage with a ME = 55.73 and RMS = 310.54. (Refer to Figure 10)

To predict flows at the Neches at Rockland gage, observed flows at Diboll and the following parameters were utilized: n = .05 at Discharge = 1642 cfs and Discharge = 1632 cfs at a Width = 113.52. These were used with a representative discharge = 1358 cfs in the CEL program to generate the following hydraulic coefficients:

A0 = 500 ft^2	W2 = .21
A1 = 10.44	DF = 129780 ft^2/s
A2 = .61	DL = 149753 ft
W1 = 24.01	

Based upon the CEL results, one day travel time was equivalent to 42.8 miles from the Neches at Diboll station using the representative discharge. These were used in the *FLOW.IN* file (Appendix G) for the DAFLOW program with DAR's ranging from .2 to .9. A DAR = .8 was chosen. With 1975-76 data (235 days of daily flows), flows at Neches at Rockland were predicted with a ME = 12.25 and a RMS = 408.33. (Refer to Figure 11) Using 1977 data (157

Figure 7: Observed and Predicted Flows at Neches at Alto, 1975-1976

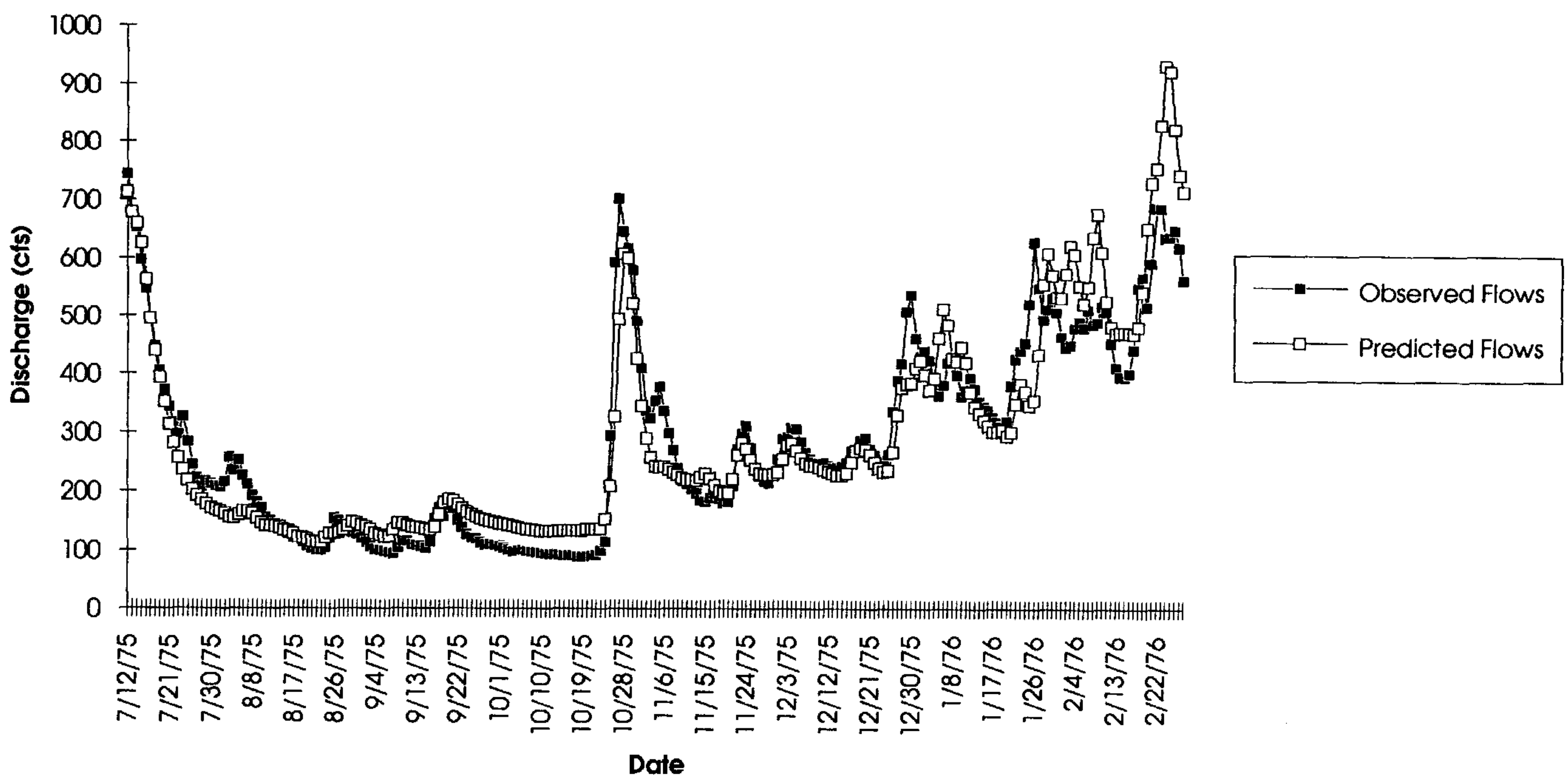


Figure 8: Observed and Predicted Flows at Neches at Alto, 1977-1978

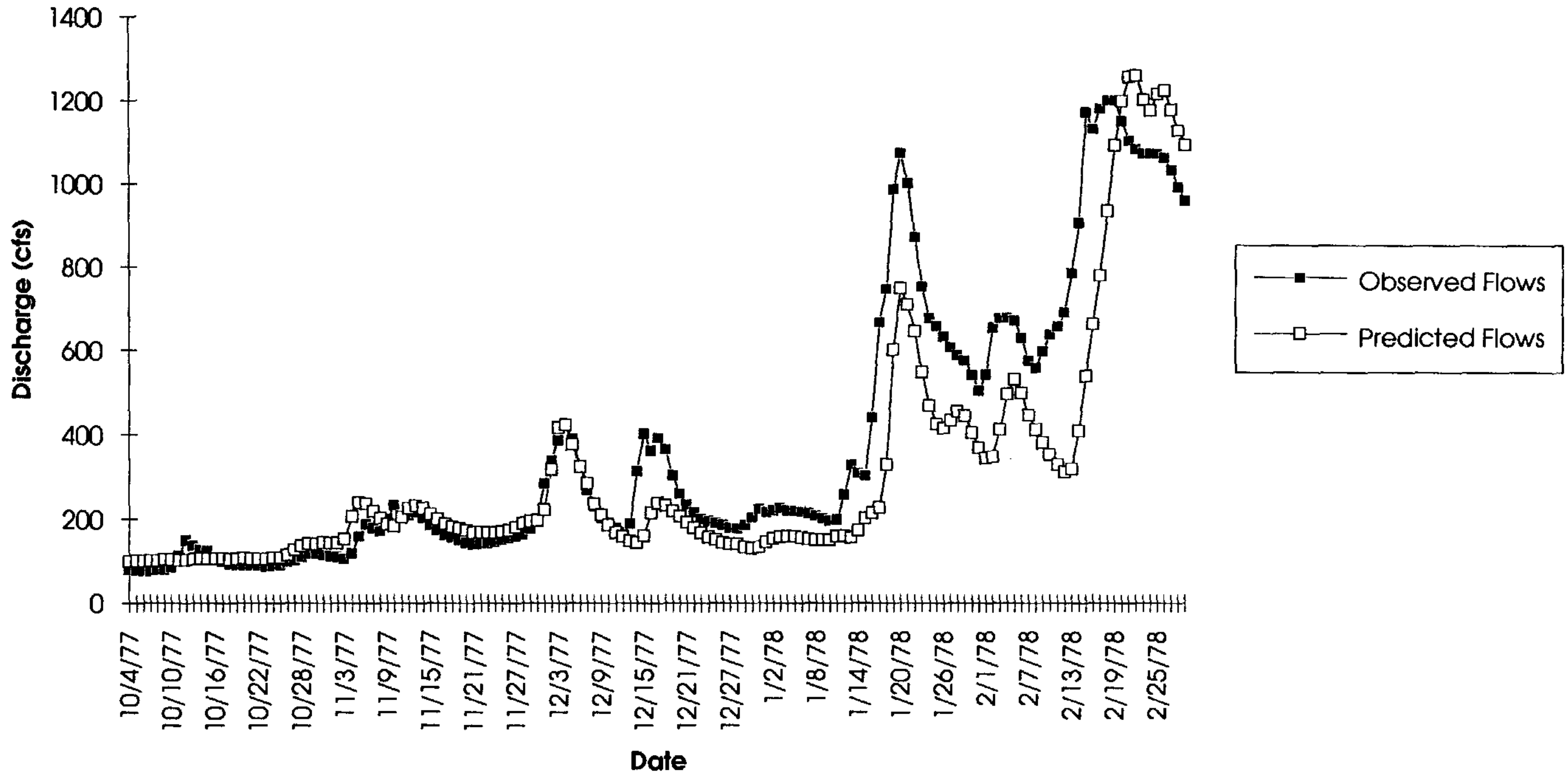


Figure 9: Observed and Predicted Flows at Neches at Diboll, 1975-1976

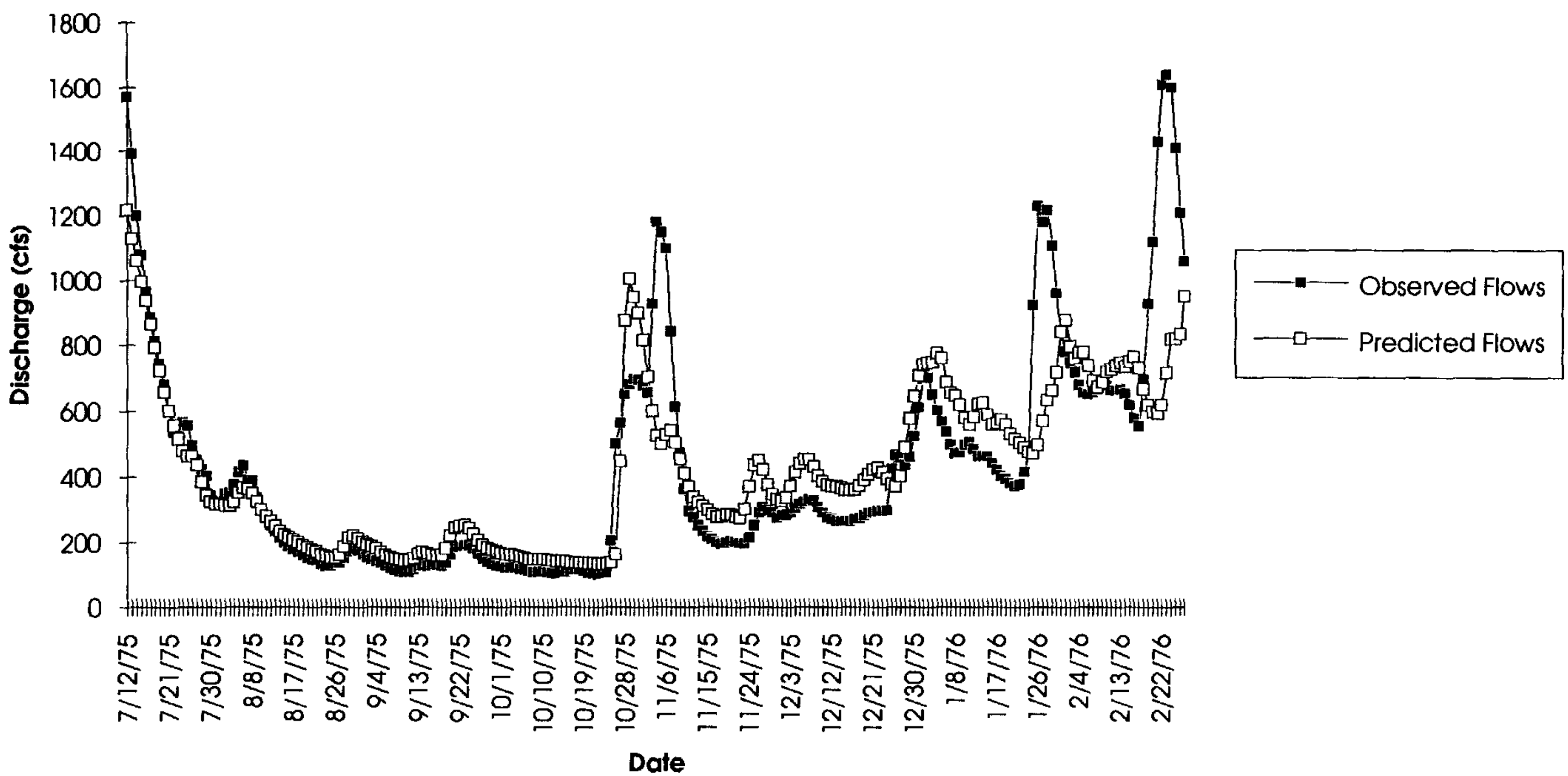


Figure 10: Observed and Predicted Flows at Neches at Diboll, 1977-1978

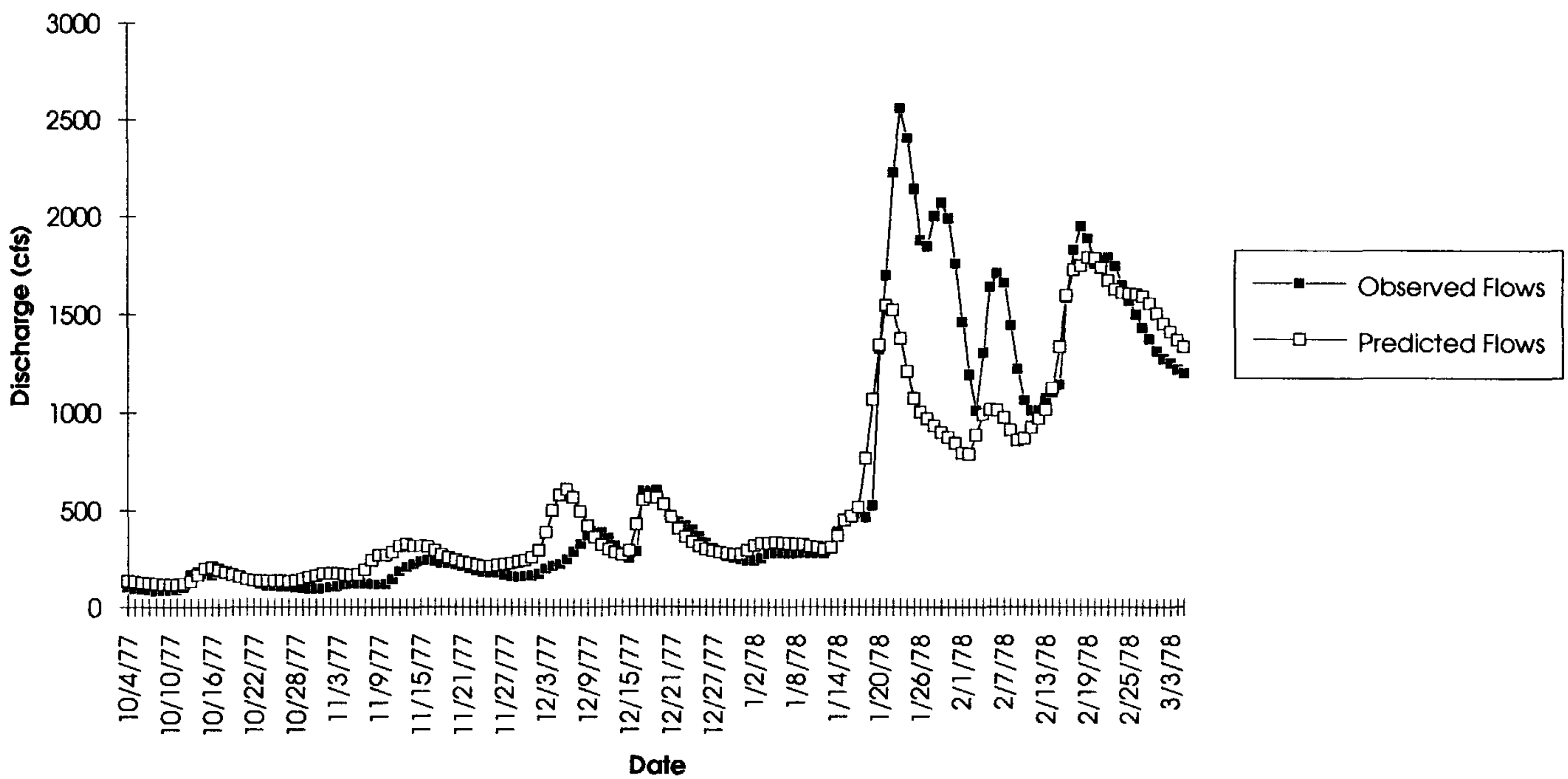
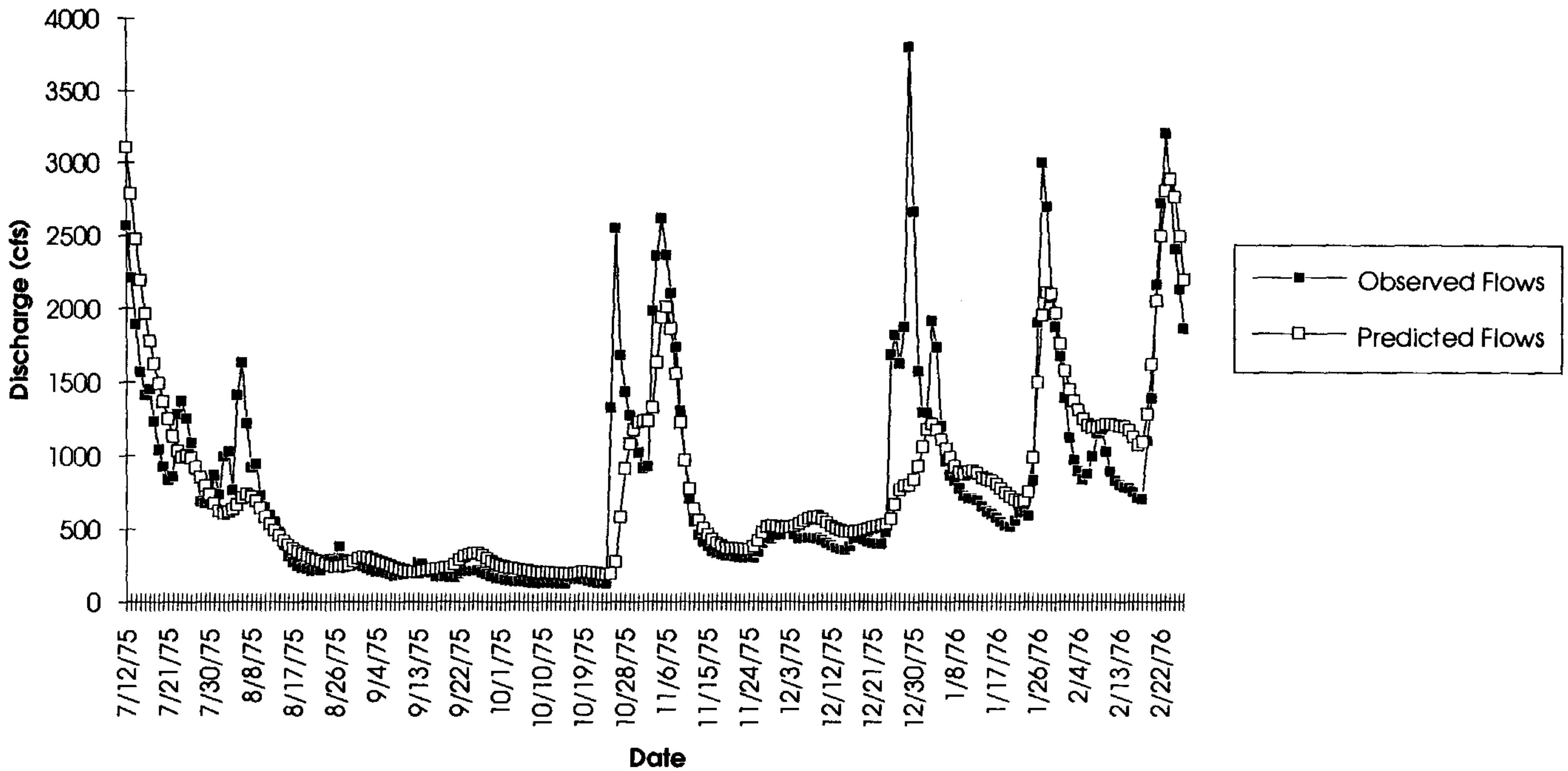


Figure 11: Observed and Predicted Flows at Neches at Rockland, 1975-1976



days) with the same parameters in *FLOW.IN* (Appendix H), the model predicted flows at the Rockland gage with a ME = -13.69 and RMS = 438.11. (Refer to Figure 12)

Flow predictions from simulation runs are only considered applicable at the locations of current or previous USGS gaging stations and any intermediate flows between gages are only estimates.

Model Discussion - Segment 0604

Important information resulted from the analysis for water quality segment regarding the model of choice:

1. The DAFLOW/BLTM model had never been used with a daily time step for flow-routing purposes before. The use of a daily time step did not allow for refinement of the hydraulic coefficients. However, daily discharge information is the only information that is readily available for time periods when all gages were operative.

2. By examining the data and graphing the daily flows at the various different stations, it was surmised that after a certain discharge was exceeded, the water velocity actually decreased instead of increasing with higher flow rates. This may be due to a rather unusual channel geometry (see below). This violates certain assumptions of the model and may be the reason that the model could not be verified at the higher flows of 1972.

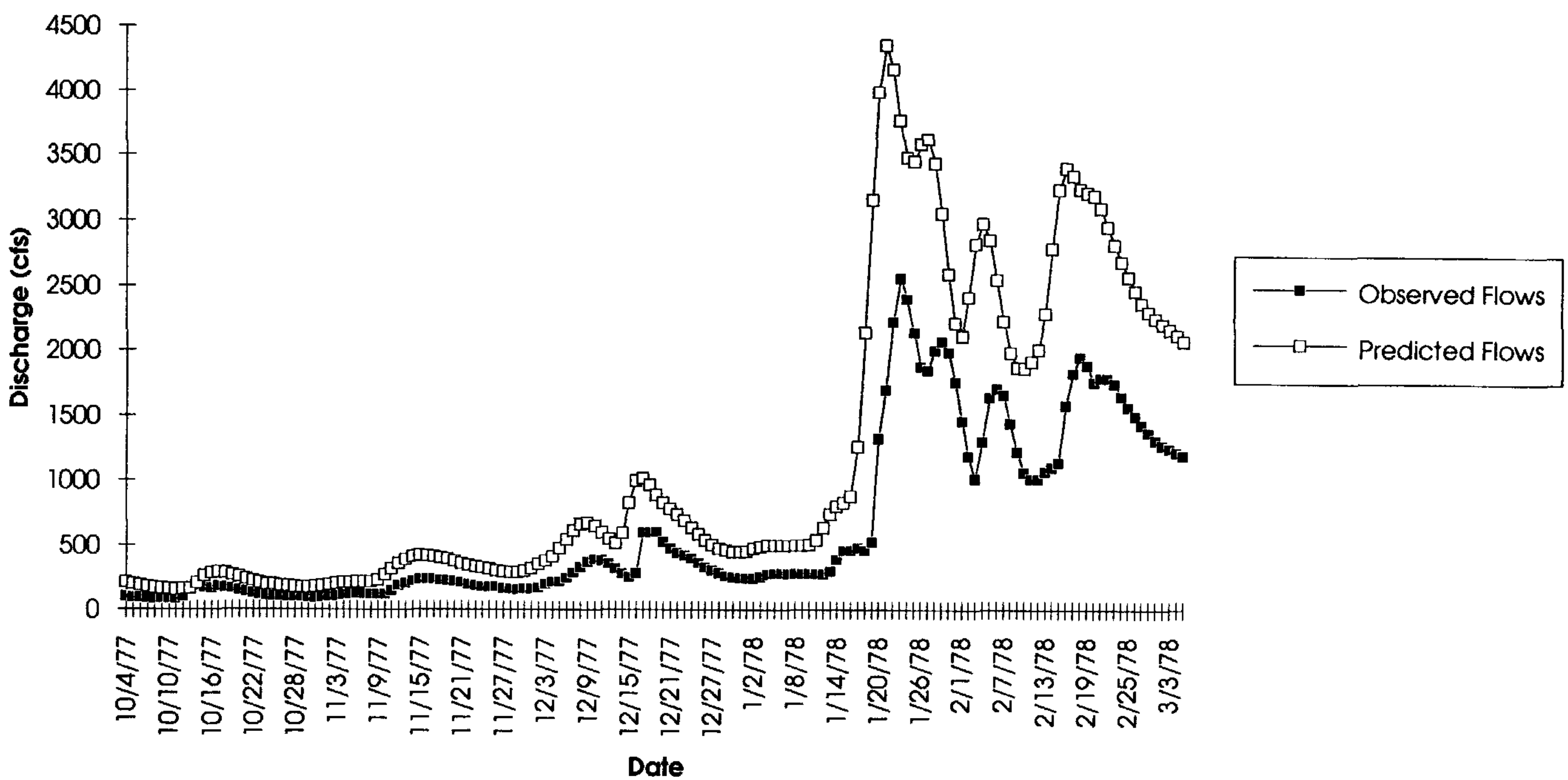
3. Ungaged flow was estimated using the DAR multiplied by the upstream gage flow. The DAR values actually used (the DAR was varied to fit the model) were all higher than the actual DAR. This is most likely due to the fact that rainfall increases as one proceeds south in the basin. It was noted however, that some of the flows could be better simulated using upstream gage measurements than others. For instance, flows at the Neches at Alto gage were well simulated using the flows at Neches at Neches.

4. Because it was necessary to use daily flow values (hourly values are readily available only for recent years, when only two gages were operating), and because there is evidence of local rainfall events between gages whose flows were not captured by the ungaged flow calculation method, the results of the model are not very accurate.

5. Due to the lack of monitoring data for hydraulic parameters, estimations of A1 and A2 and W1 and W2 were made. DAR was therefore the only variable that could be varied to fit the observed values. The mean error of each simulation could be minimized, but only to the nearest minimum.

6. The use of DAFLOW as a flow routing tool is appropriate for a rough approximation of flows during periods of relatively low flow and if there are no local storm events. Statistical methods for routing flows and determining hydrologic conditions (depth, area, etc.) for those flows could be investigated further.

Figure 12: Observed and Predicted Flows at Neches at Rockland, 1977-1978



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Modeling Approach - Segment 0611

Please refer to the map of the segment in Figure 13.

Segment 0611, the Angelina River above Sam Rayburn, is a "water-quality limited" segment and has been intensively surveyed. In the case of Segment 0611, there have been violations of water quality standards as reported by TNRCC in the 305B segment reports. Only one USGS continuous stream flow gage is presently in operation on this segment. Intensive surveys have been performed on both the entire segment (TDWR,1978;TDWR,1985) and on the tributary of West Mud Creek alone. A Waste Load Evaluation has been performed and is in draft form for the entire segment (TWC, 1991).

For Segment 0611, the approach was quite different from Segment 0604, due to the fact that several intensive surveys had been performed by TNRCC. This allowed for a complete modeling effort with comparison of the hydraulic and transport model results of DAFLOW/BLTM with the results of QUALTX on the same reach. The unsteady-state model was tested for repeatability at the steady-state conditions in 1984 that were used to calibrate QUALTX. To show the utility of DAFLOW/BLTM for dynamic water-quality modeling, a potential storm event in a portion of the basin was then superimposed over these steady-state conditions of 1984. The unsteady-state results of the model for flow, dissolved oxygen, and ammonia were plotted against standards.

The complexity of this segment (size of time step required and spatial extent) required the use of a workstation at the USGS to provide the necessary storage space to run this model. The FORTRAN code for the workstation version of DAFLOW/BLTM is slightly different than the FORTRAN code for the PC. The Advanced Hardware Configuration described in FY94-95 Program Guidance for the Texas Clean Rivers Program (ANRA, 1993) should handle the storage requirements for modeling most water quality-limited segments in the state, and may even have been sufficient for Segment 0611. However, the use of the workstation was more convenient and faster for this study.

Model Input for Steady-State Application of DAFLOW/BLTM

The QUALTX input files from the September 1984 calibration of Segment 0611 that were used to derive the input for this DAFLOW/BLTM model application can be referenced in Appendix J. Three separate simulations with QUALTX, for Bayou Lanana, the Upper Angelina River, and Mud Creek, were consolidated into one large run using the DAFLOW/BLTM model.

The QUALTX model uses reaches and elements to represent a river network. The schematization used in the QUALTX model (TWC, 1991) was translated into an equivalent schematic for the DAFLOW and BLTM model. DAFLOW/BLTM uses a series of junctions, branches, and grids. Figure 14 represents the DAFLOW/BLTM river schematization that was used in this application. A new branch was established wherever there was a junction of two flows. External junctions are numbered first, then internal junctions. Distances are measured in river miles starting from the first junction in each branch to the final junction. A branch is divided

Figure 13: UPPER NECHES RIVER BASIN, SEGMENT 0611

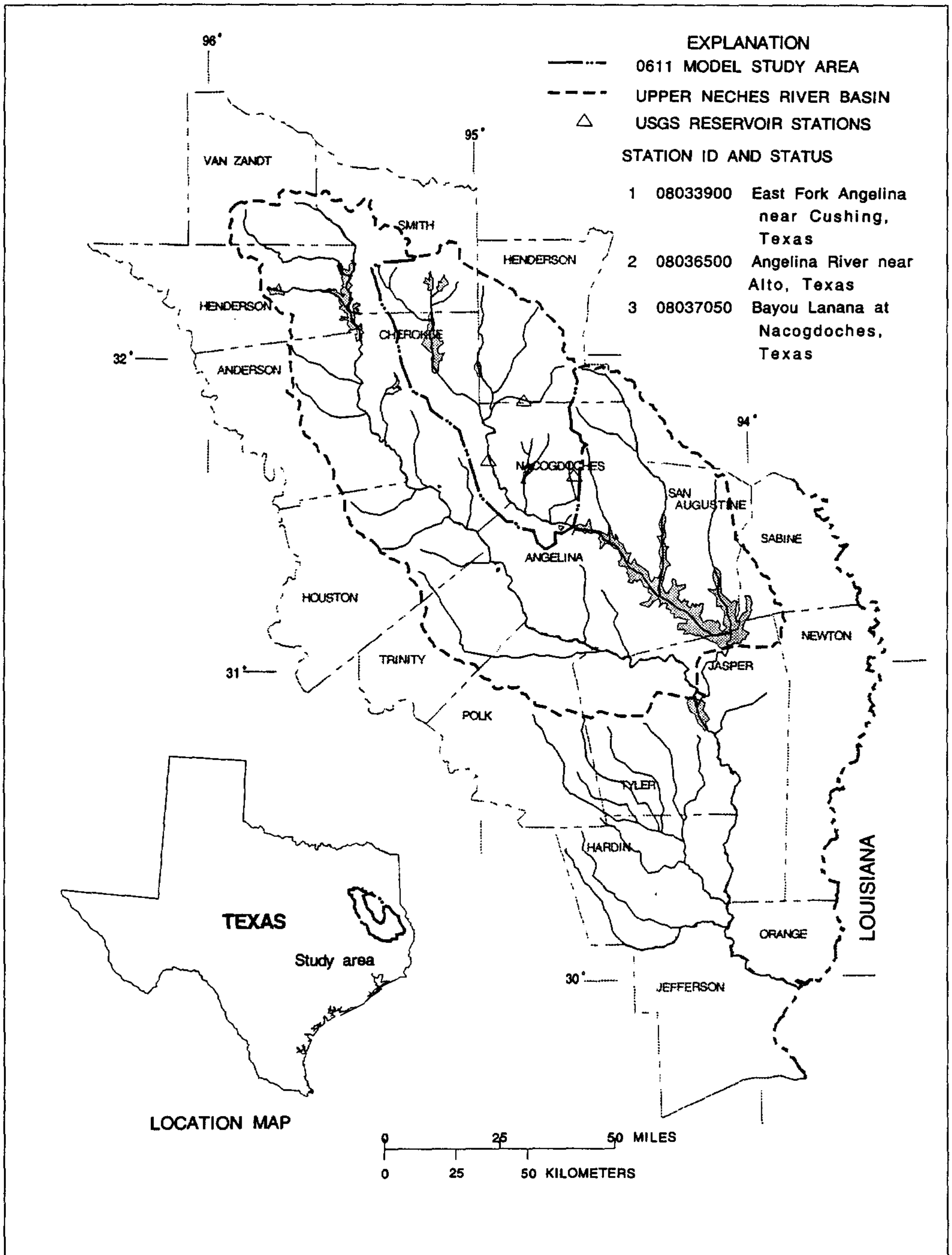
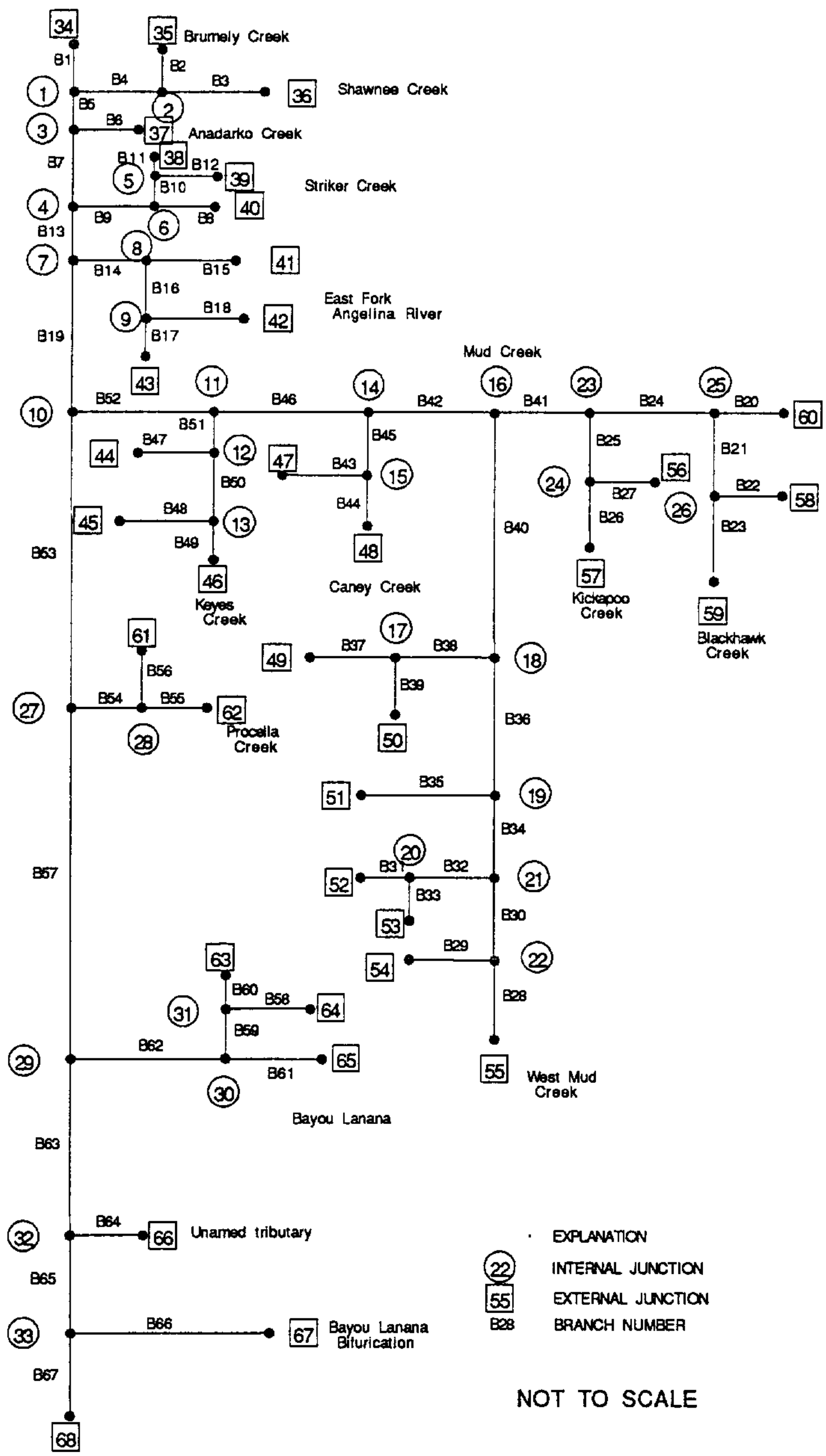


Figure 14: SEGMENT 0611 DAFLOW/BLTM SCHEMATIC



into grids for the reason explained below. Grids are not shown.

The input to the DAFLOW model for Segment 0611 at steady-state is in a *FLOW.IN* file that can be referenced in Appendix K. The time step, accuracy criteria, printout options, and initial conditions are set up in the first section of *FLOW.IN*. In the following section, the boundary conditions (NBC) are read in for each time step. If the boundary conditions do not change, NBC is set equal to zero. Previous boundary conditions will continue to repeat until they are changed or the program ends. For more information on the exact file format, please refer to the manual for DAFLOW (Jobson, 1989).

In order to create the *FLOW.IN* input file for DAFLOW, the hydraulic parameters discussed in Chapter 2, A1, A2, W1, W2, and DF, are needed for each grid. For a QUALTX application, the hydraulic parameters a,b,c,d, and e are constants that are derived from dye study data. These QUALTX parameters can be used to derive the needed DAFLOW parameters. Additional channel characteristics needed to derive the DAFLOW parameters included channel slope and channel roughness. These values were cited in the QUALTX Draft report as being .0002 and .03 respectively for the entire reach. The derivation is described in the Appendix I.

To solve for W and DF in each grid, the representative discharge was needed. In each branch, this was determined to be the low-flow discharge solved by performing a flow balance (discussed below). If there was no flow in a particular branch (Q=0), DF was set equal to .01 so that the model would work. This DF value was never used, so it did not cause an error in the results.

If the data did not pre-exist for this study, data would have had to have been collected. If this were the case, ancillary programs to DAFLOW, like CEL (described in Chapter 2), could have been used to generate the hydraulic parameters directly from measured hydraulic data.

The number of grids in each branch was determined based upon two factors. If the hydraulic parameters changed or if a flow needed to be added at a particular location, a new grid was established. The initial discharge (and DF value based on this representative discharge) for each grid was determined by performing a simple flow balance of all the flows that were added in the QUALTX application to each particular branch. These included flows due to the addition of headwater flows, flows from point source discharges, and incremental flows. These same flows were then used as the boundary condition for the first time step and were repeated for every time step.

The results of the DAFLOW application were captured in two output files - FLOW.OUT and BLTM.FLW. The steady-state flows in BLTM.FLW were then used in the application of the BLTM transport model. The subroutine which contains the kinetics formulations, called fink.f, can be referenced in Appendix L. Although temperature was not modeled in the QUALTX application, it had to be modeled in the BLTM application. This is due to the nature of the solution technique - lagrangian as opposed to a one-time matrix solution. Temperature is a factor in the kinetics of the other constituents that were modeled: ammonia, nitrate, nitrite, carbonaceous biological oxygen demand, and dissolved oxygen. Kinetics for algae, orthophosphate, and two nonconservative substances exist in the unmodified fink.f subroutine. The modeling results for these constituents are not demonstrated, as they were not modeled in the QUALTX application.

Other input files required for the BLTM simulation at steady-state included QUAL2.IN which contains the kinetic coefficients and BLTM.IN which defines the initial and boundary conditions of the modeled constituents. The formulation of the BLTM.IN file was performed interactively with a model interface program called BBLTM. Partial samples of BLTM.IN and QUAL2.IN can be found in Appendix M and Appendix N respectively..

Results and Discussion of Model Application at Steady-State Conditions

The DAFLOW model and the BLTM model were run for 1000 time steps in order for steady-state conditions for the water quality constituents to be attained. This was determined by using the CTPLT to plot concentration versus time at the last grid in Branch 67.

The results of the DAFLOW model show that the simulated steady-state discharges at certain points in the river system match the observed measurements taken during the intensivesurvey. Observed and simulated flows at the locations where flow was observed during the intensive survey is summarized in Table 3. There is some slight differences in the simulated and observed flows due to the fact that for this DAFLOW/BLTM simulation all incremental flows were added at the beginning of a branch (grid 2), instead of distributing them throughout a branch. In addition, two flows (incremental and point sources) could not be added to the same grid in DAFLOW, and flows could not be added at the exact location of an internal junction.

Concentration versus distance plots were generated using the BLTM output at the 1000th time step. Results of the BLTM steady-state simulations for dissolved oxygen, ammonia, and ultimate BOD were compared with the results of the QUALTX simulations (TWC, 1991, Figure 10-21). Figures 15 through 18 show the concentration versus distance plots of the BLTM simulations for the main stem of the Upper Angelina River, and tributaries West Mud Creek, Mud Creek and Bayou Lanana. Also included on these figures are the results of the QUALTX simulation (Marshall, 1993a).

The difference in the results of the two models may be due to a number of different factors. Incremental flows into the BLTM system were not distributed in the reach, but were added at the upstream end of a branch. The kinetics equations were slightly different between the two models. In addition, to replicate the percent reductions in BOD and NH3 that were used in QUALTX, the BLTM waste loads for BOD were reduced by the percentage indicated in QUALTX. However, the NH3 loads were not reduced by the percentage indicated in QUALTX.

Some conceptual problems with the application of this QUALTX model on this Segment include the fact that 1) temperature was not modeled, 2) negative and positive incremental flows were used at random to balance flows - these did not have any associated water quality values, and 3) percent reductions of BOD and NH3 are questionable. The percent reductions that the state uses are estimated based upon the distance from the outfall to the actual discharge into the

TABLE 3

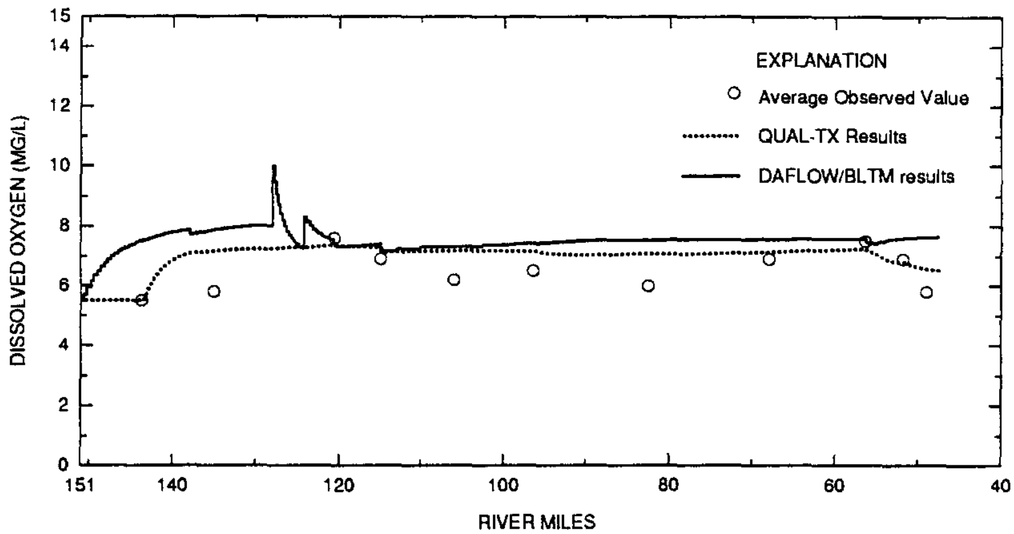
Comparison of Observed and Simulated Steady-State Flows

Location (River Kilometer, River Mile)	QUALTX River and Element	DAFLOW/BLTM Branch and Grid	DAFLOW Simulated Flows (cms)	Observed Flows (cms) 9/10/84-9/14/84
Angelina River (155.2, 151.0)	Ang. 220	B53 G1	.7132	.878
Angelina River (90.6, 56.3)	Ang. 285	B53 G4	.8912	.905
Angelina River (88.4, 54.9)	Ang. 330	B53 G9	.9182	1.246
Angelina River (85.9, 53.4)	Ang. 338	B65 G3	1.302	1.289
East Fork Angelina (9.1, 5.7)	Ang. 165	B14 G4	.195	.195
West Mud Creek (31.7, 19.7)	Mud 70	B28 G3	.159	.017
West Mud Creek (16.5, 10.3)	Mud 119	B36 G2	.120	.120
Mud Creek (74.8, 46.5)	Mud 34	B24 G4	.121	.121
Keyes Creek (2.5, 1.6)	Mud 266	B51 G3	.065	.065
Bayou Lanana (24.2, 15.0)	BL 39	B62 G5	.141	.250
Bayou Lanana (15.5, 9.6)	BL 56	B62 G7	.141	.141
Bayou Lanana (10.7, 6.6)	BL 66	B62 G9	.183	.183
Bayou Lanana (.1, .06)	Ang. 311	B62 G12	.183	.140
Bayou Lanana Bifurcation (.1, .06)	Ang. 334	B66 G2	.043	.043

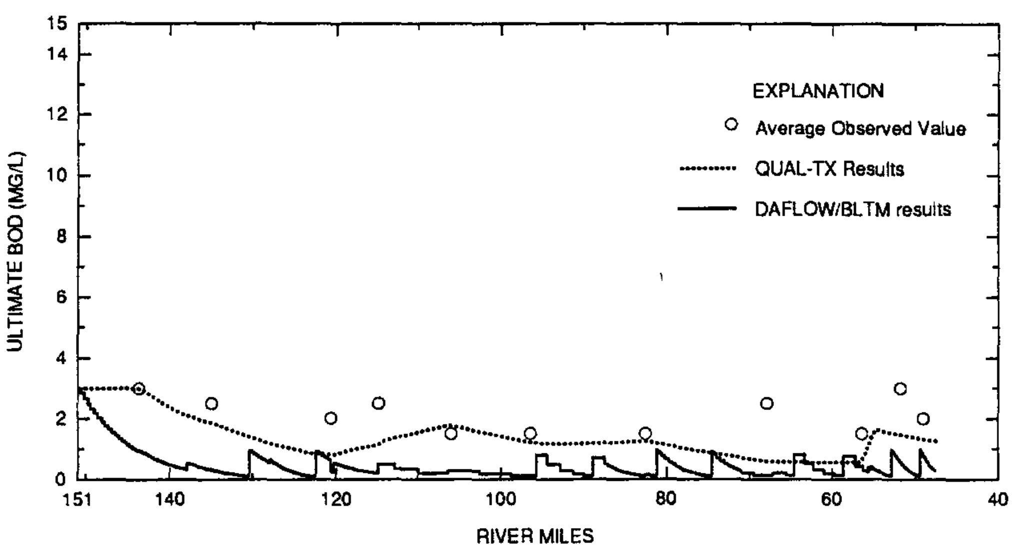
receiving waters. NH3, if reduced in the distance from an outlet pipe to the receiving water, would break down into other forms of nitrogen (NO3 and NO2) that should be included in the nitrogen cycle. It is interesting that, in some cases, the BLTM model did a better job of simulating ammonia nitrogen. Organic nitrogen was not included in the BLTM nitrogen cycle, but the percent reductions of ammonia were not applied.

Originally, this model was going to be applied on a daily time step for steady-state application. However, it was discovered that the small size of some of the grids that were used necessitated the use of a smaller time step. It should be noted that , although the model is stable at any time step, the time step chosen must take into account the level of detail provided by the

Figure 15
Comparison of QUALTX and DAFLOW/BLTM Results:
Upper Angelina River, Segment 0611

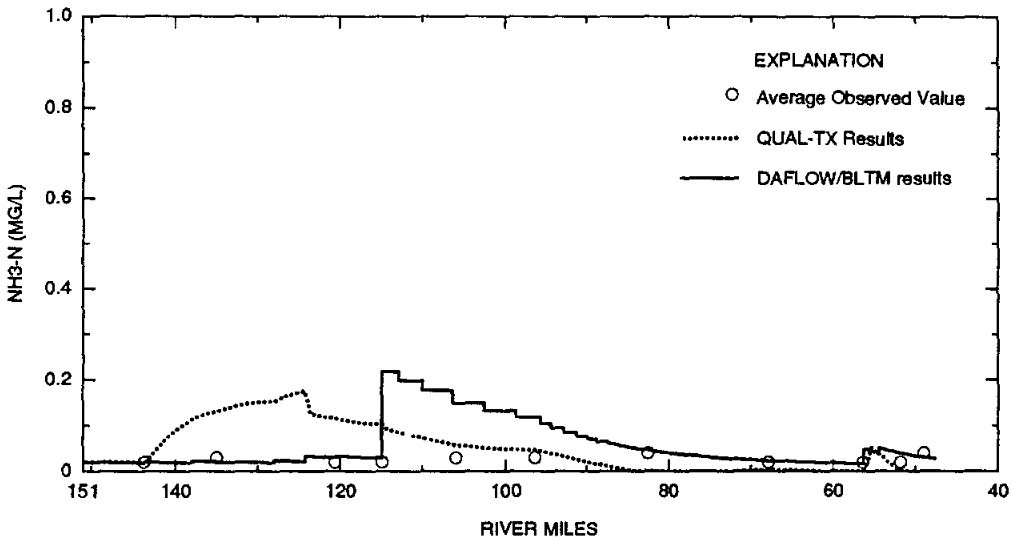


Upper Angelina River - Dissolved Oxygen Profile
September 10-14, 1984



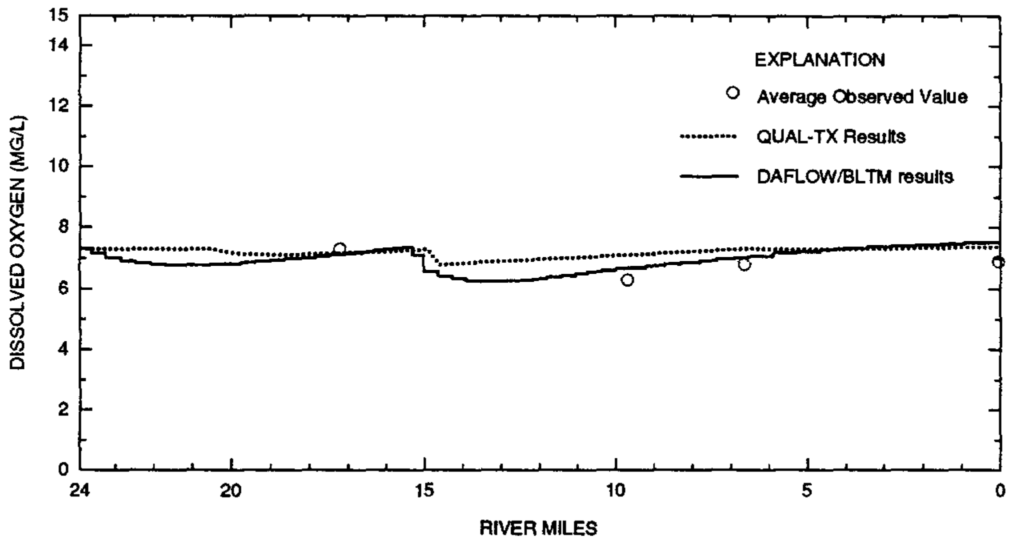
Upper Angelina River - Ultimate BOD Profile
September 10-14, 1984

Figure 15 (cont.)
Comparison of QUALTX and DAFLOW/BLTM Results:
Upper Angelina River, Segment 0611

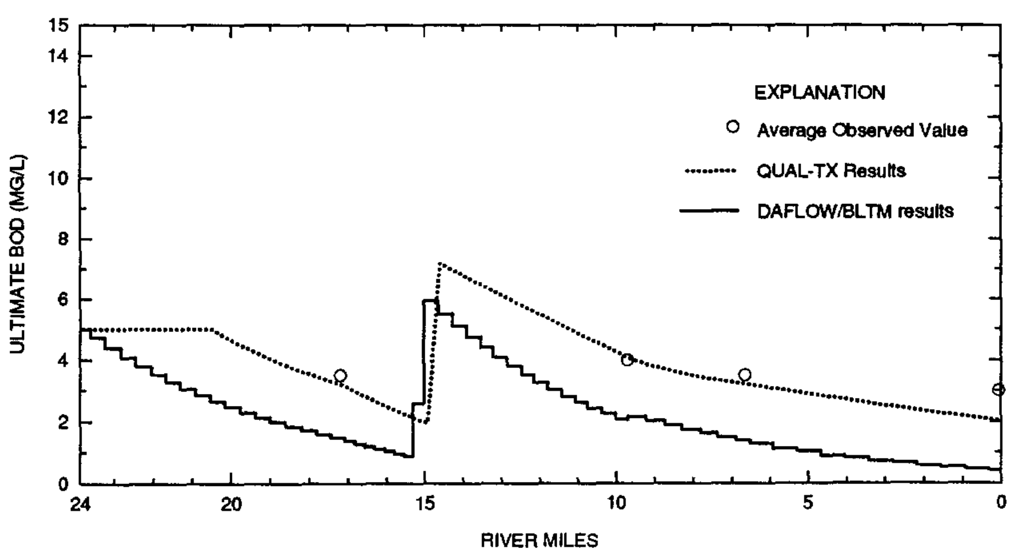


Upper Angelina River - Ammonia Nitrogen Profile
September 10-14, 1984

Figure 16
Comparison of QUALTX and DAFLOW/BLTM Results:
Bayou Lanana, Segment 0611

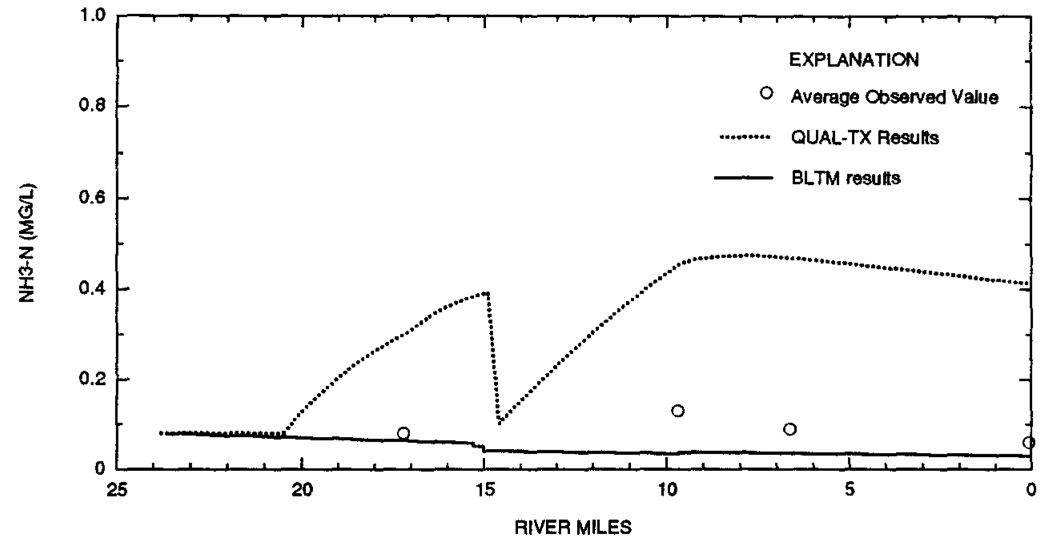


Bayou Lanana - Dissolved Oxygen Profile
September 10-14, 1984



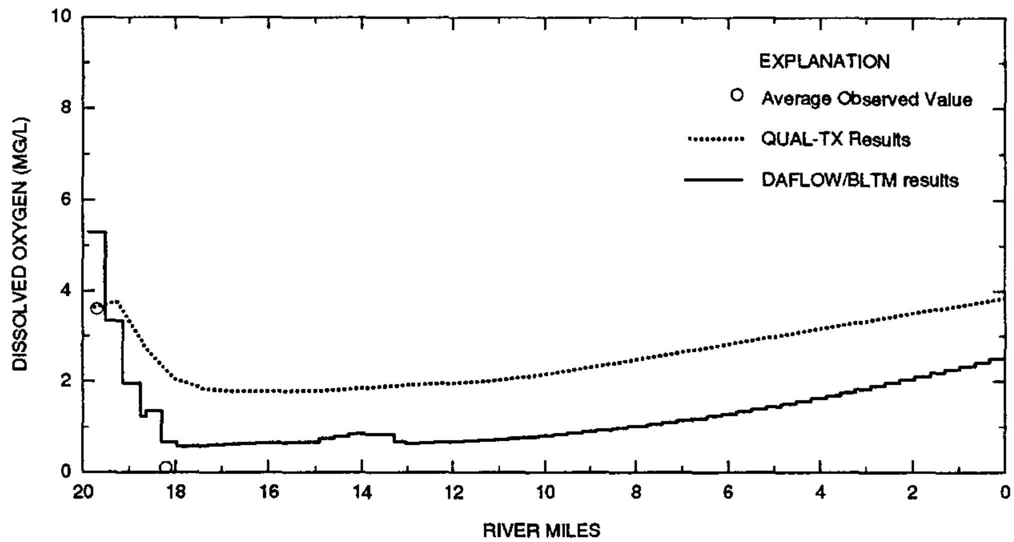
Bayou Lanana - Ultimate BOD Profile
September 10-14, 1984

Figure 16 (cont.)
Comparison of QUALTX and DAFLOW/BLTM Results:
Bayou Lanana, Segment 0611

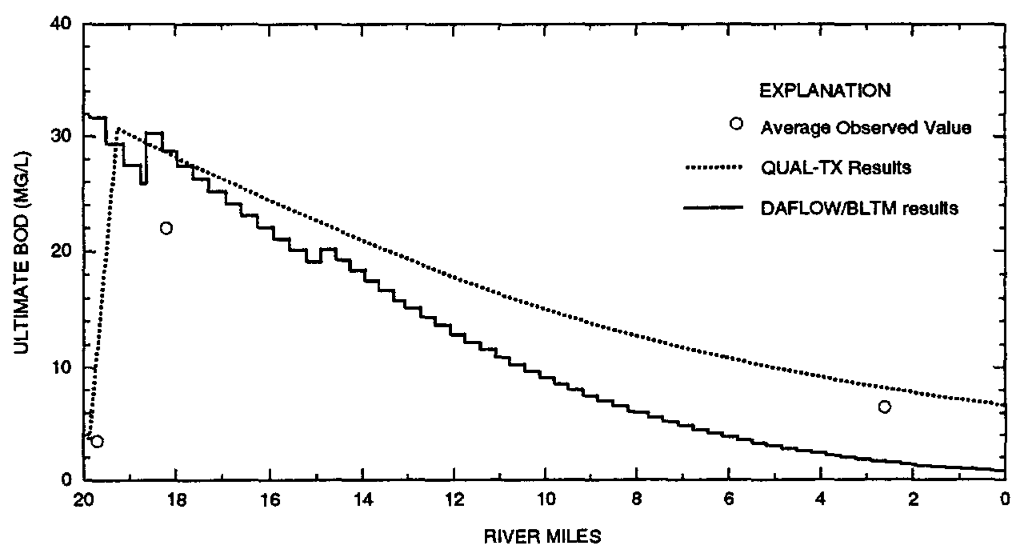


Bayou Lanana - Ammonia Nitrogen Profile
September 10-14, 1994

Figure 17
Comparison of QUALTX and DAFLOW/BLTM Results:
West Mud Creek, Segment 0611

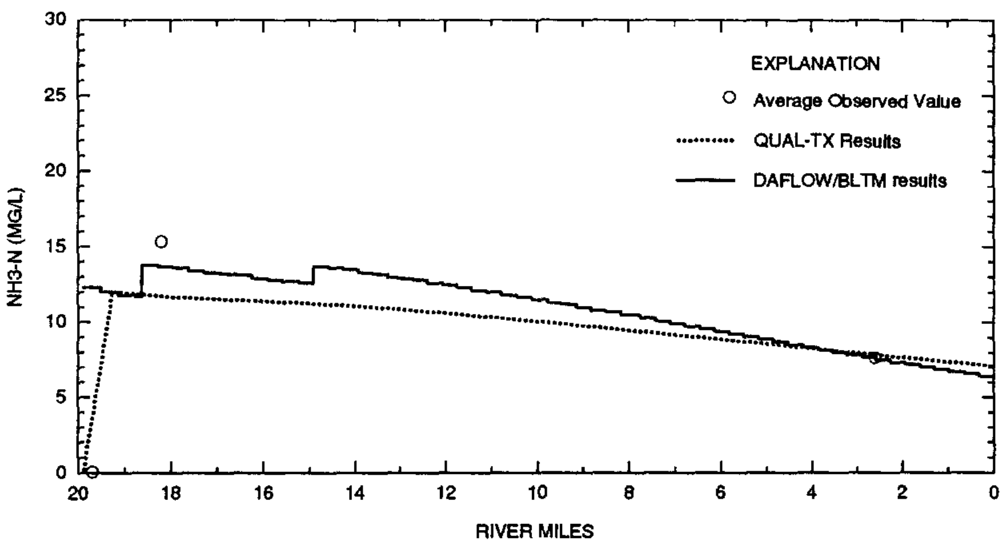


West Mud Creek - Dissolved Oxygen Profile
September 10-14, 1984



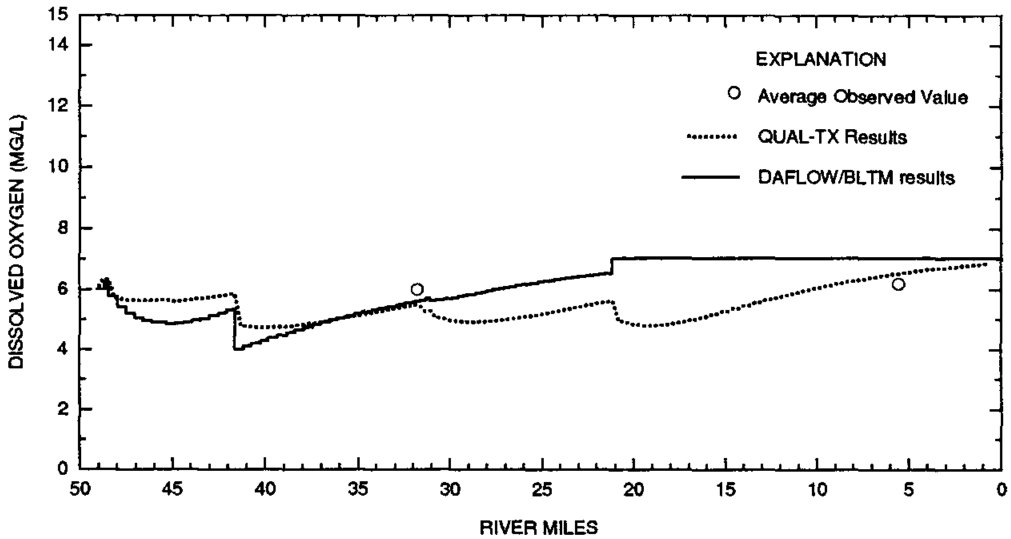
West Mud Creek - Ultimate BOD Profile
September 10-14, 1984

Figure 17 (cont.)
Comparison of QUALTX and DAFLOW/BLTM Results:
West Mud Creek, Segment 0611

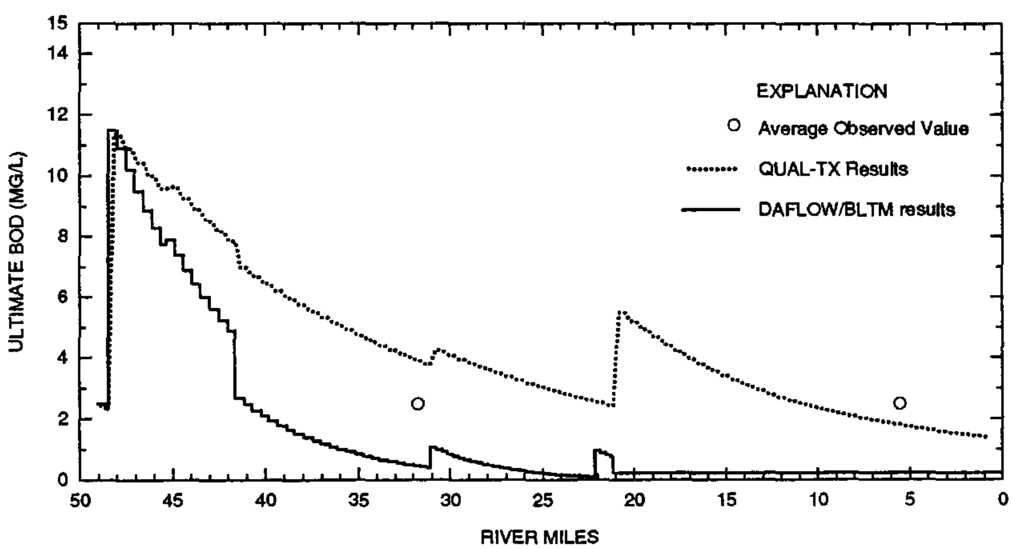


West Mud Creek - Ammonia Nitrogen Profile
September 10-14, 1984

Figure 18
Comparison of QUALTX and DAFLOW/BLTM Results:
Mud Creek, Segment 0611

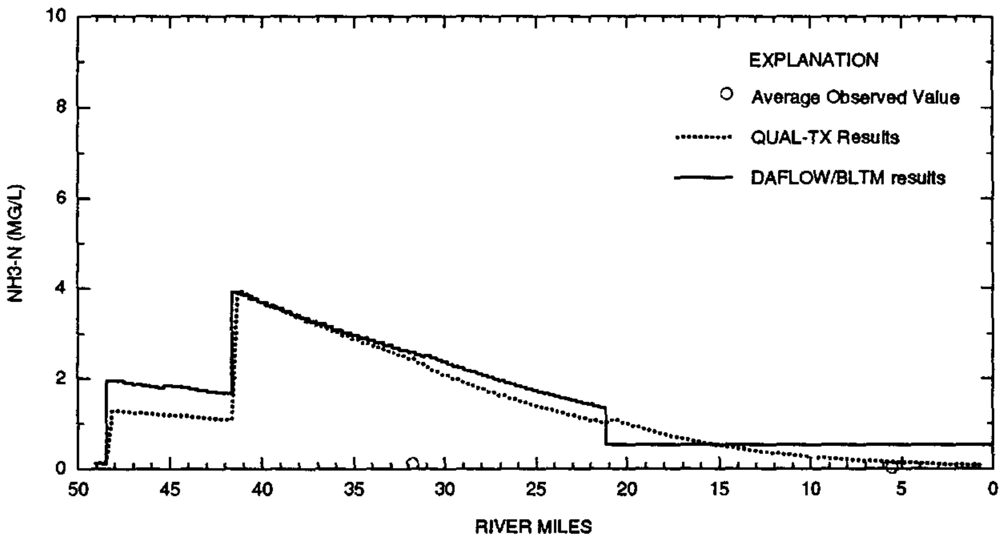


Mud Creek - Dissolved Oxygen Profile
September 10-14, 1984



Mud Creek - Ultimate BOD Profile
September 10-14, 1984

Figure 18 (cont.)
Comparison of QUALTX and DAFLOW/BLTM Results:
Mud Creek, Segment 0611



Mud Creek - Ammonia Nitrogen Profile
September 10-14, 1984

grids. A parcel volume must be able to spend at least two time steps in each grid in order for the kinetics to begin. To determine the appropriate time step and parcel size, please refer to the model documentation.

As part of this research proposal, additional kinetics were added to the model for toxic chemicals of concern in this basin. In order to add kinetics for an arbitrary toxic constituent of concern, kinetics for suspended solids were also added to the model. In addition, the kinetics were modified to include organic nitrogen and organic phosphorus in the nutrient cycles. These kinetics were added to the subroutine fink.f make the model more compatible with QUALTX kinetics and to prepare DAFLOW/BLTM to more accurately simulate water quality in rivers across Texas.

Additional differences in the kinetics between the two models (i.e. reaeration equation for dissolved oxygen) can be resolved with additional research. The first modification of the kinetics exist in a new subroutine which can be referenced in Appendix O. New parameters are described in the comment statements for this subroutine. Minor changes in the structure of the input file, QUAL2.IN, and some of the formatting statements will still be necessary to support the new kinetics. QUAL2.IN would need to be restructured to contain all the kinetic coefficients that are needed in the new kinetic equations and described in the commented statements.

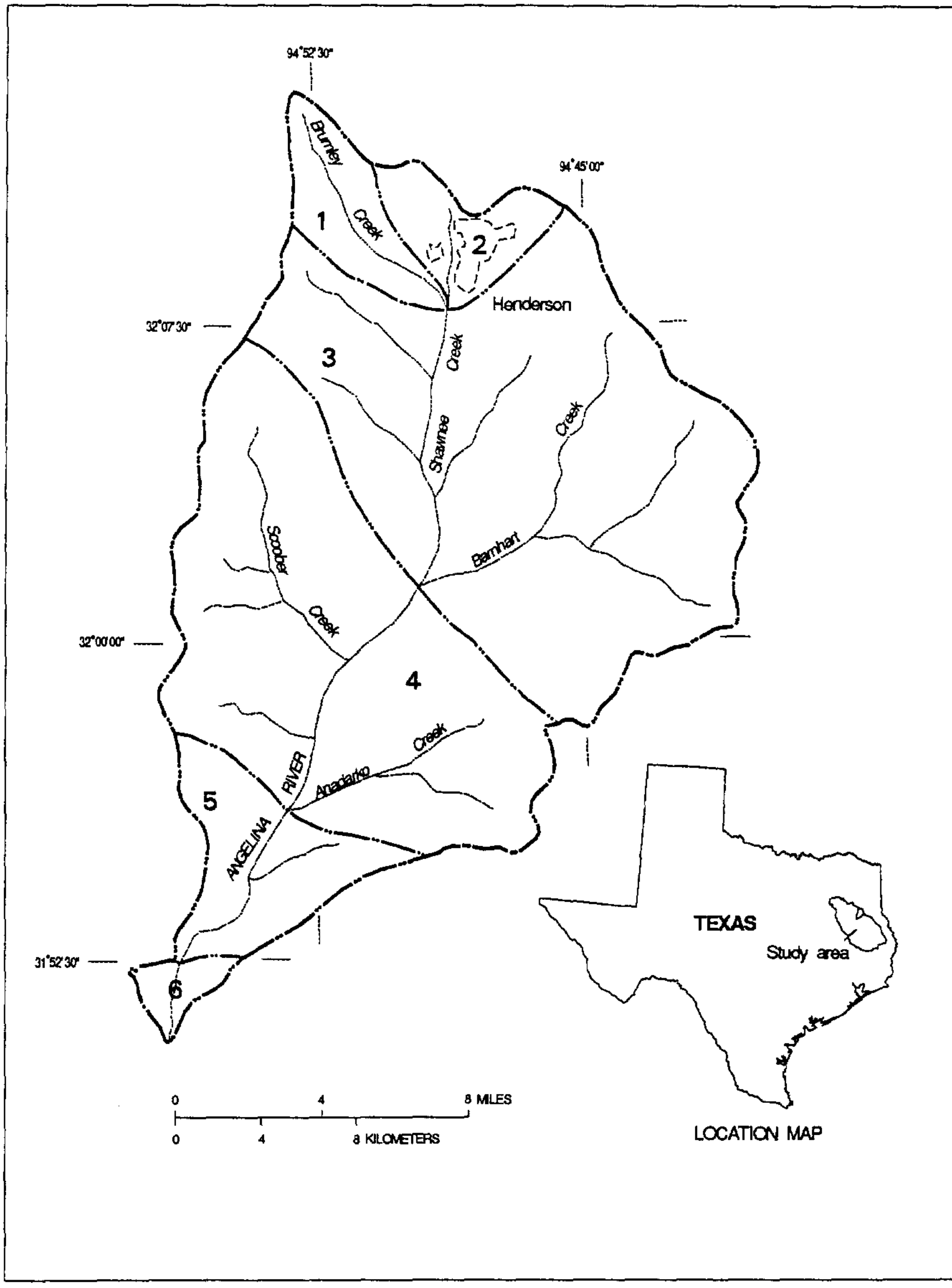
Model Input for the Hypothetical Unsteady-State Application of DAFLOW/BLTM

A complete TMDL-type approach would first identify which subbasin or subbasins are likely to present a non-point problem to the water quality-limited segment. This could be done through an analysis of different land uses in the segment's contributing drainage area or a working knowledge of the activities along the segment. Once such problem areas are defined, a "critical" storm event could be designed to "hit" that particular area or areas. A definition of a critical storm is quite elusive, as storms vary in intensity, duration, etc., and these factors have varied effects on the pollutants and flows that are generated as a result. However, historical records and additional storm event monitoring could support assumptions about the characteristics of a "critical storm."

To show the utility of the DAFLOW model and BLTM to capture dynamic water quality events, a theoretical storm event of two-year frequency was generated and superimposed upon the steady-state conditions of 1984 in Segment 0611. A subbasin in the upper portion of the segment's contributing drainage area was chosen due to suspected non-point impacts (Regional Assessment, 1992). The same water quality constituents were modeled as were modeled in the steady-state application: temperature, ammonia, nitrate, nitrite, carbonaceous biological oxygen demand, and dissolved oxygen. This hypothetical storm was assumed to have hit the entire Henderson Basin (Figure 19) uniformly in space and time.

The Henderson Basin was digitized using GIS Arc/Info and divided into five drainage areas. Hydrographs were generated for each area based upon the characteristics described in Table 4. These characteristics were determined using Arc/Info functions (drainage area and basin length) and scientific judgement (lag time and urbanization index). In some cases, where a rural

Figure 19: HENDERSON SUBBASIN OF SEGMENT 0611



hydrograph was generated, the urbanization index was not needed. The hydrographs, an example

TABLE 4
Parameters for Generating 2-Year Storm Hydrographs for Henderson Basin

Parameter	Region 1	Region 2 (Urban Area)	Region 2 (Rural Area)	Region 3	Region 4	Region 5	Region 6
Drainage Area (mi^2)	11.37	5.1	5.1	107.38	82.63	18.55	3.42
Urbanization Index: 9-36	NA	20	NA	NA	NA	NA	NA
Estimated Basin Length	7.5	1.4	2.8	13	13.5	7.5	2.2
Estimated Basin Lag Time	5	1	4	12	13.5	5	1

of which is shown in Appendix P were generated by a software package developed by the U.S. Geological Survey for a National Flood Frequency software program that is available for PC's or IBM compatibles (Jennings, 1993). The regression equations used in the program come from a USGS publication (USGS, 1994).

Water quality concentrations in runoff from the Henderson Basin were determined based on typical concentrations found in the literature (Limno-Tech, 1993). Please refer to Table 5. The land use in this basin is a combination of urban, ranchland, and forest. The runoff concentrations were dependent on whether the land was principally urban or principally rural (including ranch and forest land uses).

TABLE 5
Estimated Stormwater Concentrations from Henderson Basin

Water Quality Constituent	Estimated Rural Land Use Runoff Concentrations	Estimated Mixed Land Use Runoff Concentrations
Temperature (Celsius)	26	26
NH3-N (mg/l)	1	1
NO2 (mg/l)	1	1
NO3 (mg/l)	5	2
CBOD (mg/l)	10	15
Dissolved Oxygen (mg/l)	5.5	2

The runoff flows (derived from the hydrograph) with their associated water quality concentrations were added to the appropriate branches in the model where the runoff from the drainage areas entered the tributaries of Brumley and Shawnee Creeks. Region 1 runoff was added at Branch 2 at Grid 3. Region 2 runoff from the City of Henderson went to Branch 3 at Grid 2. Region 2 runoff from the rest of that area went into Branch 3 at Grid 3. Region 3 runoff drained into Branch 5 at Grid 2. Region 4 runoff was added to Branch 7 at Grid 2. Region 5 runoff was added to Branch 13 at Grid 2. Region 6 runoff was added to Branch 19 at Grid 2.

The model was then run using an hourly time step with the steady-state conditions determined previously used as the initial conditions in the *FLOW.IN* and *BLTM.IN* input files. Partial *FLOW.IN* and *BLTM.IN* files can be referenced in Appendix Q and Appendix R. Steady-state boundary conditions were used for the first 119 time steps in the *FLOW.IN* and *BLTM.IN* files. The storm flows and concentrations were put in from the 120th to the 153rd time step. The peak value (in the header information of *BLTM.IN*) was increased to allow for the higher flows.

Results and Discussion of Model Application at Hypothetical Unsteady-State Conditions

The hydraulic coefficients throughout this storm event were assumed to have stayed the same as during low-flow steady-state conditions. The DF value in some of the reaches, especially those in which there had been zero flow and which had a DF of .01 in the steady-state simulation, were raised slightly. This assumes that the equations derived for width and cross-sectional area are still valid at higher flows. This assumption should be tested in future use of the model.

Better estimates of stormwater concentrations should be made. Little data presently exist for estimated runoff concentrations of these constituents from rural land or mixtures of land use. Real storm data could be collected and is being collected at certain locations in the basin. This will be discussed further in the Proposed Monitoring Network section.

Plots of flow versus time at several locations in the river system and plots of concentration at several locations moving downstream in the river system shows the movement of flows and concentration plumes from the storm through the main stem of the Upper Angelina River. (There is no impact from this hypothetical storm on West Mud Creek, Mud Creek or Bayou Lanana.) Concentrations of dissolved oxygen and ammonia nitrogen were plotted. These plots of flows and concentrations are shown in Figures 20-22.

It can be seen that the impact of the storm event may vary from one grid to the next depending on a number of factors including 1) the distance of the grid from the storm inflows, and 2) the hydraulic parameters established for that grid. For instance, in Figure 21, the dissolved oxygen is impacted more severely in Branch 19 than in Branch 67. Assuming this was a critical design storm for this segment, this kind of information would lead to the identification of a new monitoring location in Branch 19.

A Proposed Monitoring Network for the UNRB

This section summarizes the analyses described above in terms of a suggested monitoring network for the UNRB and a suggested protocol for other Texas river basins to satisfy present and future water-quality planning objectives. Until an adequate number of water quantity and water quality monitoring stations with long records exist in the UNRB (and perhaps other river basins in Texas), the deterministic modeling framework is believed to offer important advantages that statistical analyses can not offer. One of the most important being the ability to test many alternative control strategies for point and non-point sources.

To define a future monitoring network, the information that is desired as a result of that

Figure 20 - Storm Flow Profiles at Various Locations on the Upper Angelina River

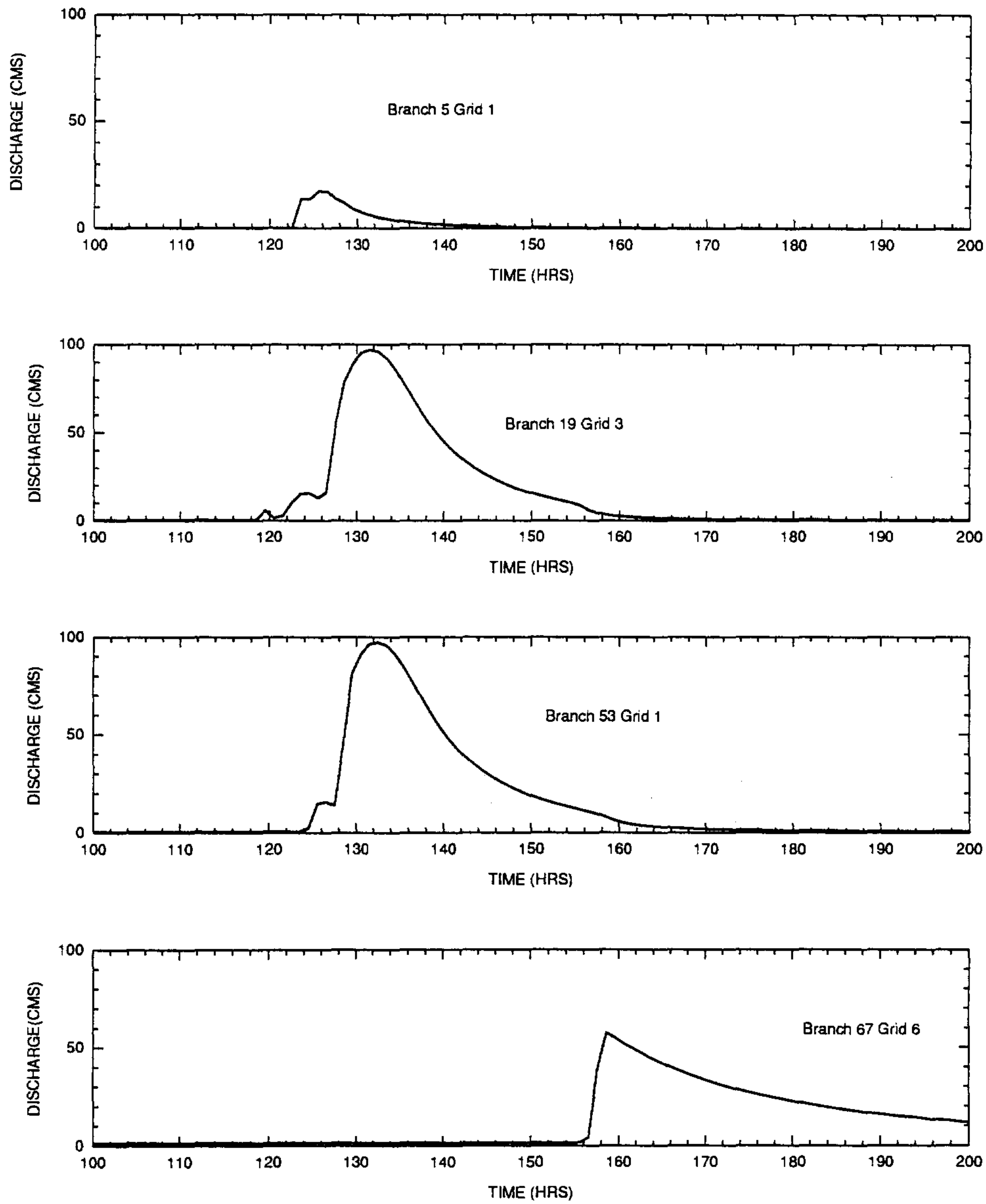


Figure 21: Dissolved Oxygen Profiles at Various Locations on Upper Angelina River

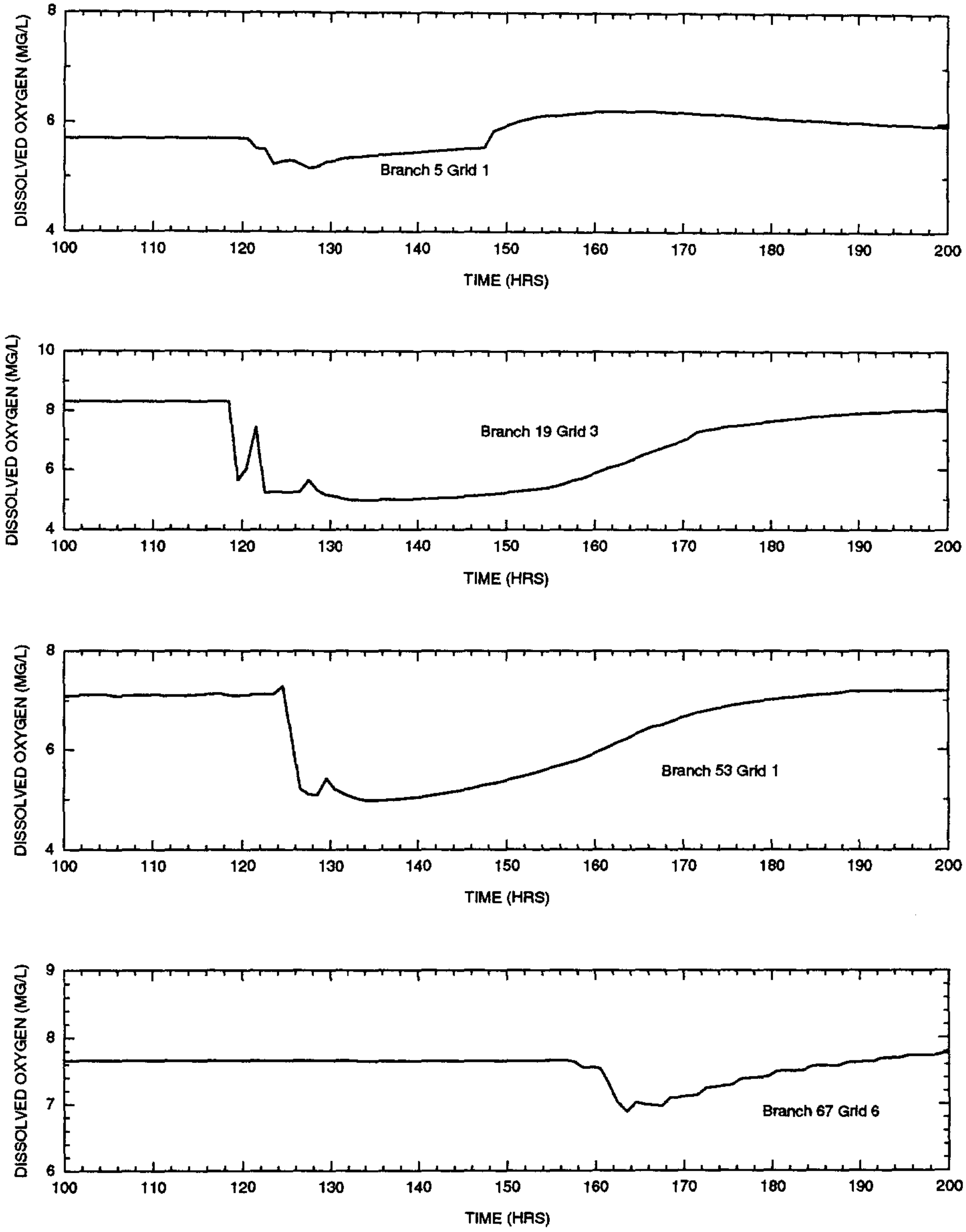
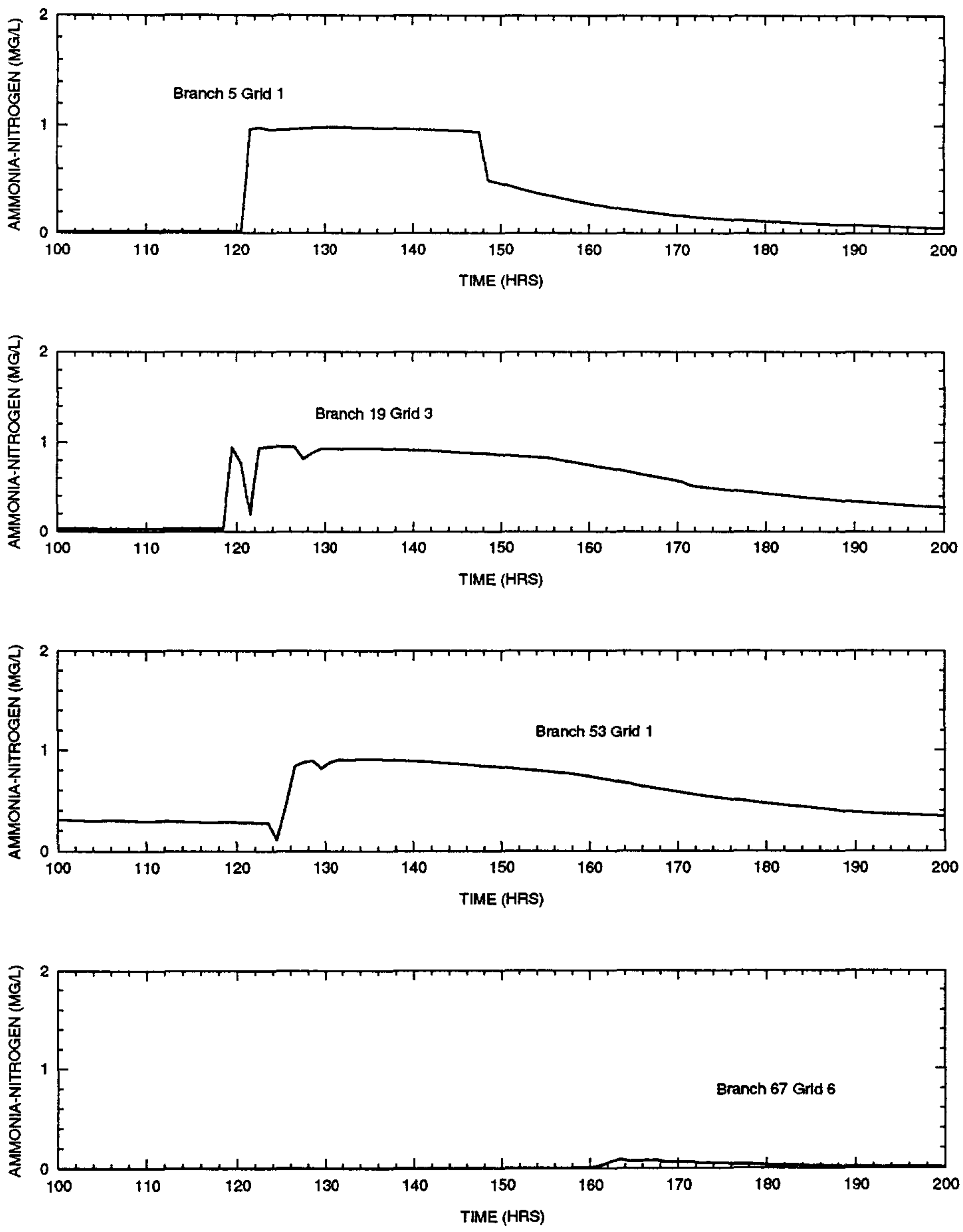


Figure 22: Ammonia-Nitrogen Profiles at Various Locations on the Upper Angelina River



monitoring must be pre-defined. Some questions that should come to mind are: What are the present uses of the data being collected? What else do I need to know? On what time step do I need to know it? Do I want to know how water quality or a water quality event in one part of the basin will affect the water quality in another part? How can the present data needs of monitoring sites (i.e. TNRCC permitting) be met while obtaining a more holistic watershed approach? Why should a "watershed" approach be used at all?

The monitoring that currently exists serves a variety of purposes and is better described as a collection of monitoring sites than as a network. A network implies a interconnectedness between the data that are being collected. TNRCC's collection of water quality reservoir and stream sites, and their performance of scattered intensive surveys, serve the purpose of NPDES permitting and compliance monitoring. The eight designated segments are treated individually as unconnected reaches. Data from USGS monitoring sites are principally used for river flow and reservoir storage trend analysis and occasional water quality studies. Sponsorship of existing gages is varied. All of the data that is currently collected is not synthesized. Cooperation between data collectors is minimal. Only recently has there been an effort to put the data in the same data base.

A watershed approach has become more and more desirable for regulatory reasons as well as water management decisions. However, it is very likely that the low-flow or other "critical" conditions will still need to be defined for regulatory purposes on a segment by segment basis. Therefore, the new monitoring network and information-gathering effort must support a variety of watershed and receiving water modeling tools. Modeling can be used as a tool to illuminate water quality issues or to experiment with different loading scenarios from point and non-point sources. However, sufficient data must be available to begin modeling and hypothesizing. So it is the chicken and egg question. What comes first? The data or the model? As in the quote at the beginning of the paper, each one depends on the other.

Due to the level of available data and deterministic modeling framework, this modeling study was based on a segment by segment delineation. It is still questionable whether future modeling and analysis for the Texas Clean Rivers Program will revolve around the segment definition. Furthermore, in this research, a one-dimensional surface water quality model was selected. This model is not suitable for analysis of reservoir segments. However, various operational reservoir water quality models are readily available and can be used for reservoir water-quality planning pending availability of data. These models include reservoir models being used currently for Texas reservoirs -- WASP4, and CEQUAL-W2, available from the Corps of Engineers Waterways Experiment Station.

The proposed receiving water model, DAFLOW, BLTM, does make use of existing QUALTX data and allows for the simulation of a "critical" dynamic inputs. Model capabilities include expansion to include kinetics for additional water quality constituents and operation in conjunction with other models. For instance, with sufficient data collection, a watershed model like HSPF could be used to provide dynamic input to DAFLOW/BLTM. Or, if HSPF was not the desired level of detail, spatial modeling tools like SWAT and Arc/INFO's GRID may be able to generate input for DAFLOW/BLTM, depending upon the time step and scale of application.

Although DAFLOW/BLTM was not applied for all the river segments or for any reservoir segments, the comprehensive evaluation of all the available data as well as the modeling results on the two river segments suggests a new monitoring network to support the current data needs and provide a stepping stone to a new level of analyses. The improved monitoring network will improve knowledge about the UNRB on a watershed level and on a segment level. It would support the data needs of QUALTX or DAFLOW/BLTM. It would be optimal if all water quality managers, monitoring agencies, and stakeholders in the UNRB could provide their input into the most effective design of flow and water-quality monitoring network. A coordination and planning meeting of representatives from the UNRB is desirable. This research and the following proposed network could serve as a starting point for conversation, perhaps leading to a generalized monitoring network to provide for all needs.

Two kinds of monitoring operations are recommended for the UNRB - fixed monitoring stations and moveable monitoring stations. Fixed monitoring stations are capable of collecting continuous or partial records of streamflow and/or water quality at a fixed site, generally for a period of years. Moveable monitoring stations are instrumentation "packages" deployed in groups of one to several sites for a short period of time - perhaps only for a few weeks to monitor for a low flow or stormflow hydrologic event. Both kinds of monitoring stations have associated communication systems. Fixed stations are generally satellite interrogated while moveable sites make use of wired or cellular telephone communications. Communication systems are crucial for the success in stormwater monitoring of non-point source events at fixed and at moveable monitoring stations.

Fixed monitoring stations are best used in the UNRB at flow and water-quality control points where such sites can serve to determine low-flow conditions or be used as boundary conditions or calibration points for a model application. Table 2 and Figure 3B, together with the modeling results of this investigation and analysis of segment data, suggests the following fixed station monitoring additions in the UNRB:

Station 08032000 Neches River near Neches

This site has long term information that is important to maintain. The site is currently in operation. It is suggested that continuous dissolved oxygen and pH sensors be added to the continuous temperature, conductance, and flow monitoring now being performed.
Reason: This location provides important dynamic information for the upper basin. It can be used as an upstream boundary condition for Segment 0604. If dissolved oxygen standards are to be changed on this segment, there should be some trend analysis of current and future levels.

Station 08032500 Neches River near Alto

It is suggested that this site be reinstalled. It was previously in existence from 1944 to 1978. In addition, a continuous automated monitoring system (CAMs) should be added to capture dissolved oxygen, pH, conductance, and temperature sensing for low flow season operation.
Reason: This site is a critical upstream boundary on the Neches, before the entrance of flows and loads from the tributaries (Hurricane and Cedar) through the City of Lufkin. Water quality

and flow information from this gage will be important for modeling those tributaries and, like Station 08032000, will be important in evaluating the proposed change in dissolved oxygen standards.

Station 08036500 Angelina River near Alto

It is suggested that the long term data at this gage be enhanced with the addition of a CAMS for low flow seasonal operation. Monthly water-quality data collection should also be added for selected constituents that are posing water-quality problems (as cited in the segment data assessments).

Reason: The monthly water quality monitoring could provide baseline information about (naturally occurring) water quality constituents of concern and also serve as a water quality control point above Sam Rayburn Reservoir.

Station 08038000 Attoyac Bayou near Chireno
and
Station 08039100 Ayish Bayou near San Augustine

These partial monitoring gages should be supplemented with water quality sampling for selected constituents. Install CAMS for low flow season operation.

Reason: Land use changes in the contributing drainage areas may have significant impact on water quality in the near future. Current nonpoint pilot projects regarding the impact of poultry litter will be supported with this monitoring. In addition, these sites represent boundary conditions for Sam Rayburn Reservoir for reservoir modeling.

Moveable monitoring stations are best used in short river reach situations, perhaps in conjunction with an intensive survey. Moveable monitoring systems typically consist of: 1) a stage sensing device, usually a pressure transducer (a stage discharge relation would be developed using hydraulic methods), 2) a CAMS (for measuring DO, pH, temperature, conductance), 3) an incremental water-quality sampler, and 4) a communications system. Refrigeration is not required at a site as samples are retrieved within a few hours of collection. These stations can be moved from the warehouse and installed within a few hours on a temporary basis.

Moveable monitoring stations are ideal for cost-effective dynamic sampling of storm-related events. These stations are more vulnerable to high water events and vandalism than fixed sites, but the overall cost is significantly less. Groups of moveable monitoring station "packages" can be used on short river reach problems with stations upstream and downstream of a reach exhibiting water quality problems. Moveable station can also be used in conjunction with one or more fixed station monitors. Some suggestions for short reach studies where moveable monitors could be used on the UNRB include trouble areas such as Paper Mill Creek, Bayou Lanana, and Shawnee and Brumley Creeks, and Hurricane and Cedar Creeks.

Monitoring of Paper Mill Creek is needed to complement ongoing stream classification studies of water quality impacts due to the Champion Paper Mill. These impacts in the past have been characterized as color and foaming in the upper portions of Sam Rayburn Reservoir, and possible dissolved oxygen, nutrient, chloride, sulphate, and fecal coliform contamination. These monitoring efforts should overlap those ongoing to establish correspondence between the studies. Some of the constituents could include, but not be limited to BOD, DO, and metals such as copper and zinc. Sampling stations should be located above the Champion discharge to ascertain background levels as well as below the mixing zone of the discharge and above the confluence of the Angelina River. Both dry and wet weather sampling is needed to separate low flow impacts from Champion from higher flow nonpoint source impacts.

Monitoring of the impacts of the City of Nacogdoches on Bayou Lanana are of special interest because of the opportunity of isolating urban runoff effects from wastewater discharge effects. Bayou Lanana essentially originates in the northeast portion of the city and flows southwesterly gathering stormwater runoff along the way. The city's wastewater discharge is southwest of the city. This would allow for monitoring of nonpoint source effects to take place upstream of the discharge. The effects of the discharge during dry weather, and the effects of the discharge plus the runoff during wet weather, could be compared. The DAFLOW/BLTM model could be slightly modified from its current configuration in order to model a storm event on this reach.

For these short reach studies, it is also recommended that some biomonitoring be performed. Of particular interest here is the relationship between water quality, the standards, and the biological condition. Using a stream that is not affected by anthropogenic activities as an indicator of the desired habitat quality, a stream segment can be assessed for its biological condition. Relating this condition back to the standards and the results of the model will give water quality managers a better understanding of the appropriateness or inappropriateness of the standards, whichever the case may be.

It is evident from the location of the planned TNRCC monitoring gages for 1994, that oftentimes politics govern the compliance monitoring network. It can be seen from Figure 2 that most of the monitoring this year will be clustered around the Paper Mill Creek tributary. This may be due to recent concerns and permitting changes for Champion Paper, Inc. On the other hand, the tributaries that flow through the City of Lufkin, which have been cited as having water-quality problems and cause Segment 0604 to be considered water quality-limited, will not be sampled. It is recommended that this compliance network be re-evaluated for its consistency and long-term effectiveness and more responsibility be given to the river authorities to oversee this type of monitoring.

Significant groundwater recharge in this basin may have an impact on the validity of surface water quality modeling results. In the QUALTX models, negative or positive incremental flows are simply added to a river sysytem to make the measured flows balance. These negative flows may represent a loss of flow to groundwater, also known as recharge. The use of the Eulerian reference frame in QUALTX enables these flows to be subtracted (or added) without having any associated water quality. A dynamic tool like BLTM can not have flows without associated water-quality concentrations. Several gain/loss studies are recommended for reaches where dynamic surface water quality is to be modeled. These studies could identify exact locations of recharge and the water quality of that recharge. This will also be important in evaluating the quality of the groundwater, which is in a state of decline (ANRA, 1992). In

Segment 0611, there were many negative flows added to the simulation, especially for the tributary Bayou Lanana. This would be a good location for a gain/loss study.

Other suggestions in addition to the new fixed sites and short reach studies include preparing data sets for reservoir modeling and watershed modeling. These models would be used in conjunction with DAFLOW/BLTM. This includes formalizing and archiving daily flow records of reservoir releases from Sam Rayburn Reservoir and adding a monthly water-quality sampler for selected constituents.

Some sampling is being performed on reservoirs in the basin by other entities. For instance, the City of Tyler operates a gage on Lake Tyler, the City of Athens has a gage on Lake Athens, and Striker Creek Reservoir is also gaged (Fisher, 1994). However, there is only a limited number of such gages, and most are simply storage indicators. More information would be needed to provide sufficient data for a flow and water-quality modeling application. Such applications are desired, especially for the Lake Palestine Study Area, Lake Jacksonville, Proposed Lake Estex, Lake Tyler, and Lake Tyler East. These reservoir studies could be phased into river authority planning for meeting the Texas Clean Rivers Program objectives.

Watershed models, and the development of critical storm information, require an evaluation of the frequency, duration and intensity of storms in the modeled basin, and selected basin characteristics including land use. Land use data needs to be analyzed in order to determine potential problem areas in terms of non-point impacts on water quality. Areas where critical storms have occurred or are likely to occur are related to land use issues. Rough estimations of loadings from each critical area could be made in simple procedures described in the TMDL documentation (Limno-Tech, 1993). Subwatersheds within the UNRB, like the Henderson Basin, should be delineated for the entire watershed, with associated land uses and other basin characteristics. Moveable storm event monitors could begin evaluating impacts from these subwatersheds to define loads and problems. For instance, at the outlet of the Henderson Basin, a storm monitor could be used to better define the nature of flows and loads from an event. Parameters that are of concern and that are identified in the segment summaries (ANRA, 1992) could be targeted.

A Network Evaluation Protocol for Other Texas River Basins

IMPORTANT: Involve as many stakeholders as possible !!! Anyone with knowledge of the basin and its water-quality problems will be beneficial to include in this process.

1. Review existing segment data that has been compiled by TNRCC for each basin and presented in the 1992 River Basin Assessment Reports.

2. Determine where USGS has continuous flow gages and where steady-state intensive surveys have been performed by TNRCC in the basin of interest.

3. Determine the relative scale of non-point to point source discharges using actual flows and pollutant loadings/concentrations in basin segments wherever possible. Land use data, local

experts with personal knowledge of problem areas, and literature values may provide the most valuable information. Statistical procedures currently being developed by TNRCC for the Texas Clean Rivers Program may aid this type of analysis in defining which reaches have water-quality problems. Define a critical storm event for simulation.

4. Code the existing intensive survey information into the input files for the DAFLOW model and the BLTM model. This may mean simply rewriting the QUALTX information into DAFLOW and BLTM input. In segments where intensive surveys do not exist and there are non-point source impacts, an intensive survey should be planned and executed. BLTM kinetics should be modified to include kinetics for water-quality constituents of concern in the basin or subbasin being modeled.

5. Repeat QUALTX model simulations at steady-state with the DAFLOW/BLTM model. Check for consistency of results. Superimpose critical non-point source events over the steady-state run or over a different flow scenario supported by flow and water-quality information from either an intensive survey or permanent gaging equipment (i.e. simulate a sudden summer storm disrupting the normal or low flow conditions).

6. Re-evaluate permit levels and relative impacts based upon the model simulation results of the unsteady-state condition.

7. Evaluate the existing flow and water-quality monitoring stations. Select boundary condition locations to set off critical locations, and choose fixed and moveable station locations to comprise an improved network monitoring plan.

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