The Town Lake Report

Volumes I and II

City of Austin
Watershed Protection & Development Review Department
Environmental Resources Management Division

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THE TOWN LAKE REPORT

VOLUME I

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TABLE OF CONTENTS

TOWN LAKE REPORT

VOLUME I

LIST OF FIGURES

VOLUME I

LIST OF TABLES

VOLUME I

TOWN LAKE ENVIRONMENTAL UPDATE REPORT
EXECUTIVE SUMMARY

Town Lake's importance as a natural resource is growing in tandem with Austin's rapid population. The lake is a source of drinking water for the City, and its greenbelt and open waters are widely used for recreation and as a focal-point for public events. In 1992, under the Clean Lakes program, a comprehensive report entitled the "Town Lake Study" (COA 1992a; COA 1992b; COA 1992c) was prepared. It examined the condition of the lake (Volume I), water quality control alternatives (Volume II) and a feasibility study (Volume III). This report updates the diagnostic study, Volume I (COA 1992a), including the current status of water quality with data analyzed through the year 2000. It also includes a summary of measures taken to reduce pollution from urban runoff since 1990.

Changes since the 1992 Town Lake Study

During the 10 years from 1990 to 2000, the population of Austin and surrounding areas grew by more than 20 percent, increasing pressure on our natural resources. Recognizing signs of mounting detrimental impacts to water quality and the environment, the City of Austin put in place enhanced measures to protect Austin's creeks and receiving water bodies. With continual increases in impervious cover, traffic, and associated non-point source pollution, it is difficult to attribute improvements to specific efforts, but protection measures continue to offset the impacts of development in our watersheds. The most far-reaching regulatory measure now protecting Town Lake is the Urban Watersheds Ordinance. This ordinance amended the Austin City Code in 1991 to provide water quality protection through requirements for buffers, structural water quality controls, and protection of critical environmental features. Other policy changes recommended in the Town Lake Report were implemented in the early 1990s, including a minimum flow (MDF) policy put in place by the Lower Colorado River Authority (LCRA) and a citywide ban on phosphorus in detergents. Multiple programmatic measures such as education efforts, as well as construction of water quality control structures, are also being implemented (Section 2.2). Current efforts and new proposals for all these aspects of water quality protection are being directed by and are described in detail in the Watershed Protection Master Plan, Phase I (COA 2001b).

Town Lake Water Quality

Analyses of water quality data demonstrate the impacts of our urbanized watersheds on the Colorado River as it courses through central Austin. Measurements of turbidity, chlorophyll-*a* and some nutrients increase in the downstream direction. During storms, the levels of many constituents and bacteria are elevated downstream of the most urbanized watersheds, exhibiting temporal effects of urban inputs. This degradation of water quality as it moves through Town Lake may eventually impact the Colorado River downstream of Austin, although the flow type as determined by releases and inputs of treated wastewater effluent below the dam may present more cause for concern in that segment of the river.

The water quality impacts from Austin's urbanized landscape were observable 10 years ago, and analysis of monitoring data collected since then presents further evidence of degradation. Given a specific combination of dam releases and storm events, slight, though statistically significant, increasing trends are observed for total Kjedahl Nitrogen (TKN), temperature, chlorophyll *a,* and dissolved copper. However, a few parameters, including ammonia and dissolved lead, appear to be improving during the recent past. Levels of nitrate as well as fecal coliform counts have a percentage of exceedances that may soon indicate a concern using TNRCC assessment procedures.

Conditions contributing to the trophic status of Town Lake have remained relatively unchanged, with new analyses indicating Town Lake's trophic status as wavering between oligotrophic and mesotrophic during most of the year. Eutrophic levels, however, are observed during most years for small periods of time. Some of the water quality parameters measured seem to suggest the potential for worsening algae conditions, but results were not consistent for similar parameters. During fall 2000, the algal counts remained high for twice as long as the previous longest period, and although the overall counts do not show a significant trend, the maximum chlorophyll-*a* concentrations have been increasing over time. Using TNRCC screening levels (TNRCC 2000), Town Lake has exceeded criteria for chlorophyll-*a* in six of the last seven years in at least 5 percent of samples. However, TNRCC requires a higher percentage of exceedances to assess this condition as a concern. It is unfortunate that the highest algal levels are located adjacent to the City's drinking water intake.

Pollutant levels, particularly nutrients, as well as algal growth affect the biological life in the lake. Decreases in dissolved oxygen (DO) may indicate a potential concern. In particular, the frequency and duration of near-anoxic conditions at the deepest downstream area of the lake are increasing over time. A clam kill was observed in September 1996, and bottom DO was 0.25 mg/L at the Lamar Street bridge where the majority of the clams were found dead. Potential causes of the abnormally low DO include an influx of organic debris and nutrients in stormwater, subsequent algal growth and atypically low releases from Tom Miller Dam (235 ft^3/s on August 31). Although LCRA put into effect their latest Minimum Daily Flow (MDF) policy in 1992, even the 100 ft^3/s flow required under non-drought conditions may be insufficient to maintain the desired minimum DO concentrations under post-storm, non-release conditions.

The significance of non-urban inflows remains critical to the condition in Town Lake, particularly during non-storm conditions. The influences of Barton Creek and Barton Springs, particularly the introduction of elevated groundwater nitrates, are demonstrated spatially with increases in the lake below the influxes. Additionally, when the annual average discharge of Barton Springs drops below 30 ft^3/s, Town Lake annual percentages of nitrate values exceeding TNRCC screening levels are lowest. Therefore, maintaining the quality of Town Lake continues to depend upon maintaining the quality and quantity of water from Barton Springs as well as Lake Austin. Tracing in the Barton Springs segment of the Edwards Aquifer (BSEA) has demonstrated surprisingly rapid travel times, which emphasize that impacts on the non-urban watersheds may be transmitted to Town Lake with little opportunity for attenuation.

During release conditions, flows in Town Lake are dominated by Lake Austin water. The water quality in Lake Austin is characterized by higher mean values of TKN, solids, and plankton than are found in Town Lake, but most concentrations are inversely related to flow. In general, cleaner water is released to Town Lake. Lake Austin may also be changing its patterns of algal levels, which may have an effect on Town Lake as well. Overall, the forecast for changes in water quality for Town Lake is unclear. Evaluations of probable future scenarios are discussed in Volume II, where modeling examines conditions and limiting nutrients in greater detail.

Town Lake Sediment

Sediment deposition and its effects in terms of clarity and siltation have been of historical concern in Town Lake as indicated by the original Town Lake goal to decrease sediment loads to the lake by 50 percent (COA 1992a). The impacts of sediment within the lake are seen as clarity decreases and turbidity increases in the downstream direction. A slight, though statistically significant decreasing trend in clarity is observed. Sediment deposition could reduce the volume in the lake, and the USGS identified a backwater area in the lake's downstream basin where they obtained a core to characterize the sediments and deposition. The core results indicate an accumulation rate in that localized area of 0.98 inches/year. However, over the majority of the lake area, sedimentation appears to be offset by scouring events that transport the sediment downstream. A volumetric survey in 1999 indicates no net sedimentation in the lake system since 1992. Comparisons using aerial photography also indicate little change in deltaic formations at creek mouths since 1951.

Sediment quality is important because sediments can reflect water quality constituents that are hydrophobic, as are many of the more toxic pollutants such as pesticides and PCBs, which resulted in the 1990 fish consumption advisory. Sediment samples from Town Lake document the long-term effects of anthropogenic emissions and the recovery of a system from persistent pollutants. New analyses of Town Lake sediment toxin concentrations confirm some of the analyses conducted in the original 1992 Town Lake Report. Many toxic constituents in the sediment remain at levels of concern and, in addition, continue to move from upland sources to the receiving water body. Some decreases in restricted chemicals are seen, although the levels of these restricted constituents are still higher relative to sediment quality guidelines (SQGs) than observed metal concentrations, which are continuing inputs.

Many lake samples had concentrations for some metals, particularly cadmium and lead, which exceeded at least one screening level. Zinc and other metals showed a fairly strong spatial pattern through the lake, increasing downstream with highest levels below the most urban watersheds at South First Street, Congress, and IH-35. These urban watersheds are the source of these pollutants, as demonstrated by the high levels detected in sediment collected from water quality control structures capturing runoff from urbanized areas. Most metal concentrations are decreasing slightly over the period of record. While control measures put in place may be promoting this improvement, sediments are also impacted by severe flood events that may re-suspend and flush older deposited sediments downstream.

The organochlorine pesticides still show concentrations over SQGs, with chlordane and DDE (the breakdown product of DDT that persists the longest) most prevalent in recent years. The presence of these banned pesticides in water quality control structures indicates their continued transport from older upland soils to Town Lake. Decreasing trends for the DDTs and chlordane were significant, as is expected with their discontinued use.

Besides pesticides, many synthetic organic materials are being produced for various purposes and as the by-products of other processes (such as the refining of gasoline and oils). PCBs and PAHs are found in sediments in the Austin area. PCB medians above detection limits have been seen in only water quality control structures, where they are the highest, and in Town Lake sediments. Similar to pesticides, PCBs are apparently still at levels of concern and are still being input into the receiving water system. PAHs have not only been identified as a problem in deposited sediments, but have been associated with suspended particulates. Many PAHs are found in creek sediments, exceeding SQGs in some creeks; however concentrations in lake sediments are below detection limits. The highest concentrations have been documented in dry tributaries and control structures, but some structures in high traffic areas had low levels. Concern about PAHs is rising as they are detected in more areas and may be showing a dramatic increase over time, as indicated in a USGS core sample from the Town Lake basin. As the City plans new policies and methods to address non-point source pollution problems, the polycyclic aromatic hydrocarbons may arise as a new focus.

Although levels of concern are not yet reflected in Town Lake sediments, there have been detections in the creeks that indicate cause for concern.

Town Lake Fish Tissue Studies

Since the 1992 Town Lake Report, fish tissue analyses has been conducted in three years, 1994, 1995, and 1998, resulting in the removal of the fish consumption advisory in October 1999. The removal of this advisory accomplished a primary goal for Town Lake. Parallel to results seen for sediment toxins, the maximum detected organochlorine pesticide concentrations in fish tissue have been decreasing over time, although some still have concentrations above the FDA action levels. Recent metal concentrations in fish tissue did not show continued decreases after 1985, contrary to sediment results. Maximum mercury concentrations, in fact, have been steadily increasing rather then decreasing, although when normalized by fish weight they peak in the middle of the time period and none of the fish tissue metal levels in 1998 were above USEPA Fish Tissue Residue Criteria.

If using a new reference dose for mercury for fish consumption, announced by USEPA in January 2001, a monthly consumption limit for Town Lake fish would be required. State criteria, however, have not yet been revised.

Trash and Debris

The impact of trash and floatable debris as a form of visible pollution has been recognized since the 1992 Town Lake Report, which identified a reduction goal. The Visual Index of Pollution (VIP) was implemented in April 1994 to provide a periodic measure of the City of Austin's litter control performance by documenting visible trash on the shores of Town Lake. An increase or decrease in the amount of trash along these waterways can indicate the usefulness of several methods of trash abatement currently used by the City. The scores have consistently decreased from the original baseline in 1994 (a decrease indicating a reduction in visual trash and debris). Continued improvements in the method and coordination, with staff responsible for cleanup efforts, should contribute to increased effectiveness, as the consistent increase in the amount of trash removed from the lake over four of the last five fiscal years has shown.

Master Planning and Lake Protection

The interplay of the continued urban development and increased protection efforts of the past 10 years can be characterized by the changes we observe in Town Lake today. Some improvements, such as decreased pesticides found in sediment and fish, are the result of national efforts, as this report concludes near the 30th anniversary of the Clean Water Act. Some signs of continued degradation emphasize the difficulty in treating runoff from new development and increased traffic. The City has undertaken the task of applying the most efficient management practices for water quality control, while also addressing the contributing problems of increased flood flows and eroding creek banks by developing Phase I of a Watershed Protection Master Plan (COA_WPD 2001). This plan revisited the goals for Town Lake using the model described in Volume II of this report and projections of future development with current regulations. The overall goals related to water quality and individual objectives for specific water bodies are summarized in Section 2 and are described in detail in the Master Plan Report. The overall goals for Town Lake are synthesized in the goals of both the state and the Clean Water Act of meeting its Designated Use Support status. Environmental Resource Management staff examined the potential problem areas that may impact its uses: aquatic life use, non-contact recreation, and public water supply. Staff devised strategies and watershed-specific goals to address algae blooms by controlling nutrient loads, sediment toxin loads, sedimentation, and trash. The Master Plan recommends solutions to address these problems, prioritized citywide and in conjunction with flood and erosion solutions. As these solutions are implemented, new Town Lake goals will be to maintain existing loads to the lake, maintain similar algae bloom conditions, and attain excellent aesthetic conditions. Continued lake monitoring, as recommended in this report, will determine if Austin will be able to achieve its goals and preserve Town Lake as a beneficial natural resource.

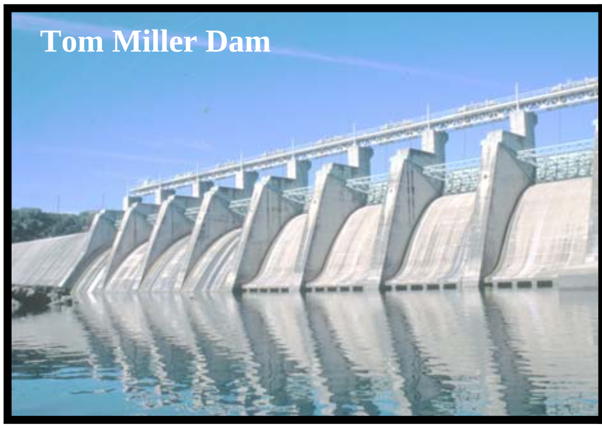
1.0 INTRODUCTION

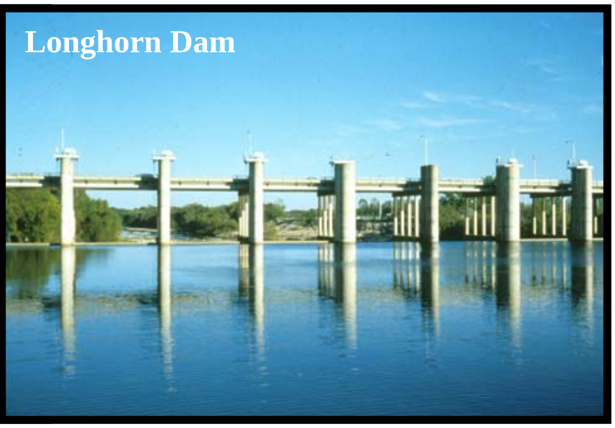
Town Lake is a riverine reservoir located in downtown Austin, Texas (Figure 1.1). The lake is a source of drinking water for the City, and its greenbelt and open waters are widely used for recreation including boating, biking, jogging, fishing, bird watching, and as a public open space for concerts and other events. Many of these functions are highly dependent upon the water quality and aesthetic conditions of the lake. The importance of Town Lake as a natural resource is growing in tandem with Austin's rapid growth. However, with increased population and traffic comes the increased potential for water quality degradation due to urban runoff pollution. Changes have occurred as a result of increasing development pressure and in response to it. The City's response has been to initiate both a comprehensive planning process to address problems, the Watershed Protection Master Plan (COA 2001b), and new methods to track the response of our water resources to both the pressures and the solutions implemented. Consequently, just as emerging problems in the lake initiated the 1992 Town Lake Study, the changing landscape of Austin as well as new management methods have prompted the revisiting of Austin's central water resource through this report.

1.1 Environmental Setting

Town Lake is the last of a series of seven Central Texas reservoirs on the Colorado River known as the Highland Lakes. Town Lake was formed in 1960 by the completion of Longhorn Dam across the Colorado River to provide cooling water for the City's two steam-electric generating plants. The lake stretches for six miles as a run-of-the-river impoundment through the heart of Austin's central business district and occupies some 420 acres. Because of the lake's urban setting, it receives non-point source pollution from nine major tributary creeks and numerous stormwater outfalls, draining both fully developed and rapidly developing watersheds. Most of these streams are now ephemeral, dominated by storm flow. The total drainage area between Tom Miller Dam and Longhorn Dam is 158 square miles.

Groundwater flow into Town Lake is also significant. During periods of low upstream releases and non-storm conditions, groundwater flows from the Barton Springs segment of the Edward’s Aquifer make up the majority of the inflow to the lake. Barton Springs is the largest of the springs feeding the lake.


Tom Miller Dam


Longhorn Dam

Town Lake is operated as a constant-level reservoir with its flow regulated by releases from Tom Miller Dam upstream and Longhorn Dam downstream. Higher flows are released during the growing season to provide irrigation water to rice farmers along the Colorado River in south Texas. These high flows provide a constant supply of water from the less-developed upstream reservoirs of Lake Austin and Lake Travis; however, during the late fall and winter, flows are reduced and water quality is dictated more by urban runoff within the Town Lake watershed.


Town Lake

Although Town Lake is vulnerable to non-point source pollution, it is also a key natural resource for the Austin community. The lake is considered excellent habitat for its diversity of fish and waterfowl. Town Lake is a source of drinking water for the Austin community and its waters are used for cooling the City's Holly Power Plant. However, long range plans for Town Lake may include decommissioning both the Green Water Treatment

Plant and the Holly Power Plant. If these plans are implemented, Town Lake's aesthetic, recreational, and wildlife habitat roles will become top priority. Town Lake is historically evolving from a lake built to supply Austin with basic needs such as water and electricity, to a lake whose primary benefits are to enhance the quality of life for Austin's human and wildlife populations.

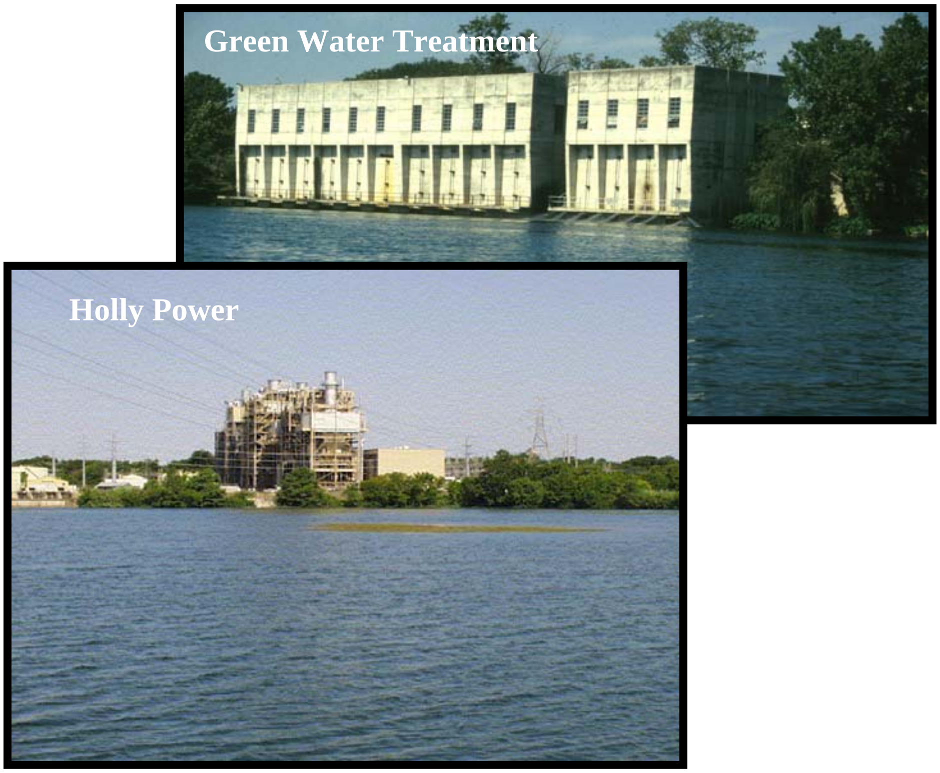
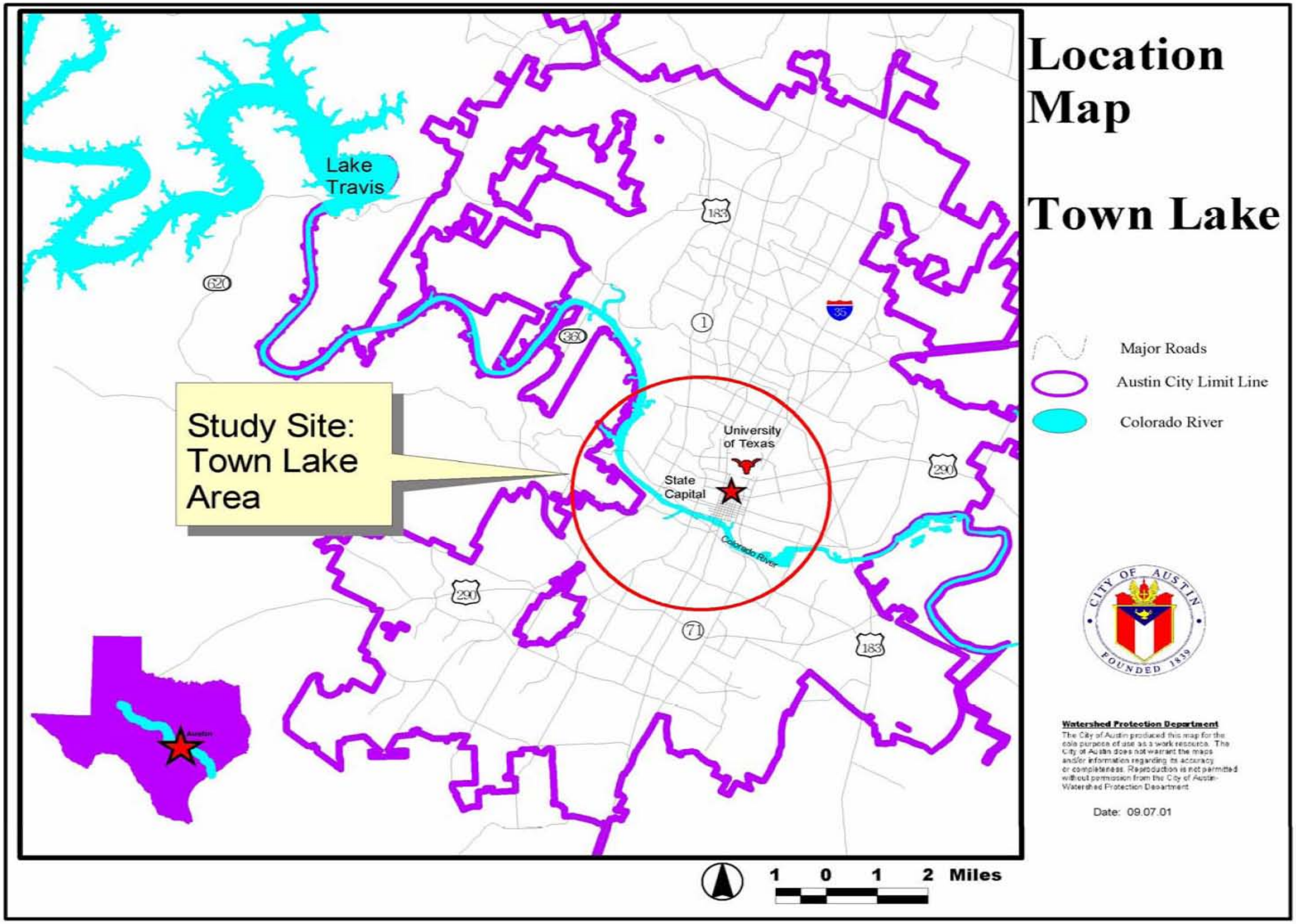


Figure 1.1 Town Lake Map



Watershed Protection Department
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Date: 09.07.01

1.2 Scope and Intent of Study

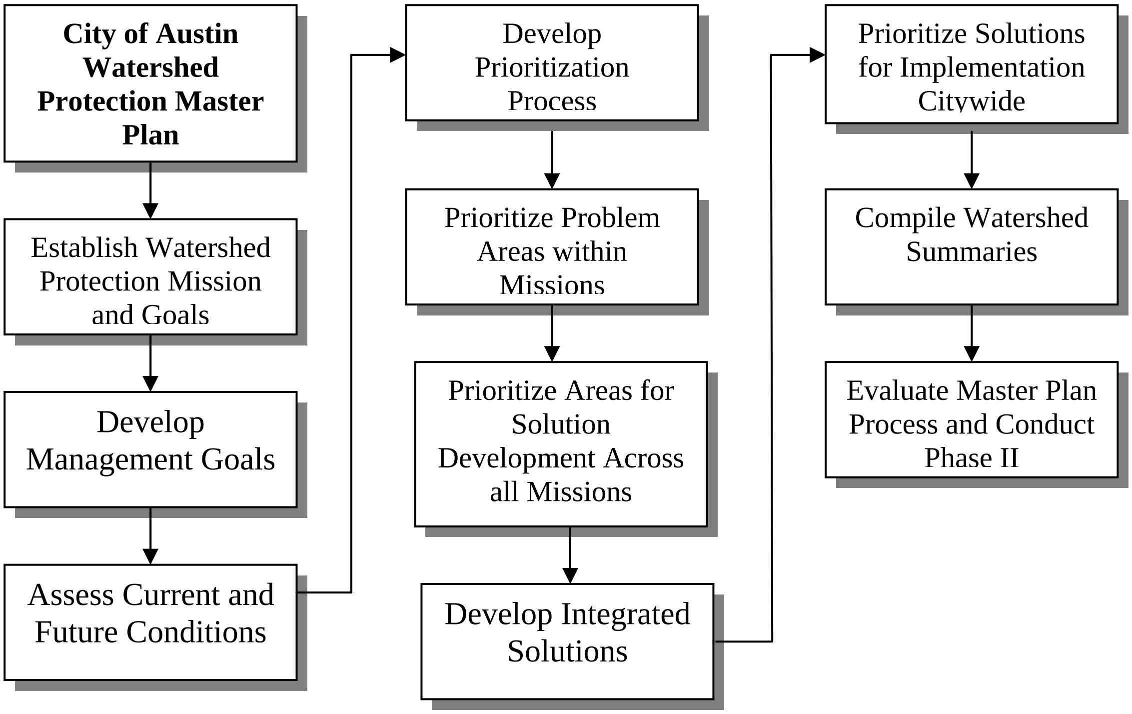
This update was completed after the City finished the first phase of a Master Plan that encompasses the evaluation of extensive data for Town Lake and its contributing creeks; assesses alternatives for addressing flood, erosion, and water quality problems; and considers goals for protecting both our citizens and our natural resources. The report updates trends and status of water quality with increased development and measures taken to retard detrimental impacts of urban runoff since the 1992 EPA Clean Lakes Grant Report on Town Lake (COA 1992a; COA 1992b; COA 1992c). The 1992 Town Lake Study was a comprehensive diagnosis of available water quality data up until 1991, pollution control alternatives, and feasibility of alternatives for implementation. Therefore, the current time, before full-scale implementation of Master Plan recommendations, is an ideal point to re-examine the status of Town Lake.

Changes in water quality management efforts will be enumerated in Section 3.0. This will provide background for consideration of the condition of Town Lake. However, the focus of this report is primary data collected within Town Lake itself. The data compiled and analyzed for this report were used to assess:

- general water quality trends,
- toxin levels of metals and organics in sediment and fish tissue,
- algae blooms,
- lake model development,
- spring contributions and influences,
- sediment deposition and accumulation, and
- trash/debris trends

This report will diagnose the present condition of Town Lake following additional monitoring, pilot retrofits, and changes in the City's regulatory policy since the 1992 Town Lake Diagnostic Report (COA 1992a). The assessment of new water quality control alternatives and prioritization of these control alternatives are not included in this report. The 1992 Town Lake Study discussed alternatives and their feasibility but capital, programmatic, and regulatory solutions for water quality problems are now incorporated within the City's Watershed Protection Department Master Plan which integrates solutions for water quality, erosion, and flood control problems. Figure 1.2 below outlines the primary features of the Watershed Protection Master Plan.

Figure 1.2 Master Plan Process



1.3 Monitoring Programs and Data

Monitoring over the last 10 years has been enhanced and redirected to improve our knowledge of water quality related problems and pollution sources in the City of Austin. As the City has grown and master planning efforts have been implemented that incorporate flood, erosion, and water quality goals, monitoring has grown to encompass assessment of erosion, aquatic habitat, and aesthetics in the urban core and developing areas that were previously non-urban. Concurrently, intensive studies have been conducted in specific Town Lake contributing watersheds and reports on these data document the local conditions and planning efforts more exetnsively. The City has also been a monitoring partner in the TCEQ Clean Rivers Program administered by LCRA for the Colorado River basin to optimize their efforts and more readily obtain extensive geographically based data through other agencies. Special studies such as bathymetric mapping, vegetative surveys, and aesthetic surveys have rounded out the data sources for this report which focuses on our primary receiving water body, Town Lake.

The 1992 Town Lake Report recommended a monitoring strategy to track water quality trends in Town Lake and to assess the effectiveness of the proposed pilot projects; the implementation and modification of the components of this strategy are addressed in the following two sections.

1.3.1 Town Lake Monitoring

The primary monitoring components addressed in this report are within Town Lake itself and were designed in 1992 to track the cumulative impacts over time. Each section of this report will deal with data that was derived from Town Lake monitoring and will address the specific elements of the individual programs. The general features of the monitoring plan are described below.

Town Lake Water Quality Monitoring – Following the 1992 Clean Lakes Grant report, City Environmental Resources Management (ERM) staff have maintained a regular monitoring plan for water chemistry to track the health of the lake over time at consistent sites from the headwaters at Red Bud Isle near Tom Miller Dam, downstream to Town Lake's basin, near Longhorn Dam. Now this program is also part of the cooperative monitoring program with the Lower Colorado River Authority (LCRA) for the Clean Rivers Program (CRP) and meets the objectives for both programs. One of the major enhancements to this program since the 1992 plan was post-storm monitoring and deployment of logging datasondes. This was done to continuously monitor dissolved oxygen fluctuations resulting from diel cycles of algae photosynthesis and respiration, senescing and decomposing algae blooms, transient storm inflows of organic matter, and inflows of other oxygen-demanding pollutants from urban tributaries.

Town Lake Algae Monitoring - Algae blooms were tracked, as recommended in the 1992 Town Lake Report, by monitoring chlorophyll-a and plankton counts, and using in-situ multi-parameter probes. Intensive sampling during algal blooms was conducted to provide data on trends in blooms and primarily for lake modeling calibration and verification. These data are discussed in detail in Sections 5 and 7.

Fish Tissue Analysis – The 1992 Town Lake Report recommended analyses related to the Texas Department of Health (TDH) fish consumption advisory. Three sampling events have occurred in cooperation with other agencies, resulting in removal of the fish consumption advisory based on results from the last sampling event in 1998. Results from fish tissue analyses are included in Section 11.

Sediment Analysis – Sediment samples are collected on an annual basis, as recommended by the 1992 Town Lake Report, and analyzed for a large suite of heavy metals and organic parameters, including many toxins. This monitoring was completed in cooperation with the USGS as described in Section 10. A modified sampling plan is now in place that will focus on sediments in the basin at the downstream end of the lake.

Town Lake Sedimentation Monitoring – Tracking sedimentation rates by measuring lake volume was also recommended in the 1992 report. Sedimentation was periodically measured by mapping depth profiles along cross sectional transects representing several locations along the lake. Macrophyte and filamentous algae growth was also monitored along these transects. Ultimately, the City of Austin contracted with the Texas Water Development Board to produce a detailed bathymetric map of Town Lake in 1999 using state-of-the-art global positioning and sonar technology. The bathymetry was analyzed for this report to examine sedimentation rates in Section 9. Future bathymetry is not planned unless evidence of lake volume loss is demonstrated.

Town Lake Visual Index of Pollution (VIP) – The aesthetics of our water resources are becoming incorporated in both the measure of their health and in the measure of how well they are being maintained. A photometric index program to measure trash and debris along the shores of Town Lake, the Visual Index of Pollution (VIP), was implemented in April 1994 to provide a periodic measure of the City of Austin's litter control performance by documenting visible trash on the shores of Town Lake. An increase or decrease in the amount of trash along these waterways can indicate the usefulness of several methods of trash abatement currently used by the City, such as trash booms and inlet filters. Section 11 describes the methods developed for tracking this measure and the results during the years that these measures were implemented.

1.3.2 Watershed Monitoring

Town Lake water quality is influenced by inflow from both upstream and adjacent urban watersheds. Two of the monitoring components recommended by 1992 Town Lake Report were focused specifically in the East Bouldin Creek watershed and were associated with implementation of pilot projects. The state and federal Clean Rivers programs, as visualized in 1992, were not funded; however, many of the components were implemented primarily through City funding. Simultaneously, as planning for water quality controls progressed, it was realized that the creeks themselves were valuable but imperiled resources to be protected, and that their current status was not well documented, particularly with regard to relative historical conditions. Some new monitoring programs were implemented to assess the creeks, and therefore, the watersheds of Town Lake. In addition, stormwater monitoring has been performed by both the City through the stormwater monitoring program and the USGS cooperative monitoring program in numerous tributaries, quantifying runoff from different land uses, and at the inflow and outflow points of numerous water quality control structures. Components of all of these programs provide information on the originally selected pilot watershed, East Bouldin Creek.

Citizen Monitoring/Environmental Integrity Index - The Citizen Monitoring Program was developed as planned in the 1992 Town Lake Report. This program was a monthly monitoring program with the dual goals of educating program participants and providing data on creeks in the Austin area. The citizen monitoring program originally focused on the Town Lake segment and the nine

streams that drain into it. Staff, however, became aware that there were many other aspects of the creeks related to water quality and aquatic life support that were not being assessed. Another tool was then developed, the Environmental Integrity Index (EII). The components of the EII included water quality, aquatic biological integrity (bioassessment component), physical integrity (habitat), recreational aesthetic, sediment quality, and channel stability evaluations. The EII and the citizens monitoring program have recently been merged to provide a comprehensive assessment tool to both assess and prioritize watersheds in the Austin area. Non-storm water quality in East Bouldin Creek has been and will continue to be assessed through this program. The results from the EII are included in the Watershed Protection Department Masterplan; however, organized large-scale citizen participation is not funded by the City.

Stormwater Monitoring - The stormwater monitoring team provides monitoring primarily of runoff from small watersheds during storm events. A station was established for a short period of time at Gillis Park in the East Bouldin watershed. These data are evaluated along with other stormwater monitoring data and effectiveness data for other control structures as part of the report "Characterization of Stormwater Pollution for the Austin, Texas Area" (COA, 1997c). Stormwater monitoring data will not be specifically evaluated as part of this report, although these data were incorporated in a GIS model of the Austin watersheds that provided new loading values from tributaries. Tributary loadings will be discussed briefly in the modeling section. Two new sites on East Bouldin and Blunn creeks are monitored by both the stormwater monitoring team as well as through the EII to characterize these fully developed urban creeks where controls are being implemented.

USGS Cooperative Monitoring Agreement – In addition to the post-storm and sediment monitoring in Town Lake itself, the USGS monitors non-storm and storm flow in several of the lake's major contributing creeks. The monitoring plan for a typical creek has included sampling during two non-storm and two storm flow

events for most of the creeks monitored. The current focus for this program is on stormwater monitoring with base flow samples provided by the City. East Bouldin Creek was added to that program because of the number of water quality controls being implemented. Barton Creek is more intensely monitored under both the USGS program and the City's Barton Creek monitoring plan. These programs provide important data for Town Lake on the amount of nitrate being introduced from this source. The creek monitoring data, as well as the City's stormwater monitoring data described above, were the primary data sources for calibration of the GIS model for the Phase I masterplanning process. As mentioned above, these data were used to calculate pollutant loadings to Town Lake. The USGS data collected within Town Lake itself was included in the main report analyses.

1.3.3 Data Storage and Quality Control

Data for this report were compiled from various sources as described above; the primary collection agency was the City of Austin. Data from other agencies, including the USGS cooperative monitoring data and some data from the Lower Colorado River Authority, are included where readily available to conduct analyses with the most extensive data set possible. All COA data analyzed for this report are stored in a mature Oracle Relational Database (COA-ERM database), and may be obtained in printed or electronic format through a written Open Records Act request to COA-ERM offices, or queried directly from the City's Web site at www.ci.austin.tx.us/wrequery. Data from other agencies were transferred from them to the COA-ERM database and may be obtained directly from those agencies.

Data stored with individual field records and laboratory analysis results include a comprehensive description of the field sample location, site, depth, collecting agencies, the laboratory analyzing the data, laboratory and field methods used, units of measure, and any unusual conditions. Data entry is performed manually by staff for field data and primarily by electronic transfer for laboratory data. All data are checked multiple times for accuracy of entry or transfer, and verification is noted. In addition, an automated QA/QC Data Evaluation Process was instituted by the City that reviews specific checks for data quality. Checks include review of results from field and laboratory tests for precision and accuracy of the data, checks for holding time errors, and logical tests of results. The process and the quality assurance objectives for the ERM programs are described in detail in the ERM Standard Operating Procedures Manual (COA 2001a). All QA/QC data for a given result can be reviewed in the COA-ERM database.

Field QA/QC procedures include QC checks such as the collection of field splits on at least a 10 percent basis and field procedures conducted in accordance with both the ERM Standard Operating Procedures Manual (COA 2001a) and the Quality Assurance Project Plan for the Colorado River Basin (Texas Clean Rivers Program, LCRA updated annually).

Laboratory analyses were completed primarily by the City's Walnut Creek Laboratory using EPA approved methods. Some analyses, particularly for samples collected by other agencies, were performed by other laboratories using EPA approved methods or USGS methods. Some historical data collected by the City of Austin from 1991 to 1996 were analyzed in the ERM laboratory (comprising less than 2 percent of the total data set). All analysis methods are stored associated with the data in the database and may be reviewed. Currently only EPA-approved methods are being used for Town Lake analyses.

2.0 CURRENT SETTING

Many components of Town Lake's hydrologic setting and environmental interactions remain unchanged. The Town Lake Diagnostic Study, Volume I (COA 1992a), includes extensive information on all the following topics.

- Lake and upstream identification and locations
- Reservoir characteristics
- Upstream impoundments and flows
- General topography
- Individual tributaries
- Geology and soils
- Climatic data
- Inflows
- Reservoir hydraulics
- Lake uses and potential impacts

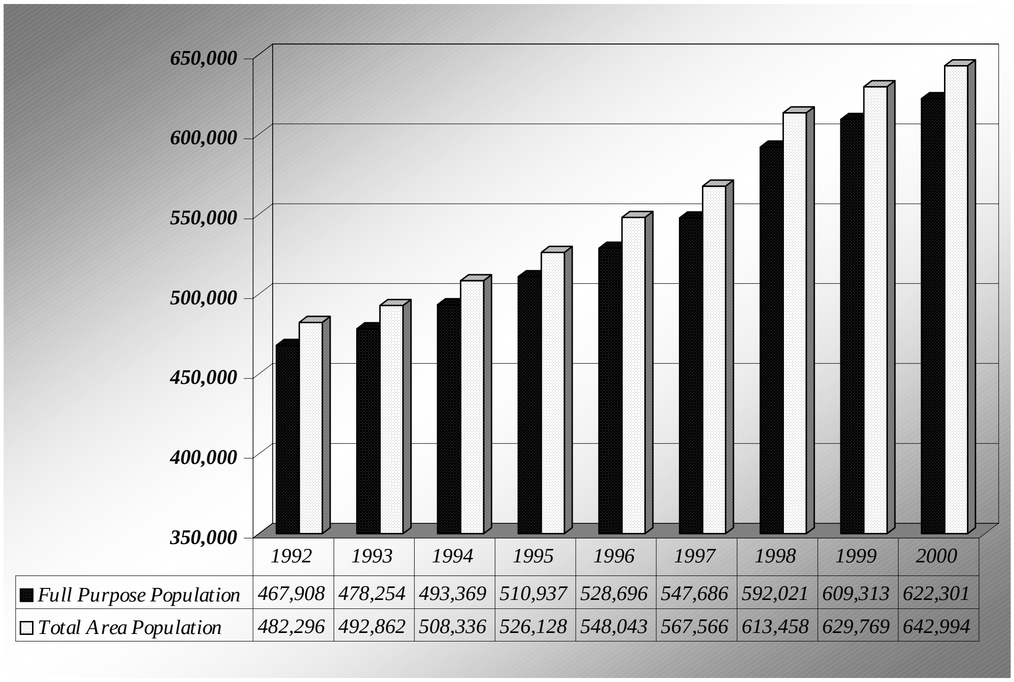
This section on current conditions will provide updates on influencing factors that have changed since the first Town Lake Report, including population growth, land use, and impervious cover.

2.1 Austin-Area Population and Growth

Population in and around the City of Austin has been steadily increasing. The chart below shows growth in Austin and the surrounding areas over the past 15 years and projected growth for the future. Since the 1992 Town Lake Report, the population in Austin and surrounding areas has increased about 30 percent, putting ever-increasing pressure on our natural resources.

These population increases have led to significant changes in the watersheds of Town Lake, such as increased roadway usage, and have compelled the City to develop new ways to mitigate impacts. Continued growth is projected by the City of Austin Department of Planning, with an estimated population increase of more than 20 percent from 2000 to 2010.

Figure 2.1 Population Changes in Austin and Surrounding Area; Estimates for 2000



	1992	1993	1994	1995	1996	1997	1998	1999	2000
■ *Full Purpose Population*	*467,908*	*478,254*	*493,369*	*510,937*	*528,696*	*547,686*	*592,021*	*609,313*	*622,301*
☐ *Total Area Population*	*482,296*	*492,862*	*508,336*	*526,128*	*548,043*	*567,566*	*613,458*	*629,769*	*642,994*

(COA Demographer, Department of Planning, COA, January 2000)

2.1.1 Land Development Data

Extensive work has gone into updates to land use and impervious cover information. Original 1990 land use information was compiled in 1985 by the Department of Planning and Growth Management; it was updated and digitized in 1991-92 by ECSD, forming the basis for the 1992 Town Lake Report on land use. The current land use information was derived from an aggregate file of the 1995, 1990, and USGS land use files in order to cover the extent of the Town Lake watershed. The primary source of new information was lot-based data incorporated by the Planning Division in 1995 and impervious cover estimates made directly from orthophotos from aerial flyovers in 1997. The land use updates covered the area within the City's two-mile Extra Territorial Jurisdiction (ETJ) and were made with the aid of aerial photos, personal knowledge of the areas, other GIS layers, such as parks and preserves, and in some instances, field checks. For the impervious cover estimates, the City contracted with ASI (Analytical Surveys, Inc.) for identification of all areas of 100 percent impervious cover from 1997 orthophotos covering Travis County (a correction factor was added to account for sidewalks and driveways based on site-specific digitized areas in the itemized list below).

The Environmental Resources Management (ERM) Division also incorporated the site-specific digitized information listed below:

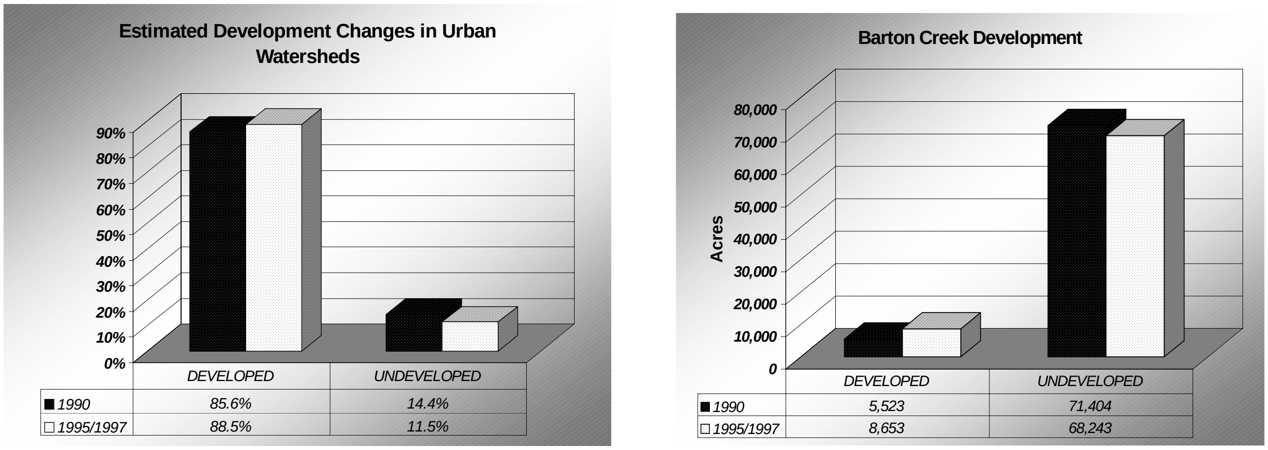
- Additional preserve land use tracts, (BCCP and Proposition 2 tracts) that did not exist in the 1995 file were added in 2000 by the Water Resources Evaluation Section.
- 1999 IC data from a study done by the City's Infrastructure Support Services for the Edwards Aquifer Barton Springs Contributing and Recharge zones. This study updated 1995 land use information by including City development records (subdivision plats etc.) dated through 1999.
- Digitized impervious surfaces as seen in the 1997 orthophotos (done by B.J. Carpenter and M. Scoggins of ERM) for watersheds draining to 54 monitoring sites. This data amounted to almost 28,000 acres distributed throughout the City and within Travis County.
- Digitized impervious surfaces as seen in the 1997 orthophotos (done by M. Scoggins, A. Boer and D. Harris of ERM) for 41 of the larger civic land use polygons from the 1995 land use file.

Based on the updated land use and impervious cover information and site-specific impervious cover data, relationships between land use and impervious cover were developed for application in watershed areas outside the orthophoto coverage.

Town Lake's watersheds, other than Barton Creek, were already highly urbanized at the time of the 1992 Town Lake Report. The first figure below shows developed and undeveloped land (parks and vacant land), as estimated from the land use coverage in the Town Lake urban watersheds, which excludes Barton Creek. Although little room for growth is present, the City's Smart Growth initiative continues to encourage redevelopment in these watersheds to prevent sprawl and excessive spread of infrastructure in the surrounding areas. The updated figures estimate that since the 1992 Town Lake Report, approximately 3 percent of the total urban watersheds that were previously vacant are now developed. This acreage (approx. 700 acres) is, however, much less than the estimated 3,100 acres (or 4 percent) additional land developed within the Barton Creek watershed during that same period.

Changes in watershed characteristics are important relative to pollutant loads. Relationships between increasing impervious cover and increasing concentrations of suspended solids, biochemical oxygen demand, fecal coliform bacteria, nitrogen, and phosphorus, have been demonstrated historically in the Austin area (Veenhuis and Slade, 1990).

Figure 2.2 Development in Urban Watersheds and Barton Creek



In addition, the USGS recently demonstrated the relationship between PAH concentrations in Town Lake sediments and increased traffic volume (USGS 1999). The City is currently working on improving estimations of pollutant loads both from runoff and eroded creek bank sediments by means of a GIS-based model.

The breakdown of land uses within the areas is illustrated in the following charts (urban watersheds exclude Barton Creek). With the new land use information, which separates roadways within each land use, transportation appears as a more significant component. It is also apparent that, when Barton Creek is included in the analysis, extensive area remains available for development, and although this development will continue to impact Town Lake, much of the vacant land is outside the City's jurisdiction.

Figure 2.3 1995-97 Land Use – Urban Watersheds, Acres

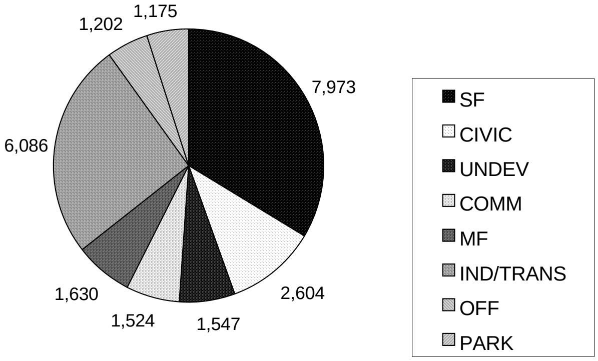
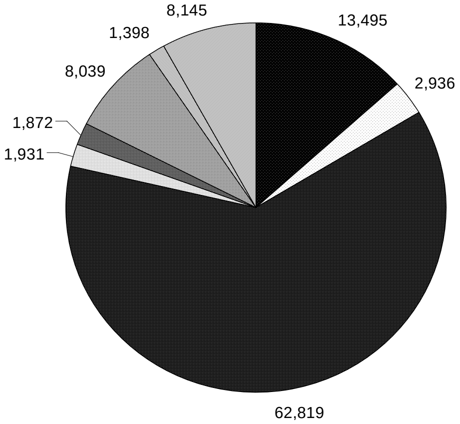


Figure 2.4 1995-97 Land Use – All Town Lake Watersheds, Acres



2.1.2 Building Permits

Not only may development increase impervious cover and pollutant loads, but the construction itself may temporarily cause pollutant pulses from construction site runoff that has long-lasting environmental consequences. Previous analyses by the City have shown a statistically significant relationship between building permits and creek concentrations (Turner 1996).

Numbers of building permits issued over time are approximated here from the City of Austin Permitting, Inspection, and Environmental Review (PIER) database to provide a semi-quantitative estimate of temporal development within the Town Lake drainage basin. Figure 2.5 presents the approximate number of permits issued over time as stored in the PIER database from 1980 to 2000, illustrating the somewhat cyclic nature of construction within the Austin area. Data collected by the City of Austin Department of Planning (also shown in Section 2.1) show population changes within Austin from 1987 to the current estimated population of 642,994 in 2000. These changes in Austin population are presented as annual percent growth rates as compared to PIER building permits in Figure 2.6. The sharp peak of 8.1 percent in 1998 is primarily due to annexation of additional areas by the City of Austin.

2.2 Watershed Protection Efforts

Recognizing signs of increasing detrimental impacts to water quality and the environment as discussed in the 1992 Town Lake Report, the City of Austin has continued to implement measures for the protection of Austin's creeks and receiving water bodies. Increases in impervious cover, traffic, and associated non-point source pollution may obscure improvements from these individual efforts, but these protection measures continue to offset ongoing development in our watersheds. The sections below briefly summarize measures put in place since the time of the first Town Lake Report. These protection measures are described in detail in the Watershed Protection Master Plan (COA 2001b), while only those recommended in the 1992 report are updated in some depth here.

2.2.1 Regulation

The City has several water quality regulatory requirements, many of which were in place prior to 1992, for activities associated with local development as well as EPA NPDES permitting (Table 2.1). Again, these regulations, as well as new proposals, are described in more detail in the Watershed Protection Master Plan, Phase I Watersheds Report (COA 2001b).

Figure 2.5 Estimated Number of Building Permits Issued in Austin in the Town Lake Watershed over time (1980-2000)

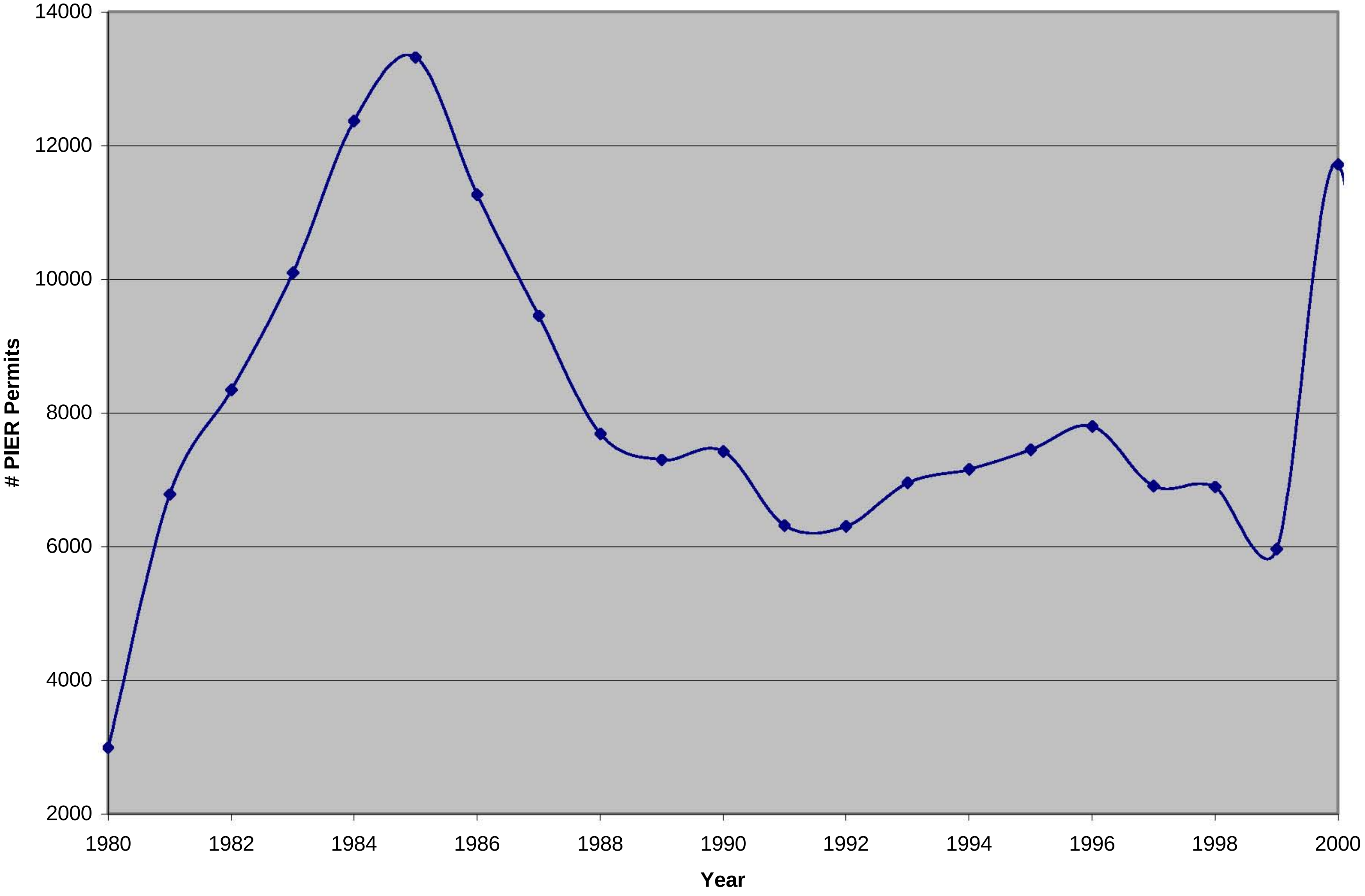


Figure 2.6 Austin Population Growth and Estimated Number of Building Permits Issued in Town Lake Watershed

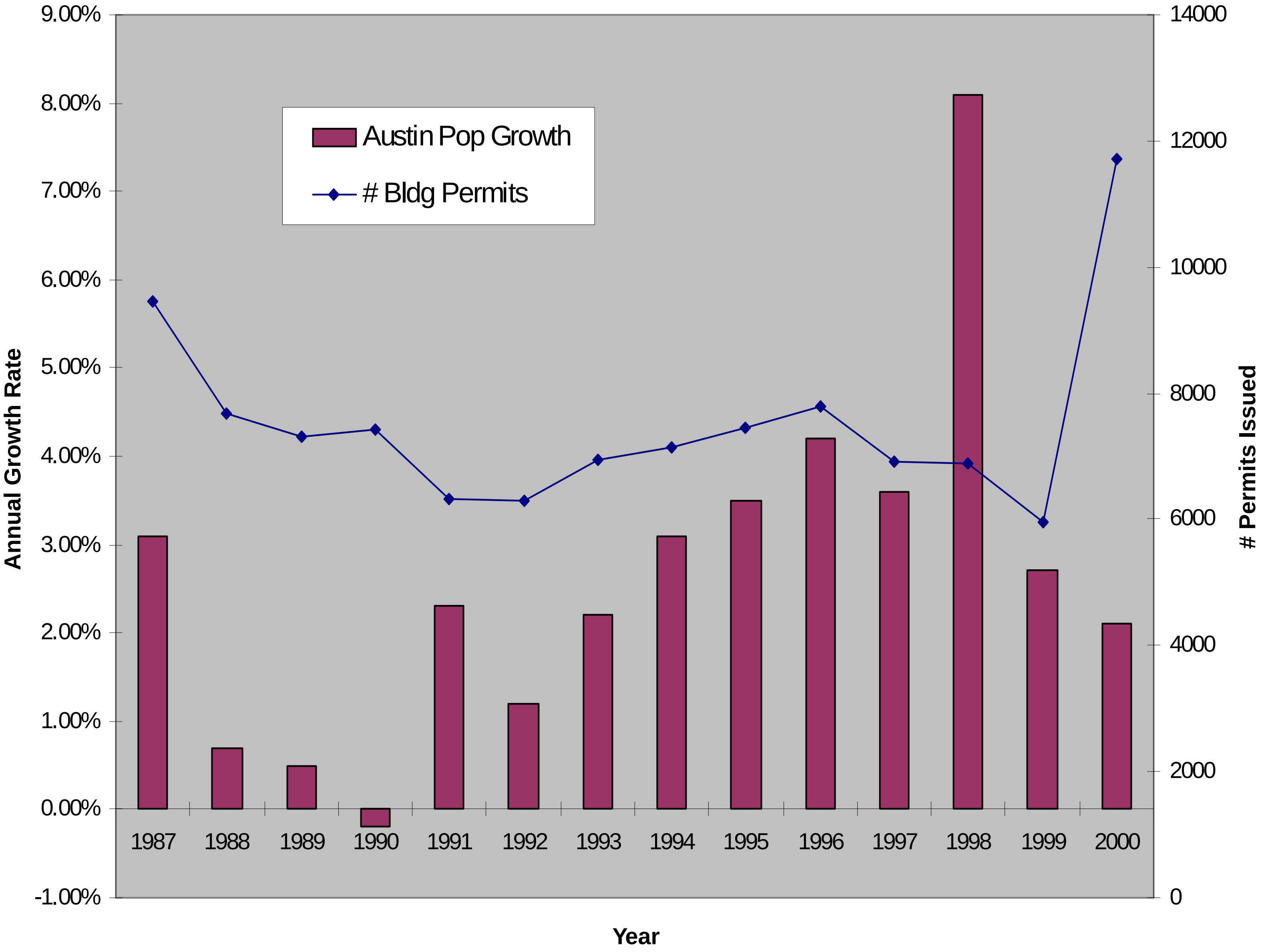


Table 2.1 City of Austin Regulatory Requirements

Regulations		
Erosion Control	**Water Quality Protection**	**Integrated**
- Shoreline Modifications & Dredging - Construction Phase Controls - Revegetation Requirements - Cut & Fill Limits - Design Storm Runoff Detention - Drainage Design Criteria	- Pollution Prohibition - Litter Laws - Animal Regulations - Municipal Solid Waste - Fertilizer & Pest Management Standards - Stormwater & Nonstormwater Discharge Permits - Industrial Storm Discharge Permits - Hazardous Material Storage & Spill Control - Hazardous Material Traps - Remediation Cleanup Standards - Wastewater Line Construction - On-site Sewage Facility Requirements - Effluent Irrigation Standards - Phosphorus Controls - Water Quality Controls - Capture Volume - Treatment Standards - Maintenance of WQ Controls	- Comprehensive Planning - Natural Channel Conveyance - Impervious Cover Limits - Impervious Cover Reductions via Development Regulations - Flow Volume Limits - Disconnected Impervious Cover - Steep Slope Restrictions - Stream Setbacks - Headwater Buffer Zone Protection - Wetlands Protection - Critical Environmental Feature Protection - Landscape Regulations - Tree Protection Standards

Source: Table 9 (COA 2001b)

2.2.1.1 Water Quality Protection Ordinances and Policies

The most far-reaching regulatory measure now protecting Town Lake is the Urban Watersheds Ordinance. This amendment to Chapter 13-7, Article 1 of the Austin City Code occurred in 1991, during the time period in which the Clean Lakes grant report for Town Lake was being written. This ordinance provides water quality protection in the Town Lake watershed in the following ways:

- Establishing additional critical water quality (no build) zones for the FEMA floodplain of no less than 50 feet and stream buffer for drainages larger than 64 acres
- Requiring structural water quality controls or payment in lieu of structural controls for new development
- Protecting remaining critical environmental features (CEFs) such a springs, caves, and sinkholes with setbacks of 50 to 150 feet.
- Protecting wetlands in an amendment added in 1996 to include setbacks as CEFs in all but the central business area (CBA)

Another major ordinance, the Save Our Springs (SOS) ordinance, was instituted in 1992 to provide increased protection for the Barton Springs Recharge Zone, including lower impervious cover limits and increased water quality controls. Controversy over this ordinance has prevented its full implementation, and grandfathering of some development by the Texas Legislature has interfered with its application when a project could claim that it began prior to the adoption of the SOS ordinance.

Other regulatory changes were recommended in the Town Lake Report and were also implemented about the time the report was being written.

- In order to maintain a minimum amount of flow for the Colorado River below Longhorn Dam during non-release periods, the LCRA instituted a minimum 100 cfs discharge (46cfs during droughts) from Town Lake at all times in 1992. This policy was enacted in order to maintain a high aquatic life use designation for the Colorado River below Town Lake. Although the policy was implemented for optimal support of the Colorado River ecosystem, it also keeps water moving through Town Lake, which may retard eutrophication and the frequency of algae blooms.

Flood Release, Tom Miller Dam

- Austin was the first city in Texas to ban phosphorus in detergents when the City Council passed Ordinance #91-0523-F in May, 1991, prohibiting the sale of a detergent with more than 0.5 percent phosphorus. This regulatory change will reduce phosphorus loading into

Town Lake from sources that are not collected in the sanitary sewer system, such as home car washing.

Ordinance revisions and development criteria also provide incremental improvements in water quality protection as they are refined and implemented. Some of these include the following:

- Requirement for increased water quality capture volume (1/2” + 1/10” Rule) – 1993
- Design criteria for wet ponds
- Increased impervious cover assumptions for single family lots – 2000

2.2.1.2 NPDES Permit

The City of Austin, based on its population, was required to apply for a National Pollutant Discharge Elimination System (NPDES) storm water permit, a federal permit that regulates the discharges of storm water from municipal separate storm sewer systems (MS4). The City submitted a two-part permit application to EPA in November 1992 and was issued a final NPDES MS4 storm water permit in September 1998 with The University of Texas at Austin as a co-permittee. The purpose of the Storm Water Permit Compliance Program is to ensure compliance with state and federal regulatory requirements for water quality protection. This is accomplished through the coordination, tracking and reporting of the activities mandated by the MS4 storm water permit and other water quality regulations. Compliance Program staff provide guidance and assistance to City of Austin staff and program managers with the compliance activities and documentation responsibilities. Most of these compliance activities fall under regulatory requirements described above, monitoring activities in Section 1, or programs below.

The MS4 storm water permit has a five-year permit term. Although the City's first MS4 permit was issued by the EPA, the Texas Natural Resource Conservation Commission (TNRCC) was delegated authority of the NPDES permitting program by EPA and is considered the permitting authority for the State of Texas. As such, the City is required to renew the MS4 storm water permit with TNRCC (now the Texas Commission on Environmental Quality).

2.2.2 Programs

Programmatic measures taken to improve water quality over the entire Town Lake watershed have included several initiatives in different areas. Most of these programs have been ongoing and all have expanded as a result of City growth.

2.2.2.1 Program Inventory

The following table lists existing Watershed Protection Department and Development Review (WPDRD) programs related to water quality. One new focus has been the land and conservation easement acquisition. This program was supported through a bond election and greatly increases the City's ability to protect land from further development. The listed programs and recommended new programs are described in detail in the Phase I Master Plan Report.

Table 2.2 Watershed Protection and Development Review Department Programs Related to Water Quality

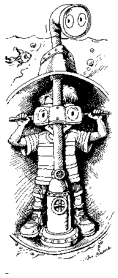
<table>
<tr><th colspan="2">Existing Watershed Protection and Development Review Programs</th></tr>
<tr><th>Erosion Control</th><th>Water Quality Protection</th></tr>
<tr><td>- Erosion Project Planning
- Implementation and Field Engineering
- Erosion Control Crew</td><td rowspan="3">- Federal Permit Compliance
- Water Quality Assessments
- Land Use Water Quality
- Structural Controls Monitoring
- Environmental Impact Assessments
- Water Quality Planning & Implementation
- Storm Sewer Discharge Permits
- Emergency Spills and Complaints
- Contaminated Site Cleanup
- Pond Operating Permits Program
- Commercial Pond Inspection
- Underground Storage Tank Permits
- Town Lake Cleanup
- Water Quality Public Education
- Ongoing Voluntary Buyout of Floodplain
- Land & Conservation Easement Acquisition</td></tr>
<tr><th>Integrated Programs</th></tr>
<tr><td>- Detention & Water Quality Pond Maintenance & Rehabilitation
- Review & Inspection of Development
- Watershed Master Planning
- Database Management and Geographic Information Systems (GIS)</td></tr>
</table>

As noted in the 1992 Town Lake Report, many of the observed water quality problems in Town Lake can be addressed through public education programs aimed at pollution prevention. The original Town Lake Alternatives Study (COA 1992b) determined that a city-wide education program could be a critical element for controlling nutrients, oil and grease, and trash. Although the payoff in terms of perceived water quality change is not always immediate or easy to measure, the gains from a well-executed campaign of public awareness and environmental education are both cost-effective and long-lasting. The cost-effectiveness of this type of program has been confirmed through the current Master Plan program and is based on the implications of incremental changes applied over residential areas, which account for approximately one-third of the entire urban watershed landscape. Areas of focus have included raising public awareness of the water quality repercussions of gardening and landscaping practices (primarily fertilizer and chemical pest control applications) and hazardous waste disposal habits. Nutrient loading to the lake is reduced by preventing contaminated stormwater rich in nitrogen or phosphorus from running off of turf or landscaping..

Many community education programs were specifically recommended in the 1992 Town Lake Report. Among them were new programs, such as Stormsewer Inlet Marking, and enhancements to ongoing programs, such as Xeriscape/Urban Landscaping/Integrated Pest Management. Overall, despite the fact that a Clean Lake grant was not received to fund the programs, all of the initiatives recommended for community education in the Town Lake Report have been accomplished as specified, some through another City department or with a different focus for the program. The following sections briefly describe major community education initiatives continued or initiated since the Town Lake Report. Assessment of the effectiveness of these programs is usually accomplished through citizen surveys, student pre- and post-tests, and workshop evaluations.

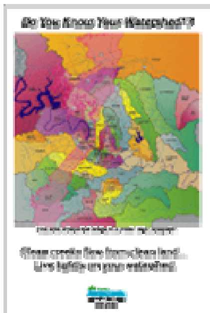
Elementary Education - Continuation and enhancement of children's environmental education programs have proceeded beyond recommendations included in the final 1992 Town Lake Report (COA 1992c). These programs focus on learning activities that reinforce the idea of waterbodies as resources and stress the impacts individuals may have on those resources (Table 2.3).

Table 2.3 Children's Environmental Education Programs

PROGRAM DESCRIPTION	No. of years in place	Estimated # of students and citizens reached per year
Earth Camp - Earth Camp is the City of Austin's award-winning four-day watershed education program bringing fifth-grade students from Austin Independent School District (AISD) an outdoor, science-based environmental education in schools with lower socio-economic ratings.	7	400
 **Earth School/Green Classroom** - Earth School offers a one-hour, hands-on watershed and aquifer lesson to schools throughout AISD.	2	1800
 **Educational Videos** – "Got Water, Got Life" videos on water quality and prevention practices provide teaching resources.	1	2,200 (through Watershed Protection; additional numbers through Water Conservation)
 **SPLASH Exhibit** - An interactive exhibit on watershed protection and the Edwards Aquifer is visited as part of the Earth Camp program and is free to visitors at the Barton Springs Pool.	3	1999 visitation: 114,000 2000 visitation: 98,000
 **Water Quality Murals** - The WPDRD offers schools funding and research materials to "COLOR THEIR WATERSHED" through the creation of a mural featuring a water quality protection theme.	3	5 schools

Watershed Awareness - Several citywide programs were recommended in the 1992 Town Lake Alternatives Report (COA 1992c). They are noted below, along with additional programs put in place.

Watershed Signs -
Watershed awareness signs were erected on major roads that crossed watershed boundaries. Installation of all Town Lake watershed signs was completed four years ago.



Posters –
To raise awareness of Austin's creeks and the issues surrounding water pollution, the WPDRD has created an annual poster. These posters have been distributed to school programs through all public libraries, at fairs, at city offices, and are advertised and available through the City’s website.

Citywide Ads – Citywide ads are produced annually in coordination with the education initiatives. They have included radio public service announcements (“Give the Lake a Break”), ads on city buses, movie theater ads, and billboards.

Mailouts – Informational mailouts have been employed in a variety of efforts. Utility inserts have been used as recommended and individual watershed-specific mailouts are currently being mailed. The current watershed postcards are related to the watershed theme and include individual practices for pollution prevention.

Neighborhood Groups and Public Information

Fairs, exhibits, and a new city Web site (www.cityofaustin.org/watershed) all provide readily available information to the citizens of Austin. Informational packets for annual education efforts are compiled and provided to neighborhood groups. Inclusive information is displayed at several fairs (such as Home and Garden Shows) and on the City Web site. In 1999 a special exhibit, “Austin’s Creeks: A Tribute to Tributaries,” was prepared and displayed at the Austin History Center.

CIP Project Signs –
Six educational signs have been installed at five water quality ponds. The signs will serve as an educational tool to describe the function of a water quality pond, surrounding wetland plants, the wildlife the ponds attract, and how we affect our watersheds.

Green Gardening (Nutrients, Pesticides and Herbicides) - The City supports both community education and technical support for xeriscape, urban landscaping, and integrated pest management (IPM) as recommended in the 1992 Town Lake Report. The IPM program includes review of IPM plans for new developments. The Xeriscape program, through the Water Conservation Division, provides rebates for landscaping with native plants that also serve the water-quality purpose of requiring less chemical care. The program is supported by the following community education programs.

Grow Green (new) - Grow Green is an education program for citizens of the Austin area and local landscape retailers. Twenty-one Grow Green Fact Sheets are provided at participating nurseries to help citizens identify and treat common landscaping problems and to offer less-toxic alternatives. Employees at participating nurseries are provided with training; the Grow Green website (www.growgreen.org) also features the education materials. Other promotional materials include shelf markers for retail pesticides and herbicides, movie ads, and T-shirts.

Grow with the Flow - Multiple copies of eleven IPM related books were purchased for Austin Public Library branches. A poster and companion bookmarks containing a book and a native plant list, pest management and fertilizer tips, and composting techniques were also made available at the libraries.

Citizen Programs - Several programs focus on providing education and support for individual citizen pollution-prevention activities.

Scoop the Poop - The Watershed Protection and Parks & Recreation Departments have teamed up to help clean up pet waste from parks and trails. Look for Mutt Mitt dispensers in many of your favorite park locations including the Town Lake hike and bike trails.

Spills and Complaints Response Program - Staff respond to citizen pollution complaints and spills that threaten our creeks or water bodies, 24 hours a day, seven days a week.

Targeted watersheds – A target watershed program was conducted in four small watersheds to examine the efficacy of a concentrated education effort. Workshops were held to provide instruction on low-impact pesticide and fertilizer use and watershed protection handbooks were produced and distributed.

Keep Austin Beautiful (KAB) – The KAB program continues its trash abatement education programs. Recycling efforts with through the City's Solid Waste Department have increased, including expanded materials accepted at curbside. Creek cleanups are sponsored occasionally.

Waste Disposal – Information on the Home Chemical Collection Facility has been provided in mailouts, at fairs, and informational packets.

Used Oil – Maps were produced showing the location of facilities that accept recycled oil (1992 Town Lake Report recommendation).

Community/Businesses/Volunteers - Activities involving business or citizen groups are used to highlight and reinforce pollution-prevention activities. The City provides the instruction, materials and/or funding for these programs.

Austin Clean Water Partners - The City of Austin is partnering with local automotive repair and fueling businesses to reduce pollution and water quality degradation of our creeks and lakes. The partnership's logo is an easy way for customers to recognize those businesses that go the extra mile to protect our environment.

Stormdrain Marking – The City of Austin Storm Drain Marking Program is a hands-on project for volunteers. Storm drain markers are affixed at storm sewer inlet opening with an emblem and slogan that denotes no dumping to inform the public about the cause and effect of pollution in Austin's storm water collection systems. This was a new program proposed in the 1992 Town Lake Report, which was subsequently established and continues with about 350 new storm drains marked each year.

Water Watchdogs - A Water Watchdog is a citizen who volunteers to help monitor and protect the watersheds in and around Austin. Volunteers (from 1991 to 1999) collected water samples at various sites along local streams and analyzed these samples for targeted water quality variables in our laboratory. This program merged with the Environmental Integrity Index (EII) program, a monitoring program developed to assess environmental conditions citywide, with the data to be used for planning purposes.

Groundwater Guardians - Austin is proud to be one of the 84 communities that received Groundwater Guardian status in 1996. The Groundwater Guardian program is administered by the Groundwater Foundation in Nebraska. Team members are from industry, civic organizations, education and local government. They work together to protect the Edwards Aquifer, the Colorado River alluvial aquifer, and other aquifers.

Austin Youth River Watch Program - The City also supports the Colorado Riverwatch Foundation (CRWF), an organization that combines peer mentoring of youth-at-risk with water monitoring and environmental stewardship activities. CRWF monitors water quality principally in the Town Lake watersheds and reports elevated concentrations of bacteria and nutrients to appropriate City departments for investigation.

2.2.3 Water Quality Control Structures

One of the initiatives of the Urban Watersheds Ordinance was to institute a retrofit program for the urban watersheds. Construction of water quality control structures in nonurban watersheds was later added as an activity in the drainage utility business plan. The objective of the water quality control program is to reduce current loads or offset future loads to receiving waters in areas where opportunities arise. The need for these programs are primarily in urban areas where space constraints limit water quality control opportunities and where areas were developed before water quality controls were required. Additional needs may be seen in small “hot spots” where higher levels of toxic pollutants might be found (e.g. roadways), areas exempt from controls, or particularly sensitive areas.

Water Quality Control Structure: Central Park Wet Pond

Through the year 2000, the City put in place a total of 17 water quality control structures, primarily in urban watersheds. These have ranged from a filtration pond in Gillis Park, as recommended in the 1992 Town Lake Report, to a large wet pond at the Central Park location in central Austin. These structures capture and filter or treat the runoff from a total of approximately 4,500 acres.

In addition to the larger structures, several programs have grown that install small-scale structures, repair eroded stream banks, and provide maintenance for our creeks. Some of these programs are listed below.

Inlet Filter Program – Filters that capture trash, debris, and sediment are installed in storm sewer inlets in the downtown core. These filters are emptied on a regular basis, usually twice a week. Filters were installed in the drainage area above Gillis Park as recommended for the East Bouldin Pilot Project. Monitoring of the sediment collected on these inlets was conducted as part of a 319EPA Nonpoint Source Grant (COA 1998).

Street Sweeping Program – Street sweeping is incorporated into the dense urban core of the City of Austin to remove concentrations of debris and associated pollutants that build up on our roadways.

Erosion Control – Erosion control efforts have begun to be coordinated with water quality efforts to prevent both bank loss and habitat loss. The erosion control crews work with water quality staff on stabilizing small streambank projects. Large erosion-control projects are also put in place, but because of space restrictions are sometimes unable to provide water quality enhancements.

2.3 Goals and Planning

The Watershed Protection Department was formed in 1996 to facilitate the integration of missions related to water quality, erosion, and flooding. At that time, the need for planning to prioritize service needs and refine program direction in these areas was recognized and a Master Plan process for the department was begun. In 2002, the solution recommendations for seventeen (17) watersheds, including all of the Town Lake watersheds, will be finalized under the Watershed Protection Phase I Master Plan.

Before beginning any technical studies for the master plan, the City had to determine what the Utility mission and management goals would be. The Citizens Advisory Group (CAG) helped the City establish these goals. Working together, City staff and the CAG identified seven watershed management goals that provide the foundation for the master plan (Table 2.4).

These goals, as compared with the goals set for Town Lake in the 1992 Town Lake Report, are more comprehensive and address erosion and flooding as well as water quality. In terms of water quality, moreover, the goals were related not only to the primary receiving water bodies, but also to their tributaries, the creeks of Austin.

Table 2.4 Watershed Protection Master Plan Interim Goals and Objectives

Protect lives and property by reducing the impact of flood events.
Protect channel integrity and prevent property damage resulting from erosion.
Protect and improve Austin’s waterways and aquifers for citizen use and the support of aquatic life.
Improve the urban environment by fostering additional beneficial uses of waterways and drainage facilities.
Meet or exceed all local, state, and federal permit and regulatory requirements.
Maintain the integrity and function of Utility Assets.
Optimize City resources by integrating erosion, flood, and water quality control measures.

Based on these goals, twenty-seven (27) corresponding objectives were also developed to guide the Master Plan. Among these was the objective for Town Lake to maintain or improve its Designated Use Support status. The beneficial uses for Town Lake are:

High ALS – Aquatic Life Support (High); the level of aquatic life support is segment specific,
NCR – Noncontact Recreation (although designated by TNRCC as contact recreation, the City of Austin does not allow swimming based on the flow and safety factors), and
PWS – Public Water Supply.

Environmental Resources Management staff examined the potential problem areas that may impact these uses and derived the list in the first column of Table 2.5, closely corresponding with the original problems identified in the 1992 Town Lake Report. An additional problem identified in that report was the public health advisory regarding Town Lake fish consumption. The goal was to eliminate the advisory. The fish consumption advisory was lifted in 1998, meeting that goal, as discussed in Section 10.

A water quality model of Town Lake was developed to assess the controlling factors for these problems and the feasibility of reduction goals. Volume II of this report on the Town Lake model discusses this in detail. Based on feasibility, the overall targets for Town Lake were revised to maintain existing conditions (Table 2.5). Individual load targets to Town Lake from upstream and tributaries as well as a scoring goal for the Visual Index of Pollution (VIP, discussed in Section 11) were then developed for the purpose of assessing problem levels in Town Lake for the Master Plan. The current status of each problem area is discussed in its respective section in the report.

Table 2.5 Town Lake Problem Areas

Problem Area	**Town Lake Target Goals**	**Strategies and Watershed Specific Target Goals**
Major Algae Blooms	**Maintain existing conditions** (i.e. frequency and magnitude of algae blooms) **by controlling nutrient loads**	⇒ Reduce loads from urban watersheds by 25%, ⇒ Maintain existing loads from Barton Creek, and ⇒ Reduce the increase of loads from Lake Austin to no more than 10% above existing loads.
Toxic Sediments	**Maintain existing toxic loads** being discharged to Town lake, represented by TOC, COD, Cu, Pb, and Zn loads, as well as by the Spills Risk Index	⇒ Reduce loads from urban watersheds by 25%, ⇒ Maintain existing loads from Barton Creek, and ⇒ Reduce the increase of loads from Lake Austin to no more than 10% above existing loads, and ⇒ Improve the Spills Risk score to Very Good status in the future.
Sedimentation	**Maintain existing TSS loads** discharged to Town Lake.	⇒ Reduce loads from urban watersheds by 25%, ⇒ Maintain existing loads from Barton Creek, ⇒ Reduce the increase of loads from Lake Austin to no more than 10% above existing loads, and ⇒ Minimize loads from future construction.
Aesthetics/ Trash and Debris	**Maintain or achieve an “Excellent” VIP score**	Currently, this goal is achieved except for the south shore of the Lower segment

3.0 CLIMATIC AND HYDROLOGIC CHARACTERISTICS

Rainfall and the controlled flows through the Colorado River system are primary factors in the hydrologic balance for Town Lake. In fact, the condition and timing of runoff and releases from the upstream dam drive the water quality and trophic status of the lake.

3.1 Rainfall

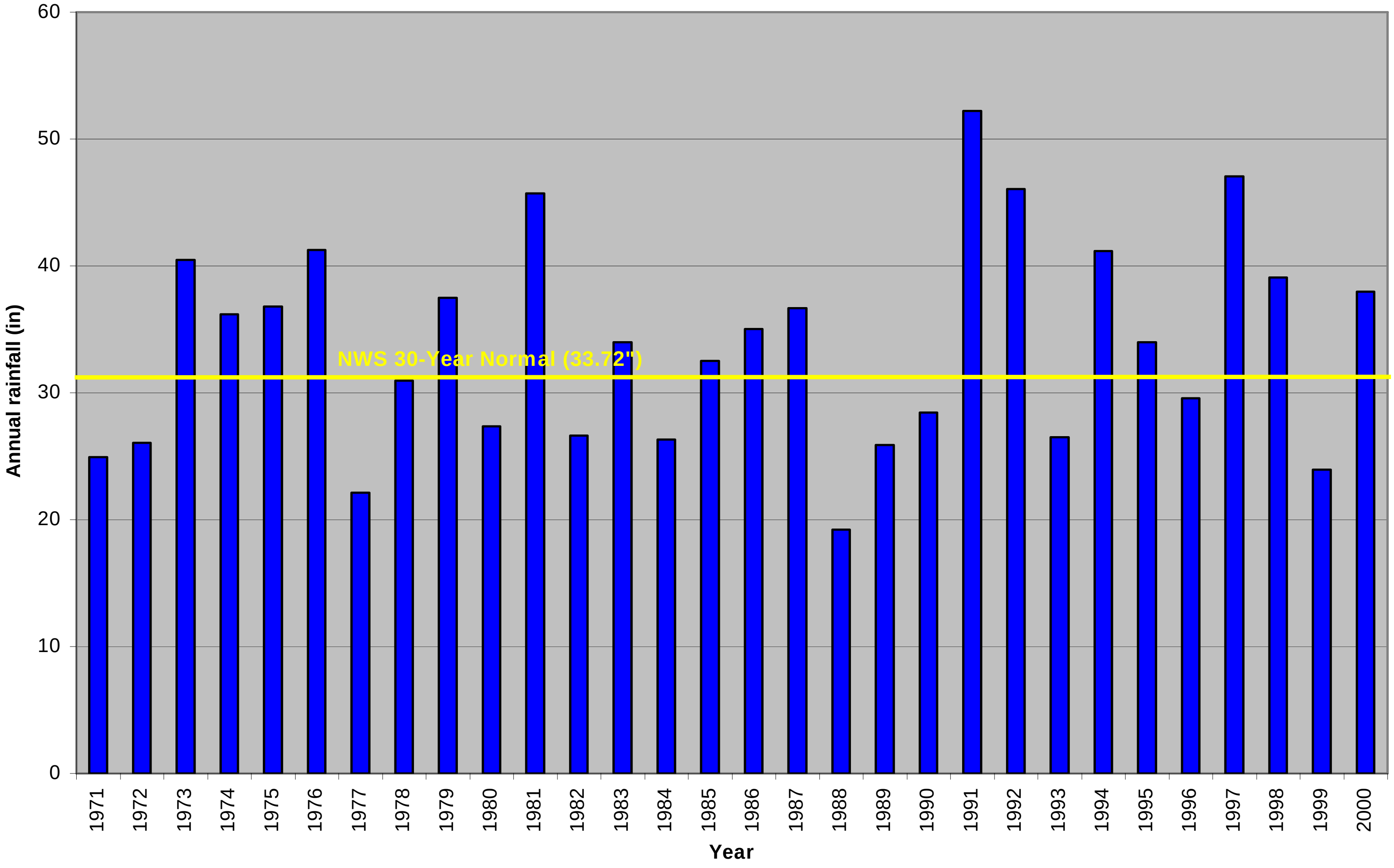
The Austin metropolitan area historically receives the highest amounts of rainfall in the spring and fall months. Rainfall totals were estimated for Town Lake using data from the Flood Early Warning System (FEWS), when possible. Gaps in the FEWS data record (particularly for the older data considered in this report) were filled using National Weather Service (NWS) data from Camp Mabry, Robert Mueller Airport, and Bergstrom International Airport. Although the NWS data is more complete (with a period of record beginning in 1856), the airport gages are not as geographically relevant to Town Lake as are the FEWS gage locations. Table 3.1 gives the name and period of record for FEWS rain gages used to estimate rainfall, and thus storm flow, conditions around Town Lake. These gages were chosen to represent the major contributing watersheds to Town Lake, and the daily rainfall totals to Town Lake were estimated by averaging the daily totals from the gages where data were present and of good quality.

Table 3.1 FEWS Rain Gage Information Used to Estimate Town Lake Rainfall

GAGE #	LOCATION	PERIOD OF RECORD
3000	Waller Creek @ 12th Street	1987 - 1999
850	East Bouldin Creek @ 1st Street	1992 - 1999
700	Eanes Creek @ Camp Craft Road	1987 - 1999
2370	Johnson Creek @ Winsted Lane	1989 - 1999
2400	Shoal Creek @ 45th Street	1987 - 1999
800	West Bouldin Creek @ Oltorf Street	1987 - 1999
810	Blunn Creek @ St. Edwards Drive	1989 - 1999
1210	Barton Creek @ Loop 360	1990 - 1999

For comparative purposes, the Austin area annual rainfall totals as measured by the NWS at the Camp Mabry station are presented in comparison with the 30-year normal from 1971 to 2000 to show the general rainfall conditions (Figure 3.1).

Figure 3.1 Austin-Area Annual Rainfall Totals (1990-2000) as Measured at NWS Camp Mabry Gage vs. the 30-Year Normal (1971-2000)



3.2 Town Lake Flow

From mid-March to mid-October, when water demand is high (especially from agricultural operations located downstream of Austin on the Colorado River) and electrical demands rise, the Lower Colorado River Authority (LCRA) releases more water through the Highland Lakes system. Under these conditions, Town Lake flow is composed primarily of water from the Lake Travis hypolimnion. The hypolimnion is water at lower depths that does not mix with the surface layer known as the epilimnion (Masters 1991). During this growing season, Town Lake functions like a river with residence times of less than two days. Mean daily discharge through the Tom Miller Dam to Town Lake during this flow period, known in this report as the 'release' period, is significantly greater ($p<0.0001$) than mean daily discharge during the winter 'non-release' period. During the 'non-release' period from mid-October to mid-March, the lower flows cause Town Lake to behave more like a typical reservoir with residence times of six to twenty-four days. Because of these differences in flow patterns, data from these two periods are generally analyzed separately in this report.

Data from the LCRA on total mean daily discharge at Tom Miller Dam, both turbine and floodgate releases, from 1976 to 2000, is summarized in Table 3.2, as well as shown seasonally in Figure 3.2. Figure 3.3 shows annual data for the period of record since the last Town Lake Report, demonstrating general dam operations. Both figures include precipitation data collected from the National Weather Service station at Camp Mabry.

Table 3.2 Tom Miller Dam Mean Daily Discharge Summary by Season (1976-2000)

	Release (ft^3/s)	**Non-Release (ft^3/s)**
Mean	1,785.6	987.24
Minimum	0.0	0.0
Q1 – 25% Percentile	988	0.0
Median	1,478.5	98.0
Q3 – 75% Percentile	1,907.5	370.0
Maximum	29,509	36,444.0

Figure 3.2 Tom Miller Dam Mean Daily Discharge by Month (1976-2000) with NWS Mean Monthly Rainfall Totals (1856-2000)

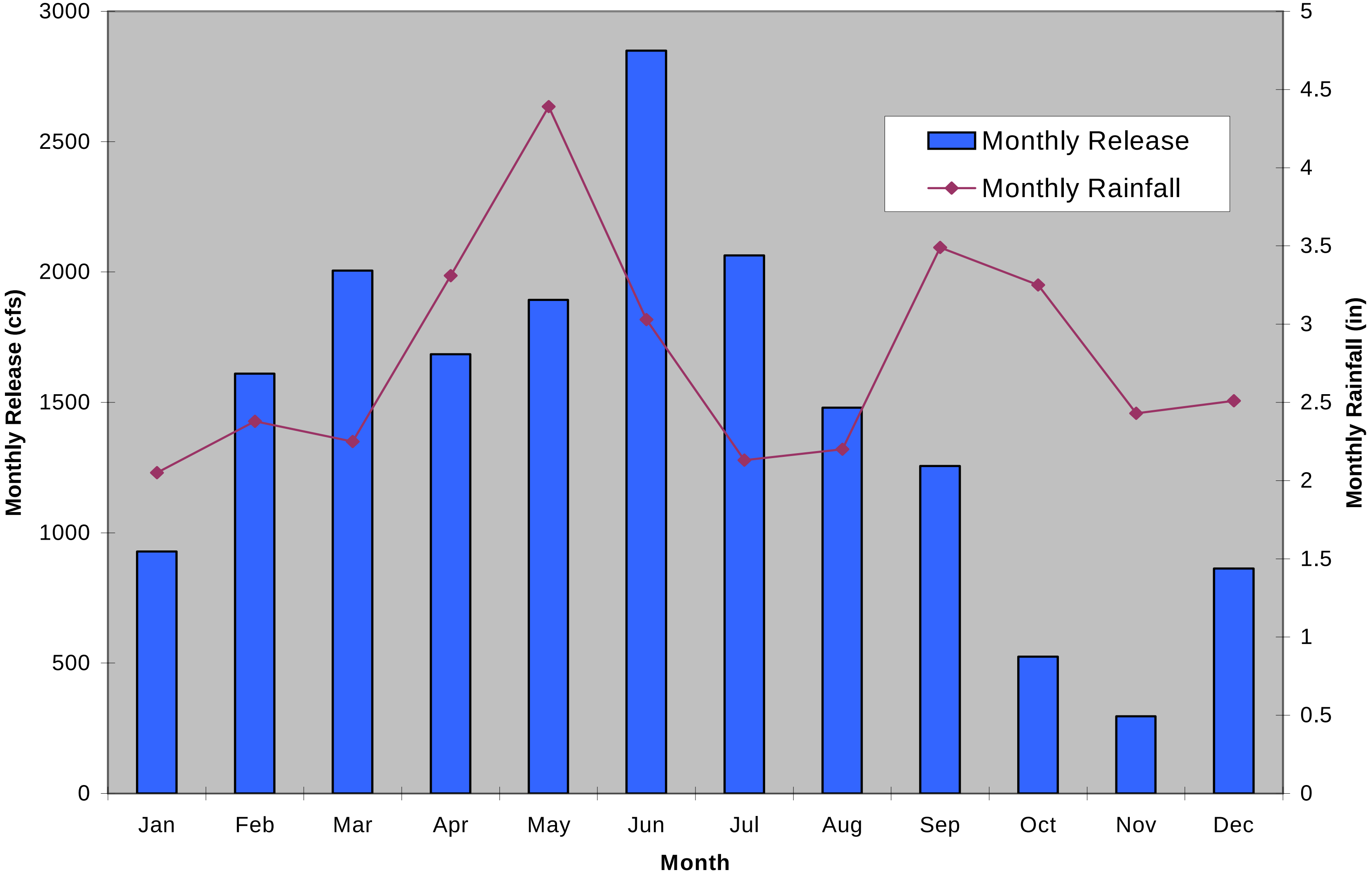
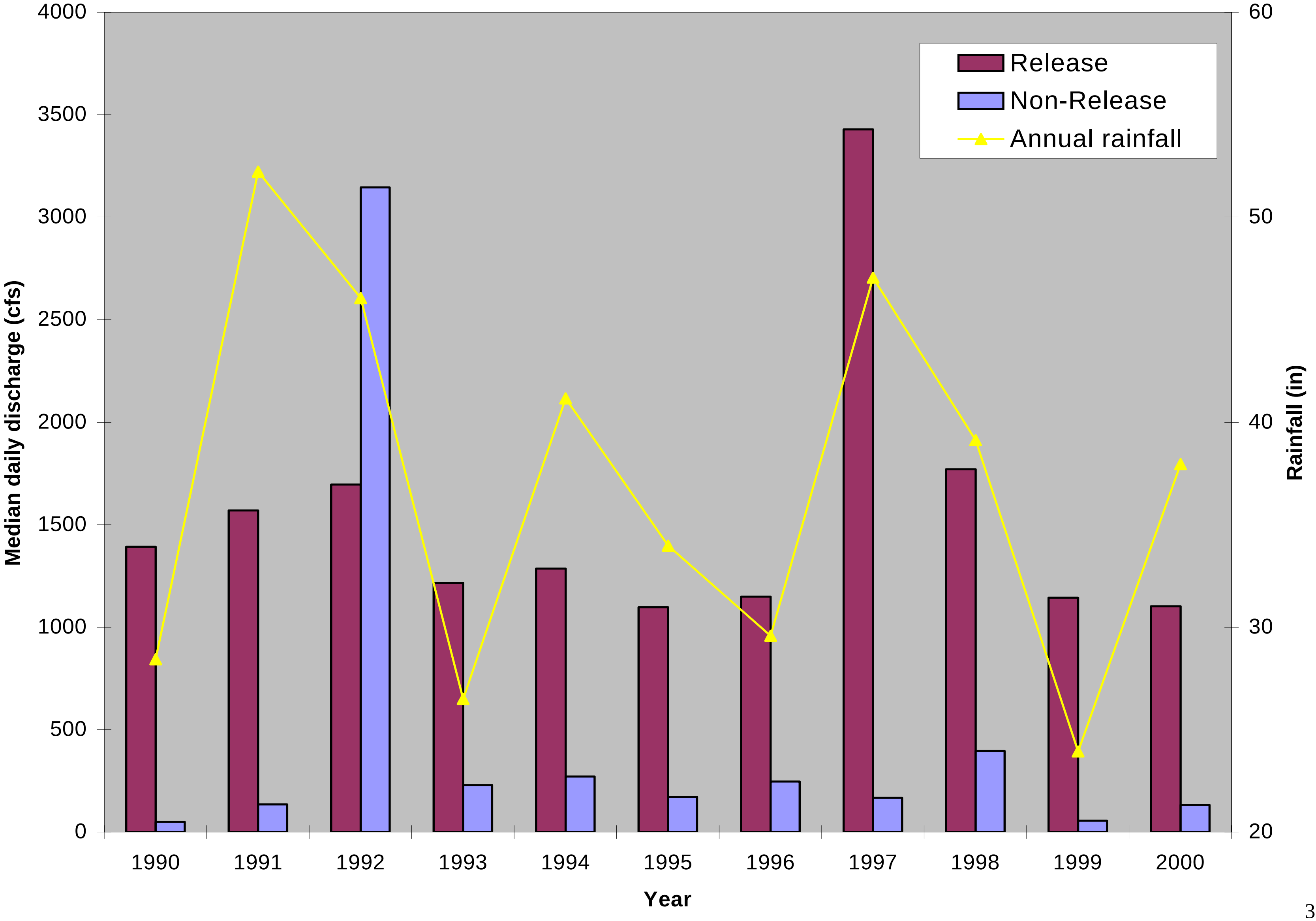


Figure 3.3 Tom Miller Dam Median Daily Discharge by Year with Annual Rainfall Totals (1990-2000).



Since discharge through the dam represents the sum of floodgate releases and turbine releases, both for power generation and irrigation needs, Figures 3.4 and 3.5 are provided to present Tom Miller Dam floodgate release information separately. In these graphs, months and years when Town Lake experienced higher flows are more clearly separated from lower flow conditions. These higher flows are most likely due to flood water management by the LCRA and power generation by water releases through the turbines. Floodgate releases are larger, in general, during the winter period from December through March (Figure 3.4), since irrigation releases are not occurring and the lakes may be full (no available storage capacity). April through July is dominated by turbine releases, but with additional floodgate discharge due to rainfall. September through November reflects periods of lower flow, perhaps due to rainfall deficits during July and August.

The years 1992 and 1997 experienced the largest annual mean daily floodgate releases during the past decade, with the maximum occurring in 1992 at approximately 4,400 ft^3/s (Figure 3.5). Comparison of Figure 3.5 with Figure 3.3 demonstrates that the 1992 high flow events occurred during a non-release period, while the 1997 high flow caused floodgate releases in addition to turbine flows.

Historically, non-release conditions occasionally caused lowered dissolved oxygen downstream of Town Lake and in Town Lake itself. In order to maintain a minimum amount of flow for the Colorado River below Longhorn Dam during low flow non-release periods, especially during low rainfall years, in 1992 the LCRA instituted a minimum target 100 ft^3/s (cfs) of discharge from Town Lake into the Colorado River. Median daily discharge measured at Tom Miller Dam before and after the minimum low-flow policy was instituted is presented in Figure 3.6. Analysis of variance demonstrates that during the non-release season, mean daily discharge downstream of Town Lake (USGS Gage #08158000 at the U.S. 183 Bridge) is significantly higher ($p<0.0001$) following the 1992 minimum discharge policy. However, mean daily discharge during the release periods is not significantly different ($p=0.1210$) since the target flow value was instituted.

Figure 3.4 Comparison of Average Daily Flood Gate Release to Total Tom Miller Dam Discharge by Month (1989-2000)

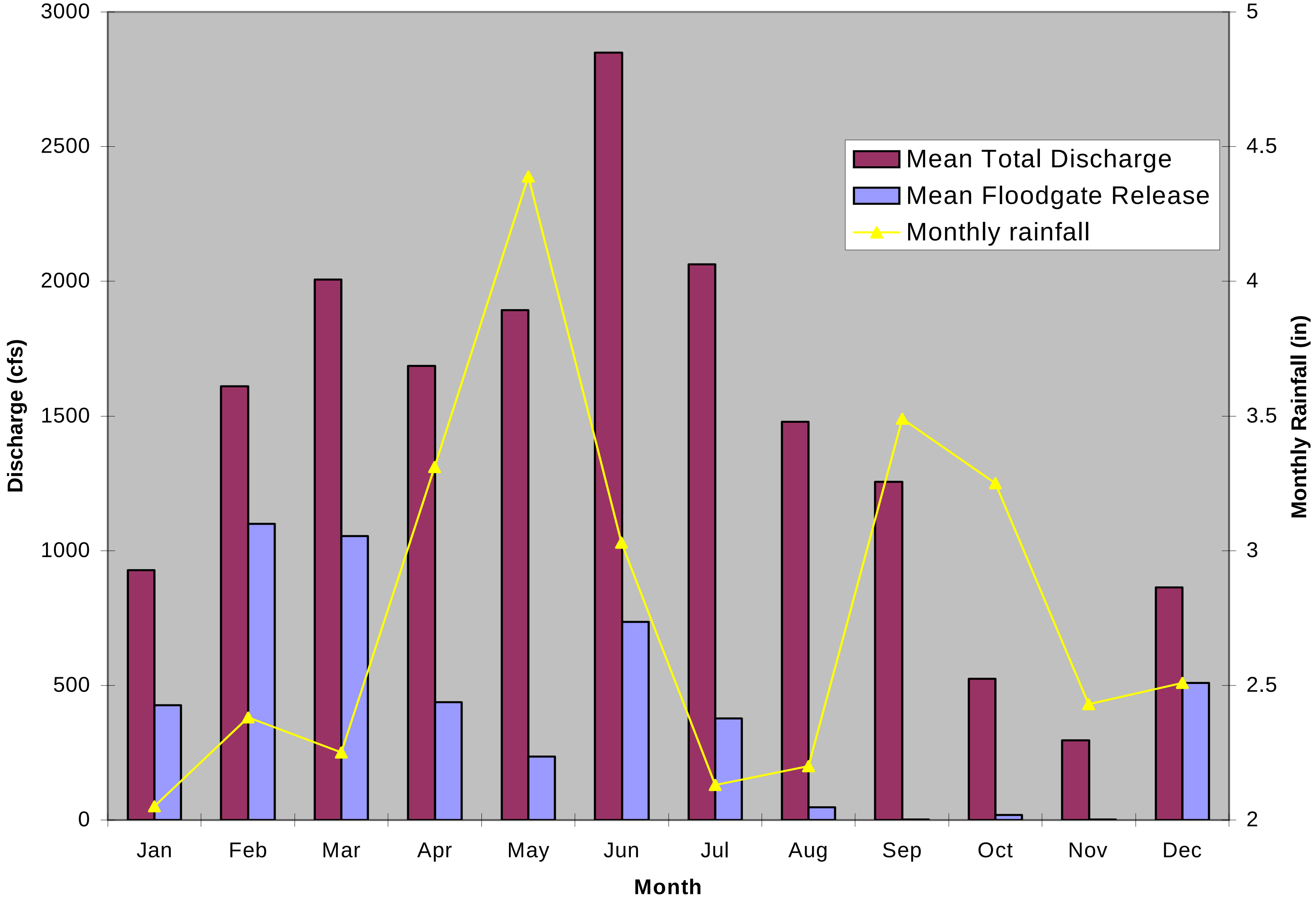


Figure 3.5 Mean Daily Floodgate Releases from Tom Miller Dam by Year (1989-2000)

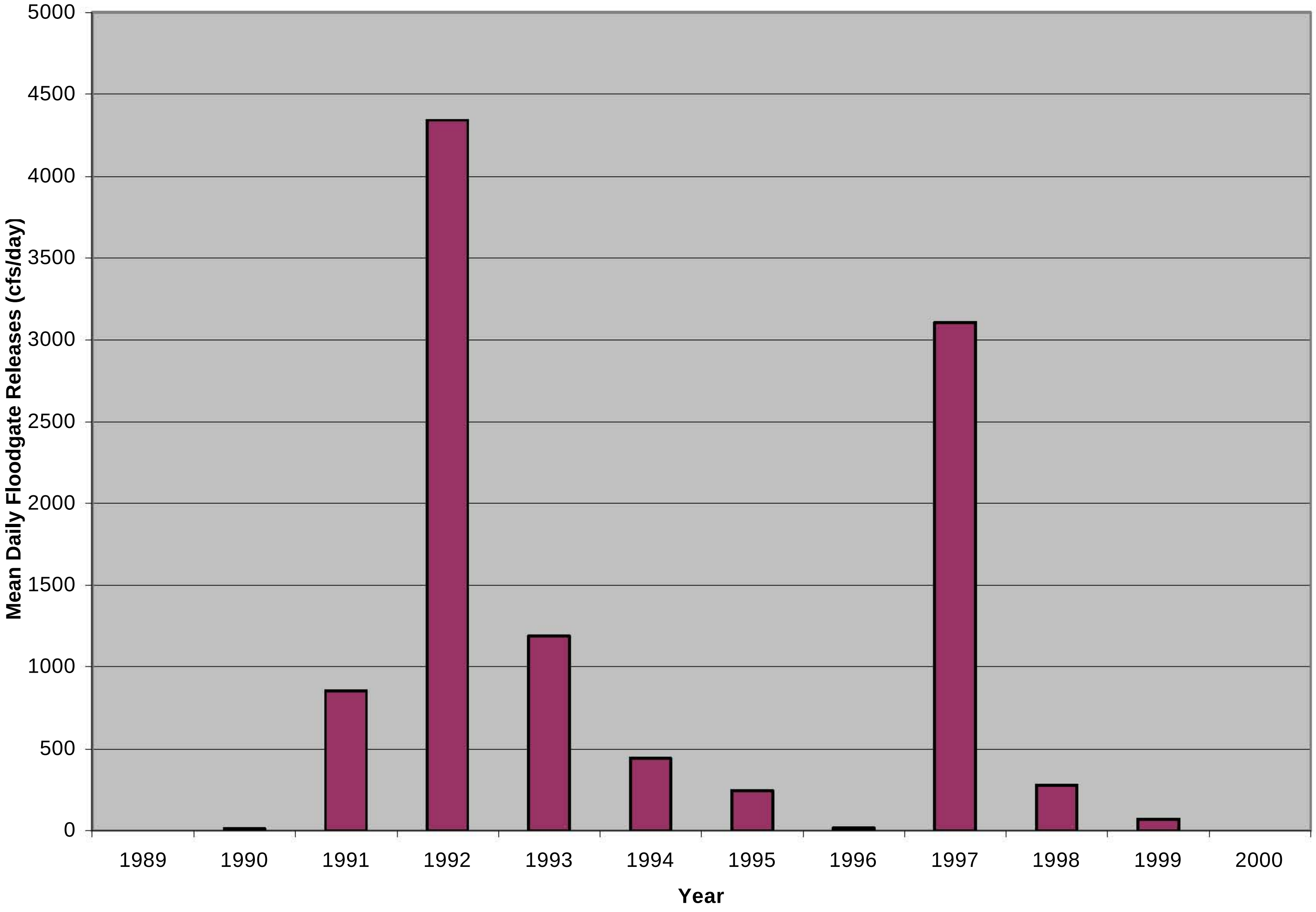
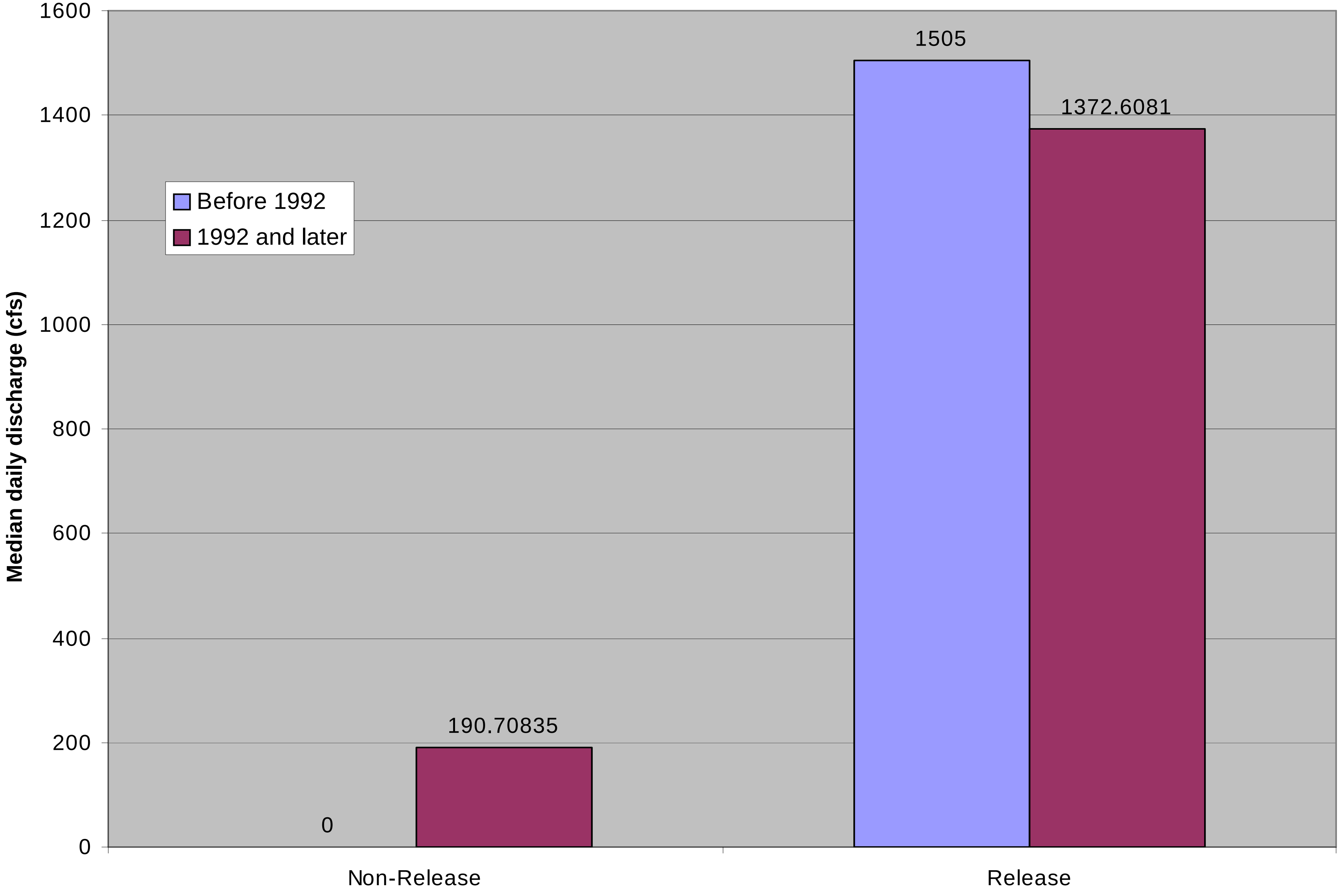


Figure 3.6 Tom Miller Dam Median Daily Discharge (1976-2000) Before and After Change in LCRA Release Practices by Season



4.0 WATER QUALITY

As Austin develops around Town Lake, pollutants are moved from the land's surface to its primary receiving water body, Town Lake. The major pathway for the movement of contaminants is the flow of rainwater from the land's surface and through the creeks to the lake. The condition of the water in Town Lake, therefore, reflects the characteristics of the water carried by the Colorado River from upstream sources with the addition of the rainfall runoff from the Austin area. The condition of the water impacts the biological life that resides in or near the lake as well as the citizens of Austin. The quality of the water in Town Lake is of ongoing concern for these reasons.

Among the objectives of the Watershed Protection Masterplan (COA 2001b) was for Town Lake to maintain or improve its Designated Use Support status (as discussed in Section 2). The beneficial uses for Town Lake are:

High ALS – Aquatic Life Support (High); the level of aquatic life support is segment specific,
NCR – Non-contact Recreation (although designated by TNRCC as contact recreation, the City of Austin does not allow swimming based on the flow and safety factors), and
PWS – Public Water Supply.

Each of these beneficial uses may be impacted by the water quality of the lake. The level of Aquatic Life Support is impacted by dissolved oxygen levels and concentrations of contaminants harmful to aquatic life within the lake. Non-contact recreation is impacted by factors such as the unappealing visual and olfactory nature of algae blooms, and the cost to treat water for a public water supply is affected by nutrients, algae and toxins. The Texas Natural Resource Conservation Commission (TNRCC) evaluates whether water bodies are impaired by using a combination of screening factors and criteria for its assessments (TNRCC 2000).

The following sections will evaluate the current status of the lake, spatial and temporal trends, and comparison with criteria for evaluating beneficial use support where available.

4.1 Description of Sampling Since the 1992 Town Lake Study

4.1.1 Routine Sampling

The Environmental Resource Management Division of the City of Austin Watershed Protection and Development Review Department (COA-ERM) has conducted routine monthly monitoring at five sites in Town Lake since 1991, according to the sampling protocols developed for the Town Lake Diagnostic Study (COA 1992a). All sample collections and field measurements are made approximately at mid-channel and are typically collected from a solar-powered boat. These sampling locations are displayed in the map of Town Lake in Figure 4.1, and written sample location descriptions appear in Table 4.1.

Table 4.1 COA-ERM Town Lake Sampling Locations in Upstream to Downstream Order

Site Name	Location	Latitude	Longitude	USGS Site #
Red Bud	Town Lake mid-channel approximately 0.5 km (0.3 mi) downstream of Tom Miller Dam south of the downstream end of Red Bud Island	30.28711	97.78573	301712097470701
MoPac	Town Lake mid-channel approximately 20 m (70 ft) upstream of MoPac bridge and downstream of Eanes Creek confluence	30.27367	97.77152	301650097453501
Lamar	Town Lake mid-channel approximately 20 m (70 ft) downstream of Lamar bridge and downstream of Barton Creek confluence	30.2657	97.75661	301558097452201
First	Town Lake mid-channel approximately 20 m (70 ft) downstream of First St bridge and downstream of Shoal Creek confluence	30.26308	97.74793	301546097445101
Basin	Town Lake slightly southeast of mid-channel approximately 0.5 km (0.3 mi) upstream of Longhorn Dam	30.24714	97.71638	301500097424801

COA-ERM staff measure field parameters at 0.2 meters above the bottom, and then at every consecutive meter above the lowest depth to 0.2 meters below the surface using a Hydrolab™ instrument. Nutrients samples are collected from the surface by simple grab sampling and from bottom depths by a Kemmerer device. Total suspended solids, volatile suspended solids and fecal coliform bacteria samples are routinely collected at the surface only. Secchi disk depth measurements are also made at every site. Table 4.2 summarizes parameters collected by COA-ERM personnel on Town Lake.

COA-ERM staff has proposed multiple changes to the Town Lake sampling protocols based on the results presented in this report in combination with considered alterations of existing monitoring objectives. The MoPac and Lamar sites will no longer be monitored on a routine basis, and sampling frequency has been reduced to six sampling events per year (two non-storm and one storm-influenced in each release condition per year). Two sediment samples will now be collected per year at the Basin site, and additional monitoring efforts, including plankton community assessments, are being planned.

Figure 4.1 Map of Town Lake Sampling Sites

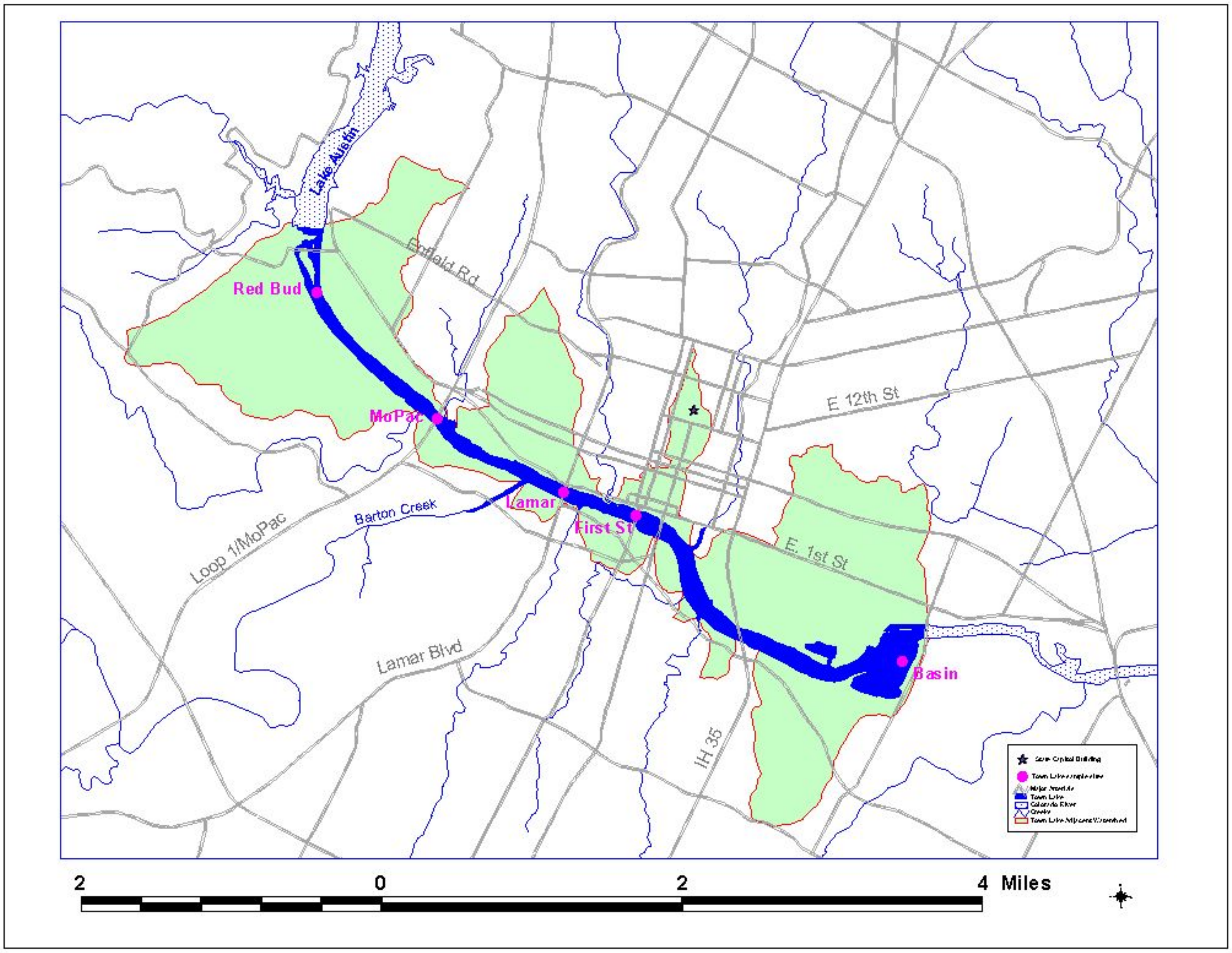


Table 4.2 Summary of Parameters Collected by COA-ERM

Parameter	Depth Collected	Analysis Method
Temperature	all depths	Hydrolab™
Conductivity	all depths	Hydrolab™
Dissolved Oxygen	all depths	Hydrolab™
Dissolved pH	all depths	Hydrolab™
Orthophosphorus as P	surface and bottom	SM 4500-P E
Total Phosphorus as P	surface and bottom	SM 4500-P x
Nitrate+Nitrite as N	surface and bottom	SM 4500-NO3 F, EPA 353.2
Ammonia as N	surface and bottom	SM 4500-NH3 F
Total Kjeldahl Nitrogen as N	surface and bottom	EPA 351.4
Total Suspended Solids	surface only	SM 2540 D
Volatile Suspended Solids	surface only	SM 2540 E
Chlorophyll-a	surface only	SM 10200 H
Fecal Coliform Bacteria	surface only	SM 9222 D
Secchi Disk Depth	variable depth	Secchi Disk
Turbidity	Surface and bottom	Hach 2100 P Turbidimeter

The City of Austin Water/Wastewater Department (COA-WWW) also collects samples from the raw intakes of the drinking water treatment plants located on Lake Austin and Town Lake as well as samples collected directly from the lake shores. Data on ammonia, phosphate, sulfate, organic carbon, major ions, bacteria, pH, conductivity and alkalinity are routinely collected approximately bi-weekly. Plankton and diatom samples are collected from the treatment plant intakes daily Monday through Friday.

Data collected by the COA-ERM for Lake Austin have been included in analyses for this report to further enable upstream/downstream comparisons and as a characterization of upstream inputs to Town Lake. Additional Lake Austin data for nutrients, physical, solid and bacteria parameters, collected at Tom Miller Dam by the Lower Colorado River Authority (LCRA) from 1982 to 2000, have been included in analyses for this purpose along with data collected by COA-WWW from the treatment plant intakes and Lake Austin shorelines (Table 4.3).

Table 4.3 Lake Austin Sample Location Summary

Site Name	Latitude	Longitude	USGS Site #
Lake Austin @ Tom Miller Dam	30.29442	97.78646	301739097471201
Lake Austin @ Walsh Boat Dock	30.29572	97.78474	n/a
Lake Austin @ Bee Creek	30.29732	97.7862	n/a
Ulrich Treatment Plant	30.29589	97.78809	n/a
Davis Treatment Plant	30.31387	97.77494	08154900
Lake Austin @ Bull Creek	30.34475	97.78942	302043097472401
Lake Austin @ Emma Long Park	30.32454	97.83959	301926097502201

4.1.2 Storm/USGS Monitoring

The USGS also performs monitoring on Town Lake and Lake Austin following significant runoff events greater than or equal to 1" in magnitude during release and non-release periods. At least one sample per year is collected during release and at least one sample during non-release periods during a storm event from four sites on Town Lake (Basin, First Street, Lamar, and Red Bud). Field parameters are collected at 10-foot depth intervals at all five normal COA-ERM monitoring locations as well as at the mouth of Barton Creek and beneath the IH-35 bridge, while lab parameters are collected only at the Basin, First Street, Lamar, and Red Bud sites.

The COA-ERM also collects samples following storm events. Storm events are defined by the COA-ERM as sampling which occurs 0-2 days after the average daily rainfall is greater than or equal to 0.10" at four FEWS gages (#3000, #2400, #810 and #800) located around Town Lake. Two storm sampling events are performed during each release period for a total of four annual samples.

4.1.3 Continuous Monitoring

Continuous monitoring, typically at one-hour time steps, of physical parameters including dissolved oxygen, conductivity, temperature and pH, is performed at two locations in Town Lake using a Hydrolab™ datasonde during periods of potential dissolved oxygen fluctuations due to algal growth, inflow variation from Lake Austin and storm-introduced oxygen demanding pollutants. A datasonde is typically deployed at the surface of the Lamar site from mid-October through mid-November when algal blooms are likely to occur, and at the bottom of the Basin site from mid-July through mid-November. Tables 4.4, 4.5a and 4.5b present summary information of continuous monitoring data included in this report. The river flow was obtained from the USGS gage at Highway 183 and plankton counts were measured at the raw intake of the Green Water Treatment Plant (WTP).

Table 4.4 Town Lake Continuous Monitoring Data Inventory

Basin Bottom		**Lamar Surface**	
Begin Date	*End Date*	*Begin Date*	*End Date*
26-Oct-1993	16-Nov-1993		
17-Nov-1993	19-Nov-1993	19-Nov-1993	01-Dec-1993
03-Dec-1993	05-Jan-1994		
26-Jan-1994	09-Feb-1994	11-Feb-1994	23-Feb-1994
		24-Feb-1994	20-Mar-1994
		13-Oct-1994	13-Nov-1994
		22-Nov-1994	14-Dec-1994
		21-Dec-1994	25-Jan-1995
11-Oct-1995	15-Nov-1995		
25-Sep-1996	09-Oct-1996	25-Sep-1996	09-Oct-1996
14-Oct-1996	15-Nov-1996	14-Oct-1996	15-Nov-1996
12-Jul-1999	17-Aug-1999	12-Jul-1999	17-Aug-1999
18-Aug-1999	14-Sep-1999	18-Aug-1999	14-Sep-1999
16-Oct-2000	01-Dec-2000	16-Oct-2000	01-Dec-2000
18-Jul-2001	20-Aug-2001		
20-Aug-2001	26-Sep-2001		

Table 4.5a Town Lake Basin Bottom Continuous Monitoring Data Inventory with Flow and Plankton Counts

Begin Date	End Date	Mean Colorado River flow	Minimum Colorado River flow	Maximum Colorado River Flow	Minimum plankton count @ Green WTP	Maximum plankton count @ Green WTP
26-Oct-1993	16-Nov-1993	201	20	741	857	306812
17-Nov-1993	19-Nov-1993	273	250	300	1408	32518
03-Dec-1993	05-Jan-1994	312	117	1030	1019	8996
26-Jan-1994	09-Feb-1994	364	239	874	979	7977
11-Oct-1995	15-Nov-1995	336	36	3550	917	19380
25-Sep-1996	09-Oct-1996	552	106	2080	4222	8078
14-Oct-1996	15-Nov-1996	252	2.4	1870	958	7832
12-Jul-1999	17-Aug-1999	1048	46	4690	979	19011
18-Aug-1999	14-Sep-1999	970	29	3850	1060	7507
16-Oct-2000	01-Dec-2000	393	7.2	8220	1300	35000
18-Jul-2001	20-Aug-2001	1575	76	5380	1400	12200
20-Aug-2001	26-Sep-2001	1567	16	15600	2100	9500

Table 4.5b Town Lake Lamar Surface Continuous Monitoring Data Inventory with Flow

Begin Date	End Date	Mean Colorado River flow	Minimum Colorado River flow	Maximum Colorado River Flow
19-Nov-1993	01-Dec-1993	294	250	347
11-Feb-1994	23-Feb-1994	364	267	674
24-Feb-1994	20-Mar-1994	336	56	498
13-Oct-1994	13-Nov-1994	298	17	4370
22-Nov-1994	14-Dec-1994	199	14	2570
21-Dec-1994	25-Jan-1995	514	65	3840
25-Sep-1996	09-Oct-1996	552	106	2080
14-Oct-1996	15-Nov-1996	252	2.4	1870
12-Jul-1999	17-Aug-1999	1045	46	4690
18-Aug-1999	14-Sep-1999	968	29	3850
16-Oct-2000	01-Dec-2000	393	7.2	8220

4.2 Data Analyses

Water quality data for Town Lake from all data sources was compiled for the entire period of record through December 2000. Conditions in the lake are highly dependent on both weather conditions (storm and non-storm) and lake operations (release and non-release). Thus, these varying periods are examined separately. Rainfall runoff during storms creates conditions with increased inflows that may have higher pollutants due to wash-off or dilution of some chemical constituents such as dissolved solids. Flows through the lake and corresponding percentage contribution of tributary flows vary greatly with the presence or absence of dam releases as described in Section 3. The release conditions correspond somewhat to climatic seasons, releases occurring during the growing season (March-September) and non-release conditions with low flow-through during the fall and winter (October-February).

Data analysis procedures used to investigate water quality conditions for this report are discussed within this section. As a summarization tool, a graphical summary of statistical analysis results is presented for each water quality parameter. The elements of this graphical summary are described below for each of the corresponding analysis factors.

4.2.1 Analysis Factors

Spatial analyses look at the changes from Lake Austin to Town Lake and longitudinal variations from upstream to downstream within the lake itself. Increases from upstream to downstream indicate the impact of runoff and inputs such as Barton Springs on the Town Lake segment of the Colorado River. Where increases are not seen, the upstream flows or diluting inputs may be the major contributors.

In addition, depth variations are examined to describe processes related to settling that occur in the lake. During storm conditions the lake is well mixed; therefore, non-storm conditions are primarily discussed. The graphical summary presents how concentrations in Town Lake differ from Lake Austin, how concentrations change from Red Bud to the Basin and how concentrations vary with depth.

The evaluation of data grouped by season (separated by release and non-release conditions) and also by storm and non-storm (or base flow) conditions provides information on the dominant processes during each period. Urban runoff contaminant loads from Austin may be important factors in Town Lake only under specific conditions, while upstream inflows or the Barton Springs groundwater source may dominate at other times. Thus, analyses categories will be designated by release and storm conditions. Monthly and seasonal changes are also discussed in this section as the release conditions are related to the seasons. Relationships of the water quality concentrations with flow (which varies with release and storm conditions) and depth (influenced by mixing processes) are also examined.

The graphical summary presents how concentrations change with discharge from Tom Miller Dam, how concentrations differ between release and non-release periods during both storm and non-storm flows, and the conditions under which maximum average concentrations are observed. Changes in mean concentration in the days following storm events are presented for each release condition, along with monthly variation in mean concentrations and daily variation in concentration (if continuous monitoring data exist).

Levels of constituents were compared with year 2000 screening criteria developed by the TNRCC (2000). The number of exceedances of these criteria determines if the state lists a water body as a concern during an assessment that results in a statewide list of impaired water bodies. This report evaluates the data on an annual basis (percentage of exceedances by year) where sufficient data exist to meet TNRCC requirements, typically from 1990 to 2000. The TNRCC, however, conducts this assessment on a periodic basis with data collected during a 5-year period. Therefore, individual annual results will not correspond directly with the TNRCC water body assessment for Town Lake but are still useful as a screening tool for comparing contaminant concentrations in Town Lake to applicable screening levels and standards. Patterns in exceedances of TNRCC criteria over time are presented in the graphical summaries with other temporal trend assessment results.

Finally, data were analyzed for temporal trends. For these analyses, data review was extended historically back as far as sufficient data were available. Long-term trend analyses are limited by changes in monitoring, including the increase in City sampling since the 1992

Town Lake Report, and a strong bias toward storm sampling in the historical data performed primarily by the USGS. In addition, the implementation of the minimum flow policy in 1992 may be a factor in hydrologically-driven changes since that time.

General long-term temporal patterns are presented on the graphical summary in the temporal section along with regression results for each storm and release condition at surface and bottom depths for both Town Lake and Lake Austin sites.

4.2.2 Data Processing, Censored Data and Statistical Analyses

All water quality data were tested to determine spatial and temporal trends using the SAS Software System, version 8. Statistical significance for this report is defined by a type I, or false rejection of a true hypothesis, error ($\alpha \leq 0.05$) of 5 percent corresponding to one type I error in 20 experimental trials (Sokal and Rohlf 1995).

Means and summary statistics for data sets that did not contain censored data points, or data below reporting levels also known as ‘less-thans,’ were computed using traditional methods described in the SAS PROC UNIVARIATE procedures (SAS 1990a). Summary statistics for data sets with censored data points were calculated using non-parametric robust log-probability plotting methods (Helsel and Cohn 1988; Helsel and Hirsch 1992). Although historical data analyses used substitution methods for estimating censored data points, usually as one-half of the detection limit (Town Lake Report 1992; TNRCC 2002), these methods have no applied basis and perform poorly in comparison to distribution estimation or robust methods (Gilliom and Helsel 1986; Helsel and Cohn 1988). The log-probability regression method is recommended over maximum-likelihood estimation methods since it is distribution independent, avoids all transformation bias and typically exhibits lower root mean square error rates (Helsel 1990; Helsel and Cohn 1988).

Comparisons to determine significant differences between sampling locations and parameter concentrations in the various release and storm periods were performed on ranked data sets. This was done by using analysis of variance tests in the SAS PROC GLM (SAS 1989) in combination with Duncan’s multiple-range test to explore other potential statistically significant groupings (Duncan 1975). Data were ranked to avoid the normal data distribution assumption of parametric ANOVA procedures as well as to account for censored data points similar to the procedures for a rank-sum test (Helsel and Hirsch 1992). Additional comparison analyses were performed using simple t-tests on summary statistics generated by the log-probability plotting method results as described above.

Temporal, depth and discharge-related trend analyses were performed using ordinary least-squares (OLS) methods in the SAS PROC REG (SAS 1989) on ranked data sets and with correlation analysis using Spearman's non-parametric partial (with depth) ranked correlation test (SAS 1990a). Trends observed from the OLS methods on ranked data sets containing censored observations were confirmed using Cox Proportional Hazards regression methods adapted from biological statistical methods and applied using the SAS PROC PHREG (Allison 1995). Although originally designed for left-censored survival data, the Proportional Hazards or Maximum Partial Likelihood method can be applied to right-censored data through simple transformation for a robust semi-parametric regression analysis (Allison 1995; Helsel 1998).

4.3 Nutrients

Nutrients are essential to the growth of living things (Campbell 1993). Aquatic species of plants require relatively large amounts of three major macronutrients (excluding oxygen and hydrogen): carbon, nitrogen and phosphorus (Masters 1991). If the supply of one of the macronutrients in a system is less than the requirements of the organisms that live in that system, then that nutrient will limit the amount of growth of the organisms and is said to be a limiting nutrient. Since a number of naturally occurring sources of carbon in the environment exist such as atmospheric carbon dioxide (CO_2) and decaying organic matter, carbon is typically not a limiting nutrient (Masters 1991). In freshwater systems, nitrogen and phosphorus are the primary limiting nutrients controlling the growth of aquatic plants (Novotny and Chesters 1981; Masters 1991; Miertschin and Armstrong 1986).

4.3.1 Nitrogen

Nitrogen is one of the major macronutrients required by organisms to build nucleic acids and proteins (Campbell 1993). Although nitrogen comprises 78.08 percent of the volume of the atmosphere as gaseous molecular nitrogen (N_2) (Rowland and Isaksen 1987), most plants can use nitrogen only in the fixed form of ammonia (NH_3) or nitrate (NO_3^-) (Smith 1990; Campbell 1993). As living organisms and organic wastes decompose, nitrogen is released first in the form of ammonia or ammonium ions (NH_4^+). Atmospheric nitrogen may also be split into two free nitrogen molecules (N) which then combine with hydrogen (H^+) to produce ammonia. In oxygenated aquatic systems, ammonia is converted to nitrite (NO_2^-), and nitrite is then quickly converted to nitrate by in a process known as nitrification (USEPA 1987). Some nitrate is converted back to nitrogen (N_2) and released to the atmosphere during de-nitrification (Campbell 1993).

Excess ammonia levels have a harmful impact on fish (NRC 1979). Free ammonia may accumulate in fish, resulting in decreased hatching success, reduction in growth rate and damage to gill and kidney tissue (USEPA 1987). Extreme ammonia levels may result in fish mortality.

The USEPA reports 96-hour LC50, or the concentration at which 50 percent of the test subjects died, for freshwater non-salmonid fish from 0.14 to 4.60 mg/L (USEPA 1986). The USEPA (USEPA 1987) reports chronic effects of ammonia for freshwater fish occurring in the range of 0.0017 to 0.612 mg/L. The World Health Organization (WHO 1984) gives guidelines for ammonia as an aesthetic parameter with a level of 1.5mg/L, and TNRCC 2000 screening levels for identifying water quality concerns for nitrogenous nutrient parameters in reservoirs (TNRCC 2000) are listed in Table 4.6.

Table 4.6 TNRCC 2000 Nitrogen Screening Levels in Reservoirs

Nutrient Parameter	Screening Level (mg/L)
Ammonia	0.12
Nitrate	0.34

Nitrate in drinking water may pose more serious public health risks than ammonia, especially to children younger than six months old (USEPA 1987; Masters 1991). At concentrations greater than 10 mg/L of nitrate (NO_3-N), a condition known as Methemoglobinemia (Blue Baby Syndrome) may occur, causing asphyxia and possibly death as nitrate is converted to nitrite, which reacts with hemoglobin in the body (Droste 1997). The World Health Organization (1984) gives drinking water guidelines for nitrate as 11.3 mg/L, although U.S. standards are 10mg/L (USEPA 1987; AWWA 1990). Fish appear to be less susceptible to nitrate than they are to ammonia, and the EPA (USEPA 1987) reports that warm-water fish can be maintained in water with concentrations of nitrate up to 90 mg/L.

4.3.1.1 Anthropogenic Sources of Nitrogen

Numerous sources of anthropogenic non-point, or non-localized pollution exist primarily from storm water runoff (Novotny and Chesters 1981). Most of these pollutant sources are also sources of nitrogen addition to aquatic systems in urban areas. Residential nitrogenous fertilizer application and animal manure are important non-point sources of nitrogen (Puckett 1994; Novotny and Chesters 1981; USEPA 1987). Approximately 11.5 million tons of nitrogen are applied as commercial fertilizer per year in the United States. Adding to the problem are the 7 billion farm animals in the United States that produce an estimated 6.5 million tons of nitrogen from manure (Puckett 1994). Natural bacterial decomposition of proteins and nitrogenous organic substances also contribute nitrogen to the environment. These and other non-point sources are estimated to contribute approximately 80 percent of the total nitrogen load delivered to streams and lakes in the U.S. (Novotny and Chesters 1981).

Atmospheric deposition of nitrogen is also a major, though non-traditional, non-point source of nitrogen inputs to freshwater systems that has largely been ignored by water quality modeling and legislative prevention efforts of the past (Puckett 1994). Nitrogen in the urban atmosphere originates from combustion of fossil fuels by electric utilities, large industries and vehicle emissions (Masters 1991) in the form of nitrogen oxides (NO_x).

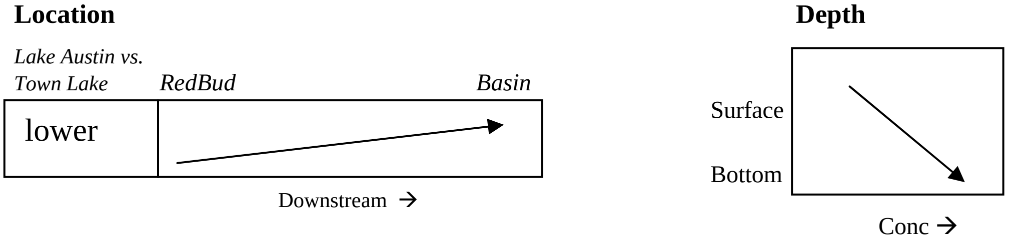
Point sources, or discrete identifiable pollutant-discharging locations (Novotny and Chesters 1981), that contribute nitrogen to aquatic systems include industrial and sewage treatment processes (Puckett 1994). However, since all of the City of Austin wastewater discharges to the Colorado River occur downstream of the Longhorn Dam, which impounds Town Lake, and no major wastewater treatment plant outfalls occur upstream of Town Lake, non-point and natural sources would be expected to contribute the majority of the nitrogen load to Town Lake. Groundwater discharges to Town Lake such as Cold Springs and Barton Springs, because of their relatively higher nitrogen concentration, also act as a point source input of nitrogen as discussed in Section 7.0.

4.3.1.2 Summary of Results

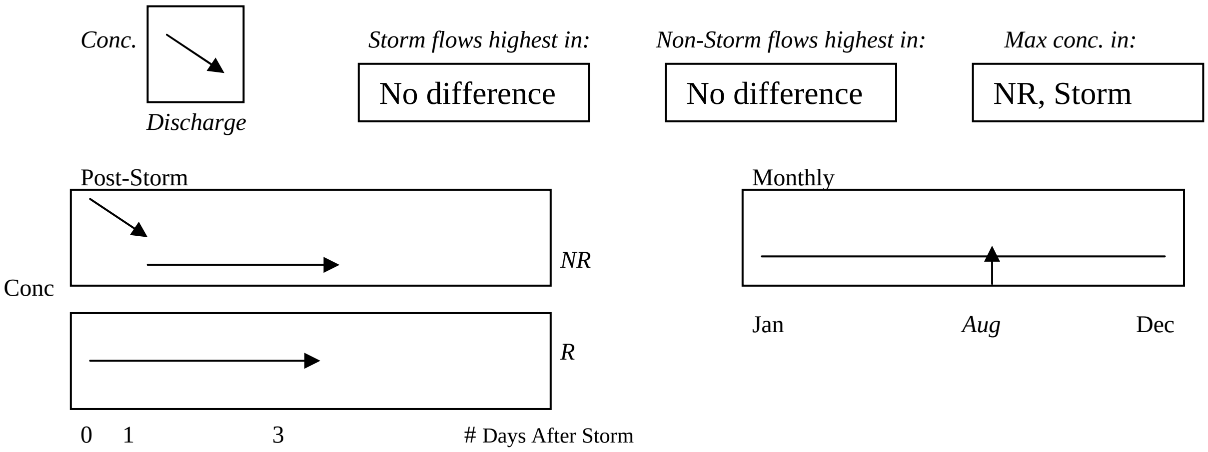
Graphical summaries of Town Lake nitrogen data are presented by parameter in Figures 4.2, 4.3 and 4.4. For purposes of presentation, this report will describe nitrogenous nutrients in the following manner: total ammonia as nitrogen will be described as “ammonia,” total nitrate plus nitrite as nitrogen will be described as “nitrate,” and total Kjeldahl nitrogen as nitrogen will be described as “TKN.”

Figure 4.2 Graphical Summary of Town Lake Ammonia Results

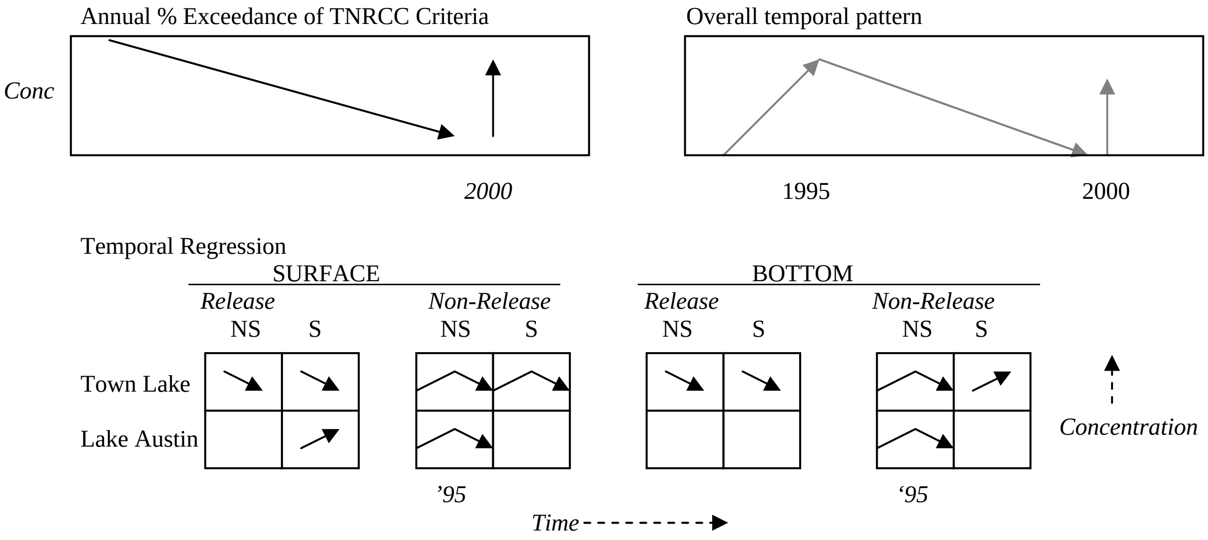
SPATIAL



FLOW/SEASONALITY



TEMPORAL



Comments:

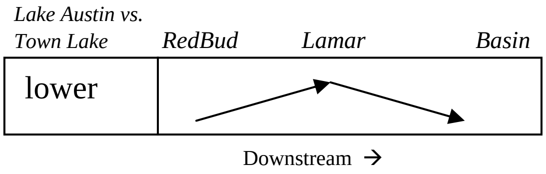
Spike in ammonia values in 2000 possibly due to increased algae bloom sampling.

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

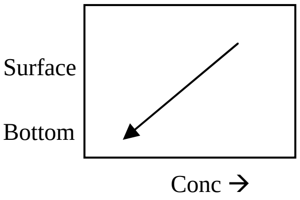
Figure 4.3 Graphical Summary of Town Lake Nitrate Results

SPATIAL

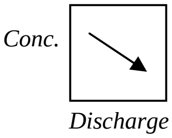
Location



Depth



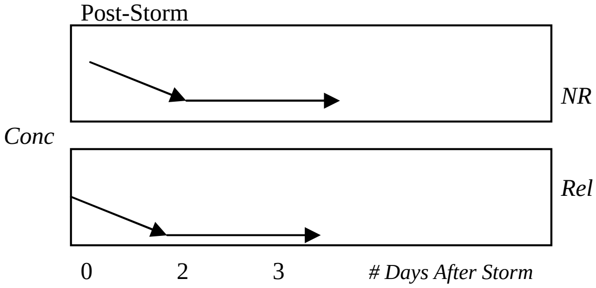
FLOW/SEASONALITY

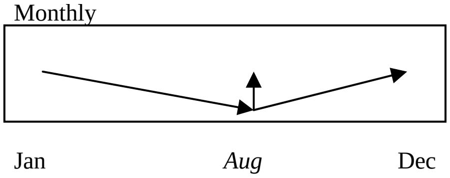


Storm flows highest in: Non-release

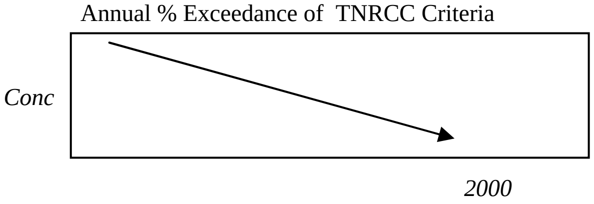
Non-Storm flows highest in: Non-release

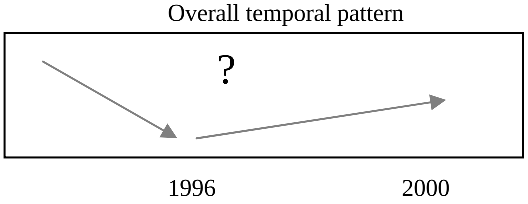
Max conc. in: NR, Storm

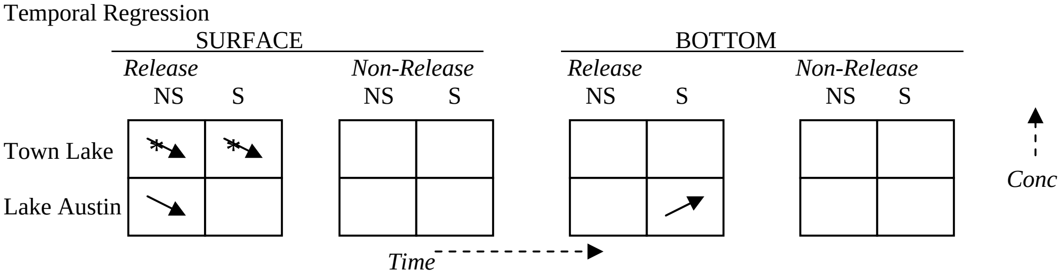




TEMPORAL







* = non-significant

Comments:

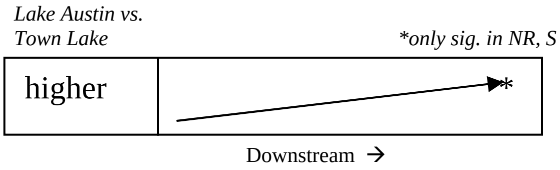
Strong Barton Springs influences evident in concentration-depth profiles (higher nitrate concentrations at the surface during NR). Non-release shows stronger storm impacts than release. Lowest monthly mean concentrations observed when Barton Springs water is less diluted by Barton Creek flows during dry summer months. Annual means are clearly related to annual mean BS discharge (lowest % exceedances occurred in only three years when Barton Springs discharge dropped below 30cfs).

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

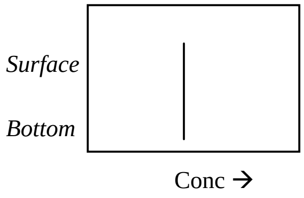
Figure 4.4 Graphical Summary of Town Lake TKN Results

SPATIAL

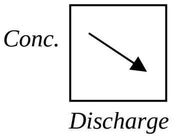
Location



Depth



FLOW/SEASONALITY

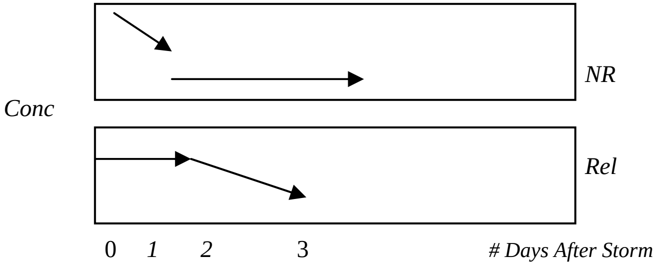


Storm flows highest in: No difference

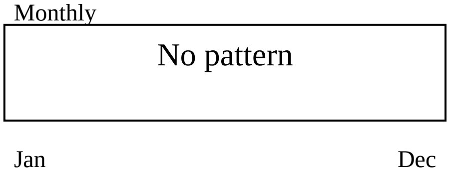
Non-Storm flows highest in: No difference

Max conc. in: NR, Storm

Post-Storm



Monthly



TEMPORAL

Annual % Exceedance of TNRCC Criteria

No TNRCC criteria exist for TKN

Overall temporal pattern

Generally decreasing, although NR, NS conc. increasing since 98

Temporal Regression

	SURFACE				BOTTOM			
	Release		*Non-Release*		*Release*		*Non-Release*	
	NS	S	NS	S	NS	S	NS	S
Town Lake	↘	↘	↗		↘	↘		
Lake Austin	↘	↘	↘	↘	↘	↘	↘	↘

Time - - - - - - - - - - - - - - - ▶

↑ *Conc*

Comments:

TKN concentrations are increasing during non-release, non-storm flow conditions although Town Lake storm flows are exhibiting some improvement. Power analysis and lack of depth differences provides an opportunity for reducing sampling to only one depth (surface or mid-depth) per site.

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

Although Lake Austin is expected to be less impacted by urbanization than Town Lake, Lake Austin exhibits higher mean TKN concentrations than Town Lake. However, nitrogenous nutrients (even though Lake Austin exhibits higher mean TKN values) show inverse correlation to Lake Austin discharge through Tom Miller Dam into Town Lake. Both ammonia and TKN display increasing longitudinal patterns in concentration from upstream to downstream sites, potentially due to urban runoff and urban tributary loading. Mean Town Lake nitrate concentrations yield a spike in values at the Lamar site, indicating strong Barton Springs/Barton Creek loading influences. However, nitrate concentrations are still higher upon discharge from Town Lake than Lake Austin input concentrations. Town Lake is also increasing the concentrations of ammonia in the Colorado River, since concentrations upon discharge from Town Lake at Longhorn Dam are significantly greater than concentrations at Red Bud. Despite longitudinal increase in mean TKN concentrations in Town Lake, mean TKN concentrations at the Basin are still less than mean concentrations in Lake Austin, suggesting that Town Lake may be reducing organic nitrogen in the Colorado River through Austin.

Nitrate and ammonia values exhibit differences in surface and bottom depth concentrations during the winter and summer months, illustrating the potential temperature mixing effects of the temperature-constant Barton Springs discharge waters. Additionally, the annual percentage of Town Lake nitrate values exceeding TNRCC screening levels are at a minimum when the annual average discharge of Barton Springs drops below 30 ft^3/s.

Temporal trend analysis indicates that Town Lake concentrations of TKN are increasing over time during the non-release season in non-storm flow conditions when the high-TKN waters of Lake Austin and Town Lake are theoretically most isolated. Despite the increase observed during non-release conditions, Town Lake TKN concentrations during release appear to be decreasing over time, following similar patterns observed in Lake Austin. Town Lake concentrations of ammonia, however, generally appear to be improving over time.

Comparison of nitrogen data in Town Lake to 2002 TNRCC screening criteria in water reveal that Town Lake is of “no concern” for ammonia, according to official assessment methodologies. However, the percent exceedances of nitrate indicate that Town Lake is potentially of “concern” status.

Well-characterized TKN mean values in Town Lake, in combination with lack of depth differences (and a decreasing temporal trend) suggests that sampling could be reduced to only one depth (surface or mid-depth) per site. The amount of Town Lake nitrate data in excess of the TNRCC screening criteria suggests that additional monitoring may be necessary not only to ensure that the most representative dataset is available for assessment against the criteria but also to better identify temporal trends and sources of nitrate input to Town Lake.

4.3.1.3 Spatial Distribution

Ammonia yields generally increasing longitudinal trends from upstream to downstream, more noticeably when Town Lake is most isolated from Lake Austin during non-storm, non-release conditions (Figure 4.5). Mean ammonia concentrations at the most downstream Basin site are always significantly different from concentrations at the most upstream Red Bud site, and Town Lake mean ammonia concentrations are significantly greater than Lake Austin mean ammonia concentrations during all storm and release conditions (Figure 4.6). Interestingly, mean ammonia concentrations during the summer non-storm release months are significantly higher at the MoPac and Lamar sites than mean concentrations at the more downstream First Street site.

Figure 4.5 Mean Ammonia Site Concentrations by Season and Flow Type

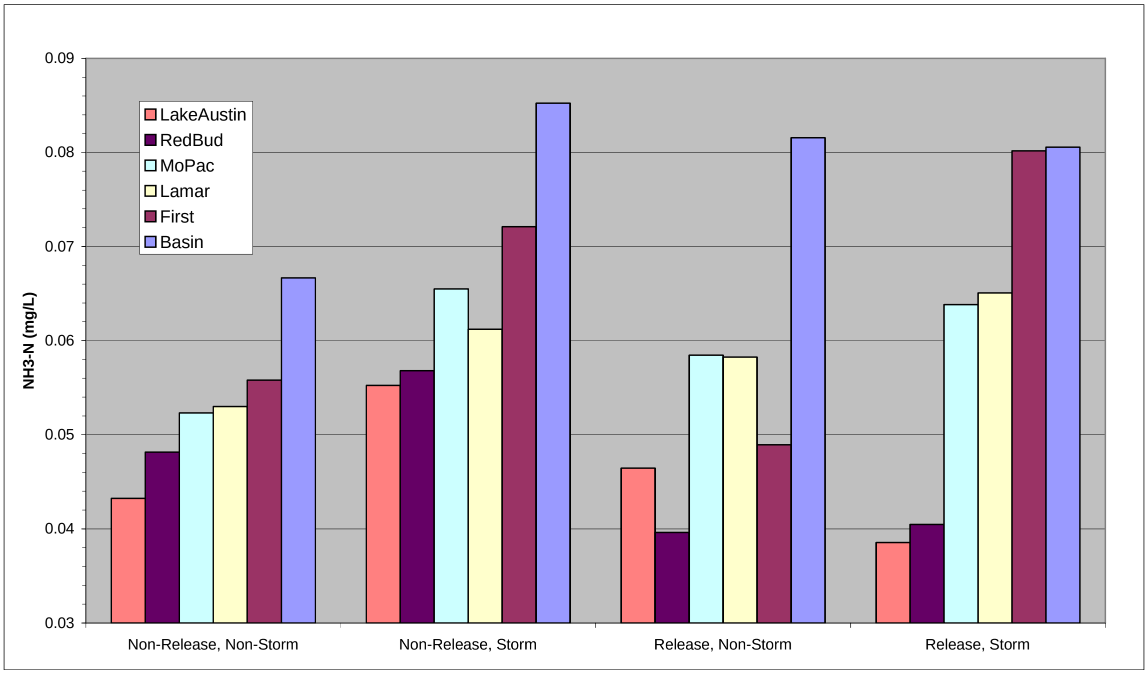
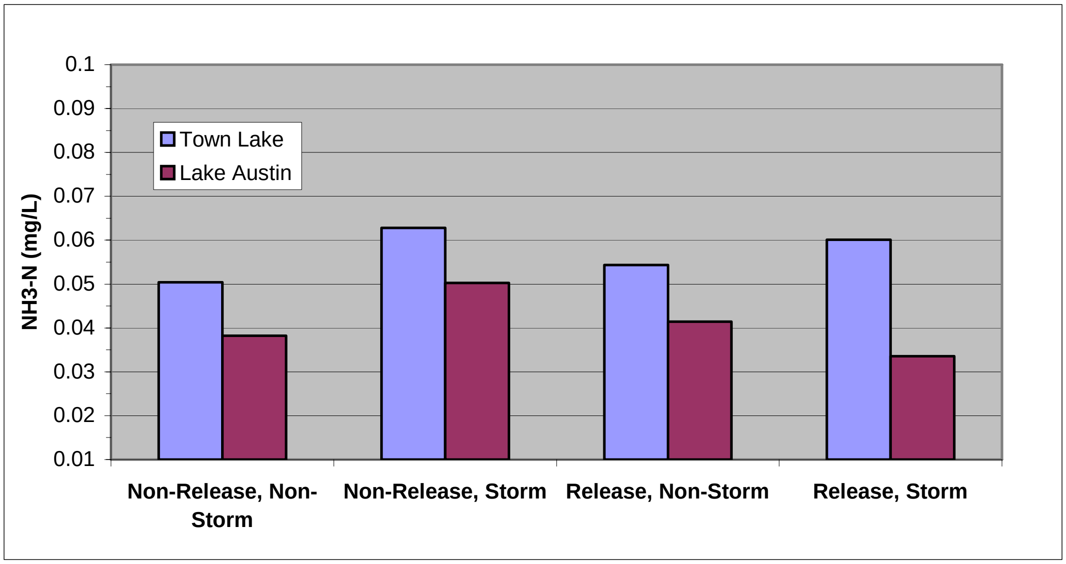


Figure 4.6 Mean Ammonia Watershed Concentrations by Season and Flow Type



Unlike ammonia, mean TKN, or organic nitrogen plus ammonia (Masters 1991), in Lake Austin is typically significantly greater than mean TKN in Town Lake, indicating that organic nitrogen levels are potentially greater in Lake Austin relative to Town Lake. A potential source of the increased amounts of organic nitrogen in Lake Austin is residential run-off containing organic lawn fertilizer. More single-family homes are located on the shores of Lake Austin than on Town Lake; therefore, theoretically organic nitrogen should be higher for the immediate Lake Austin contributing drainage area. Only during release storm flow conditions, when the waters of Town Lake and Lake Austin are most mixed, is the mean TKN concentration not significantly greater in Lake Austin than in Town Lake. Mean TKN concentrations in Town Lake do exhibit a general upstream-to-downstream increase, although average levels at the Basin are only significantly higher than concentrations at Red Bud during non-release, storm flow conditions (Figures 4.7 and 4.8).

Figure 4.7 Mean TKN Site Concentrations by Season and Flow Type

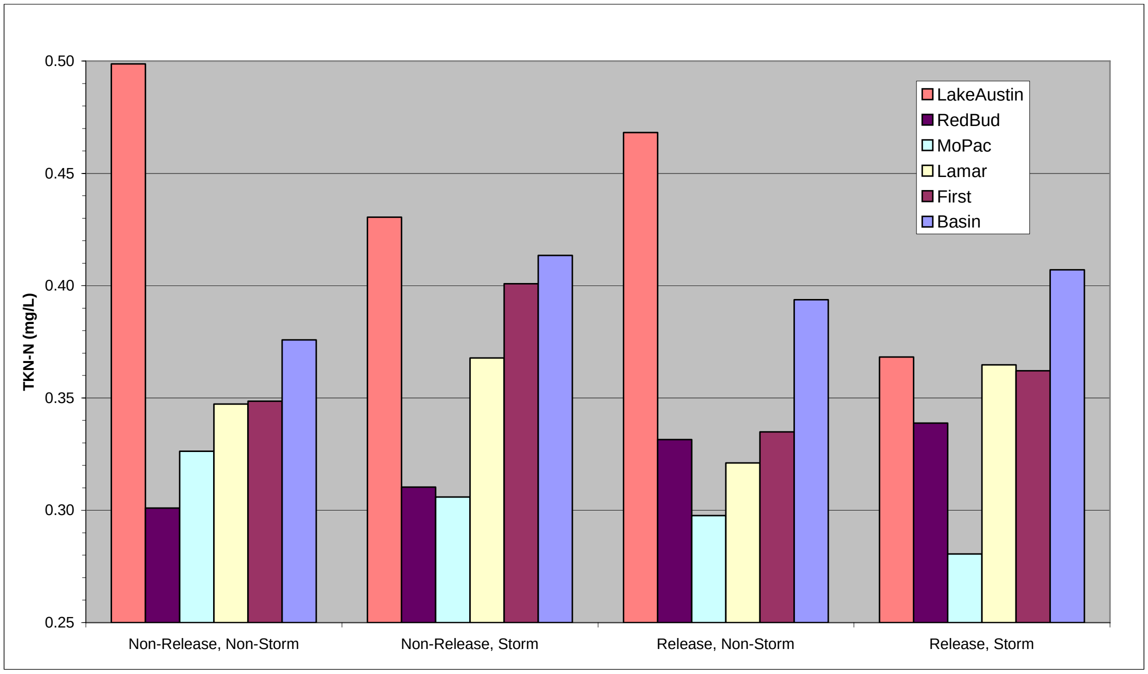
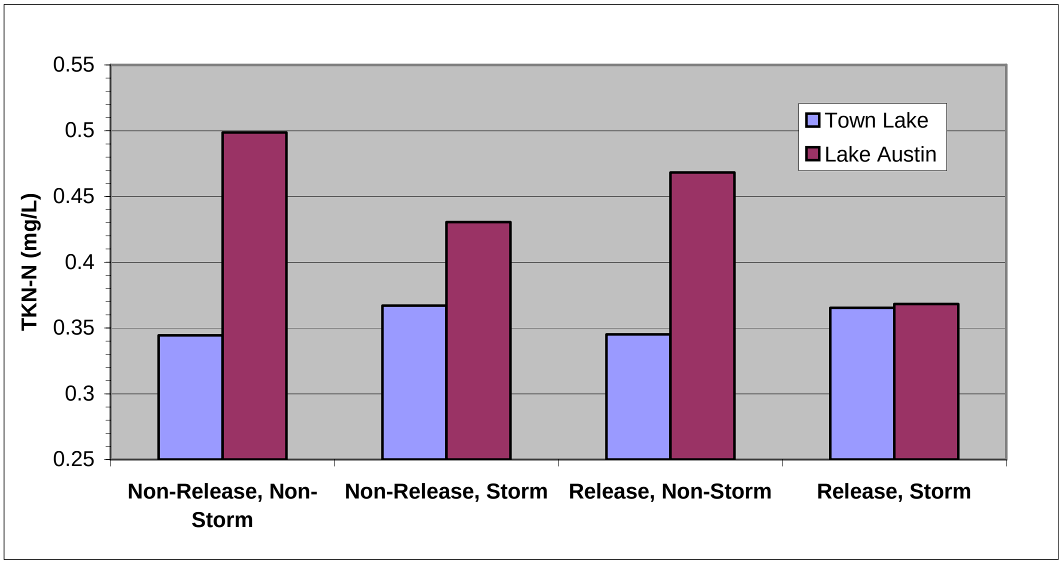


Figure 4.8 Mean TKN Watershed Concentrations by Season and Flow Type



Nitrate exhibits an altogether different pattern in mean site concentrations, with mean concentrations highest at the Lamar site. This is potentially due to nitrogen input from Barton Springs, which discharges into Town Lake via Barton Creek upstream of the Lamar site. Mean nitrate concentrations are not significantly higher at the Basin than at Red Bud during any storm or release condition, indicating that nitrates introduced to Town Lake at Lamar are somewhat mitigated between Lamar and the Basin (Figure 4.9). Town Lake nitrate concentrations are always significantly higher than Lake Austin concentrations (Figure 4.10), and even mean nitrate concentrations at Red Bud are significantly greater than mean concentrations in Lake Austin during all flow types and seasons, except release storm flows, when Town Lake and Lake Austin are most similar.

Figure 4.9 Mean Nitrate Site Concentrations by Season and Flow Type

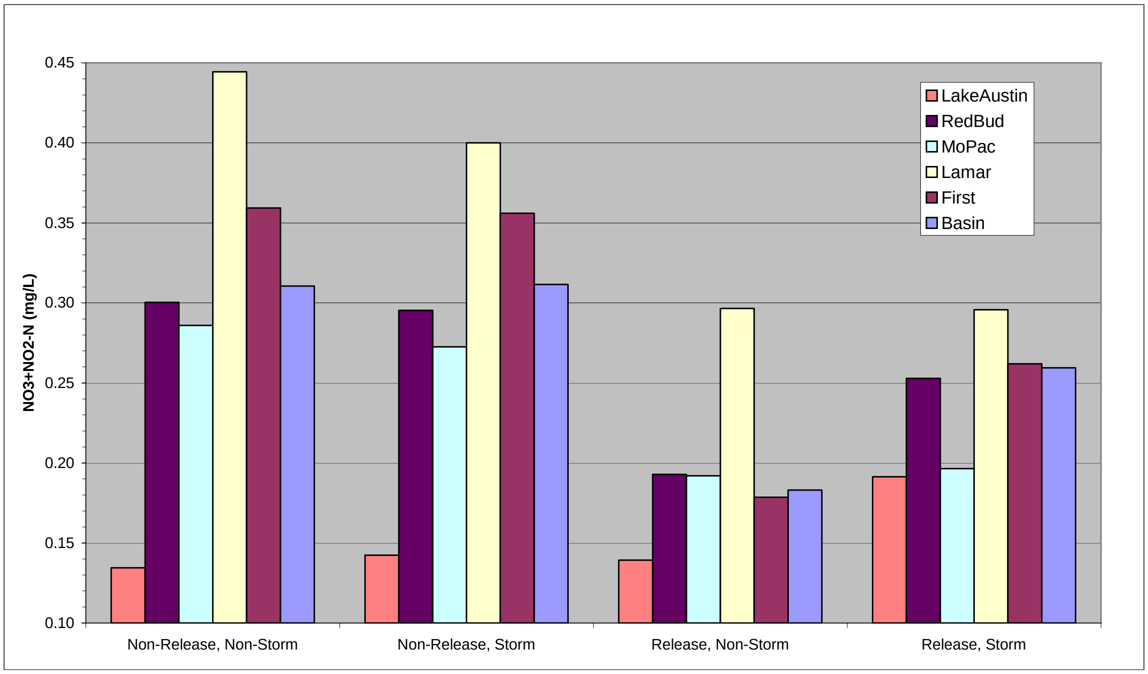
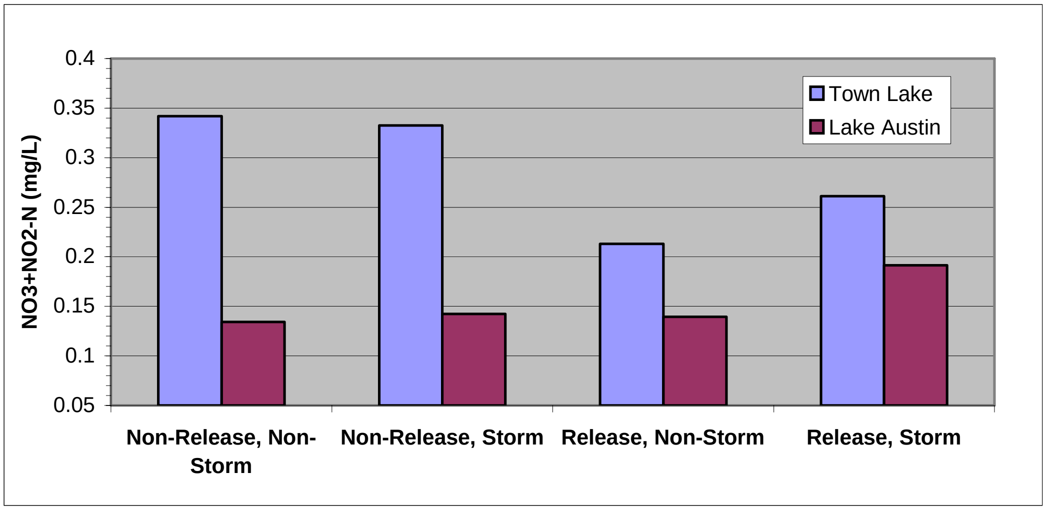


Figure 4.10 Mean Nitrate Watershed Concentrations by Season and Flow Type



4.3.1.4 Storm and Release Conditions

Although storm flow mean total ammonia concentrations in Town Lake are consistently greater than non-storm concentrations, the difference is only statistically significant during the non-release season (Table 4.7). No statistically significant difference was shown between release and non-release periods during any flow condition. This may indicate that nitrogen inputs from local Town Lake contributing watersheds dominate even irrigation release volumes from Lake Austin.

Although storm flow mean TKN concentrations in Town Lake are slightly greater than non-storm concentrations, no statistically significant difference was shown during either the non-release or release seasons (Table 4.7). No statistically significant difference in Town Lake TKN concentrations occur between release and non-release periods during any flow condition.

During both storm and non-storm flow types, non-release Town Lake nitrate concentrations are significantly greater than mean release concentrations (when lower nitrate water from Lake Austin is introduced). During the non-release conditions, when no diluting inflows are available from Lake Austin, the nitrate concentrations do not differ between storm and non-storm conditions. However, in the summer release season, when overall nitrate concentrations in the lake are lower, mean nitrate storm flow concentrations are increased significantly above the base flow mean concentrations (Table 4.7).

Table 4.7 Town Lake Mean Nitrogen Concentrations by Season and Flow Type

Parameter	**Release**		**Non-Release**	
(mg/L)	*Non-Storm*	*Storm*	*Non-Storm*	*Storm*
Ammonia	0.054	0.060	0.050	0.063
TKN	0.345	0.365	0.344	0.367
Nitrate	0.213	0.261	0.342	0.333

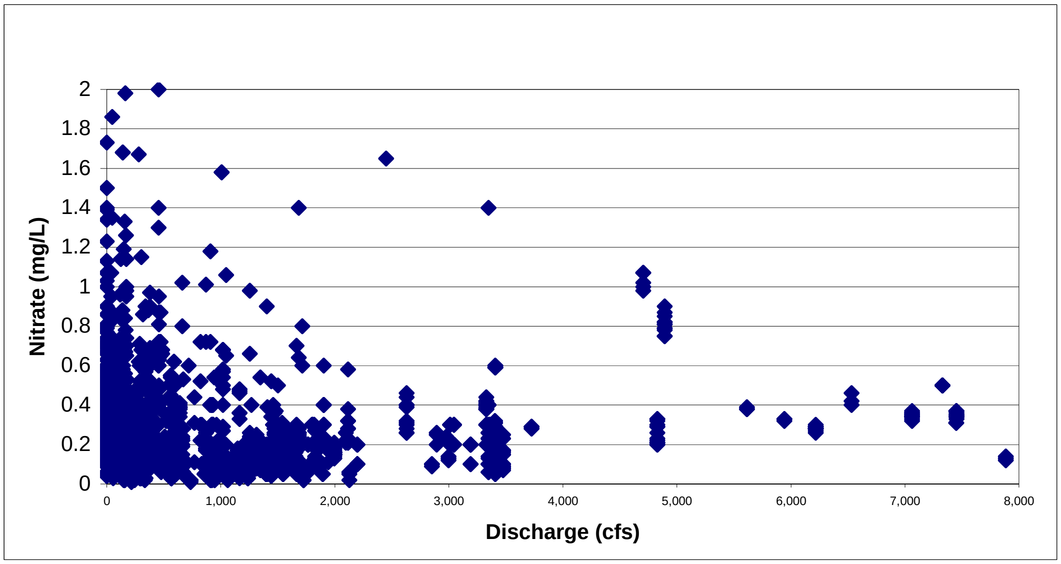
Ammonia and TKN levels in Town Lake are inversely correlated, though weakly, with total discharge from Tom Miller Dam when data from all sites are combined and adjusted for varying depths. Spearman’s non-parametric partial correlation coefficient adjusted for depth for all sites in Town Lake combined are listed in Table 4.8 for TKN and ammonia.

Table 4.8 Ammonia and TKN Correlation Coefficients with Tom Miller Dam Total Discharge, All Sites Combined

Parameter	Spearman's Partial θ	p(θ = 0.0)
Ammonia	-0.1381	<0.0001
TKN	-0.0760	0.003

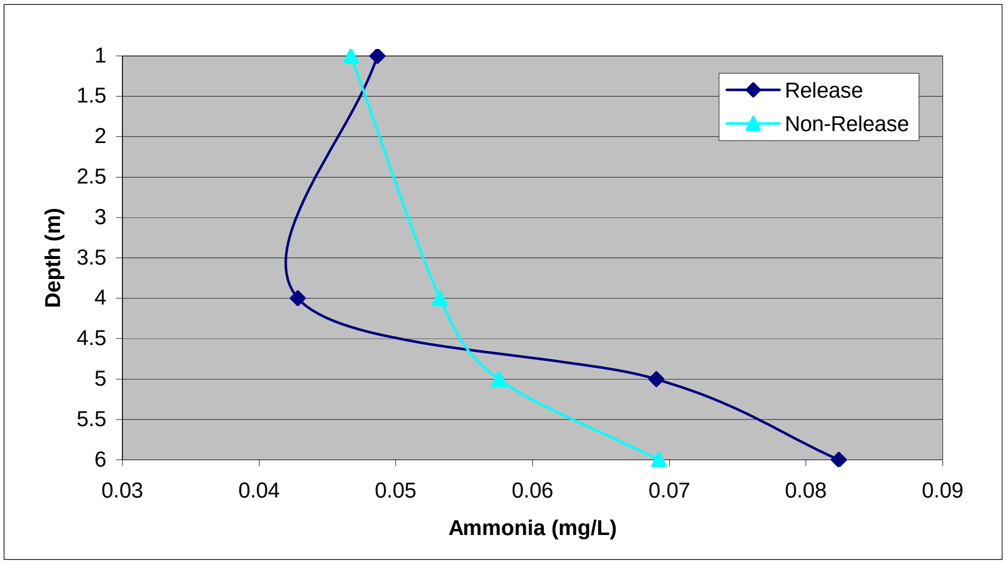
Nitrate concentrations in Town Lake demonstrate a similar inverse relationship with upstream discharge, yielding a partial (adjusted for depth) Spearman's correlation coefficient of -0.2428 (p<0.0001) when data from all sites are combined (Figure 4.11). This may indicate only less spread in values as the higher flows from Lake Austin dominate the lake characteristics.

Figure 4.11 Town Lake Nitrate versus Total Mean Daily Discharge From Tom Miller Dam



Mean ammonia concentrations significantly (p<0.0001) increase during non-storm flow conditions with increasing depth below the surface for both release and non-release seasons when data from all sites are aggregated for analysis, perhaps indicating decomposition of organic matter (Figure 4.12). Note that mean ammonia concentrations for depths greater than 5 meters are almost exclusively from the Basin site.

Figure 4.12 Town Lake Ammonia Depth Profiles by Season



Under non-storm flow conditions, TKN and nitrates in Town Lake do not exhibit any clear trends with depth when data from all sites are aggregated during either the release or non-release conditions. A specific pattern in mean nitrate concentration is observed at the Lamar site, when the general depth profiles differ between the release and non-release seasons during non-storm flow conditions for nitrate (Figure 4.13). This is potentially due to influences of colder nitrate-loading Barton Creek flows sinking below the warmer summer waters of Town Lake and vice-versa during winter as warmer Barton Creek inflows rise above the cooler winter Town Lake water.

Comparison of mean monthly nitrate (Figure 4.14) and ammonia (Figure 4.15) averaged from 1990 to 2000 during non-storm flow conditions for all sites in Town Lake with mean monthly flow values on Barton Creek from the USGS Gage at Loop 360 (USGS #08155300), averaged from 1990 through 1999 indicated that mean nitrate values generally are lowest when Barton Creek flows approach zero, whereas ammonia values tend to track inversely with Barton Creek flows.

Figure 4.13 Lamar Nitrate Depth Profiles by Season During Non-Storm Flow

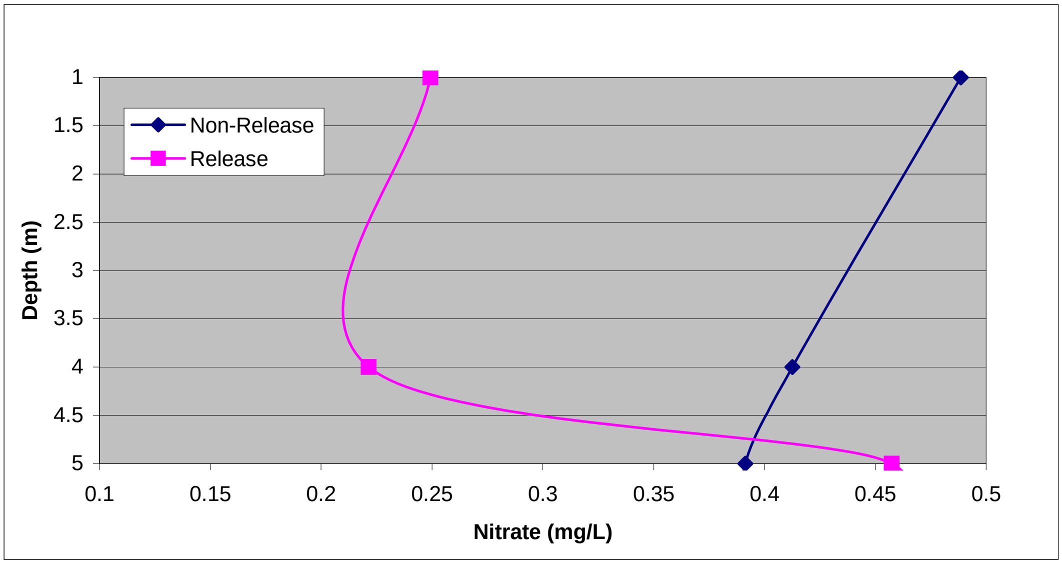


Figure 4.14 Town Lake Non-Storm Mean Monthly Ammonia with Mean Barton Creek Flow at Loop 360

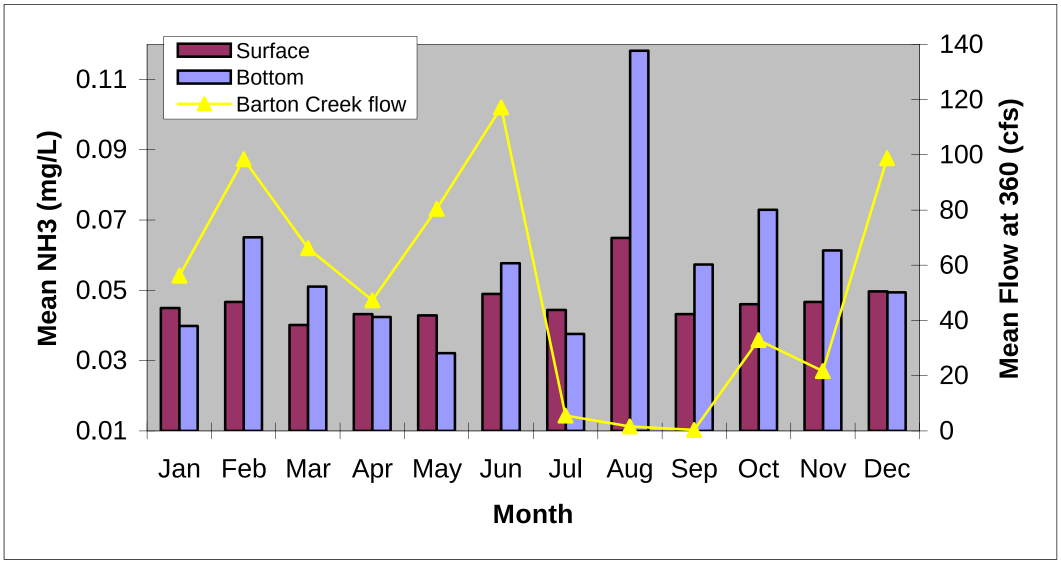
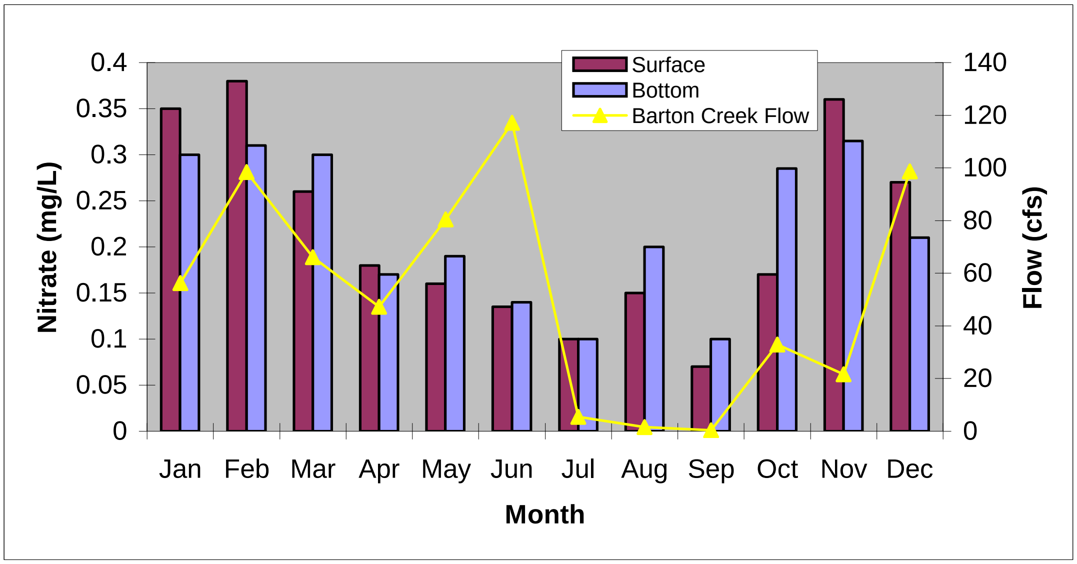


Figure 4.15 Town Lake Non-Storm Mean Monthly Nitrate with Mean Barton Creek Flow at Loop 360



The immediate effects of storm water run-off in Town Lake are demonstrated with mean concentrations by number of days following rainfall. In the days following larger individual storm events, with rainfall greater than or equal to 0.5" in magnitude and with no rain in at least three days prior to the storm event, mean ammonia concentrations exhibit markedly different patterns during the release and non-release seasons (Figures 4.16, 4.17 and 4.18). Concentrations at the surface are typically unaffected during release periods. Under non-release conditions, however, both surface and bottom concentrations are highest the day after the storm event, and quickly return to lower levels.

Figure 4.16 Town Lake Mean Ammonia by Depth Following Large Storm Events During Release Conditions

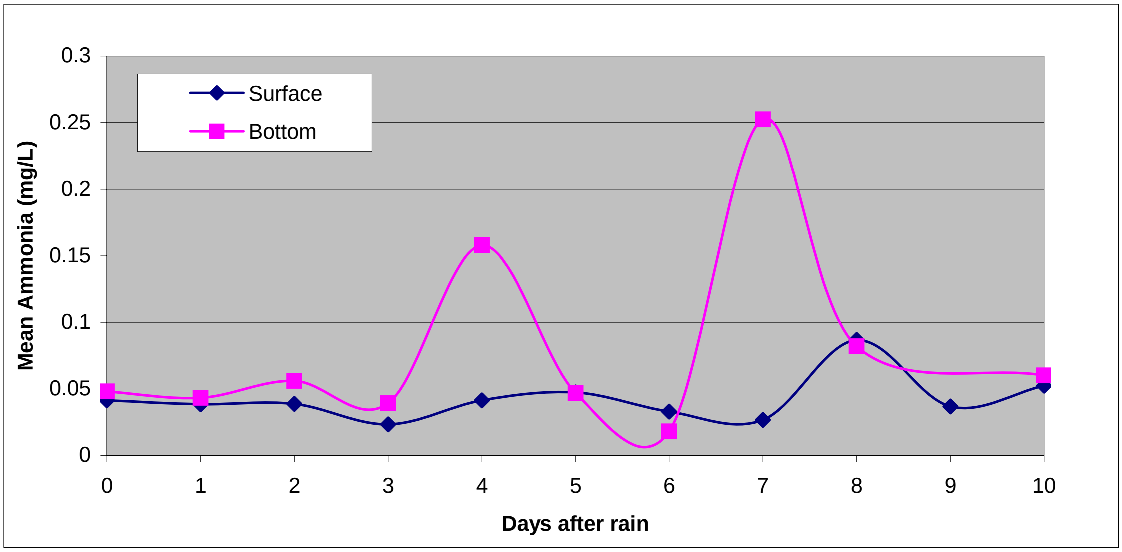


Figure 4.17 Town Lake Mean Ammonia by Depth Following Large Storm Events During Non-Release Conditions

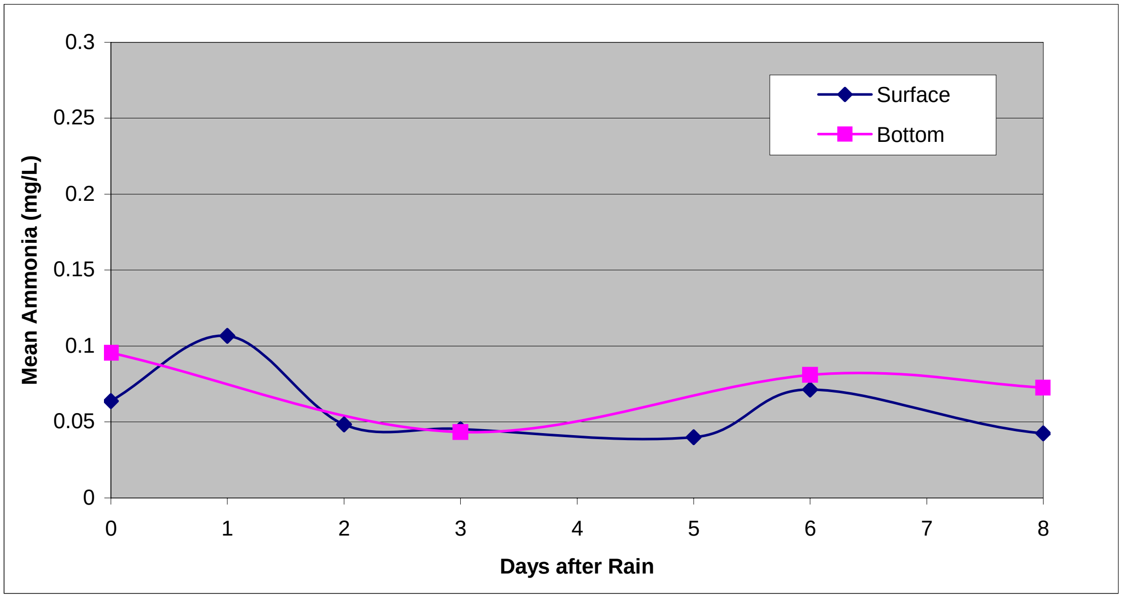
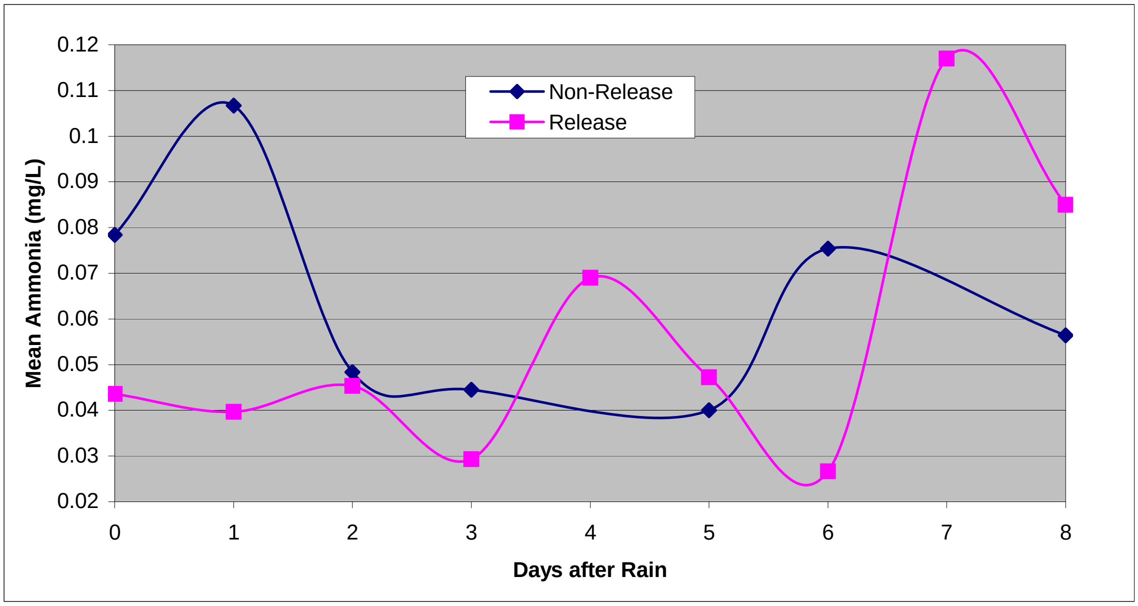


Figure 4.18 Town Lake Mean Ammonia Following Large Storm Events by Season



Mean post-storm Town Lake TKN concentrations during release conditions remain fairly constant, similar to total ammonia, until the third day after the storm event. At that time, concentrations at both the surface and bottom drop sharply. This indicates a potential organic nitrogen debt in Town Lake, since ammonia concentrations do not change on the third day. The rise in mean TKN concentrations, particularly at the lower depths, on the fourth day and again on the seventh day after a storm, mirrors the rises in total mean ammonia concentrations (Figure 4.19). No differences in TKN between surface and bottom depths are observable during the non-release season, and the general pattern mimics the general trend in ammonia concentrations following storms (Figure 4.20). TKN concentrations are generally greater and subject to larger fluctuations in release periods (Figure 4.21) than non-release periods, contrary to total ammonia patterns.

Figure 4.19 Town Lake Mean TKN by Depth Following Large Storm Events During Release Conditions

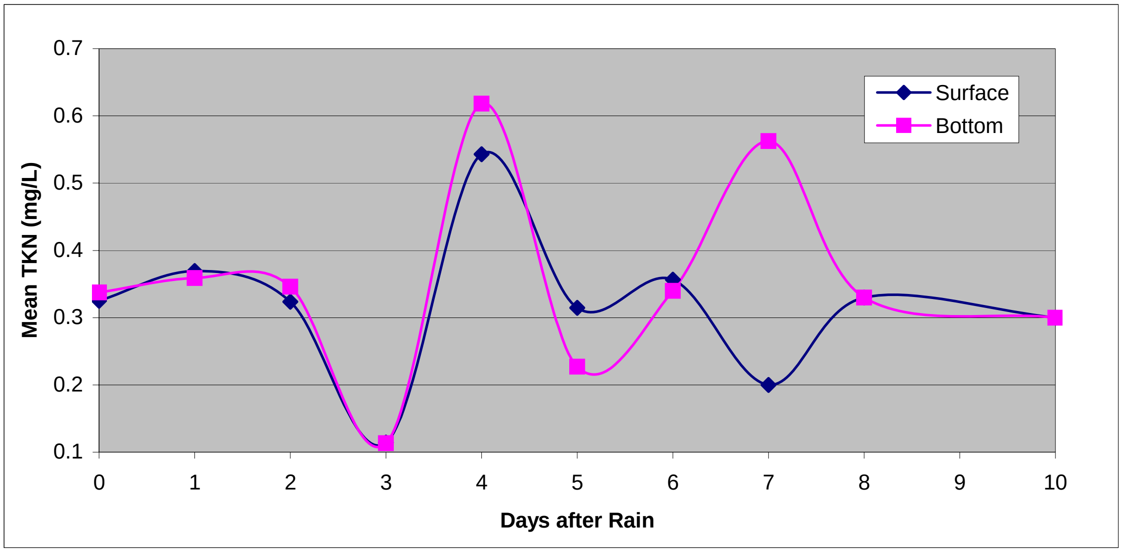


Figure 4.20 Town Lake Mean TKN by Depth Following Large Storm Events During Non-Release Conditions

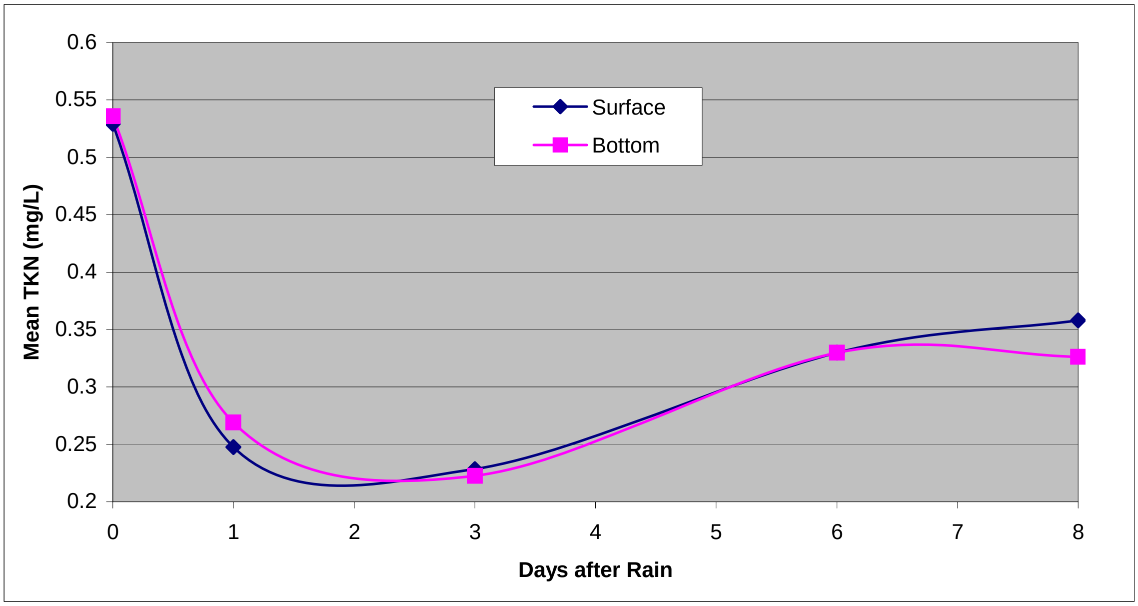
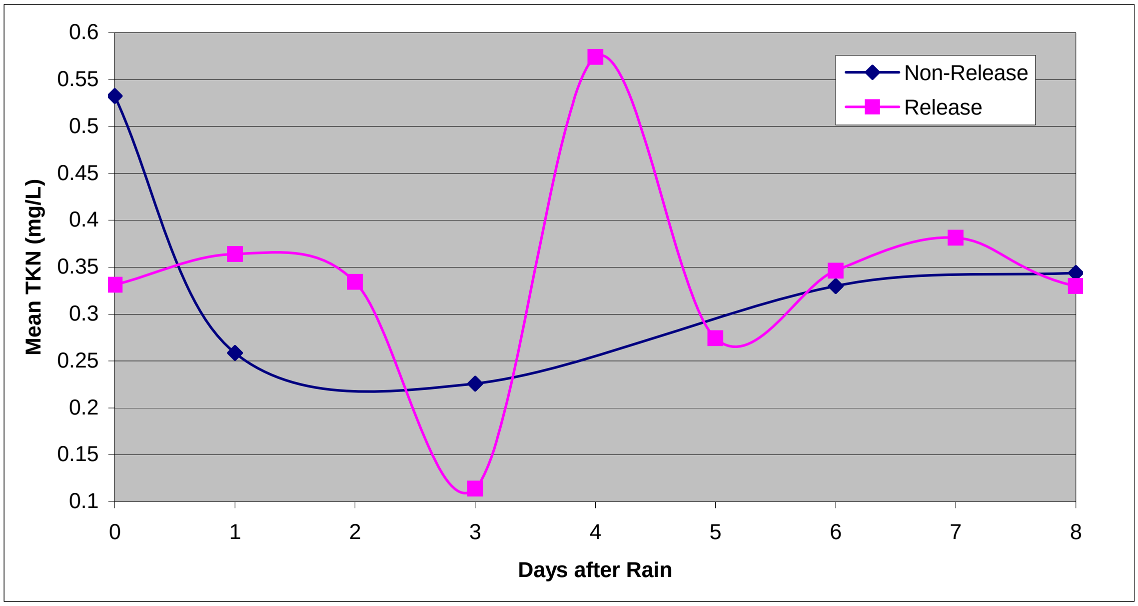


Figure 4.21 Town Lake Mean TKN Following Large Storm Events by Season



Mean total nitrate concentrations in Town Lake following storm events follow fairly uniform patterns at surface and bottom depths during release periods (Figure 4.22). Under non-release conditions, however, surface and bottom mean nitrate concentrations are inversely related, with an initial increase in surface followed by a sharp rise in bottom concentrations almost a week after the storm event (Figure 4.23). Although non-release post-storm mean nitrate concentrations are greater than release concentrations, both seasons exhibit the same general pattern of fluctuating nitrate concentrations following storm events (Figure 4.24).

Figure 4.22 Town Lake Mean Nitrate by Depth Following Large Storm Events During Release Conditions

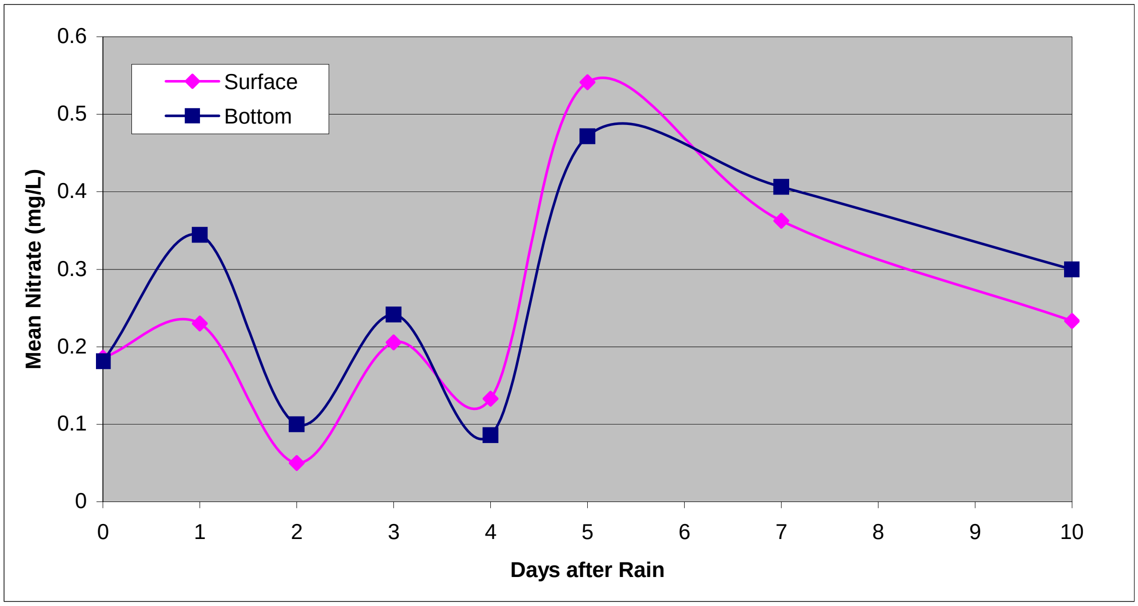


Figure 4.23 Town Lake Mean Nitrate by Depth Following Large Storm Events During Non-Release Conditions

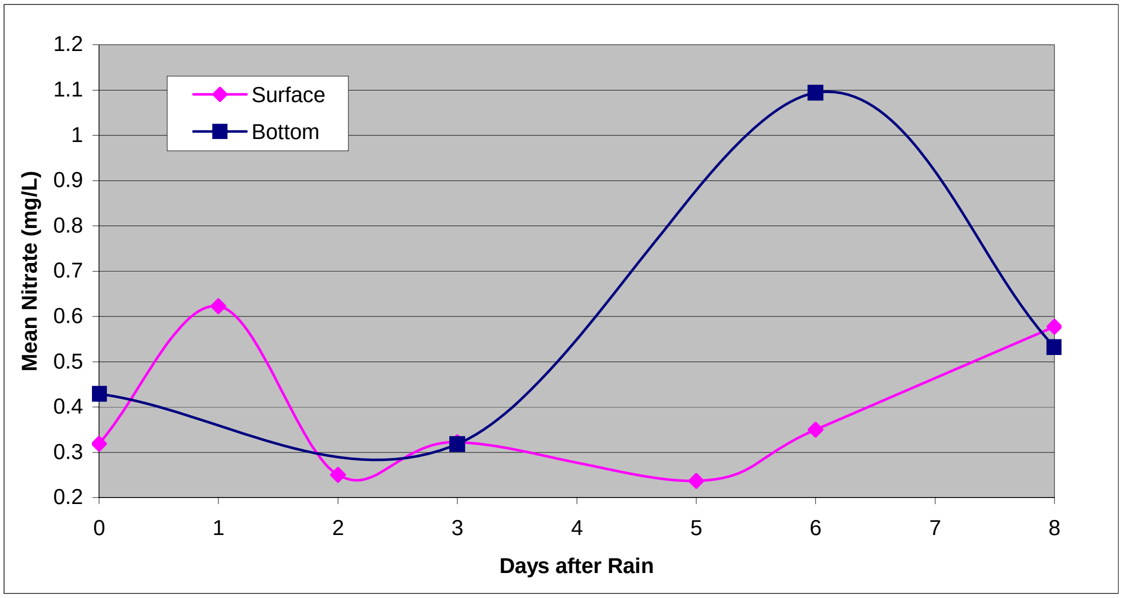
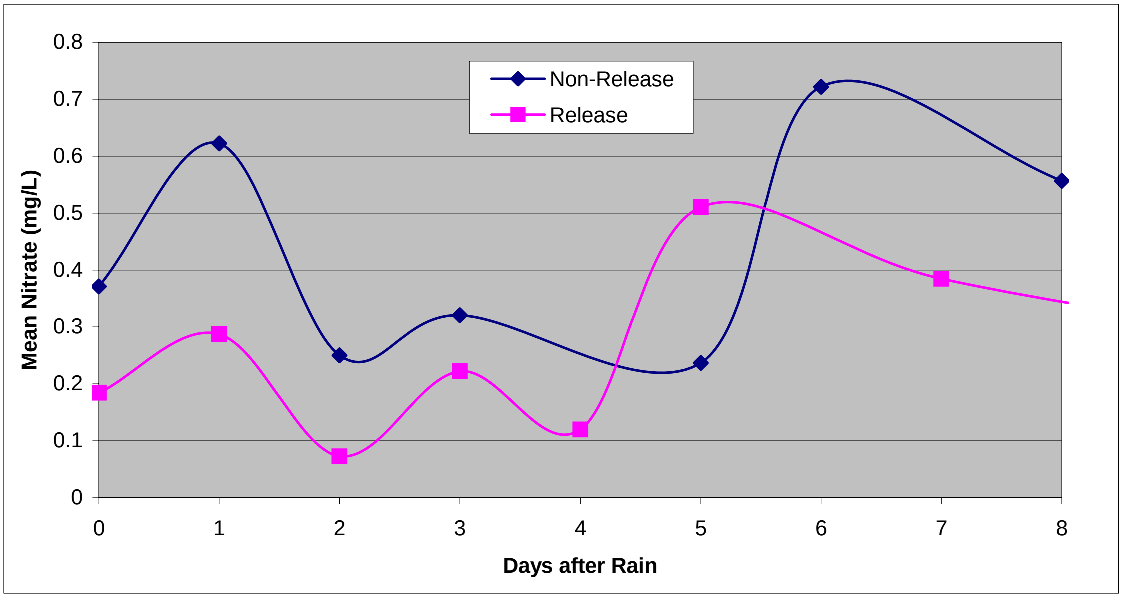


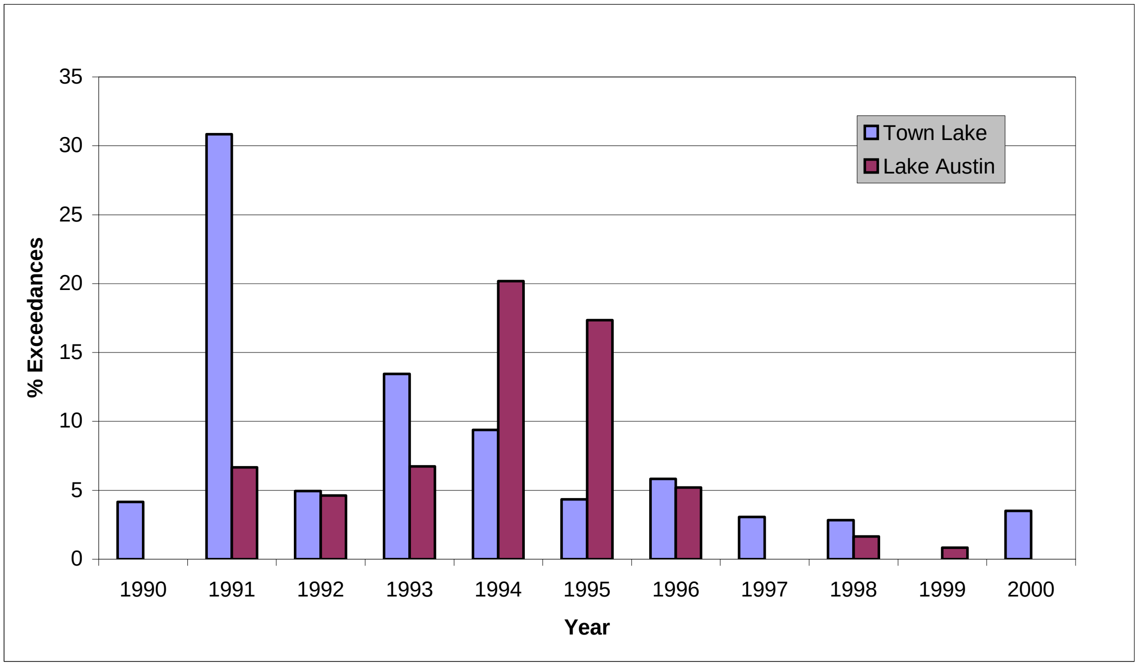
Figure 4.24 Town Lake Mean Nitrate Following Large Storm Events by Season



4.3.1.5 Concern Status

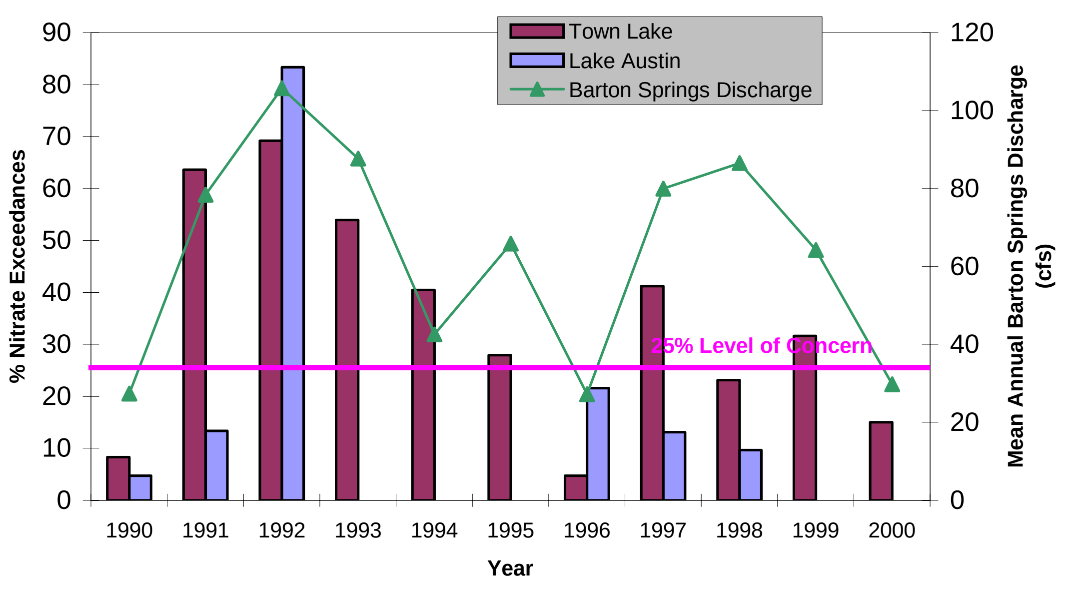
Town Lake and Lake Austin surface ammonia levels were compared to the 0.12 mg/L screening criteria (TNRCC 2000) from the TNRCC guidance (Figure 4.25). Only in 1991 did Town Lake exceed the level of "concern" for ammonia for 25 percent of the observations, exceeding the screening criteria according to the TNRCC framework for identifying water quality concerns. However, the percentage of ammonia exceedances has decreased over time since the large number of high values observed in 1991.

Figure 4.25 Annual Percentage of TNRCC Screening Criteria Exceedances for Ammonia (1990-2000)



Similar to ammonia, nitrate concentrations in Town Lake and Lake Austin also exhibit a general decrease from 1990 to 2000 following extreme highs in 1991 and 1992, as demonstrated by annual percentage of exceedances of the 2000 TNRCC 0.34 mg/L screening criteria (Figure 4.26). However, Town Lake was of "concern" for nitrate from 1991 through 1995, and again in 1997 and 1999 according to the TNRCC (2000) framework for identifying water quality concerns for evaluation of pollution impacts. Note that the lower percentages of Town Lake samples exceeding TNRCC screening criteria, which occurred in 1990, 1996 and 2000, occurred at the only times in which annual mean Barton Springs discharge was below 30 ft^3/s.

Figure 4.26 Percentage of Nitrate Exceedances of TNRCC Screening Criteria with Mean Annual Barton Springs Discharge (1990-2000)



The highest TKN and ammonia measurements on Town Lake were recorded by the USGS during non-storm conditions at the Basin site. Ammonia measuring 1.9 mg/L and TKN measuring 3.1 mg/L were recorded at a depth of approximately 8m on 10 August 1992, seven days following a rain of 0.3" measured at the Robert Mueller Airport. Average flows in Town Lake at this time were approximately 1,664 ft^3/s as measured by the LCRA at Tom Miller Dam. Only four other measurements of ammonia in Town Lake have ever exceeded 1 mg/L as recorded by the USGS and COA-ERM, and all occurred prior to the inception of the minimum flow policy in 1992.

The maximum measured value in Town Lake for nitrate of 3.0 mg/L occurred on 8 October 1991 from a depth of 5m at the Lamar site four days after a rain of 0.31" as measured at the Robert Mueller Airport. Nitrate concentrations in Town Lake have exceeded 2 mg/L on only three other occasions, most recently during storm flow at the Basin site from the surface on 22 July 1999.

4.31.6 Temporal Patterns

Mean non-storm ammonia and TKN concentrations were significantly greater before the minimum flow policy instituted in 1992 during both release and non-release conditions. Pre-1992 non-storm mean nitrate concentrations were also greater than post-1992 concentrations during release, although the difference did not meet the criteria for significance (p = 0.0715) during non-release conditions.

Analysis of temporal trends in total ammonia concentrations in Town Lake during the non-release season yields a general pattern of increasing concentration through 1995, when ammonia values are at a maximum, followed by a decrease in concentration through 2000 (Figure 4.27). The spike in values during 2000 represent samples collected with increased frequency during a period of extended algae blooms in Town Lake. Although storm flow concentrations during the non-release season follow the same general pattern at surface levels, an overall significantly increasing trend (p=0.0097) in Town Lake ammonia levels at depth occurred during non-release storm flow conditions (Figure 4.28). This increase is primarily due to the large values observed in post-storm flows of 2000. Lake Austin ammonia concentrations at surface depths during the non-release season mimic Town Lake patterns of increase through 1995, followed by a general decrease in concentration during both storm and non-storm flow conditions.

Figure 4.27 Town Lake Ammonia During Non-Release, Non-Storm Flow Conditions, All Sites and Depths

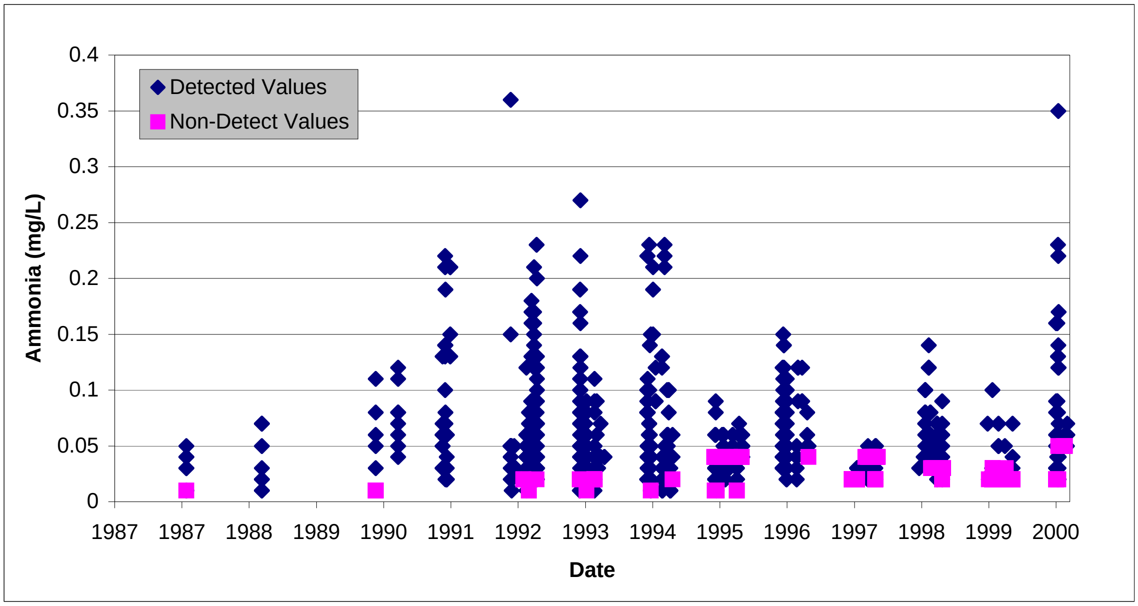
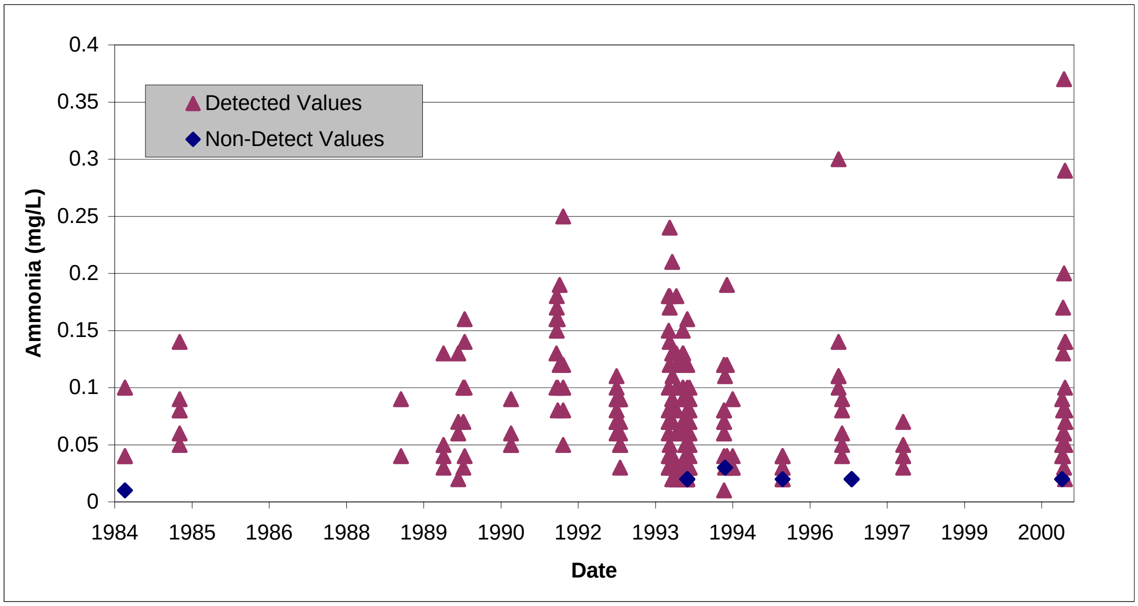
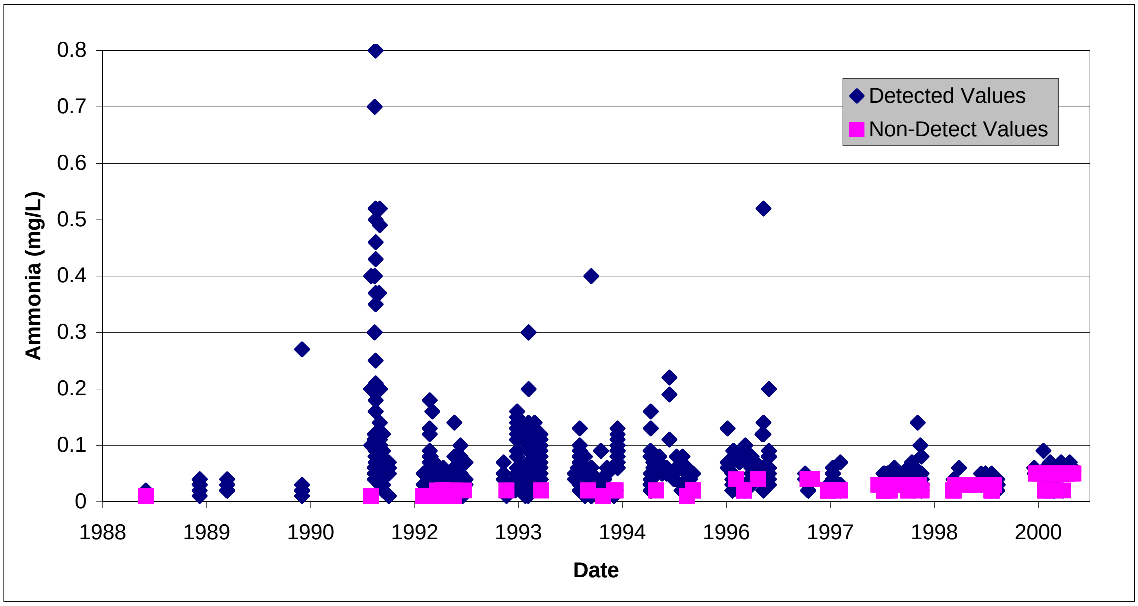


Figure 4.28 Town Lake Ammonia Concentrations During Non-Release, Storm Flow Conditions at Bottom Depths, All Sites



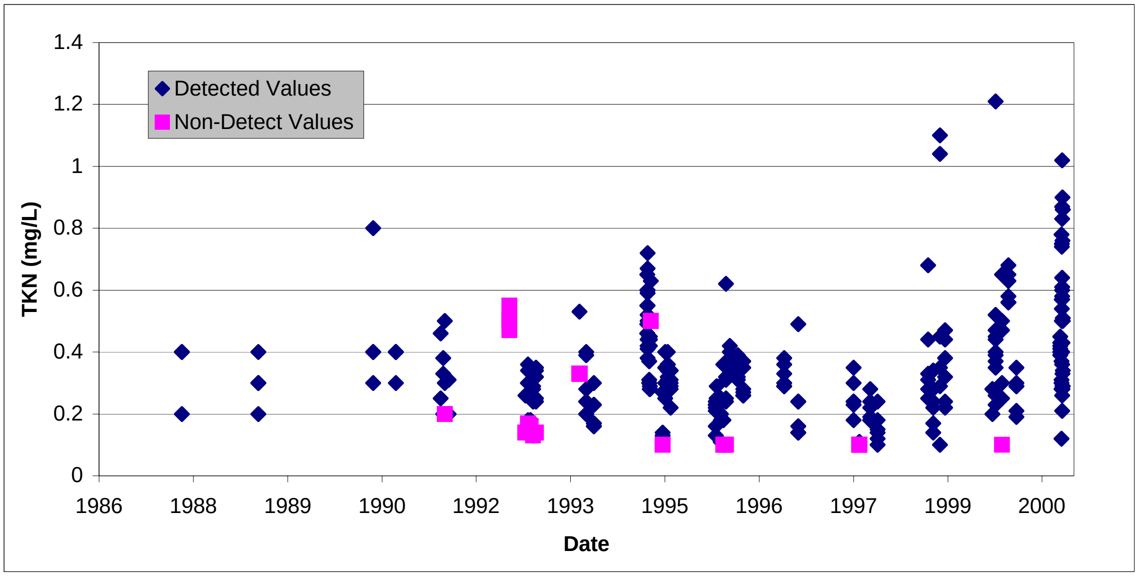
During release seasons, however, Town Lake ammonia concentrations are generally decreasing from maximum values measured in the summer of 1991 to 2000, during both storm and non-storm flow conditions at both surface and bottom depths (Figure 4.29). Note that the large spike in ammonia values observed in August 1991 represents an extended period of multi-day, post-storm sampling.

Figure 4.29 Town Lake Ammonia During Release, Non-Storm Flow Conditions, All Sites and Depths



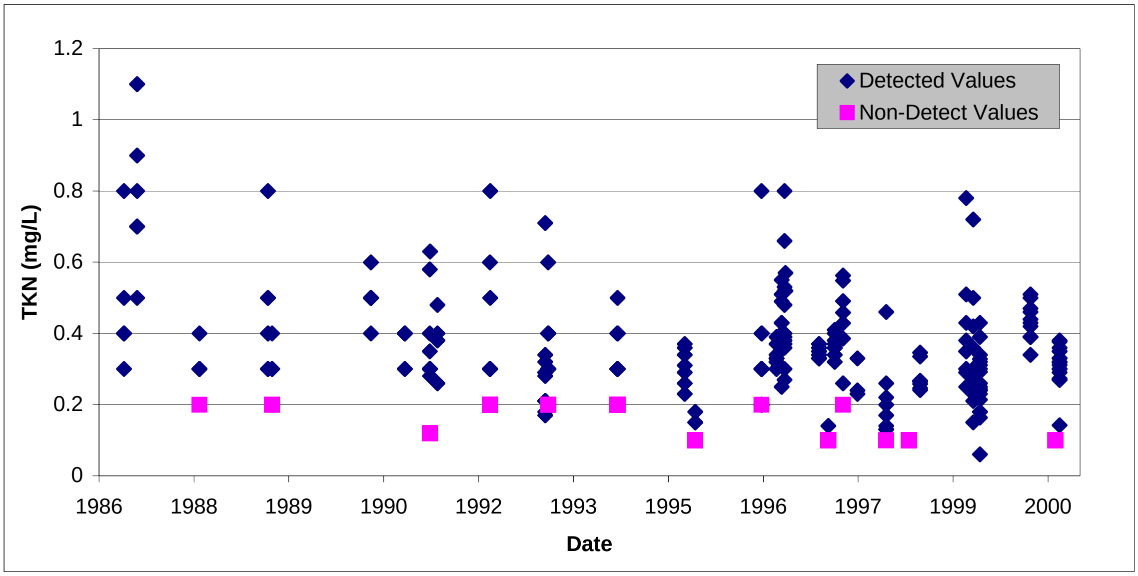
Lake Austin TKN concentrations demonstrate decreasing trends over time for surface and bottom depths under all storm and release conditions. TKN levels during non-release, non-storm flow conditions at the surface are increasing (p = 0.0394) over time, with a noticeably sharp increase in concentrations occurring from 1998 to 2000 (Figure 4.30). Although no trends are evident in Town Lake TKN concentrations during non-release storm flow conditions, the TKN spikes in 1994 and 2000 are also evident during storm flow conditions at the surface.

Figure 4.30 Town Lake TKN during Non-Storm, Non-Release Conditions at the Surface, All Sites



During release conditions, TKN concentrations in Town Lake are significantly decreasing with time at surface and bottom depths in both storm and non-storm flow conditions, mirroring similar decreases observed in Lake Austin. Decreasing TKN in Town Lake during the release season is particularly evident in storm flow conditions (Figure 4.31), despite the occasional spike in TKN values such as those that occurred in 1996 and 1999. As Lake Austin TKN is significantly higher than Town Lake, the Town Lake decreases may correspond to those decreases in Lake Austin.

Figure 4.31 Town Lake TKN During Storm, Release Conditions at the Surface, All Sites



No clear temporal trends are evident in nitrate concentrations in Town Lake or Lake Austin in any release or storm condition. A clear spike in nitrate values in both non-storm (Figure 4.32) and storm flow (Figure 4.33) conditions around 1993 is evident.

Figure 4.32 Town Lake Nitrate During Non-Storm Flow, All Sites and Depths

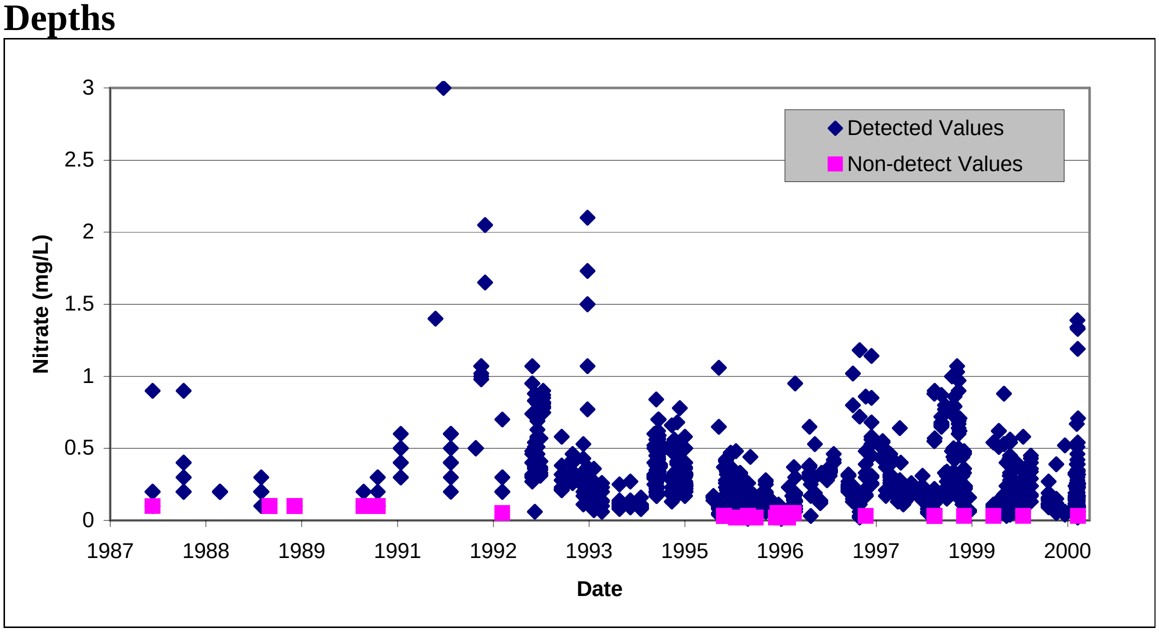
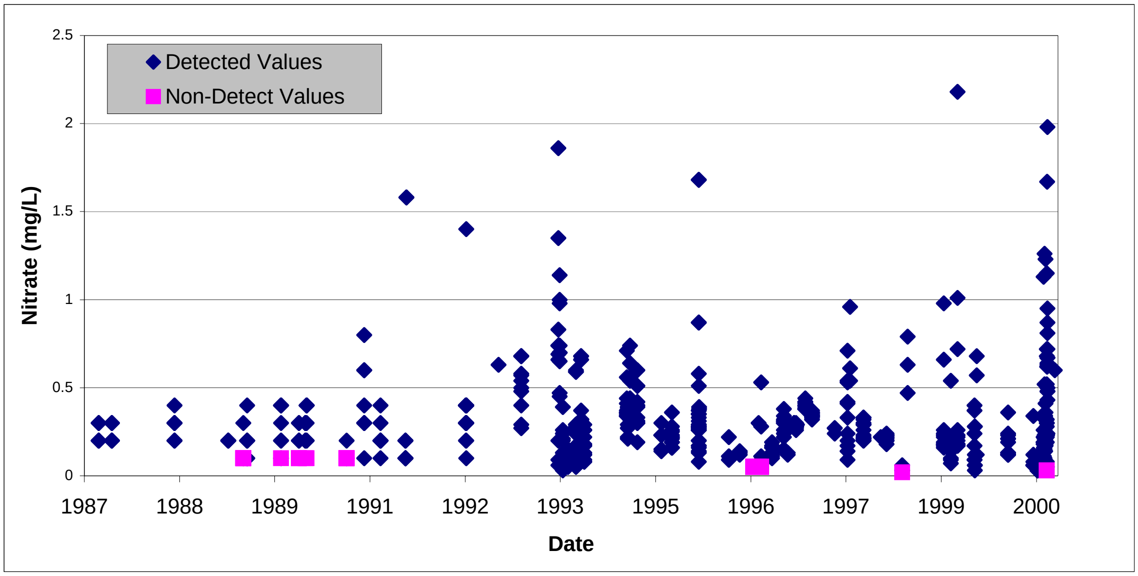


Figure 4.33 Town Lake Nitrate During Storm Flow at the Surface, All Sites



4.3.1.7 *Monitoring Recommendations*

Sample frequency analysis results for Town Lake nitrogen parameters (Table 4.9) were based on estimated summary statistics and current sampling rates projected into the future for the next one to five years. The minimum significant detectable difference in watershed means, expressed as a concentration and a percentage of the current estimated watershed mean, is shown by release and flow condition.

Table 4.9 Minimum Significant Detectable Difference in Watershed Mean Nitrogen Values (as a value and percentage of current mean) if Sampling Continued at Current Rates Over Specified Time Periods

PARAM (mg/L)	**Non-Release**				**Release**			
	Non-storm		**Storm**		**Non-storm**		**Storm**	
	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 1 yr
Ammonia	0.016 (31)	0.007 (14)	0.02 (33)	0.009 (14)	0.038 (69)	0.017 (31)	0.044 (73)	0.019 (32)
TKN	0.080 (23)	0.036 (10)	0.081 (22)	0.036 (10)	0.085 (25)	0.038 (11)	0.094 (26)	0.042 (11)
Nitrate	0.091 (27)	0.040 (12)	0.101 (30)	0.045 (13)	0.084 (40)	0.037 (18)	0.087 (33)	0.039 (15)

The relatively large minimum detectable difference in ammonia values is due to the high standard deviation of current data. Thus, while TKN and nitrate are reasonably well characterized after five more years of sampling by existing protocol, detectable differences in ammonia values, particularly during the release season, remain large. Even though ammonia values show improvement over time in Town Lake, the need to better characterize ammonia concentrations in the lake would not indicate any potential for reduction in sampling.
The continual exceedance of TNRCC criteria for nitrates in Town Lake and lack of clear temporal trend conclusions also do not provide a good opportunity to reduce existing sampling efforts.

However, the lack of depth profile patterns for TKN, in combination with power analysis results showing well-characterized mean watershed concentrations after five years of additional sampling and generally decreasing temporal trends, provides an opportunity for sample reduction or resource redirection. If TKN were monitored only at the surface or at mid-depth for each site, the minimum detectable difference in mean Town Lake TKN values would still be less than 16 percent of the current mean value after five years of sampling.

4.3.3 Phosphorus

Phosphorus is one of the major macronutrients that organisms require to build deoxyribonucleic acids (DNA) and adenosine triphosphate (ATP) molecules, and it actually comprises approximately 1 percent of the dry weight of a human body (Campbell 1993). The average human body typically excretes approximately 1 pound of phosphorus per person annually (USEPA 1987). Phosphorus is the 11th most abundant mineral in the earth's crust (Craig et al 1988) and does not exist in gaseous form (Campbell 1993). Plants can absorb and use phosphorus only in the inorganic form of phosphate (PO_4^{3-}) (Campbell 1993), or orthophosphate in aquatic systems (Miertschin and Armstrong 1986). In freshwater systems, phosphorus is in mostly solid form adsorbed to particulates (Miertschin and Armstrong 1986). Because soil quickly binds phosphorus as mostly calcium phosphate or iron phosphate, and because phosphorus turnover is rapid, phosphorus cycling in ecosystems tends to be localized (Campbell 1993; Holtan et al 1988; Miertschin and Armstrong 1986). Almost all phosphorus from natural weathering of rocks, fertilizer application, and atmospheric deposition remains near the point of application due to the reduced mobility of phosphorus (Novotny and Chesters 1981).

Most phosphorus is transported to receiving water bodies in the bound particulate form. Estimates for total phosphate input in the solid form to the Great Lakes are as high as 75 percent (Novotny and Chesters 1981). Other studies have indicated that only 5 percent of the phosphorus in applied fertilizer reaches receiving water bodies in the dissolved form (Miller 1996).

Interactions between sediments and water are an important part of the phosphorus cycle since sedimentation of particulate phosphorus and phosphorus bound in organic matter can result in a net transport of phosphorus to reservoir sediments (Holtan et al 1988; Miertschin and Armstrong 1986). Under anaerobic conditions, or reducing conditions such as those that occur during summer months in the hypolimnion of many lakes, dissolved phosphorus can be released from sediments back into the water (Miertschin and Armstrong 1989).

Although phosphate does not have any serious public health effects, concentrations greater than 1 mg/L may interfere with coagulation and flocculation in water treatment processes, resulting in a loss of particulate removal efficiency (Droste 1997; USEPA 1987). Increased phosphorus concentrations can also lead to the eutrophication of lakes, especially since freshwater lakes are most often limited by phosphorus (Welch 1980; Miller 1996; Novotny and Chesters 1981).

Elemental phosphorus is toxic and may bioaccumulate in the tissue of living organisms (USEPA 1987). A 48-hour LC50 of 0.105 mg/L for bluegill sunfish exposed to elemental phosphorus has been reported (USEPA 1987), and fish may bioaccumulate phosphorus at levels greater than or equal to 0.1 μg/L.

The TNRCC screens water bodies for concerns based on levels of nutrients statistically derived from long-term SWQM monitoring data (September 1988 – August 1998, TNRCC 2000) with the screening levels set at the 85th percentile values (Table 4.10).

Table 4.10 TNRCC 2000 Phosphorus Screening Levels in Reservoirs

Nutrient Parameter	Screening Level (mg/L)
Dissolved Orthophosphorus as P	0.10
Total Phosphorus as P	0.24

Although historical City of Austin orthophosphorus data were analyzed as total orthophosphorus, analyses were redirected to detect dissolved orthophosphorus in 1998 in order to assess potential Town Lake orthophosphorus concerns, according to TNRCC screening methodology. Concurrent monitoring of total and dissolved orthophosphorus revealed that although total orthophosphorus concentrations were slightly greater than dissolved concentrations as expected, there was no statistically significant difference in mean Town Lake orthophosphorus between the total and dissolved fractions. Thus, in the interest of evaluating a comprehensive dataset over time, total and dissolved orthophosphorus will be considered together in this report as simply orthophosphorus (OP), unless otherwise stated. Total phosphorus will be considered simply as phosphorus.

4.3.3.1 Anthropogenic Sources

Domestic wastewater discharge is the typically the primary point source of phosphorus in the environment (Miertschin and Armstrong 1986). Phosphorus in wastewater originates from human waste as well as from common household products such as detergents (Miller 1996). In the U.S., an estimated 2.5 pounds of phosphorus per person are generated annually from domestic phosphate uses (USEPA 1987). It is estimated that approximately 50 percent of the total phosphorus load in the U.S. is from point sources (Novotony and Chesters 1981). The sporadic re-release and seclusion of phosphorus by lake sediments may cause phosphorus reduction strategies to be ineffective for several years (Maki et al 1983). Austin, Texas, was the first city in Texas to ban phosphorus in detergents (Ayala 1992) when the City Council passed Ordinance #91-0523-F in May 1991, prohibiting the sale of a detergent with more than 0.5 percent phosphorus. As stated previously, however, no wastewater treatment plants discharge directly into the Town Lake segment of the Colorado River.

Non-point sources of phosphorus include runoff from agricultural areas where phosphorus-containing fertilizer is applied, uncontrolled livestock manure, urban stormwater runoff, and atmospheric deposition (Novotny and Chesters 1981). In areas where no major sources of point and non-point pollutant inputs exist, rainwater may be the major contributor of phosphorus to surface waters as atmospheric inputs of nutrients in undisturbed watersheds are the primary source of nutrients (Novotny and Chesters 1981). Previous City of Austin studies have estimated local rainfall concentrations of total phosphorus (as P) as high as 0.094 mg/L, although mean total phosphorus rainfall concentrations measured by the COA-ERM are 0.023 mg/L. Contribution of phosphorus from precipitation to Lake Michigan has been estimated at 26 percent, almost half of the total phosphorus load contribution from urban runoff (Novotny and Chesters 1981).

4.3.3.2 Summary of Town Lake Phosphorous Results

Figures 4.34 and 4.35 present graphical summary of statistical analyses for phosphorous nutrients in Town Lake.

Phosphorus displays increasing longitudinal patterns in concentration from upstream to downstream sites, potentially due to urban runoff and urban tributary loading, although during storm flow conditions phosphorus is elevated at the First Street site where site-related storm impacts are expected from downtown runoff. Orthophosphorus exhibits elevated mean concentrations at the Lamar and First Street sites even during non-storm conditions, although this increase in mid-lake concentration is not readily explained by expected Barton Creek influences.

Town Lake is increasing the concentrations of orthophosphorus from initial concentrations upon entrance to Town Lake from Lake Austin, potentially impacting the Colorado River. Both orthophosphorus and total phosphorus are inversely related to Lake Austin discharge into Town Lake.

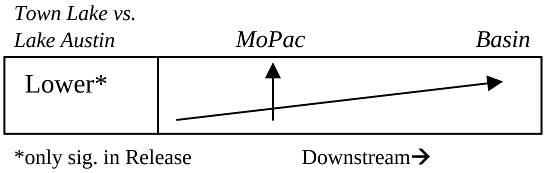
Orthophosphorus concentrations, despite anomalous spikes during the non-release seasons of 1993/1994 and 1996, are decreasing over time during all storm and release conditions. No clear temporal trends are evident in the total phosphorus dataset.

Comparison of data in Town Lake to 2000 TNRCC screening criteria in water indicate that Town Lake is of “no concern” for dissolved orthophosphorus and total phosphorus, according to official assessment methodologies.

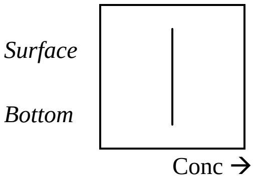
Figure 4.34 Graphical Summary of Town Lake Phosphorus Results

SPATIAL

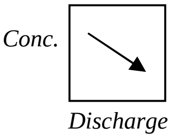
Location



Depth



FLOW/SEASONALITY



Storm flows highest in:

No difference

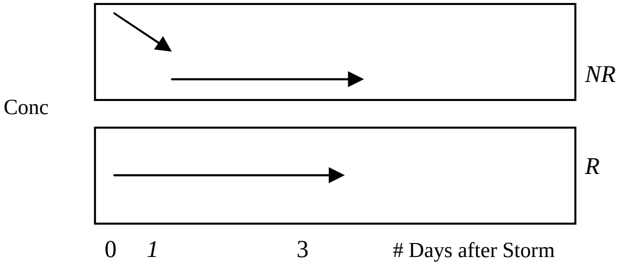
Non-Storm flows highest in:

No difference

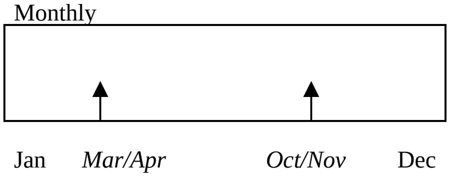
Max conc. in:

NR, Storm

Post-Storm



Monthly



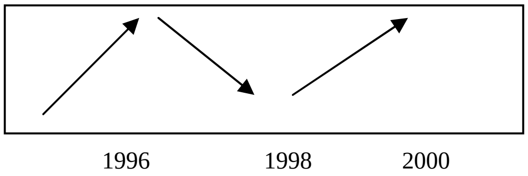
TEMPORAL

Annual % Exceedance of TNRCC Criteria

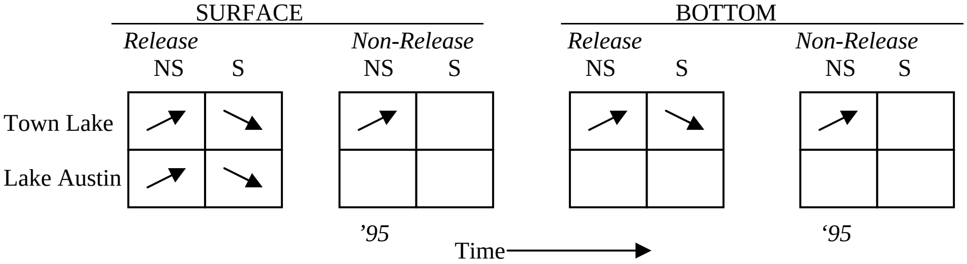
No trend and no concern; no year with exceedances > 5%

2000

Overall temporal pattern



Temporal Regression



Comments:

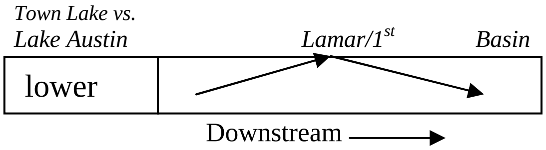
Maximum TP concentrations observed in months when flow regimes switch.

NR = Non-Release   R = Release
NS = Non-Storm   S = Storm
Blank cells indicate no statistically significant pattern

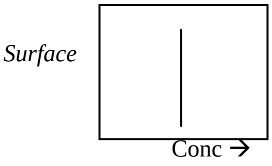
Figure 4.35 Graphical Summary of Town Lake Orthophosphorus Results

SPATIAL

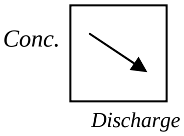
Location



Depth



FLOW/SEASONALITY



Storm flows highest in:

Non-release

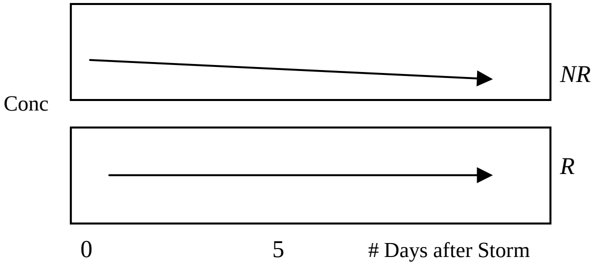
Non-Storm flows highest in:

No difference

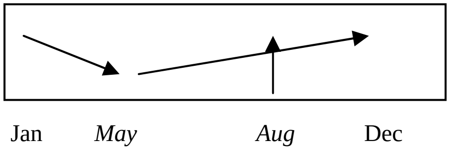
Max conc. in:

NR, Storm

Post-Storm



Monthly Averages

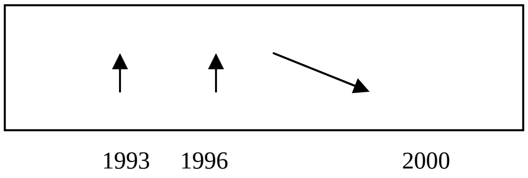


TEMPORAL

Annual % Exceedance of TNRCC Criteria

Only 2 samples ever in exceedance (1995 and 2000); no concern

Overall temporal pattern



Temporal Regression

SURFACE & BOTTOM (TOGETHER)

	Release		*Non-Release*	
	NS	S	NS	S
Town Lake	↘	↘	↘	↘
Lake Austin			↘	

Concentration

Time →

Comments:

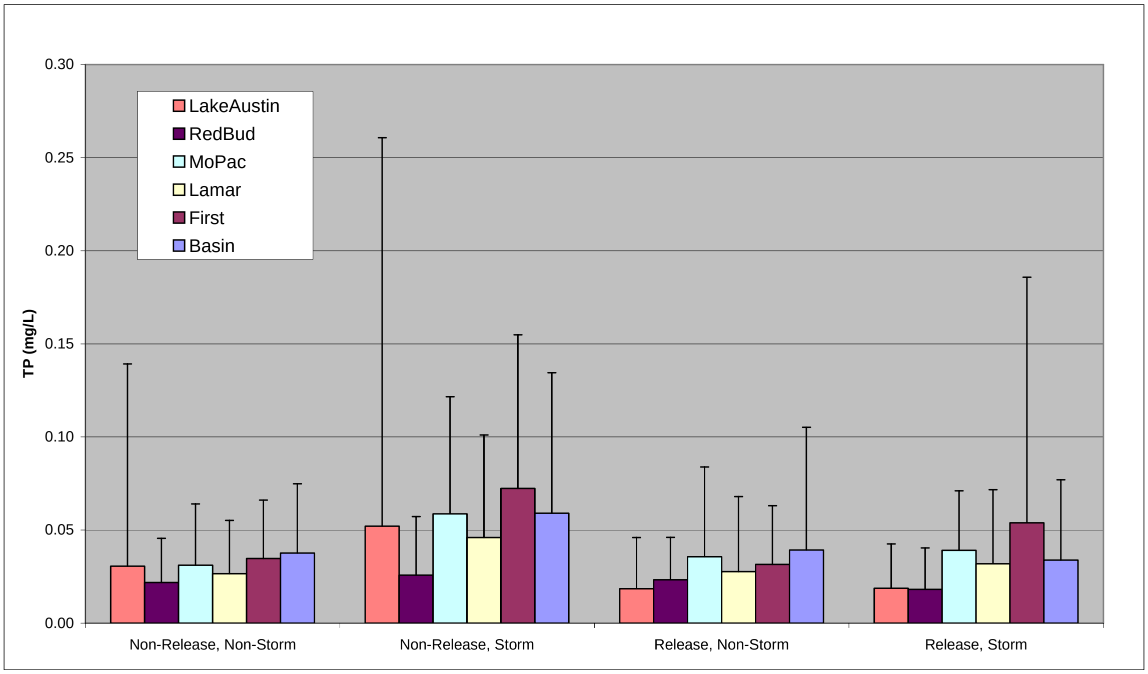
Despite overall decreasing trends in Town Lake concentrations over time in all storm and release conditions, elevated values occur during non-release in 1993/1994 and a sharp spike in OP again in 1996

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

4.3.3.3 Spatial Distribution

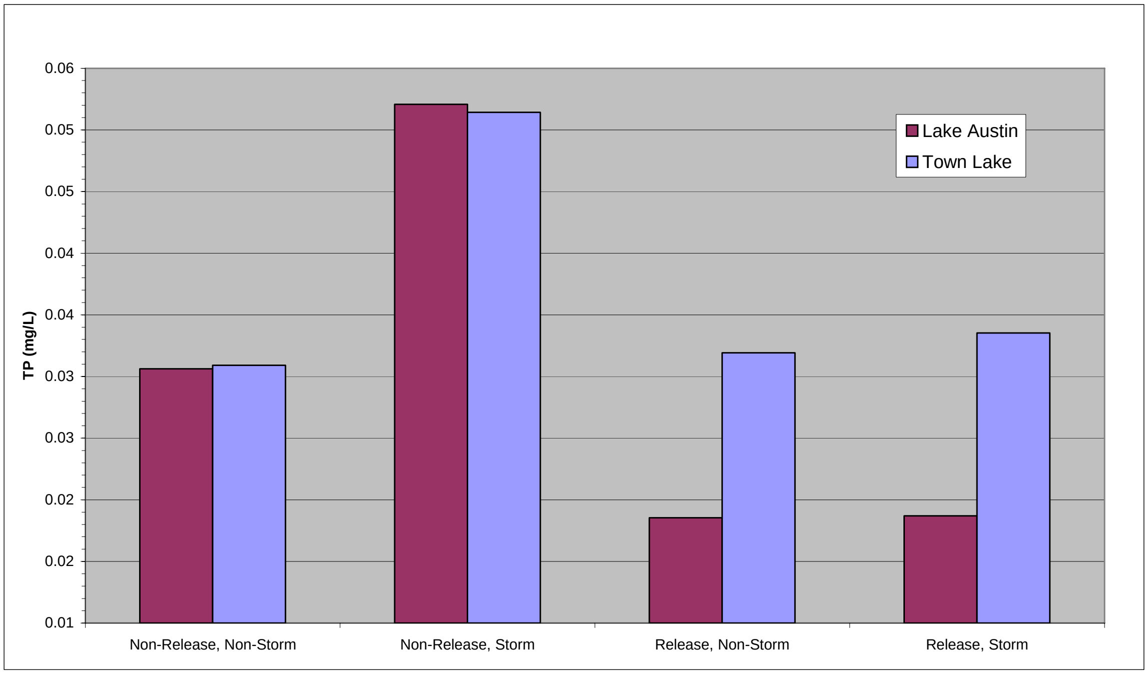
Total phosphorus site averages demonstrate generally increasing longitudinal trends within Town Lake during non-storm flow conditions, although mean concentrations at the Basin are only significantly greater than mean concentrations in Lake Austin during release, non-storm flow conditions. Little statistically significant variation in mean phosphorus concentrations was observed between sites during non-storm flow conditions. Mean phosphorus levels at MoPac are always significantly greater than mean concentrations at Red Bud, and typically higher (though non-significantly) than concentrations at Lamar, despite a lack of clearly identifiable sources between Red Bud and MoPac other than residential property run-off. During storm flow periods on Town Lake, mean concentrations at the First Street site experience a marked spike to the highest average concentrations measured for any given flow or release condition (Figure 4.36).

Figure 4.36 Mean Phosphorus Site Concentrations by Season and Flow Type



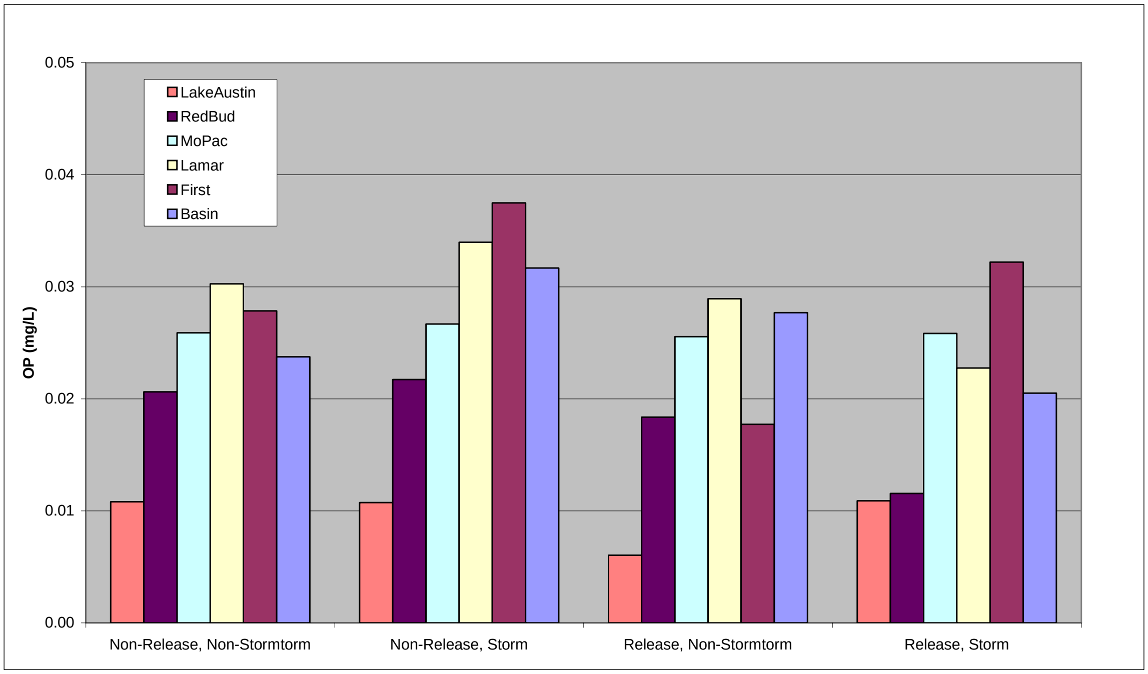
Release condition mean phosphorus levels in Town Lake are significantly greater than mean levels in Lake Austin during both storm and non-storm flows, although Town Lake and Lake Austin phosphorus concentrations show no significant difference during non-release periods in either storm or non-storm flows (Figure 4.37).

Figure 4.37 Mean Phosphorus Watershed Concentrations by Season and Flow Type



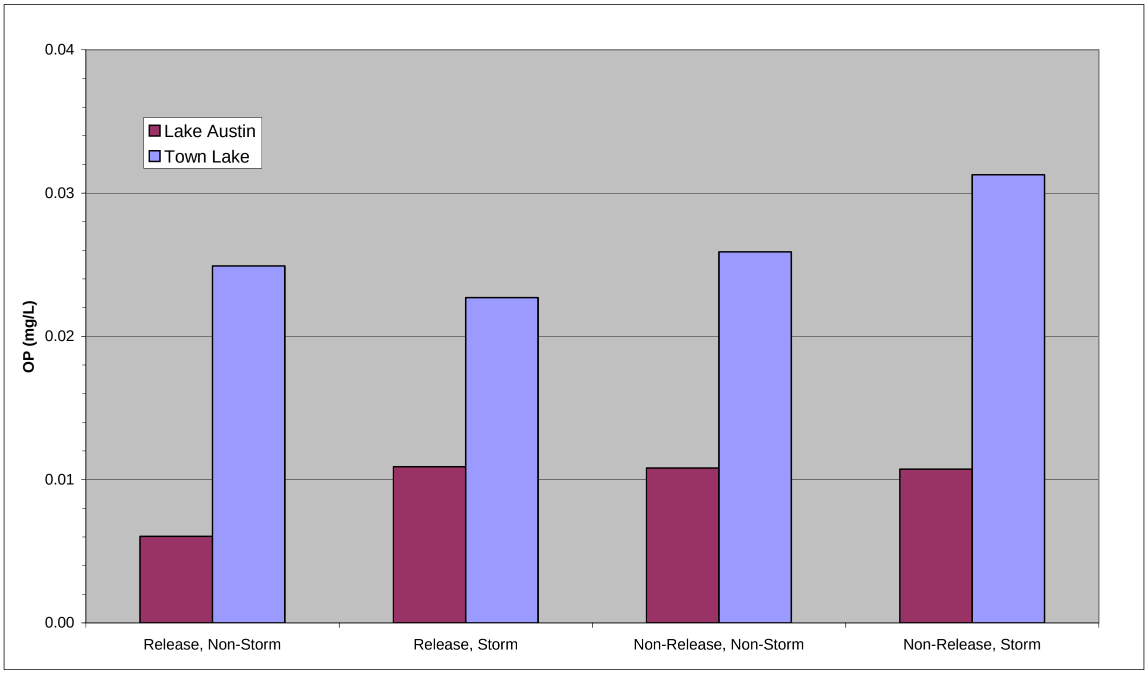
Orthophosphorus concentrations demonstrate a different pattern from total phosphorus concentrations. During non-release conditions, orthophosphorus increases from Red Bud to the Lamar and First Street sites, and then decreases at the Basin. However, no statistically significant difference exists between the most upstream Red Bud and most downstream Basin sites in Town Lake during non-release, non-storm flow conditions. Orthophosphorus concentrations during release conditions do not exhibit a consistent pattern (Figure 4.38).

Figure 4.38 Mean Orthophosphorus Site Concentrations by Season and Flow Type



Lake Austin orthophosphorus concentrations are always significantly less than concentrations at the Basin, and overall watershed averages indicate that Town Lake maintains consistently higher average orthophosphorus concentrations than Lake Austin in all storm and release conditions (Figure 4.39). Orthophosphorus concentrations during storm flow are significantly greater during the non-release season, although no difference was shown between the release and non-release season during non-storm flow. Average concentrations are well below 2000 TNRCC screening criteria of 0.10 mg/L, and all differences mentioned above, though statistically significant, are small in magnitude.

Figure 4.39 Mean Orthophosphorus Watershed Concentrations by Season and Flow Type



4.3.3.4 Storm and Release Conditions

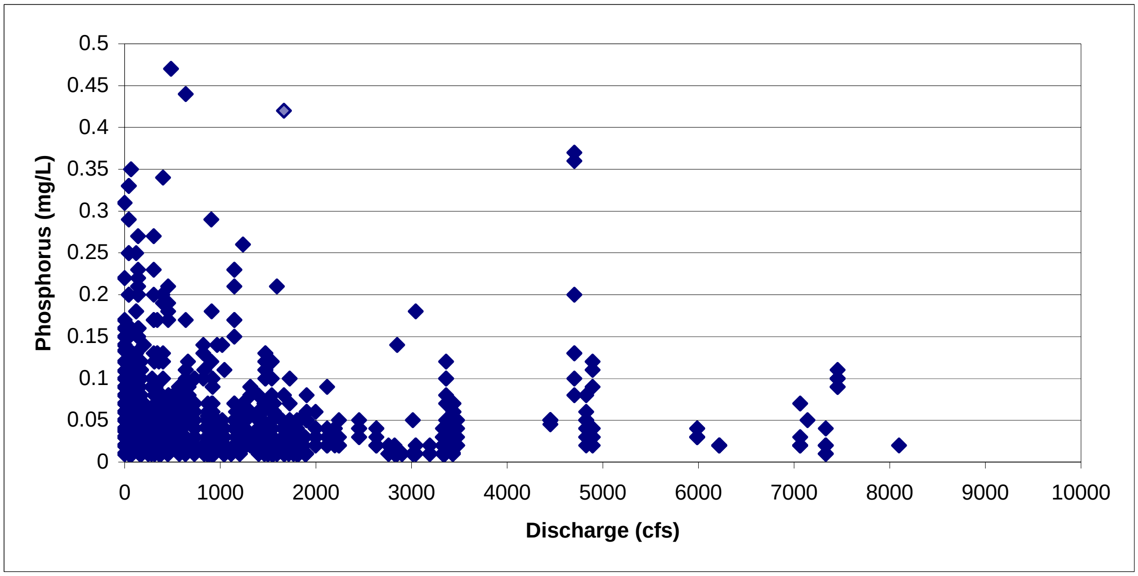
Town Lake non-storm and storm phosphorus concentrations exhibit little variation in the release season (Table 4.11).

Table 4.11 Town Lake Phosphorus Mean Concentrations by Season and Flow Type

Parameter (mg/L)	**Release**		**Non-Release**	
	Non-Storm	*Storm*	*Non-Storm*	*Storm*
Phosphorus	0.032	0.034	0.031	0.051
Orthophosphorus	0.023	0.016	0.023	0.027

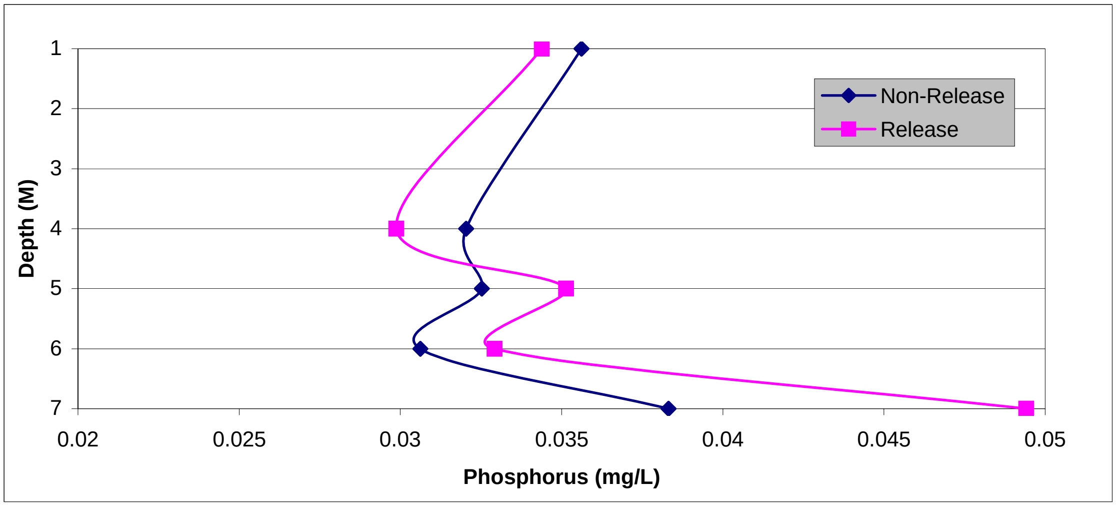
However, Town Lake total phosphorus levels are inversely proportional to increasing total discharge from Tom Miller Dam when data from all sites are combined (Figure 4.40), yielding a Spearman's partial (adjusted for depth) correlation coefficient of –0.1278 ($p<0.0001$). Though slightly weaker than the relationship observed for total phosphorus, orthophosphorus also yields a statistically significant negative partial correlation with upstream discharge for all sites ($\theta = -0.0747$, $p<0.0001$), adjusting for depth as a covariate.

Figure 4.40 Town Lake Phosphorus versus Total Discharge from Tom Miller Dam, All Sites and Depths



Phosphorus concentrations are almost constant with increasing sample depth (Figure 4.41) in Town Lake during non-storm flow conditions when data from all sites are combined during either the non-release ($p_{TP \propto depth} = 0.8161$) or release seasons ($p_{TP \propto depth} = 0.6832$). Note that depths greater than 5m are almost exclusively from the Basin. Orthophosphorus concentrations in Town Lake yield no significant trend with increasing sample depth at any site (individually or combined for analysis) and no statistical difference between surface and bottom concentrations for any storm or release condition. Review of regression analysis data suggest that surface concentrations are slightly greater than bottom concentrations, particularly at the deeper Basin site, although this difference is not statistically significant by either ANOVA or regression analysis.

Figure 4.41 Town Lake Phosphorus Depth Profiles During Non-Storm Flow by Season



Although Town Lake estimated mean total phosphorus concentrations do not directly correlate with rainfall, flow, or input from Barton Creek, maximum concentrations occur in the months during which flow regimes switch from non-release to release and vice versa (Figure 4.42). Orthophosphorus concentrations in Town Lake show little monthly variation at either surface or bottom depths, although the late summer and fall months are slightly elevated (Figure 4.43), potentially corresponding to application of residential lawn fertilizer at a time when plant uptake rates are reduced.

Figure 4.42 Town Lake Mean Monthly Non-Storm Phosphorus by Depth

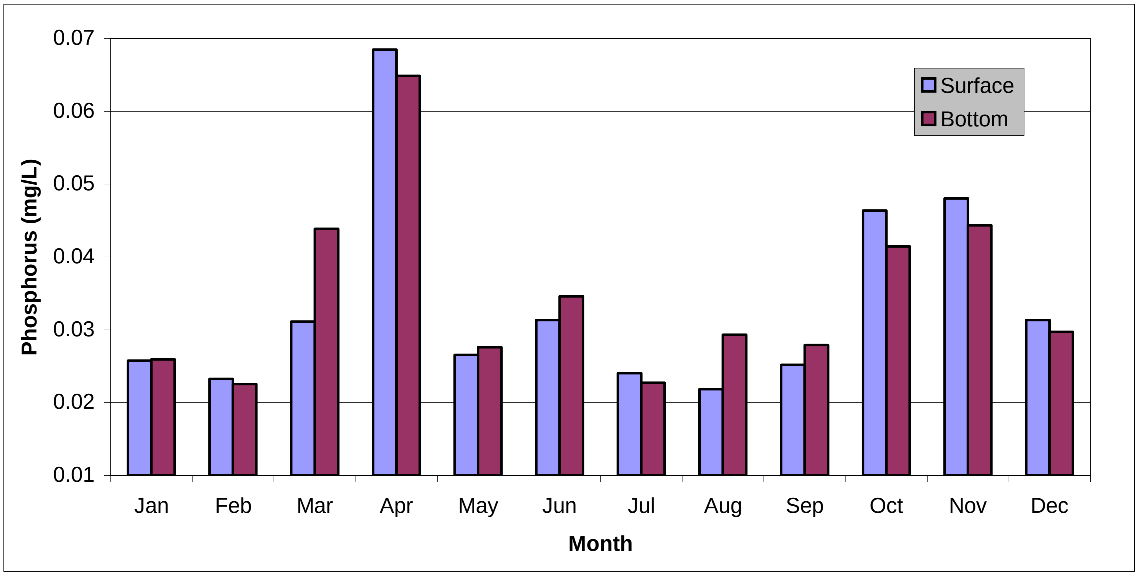
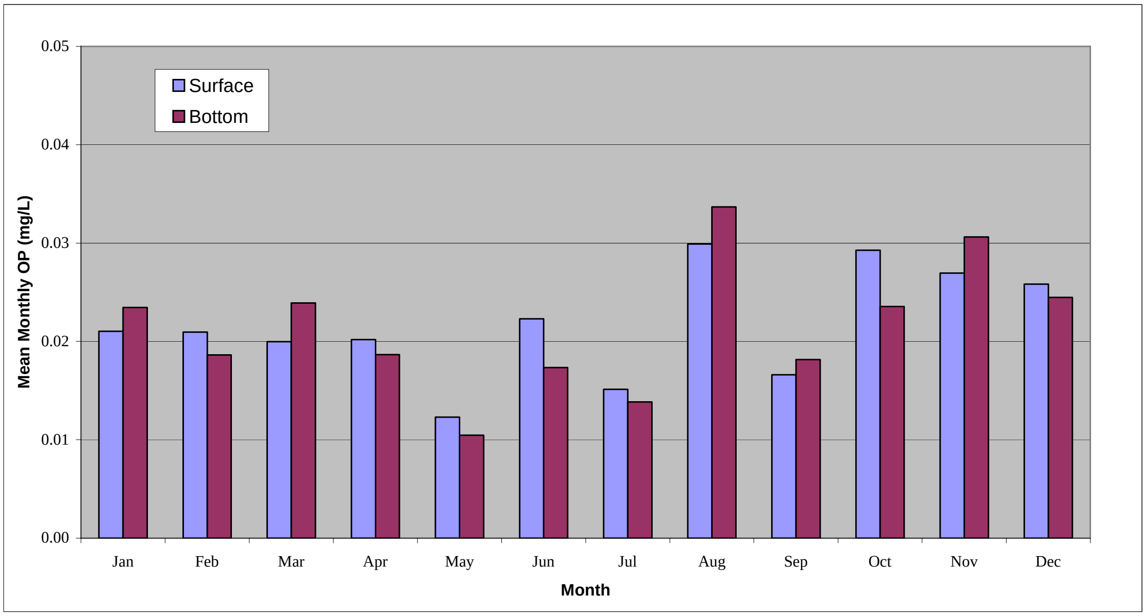


Figure 4.43 Town Lake Mean Monthly Orthophosphorus by Depths



Total phosphorus in Town Lake following storm events ≥ 0.5" in magnitude, with at least three days between events, demonstrate markedly different patterns in the release and non-release seasons. During the non-release season, little difference is shown between estimated mean total phosphorus concentrations at the surface and bottom, and although a spike occurred in concentration on the day of the event, total phosphorus levels quickly drop back to steady, near-detection limit values (Figure 4.44). During the release season, however, little change in estimated total phosphorus concentrations occurs at either the surface or bottom depths until the third day after the storm, when phosphorus concentrations rise sharply (Figure 4.45). It is possible that under non-release conditions, when the potential for algae growth is increased, total phosphorus introduced by storm events is quickly incorporated into algal biomass. The rise in phosphorus concentrations during release conditions, however, may be attributable to either tributary or upstream inputs associated with increased suspended solid loading. The lack of variation in the days immediately following large storm events during the release season may be caused by the "flushing" effects of higher release season flows through Town Lake.

Figure 4.44 Town Lake Mean Phosphorus Following Large Storm Events During Non-Release

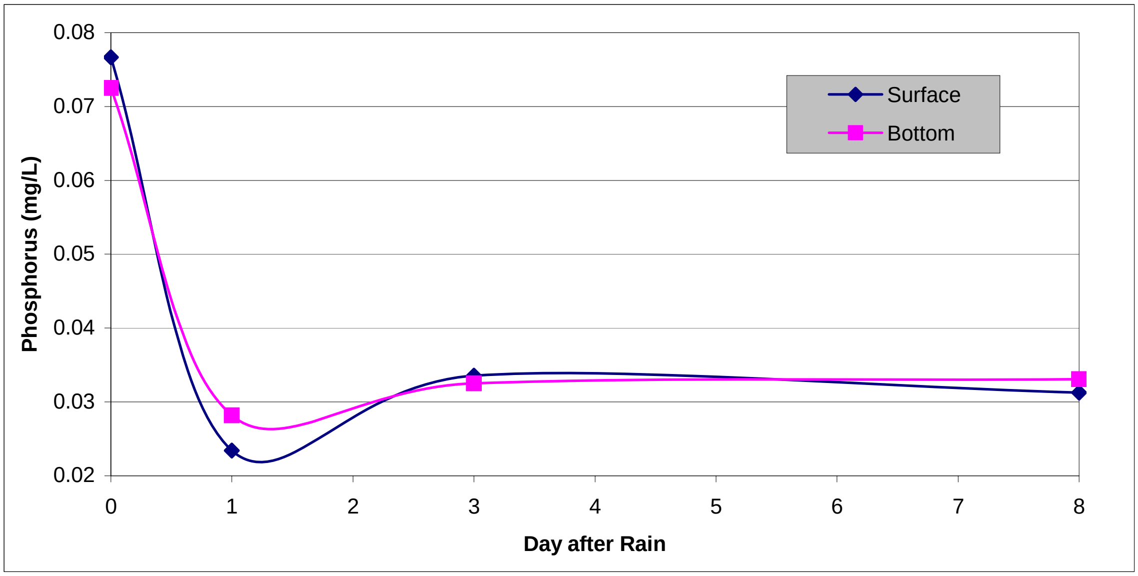
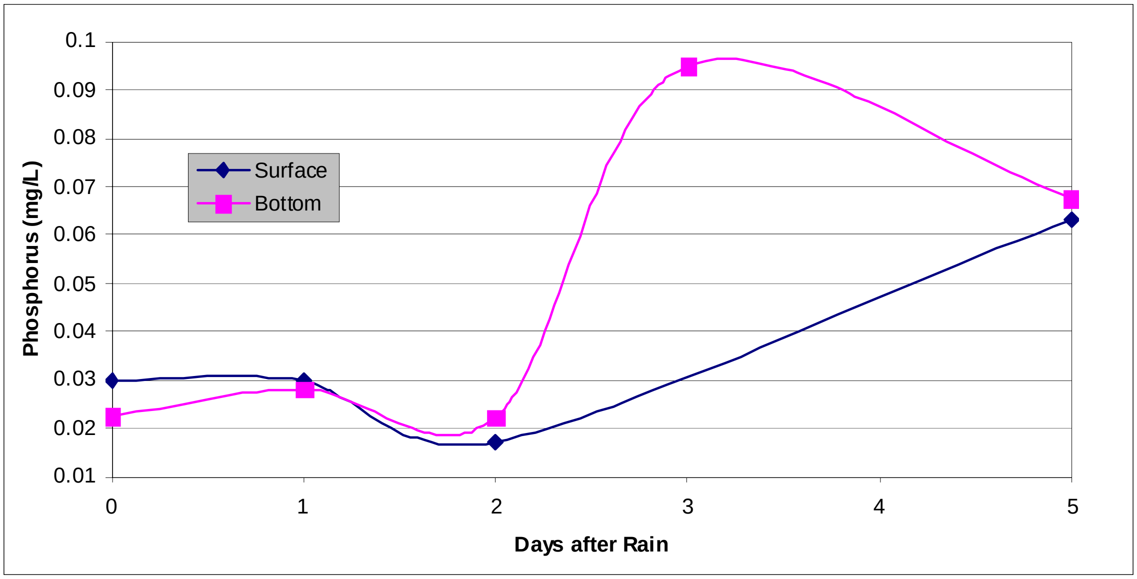
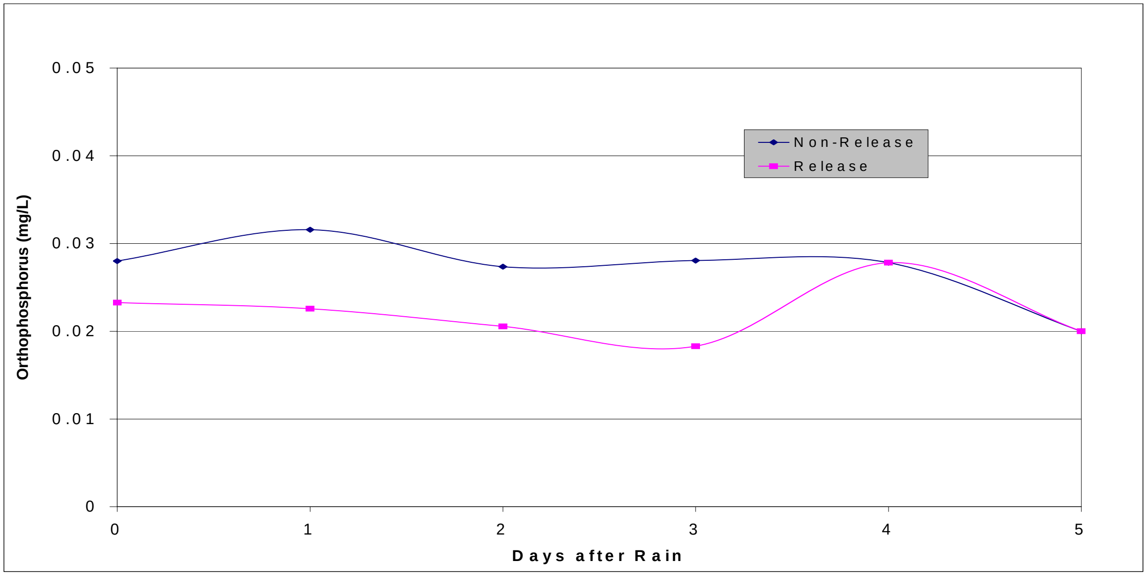


Figure 4.45 Town Lake Mean Phosphorus Following Large Storm Events During Release



Mean Town Lake orthophosphorus concentrations demonstrate little response to storm events ≥ 5" with no rain in at least the three days preceding those events in Town Lake (Figure 4.46), and median orthophosphorus in Town Lake in the first five days following rainfall does not change from the value of 0.02 mg/L in either the release or non-release season.

Figure 4.46 Town Lake Mean Orthophosphorus Following Large Storm Events by Season



4.3.3.5 Concern Status

Town Lake phosphorus concentrations are of “no concern” according to the TNRCC (2000) framework for identifying water quality concerns in freshwater reservoirs. In no year since 1975 have 25 percent or more of measured phosphorus values exceeded the screening level of 0.24 mg/L. In fact, in no year since 1975 have Town Lake total phosphorus percentage of exceedances been greater than 5 percent (Figure 4.47). Actual measured concentrations of dissolved orthophosphorus in Town Lake have exceeded the 2000 TNRCC screening criteria of 0.10 mg/L in only two years (1995 and 2000), and thus Town Lake and the lower portion of Lake Austin are of “no concern” for dissolved orthophosphorus. Analyses of the combined total and dissolved orthophosphorus dataset against the screening criteria further demonstrates that not only is Town Lake of “no concern” for orthophosphorus, but also that orthophosphorus appears to be decreasing over time (Figure 4.48).

Figure 4.47 Phosphorus Percentage Exceedances of TNRCC Screening Criteria for Town Lake and Lake Austin

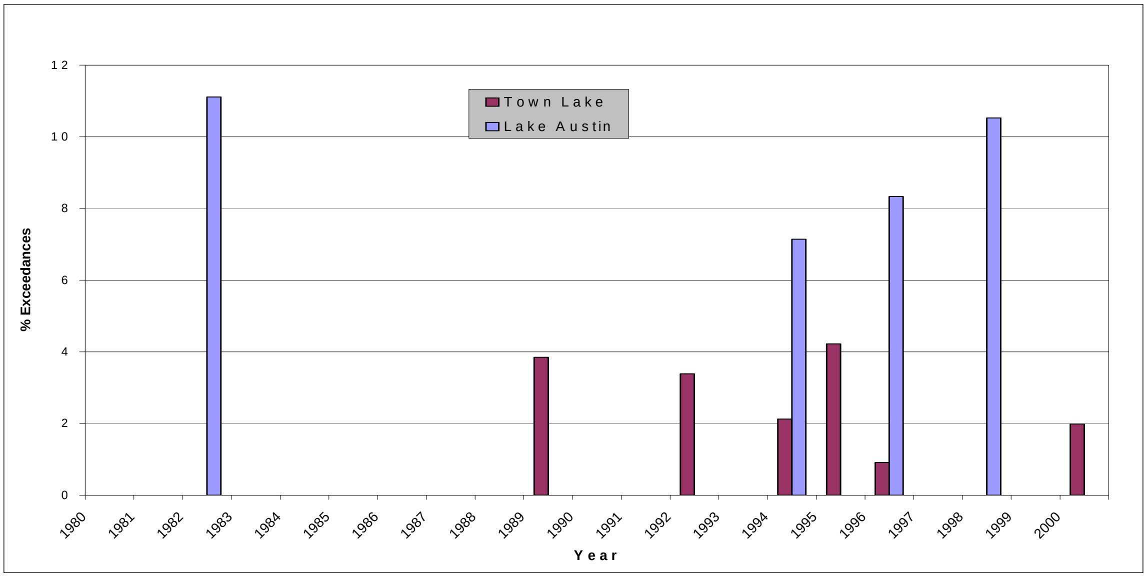
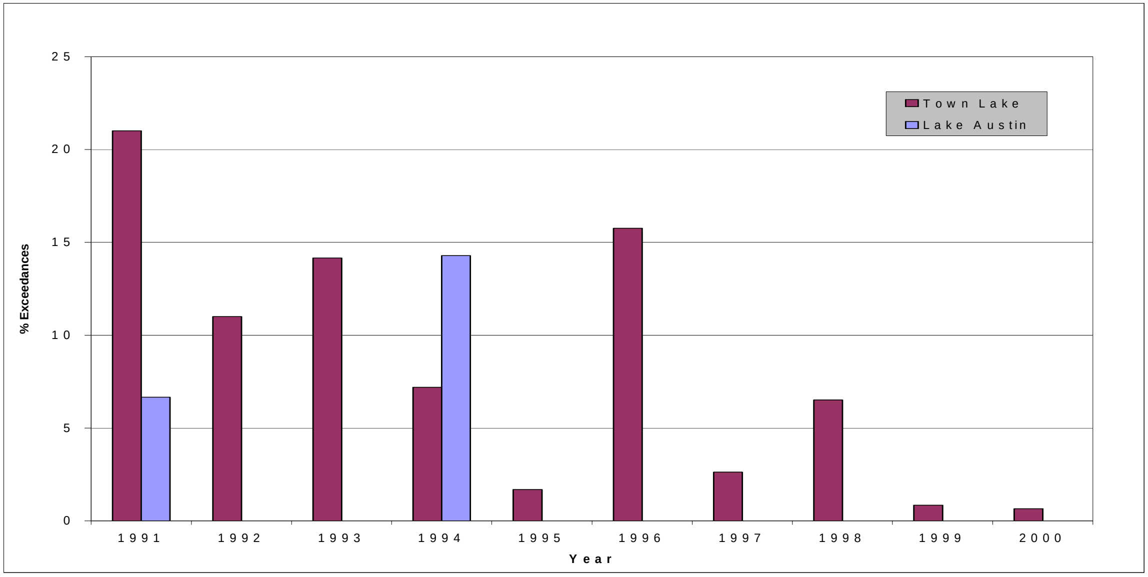


Figure 4.48 Orthophosphorus Percentage Exceedances of TNRCC Screening Criteria for Town Lake and Lake Austin



Town Lake total phosphorus concentrations have exceeded 1 mg/L only on 29 June 1992 as measured by the USGS from the surface of the First Street site one day after a storm event of approximately 0.16". Lake Austin total phosphorus concentrations have exceeded 1 mg/L three times during the period of record, with the latest occurrence on 21 October 1996. The maximum observed total orthophosphorus concentration of 0.72 mg/L measured in Town Lake occurred on 17 October 1996 at the surface of the Lamar site during non-storm flow conditions.

4.3.3.6 Temporal Patterns

Comparison of Town Lake before and after the 1992 ban on phosphorus in detergents and the institution of minimum flow policy by the LCRA shows that total phosphorus concentrations after 1992 are significantly greater than pre-1992 concentrations by ranked ANOVA during non-storm flow conditions in both non-release and release seasons at surface and bottom depths. Pre-1992 concentrations of orthophosphorus are also significantly greater than post-1992 concentrations during all storm and release conditions except release, non-storm flow. Although the phosphorus ban would directly affect the influent to Austin's wastewater treatment plants, temporal changes in phosphorus loading from non-point sources appears to be increasing over time.

Total phosphorus concentrations in Town Lake during non-release, non-storm flow conditions exhibit generally increasing, though non-significant (p ≈ 0.12), temporal trends at both surface and bottom depths when data from all sites are aggregated. This has happened despite a decrease in total phosphorus concentrations observed during the 1997/1998 non-release season (Figure 4.49). Despite a lack of recent data, Lake Austin total phosphorus levels also exhibit a similar increasing trend (p = 0.0604) at surface depths during non-release, non-storm flow conditions. Town Lake non-release, storm flow total phosphorus concentrations exhibit no clear trends over time, although a graphical increase is evident through 1996, followed by a period of low concentrations with a spike in phosphorus evident in 2000 (Figure 4.50).

Figure 4.49 Town Lake Phosphorus During Non-Release, Non-Storm Flow, All Sites and Depths

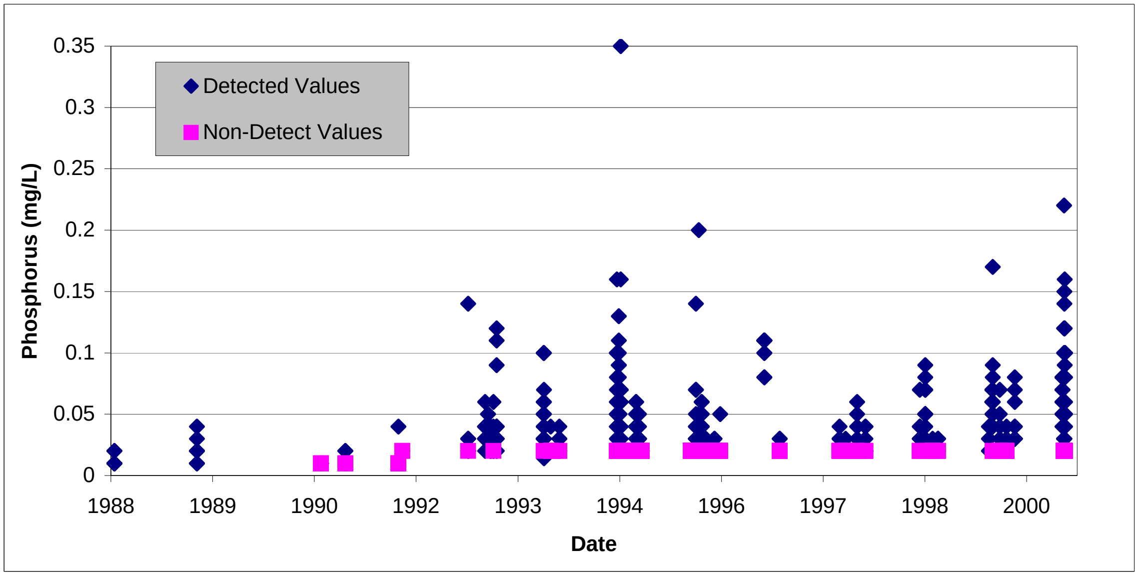
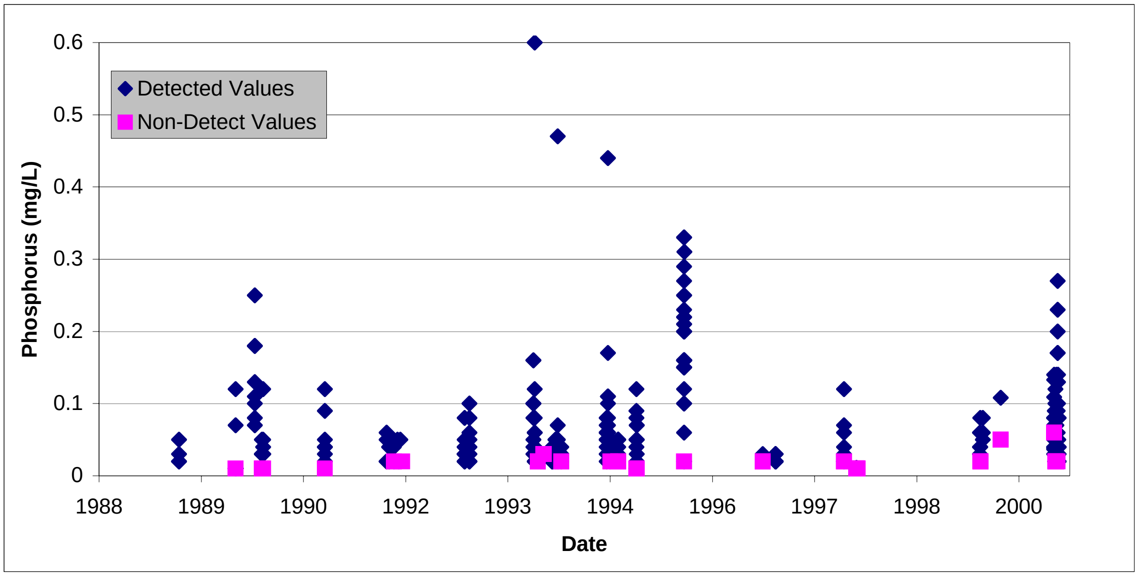


Figure 4.50 Town Lake Phosphorus during Non-Release, Storm Flow, All Sites and Depths



Town Lake phosphorus release concentrations exhibit a significant ($p < 0.0001$) increasing trend with time during non-storm flow at both surface and bottom depths when data from all sites are combined for analysis. Town Lake total phosphorus spiked in 1992, but continued to slightly increase through 2000 (Figure 4.51). Despite a paucity of recent data, Lake Austin total phosphorus concentrations corroborate the increasing trend ($p = 0.0287$) observed in Town Lake during release, non-storm flow conditions at surface depths. Patterns in total phosphorus concentrations during release storm flow periods indicate a slight decrease at both surface ($p = 0.1110$) and bottom ($p = 0.0068$) over time (Figure 4.52). Lake Austin total phosphorus concentrations over time ($p < 0.01$) again mirror the decrease observed in Town Lake during release, storm flow conditions.

Figure 4.51 Town Lake Phosphorus During Release, Non-Storm Flow, All Sites and Depths

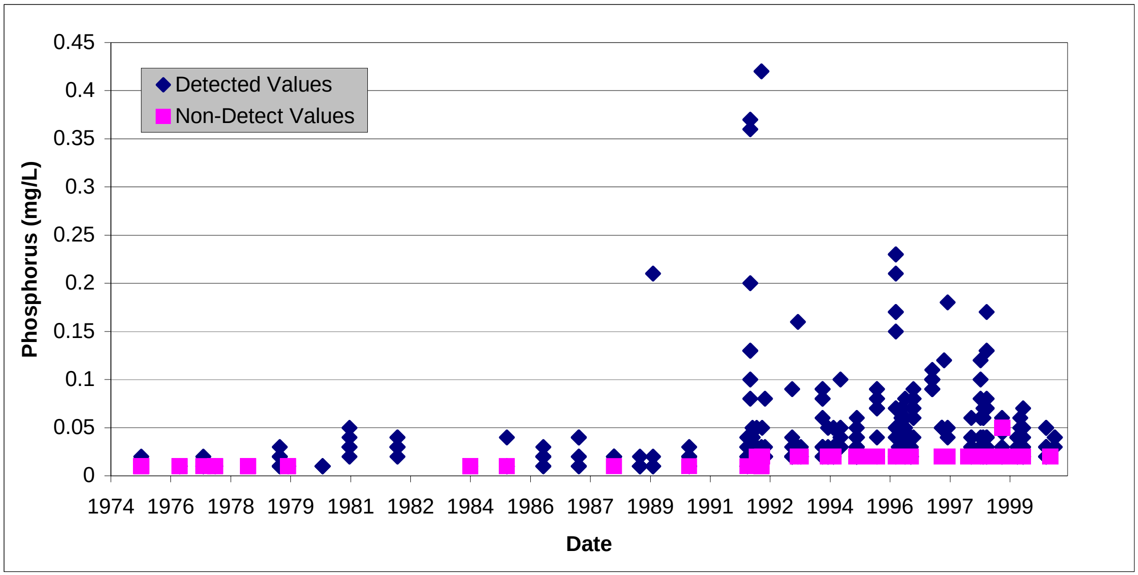
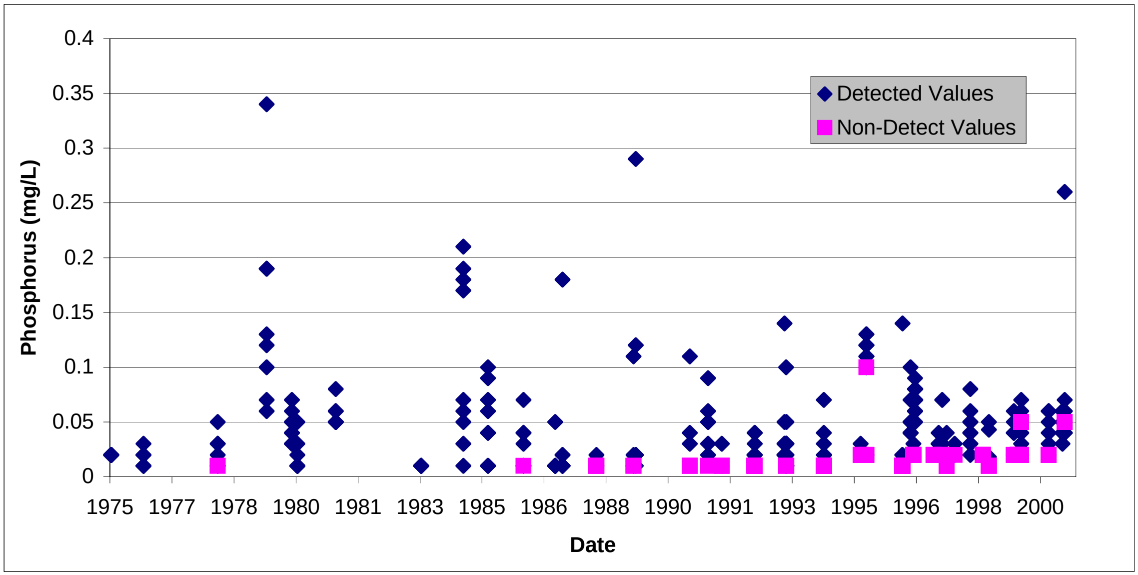


Figure 4.52 Town Lake Phosphorus During Release, Storm Flow, All Sites and Depths



Town Lake orthophosphorus data exhibit statistically significant decreasing trends over time during all storm and release conditions when data from all sites and depths are combined for analysis (Figure 4.53 and 4.54). Under both storm and non-storm flow conditions during non-release, Town Lake orthophosphorus levels exhibited elevated levels in 1993/1994 and a sharp spike in values again in 1996, though a decline was observed over time from 1996 to

2000. Temporal analysis at the individual site level confirms decreasing concentrations of orthophosphorus over time for all storm and release conditions at the Basin and MoPac sites, which have historically exhibited the highest mean concentrations. Non-storm concentrations at the Lamar site also exhibit significant decreasing trends over time during both release and non-release seasons. The same anomalous non-release spikes in 1993/1994 and 1996 are evident at the site level as well as primarily for the First Street, Lamar and Red Bud sites.

Figure 4.53 Town Lake Orthophosphorus During Non-Release, All Sites and Depths

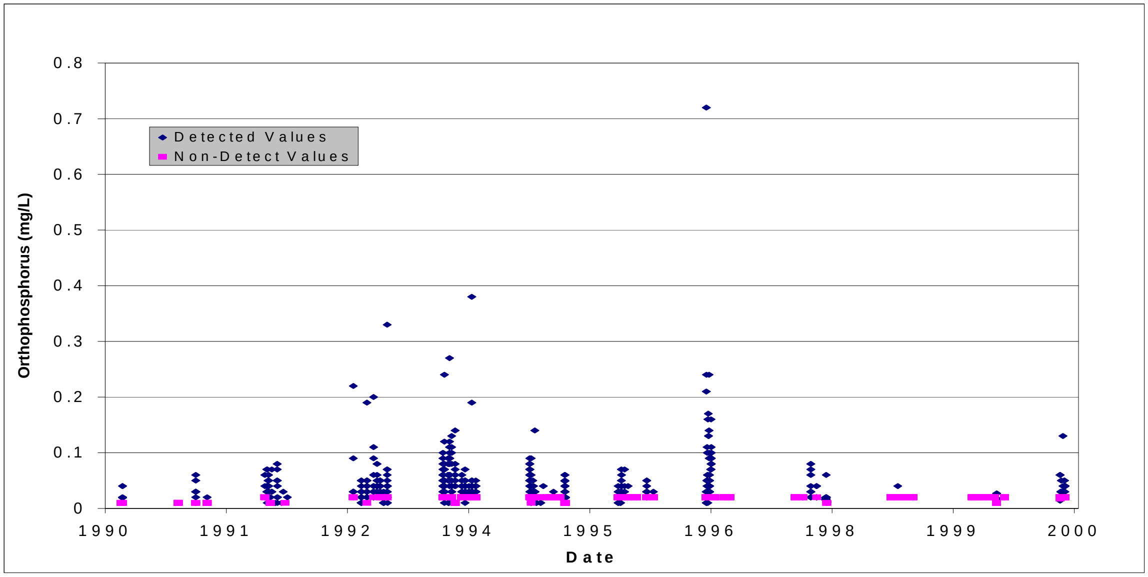
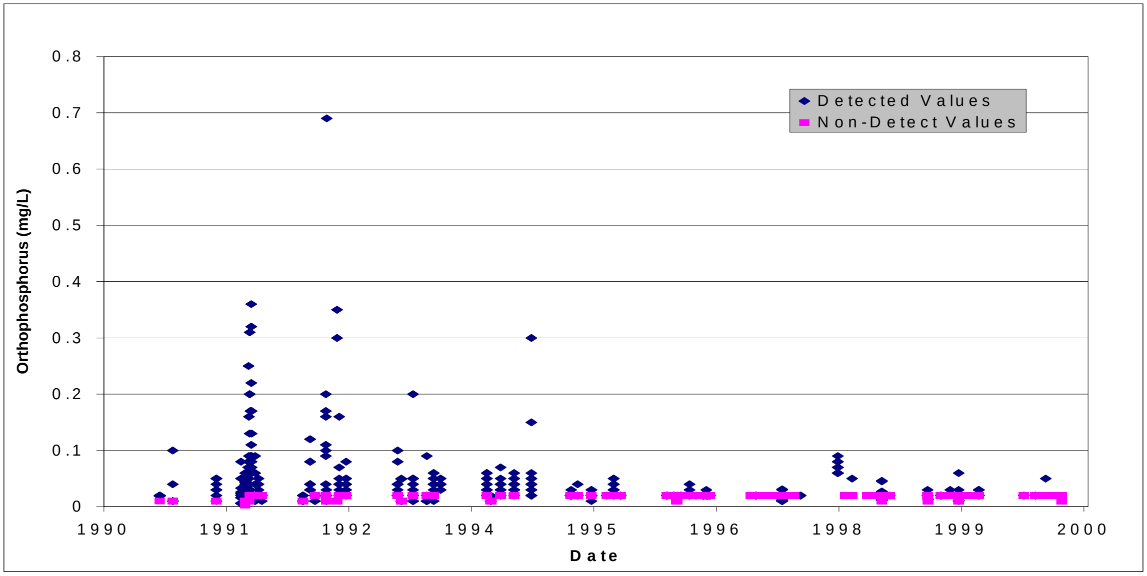


Figure 4.54 Town Lake Orthophosphorus During Release, All Sites and Depths



4.3.3.7 Monitoring recommendations

Although it would appear that Town Lake concentrations of phosphorus nutrients were not well-characterized by the detectable percent change in means obtained from sample frequency analysis (Table 4.12), the actual values that could be detected are small, particularly for total phosphorus. The small variation which is measurable and the lack of trend or difference in either total or orthophosphorus with depth in Town Lake suggest the possibility of reducing current sampling protocols to surface-only samples.

Table 4.12 Minimum Significant Detectable Difference in Watershed Mean Phosphorus Concentrations (as a value and percentage of current mean) if Sampling Continued at Current Over Specified Time Periods

Parameter (mg/L)	**Non-Release**				**Release**			
	Non-storm		**Storm**		**Non-storm**		**Storm**	
	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 1 yr
Phosphorus	0.012 (38)	0.005 (17)	0.024 (46)	0.011 (21)	0.017 (54)	0.008 (24)	0.023 (69)	0.01 (31)
Ortho-phosphorus	0.014 (60)	0.006 (27)	0.011 (39)	0.005 (18)	0.013 (56)	0.006 (25)	0.015 (94)	0.007 (42)

4.4 Solids and Salts

Human activities can increase the amount of particles and dissolved ions moving into receiving waters. The following sections will discuss suspended solids, where some pollutants are adsorbed, measurements related to how these solids affect water clarity, Secchi depth and turbidity, and dissolved solids and salts.

4.4.1 Suspended Solids, Secchi and Turbidity

The parameter total suspended solids (TSS), historically known as total non-filterable residue, refers to the dry weight of the amount of solid matter in a known quantity of water (APHA 1992). The solids suspended in water may be clay, silt, microscopic organisms or other solid matter. Volatile suspended solids (VSS) refers to the weight fraction of total suspended solids lost on ignition of the sample and generally describes the amount of organic solids suspended in a solution (APHA 1992; Droste 1997).

Turbidity in a water sample is caused by suspended solids, which absorb and scatter light rather than allowing light to pass through the sample in a straight line (APHA 1992). Although turbidity does not yield a quantitative estimate of solid matter in a water sample, it is useful as a measurement of the aesthetic clarity of water. Turbidity can be measured in Nephelometric Turbidity Units (NTU) and Formazine Turbidity Units (FTU). Unfortunately, the results obtained with different types of turbidity instruments are not directly comparable, even when calibrated to the same standard (APHA 1992), and thus turbidity is presented separately in both NTU and FTU analyses for this report.

The Secchi disk is a method of measuring turbidity in the field using a weighted disk attached to rope marked with length measurements. The disk is lowered until the observer can no longer clearly see the black and white markings on the disk, and the depth of the disk is recorded from the rope. The Secchi disk depth may then be used to calculate light extinction, a factor used when modeling algae blooms.

Erosion of soils, decomposition of rocks, and decomposing plant material are natural sources of suspended solids in aquatic systems, although these processes may be accelerated by anthropogenic influences such as land clearing and construction practices (USEPA 1977). Although point sources of suspended solids input to a water body include municipal wastewater effluent and construction site runoff directly to a water body, non-point sources, which are primarily composed of erosion of soil, are typically much greater contributors (USEPA 1977).

High concentrations of suspended solids may negatively impact aquatic plants and fish due to increased light extinction coefficients and may generally indicate the potential loss of reservoir capacity as sediment accumulates (Paulet et al 1972). Toxic substances such as metals and pesticides, as well as nutrients like phosphorus, may attach to solid material and be transported to receiving water bodies. Increased turbidity in a water body may be less aesthetically appealing and may result in a reduction in the use of the water resource as a source of recreation (USEPA 1977). TNRCC has no quantitative guidelines or criteria for acceptable levels of TSS or turbidity in water bodies.

4.4.1.1 Summary of Results

Figures 4.55, 4.56, 4.57 and 4.58 present graphical summaries of statistical results for Town Lake suspended and dissolved solid parameters.

Figure 4.55 Graphical Summary of Results for TSS

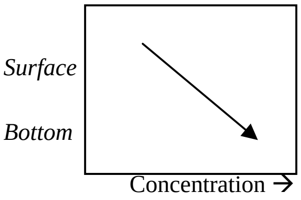
SPATIAL

Location

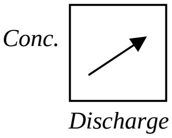
Town Lake vs. Lake Austin	*Upstream*	*Downstream*
Higher	———	

*Basin, First, Lamar elevated in storm flow

Depth



FLOW/SEASONALITY



storm flow only (non-sig.)

Storm flows highest in:	*Non-Storm flows highest in:*	*Max conc. in:*
Release	Release	Release, Storm

Post-Storm

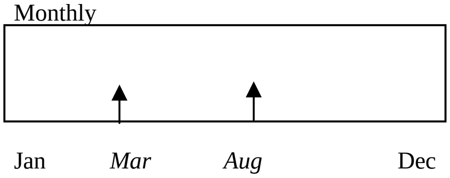
Conc

NR: No clear pattern

R: No clear pattern

0 *1* 3 # Days after Storm

Monthly



TEMPORAL

Annual % Exceedance of TNRCC Criteria

No applicable screening criteria

Overall temporal pattern

No clear pattern

Temporal Regression

	SURFACE				BOTTOM			
	Release		*Non-Release*		*Release*		*Non-Release*	
	NS	S	NS	S	NS	S	NS	S
Town Lake	↘	↘		↘	↘	↘		↘
Lake Austin								

Concentration

Time →

Comments:

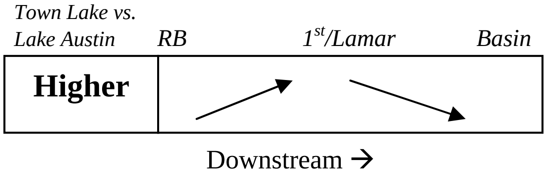
TSS and VSS strongly correlated and vary together, indicating a consistent amount of organic material in Town Lake suspended sediments.

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

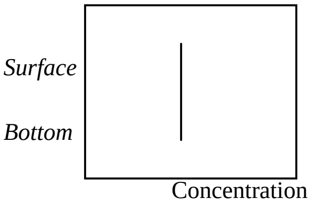
Figure 4.56 Graphical Summary of Results for VSS

SPATIAL

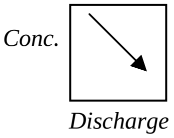
Location



Depth



FLOW/SEASONALITY



Storm flows highest in:

Release

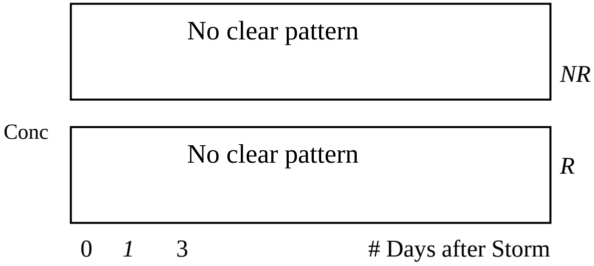
Non-Storm flows highest in:

No difference

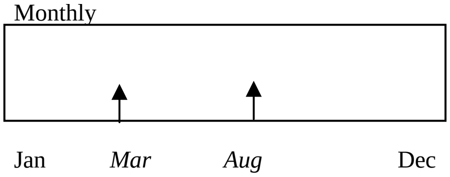
Max conc. in:

Release, Storm

Post-Storm



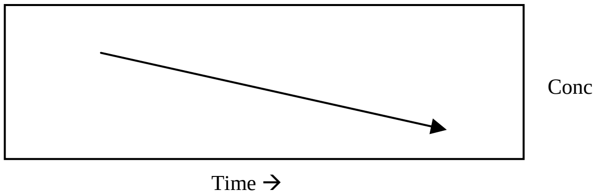
Monthly



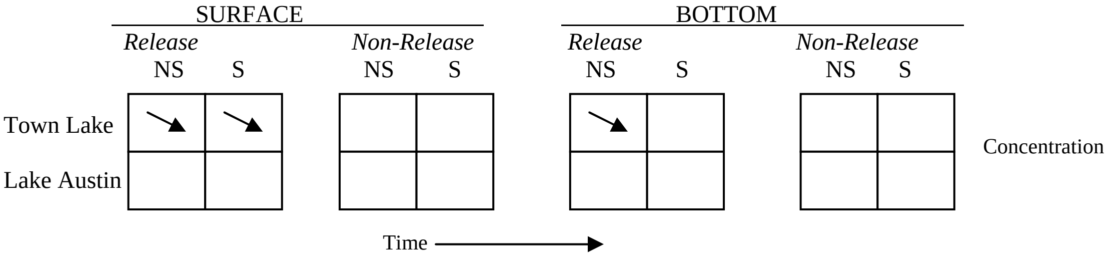
TEMPORAL

Annual % Exceedance of TNRCC Criteria

Overall temporal pattern



Temporal



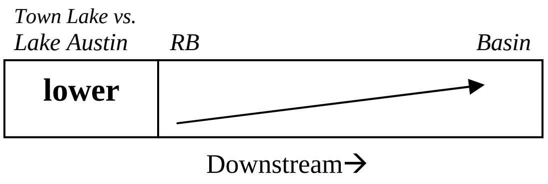
Comments:

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

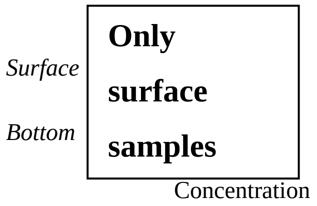
Figure 4.57 Graphical Summary of Results for Turbidity

SPATIAL

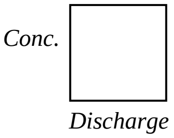
Location



Depth

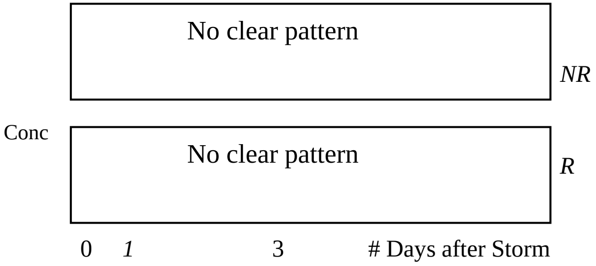


FLOW/SEASONALITY

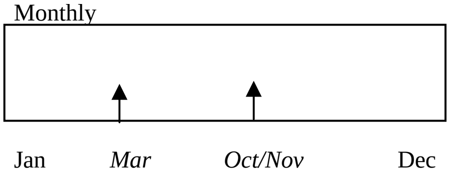


Storm flows highest in:	*Non-Storm flows highest in:*	*Max conc. in:*
No difference	Non-Release	Storm

Post-Storm



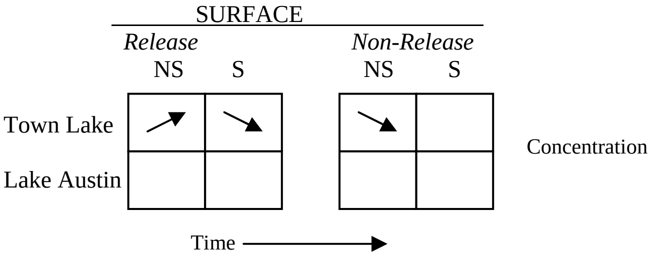
Monthly



TEMPORAL

Annual % Exceedance of TNRCC Criteria	Overall temporal pattern
No applicable screening criteria	No clear pattern

Temporal



Only surface samples evaluated in this report.

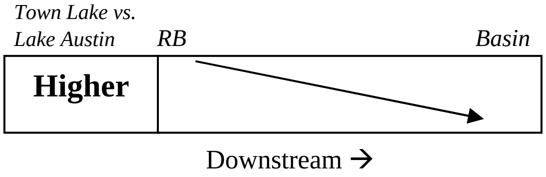
Comments:

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

Figure 4.58 Graphical Summary of Results for Secchi Disk

SPATIAL

Location



Depth

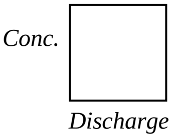
Surface

Bottom

Not applicable

Concentration

FLOW/SEASONALITY



Storm flows highest in:

No difference

Non-Storm flows highest in:

Non-Release

Max conc. in:

Non-Release, Non- Storm

Post-Storm

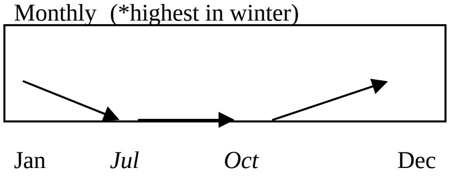
Conc

No clear pattern *NR*

No clear pattern *R*

0 *1* 3 # Days after Storm

Monthly (*highest in winter)

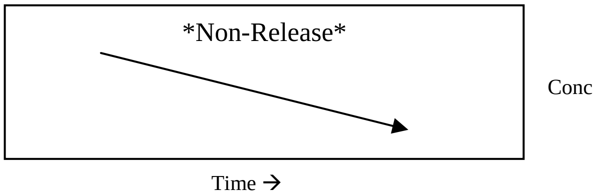


TEMPORAL

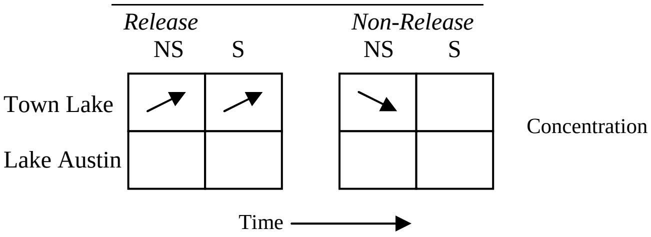
Annual % Exceedance of TNRCC Criteria

No applicable screening criteria exists

Overall temporal pattern



Temporal



Comments:

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

Although Lake Austin is expected to be less impacted by urbanization than Town Lake, Lake Austin exhibits higher mean VSS and TSS concentrations. However, Lake Austin still maintains larger average Secchi disk depths (indicating better clarity), and is visibly clearer than Town Lake waters under normal conditions.

The relationships observed in turbidity and TSS indicate that Lake Austin may be a source of clarity-reducing solids input to Town Lake during non-storm conditions, although Lake Austin inflows may improve Town Lake clarity during storm events. VSS is inversely related to Lake Austin discharge into Town Lake, even though Lake Austin maintains a higher average algal count than Town Lake under normal conditions.

Average Secchi disk depths for Town Lake decrease from upstream to downstream sites, indicating that Town Lake may be decreasing Colorado River clarity through Austin. Town Lake VSS concentrations exhibit elevated values at the Lamar and First Street sites, although VSS concentrations upon discharge from Town Lake are less than initial inputs from Lake Austin. Site-related storm impacts at the First Street site are evident in the elevated mean concentrations of TSS, turbidity, and VSS during storm flow conditions.

In general, solids (represented by TSS, VSS, turbidity and reduced Secchi disk depth) exhibit higher mean storm flow concentrations than non-storm flow concentrations, as expected.

Secchi disk depths are decreasing over time during the non-release season (during non-storm flow) in Town Lake, though the decrease is minor and would not bring average Town Lake transparency to zero until approximately 2096. Despite decreasing transparency in non-release, Secchi disk depth measurements appear to be improving during release (particularly in storm flow).

4.4.1.2 Spatial Distribution

During non-storm flow conditions in Town Lake, little observable variation was found in mean site total suspended solid (TSS) concentrations (Figure 4.59). However, Lake Austin concentrations are significantly greater than Town Lake concentrations during non-storm flows in both release and non-release seasons (Figure 4.60), potentially due to higher mean VSS loads in Lake Austin. In Town Lake during non-storm flow conditions, mean TSS is significantly greater during the release season than the non-release season, further implicating Lake Austin as a potential source of solids loading to Town Lake. However, during non-storm, non-release conditions, when Town Lake is most isolated from upstream Lake Austin input, mean TSS at the Basin and First Street sites are significantly greater than all other Town Lake sites. Comparing patterns in TSS concentrations between release and non-release seasons in non-storm flow conditions yields two different patterns. In release, mean TSS values decrease from Lake Austin inputs to MoPac, but then increase from Lamar to the Basin, potentially due to loading from urban creeks discharging to Town Lake. However, in non-release, a much steadier longitudinally increasing trend exists from upstream to downstream sites, although Lake Austin concentrations are still greater than mean TSS at the Basin.

Figure 4.59 Mean TSS Site Concentrations by Season and Flow Type

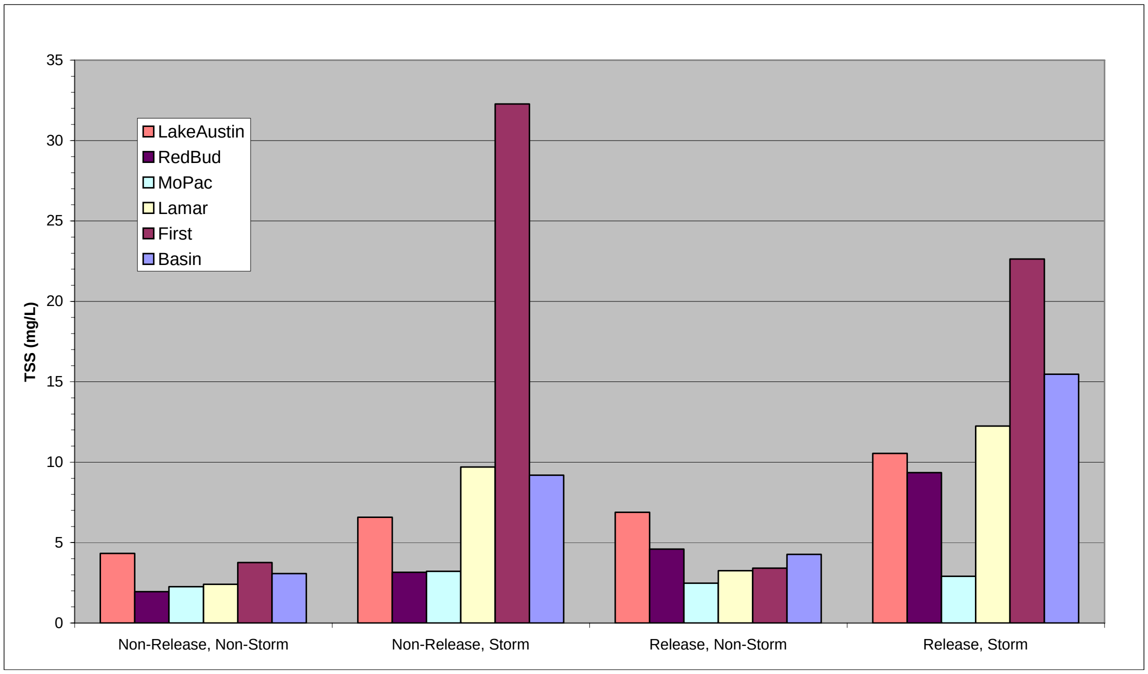
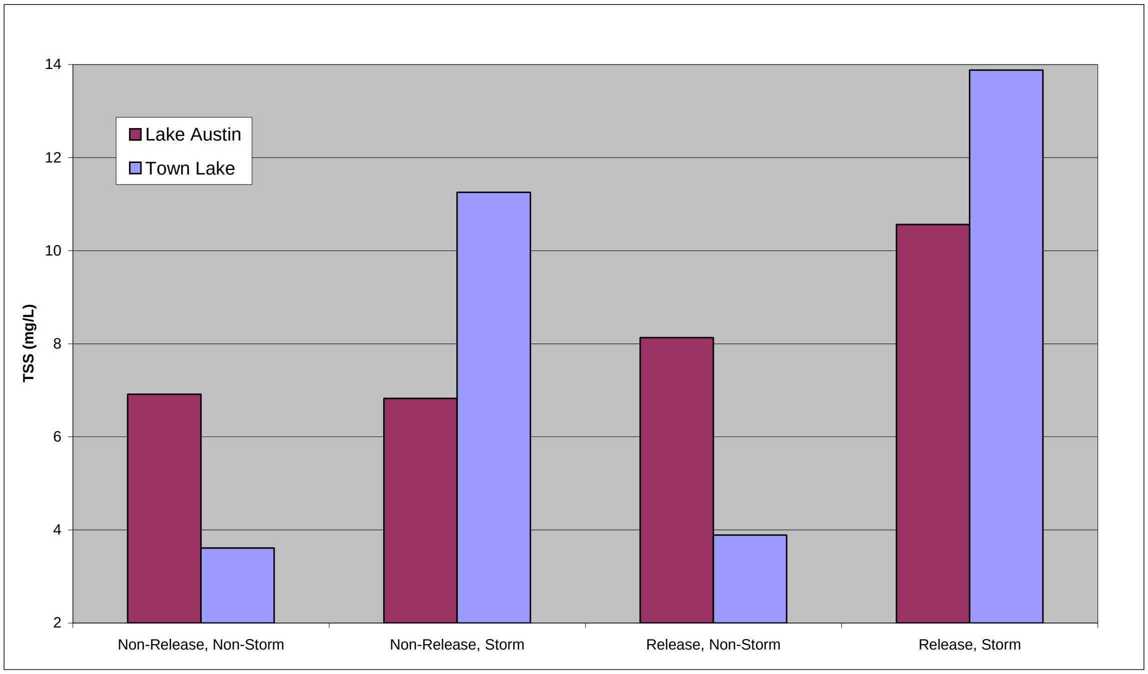


Figure 4.60 Mean TSS Watershed Concentrations by Season and Flow Type



A potential pattern of solids introduction to the lake followed by solids settling is more apparent in mean TSS concentrations during storm flow conditions. Decreasing TSS concentrations occur at Red Bud and MoPac, followed by increasing concentrations at Lamar with a sharp increase in mean TSS at First Street, likely resulting from the downtown storm sewer outfalls in combination with suspended solids loading from Barton Creek. Although concentrations at the Basin are still elevated in storm flow conditions, the decline from the sharp peak at First Street is readily apparent as solid material has approximately 4 km of travel distance, allowing for some settling.

Although Lake Austin possesses higher mean TSS levels than Town Lake, Lake Austin clarities, as represented by mean Secchi disk depths, are always greater than Town Lake transparency. The source of this discrepancy is not immediately evident. During non-release non-storm flow conditions in Town Lake, a clear decreasing longitudinal trend in Secchi disk depth is evident from upstream to downstream sites (Figure 4.61). The impacts of particulate matter on downstream sites during storm events, potentially from Barton Creek loading and downtown storm sewer outfalls, appears to be greater at downstream sites since storm and non-storm Secchi depths at MoPac and Red Bud are approximately the same. The increased average clarity of Lake Austin relative to Town Lake is plainly evident (Figure 4.62).

Figure 4.61 Mean Secchi Disk Site Depths by Season and Flow Type

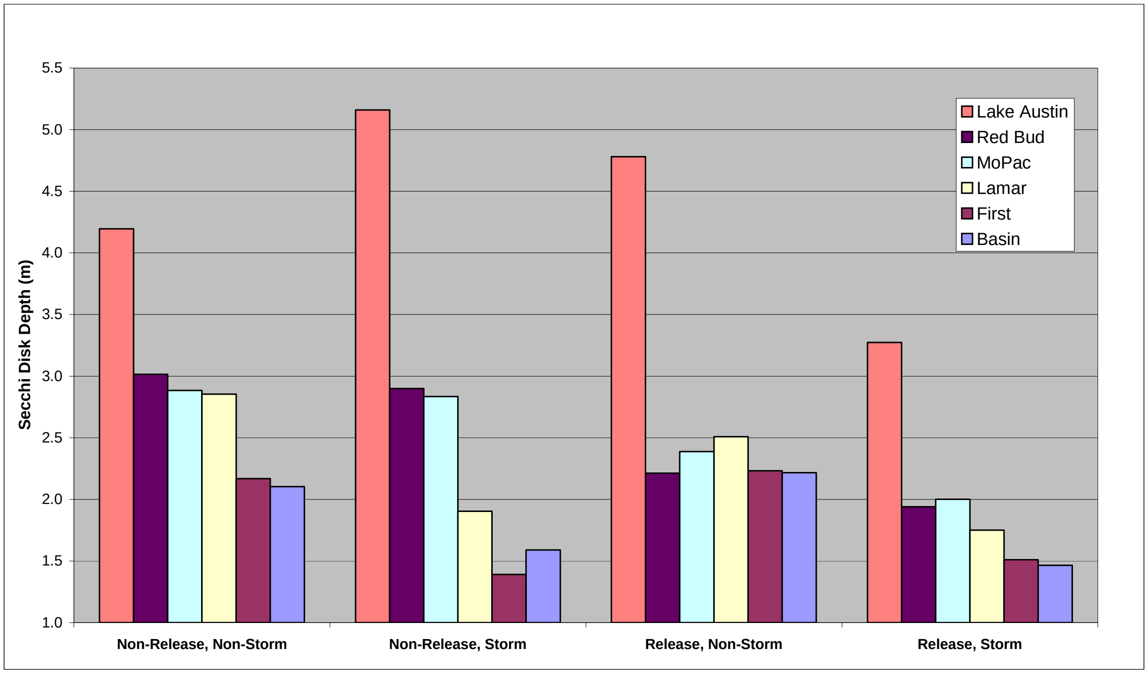
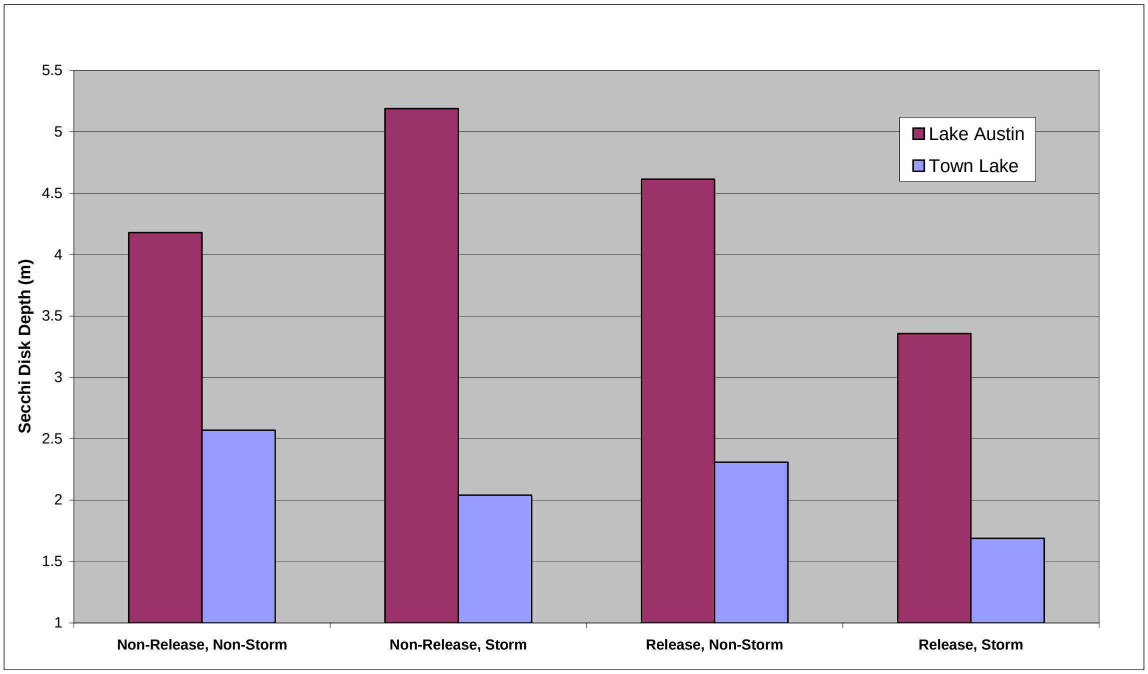


Figure 4.62 Mean Secchi Disk Watershed Depths by Season and Flow Type



Turbidity levels in Town Lake follow the same general trends as TSS, and a clear increasing longitudinal trend in mean turbidity measured (as measured in FTU) from upstream to downstream sites is apparent during non-release, non-storm flow conditions (Figure 4.63). Note the same spike in turbidity levels at First Street following storm events in both the release and non-release seasons. Both NTU and FTU turbidity measurements are significantly greater in Town Lake than Lake Austin during both storm and non-storm flow conditions in the non-release season (Figure 4.64). No statistically significant difference exists between mean Town Lake and Lake Austin NTU turbidity levels during the release season in either storm or non-storm flows when both water bodies are typically more mixed.

Figure 4.63 FTU Turbidity Site Means by Season and Flow Type

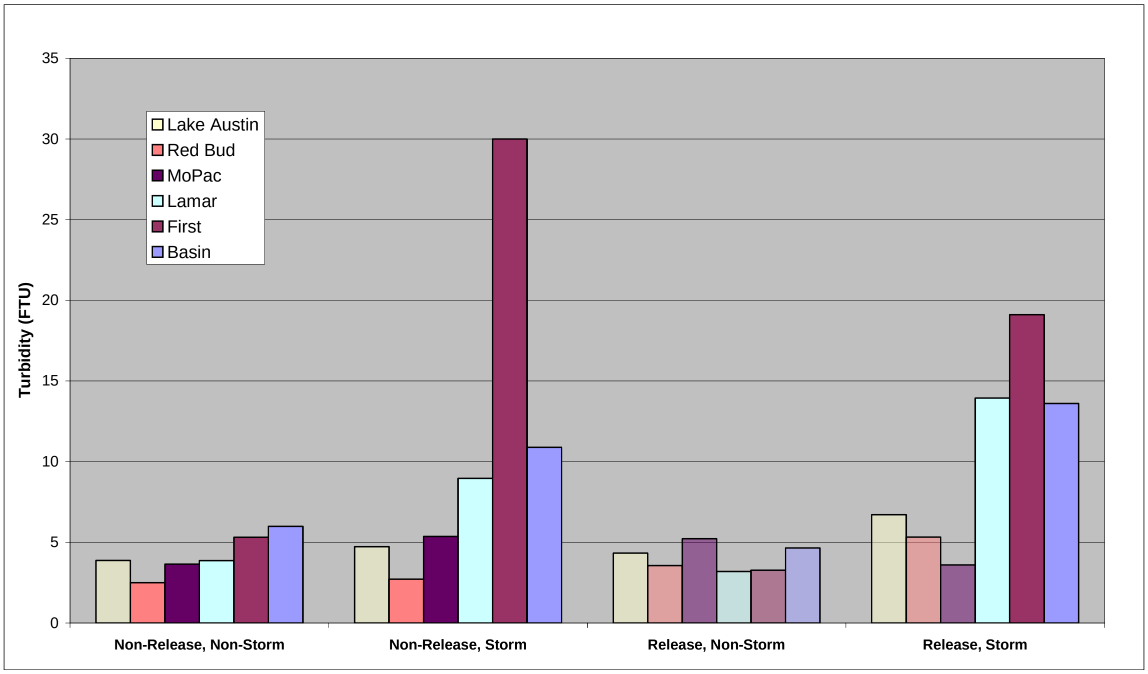
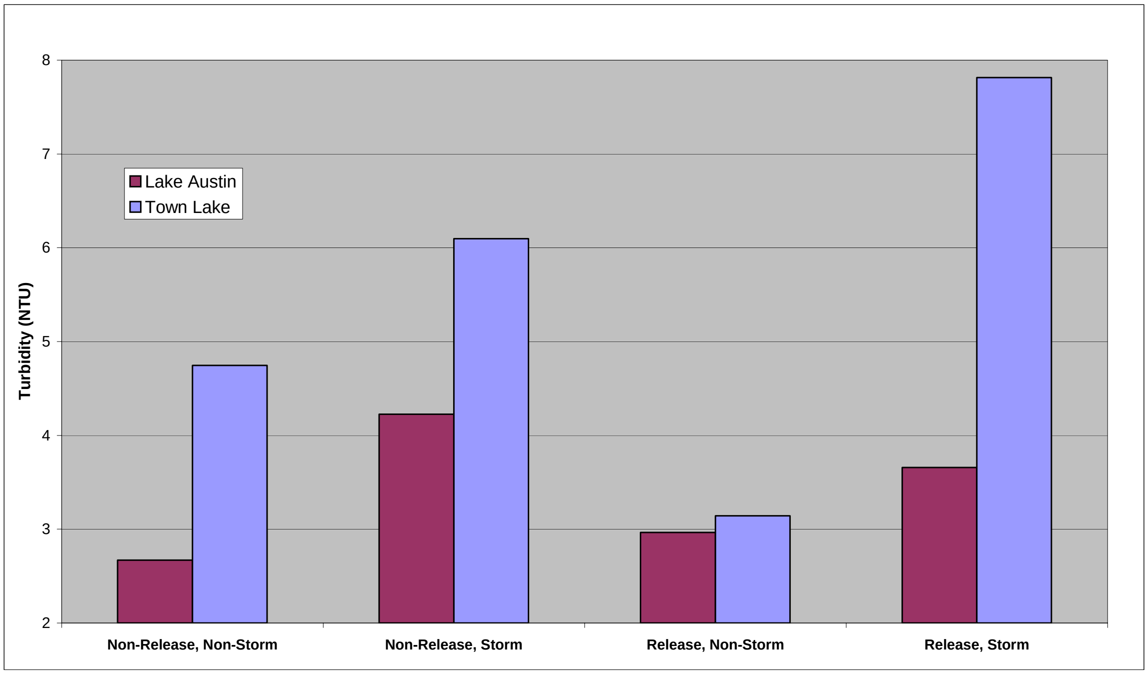


Figure 4.64 NTU Turbidity Watershed Means by Season and Flow Type

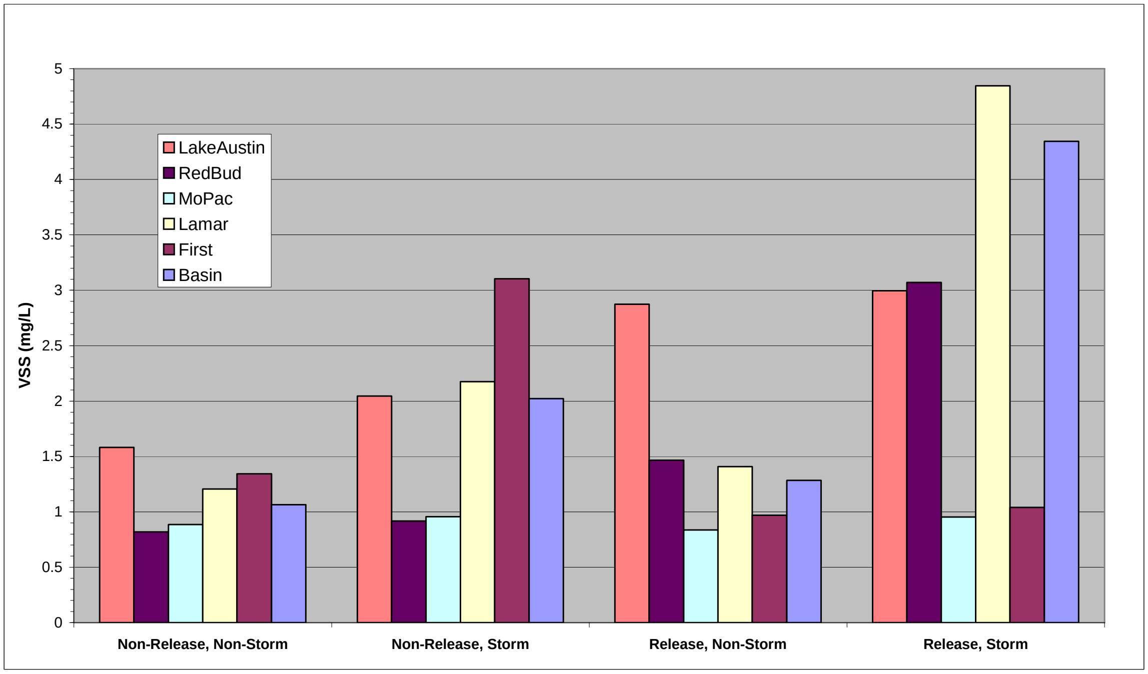


Field observations during post-storm sampling events on Town Lake verify the observed statistical trend in spatial TSS concentration distributions. Highly visible changes in water clarity and color are observable immediately upstream of the confluence of Barton Creek and Town Lake. Following large storm events, Town Lake below the confluence of Barton Creek, located upstream of the Lamar Bridge site, is extremely turbid and brown with large amounts of floatable organic debris and litter on the water's surface. Upstream of its confluence with Barton Creek, Town Lake is markedly clearer and closer to the normal natural green color with much less floating debris on the surface, despite influxes of storm runoff from Eanes and Johnson creeks. During large storm events, Secchi disk depths frequently approach zero in Town Lake. Even during non-storm sampling events, Town Lake clarity noticeably changes from Red Bud, where the bottom is often visible at a depth of approximately 5 m, to the Basin, where average non-storm Secchi disk depths are approximately 2.1 m.

Mean Lake Austin VSS concentrations are significantly greater than mean Town Lake VSS levels in all storm and release conditions (Figure 4.65). During the non-release season in both storm and non-storm flow conditions, Town Lake VSS concentrations are higher at downstream sites, with maximum mean concentrations observed at the First Street site.

However, during the release season, mean VSS is elevated at the Basin, Lamar and Red Bud sites.

Figure 4.65 Mean VSS Site Concentrations by Season and Flow Type



Only 15 measurements of TSS have been recorded by the USGS or COA in excess of 100 mg/L, with all 15 measurements above 100 mg/L occurring during storm events prior to 1992. The maximum VSS concentration of 43 mg/L measured in Town Lake occurred on 11 October 1984 at the bottom of Lamar, as recorded by the USGS during a storm event.

4.4.1.3 Release and Storm Conditions

Maximum values for TSS, VSS, and turbidity are seen during storm conditions, as expected, as well as the lowest Secchi depth (Table 4.13). Maximum values for VSS and TSS are observed during release, storm flow conditions when highest flows are expected.

During non-storm flow conditions, the mean Secchi disk depth is significantly greater in the non-release season than the release, which could indicate either better settling of particulate material during low flow or less solid loading from upstream Lake Austin inputs.

Table 4.13 Town Lake Mean Suspended Solid Measures by Season and Flow Type, All Sites Combined

Parameter	Release Conditions		Non-Release	
	Non-Storm	*Storm*	*Non-Storm*	*Storm*
TSS, mg/L	3.75	13.75	2.75	11.52
VSS, mg/L	1.35	3.65	1.17	1.94
Secchi Depth, meters	2.31	1.69	2.59	2.04
Turbidity, FTU	3.86	12.24	4.28	12.25

Secchi disk depth measurements in Town Lake are inversely correlated (Pearson's θ = -0.1533, $p < 0.0001$) to total mean daily discharge only during non-storm flow conditions. This inverse relationship of Town Lake transparency with Lake Austin discharge into Town Lake, though significant, is slight (Figure 4.66). No significant correlation exists between TSS levels in Town Lake with mean daily discharge from Tom Miller when both storm and non-storm flow data are combined, perhaps because the large storm inflows downstream of Tom Miller are not accurately reflected by the Tom Miller Dam discharge measurements. However, significant, though slight, inverse relationships exist between TSS and Tom Miller discharge during storm flows in both release (Spearman's θ, partial with depth = -0.1516, p = 0.0032) and non-release (Spearman's θ, partial with depth = -0.1879, $p < 0.0001$) seasons when non-storm flow conditions are excluded from the analysis. Thus, although it appears Lake Austin may decrease Town Lake clarity during non-storm flow conditions, Lake Austin inflows may actually help mitigate suspended solids during storm flow.

VSS levels show slight, though significant, inverse ranked correlation with Lake Austin inflows in all release and storm conditions when adjusted for variations with depth (depth used as a covariate in the correlation analysis), implicating Lake Austin as a potential source of organic particulate matter loading to Town Lake (Table 4.14). Lake Austin as a source of organic matter loading to Town Lake is further evident in the higher mean TKN values observed in Lake Austin.

Figure 4.66 Town Lake Secchi Disk Depth Versus Tom Miller Mean Total Daily Discharge During Non-Storm Flow

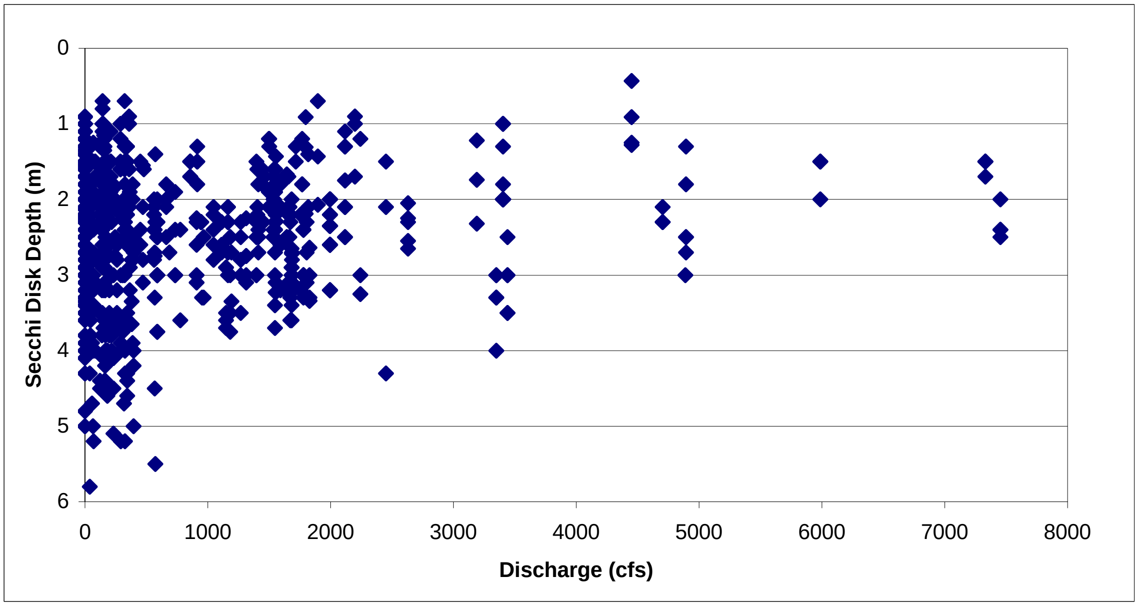


Table 4.14 Town Lake VSS Correlation Coefficients with Tom Miller Dam Mean Daily Discharge by Storm and Release Condition

FLOW	SEASON	Spearman's θ, partial with depth	p (θ not equal 0)
Non-Storm	Non-Release	-0.0954	0.0357
	Release	-0.1080	0.0186
Storm	Non-Release	-0.1633	0.0032
	Release	-0.1719	0.0137

Both NTU (Spearman's θ = 0.2541, p < 0.0001) and FTU (Spearman's θ = 0.1814, p = 0.0069) turbidity indicate a significant, positive correlation with total mean daily discharge from Tom Miller Dam during non-release, non-storm flow conditions. NTU turbidity also shows a significant, positive correlation with total Tom Miller flows during release, non-storm flow conditions (Spearman's θ = 0.1569, p = 0.0053). During storm flow conditions, however, FTU turbidity is significantly and inversely related to Lake Austin inflow through Tom Miller Dam (Spearman's θ = -0.2006, p < 0.0001). Again, it appears Lake Austin may decrease Town Lake clarity during non-storm flow conditions but may help mitigate suspended solid concentrations during storm flow.

4.4.1.4 Monthly Variations

Monthly mean Secchi disk depths in Town Lake under non-storm flow conditions reveal that lake transparency is generally highest in winter months when cooler temperatures might restrict algal growth and Lake Austin inflows are at a minimum (Figure 4.67). Note that while storm flow Secchi readings are consistently less (reduced clarity) than non-storm flow readings, the monthly temporal patterns are nearly identical. Monthly mean Secchi disk depth measurements are also inversely correlated with mean monthly TSS measurements, as expected (Figure 4.68). As non-storm surface TSS concentrations peak in the summer months toward the end of the release season, Secchi disk depths decline to annual minimums.

Figure 4.67 Town Lake Mean Monthly Secchi Disk Depth by Flow Type versus Mean Monthly Tom Miller Dam Daily Discharge

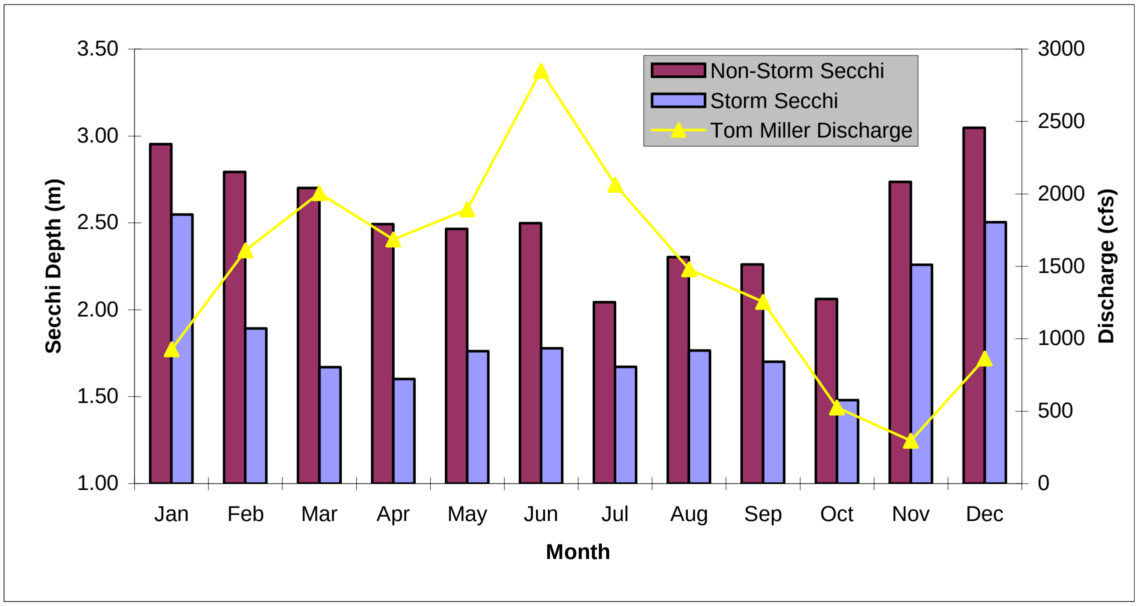
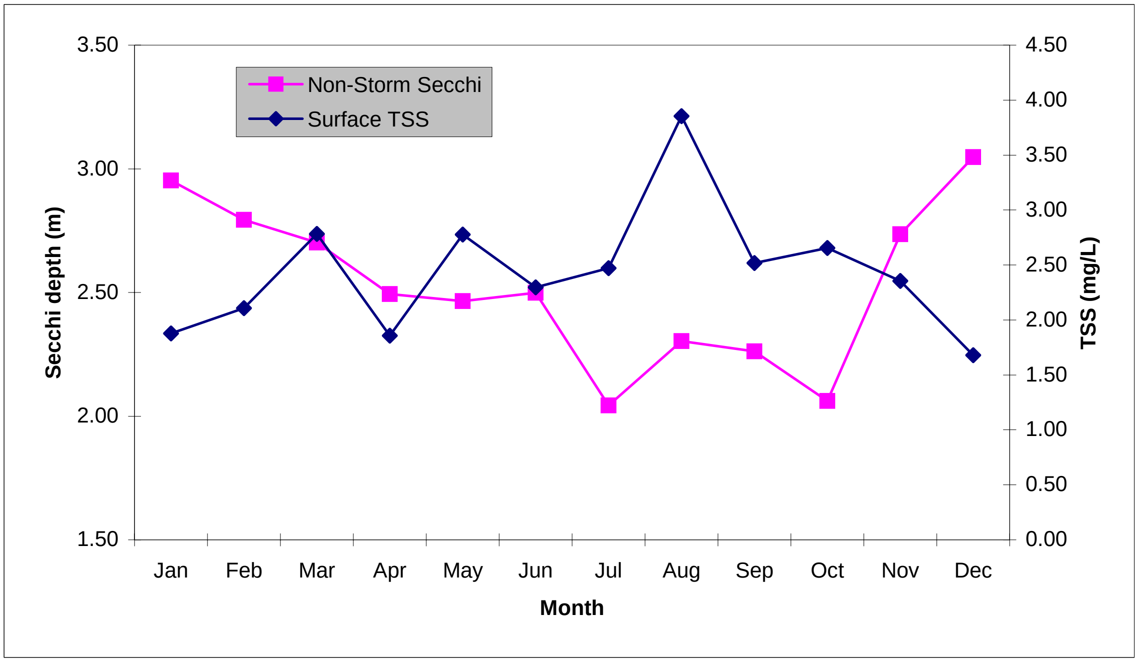


Figure 4.68 Town Lake Non-Storm Mean Monthly Secchi Disk Depth versus Mean Monthly Non-Storm TSS (at the surface)



Although mean monthly non-storm TSS concentrations at bottom depths are always greater than mean monthly TSS at surface depths (Figure 4.69), mean non-storm VSS concentrations do not differ as greatly between surface and bottom depths (Figure 4.70). Non-storm VSS and TSS concentrations are strongly related, particularly at surface depths (Figure 4.71), with near mirror image symmetry in the sinusoidal oscillations exhibited from month to month, reflecting a consistent source of upstream sediment with a non-varying organic component. The potential for TSS/VSS sampling interference at depth when the Kemmerer device strikes the bottom, re-suspending sediments into the water column, has lead to the cessation of TSS/VSS sampling at depth. However, observed patterns are consistent with expectations.

Monthly mean non-storm NTU turbidity in Town Lake exhibits an altogether different and anomalous pattern from other transparency-related parameters, in which values spike in March and October, the transition months between flow regimes. This is followed by declining turbidity for the remaining months of either season (Figure 4.72).

Figure 4.69 Town Lake Non-Storm Mean Monthly TSS by Depth

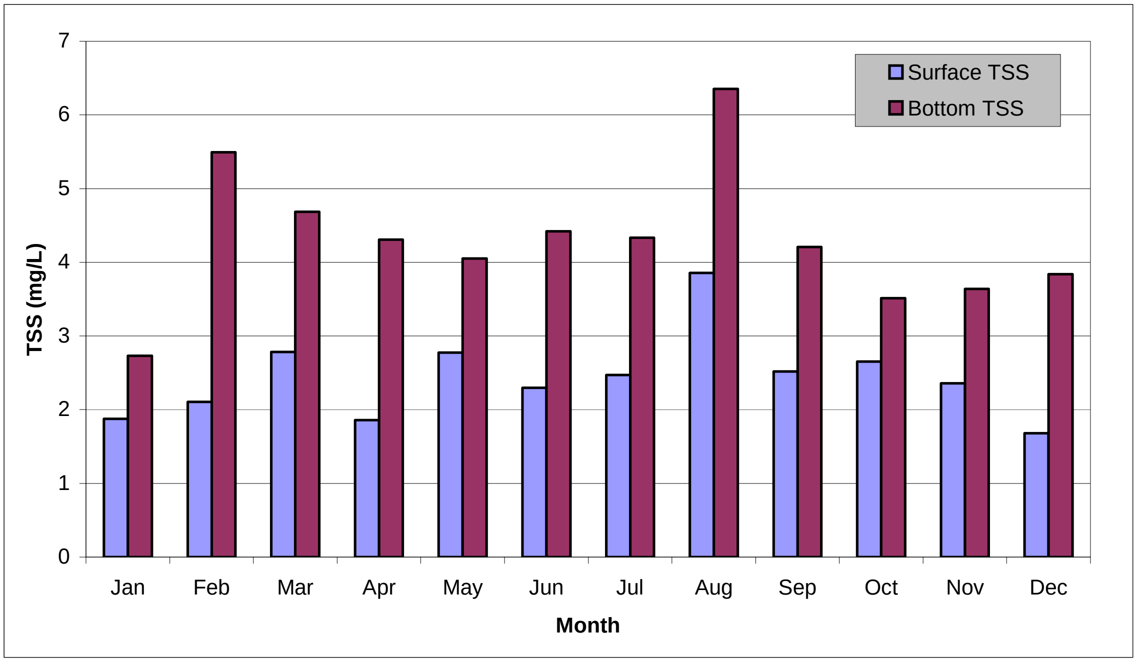


Figure 4.70 Town Lake Non-Storm Mean Monthly VSS by Depth

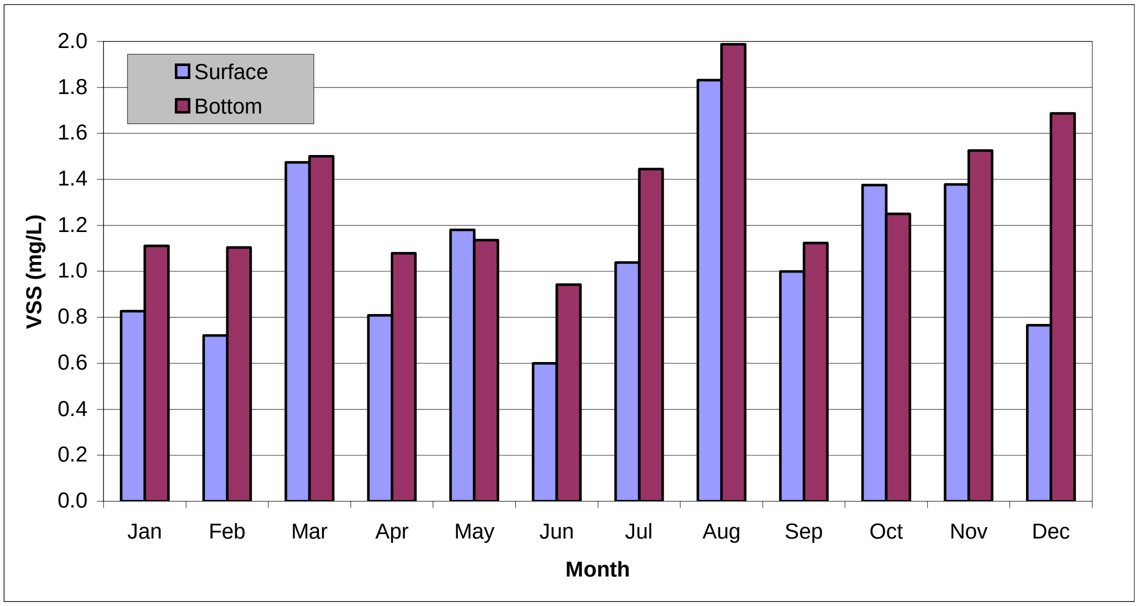


Figure 4.71 Town Lake Mean Monthly Non-Storm TSS versus Mean Monthly Non-Storm VSS at Surface Depths

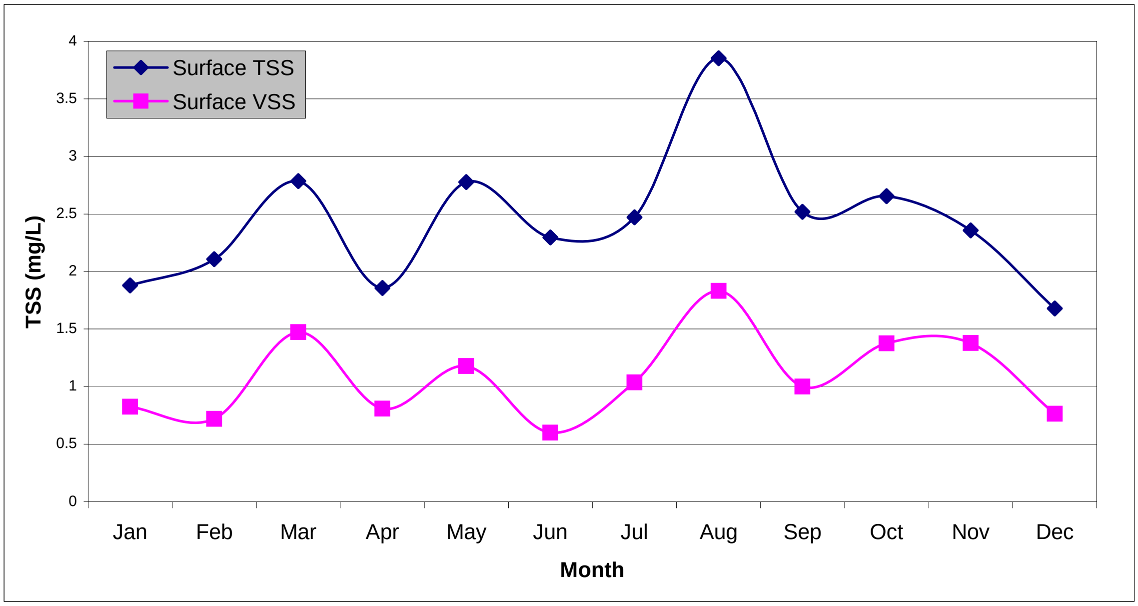
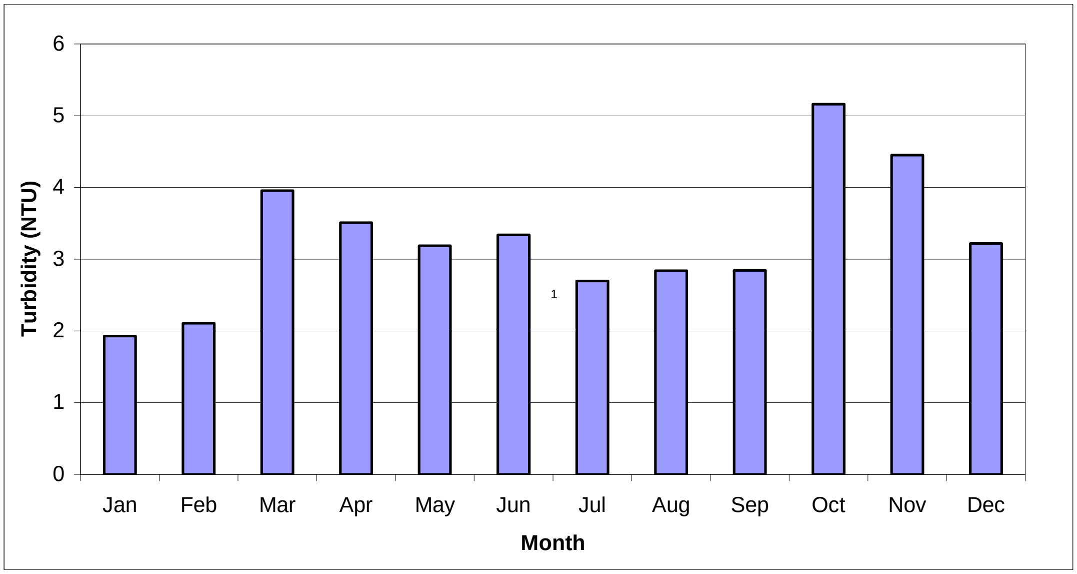


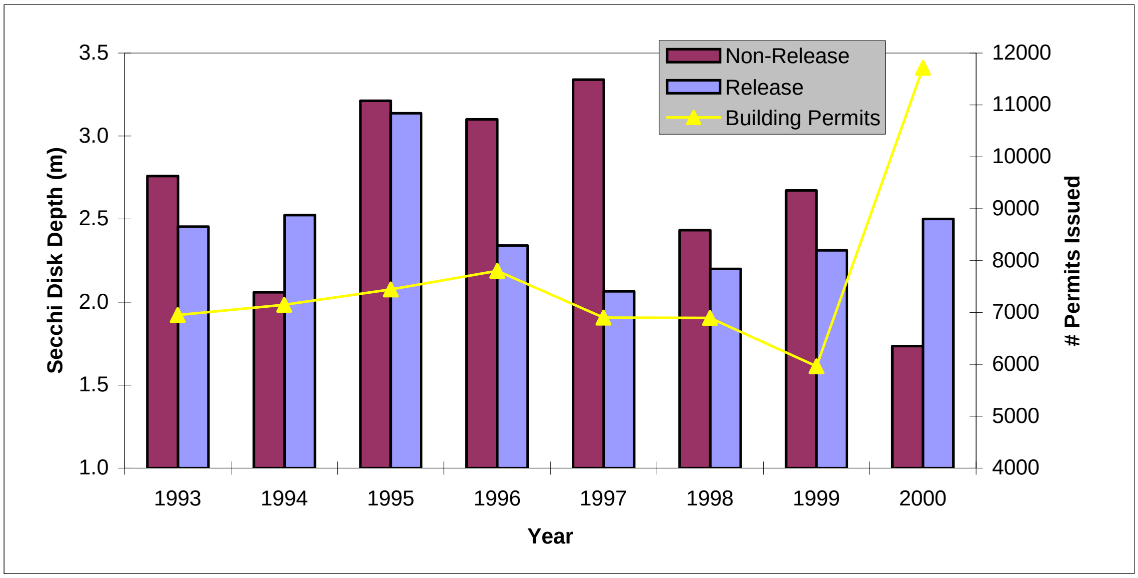
Figure 4.72 Town Lake Mean Monthly Non-Storm NTU Turbidity



4.4.1.5 Temporal Trends

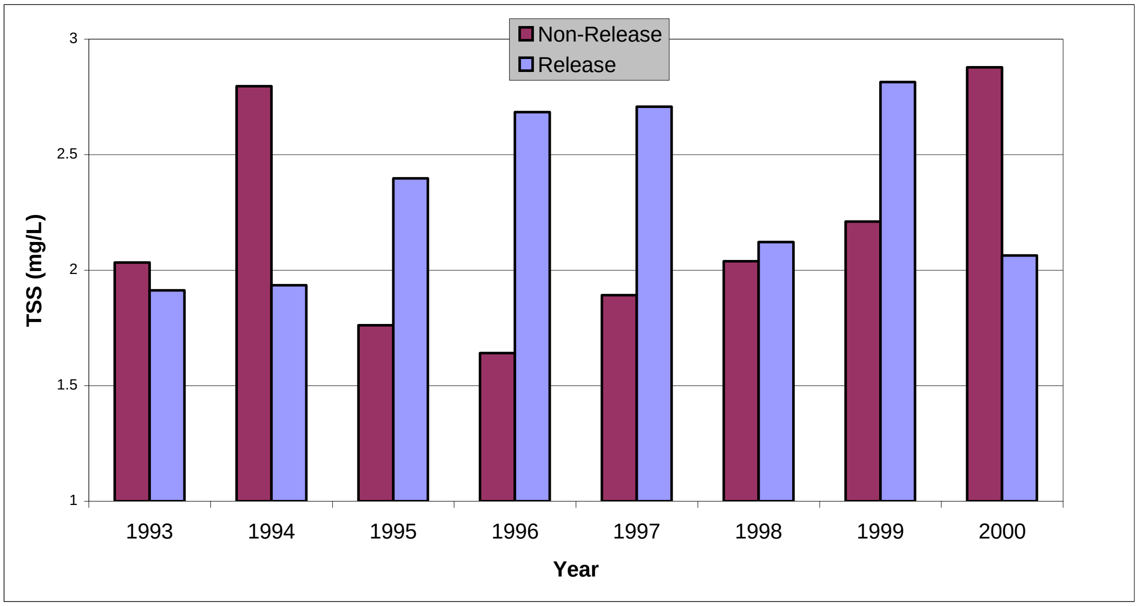
Patterns in mean annual non-storm Secchi disk depth in Town Lake do not appear to correlate with the estimated number of building permits issued in the contributing watershed (Figure 4.73), although the lowest observed annual mean depths (lowest clarity) do occur in 2000, in which record numbers of permits were issued. A general decline in transparency was observed during non-release conditions from 1997 to 2000, while release clarity levels appear to be increasing during the same time period.

Figure 4.73 Town Lake Non-Storm Annual Mean Secchi Disk Depth by Season with Estimated Number of Building Permits in Town Lake Watersheds



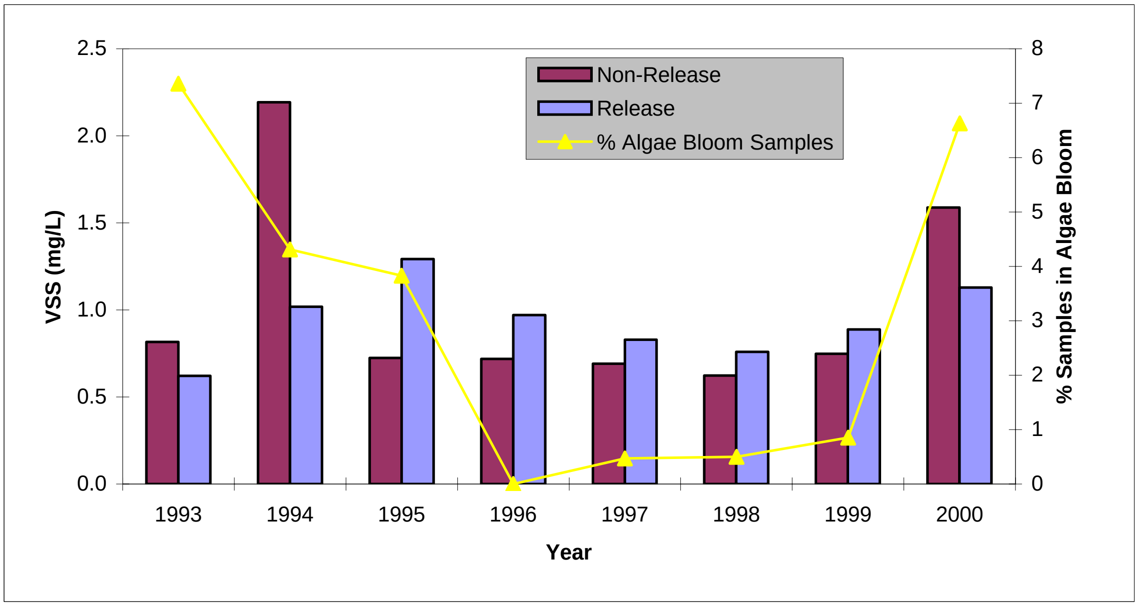
Another perspective of large-scale temporal changes in Town Lake is shown with TSS annual non-storm mean values (Figure 4.74). A difference of patterns between annual average TSS values was observed in the release and non-release seasons. Though clear differences occur between seasons for various years, the source of the variation is unknown.

Figure 4.74 Town Lake Non-Storm Annual Mean Surface TSS by Season



Annual Town Lake mean non-storm VSS levels during non-release seasons appear relatively constant, with two notable exceptions in 1994 and 2000 (Figure 4.75). Although some correlation with algae blooms in Town Lake is present, as represented by percentage of daily plankton counts at the Green Water Treatment Plant on Town Lake, exceeding 10,000 org/mL, plankton in Town Lake does not appear to be the source of fluctuations in VSS. Annual VSS levels during release seasons show more fluctuation, with elevated levels observed in 1995 and 2000.

Figure 4.75 Town Lake Non-Storm Annual Mean Surface VSS by Season with Percent of Daily Plankton Counts at Green WTP Exceeding 10,000 org/mL



4.4.1.6 Post Storm Effects

Mean Town Lake TSS concentrations are significantly greater before 1992 for all storm and release conditions except non-release, non-storm flow (p = 0.8705). However, mean Town Lake VSS concentrations are significantly greater before 1992 for all storm and release conditions. Consistent with observed temporal trends discussed below, mean Town Lake Secchi disk depths are significantly greater after 1992 during the release season in both storm and non-storm flow conditions. No statistically significant difference was observed in mean Secchi disk depth before and after 1992 during the non-release season. Town Lake turbidity, however, presents somewhat conflicting results when mean values are compared before and after 1992. Mean NTU turbidity values indicate that post-1992 mean values are significantly greater ($p<0.001$) than pre-1992 values during the non-release season in both storm and non-storm flow conditions. Although post-1992 FTU turbidity values are greater, the difference is not significant during non-release storm flows. However, during release, storm flows, both pre-1992 NTU and FTU mean turbidity values are significantly greater ($p<0.0001$) than post-1992. Although mean NTU turbidity during release, non-storm flow conditions is also greater before 1992, FTU turbidity in the same period indicates that post-1992 mean are significantly higher.

No clear temporal trends in TSS concentrations in Town Lake emerge when data are scrutinized at either the site or watershed levels during the non-release season in both non-storm flow (Figure 4.76) and storm (Figure 4.77) conditions. However, Town Lake release TSS concentrations at a watershed level exhibit slight, though statistically significant, decreasing temporal trends during both non-storm (Figure 4.78) and storm (Figure 4.79) flows at both surface and bottom depths. The decreasing temporal trend in TSS during the release season is also statistically evident at the Basin, Lamar, and Red Bud sites during both storm and non-storm flow conditions.

Figure 4.76 Town Lake Surface TSS During Non-Release, Non-Storm Flow, All Sites

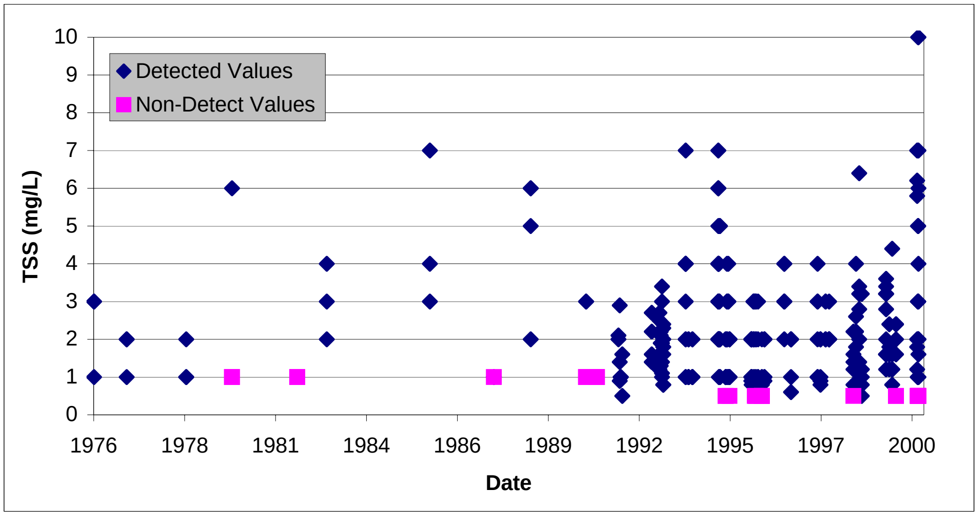


Figure 4.77 Town Lake Surface TSS During Non-Release, Storm Flow, All Sites

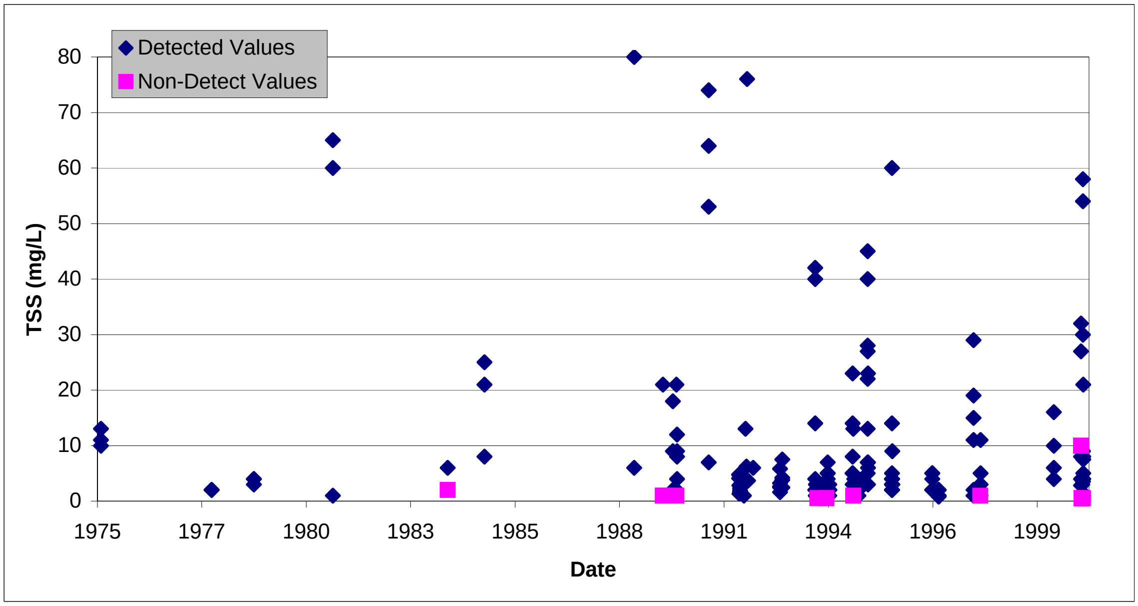


Figure 4.78 Town Lake Surface TSS During Release, Non-Storm Flow, All Sites

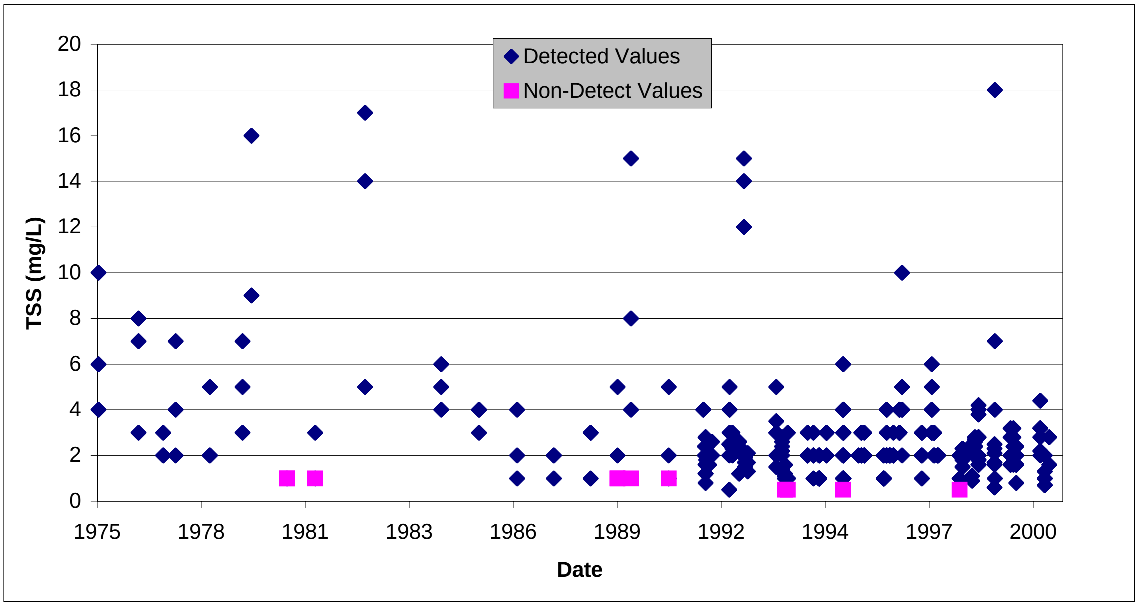
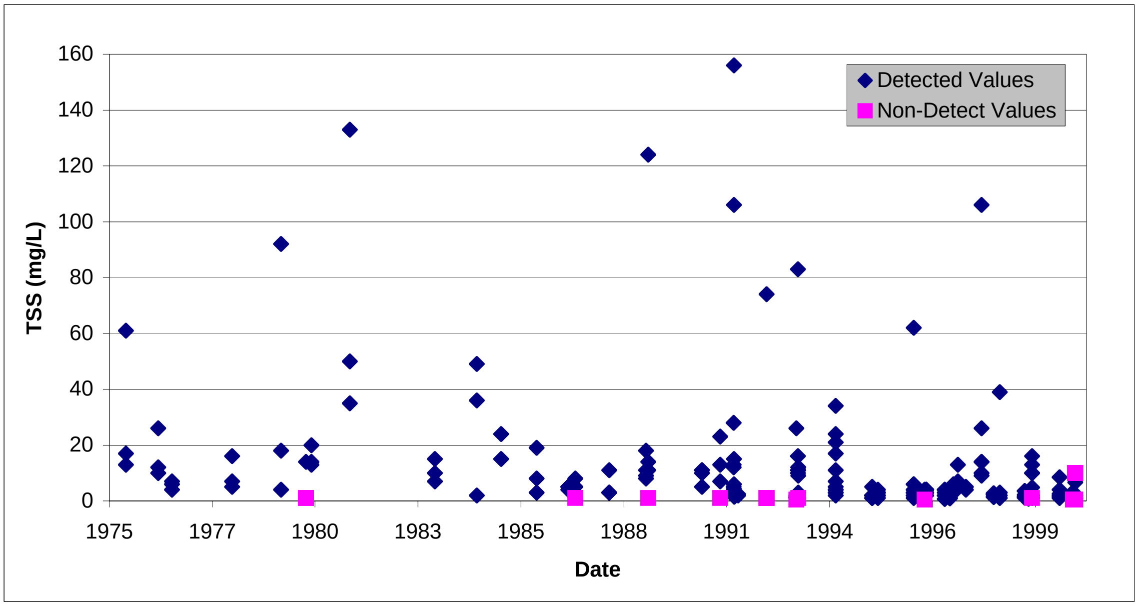


Figure 4.79 Town Lake Surface TSS During Release, Storm Flow, All Sites



Although no clear trends in TSS are observed during the non-release season, Town Lake clarity is potentially decreasing over time as measured by Secchi disk. Town Lake exhibits a statistically significant decreasing temporal trend in transparency during non-release, non-storm flow conditions, not only for all sites composited together, but also for all sites individually, except Red Bud. Red Bud does exhibit a graphically decreasing, though non-significant, trend in Secchi disk depth since 1992. A slight increase in Town Lake Secchi disk depths occurred during non-release, non-storm flow conditions from 1986 through 1996, followed by decreasing values from 1996 to 2000 (Figure 4.80). This pattern is particularly evident at the Lamar and First Street sites (Figure 4.81). The degradation of Town Lake clarity is minor in slope, however, and would not approach zero until 2096 if the current rate of decrease were to remain constant. No trends are evident in Town Lake Secchi disk depths during non-release, storm flow conditions.

Figure 4.80 Town Lake Secchi Disk During Non-Release, Non-Storm Flow, All Sites

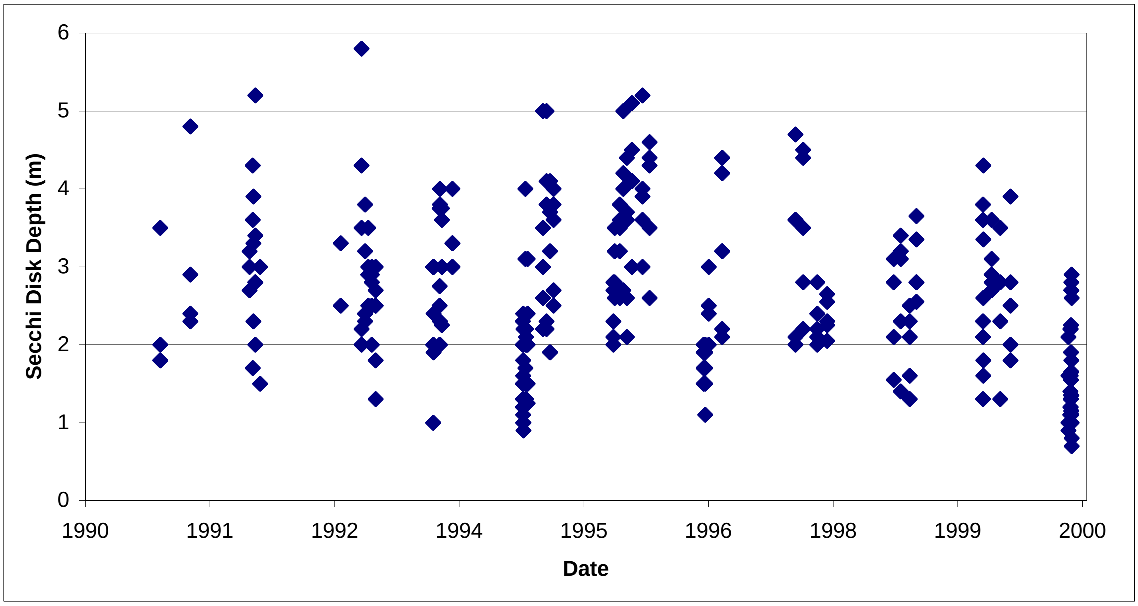
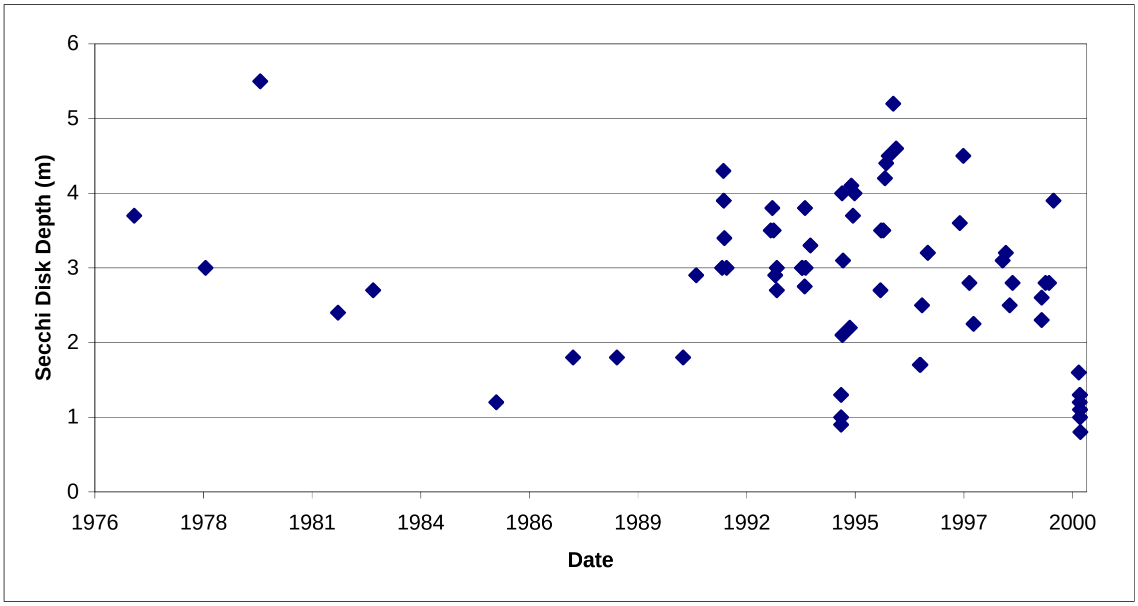


Figure 4.81 Town Lake Secchi Disk Depth at Lamar During Non-Release, Non-Storm Flow



Contrary to decreasing non-release Secchi disk depth measurements, transparency during release conditions appear to be improving in Town Lake, particularly during storm flow. Statistically significant increasing temporal trends in Secchi disk depth measurements occur during release, storm flow conditions for all sites composited together (Figure 4.82) as well as individually for the Basin, Lamar, and Red Bud sites. Data from the Red Bud site are presented individually, not only to verify the observed improvement in Town Lake transparency, but also to exemplify the pattern of declining clarity observed from 1993 to 1997 (Figure 4.83). Although Secchi disk depth measurements in Town Lake are also increasing slightly, though significantly (p = 0.0021), for all sites combined during non-storm, release conditions, a pattern of general decline is shown from 1995 to 1999 (Figure 4.84).

Figure 4.82 Town Lake Secchi Disk Depths During Release, Storm Flow, All Sites

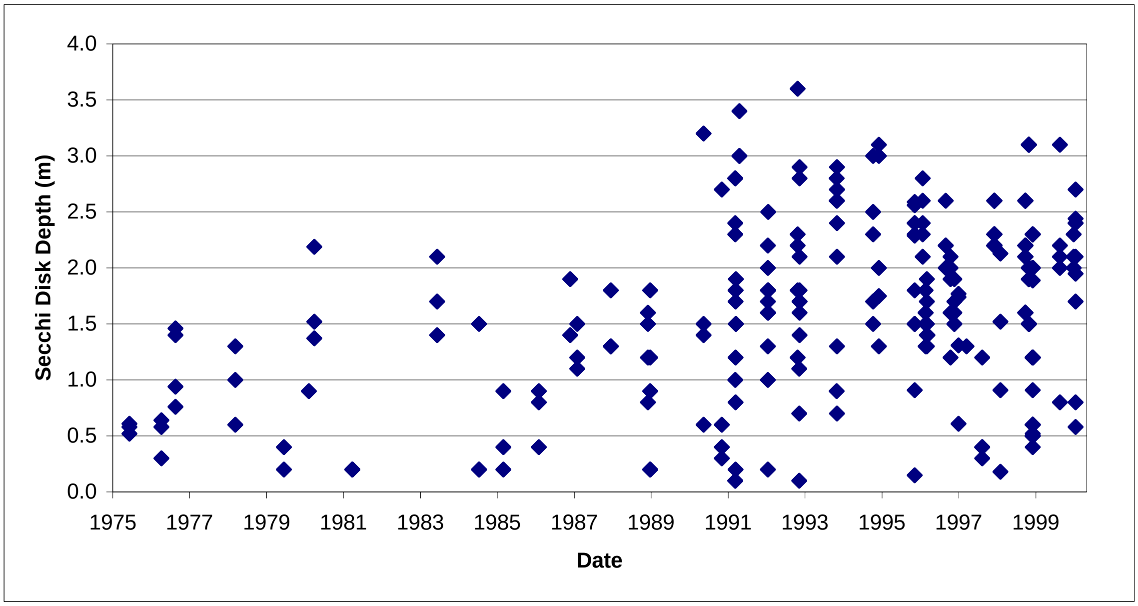


Figure 4.83 Town Lake at Red Bud Secchi Disk Depths During Release, Storm Flow

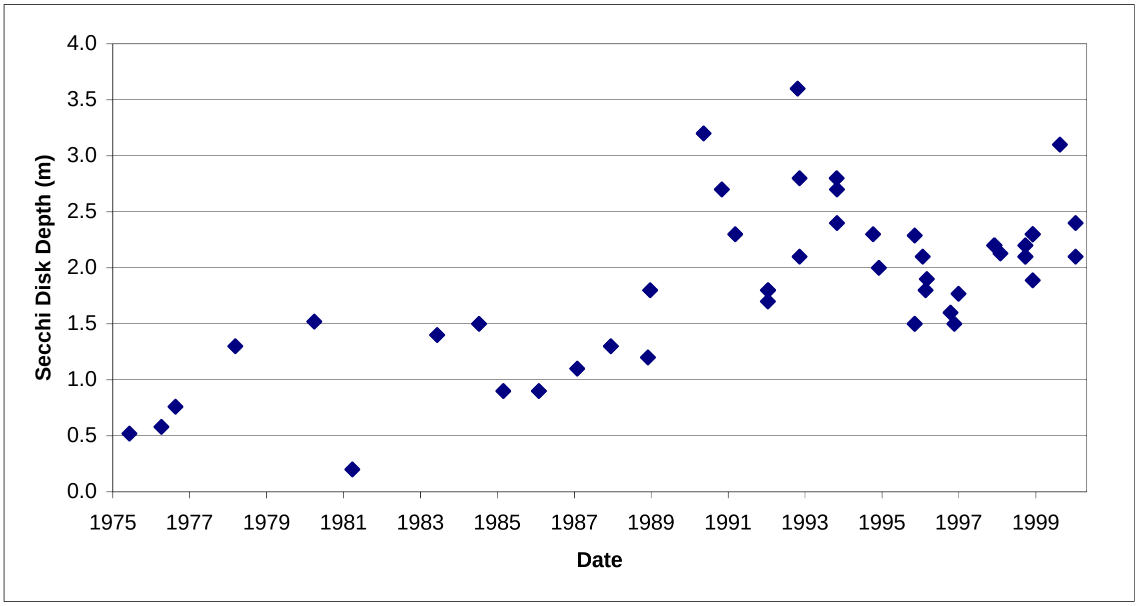
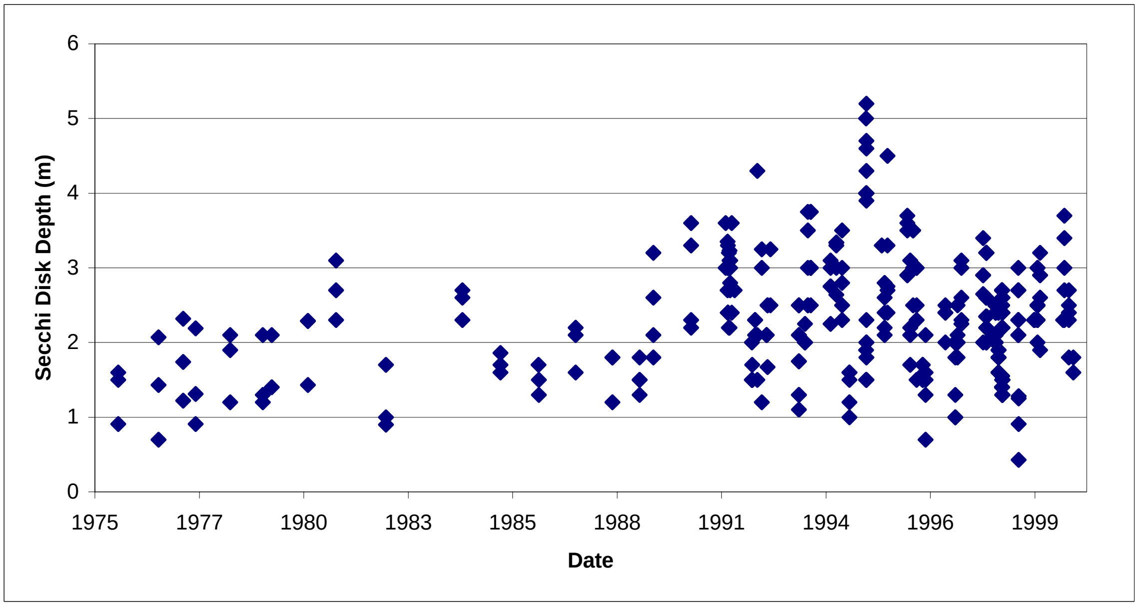


Figure 4.84 Town Lake Secchi Disk Depths During Release, Non-Storm Flow, All Sites



Town Lake VSS concentrations are significantly decreasing with time during the release season in non-storm flow conditions for all sites combined at both surface and bottom depths (Figure 4.85). No clear trends are evident in Town Lake VSS during non-release, non-storm flow conditions (Figure 4.86), although spikes in VSS levels occurred in October of 1995 and 2000 during periods of large algae blooms.

A clear pattern in Town Lake VSS was shown during storm flow conditions, evident in both release and non-release seasons at surface and bottom depths when data from all sites are combined (Figure 4.87), in which VSS concentrations increase from 1975 to peak storm values in 1981, followed by statistically significant decreasing trends from 1981 to 2000 for all storm conditions.

Figure 4.85 Town Lake VSS During Release, Non-Storm Flow, All Sites and Depths

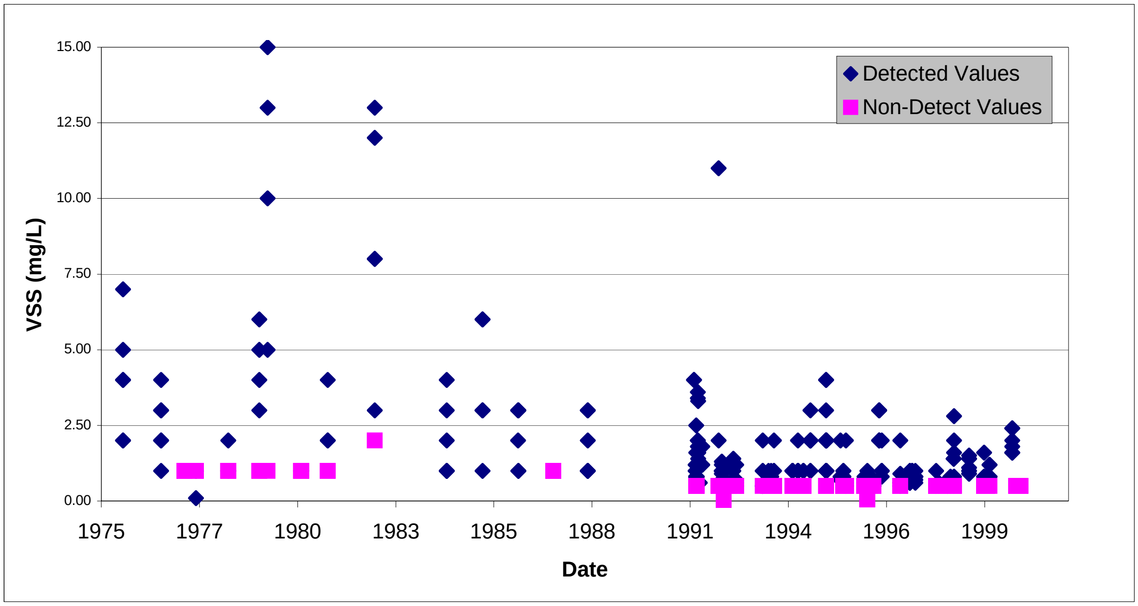


Figure 4.86 Town Lake VSS During Non-Release, Non-Storm Flow, All Sites and Depths

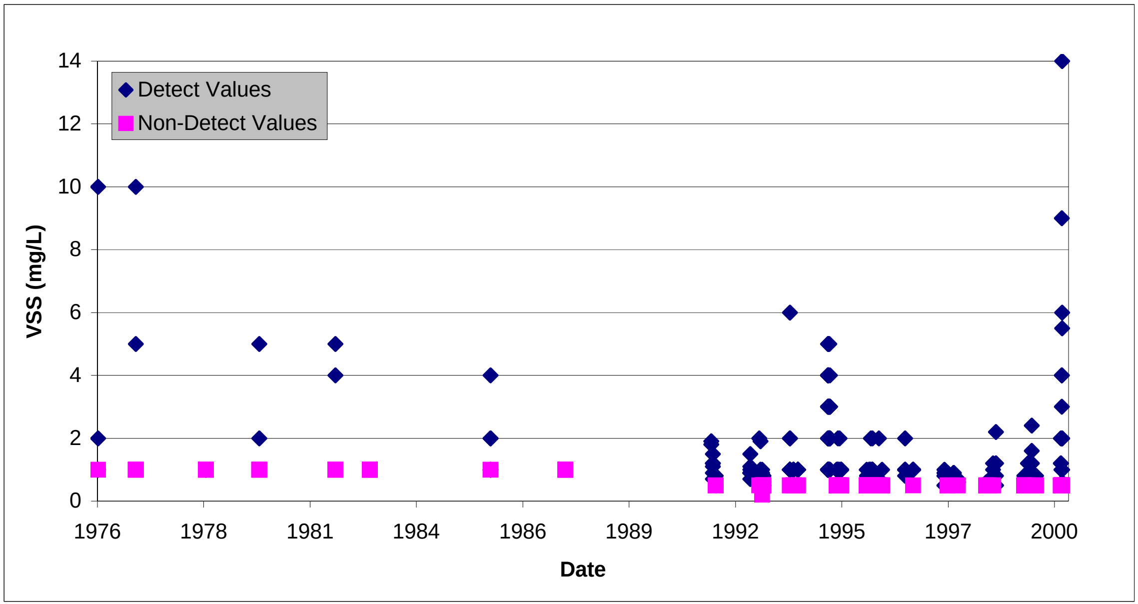
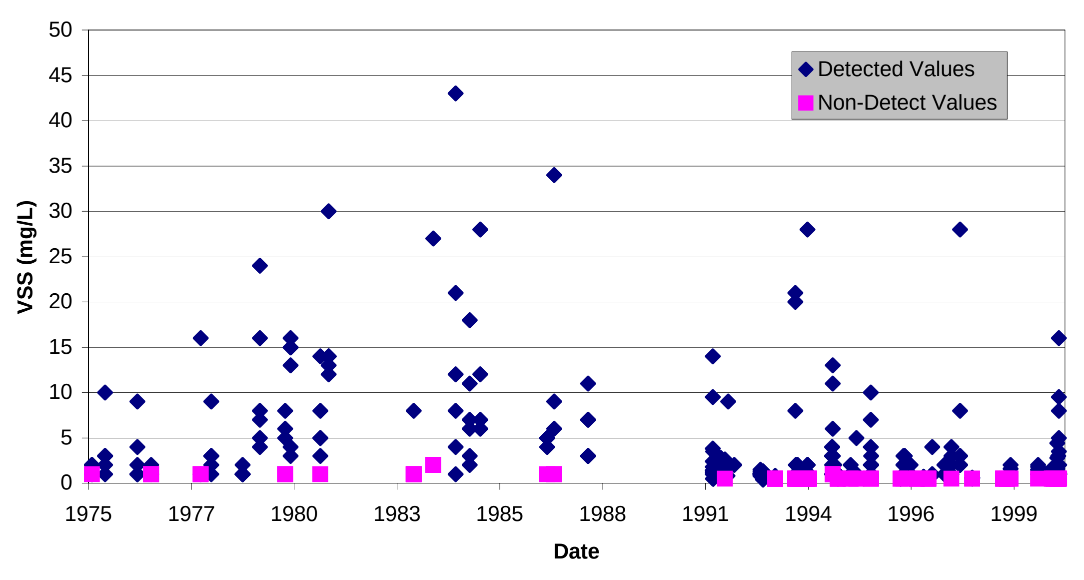


Figure 4.87 Town Lake VSS During Storm Flow, All Sites and Depths



4.4.1.7 Monitoring Recommendations

Sample frequency analysis was performed to yield the minimum significant detectable difference based on current estimates of summary statistics and sampling rates projected into the future for one- and five-year periods (Table 4.15).

Table 4.15 Minimum Significant Detectable Difference in Watershed Mean Solids Concentrations (as a value and percentage of current mean) is Sampling Continued at Current Rates Over Specified Time Periods

PARAM (mg/L)	**Non-Release**				**Release**			
	Non-Storm		**Storm**		**Non-Storm**		**Storm**	
	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 1 yr
Secchi Disk (m)	0.531 (21)	0.234 (9)	0.645 (32)	0.285 (14)	0.369 (16)	0.163 (7)	0.400 (24)	0.177 (10)
TSS	1.613 (59)	0.712 (26)	20.17 (175)	8.898 (77)	2.438 (65)	1.076 (29)	15.71 (114)	6.934 (50)
Turbidity (NTU)	1.555 (39)	0.686 (17)	4.228 (63)	1.865 (28)	0.897 (29)	0.396 (13)	6.784 (87)	2.994 (38)
VSS	0.673 (58)	0.297 (25)	1.773 (91)	0.782 (40)	1.028 (76)	0.454 (34)	3.19 (87)	1.408 (39)

The high variability in suspended solid and clarity estimates in Town Lake, though potentially related to inaccuracies in the storm/non-storm flow separation process, in combination with the potentially degrading conditions observed over time, provide no opportunities for monitoring reduction at this time. However, unless further characterization of the estimated organic content of suspended sediment is desired, monitoring of VSS could be reduced to more periodic screening efforts.

4.4.2 Dissolved Solids and Ions

The parameter total dissolved solids (TDS), historically known as total filterable residue, refers to the amount of matter dissolved in water that will pass through a filter with a pore size typically less than or equal to 2 μm (APHA 1992). Conductivity, a relative of TDS, refers to the ability of water to conduct an electric current and also reflects the dissolved ionic content of water (APHA 1992). COA-ERM measures conductivity in the field as an indicator of Town Lake TDS concentrations. Some of the principal ions dissolved in water that constitute the TDS parameter are reviewed in this section; they are chloride, sulfate, sodium, calcium, and magnesium.

Drinking water with high amounts of dissolved solids may have a bad smell and poor taste and may result in increased drinking water treatment costs (USEPA 1987). Concentrations of dissolved solids above 500 mg/L may induce physiological effects, including diarrhea, in human consumers (APHA 1992; USEPA 1987). Water with high dissolved solute concentrations may also increase corrosion of pipes and be unsuitable for agricultural purposes (USEPA 1987). Although freshwater fish do have a limit of exposure to dissolved solids in water, these limits are extremely high, with some freshwater fish surviving 10,000 mg/L of dissolved solids (USEPA 1987), well above even extreme Town Lake levels and TNRCC (2000) screening criteria (Table 4.16).

Table 4.16 TNRCC 2000 Dissolved Solid and Ion Screening Levels in Reservoirs*

Parameter	Screening Level (mg/L)
TDS	400
Chloride (Cl^{-1})	75
Sulfate (SO_4^{-2})	75

*Note that these are segment-specific criteria applying only to Town Lake

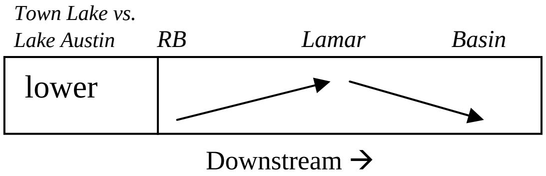
4.4.2.1 Summary of Results

The following figures present graphical summaries of statistical analyses by parameter for dissolved solids and ions in Town Lake.

Figure 4.88 Graphical Summary of Town Lake Alkalinity Results

SPATIAL

Location



Depth

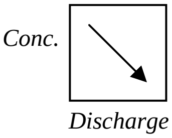
Surface

No depth data

Bottom

Conc →

FLOW/SEASONALITY



Storm flows highest in: Non-Release

Non-Storm flows highest in: Non-Release

Max conc. in: NR, NS

Post-Storm

Conc

No clear pattern *NR*

No clear pattern *R*

1 3 # Days after Storm

Monthly

No clear pattern

Jan Dec

TEMPORAL

Annual % Exceedance of TNRCC Criteria

No applicable screening criteria

Overall temporal trend

Time →

Temporal Regression

	SURFACE				BOTTOM			
	Release		*Non-Release*		*Release*		*Non-Release*	
	NS	S	NS	S	NS	S	NS	S
Town Lake								
Lake Austin								

Conc

Time →

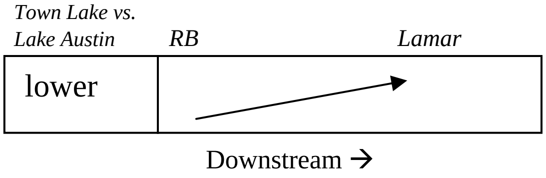
***Comments*:**
Site variability decreased in release. Influenced by Barton Springs inputs (alk = f(Ca^{2+})).

NR = Non-Release   R = Release
NS = Non-Storm   S = Storm
Blank cells indicate no statistically significant pattern

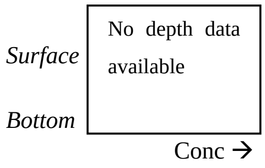
Figure 4.89 Graphical Summary of Town Lake Calcium Results

SPATIAL

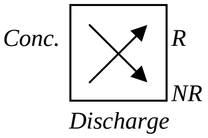
Location



Depth



FLOW/SEASONALITY

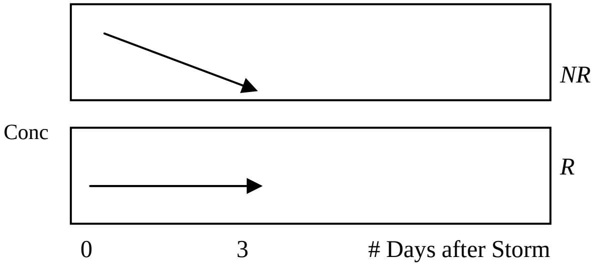


Storm flows highest in: Non-Release

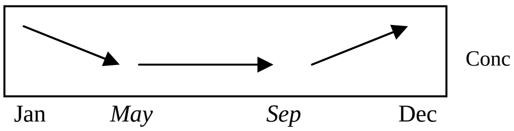
Non-Storm flows highest in: Non-Release

Max conc. in: Non-Release

Post-Storm



Monthly

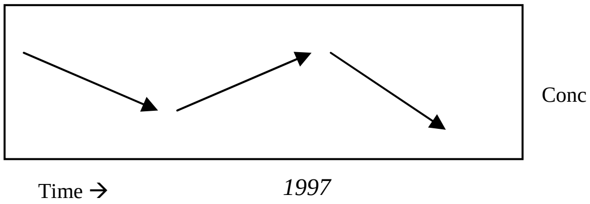


TEMPORAL

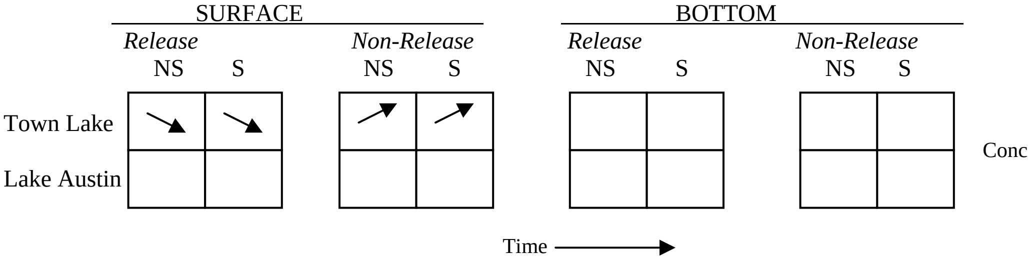
Annual Means / TNRCC Criteria

No applicable criteria

Overall temporal trend



Temporal



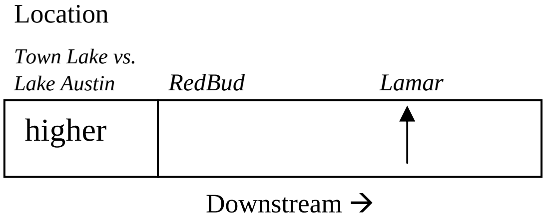
Comments:

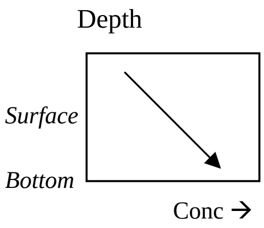
Little difference between storm and non-storm averages.

NR = Non-Release   R = Release
NS = Non-Storm   S = Storm
Blank cells indicate no statistically significant pattern

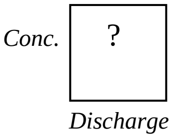
Figure 4.90 Graphical Summary of Town Lake Conductivity Results

SPATIAL





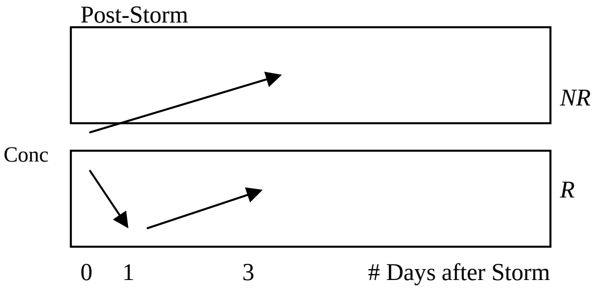
FLOW/SEASONALITY

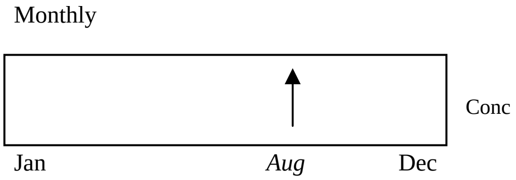


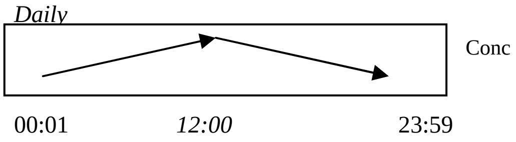
Storm flows highest in: Non-Release

Non-Storm flows highest in: Release

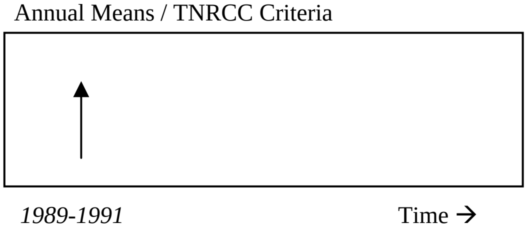
Max conc. in: Non-storm

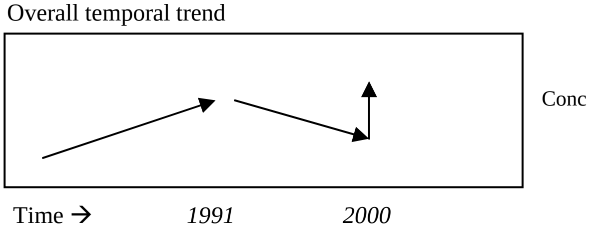


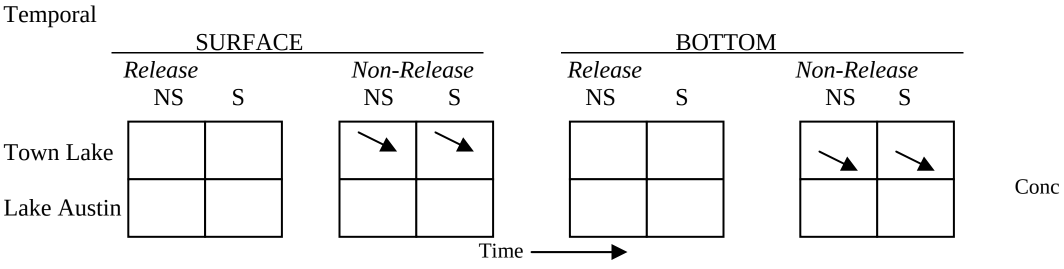




TEMPORAL







Comments:

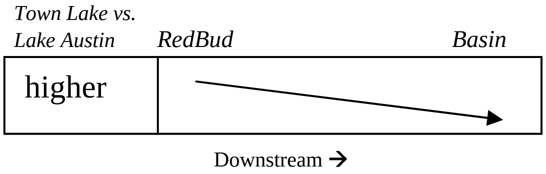
Basin max monthly conductivity in December-February; Lamar max monthly conductivity in December and January. Little variation in daily conductivity at Basin bottom. Lamar daily conductivity nearly constant except in July – September. Red Bud conductivity increasing over time.

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

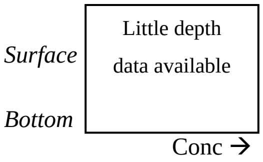
Figure 4.91 Graphical Summary of Town Lake Chloride Results

SPATIAL

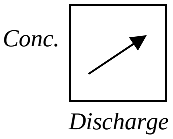
Location



Depth



FLOW/SEASONALITY

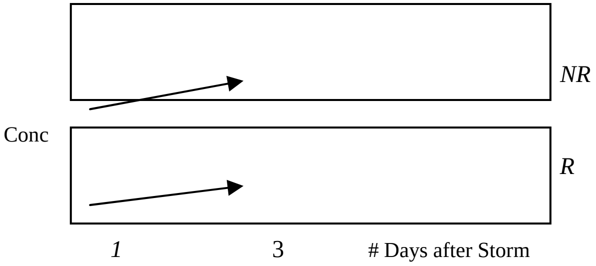


Storm flows highest in: No difference

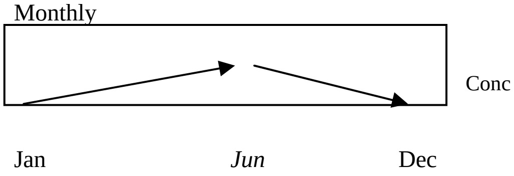
Non-Storm flows highest in: Release

Max conc. in: NR, NS

Post-Storm

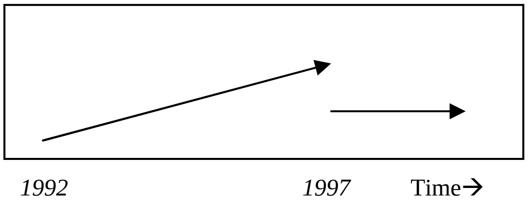


Monthly

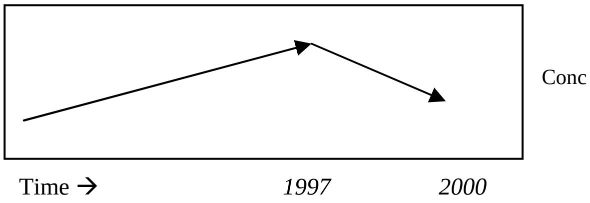


TEMPORAL

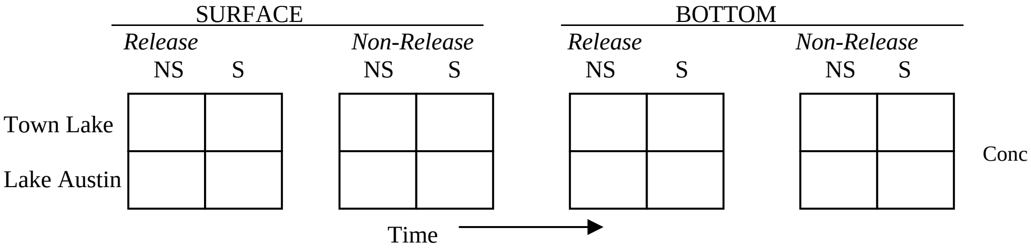
Annual % Exceedance of TNRCC Criteria



Overall temporal trend



Temporal



***Comments*:**
No correlation in monthly chloride with rain, Barton Creek inflows, or Town Lake flow.

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

Figure 4.92 Graphical Summary of Town Lake Fluoride Results

SPATIAL

Location

Town Lake vs. *Lake Austin*	*RB*	*Lamar*
Higher*		

**higher during NR, NS*

Depth

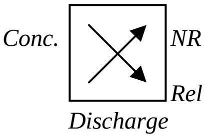
Surface

Little depth data available

Bottom

Conc →

FLOW/SEASONALITY



Storm flows highest in: Release

Non-Storm flows highest in: Release

Max conc. in: Release

Post-Storm

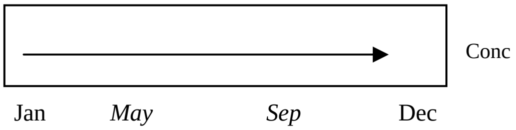
No clear pattern *NR*

Conc

No clear pattern *R*

0 3 # Days after Storm

Monthly



TEMPORAL

Annual Means / TNRCC Criteria

No applicable screening criteria

Time →

Overall temporal trend

No clear temporal trend

Conc

Time →

Temporal

	SURFACE				BOTTOM				
	Release		*Non-Release*		*Release*		*Non-Release*		
	NS	S	NS	S	NS	S	NS	S	
Town Lake									Conc
Lake Austin									

Time →

Comments:

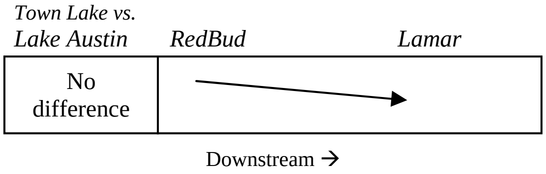
Data only at Lamar and Lake Austin.

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

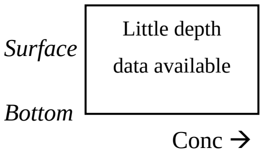
Figure 4.93 Graphical Summary of Town Lake Magnesium Results

SPATIAL

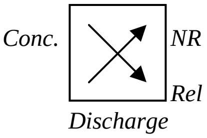
Location



Depth



FLOW/SEASONALITY

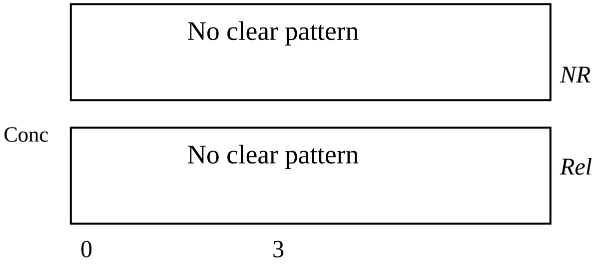


Storm flows highest in: Release

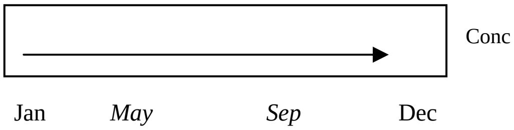
Non-Storm flows highest in: No diff.

Max conc. in: Non-storm

Post-Storm



Monthly

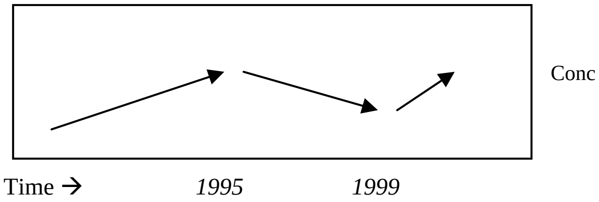


TEMPORAL

Annual Means / TNRCC Criteria

No applicable screening criteria

Overall temporal trend



Temporal

SURFACE

	Release NS	*Release* S	*Non-Release* NS	*Non-Release* S
Town Lake	↗	↗		→
Lake Austin				

Conc

Time →

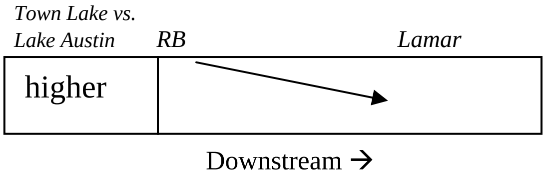
Comments:

NR = Non-Release   R = Release
NS = Non-Storm   S = Storm
Blank cells indicate no statistically significant pattern

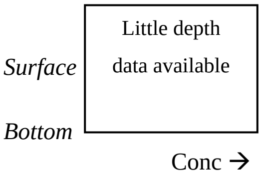
Figure 4.94 Graphical Summary of Town Lake Sodium Results

SPATIAL

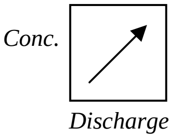
Location



Depth



FLOW/SEASONALITY

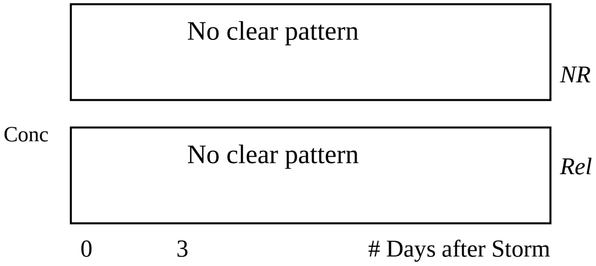


Storm flows highest in: No diff.

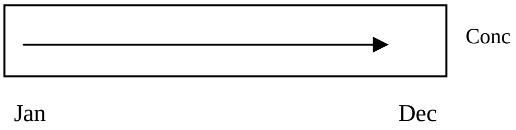
Non-Storm flows highest in: No diff.

Max conc. in: Release, NS

Post-Storm



Monthly

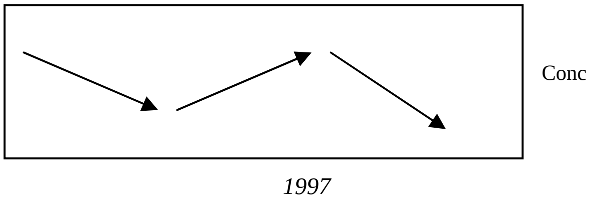


TEMPORAL

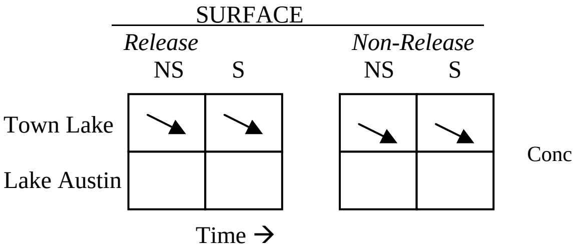
Annual % Exceedance of TNRCC Criteria

No applicable screening criteria

Overall temporal trend



Temporal



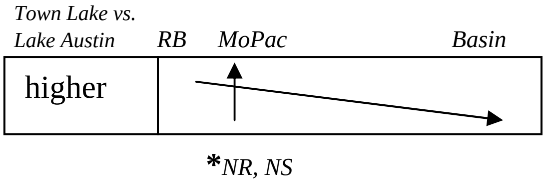
Comments:

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

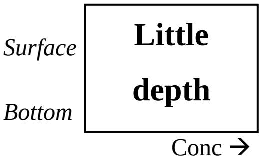
Figure 4.95 Graphical Summary of Town Lake Sulfate Results

SPATIAL

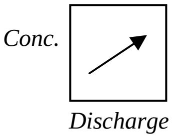
Location



Depth



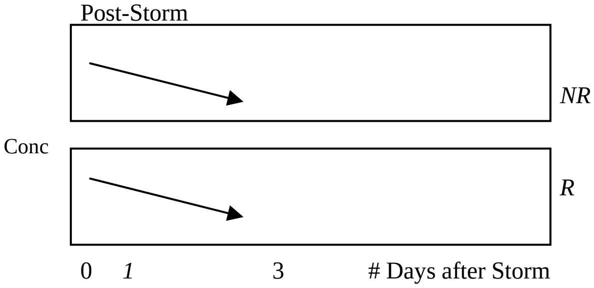
FLOW/SEASONALITY

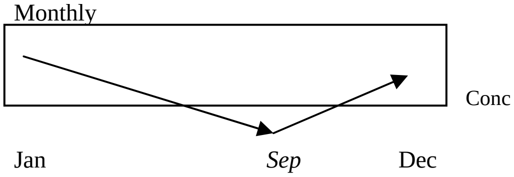


Storm flows highest in: Non-Release

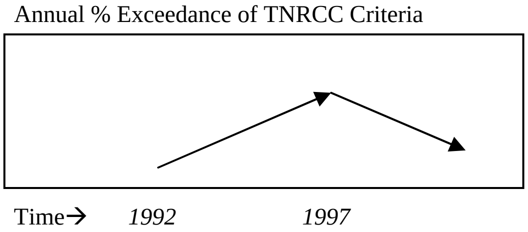
Non-Storm flows highest in: Non-Release

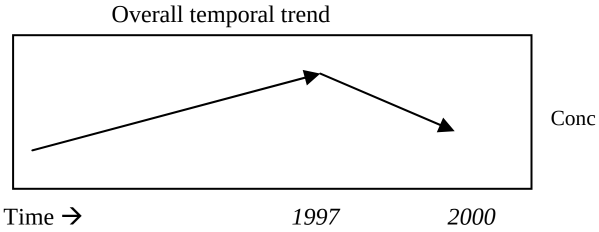
Max conc. in: Non-release

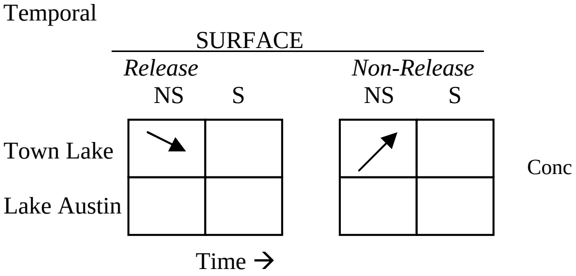




TEMPORAL







***Comments*:**
No correlation in monthly sulfate with rain, Barton Creek inflows, or Town Lake flow.

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

Although Lake Austin is expected to be less impacted by urbanization than Town Lake, Lake Austin maintains higher mean chloride, sulfate, and sodium concentrations. Chloride, sulfate, and sodium also yield direct relationships with Lake Austin discharge through Tom Miller Dam into Town Lake. Calcium concentrations are directly related to Lake Austin discharge during the release season, but are inversely correlated with Tom Miller discharge into Town Lake during the non-release season. Opposite patterns of direct correlation with inflows during non-release and inverse correlation during release are observed for fluoride and magnesium.

Alkalinity and conductivity show spikes in concentrations at the Lamar site, indicating strong Barton Springs/Barton Creek loading influences. Alkalinity and dissolved ions (chloride, conductivity, magnesium, and sodium) yield higher mean non-storm flow concentrations than storm concentrations.

Town Lake may be increasing the concentrations of alkalinity (and calcium). Conversely, Town Lake appears to be decreasing the concentrations of chloride, sodium, and sulfate in Colorado River water from initial Lake Austin input concentrations to discharge into the Colorado River at Longhorn Dam.

Chloride, sodium, and sulfate yield increasing temporal trends in concentration from approximately 1992 to 1997, although these ions exhibited reduced and more stable concentrations from 1998 to 2000. Town Lake conductivity and calcium (during the release season) generally appear to be improving over time in the recent past.

Comparison of data in Town Lake to 2000 TNRCC screening criteria in water reveal that Town Lake is of “no concern” for sulfate and TDS, according to official assessment methodologies. Although Town Lake chloride concentrations appeared to be steadily approaching the screening criteria from 1992 through 1997, Town Lake chloride exceedances have been consistently of “no concern” from 1997 to 2000.

Chlorides and sulfates have been well characterized by previous sampling efforts, although monitoring should most likely not be reduced as TNRCC screening criteria exist and further tracking of the unusual temporal trends observed for these parameters is necessary.

4.4.2.2 Spatial Distribution

Total alkalinity shows clear increasing trends in mean site concentrations from Lake Austin to Lamar, followed by decreasing concentrations from Lamar to the Basin for all release and flow conditions. Mean site alkalinity at Lamar is consistently greater than all other sites, although this difference is significant only during non-release, non-storm flows (Figure 4.96). Note that median total alkalinity in Barton Springs groundwater discharge is approximately 260 mg/L as $CaCO_3$, well above even mean site levels at Lamar in Town Lake. Not only are mean site alkalinity levels significantly greater during non-release seasons than in release seasons during both storm and non-storm flows, but also variability in mean site alkalinity is decreased during the release season (Figure 4.97).

Figure 4.96 Mean Site Total Alkalinity by Season and Flow Type, All Depths

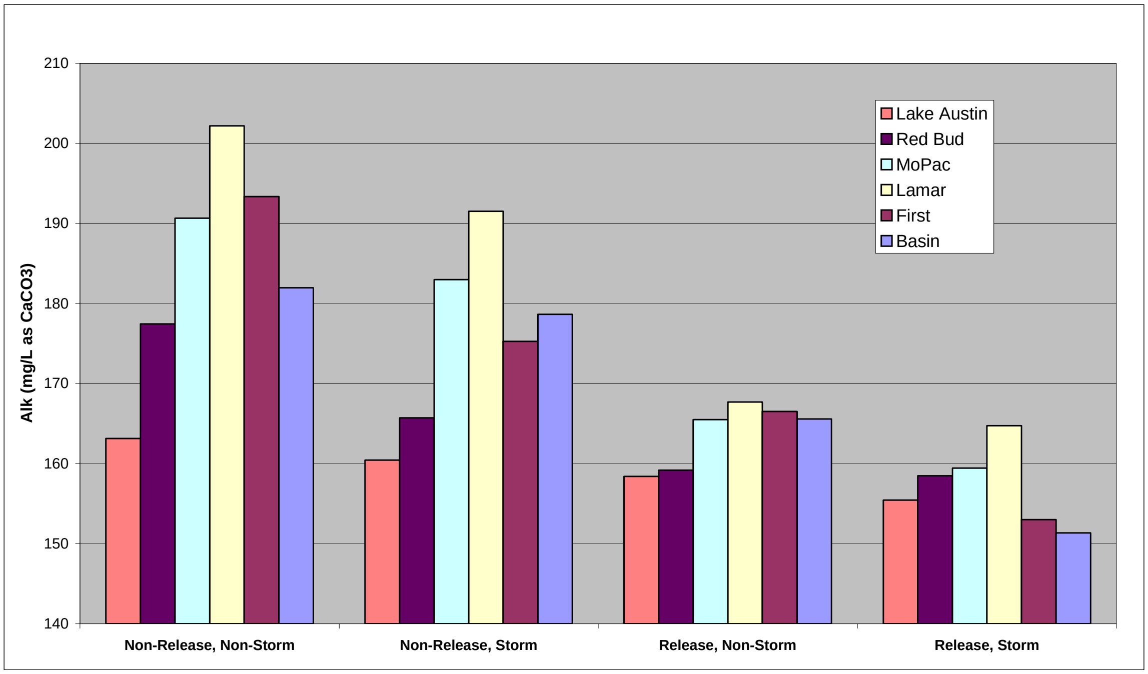
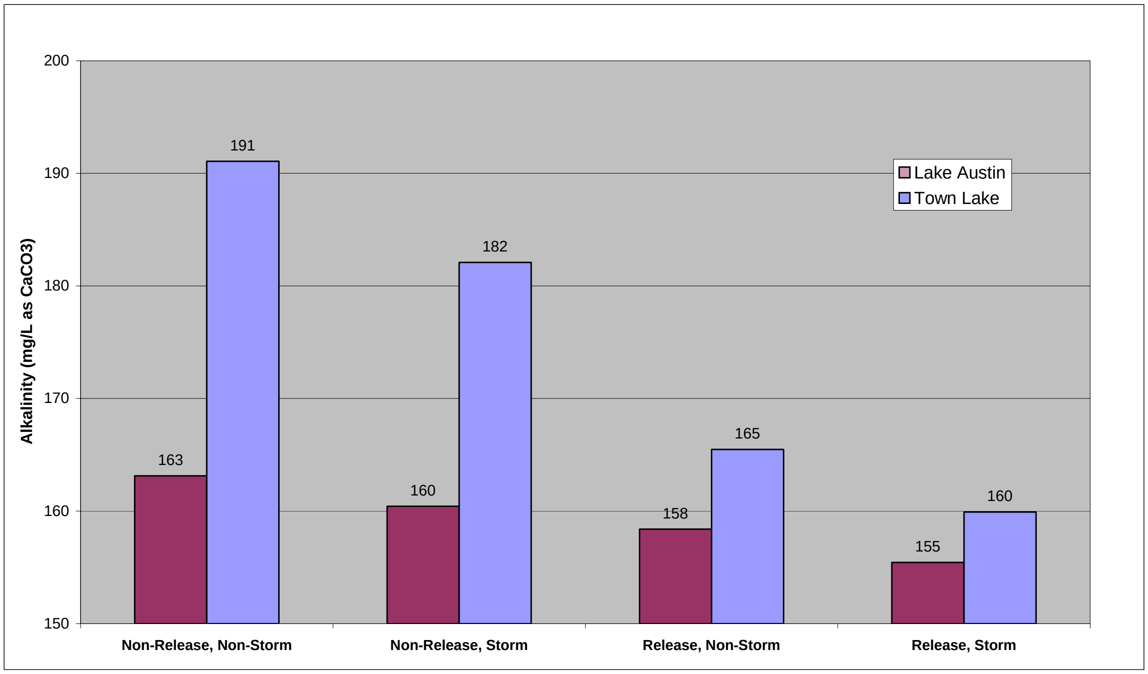


Figure 4.97 Mean Watershed Total Alkalinity by Season and Flow Type, All Depths



Similar to total alkalinity, mean site calcium concentrations generally increase from Lake Austin to Lamar in Town Lake (Figure 4.98) during all storm and release conditions, although a lack of data downstream of the Lamar site prevents further comparison of Lake Austin concentrations to Town Lake discharge levels. Mean concentrations at Lamar are significantly greater than all other sites during the non-release season in both storm and non-storm flows. Average calcium concentrations in Town Lake are significantly greater in non-release during both storm and non-storm flows, though little difference is observed between storm and non-storm flow concentrations within either season (Figure 4.99). Mean calcium in Town Lake is always significantly greater than mean calcium in Lake Austin.

Figure 4.98 Mean Calcium Site Concentrations by Season and Flow Type, All Depths

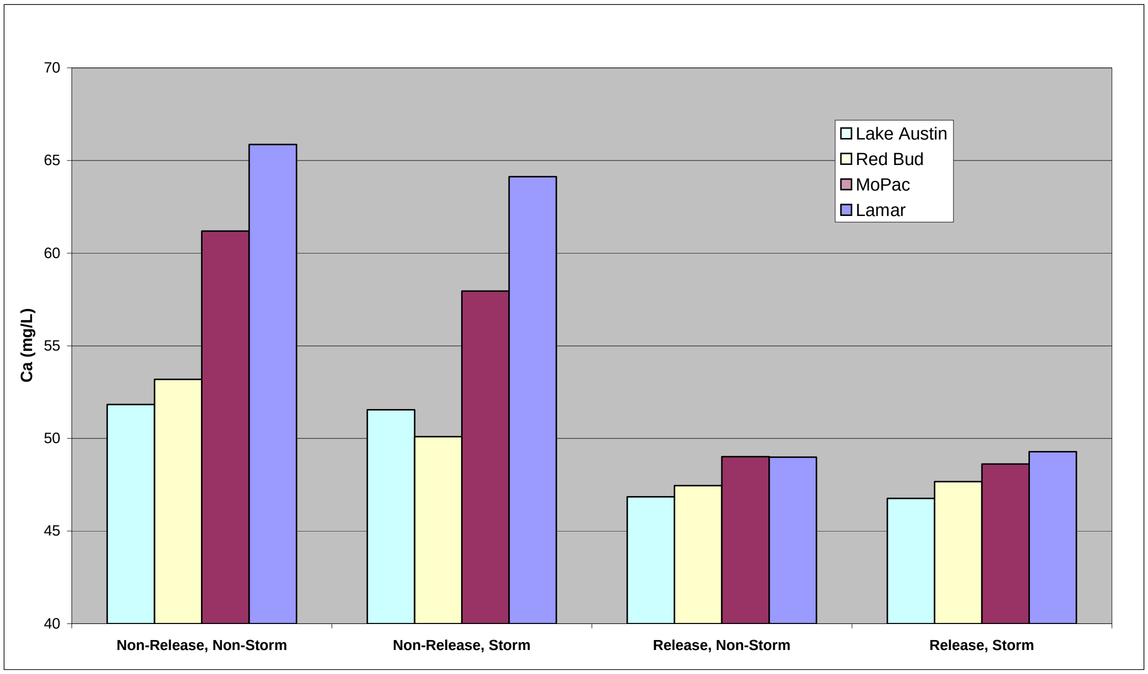
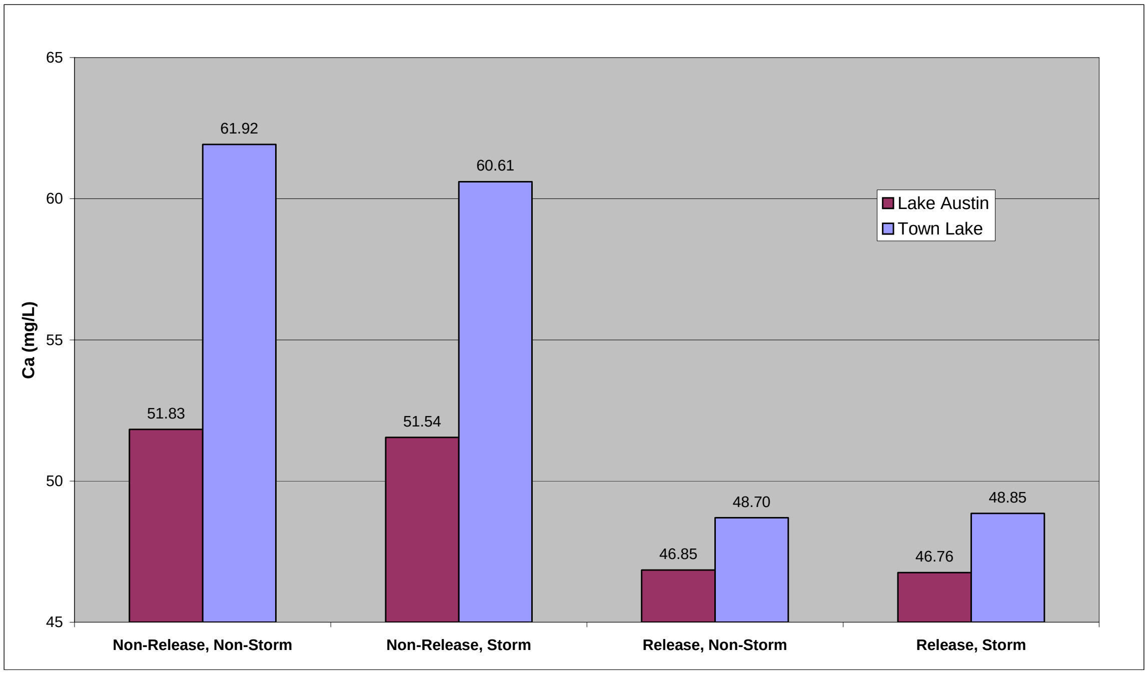


Figure 4.99 Mean Calcium Watershed Concentrations by Season and Flow Type, All Depths



Mean site chloride levels show consistently decreasing longitudinal trends during all storm and release conditions (Figure 4.100). Lake Austin exhibits significantly greater mean chloride concentrations during all storm and release conditions than Town Lake (Figure 4.101). Although Town Lake exhibits significantly greater chloride levels in the release season than the non-release season during non-storm flow conditions, no significant difference exists between seasons during storm flows. Although minimal difference is evident between mean Town Lake storm and non-storm chloride averages during the non-release season, the variation between flow types is more prevalent during the release season.

Figure 4.100 Mean Chloride Site Concentrations by Season and Flow Type, All Depths

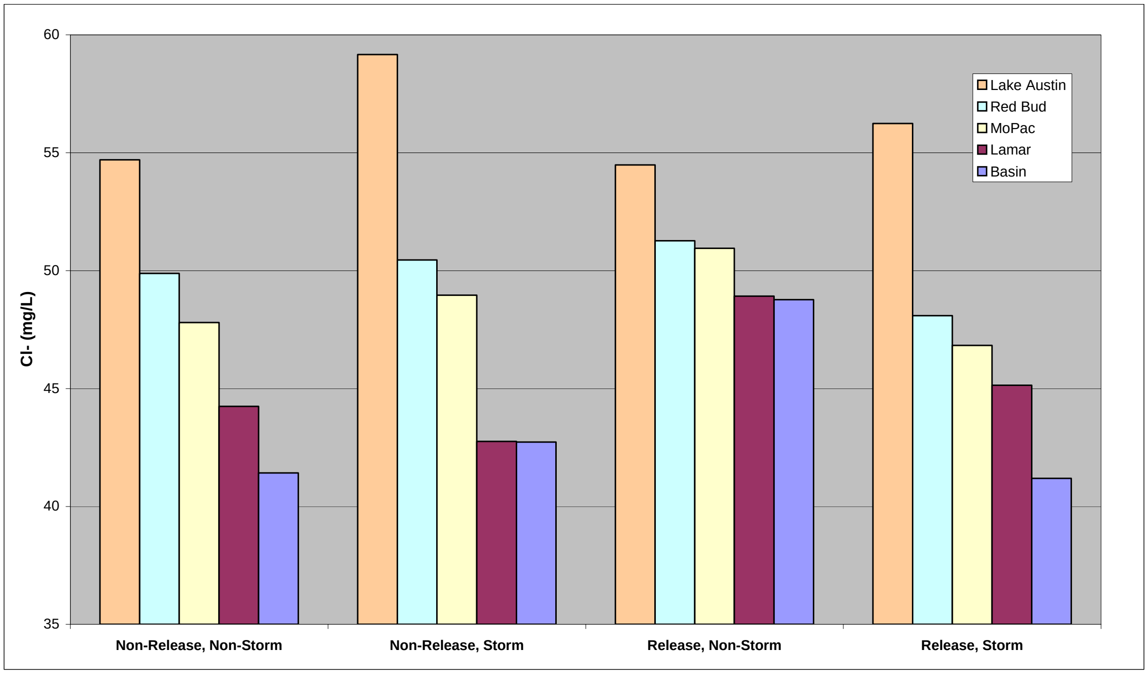
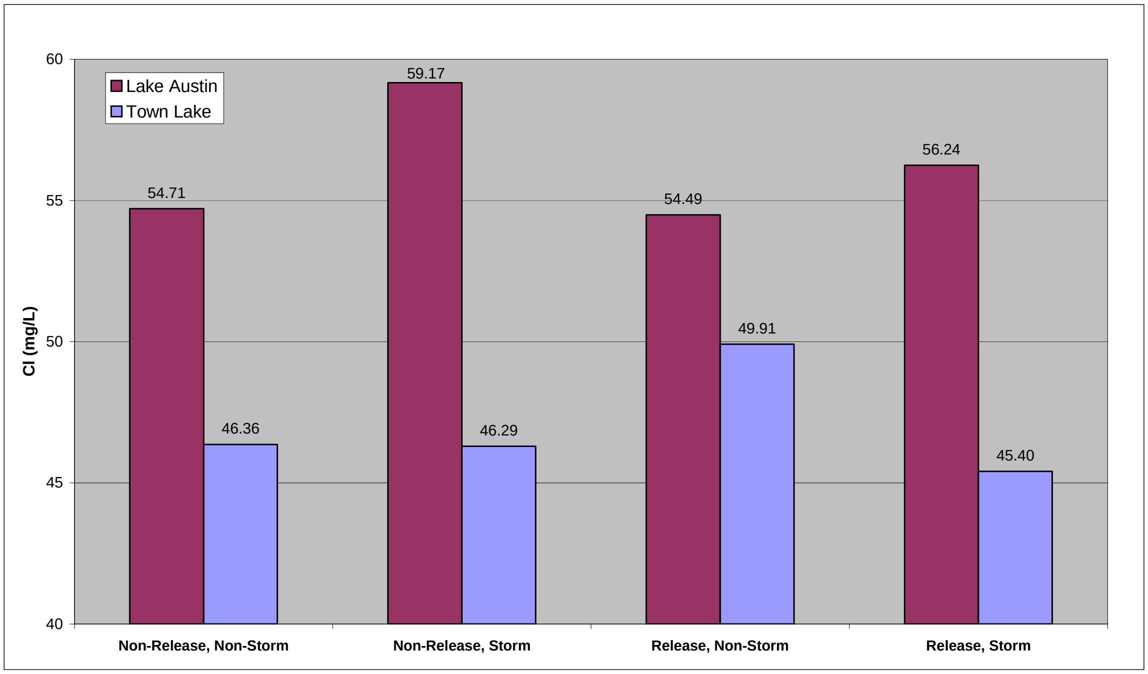
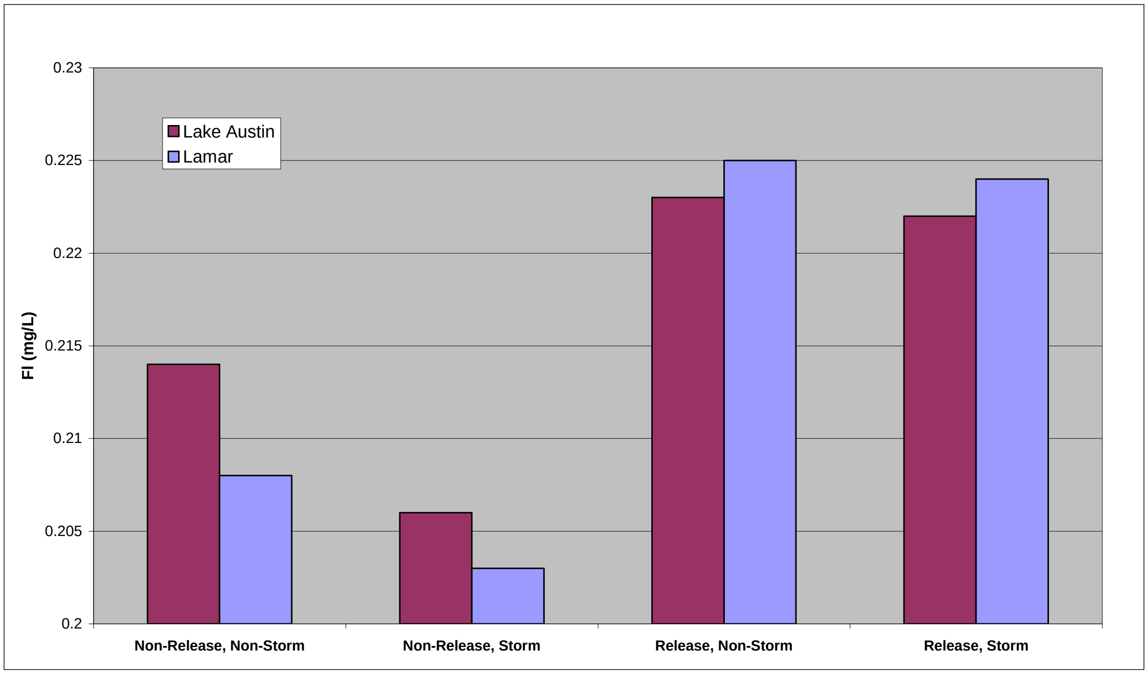


Figure 4.101 Mean Chloride Watershed Concentrations by Season and Flow Type, All Depths



Fluoride data are available only at the Lamar and Lake Austin sites (as fluoride is regularly measured only at the intakes of the water treatment plants) and within a limited range of only 1998 to 2000. However, existing data show that little difference exists between Town Lake and Lake Austin fluoride levels, with mean Lake Austin concentrations only significantly greater than Town Lake concentrations during non-release, non-storm flow conditions. At the Lamar site, release concentrations are significantly greater than non-release concentrations during both storm and non-storm flows (Figure 4.102).

Figure 4.102 Mean Fluoride Sites Concentrations by Season and Flow Type



Although mean conductivity levels at First Street are significantly less than all other sites during storm flow conditions in both the release and non-release season, little statistically significant difference occurs between Town Lake sites during storm-impacted flows (Figure 4.103). Lake Austin mean storm conductivity levels are significantly higher than average Town Lake conductivity during storm flow in both the release and non-release season. Within Town Lake during storm flows, mean conductivity is significantly less during the release season than the non-release season. During non-storm flow conditions, however, Town Lake conductivity is significantly higher in the release season, indicating that conductivity levels are more variable during the summer months. Mean conductivity levels at Lamar are significantly greater than all other Town Lake sites during non-release, non-storm flow, and significantly higher than all sites except the Basin during release, non-storm flow conditions. Although no statistically significant difference exists between Town Lake and Lake Austin conductivity levels during non-release, non-storm flow conditions, Town Lake average conductivity is significantly greater than Lake Austin during release, non-storm flows (Figure 4.104).

Figure 4.103 Mean Site Conductivity by Season and Flow Type, All Depths

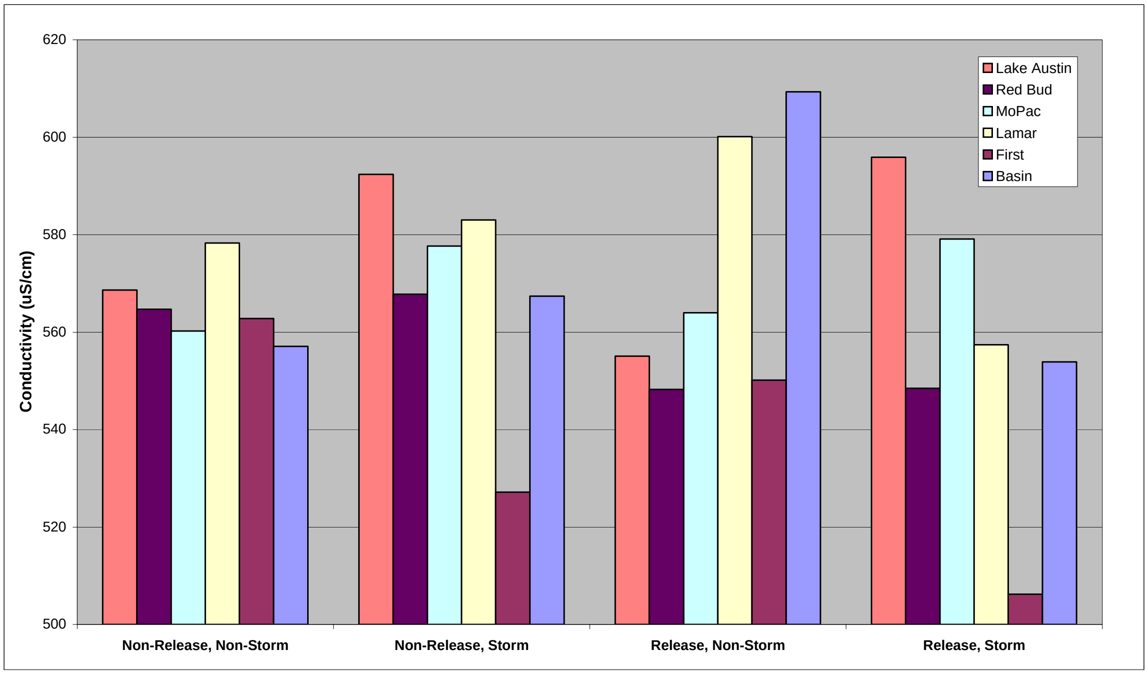
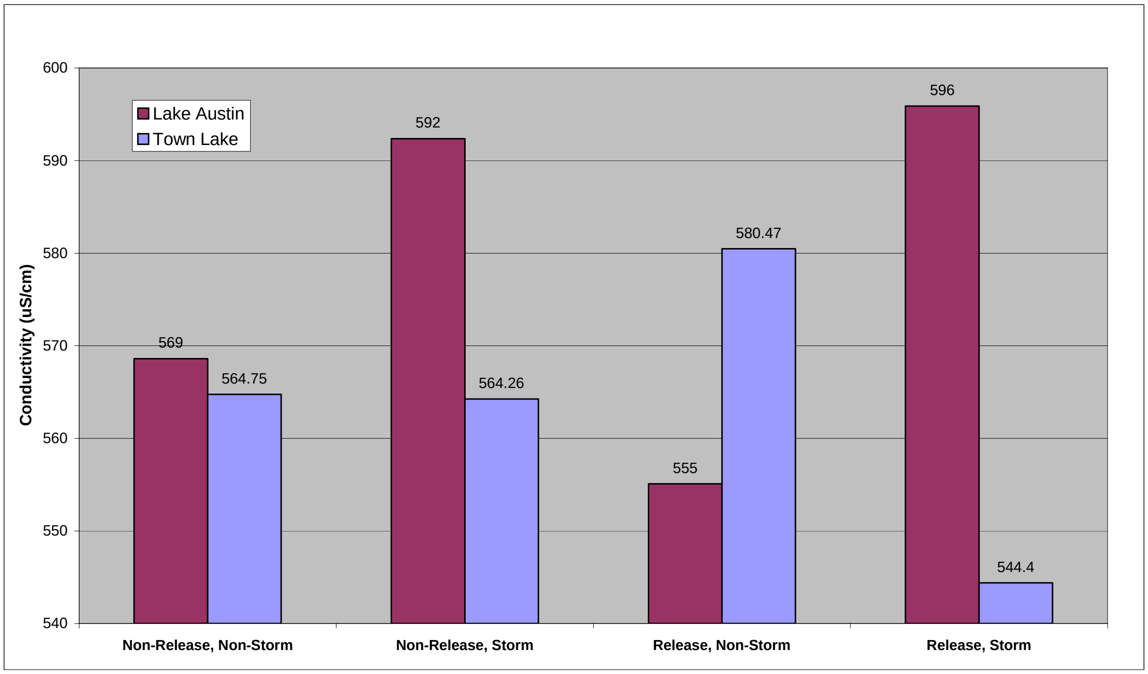


Figure 4.104 Mean Watershed Conductivity by Season and Flow Type, All Sites and Depths



No statistically significant difference within Town Lake sites, or between Town Lake and Lake Austin watershed mean magnesium concentrations, exists during the release season in either storm or non-storm flows. During the non-release season, concentrations at Red Bud and MoPac are significantly greater than concentrations at Lamar in both storm and non-storm flow conditions (Figure 4.105). Within Town Lake, no difference occurs between release and non-release total magnesium concentrations in non-storm flow, although release concentrations are significantly greater than non-release concentrations during storm flow (Figure 4.106).

Figure 4.105 Mean Magnesium Site Concentrations by Season and Flow Type, All Depths

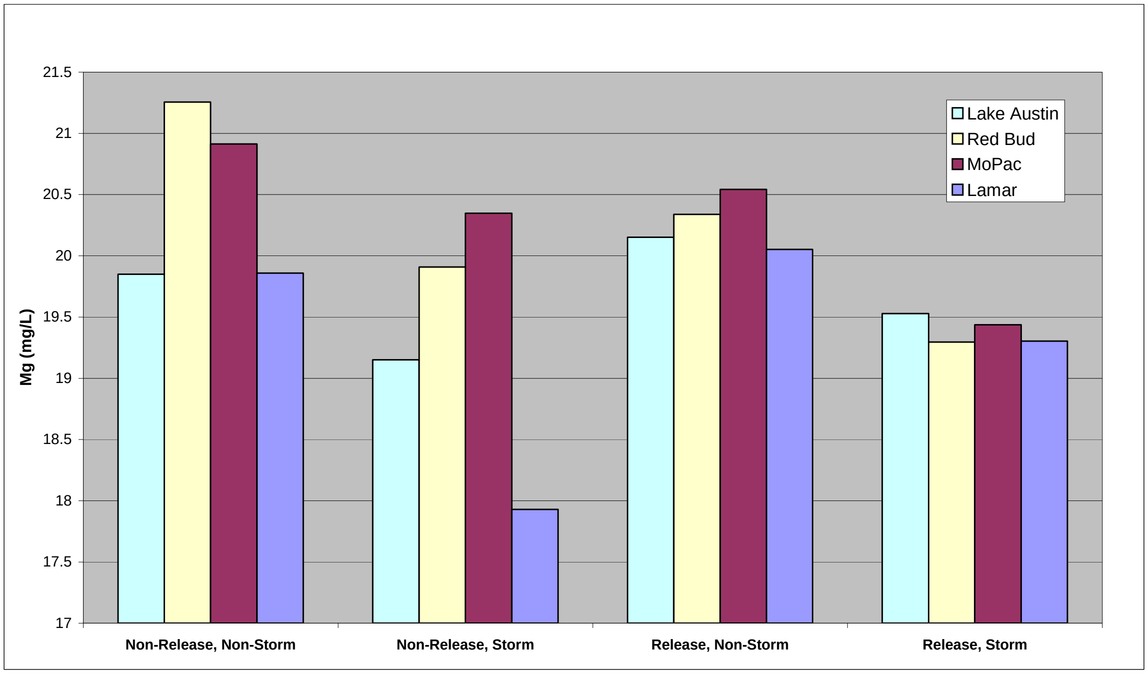
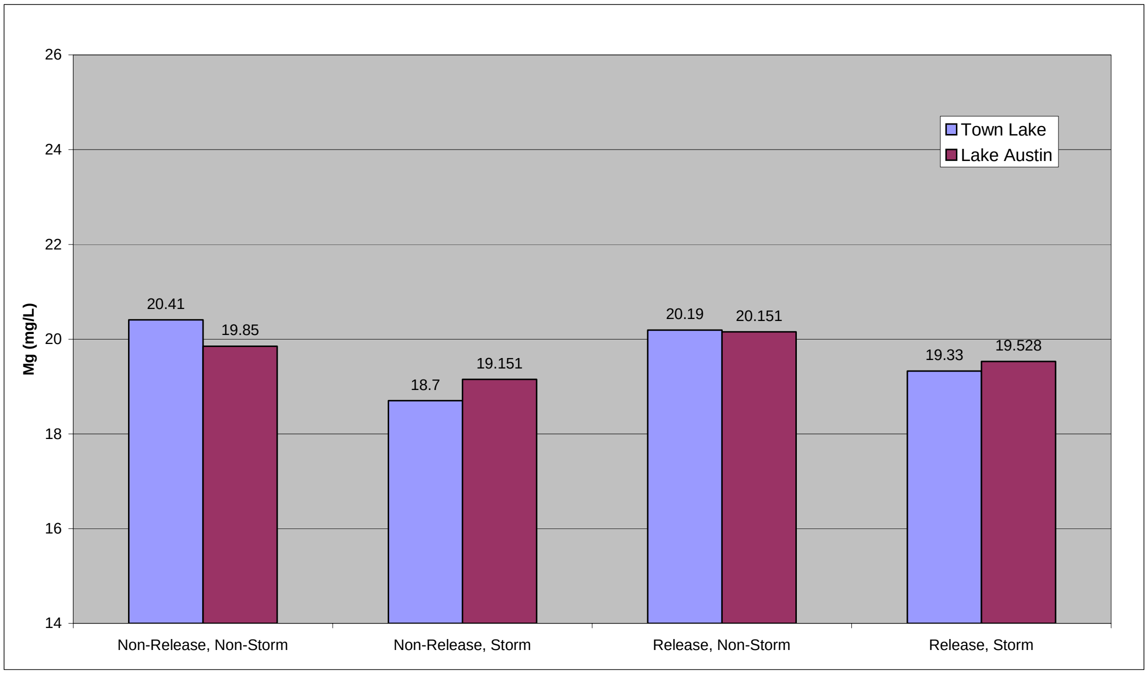


Figure 4.106 Mean Magnesium Watershed Concentrations by Season and Flow Type, All Sites and Depths



During the non-release season, total sodium is significantly lower at Lamar than at all other Town Lake sites in both storm and non-storm flow conditions. No significant difference exists in mean sodium concentrations at any Town Lake site during the release season in all flow conditions. In general, a slightly decreasing longitudinal pattern in total sodium concentrations occurs from upstream to downstream (through the Lamar site as no regular data exist for the more downstream sites) for all storm and release conditions (Figure 4.107). Total sodium averages in Lake Austin are significantly greater than Town Lake during all storm and release conditions except release, storm flows (Figure 4.108). Within Town Lake, no significant difference was shown between release and non-release concentrations in either storm or non-storm flows.

Figure 4.107 Sodium Site Averages by Season and Flow Type for All Depths

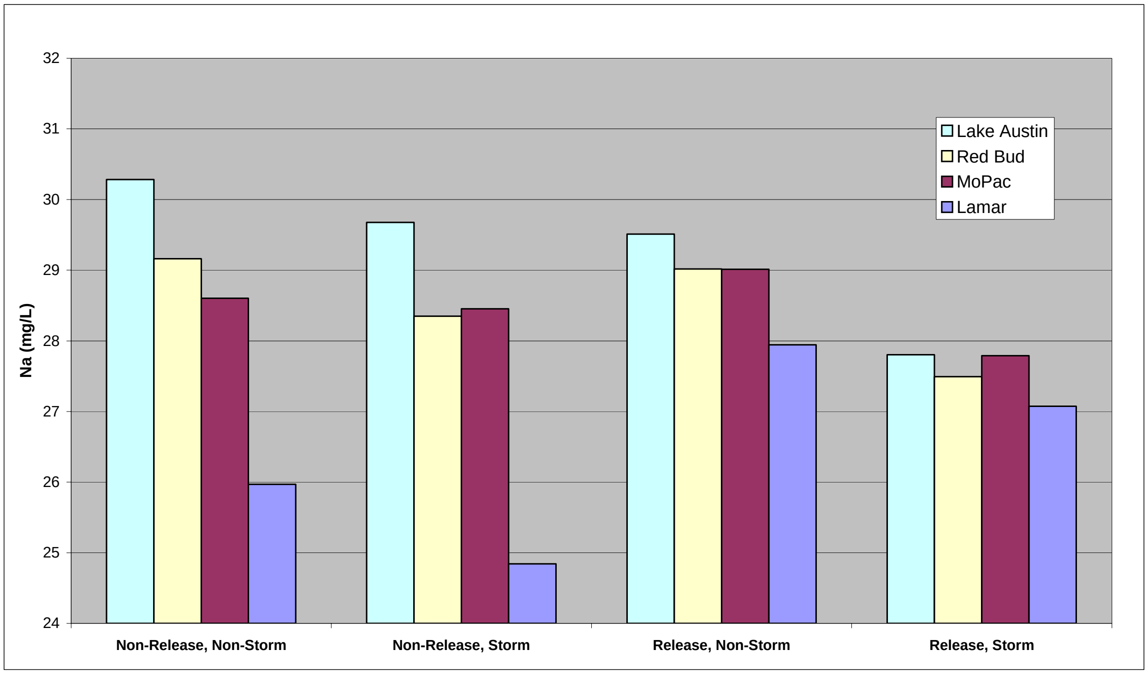
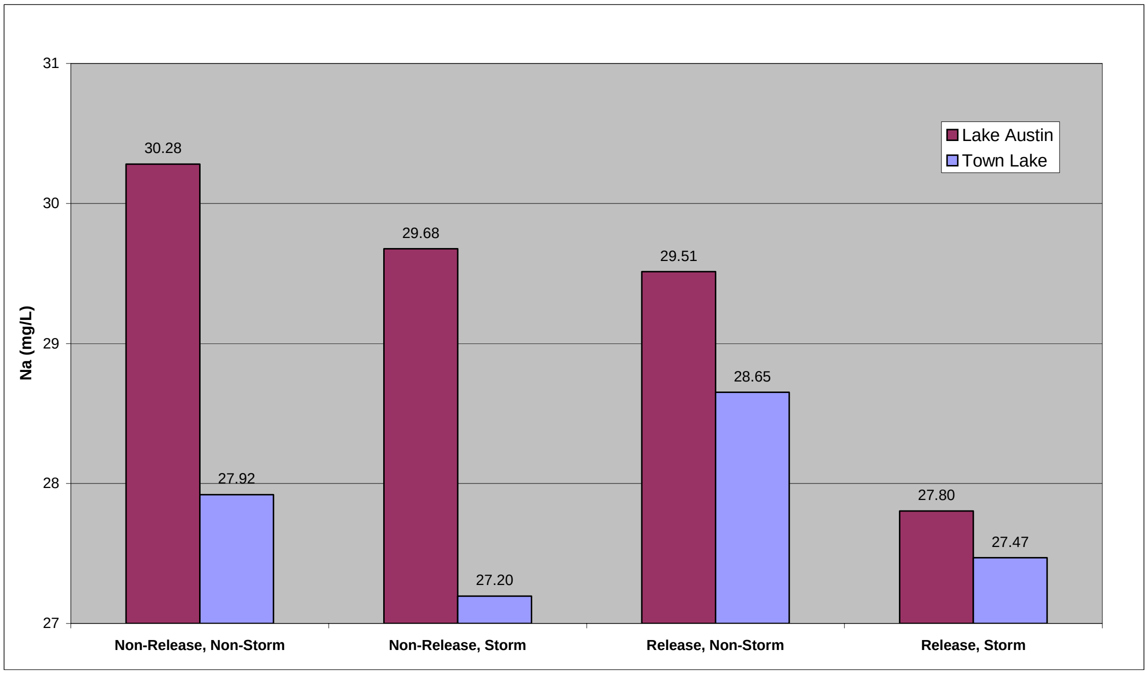


Figure 4.108 Sodium Watershed Averages by Season and Flow Type for All Sites and Depths



During storm flow conditions in both the release and non-release seasons, no statistically significant difference was shown between Town Lake sites in total sulfate concentrations (Figure 4.109). Although no significant difference was shown between Town Lake sites for mean total sulfate during non-release storm flows, mean concentrations at the MoPac site are significantly greater than all other sites during non-release, non-storm flow conditions. During non-storm flow conditions in general, a decreasing longitudinal pattern is present in mean total sulfate from upstream to downstream. Although Lake Austin mean sulfate concentrations are always significantly greater than Town Lake watershed mean concentrations (Figure 4.110), mean non-release concentrations within Town Lake are significantly greater than release concentrations in both storm and non-storm flow conditions.

Figure 4.109 Sulfate Site Averages by Season and Flow Type for All Depths

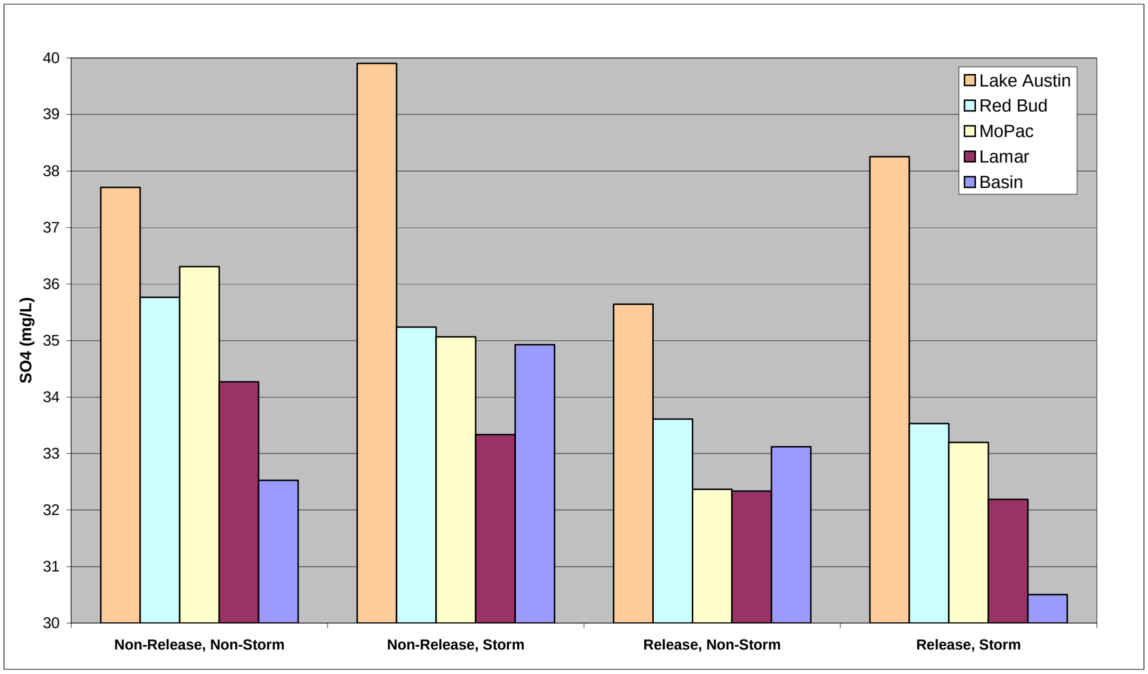
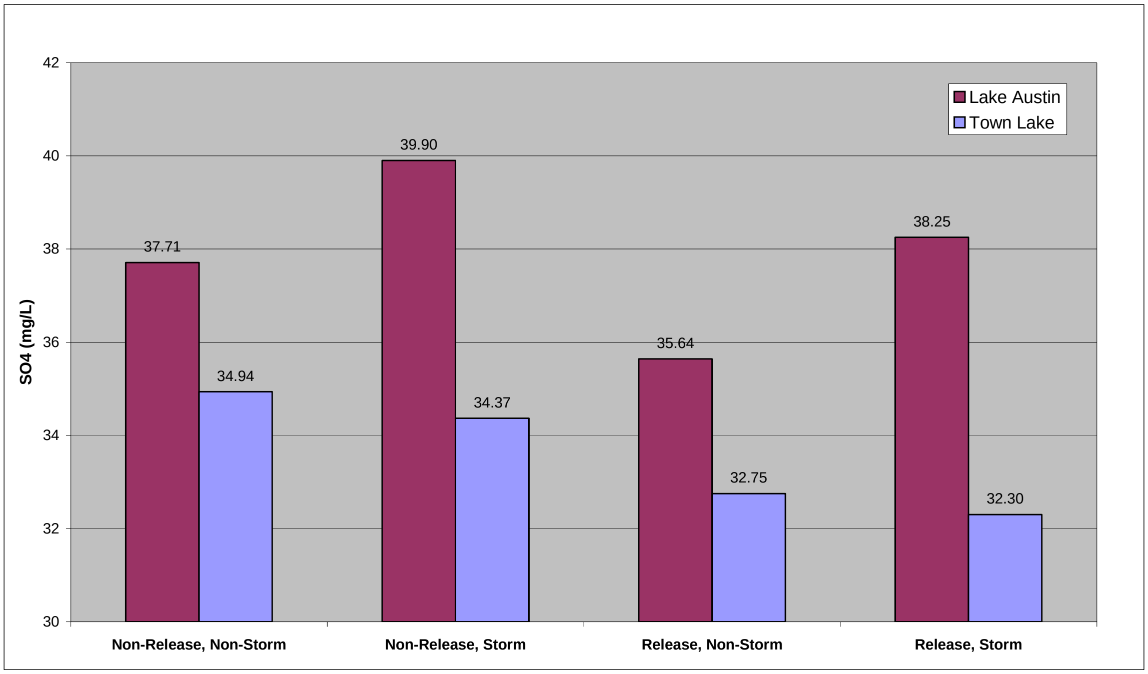


Figure 4.110 Total Sulfate Watershed Averages by Season and Flow Type for All Sites and Depths



Town Lake conductivity generally increases with increasing depth below the surface for all storm and release conditions (Figure 4.111). Average conductivity within Town Lake not only exhibits more variation with depth during the release season than in the non-release season, but also the disparity between storm and non-storm averages during release is greater than the difference observed during non-release. The general patterns are nearly identical within either season for storm and non-storm flows. Examining individual site patterns of conductivity with sampling depth during release, non-storm flow conditions (Figure 4.112) reveals that the Lamar and Basin sites exhibit not only higher conductivity variations, but also the same sharp spike in conductivity between 2 and 3 meters in depth. In contrast, during non-release, non-storm flow conditions in Town Lake (Figure 4.113), conductivity appears to fluctuate more with depth at the First Street and Red Bud sites, although the Basin still generally maintains higher conductivity levels than other Town Lake sites.

Figure 4.111 Town Lake Conductivity Depth Profiles by Season and Flow Type

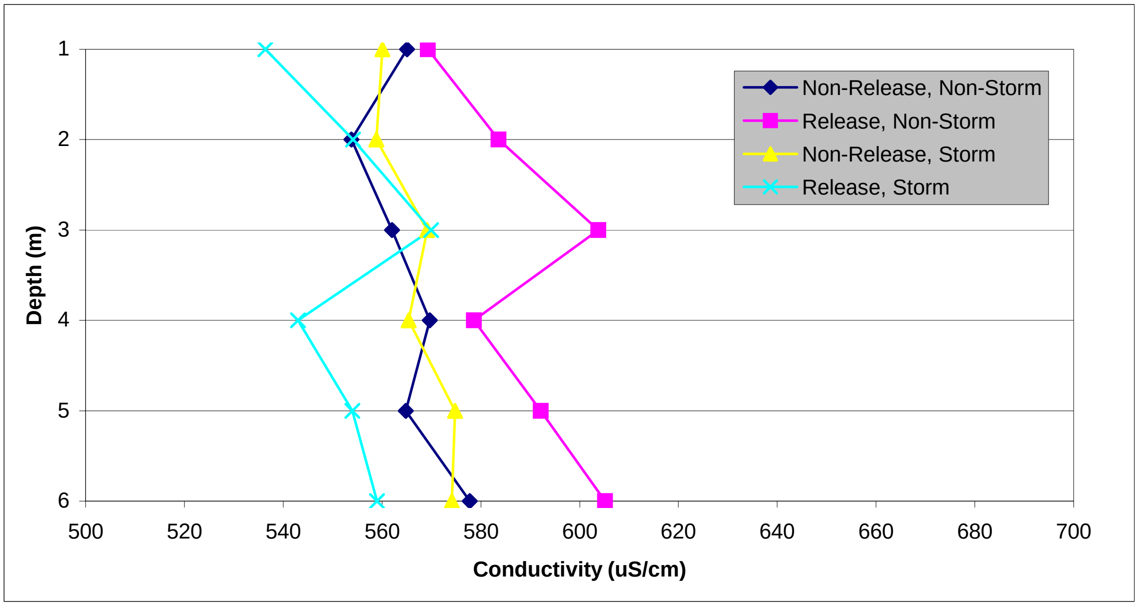


Figure 4.112 Town Lake Conductivity Profiles During Release, Non-Storm Flow by Site

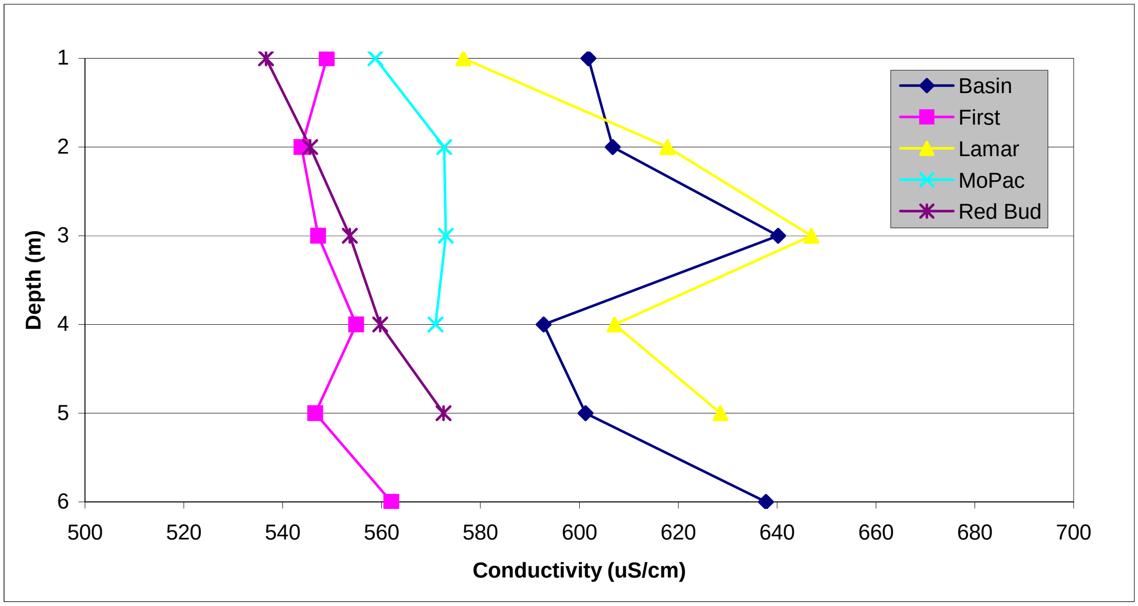
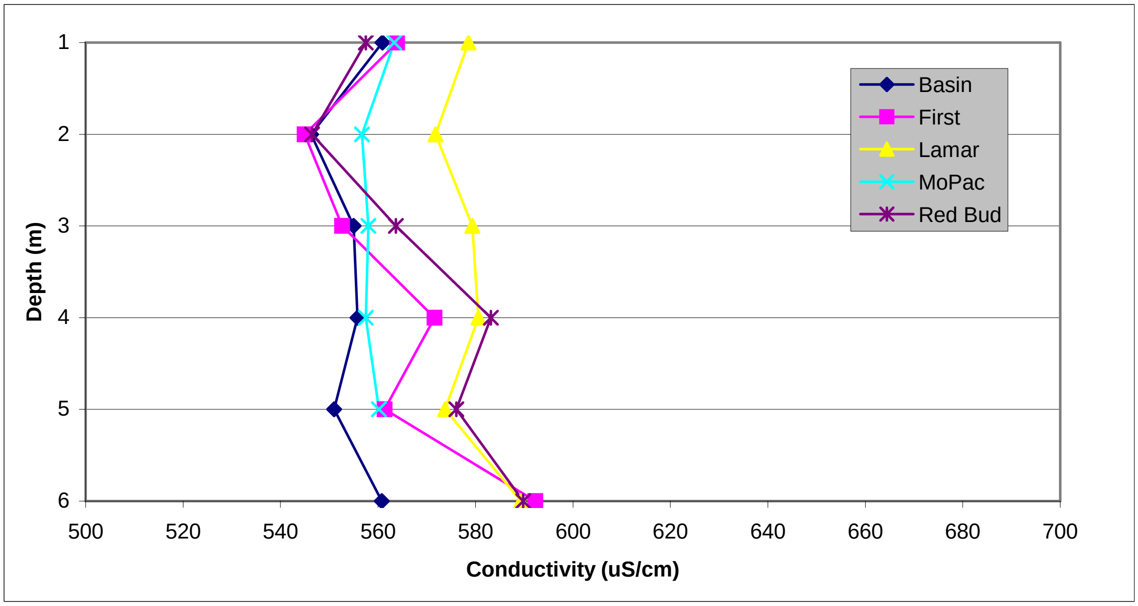


Figure 4.113 Town Lake Conductivity Depth Profiles During Non-Release, Non-Storm Flow by Site



4.4.2.3 Storm and Release Conditions

The maximum alkalinity value of 460 mg/L as $CaCO_3$ measured in Town Lake was taken from the surface of the MoPac site during storm flows on 16 December 1992 by COA-ERM. Only four other measurements of alkalinity in Town Lake have ever exceeded 400 mg/L as $CaCO_3$, with all four collected from August to December of 1992 at Lamar. Minimum recorded alkalinity in Town Lake was 68 mg/L as $CaCO_3$, as measured by COA-ERM from the bottom of the Basin on 16 September 1992 during non-storm flow conditions. Measured alkalinity in Town Lake has not dropped below 100 mg/L as $CaCO_3$ on any other sampling event since 1990.

The maximum measurement of total calcium recorded in Town Lake was 95 mg/L, as measured by COA-W/WW from the surface near the MoPac site during non-storm flow on 9 November 1992. The lowest calcium concentration measured in Town Lake of 39 mg/L was recorded by COA-W/WW from the Green Treatment Plant intake on four occasions during September and October 2000.

Magnesium concentrations as high as 32 mg/L have been measured in Town Lake as recently as February 1999, although minimum concentrations of 9 mg/L were measured in 1998.

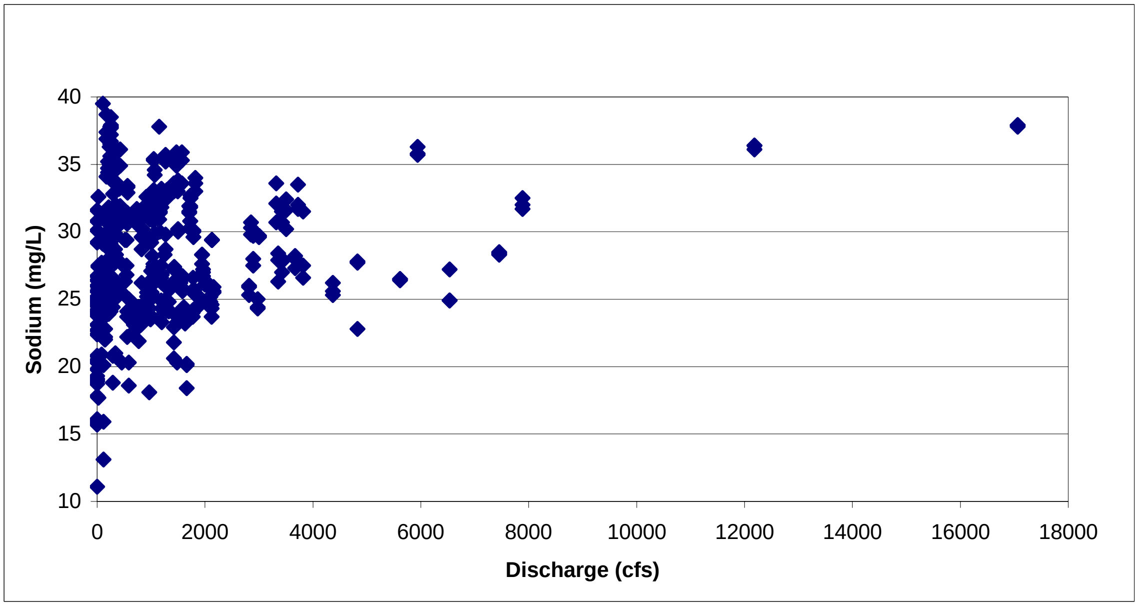
Minimum and maximum sodium concentrations in Town Lake have also occurred fairly recently, with the highest recorded observation of 38.5 mg/L taken near MoPac during storm flow in January 1997, and the lowest recorded observation of 11.1 mg/L taken during storm flows at the Green Treatment Plant intake in November 1998.

The highest sulfate concentration measured in Town Lake of 85.2 mg/L was recorded by COA-ERM from the surface of the Lamar site during storm flow on 13 April 2000. At least six measurements of sulfate concentrations less than 20 mg/L, however, have been recorded in Town Lake by the USGS during storm events from 1976 to 1985 at the Lamar and Basin sites.

Total alkalinity is negatively correlated with increasing discharge from Tom Miller Dam through Town Lake in both release and non-release seasons. Although calcium in Town Lake is significantly and inversely related to Lake Austin inflows during the non-release season, a significant positive correlation was indicated with discharge from Tom Miller Dam during the release season.

Chloride levels in Town Lake are significantly and directly correlated with Tom Miller Dam discharge for both release and non-release seasons. Sodium concentrations are also significantly and positively correlated with increasing discharge from Lake Austin for all release conditions (Figure 4.114), as are total sulfate concentrations.

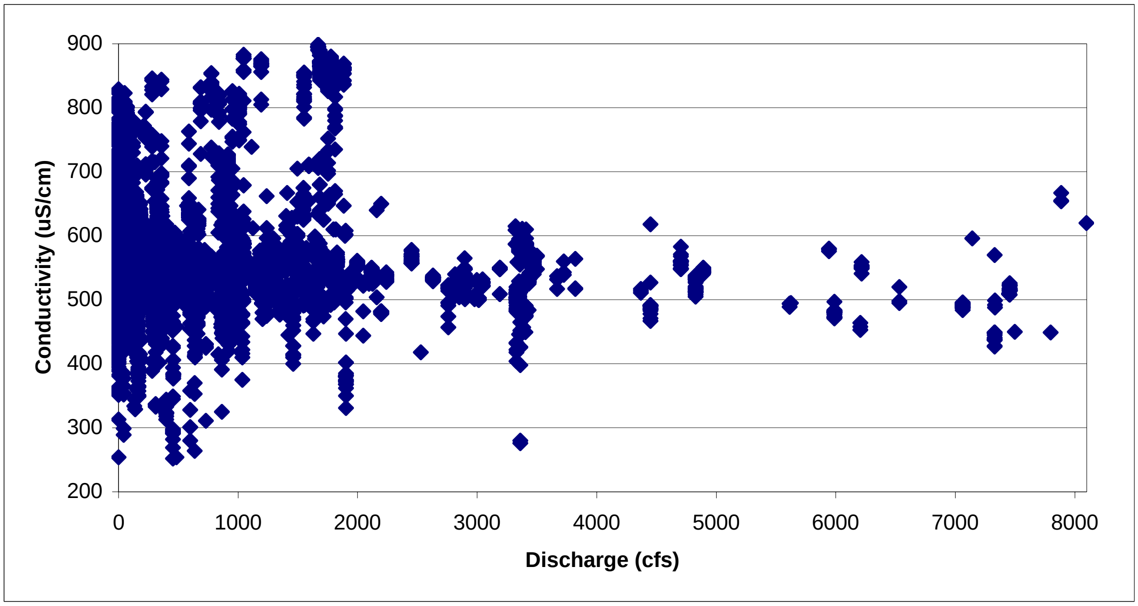
Figure 4.114 Town Lake Sodium versus Mean Daily Discharge from Tom Miller Dam



Although fluoride levels in Town Lake are significantly and positively correlated with Lake Austin discharge during the non-release season, a significant inverse relationship is shown during release conditions. The same pattern of direct correlation with Lake Austin inflows during non-release seasons, with an inverse correlation exhibited during the release season, is observed for total magnesium in Town Lake.

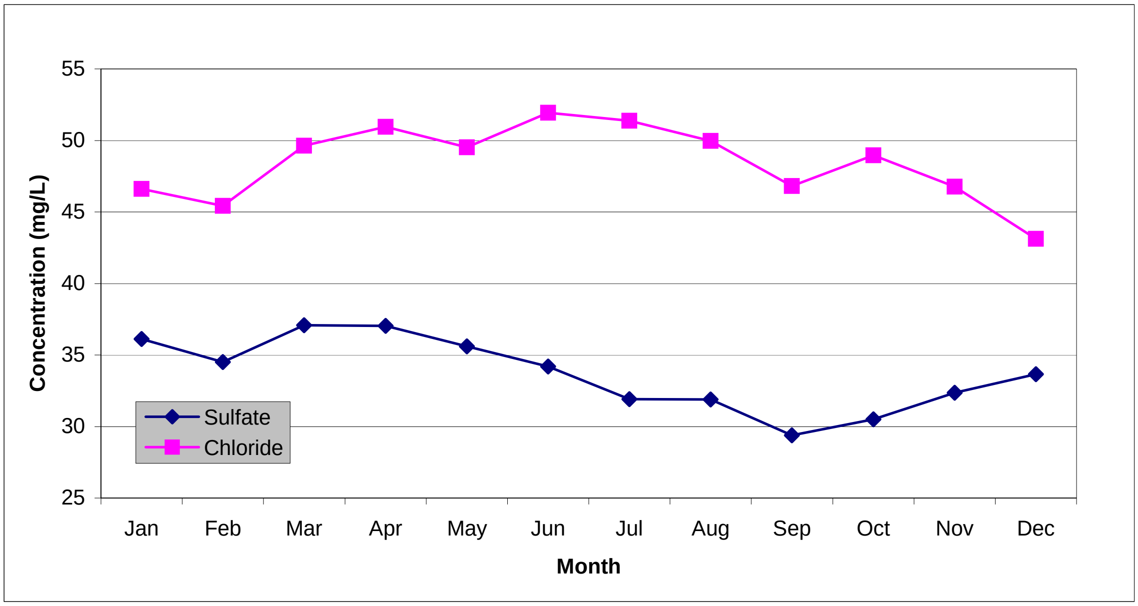
Town Lake conductivity exhibits no strong relationship with discharge from Tom Miller Dam. Although a statistically significant weak negative correlation of conductivity with increasing discharge from Tom Miller Dam was shown for all storm and release conditions, conductivity levels actually appear to be positively correlated with Lake Austin releases up to approximately an average daily release of 2,000 ft^3/s, after which conductivity levels slightly decrease with flow (Figure 4.115).

Figure 4.115 Town Lake Conductivity versus Mean Daily Discharge from Tom Miller Dam



Monthly average Town Lake non-storm chloride and sulfate show no correlation with monthly rainfall averages, monthly average Barton Creek inflows, or monthly average Town Lake flows. Although little variation is evident in monthly averages for either chloride or sulfate, during the transition from release to non-release in the fall monthly average chloride levels increase while sulfate concentrations decrease (Figure 4.116).

Figure 4.116 Town Lake Non-Storm Mean Monthly Chloride and Sulfate



Lowest average monthly conductivity, as determined by routine grab samples in Town Lake, occurs from May to July, when monthly average outflows from Town Lake, as measured by the USGS gage at U.S. 183, are at a maximum. However, a strong correlation with flow does not exist because of the anomalous peak in mean monthly conductivity levels in August, a month with a median flow through Town Lake (Figure 4.119). No correlation in mean Town Lake monthly conductivity levels is observed with Barton Creek inflow.

Continuous monitoring data present a different pattern of monthly variation in conductivity at the bottom of the Basin site (Figure 4.117) and at the surface of the Lamar site (Figure 4.118).   Surface conductivity at Lamar exhibits maximum levels in December and January, while bottom conductivity at the Basin is elevated from December to February.

Figure 4.117 Town Lake Basin Bottom Mean Hourly Conductivity by Month

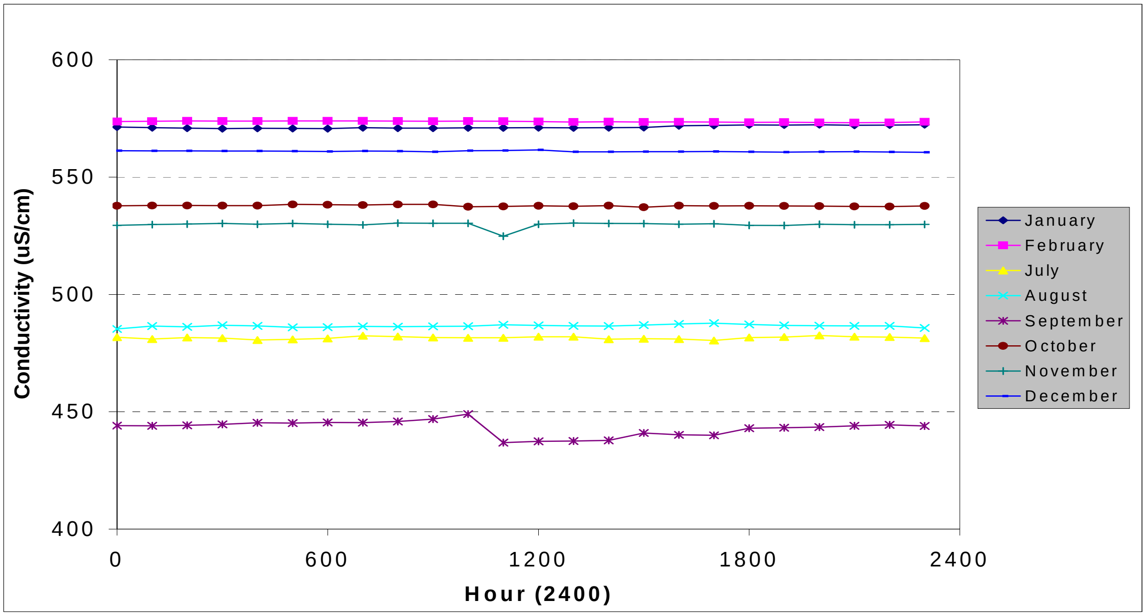
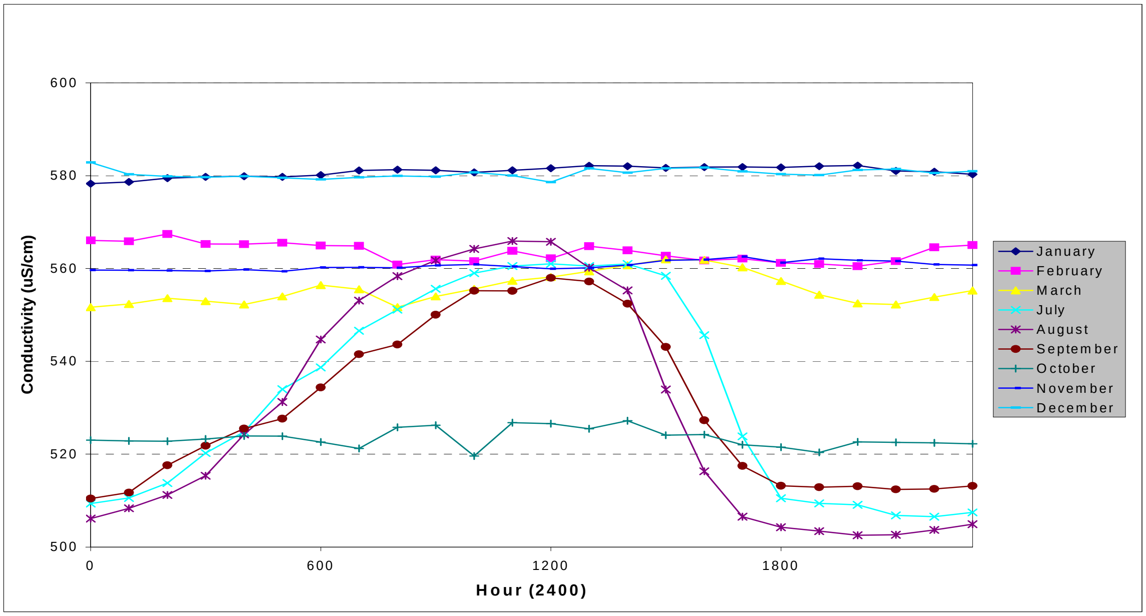
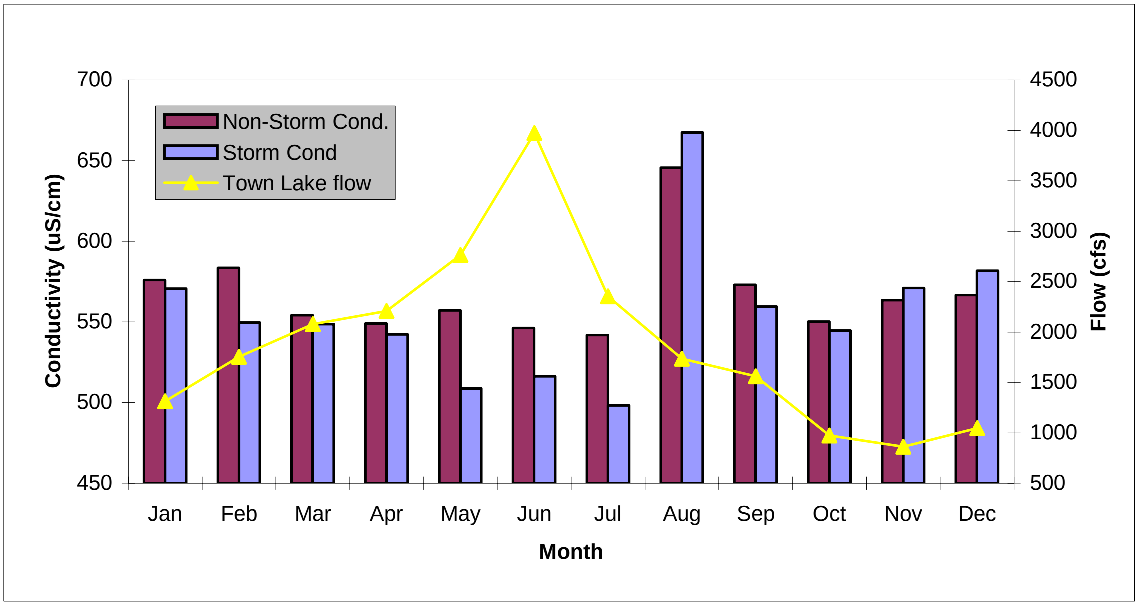


Figure 4.118 Town Lake Lamar Surface Mean Hourly Conductivity by Month from Continuous Monitoring Data



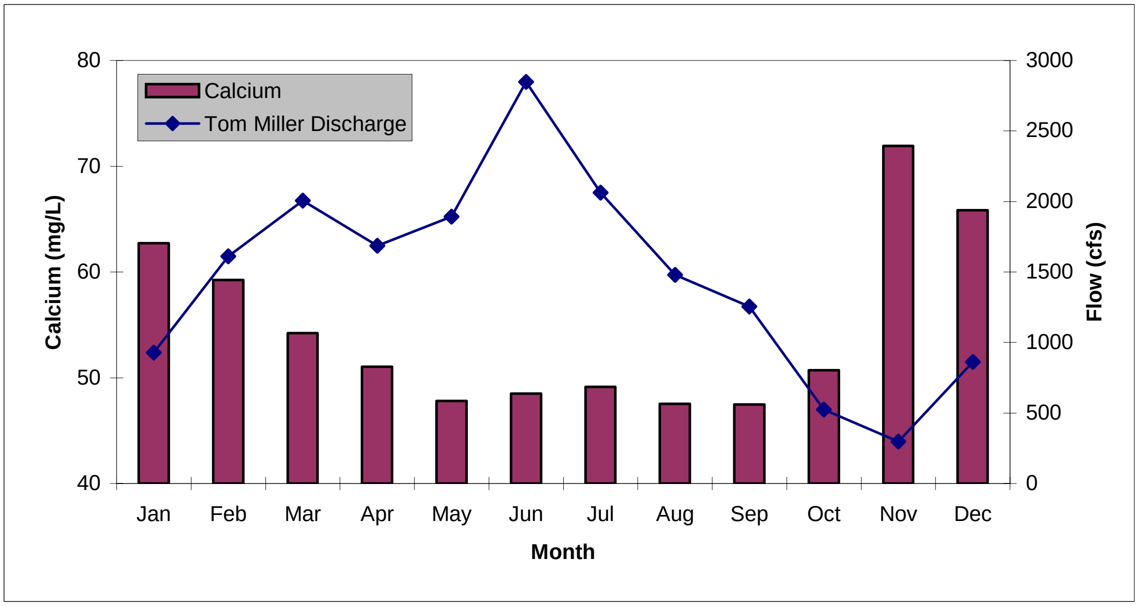
Although little change in diel conductivity at the bottom of the Basin occurs during any month in which continuous monitoring datasondes have been deployed, Lamar exhibits clear daily fluctuations during the end of the summer season from July to September, with peak daily conductivity levels observed around noon. In other months, Lamar mean surface conductivity varies little during the course of a day. Overall mean surface conductivity levels at Lamar, as determined by continuous monitoring data, are greater than mean conductivity levels at the bottom of the Basin throughout the entire day. Despite the disparity in mean conductivity levels throughout the day, however, a reasonable positive correlation (Spearman's $\theta = 0.77$, $p_{\theta=0} < 0.0001$) between monthly average Lamar surface and Basin bottom conductivity levels was indicated, as measured by the datasondes.

Figure 4.119 Town Lake Mean Monthly Conductivity with Mean Town Lake Flows as Measured by USGS Gage (Colorado River at US183)



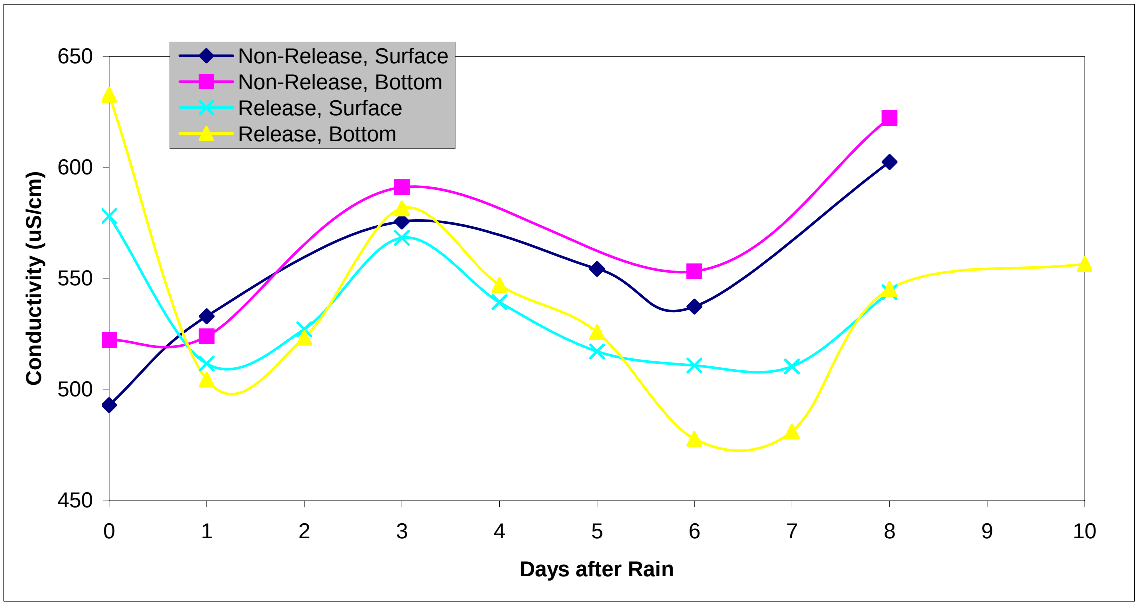
Mean monthly Town Lake non-storm magnesium concentrations exhibit practically no variation through the year, with the minimum monthly averages of 19.6 mg/L observed in November differing only 1.2 mg/L from maximum monthly averages observed in February. Mean monthly non-storm fluoride and mean monthly non-storm sodium concentrations also exhibit little to no variation through the year in Town Lake. Calcium monthly average concentrations in Town Lake, however, appear to be somewhat inversely related to upstream input from Lake Austin (Figure 4.120).

Figure 4.120 Town Lake Mean Monthly Calcium Versus Mean Daily Discharge from Tom Miller Dam



Analysis of average Town Lake conductivity concentrations following storm events ≥ 0.5" in magnitude with at least three non-storm days prior to the rain event indicates that little variation occurs between surface and bottom depths within either the release or non-release seasons (Figure 4.121). The general pattern in conductivity following large isolated storm events is fairly consistent between seasons with mean conductivity rising from the first to the third day following the storm event, then declining from the fourth through the seventh day.

Figure 4.121 Town Lake Mean Conductivity Following Large Storm Events by Season and Flow Type



Mean sulfate levels yield slightly decreasing trends in Town Lake following storm events during both release and non-release seasons (Figure 4.122). Average chloride concentrations, however, appear to generally increase slightly following storm events in both the release and non-release seasons (Figure 4.123).

Figure 4.122 Town Lake Mean Sulfate Following Large Storm Events

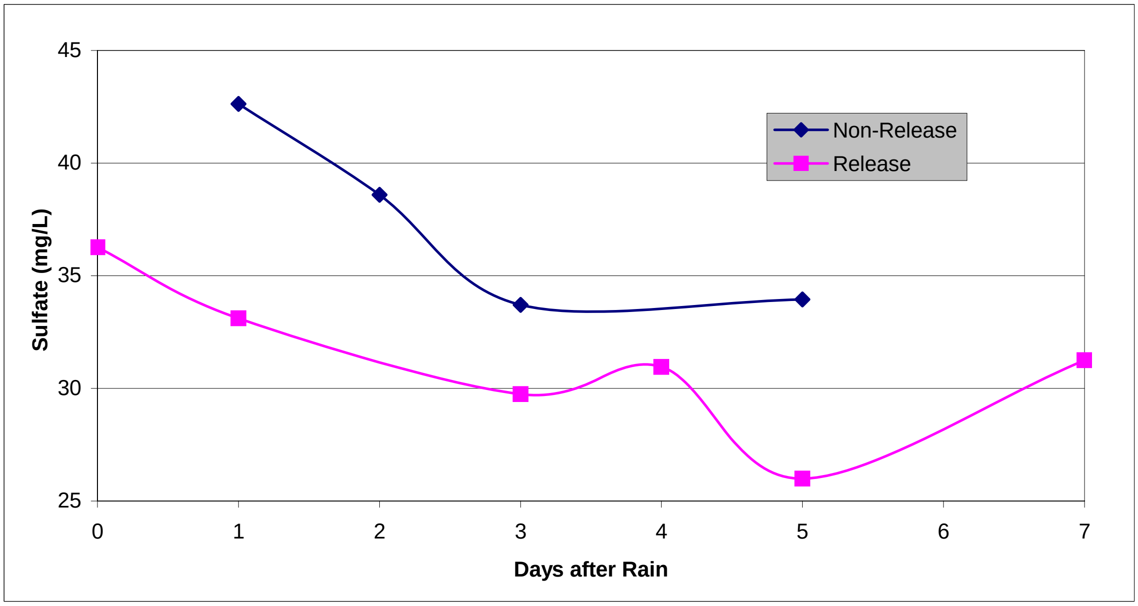
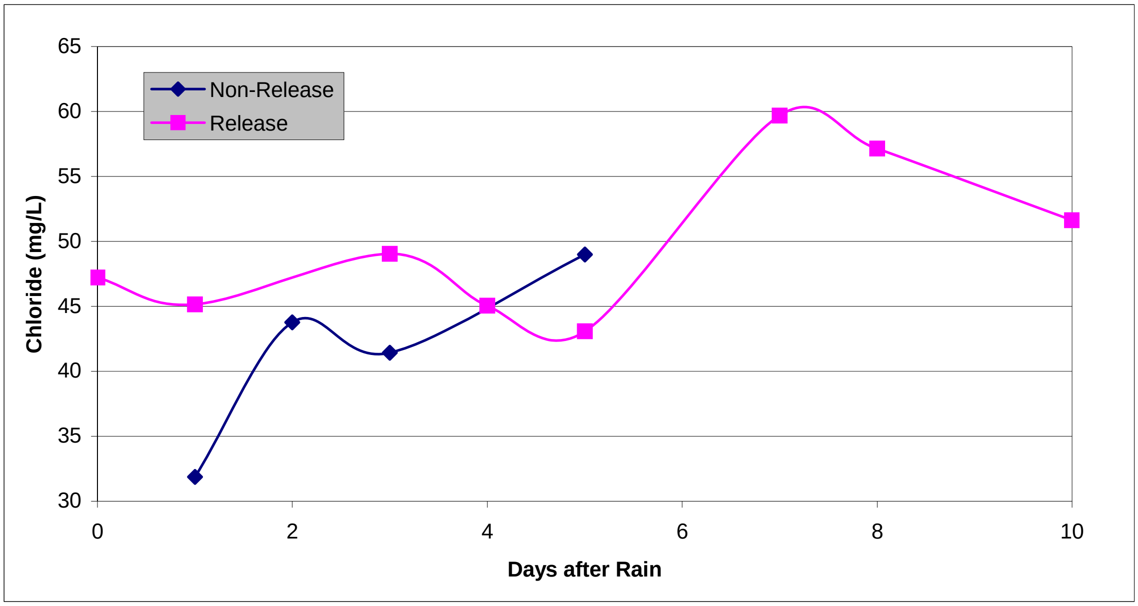
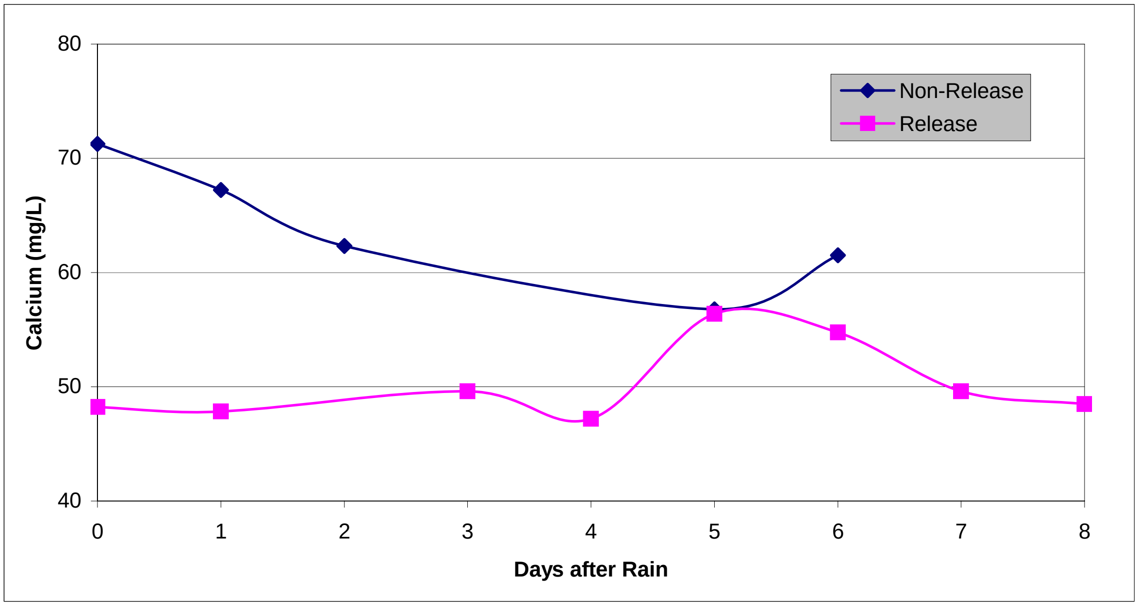


Figure 4.123 Town Lake Mean Chloride Following Large Storm Events



Average Town Lake post-storm calcium concentrations appear fairly constant in both seasons, though a slight decrease occurred during non-release through the fifth day (Figure 4.124).

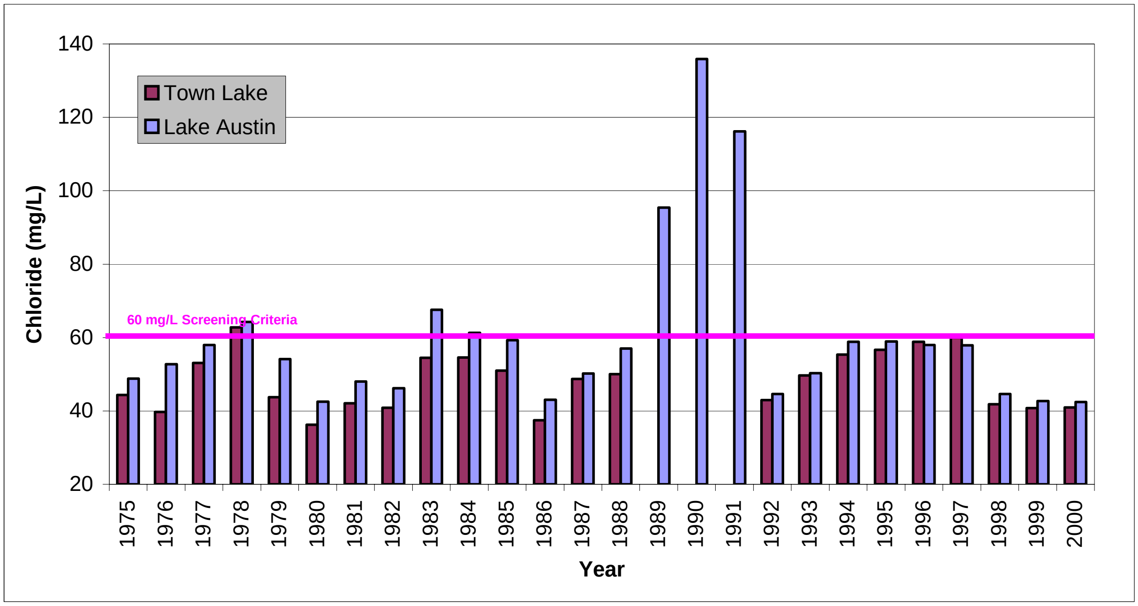
Figure 4.124 Town Lake Mean Calcium Following Large Storm Events



4.4.2.4 Concern Status

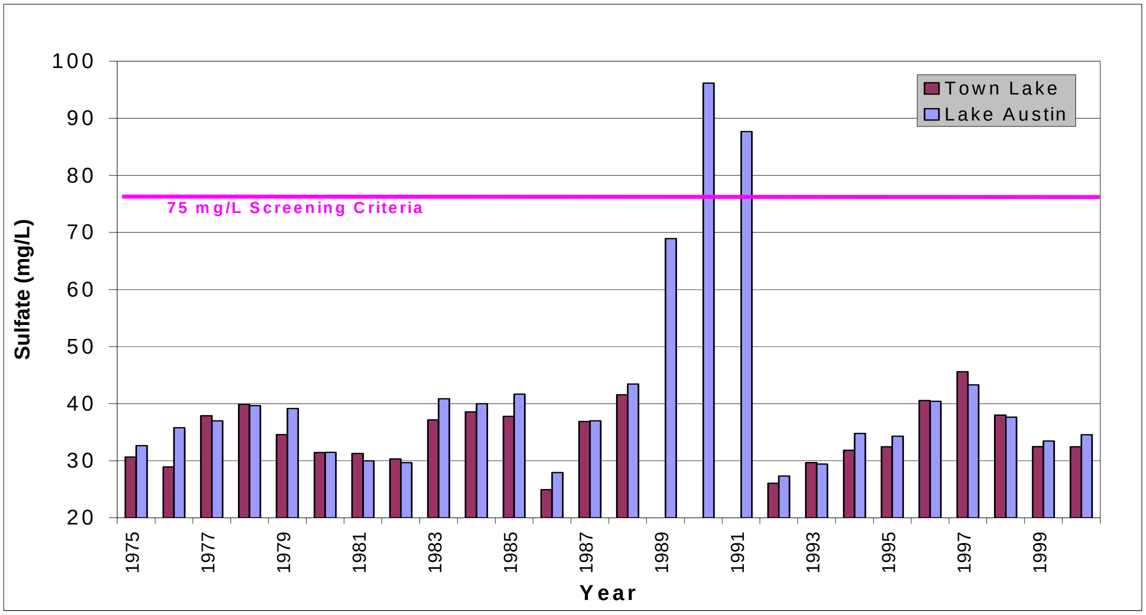
Annual average chloride levels in Lake Austin and Town Lake (Figure 4.125) were compared to the 60 mg/L TNRCC segment-specific water quality standard. The Lake Austin standard is actually 100 mg/L, but the graph presents data in comparison to the Town Lake standard value of 60 mg/L. Town Lake annual average chloride concentrations have rarely exceeded the 60 mg/L standard. A consistent rise in chloride concentrations in Town Lake was observed from 1992 to 1997 to levels nearing the 2000 TNRCC screening criteria of 60 mg/L.

Figure 4.125 Annual Mean Chloride in Comparison to TNRCC Segment-Specific Standard by Watershed



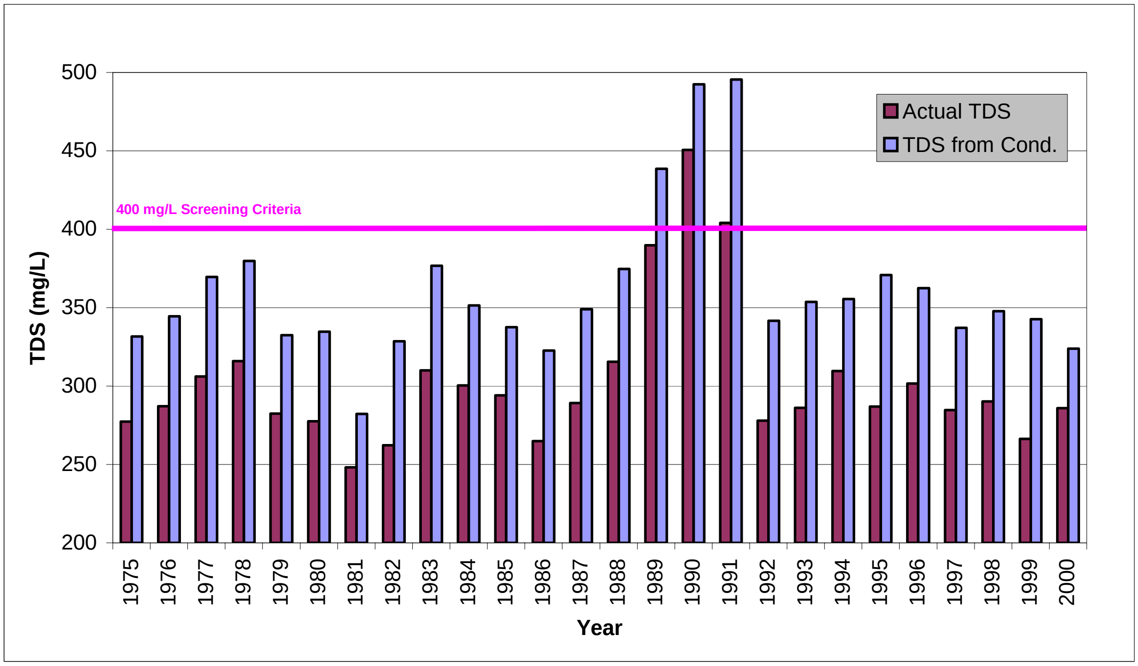
Annual average sulfate levels in Lake Austin and Town Lake versus the 75 mg/L 2000 Town Lake TNRCC segment-specific water quality standards (Figure 4.126). Town Lake annual average sulfate concentrations have never exceeded the 75 mg/L standard. A consistent rise in sulfate concentrations in Town Lake was observed from 1992 to a maximum annual average of 45.6 in 1997, the highest average observed from 1975 to 2000.

Figure 4.126 Annual Average Sulfate in Town Lake and Lake Austin in Comparison to TNRCC 2000 Segment-Specific Standard



Annual average TDS concentrations in Town Lake were compared to TNRCC segment-specific water quality standards (Figure 4.127) using actual TDS measurements as well as estimated TDS measurements calculated by multiplying conductivity by an empirical conversion factor of 0.65. Although a larger number of conductivity measurements are typically available, the conversion factor is dependent upon ionic content and temperature of the water (APHA 1992) and thus may not be as accurate as actual TDS measurements. Only in 1989, 1990, and 1991 did either actual or converted Town Lake average annual TDS exceed the 400 mg/L TNRCC segment-specific standard.

Figure 4.127 Annual Mean Town Lake Measured and Estimated TDS in Comparison to TNRCC Segment-Specific Standard

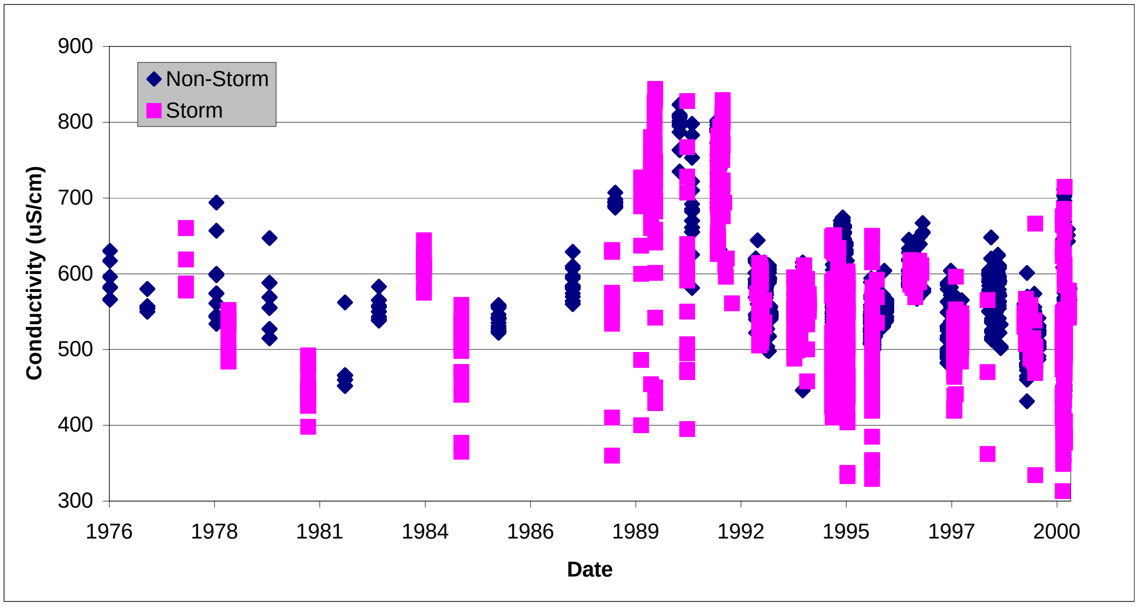


4.4.2.5 Temporal Patterns

In assessing the potential impacts of instituting the minimum low-flow policy by the LCRA in 1992, comparisons of average Town Lake non-storm flow dissolved solids and major ion concentrations yielded mixed results. Pre-1992 conductivity levels are significantly greater than post-1992 levels in both release and non-release seasons. Both calcium and alkalinity exhibit significantly higher mean Town Lake levels during non-release prior to 1992. Total chloride, sulfate, and magnesium, however, exhibit significantly higher concentrations after 1992 in Town Lake.

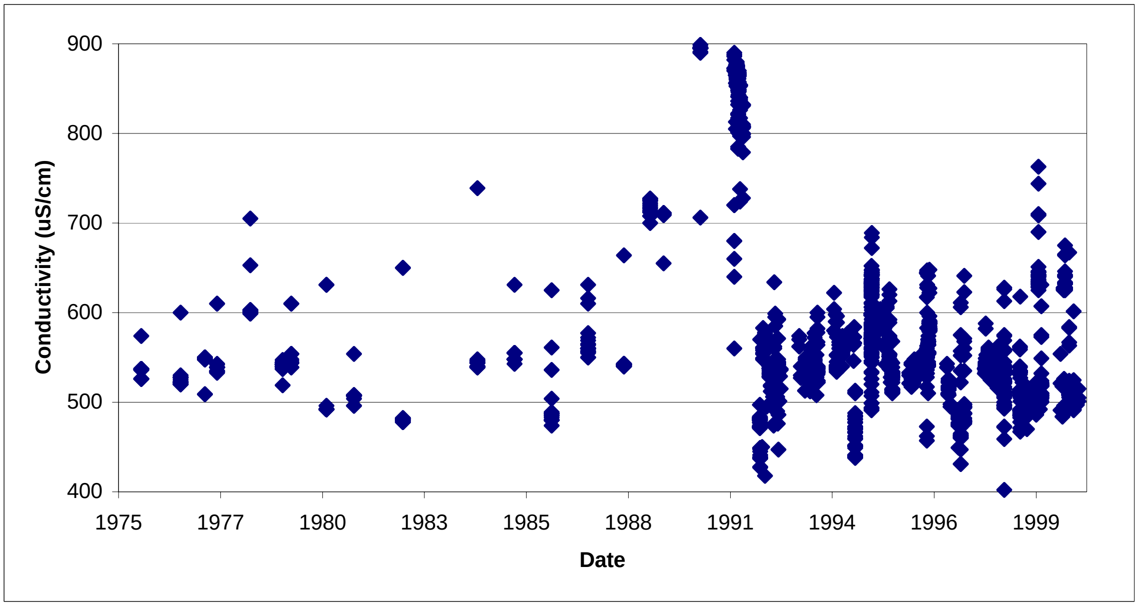
Despite periods of apparent increasing historical conductivity in Town Lake during the non-release season, such as that observed from approximately 1984 to 1990, a significant overall decreasing temporal trend in both storm and non-storm flow conditions was shown when data from all sites are composited during the non-release season at both surface and bottom depths (Figure 4.128). Although Town Lake experienced decreasing conductivity throughout the later half of the 1990s during non-release, note the sharp spike in conductivity values experienced in the fall and winter of 2000.

Figure 4.128 Town Lake Conductivity During Non-Release, All Sites and Depths



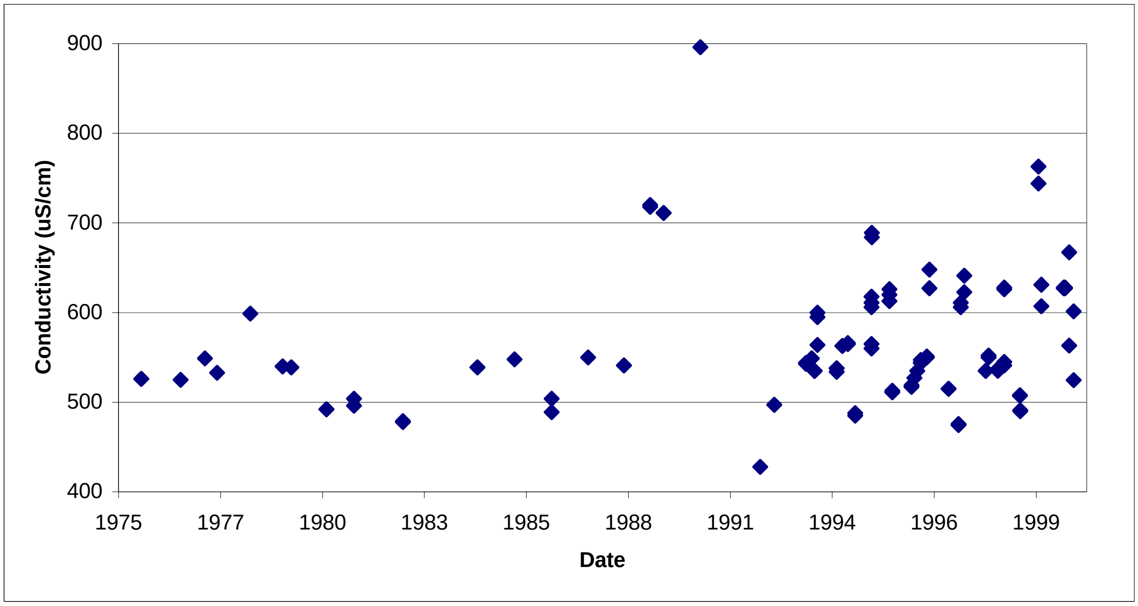
The sharp peak in conductivity values in 1991 is clearly visible during the release season as well as the non-release season, although overall Town Lake release, non-storm conductivity does exhibit a slight, though statistically significant, decreasing trend over time (Figure 4.129). In general, release conductivity levels in Town Lake are more constant than during non-release season. While the same general patterns of conductivity are evident during release, storm flows in Town Lake, no statistically significant trend with time was indicated for release, storm flow conductivity at either surface or bottom depths.

Figure 4.129 Town Lake Conductivity During Release, Non-Storm Flow, All Sites and Depths



Analysis of non-storm flow conductivity levels in Town Lake at the site level yield the same general patterns of significant overall decrease with time, evident at surface and bottom depths during the release and non-release season for all sites except First Street and Red Bud. Although non-storm release concentrations at First Street are not decreasing but remaining fairly constant at both surface and bottom depths, conductivity at the bottom depths of the Red Bud site are slightly, though significantly, increasing over time during non-storm release flows (Figure 4.130). Field staff have suspected a possible spring upwelling at the bottom of Town Lake near the Red Bud site based on sharp spikes in nitrogen levels during more recent routine sampling events, and the increased frequency of sampling within this higher conductivity spring water could be driving the increasing temporal trend in conductivity at depth near the Red Bud site.

Figure 4.130 Town Lake Conductivity at Red Bud During Release, Non-Storm Flow at Bottom Depths



Despite a lack of statistically significant overall trends in Town Lake chloride concentrations during any release or flow condition, a pattern emerges in which non-storm chloride concentrations increase sharply from approximately 1992 to 1997, surpassing the 60 mg/L TNRCC screening criteria, then decline sharply through 2000 (Figure 4.131). A nearly identical pattern is evident in non-storm total sulfate concentrations in Town Lake in both release and non-release seasons (Figure 4.132). However, the increase in Town Lake sulfate from 1992 to 1997 did not approach the 75 mg/L TNRCC screening criteria as closely as chloride. Although strong fluctuations occur with time in total sulfate concentrations a statistically significant increasing trend in overall concentration over time does exist during non-release, non-storm flows. Conversely, a significant decreasing overall temporal trend is found in non-storm, release total sulfate concentrations for all sites combined.

Figure 4.131 Town Lake Non-Storm Chloride, All Sites

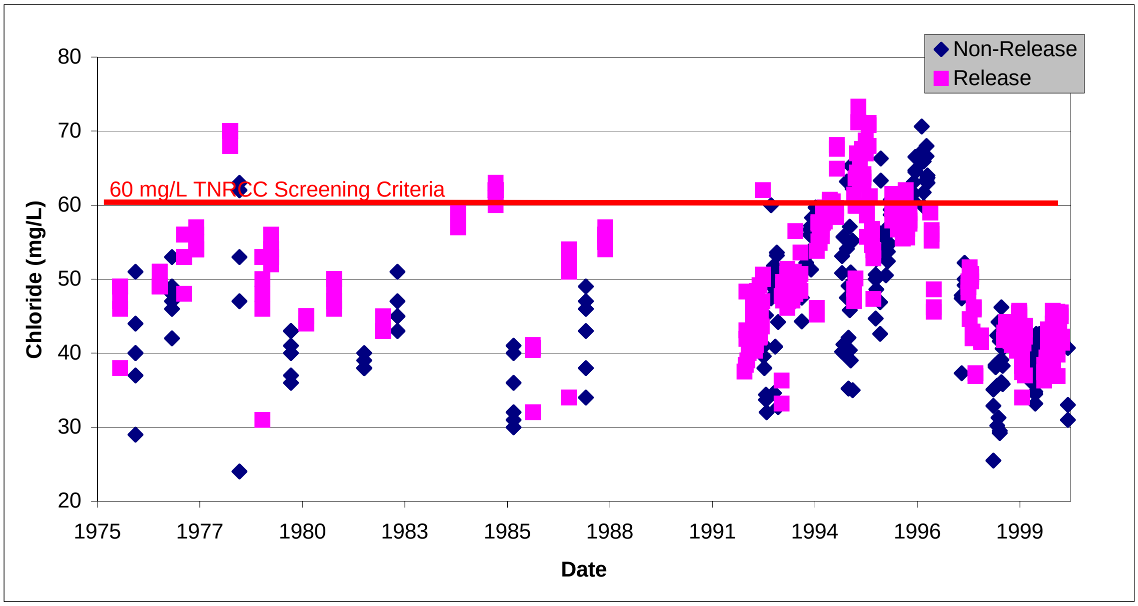
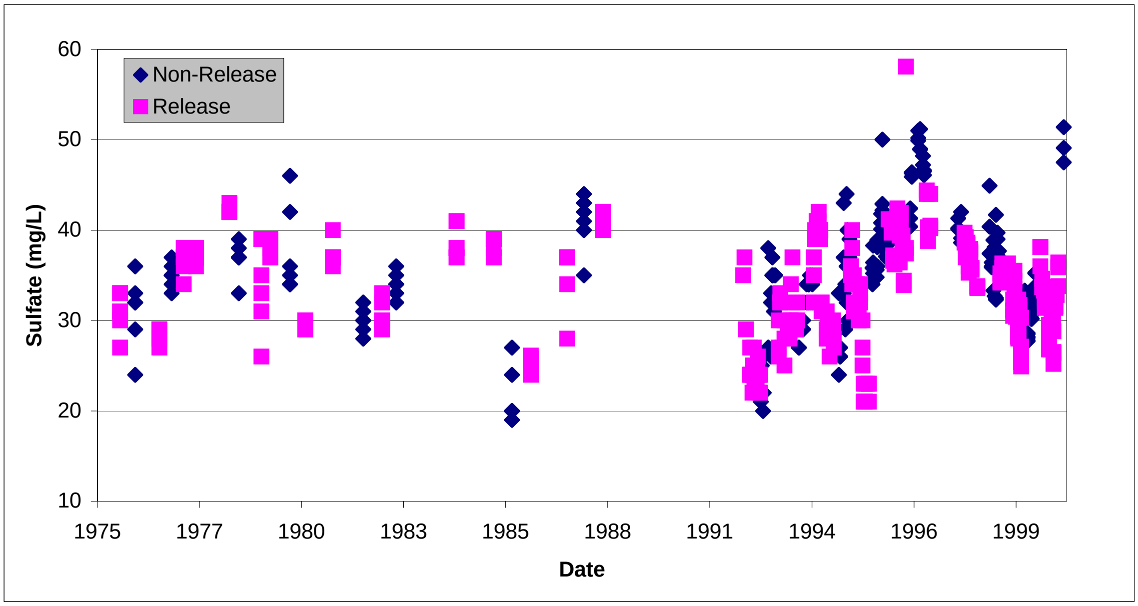


Figure 4.132 Town Lake Non-Storm Sulfate, All Sites



Total calcium in Town Lake exhibits similar overall temporal patterns to total sulfate, with a statistically significant increasing trend over time observed in non-release seasons (Figure 4.133) and a statistically significant decreasing trend in concentration over time observed during release (Figure 4.134). Comparable temporal trends in total calcium are observed in Lake Austin.

Figure 4.133 Town Lake Calcium During Non-Storm, Non-Release Conditions, All Sites and Depths

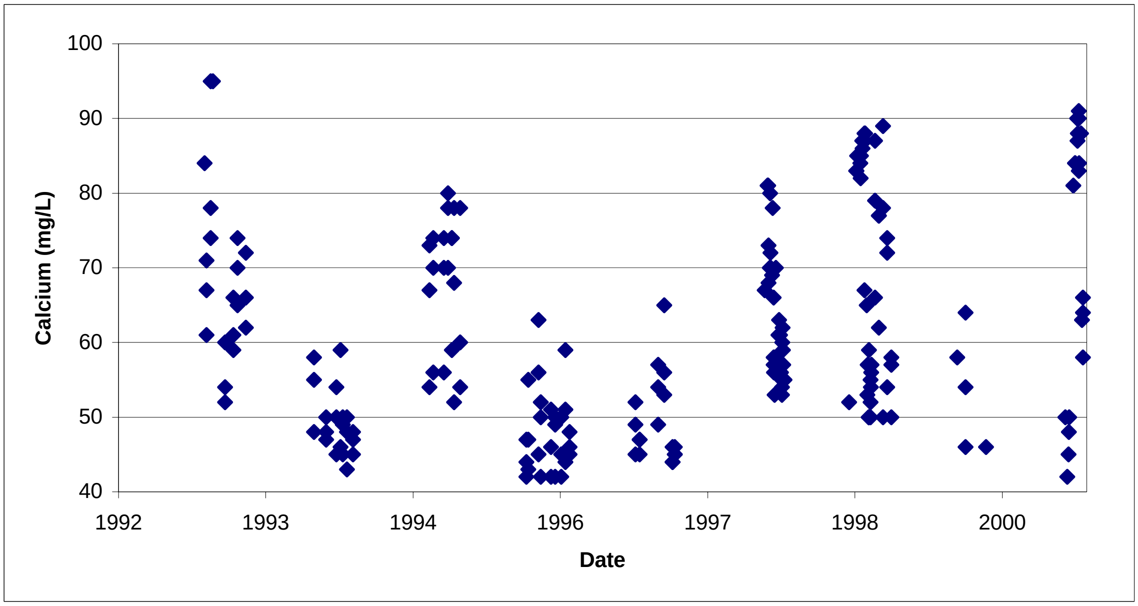
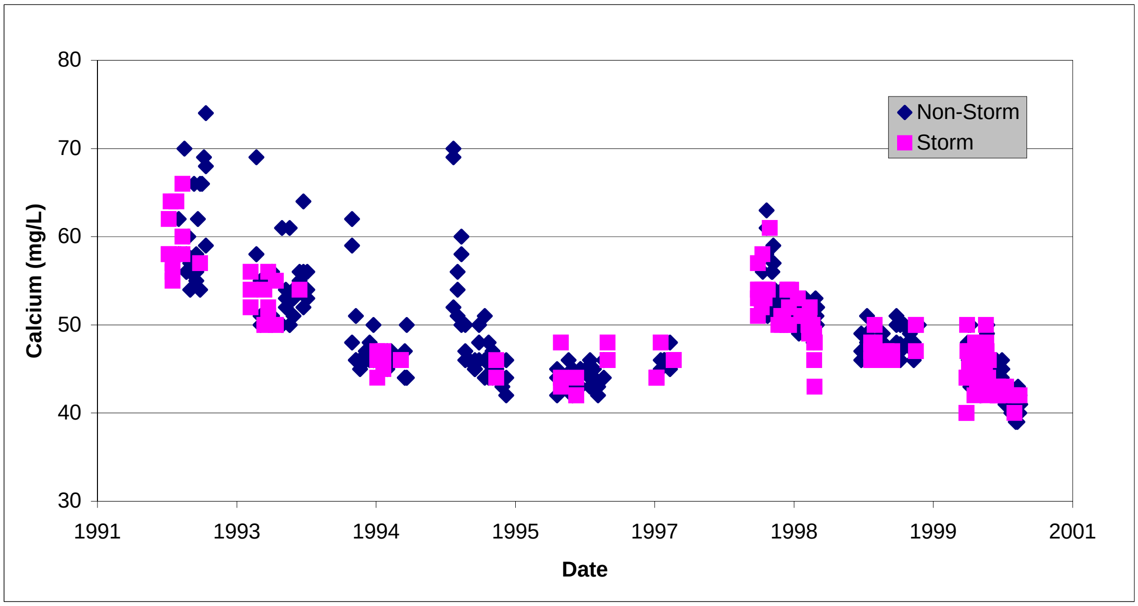
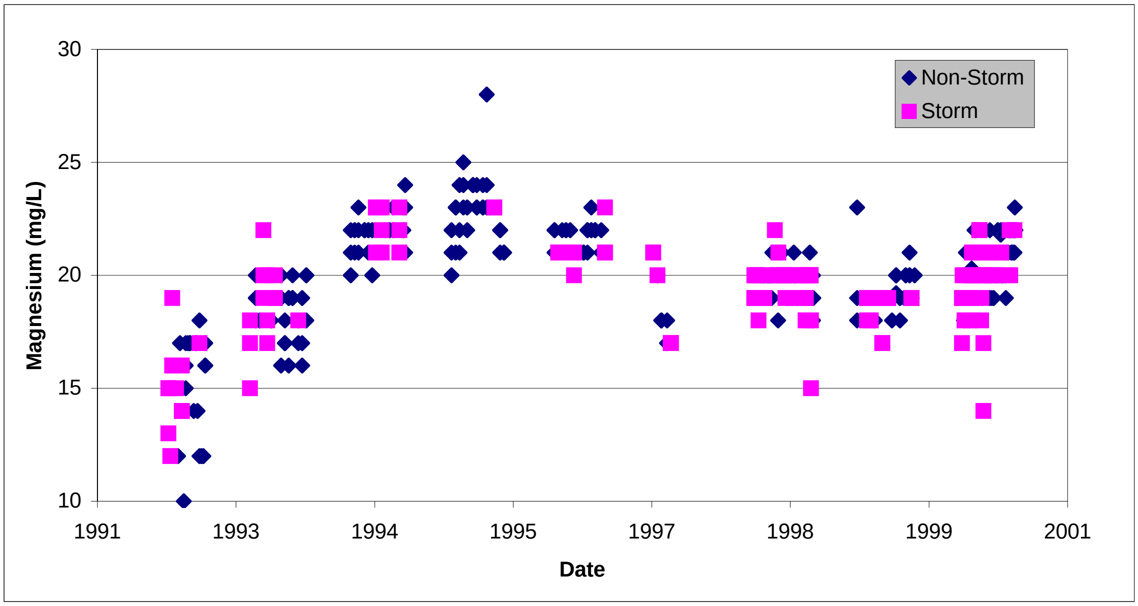


Figure 4.134 Town Lake Calcium During Release, All Sites and Depths



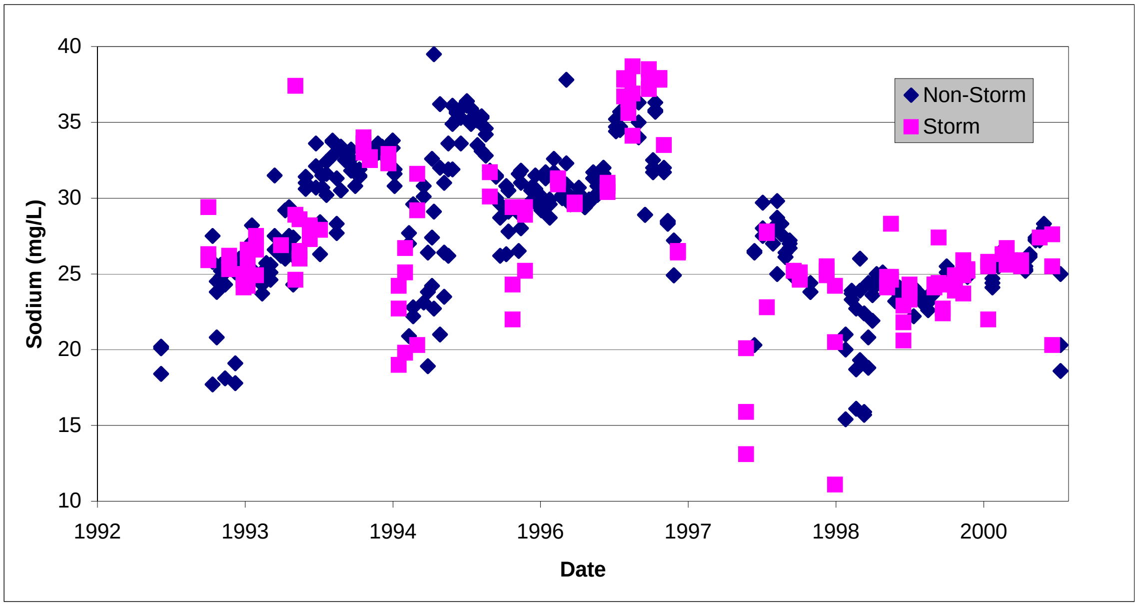
Although total magnesium concentrations during the non-release season are fairly constant over time and exhibit no significant temporal trends, Town Lake release total magnesium is significantly increasing, despite a period of slightly declining concentration from approximately 1995 to 1999, in both storm and non-storm flow conditions (Figure 4.135).

Figure 4.135 Town Lake Magnesium During Release, All Sites and Depths



Town Lake sodium, however, is significantly decreasing in both release and non-release seasons (Figure 4.136). Despite these statistically significant overall decreasing temporal trends in Town Lake, total sodium approximates the general pattern of increase through 1997, followed by decreases in both chloride and sulfate concentrations.

Figure 4.136 Town Lake Sodium by Flow Type, All Sites and Depths



4.4.2.6 Monitoring Recommendations

Power analysis of sample frequency for selected ion parameters in Town Lake monitored by the COA-ERM was completed to yield the minimum significant detectable differences in mean watershed concentrations over time using current estimates of summary statistics and sampling rates projected into the future for the next one and five years (Table 4.17).

Table 4.17 Minimum Significant Detectable Differences in Watershed Mean Dissolved Solid Concentrations (as a value and percentage of current mean) if Sampling Continued at Current Rates Over Specified Time Periods

PARAM (mg/L)	**Non-Release**				**Release**			
	Non-storm		**Storm**		**Non-storm**		**Storm**	
	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 1 yr
Conductivity (µS/cm)	17.60 (3)	7.84 (1)	23.87 (4)	10.64 (2)	28.41 (5)	12.66 (2)	26.54 (5)	11.83 (2)
Chloride	3.59 (8)	1.60 (3)	4.22 (9)	1.87 (4)	3.17 (6)	1.41 (3)	4.25 (9)	1.89 (4)
Sulfate	2.38 (7)	1.06 (3)	2.64 (8)	1.17 (3)	2.04 (6)	0.90 (3)	2.63 (8)	1.17 (4)

As revealed by power analysis results, mean Town Lake concentrations of conductivity, chloride, and sulfate have been well-characterized by current monitoring efforts. In fact, conductivity has been extremely well-characterized within the lake. Unless further interest exists in developing better depth profiles for conductivity or in collecting more conductivity values at depth for model input, the current process of sampling conductivity at 1-meter depth intervals could be reduced to simple surface and bottom monitoring. Although current sampling rates appear to be effectively monitoring the concentrations of chloride and sulfate in Town Lake, the unusual temporal trends and the proximity of annual average chloride concentrations to TNRCC screening criteria suggest no opportunities for reduction in current sampling.

4.5 Bacteria

Because it would not be time- and cost-effective to identify and quantify all microscopic pathogenic organisms in a water sample, indicator bacterial tests have been developed (Masters 1991; Brock et al 1994; Droste 1997). Use of bacteria as indicators of water contamination began in the late 1800s (Geldreich 1978), and fecal coliform bacteria are the most widely used indicator organism (Droste 1997). More than 90 percent of the total coliform bacteria in the feces of warm-blooded animals are fecal coliforms (Geldreich 1978). Coliform bacteria are aerobic and facultative anaerobic Gram-negative rod-shaped bacteria (Brock et al 1994), which normally live in the intestines of animals and humans and are required for digestion (Droste 1997). The presence of fecal bacteria in water indicates the possibility of contamination of the water from an intestinal source, making the water potentially unsafe for consumption or recreation.

Feces is the major source of microbiological health problems in water (Droste 1997). Broken or leaking sewage transport systems and uncontrolled animal manure are important sources of fecal contamination of water resources as rainfall events convey the fecal matter into streams and reservoirs. Contaminated waters may deliver pathogens to human beings not only by ingestion, but also simply by incidental contact with the polluted water (Masters 1991). Fecal coliform contact recreation standards were established by the TNRCC (2000) for the Town Lake segment of the Colorado River (Table 4.18) as annual geometric means. At this level, it is estimated by the USEPA (1987) that eight swimmers per 1,000 would be affected by waterborne pathogenic illness. Criteria for drinking water in the United States are much lower, and the USEPA mandates that water for human consumption must have less than one coliform colony per 100mL of water.

Table 4.18 2000 TNRCC Bacteria Contact Recreation Standards in Reservoirs*

Bacteria Parameter	Standard (colonies/100mL)
Fecal Coliform	200
E. Coli	126

*Note that these are segment-specific criteria applying only to Town Lake

Increased fecal coliform bacteria in Town Lake not only would limit the use of the lake for recreational and drinking water supply purposes, but also would indicate increasing problems with sewage transport systems throughout Austin.

4.5.1 Summary of Results

Figure 4.137 presents a graphical summary of Town Lake fecal coliform data.

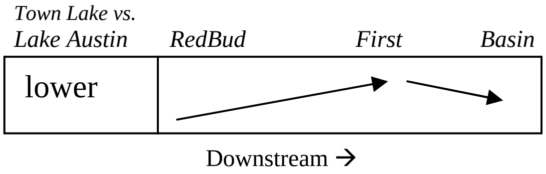
Fecal coliform bacterial counts are inversely related to Lake Austin discharge into Town Lake during storm flow conditions. Fecal coliform bacteria counts are elevated at First Street during storm flow conditions. It appears that Town Lake is increasing the concentrations of fecal coliform from initial concentrations upon entrance to Town Lake from Lake Austin to discharge through Longhorn Dam, negatively impacting the Colorado River. The percentage of exceedances of 2000 TNRCC screening criteria for fecal coliform indicates that Town Lake is potentially of “concern” status for bacteria.

Because of the strong correlation between E. coli and fecal coliform indicator bacteria, monitoring efforts should be directed solely toward E. coli bacteria as new state and federal criteria are adopted and analysis methods are approved.

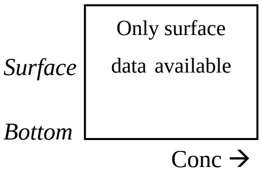
Figure 4.137 Graphical Summary of Town Lake Fecal Coliform Results

SPATIAL

Location

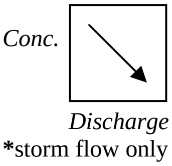


Depth



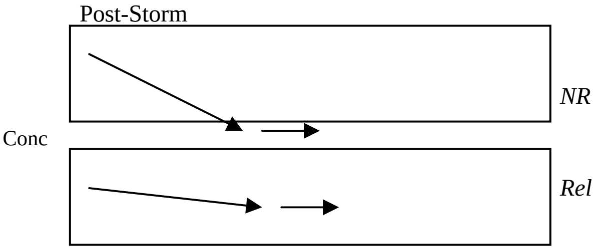
Only surface data available

FLOW/SEASONALITY

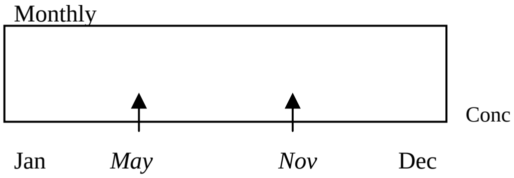


*storm flow only

Storm flows highest in:	*Non-Storm flows highest in:*	*Maximum conc. in:*
No difference	No difference.	Storm

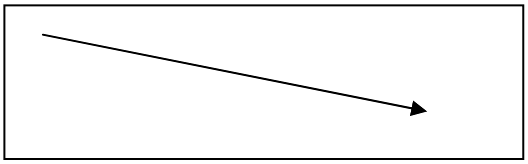


Release post-storm decline more gradual



TEMPORAL

Annual % Exceedance of TNRCC Criteria

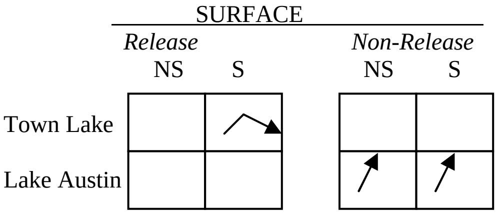


Overall temporal trend

No clear temporal trends

Conc

Temporal Regression



*break-point in 1995

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

Comments:

Town Lake was "of concern" status for fecal coliform in 16 of last 25 years. Strong correlation between E coli and fecal coliform results suggest that as methods and criteria are approved by state and federal agencies, monitoring should switch entirely to E coli.

4.5.2 Spatial Distribution

In storm-impacted flow conditions in Town Lake, fecal coliform bacteria counts are significantly higher at First Street than at any other Town Lake site in both the release and non-release seasons (Figure 4.138). However, concentrations at the most downstream Basin site, though still significantly greater than Red Bud, are significantly less than fecal coliform levels at First Street during both release and non-release storm flow conditions, indicating that potential fecal loading to Town Lake from downtown Austin run-off via storm sewer and tributary input are at least partially mitigated before water exits Town Lake through Longhorn Dam. The general pattern of increasing average bacterial concentrations from Red Bud through First Street, with a decrease from First Street to the Basin, is observed in both release and non-release seasons.

During non-storm flow conditions, concentrations at Red Bud are significantly lower than all other Town Lake sites. The generalized pattern of increase in fecal coliform bacteria from upstream to mid-reach Town Lake, followed by decreasing levels from mid-reach Town Lake to the Basin site observed during storm flow, is also exhibited during non-release, non-storm flow conditions. During non-storm flow conditions in both seasons, however, concentrations at the Lamar and MoPac sites are elevated, as are bacteria levels observed at First Street.

Average Town Lake fecal coliform levels are significantly greater than average Lake Austin concentrations for all release and flow conditions (Figure 4.139).

Figure 4.138 Mean Fecal Coliform Site Counts by Season and Flow Type

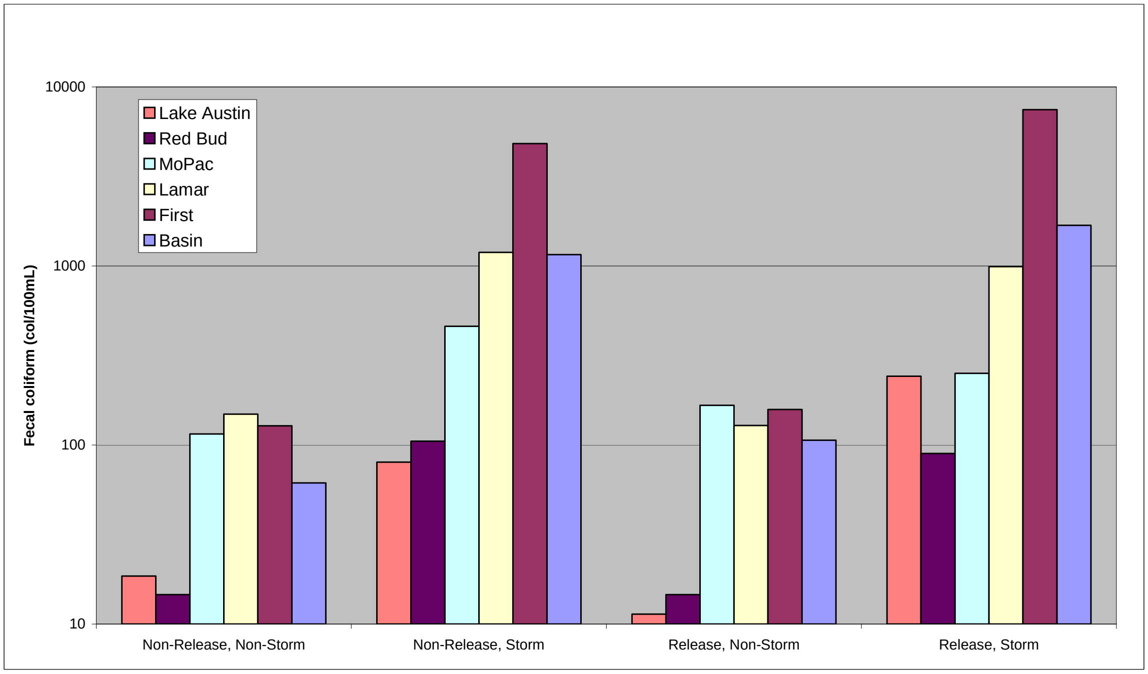
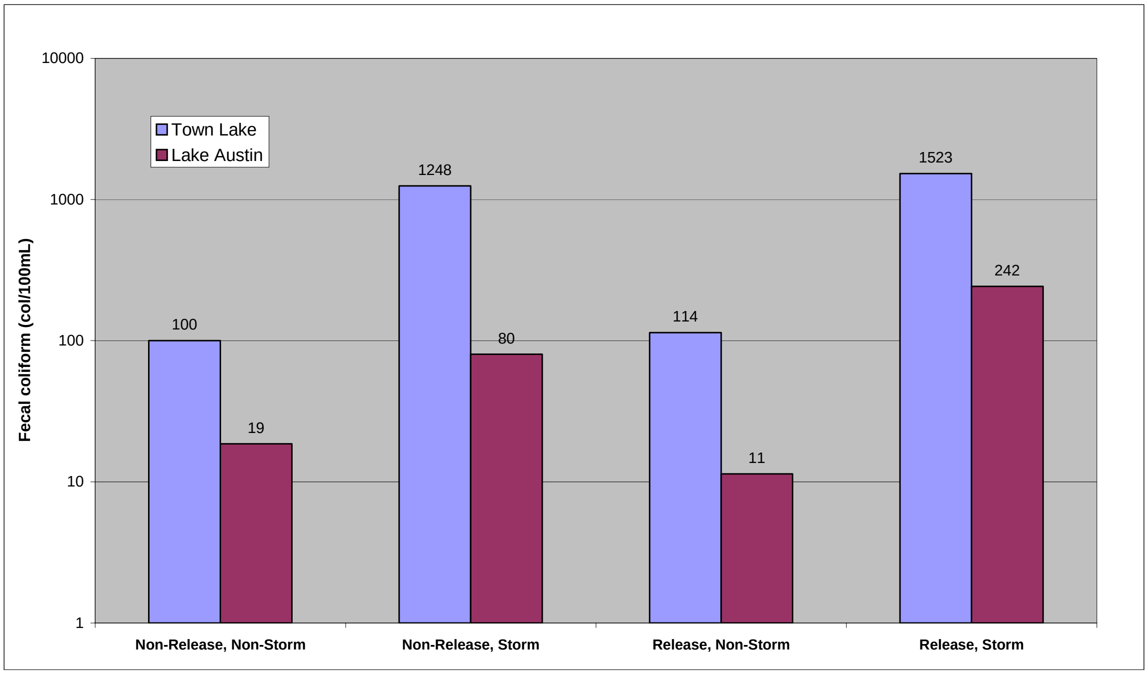
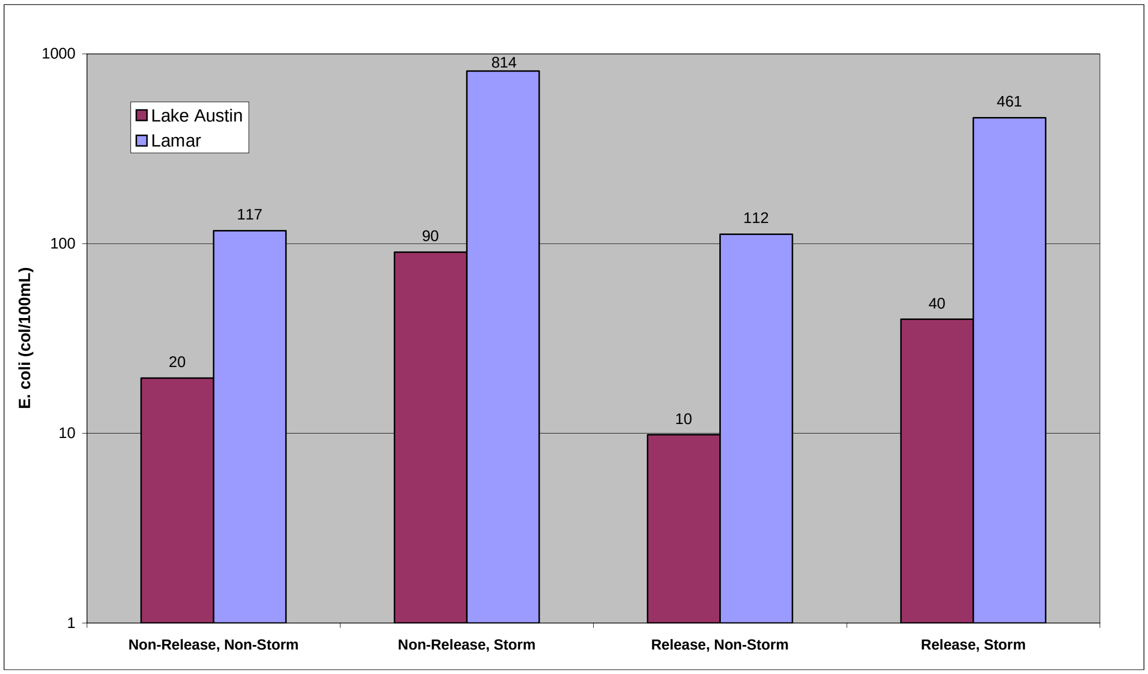


Figure 4.139 Mean Fecal Coliform Watershed Counts by Season and Flow Type



COA-W/WW has also collected E. coli bacterial data from the raw intakes of the treatment plants on Lake Austin and Town Lake since 1998. Because E. coli has been identified as a replacement indicator organism for fecal coliform, analysis of even the limited E. coli data is especially relevant. Correlation analysis reveals a strongly significant ($p<0.0001$) direct relationship between E. coli counts and fecal coliform counts in Town Lake and Lake Austin in every release and flow condition, with an overall Pearson's $\theta = 0.9074$ ($p<0.0001$) for all data combined for analyses. Similar to fecal coliform bacteria concentrations, Town Lake average E. coli levels as measured at Lamar are significantly greater than Lake Austin average bacteria concentrations in all storm and release conditions (Figure 4.140).

Figure 4.140 Mean E Coli Site Counts by Season and Flow Type



4.5.3 Storm and Release Conditions

Although storm flow bacteria concentrations are significantly greater than non-storm bacteria levels in both release and non-release seasons, no significant difference between the release and non-release season was shown during either storm or non-storm flows.

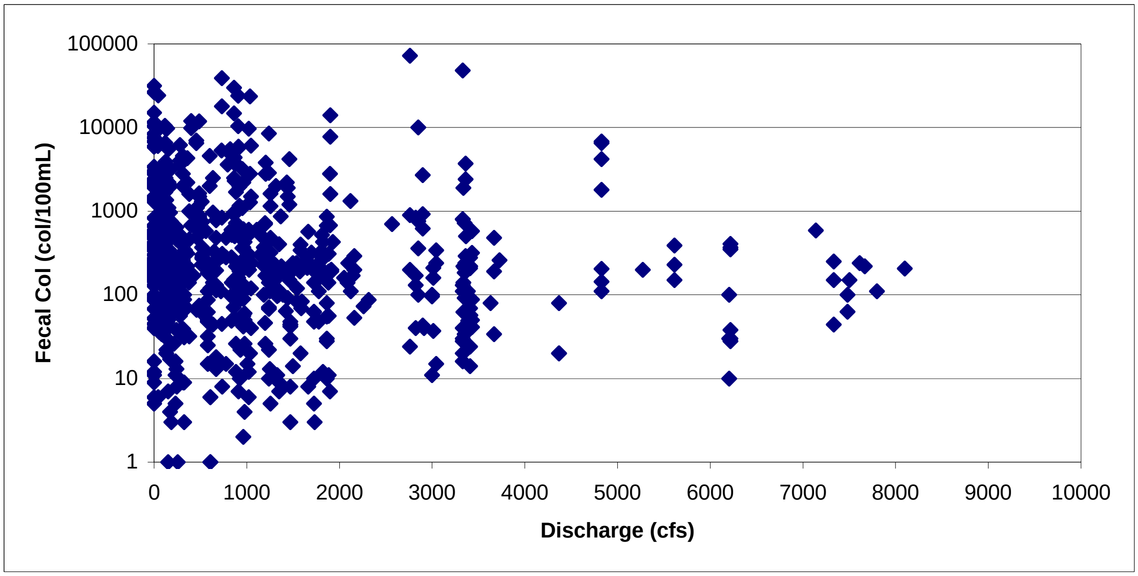
Like fecal coliform bacteria, E. coli levels are higher in storm flow than non-storm flow in both seasons. E coli also shows no statistically significant difference between release and non-release seasons in either storm or non-storm flow conditions.

No significant correlation was shown between Town Lake fecal coliform counts and average daily discharge from Tom Miller Dam during non-storm conditions. However, Town Lake fecal coliform counts are negatively correlated with Lake Austin inflows during storm flows (Figure 4.141), corroborating suspended solid results that suggest Lake Austin may partially mitigate storm flow impacts to Town Lake.

Table 4.19 Spearman Correlation Coefficients for Town Lake Fecal Coliform Counts versus Mean Daily Discharge from Tom Miller Dam During Storm Flow

Non-Release		Release	
θ	***p***	***θ***	***p***
-0.2569	< 0.0001	-0.2520	<0.0001

Figure 4.141 Town Lake Fecal Coliform Counts versus Mean Daily Discharge from Tom Miller Dam



Monthly patterns in non-storm average fecal coliform bacteria within Town Lake generally follow the average monthly frequency of floodgate releases from Tom Miller Dam (Figure 4.142), but do not directly relate to rainfall or average daily total release into Town Lake. Although elevated fecal coliform averages do occur in May, September, and October, when average monthly rainfall totals are highest, the peak in fecal coliform concentrations in November occurs in a month that typically receives only moderate rainfall. Average monthly fecal coliform bacteria counts during storm flow conditions in Town Lake, however, more closely mimic observed patterns in monthly rainfall totals, with a notable exception during July, when rainfall is low but fecal coliform counts remain elevated (Figure 4.143).

Figure 4.142 Town Lake Mean Monthly Non-Storm Fecal Coliform Counts with Mean Monthly Frequency of Floodgate Releases from Tom Miller Dam

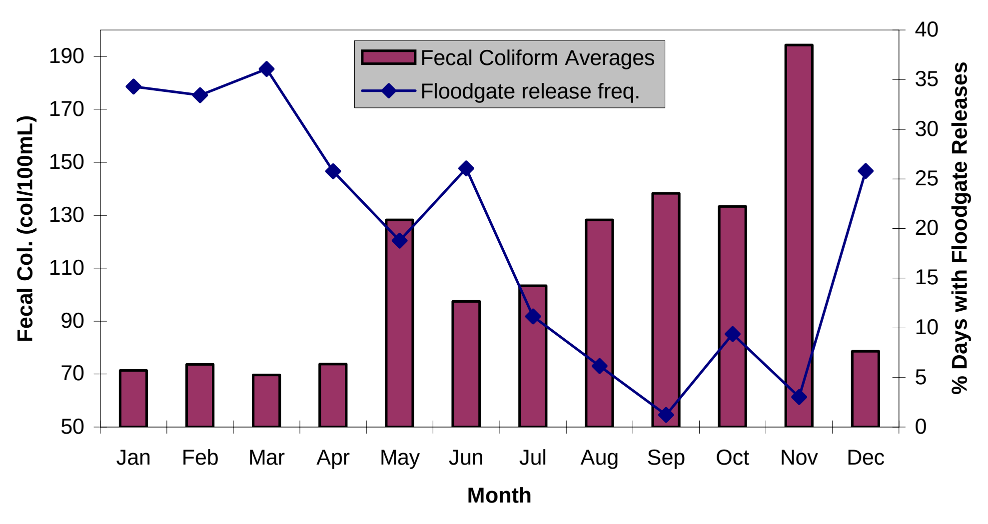
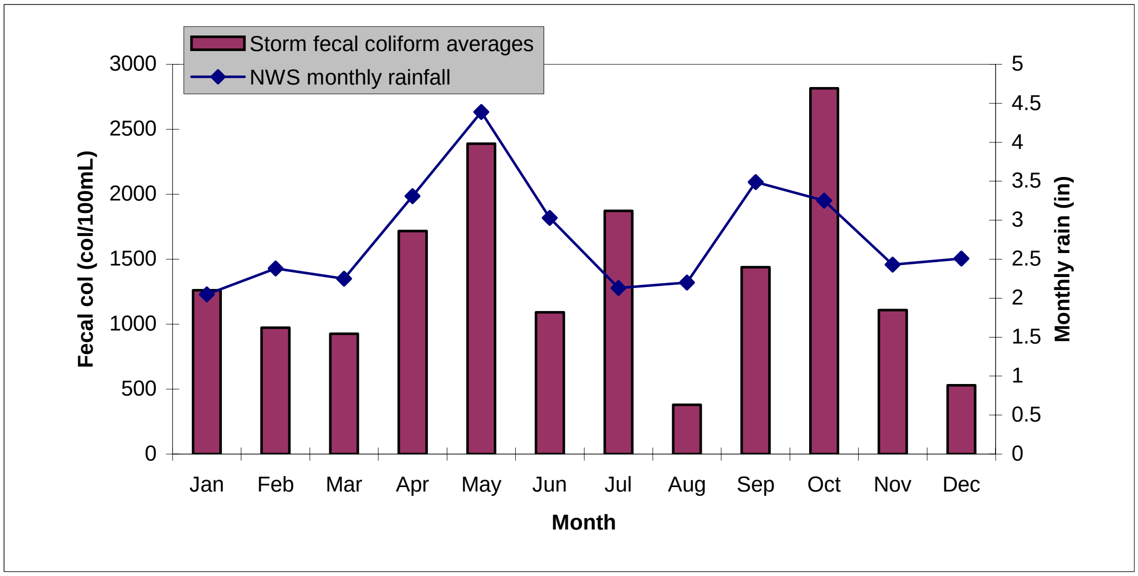


Figure 4.143 Town Lake Mean Monthly Storm Fecal Coliform Counts with Mean Monthly NWS Rainfall Totals



Following storm events greater than or equal to 0.5" in magnitude with at least three dry days prior to the storm event, fecal coliform levels in Town Lake decrease substantially in both release and non-release seasons within the first three days (Figure 4.144). During the release season, however, an anomalous spike in average fecal coliform counts occurred on the fifth day after the storm event, though average concentrations return to the pattern of continual decline on the sixth day. Despite a lack of data due to the fairly recent addition of E. coli bacteria to the COA-W/WW sampling protocols, similar patterns of decreasing E. coli bacteria levels are observed following storm events greater than or equal to 0.5" with at least three dry days prior to the storm event (Figure 4.145). Note that in both E. coli and fecal coliform average bacteria counts, concentrations during release are substantially higher than non-release on the day of storm event.

Figure 4.144 Town Lake Mean Fecal Coliform Counts Following Large (≥0.5”) Storm Events by Season

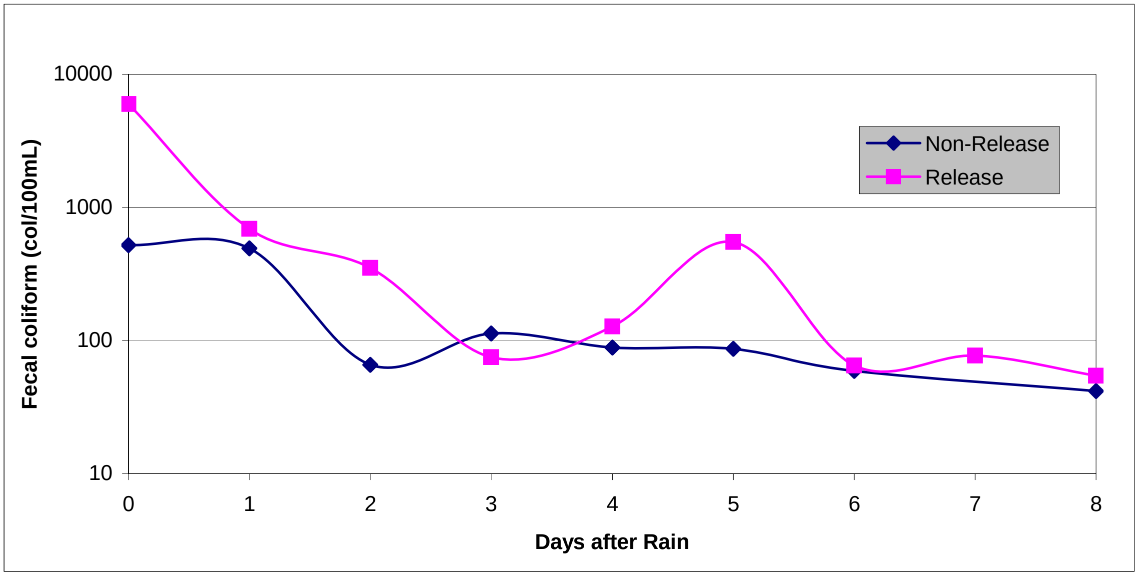
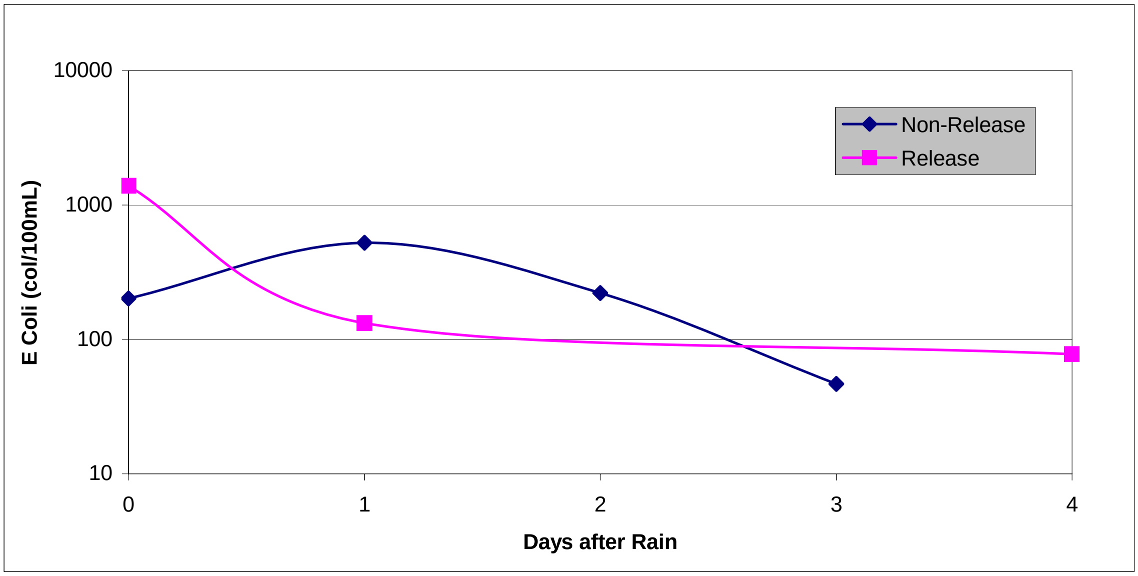


Figure 4.145 Town Lake Mean E Coli Counts Following Large (≥0.5”) Storm Events by Season



In order to increase the available dataset to display post-storm effects on Town Lake fecal coliform bacteria at individual sample sites, analysis of average fecal coliform counts following storm events greater than or equal to 0.1" in magnitude was performed (Figures

4.146 and 4.147). During non-release on the day of the storm event, average fecal coliform levels at First Street are approximately 7,000 colonies/100mL greater than all other sites. Red Bud and Lake Austin non-release average fecal coliform counts not only are considerably less than all other sites on the day of the storm, but also generally remain lower than all other sites through at least the eighth day after the storm event. The slightly elevated levels observed during the release season on the fifth day after the storm event are also observed at the First Street, Lamar and Red Bud sites during non-release. During the release season, the same significantly higher average fecal coliform counts are at the First Street site on the day of the storm. Note the distinctly lower average fecal coliform levels observed at the Red Bud and Lake Austin sites during release, as seen in the non-release season as well.

Figure 4.146 Mean Fecal Coliform Counts Following Medium (≥ 0.1") Storm Events During Non-Release by Site

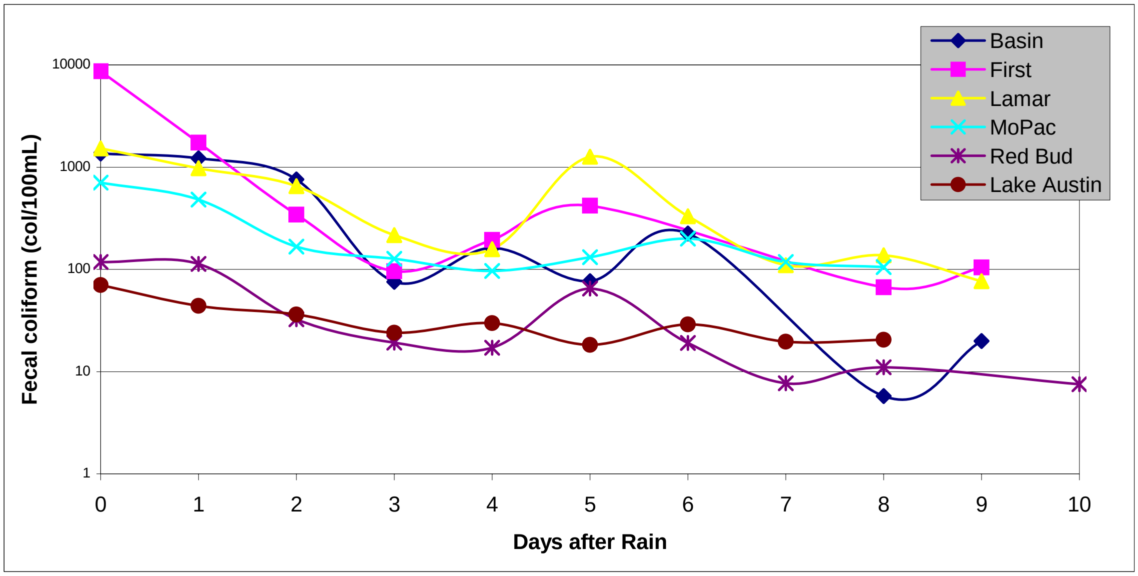
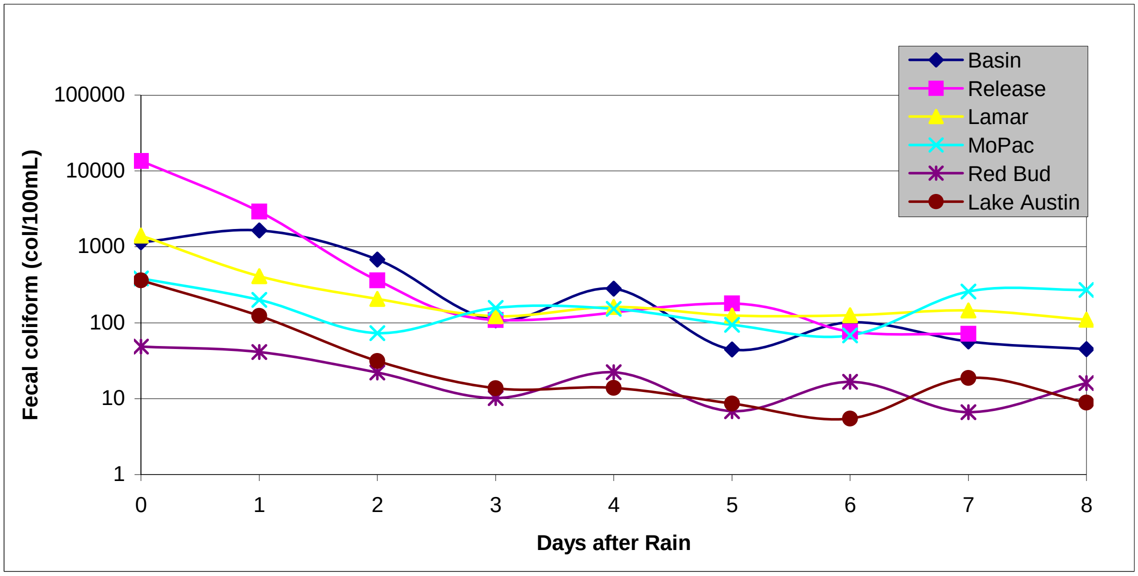


Figure 4.147 Mean Fecal Coliform Counts Following Medium (≥0.1") Storm Events During Release by Site



4.5.4 Concern Status

Comparison of Town Lake fecal coliform bacteria levels to TNRCC contact recreation standards indicates that since 1975, the percentage of Town Lake fecal coliform bacteria samples exceeding the 200 colony/100mL criteria has been greater than 25 percent. Or in other words, fecal coliform levels have been too high to support general use in 16 of the last 25 years (Figure 4.148). However, the annual geometric average of Town Lake fecal coliform counts has not exceeded 200 mg/L since 1990 (Figure 4.149). A general correlation was observed between annual average fecal coliform levels and annual rainfall totals as measured by the NWS at the Austin-Camp Mabry gage. Comparison of E. coli bacteria concentrations in Town Lake since 1998 reveals that in all three years from 1998 to 2000, at least 28 percent of E. coli samples exceeded the 126 colonies/mL screening criteria, with as many as 48 percent of the 215 samples in 2000 exceeding 126 colonies/100mL.

Figure 4.148 Percentage of Fecal Coliform Samples Exceeding TNRCC Contact Recreation Standards by Watershed

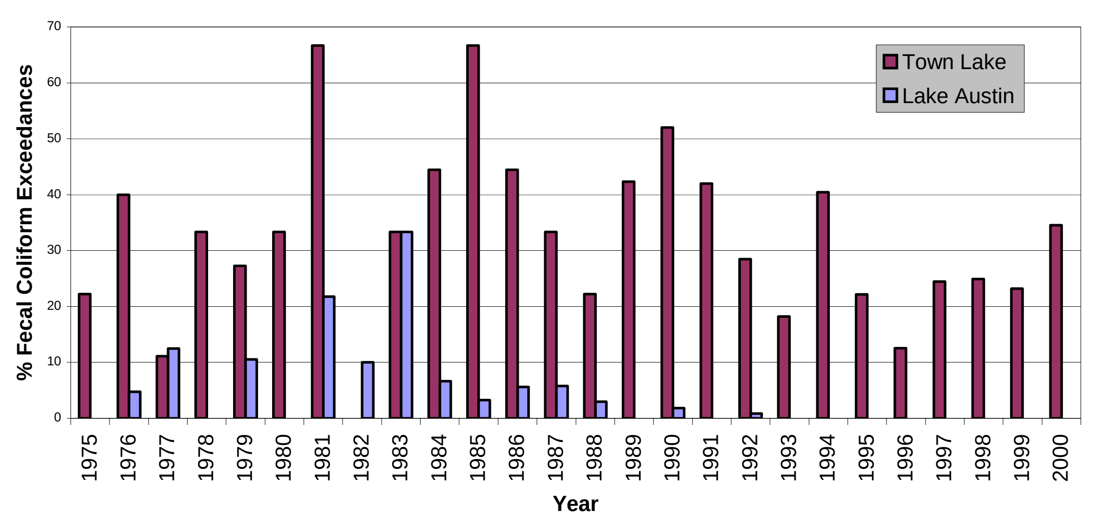
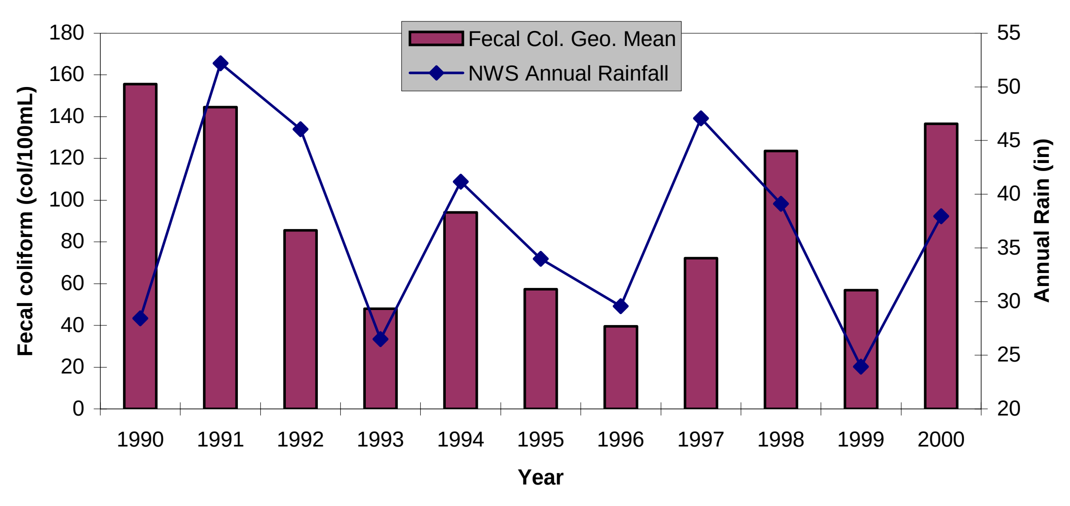


Figure 4.149 Town Lake Annual Geometric Mean Fecal Coliform Counts versus NWS Annual Rainfall



The maximum fecal count of 72,000 colonies/100mL recorded in Town Lake was measured by the USGS from the surface of the First Street site in 1996 during a storm event totaling approximately 0.6 inches, with no rain in the previous 17 days. The USGS also recorded the maximum E coli count of 22,400 colonies/100mL in October 2000, also measured during a storm event from the surface of the First Street site.

4.5.5 Temporal Patterns

Fecal coliform levels during non-release, non-storm flow were significantly greater before 1992, indicating a potential beneficial effect in Town Lake from the minimum flow policy instituted by LCRA in 1991. Non-storm, release fecal coliform levels, however, are significantly higher in post-1992 data. No statistically significant difference was indicated between pre- and post-1992 concentrations during storm flow in either the release or non-release season.

No statistically significant temporal trends occur in overall Town Lake fecal coliform concentrations during either the non-release season in either non-storm (Figure 4.150) or storm flows (Figures 4.151). Evaluating fecal coliform counts at each of the individual sites during the non-release season in both storm and non-storm flow conditions also shows no statistically significant temporal trends.

Figure 4.150 Town Lake Fecal Coliform During Non-Release, Non-Storm Flow, All Sites

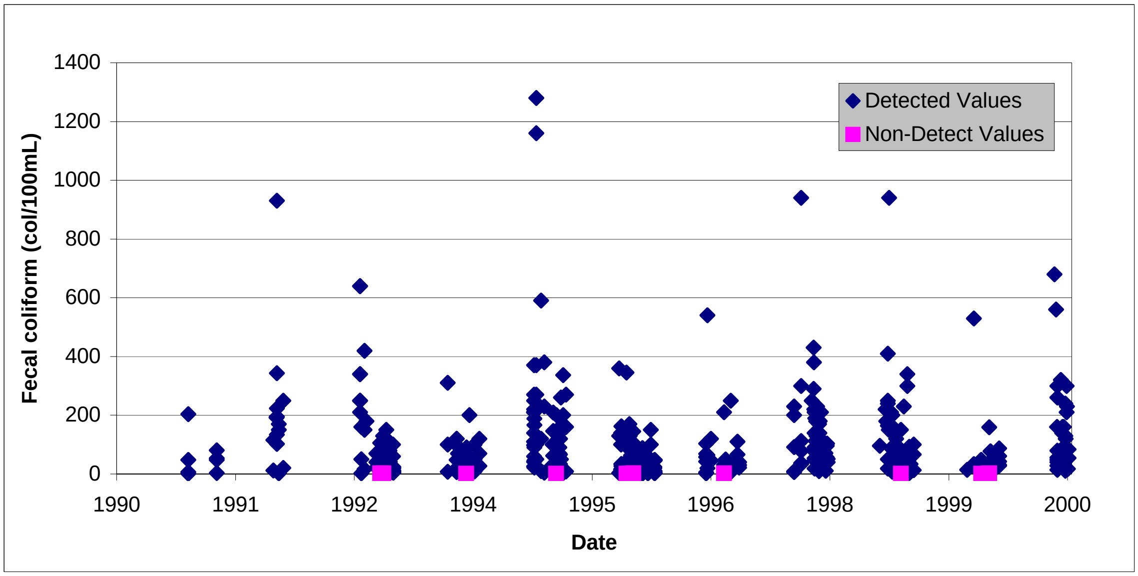
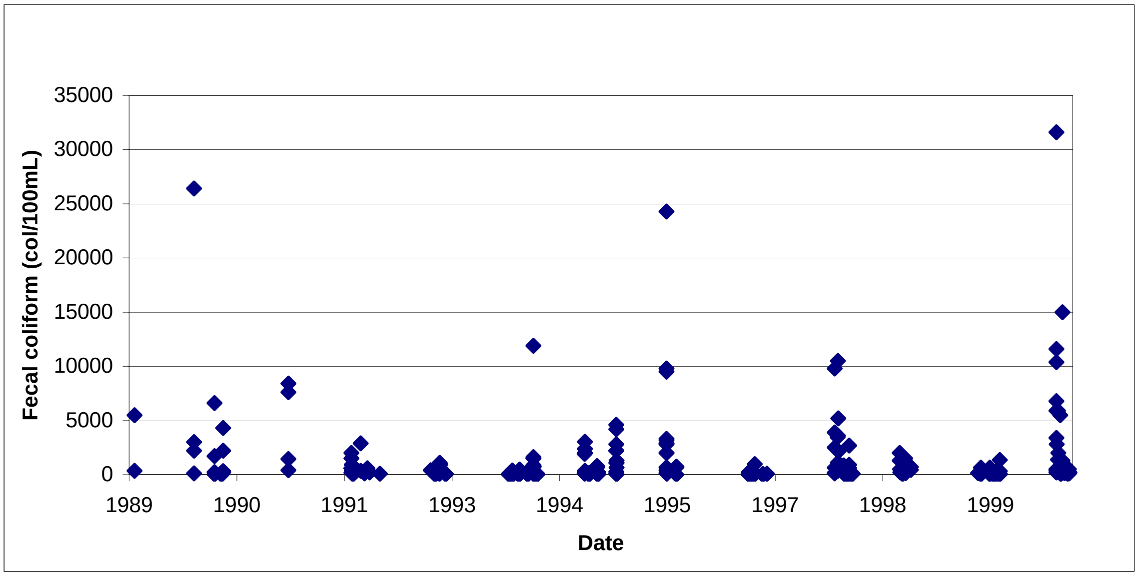


Figure 4.151 Town Lake Fecal Coliform During Non-Release, Storm Flow, All Sites



During the release season in Town Lake, a statistically significant, though slight, increasing trend in fecal coliform counts over time occurred in the non-storm flow category (Figure 4.152). Similar to non-release data, however, no trend occurred during storm flow periods (Figure 4.153). The Lamar site is the only individual site in Town Lake that exhibits a statistically significant decreasing temporal trend in fecal coliform counts during release, non-storm flow conditions. No other sites exhibit any significant trend in fecal coliform concentrations over time during the release season in non-storm flow. Despite the lack of an overall trend in release, storm flow fecal coliform concentrations, statistically significant decreasing trends in bacteria counts during release storms occur at the Basin, Lamar, and Red Bud sites.

Figure 4.152 Town Lake Fecal Coliform During Release, Non-Storm Flow, All Sites

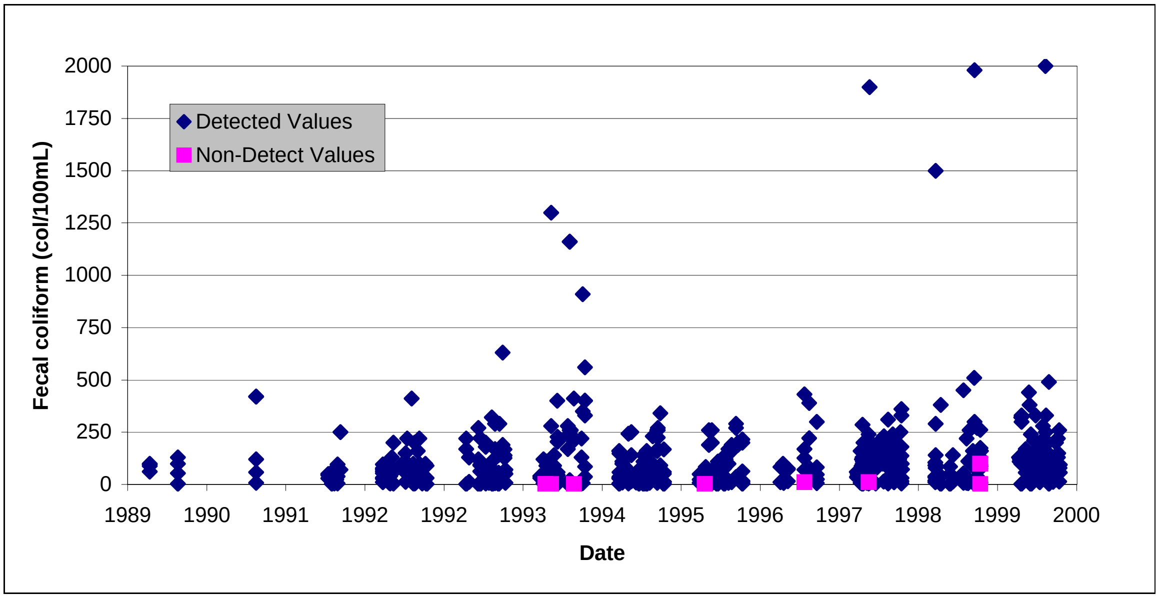
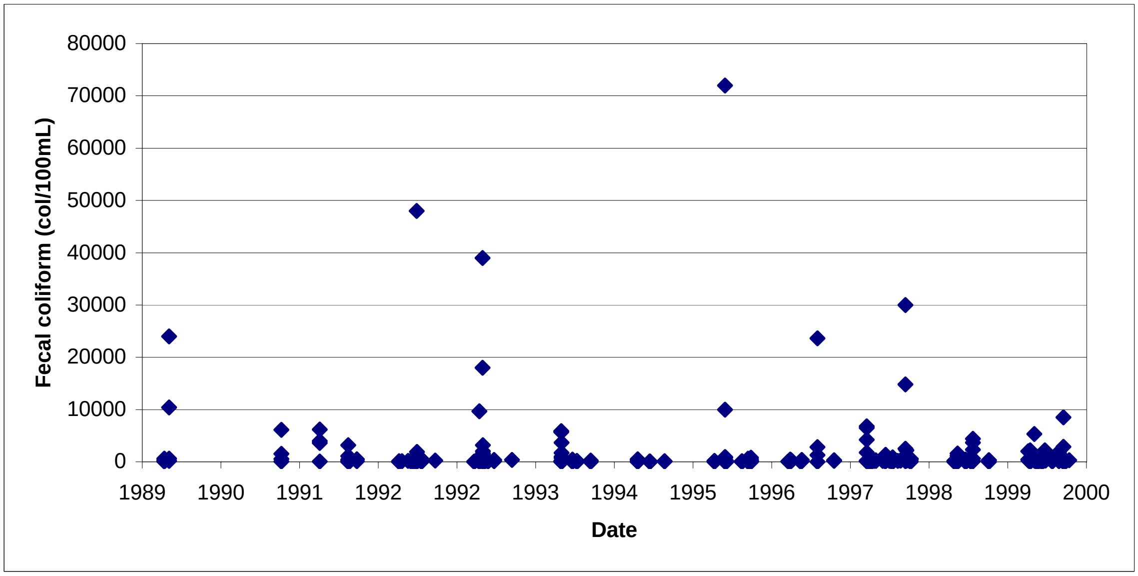


Figure 4.153 Town Lake Fecal Coliform During Release, Storm Flow, All Sites



4.5.6 Monitoring Recommendations

A sample frequency analysis was conducted to determine the minimum significant detectable difference in mean watershed concentration if current sampling rates were projected into the future for the next one and five years (Table 4.20).

Table 4.20 Minimum Significant Detectable Difference in Watershed Mean Bacteria Levels (as a value and percentage of current mean) if Sampling Continued at Current Rates Over Specified Time Periods

Parameter	Non-Release				Release			
	Non-Storm		Storm		Non-storm		Storm	
(Col/100 mL)	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 1 yr
Fecal Coliform	74.584 (75)	32.91 (33)	1688.773 (135)	745.168 (60)	92.064 (81)	40.623 (36)	2956.788 (194)	1304.677 (86)

The high standard deviation in fecal coliform counts, most likely due to imprecision in the storm/non-storm separation procedure as well as large amounts of natural variability, is evident in the large size of minimum detectable difference in mean watershed bacterial levels even during non-storm flow conditions. Due to the lack of temporal trend information and the high percentage of fecal coliform counts exceeding the TNRCC contact recreation standards, in combination with the lack of well-characterized mean fecal coliform counts, no reduction in monitoring is possible at this time.

Because many environmental monitoring agencies are switching to E. coli for indicator bacteria standards, the COA-ERM has conducted concurrent monitoring of both fecal coliform and E. coli in Town Lake. Analysis of the simultaneous monitoring events of both indicator bacteria in Town Lake indicate a strong and significant correlation between E. coli and fecal coliform in every release and storm condition. Thus, as the EPA and TNRCC adopt standards for E. coli, COA-ERM monitoring should change to E. coli, rather than fecal coliform, for future monitoring.

4.6 Physical Parameters (DO, pH and Temperature)

The amount of dissolved oxygen (DO) in a water body is perhaps the most important indicator parameter of water quality (Masters 1991). Oxygen dissolved in water is required not only for animal respiration but also for the oxidation of organic and inorganic compounds present in the water. The ultimate amount of oxygen that can be dissolved in water is dependent upon the temperature and salinity of the water, and oxygen solubility decreases with increasing temperature (Masters 1991; Droste 1997). As organic wastes such as those contained in municipal wastewater effluent are oxidized, the amount of dissolved oxygen in water is reduced (Masters 1991). Five-day biochemical oxygen demand, or BOD, is the amount of oxygen demanded by microorganisms in the biological process of degrading the wastes present in the water in a five-day period and is traditionally considered to be one of the important measures of the organic pollution of water (Masters 1991; Droste 1997).

Dissolved oxygen in water results from the respiration of aquatic plants during photosynthesis and diffusion from the atmosphere. If algal production is stimulated to extreme levels during an algal bloom, DO levels in a reservoir may drastically increase. As the nutrients required to support the excessive algal growth are exhausted, however, the algae will begin to die and the decomposition of the organic plant material will drive DO concentrations down to levels that may be toxic to fish. This process is a part of eutrophication, or aging, of a lake. The USEPA (1987) gives acute lethal limits of DO concentrations for warmwater fish as 3.0 mg/L, although effects in fish populations may be observed at higher DO levels near 5.0 mg/L as benthic organisms die or if fish are in vulnerable early life stages. TNRCC (2000) has established screening criteria for Town Lake physical parameters such as DO (Table 4.21).

Table 4.21 TNRCC 2000 Physical Parameter Standards in Reservoirs*

Physical Parameter	Screening Level (mg/L)
Dissolved Oxygen	5.0
pH	6.5 – 9.0
Water Temperature	90°F

*Note that these are segment-specific criteria applying only to Town Lake

Low DO waters typically exhibit bad tastes and odors, reducing the usability of the resource for recreation and public water consumption. They also may limit the use of the resource by aquatic life (Masters 1991). DO levels and water temperature are inter-related. As water temperature increases, the metabolic rates of aquatic animals typically also increase resulting in an increased requirement for dissolved oxygen. At the same time, the warmer water is physically able to retain less dissolved oxygen (Masters 1991).

Temperature stratification may occur in some lakes where colder waters in the hypolimnion, or bottom depths of the lake, become separated from the warmer waters at the surface of the lake, known as the epilimnion, by a layer of water called the thermocline where the temperature changes rapidly. This stratification typically occurs during summer and winter months as water density reacts to changes in temperature. During stratification, waters of the hypolimnion are separated from the oxygen-rich waters of the epilimnion, although organic matter continues to fall into the hypolimnion. Thus, oxygen demand continues to increase but oxygen supply decreases, driving fish into the warmer waters of the epilimnion. In extreme cases when the hypolimnion becomes anoxic, fish may be killed and toxic substances adsorbed to sediments may be re-released into the water column.

pH, or the negative logarithm of hydrogen ion concentration in solution, is also important in the biological and chemical process of aquatic systems (USEPA 1987). Some compounds become more toxic as pH increases or decreases and metals attached to bottom sediments may be re-released to the water column if the pH reaches certain extreme levels. Changes in normal or established temperature and pH can alter existing aquatic community structures, resulting in loss of recreational resource value through fish and plant community re-structuring and indicating long-term impacts to aquatic systems (USEPA 1987).

4.6.1 Summary of Results

Though not at a magnitude that is problematic, Lake Austin presents more basic mean pH values than Town Lake. Both DO and pH exhibit direct relationships with Lake Austin discharge through Tom Miller Dam into Town Lake. However, Town Lake water temperature is inversely related to Lake Austin discharge into Town Lake.

Town Lake water temperature (despite generally increasing depth) displays increasing longitudinal patterns in concentration from upstream to downstream sites. DO is depressed at the Basin, with a sharp drop in mean concentrations observed from the First Street site to the Basin.

DO is higher in non-storm flow conditions than storm conditions, on average. Town Lake is depleting dissolved oxygen from initial concentrations upon entrance to Town Lake from Lake Austin to its discharge, although Colorado River downstream is more likely to be impacted by oxygen-demanding treated wastewater effluent.

According to temperature information from continuous monitoring instruments, it would appear that Town Lake is more likely to stratify in March, October, and November. Although lake turnover would be expected to occur in April and May, historical observations indicate that turnover in Town Lake is a rare event due to unusual flow patterns. Town Lake turnover, though rare, is most likely to occur in late summer when a period of strong stratification is followed by a large storm event.

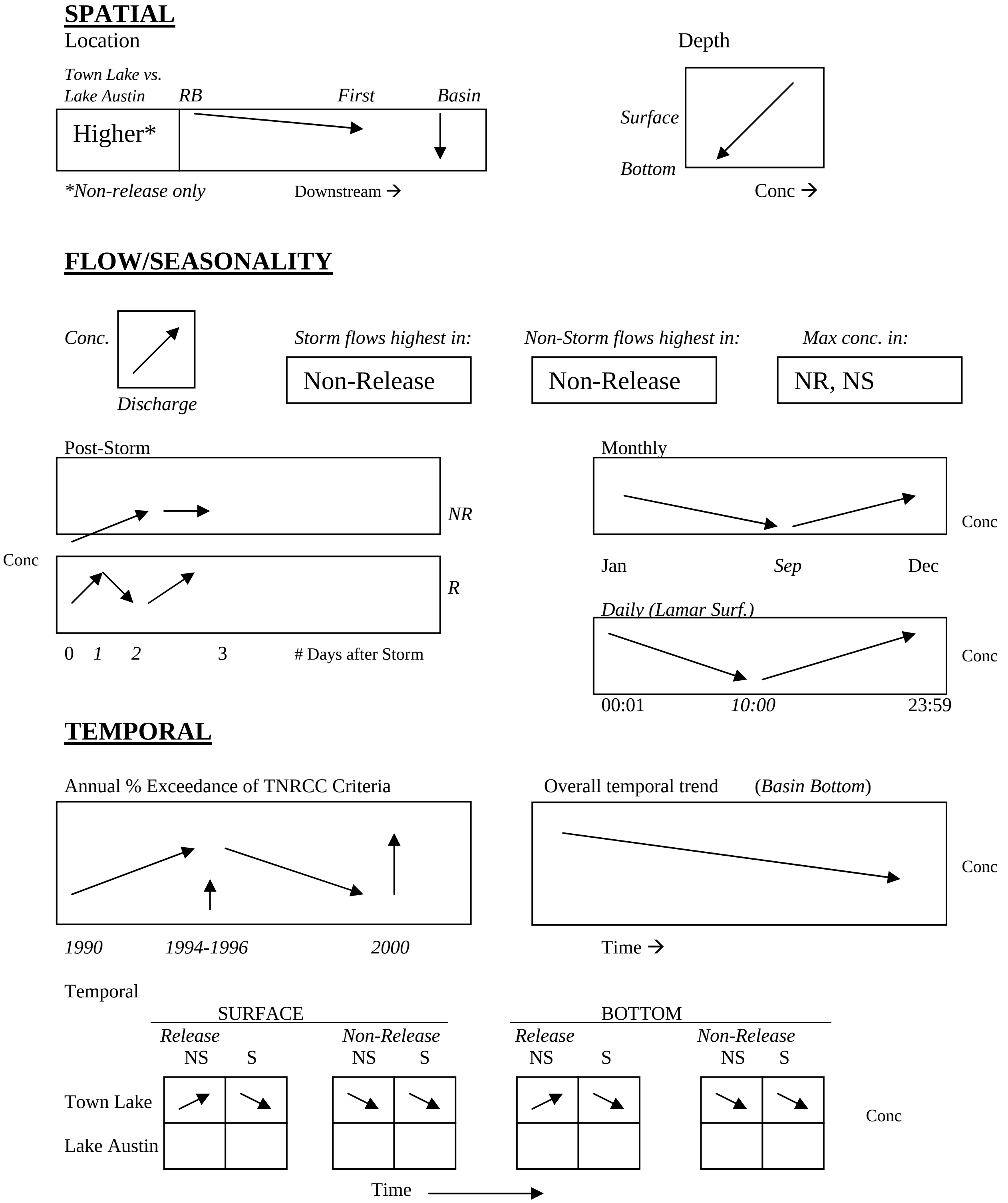
The frequency and duration of near-anoxic conditions at the bottom of the Basin are increasing over time, and DO levels are showing decreasing trends over time during non-release in both storm and non-storm flow conditions. At the present rate of decrease (not considering the large amount of both daily and seasonal variation), mean Town Lake DO during non-release, non-storm conditions would approach the 5mg/L screening criteria in approximately 50 years. Although not currently a problem in Town Lake according to TNRCC assessment methodology, decreases in DO indicate a potential for additional "concern" status due to DO impairment.

Town Lake temperatures exhibit very slight, though significant, increasing trends during non-release conditions in both storm and non-storm flows, potentially contributing to observed decreases in DO.

Field parameters, including DO, temperature, and pH, have been well-characterized in Town Lake. Current sampling rates could be reduced to only surface and bottom depths to reduce sampling time costs. However, the use of data collected at various depths in modeling efforts suggest that this reduction should occur only if a strong need to reduce staff resource expenditures is indicated.

Graphical summaries of Town Lake physical parameter results are presented in Figure 4.154 through 4.156.

Figure 4.154 Graphical Summary of Town Lake DO Results

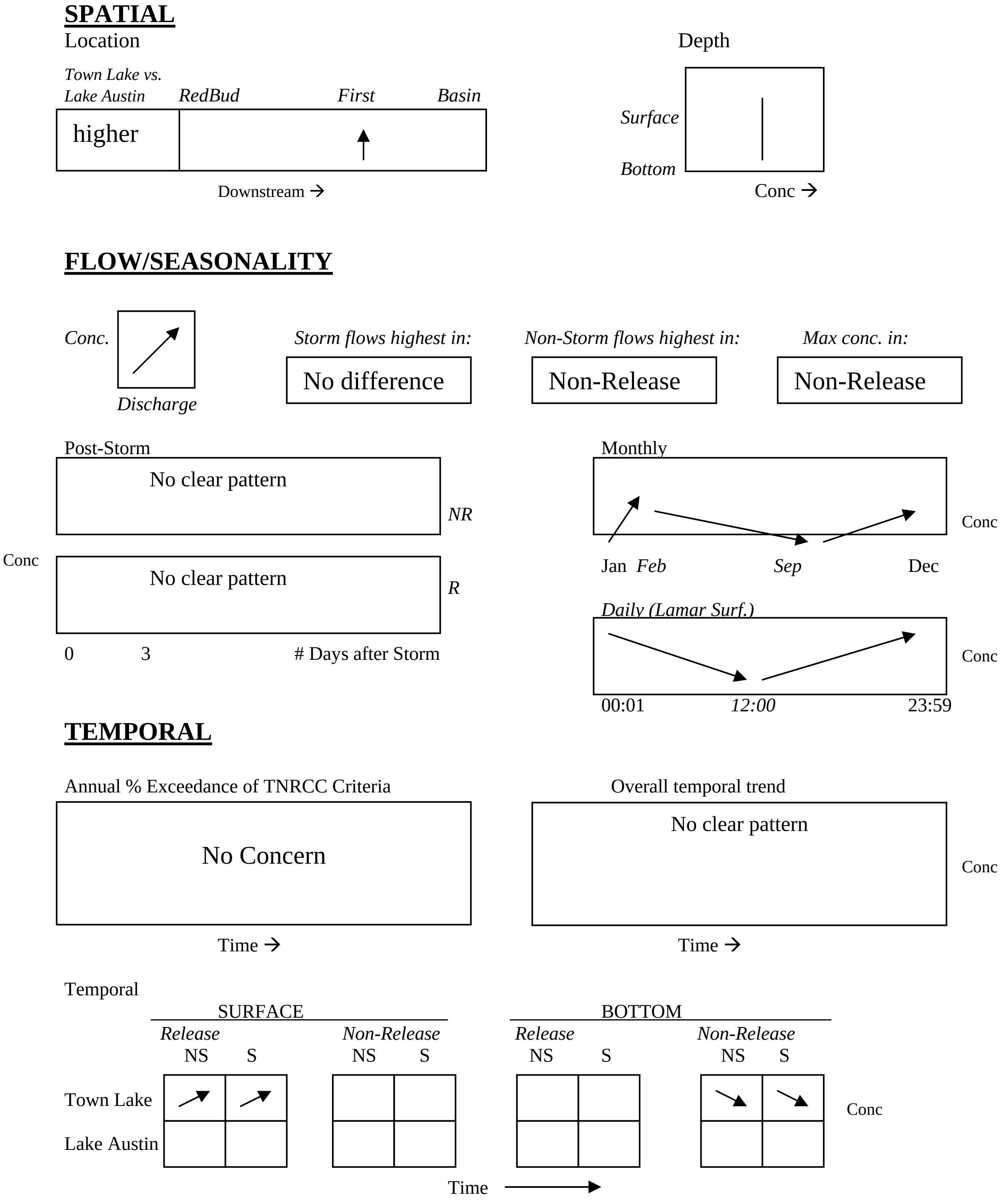


Comments:

Hourly average DO at the Basin bottom nearly constant. Increase in frequency and duration of low DO at the bottom of the Basin. At present rate of decrease, Town Lake mean DO during NR, NS would approach TNRCC screening criteria of 5mg/L in 50 years.

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

Figure 4.155 Graphical Summary of Town Lake pH Results.

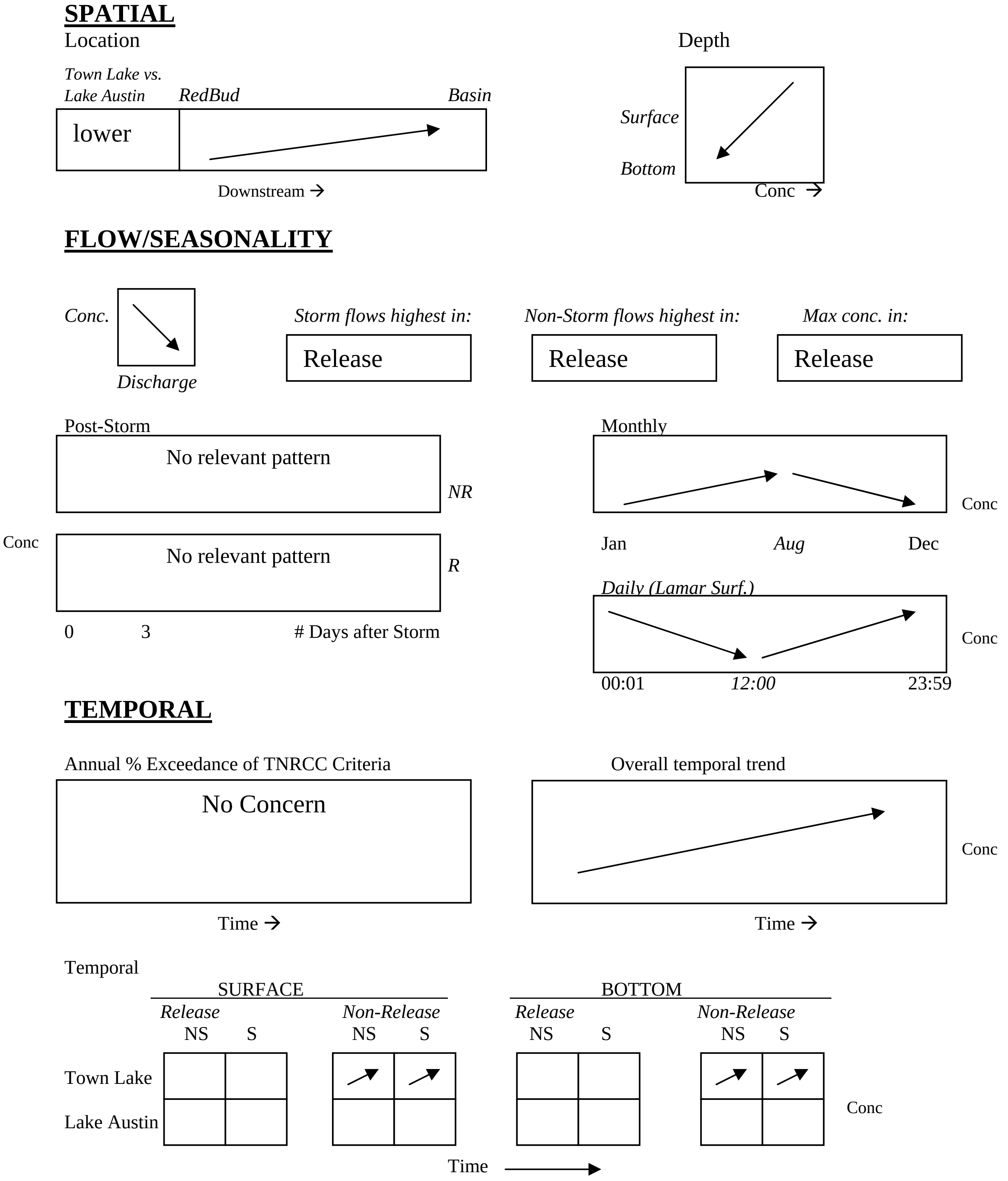


Comments:

Hourly average pH at the Basin nearly constant.

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

Figure 4.156 Graphical Summary of Town Lake Water Temperature Results



Comments:

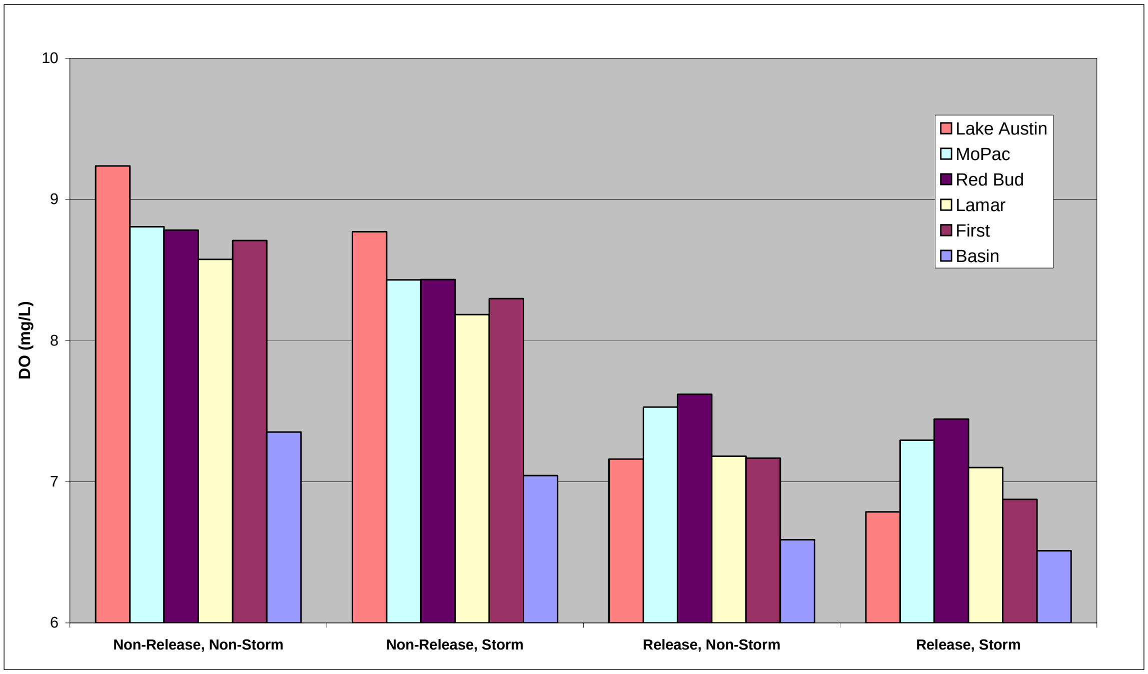
Hourly average temperature at the Basin bottom nearly constant. Clear temperature seasonality. Stratification most likely in October/November.

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

4.6.2 Spatial Distribution

DO levels, when averaged for all depths, are significantly lower at the Basin than all other Town Lake sites during all storm and release conditions (Figure 4.157). Basin, the site on Town Lake with the greatest depth, more frequently experiences low DO values than any other site during all storm and release conditions (Figure 4.158), most likely accounting for the lower total site averages exhibited at the Basin site. During non-release, no statistically significant difference occurred between average DO levels at the First Street, Lamar, MoPac, and Red Bud sites during either storm or non-storm flows. During the release season in non-storm flow conditions, however, concentrations at MoPac and Red Bud are significantly higher than all other Town Lake sites. In storm flows during release, a clear and decreasing longitudinal trend in DO concentration was shown from upstream to downstream sites.

Figure 4.157 Mean DO Site Concentrations by Season and Flow Type, All Depths



Lake Austin DO levels are significantly greater than average Town Lake levels during non-release in both storm and non-storm flow conditions (Figure 4.159). However, no significant difference was indicated between Town Lake and Lake Austin DO levels during the release season in either storm or non-storm flows.

Figure 4.158 Percentage of Samples at Bottom Depths with DO Values < 4 mg/L by Season and Flow Type

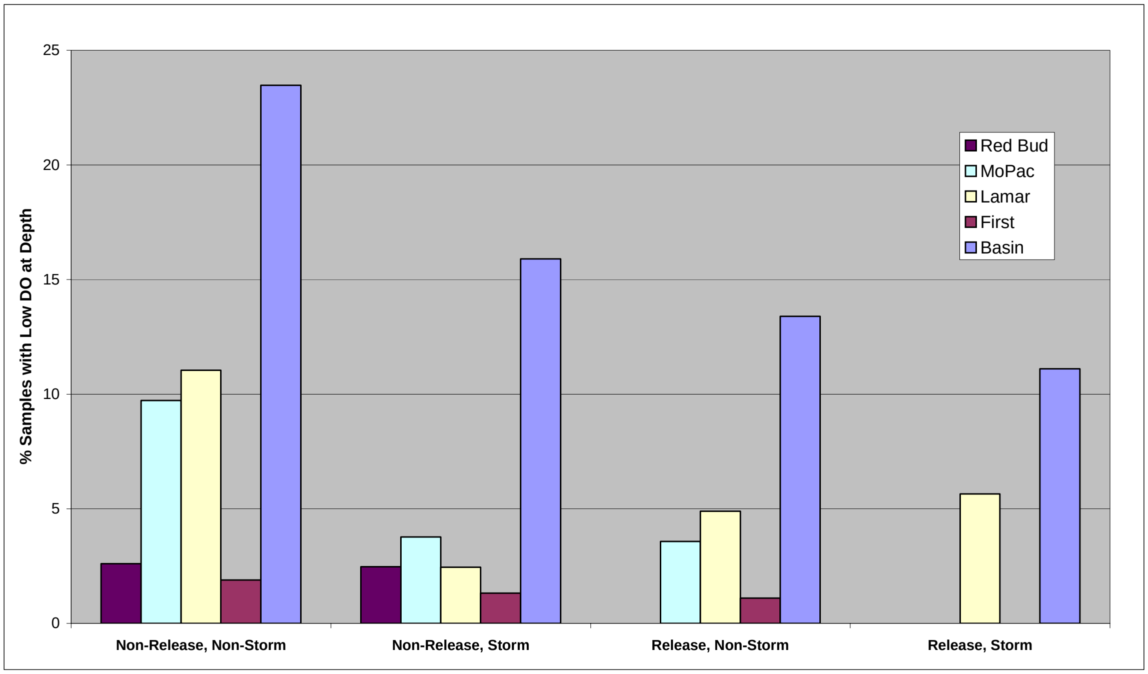
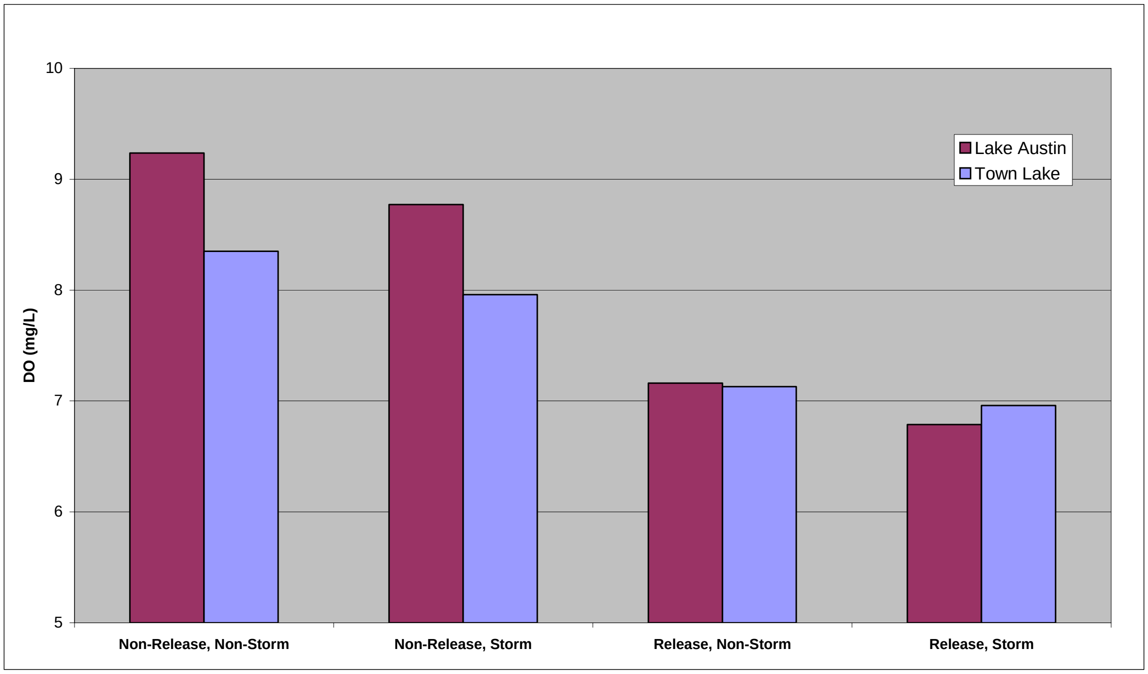


Figure 4.159 Mean DO Watershed Concentrations by Season and Flow Type, All Sites and Depths



Average pH levels at the First Street site are significantly more basic than all other Town Lake sites during non-release, non-storm flow conditions (Figure 4.160), when data from all depths are combined for analyses. During non-release storm flows, pH levels at First Street and Red Bud are significantly higher than all other Town Lake sites. No statistically significant difference was observed between the Basin, Lamar, and MoPac sites during either storm or non-storm flows in the non-release season. During the release season, average pH levels are significantly higher at Red Bud than all other Town Lake sites in both storm and non-storm flow conditions. In non-storm flows during release, pH levels at the Basin are significantly lower than all other Town Lake sites. Although pH levels are significantly higher in Lake Austin than any Town Lake site during all storm and release conditions, the increase in average pH levels at Red Bud during release suggests a potential influx of more basic water to Town Lake, although the lack of increase in average pH at any other site would indicate that this effect is quickly mitigated by Town Lake's slightly more acidic conditions.

Lake Austin exhibits a more basic average pH than Town Lake during all storm and release conditions when data from all sites and depths are composited for analyses (Figure 4.161).

Figure 4.160 Mean Site pH by Season and Flow Type, All Depths

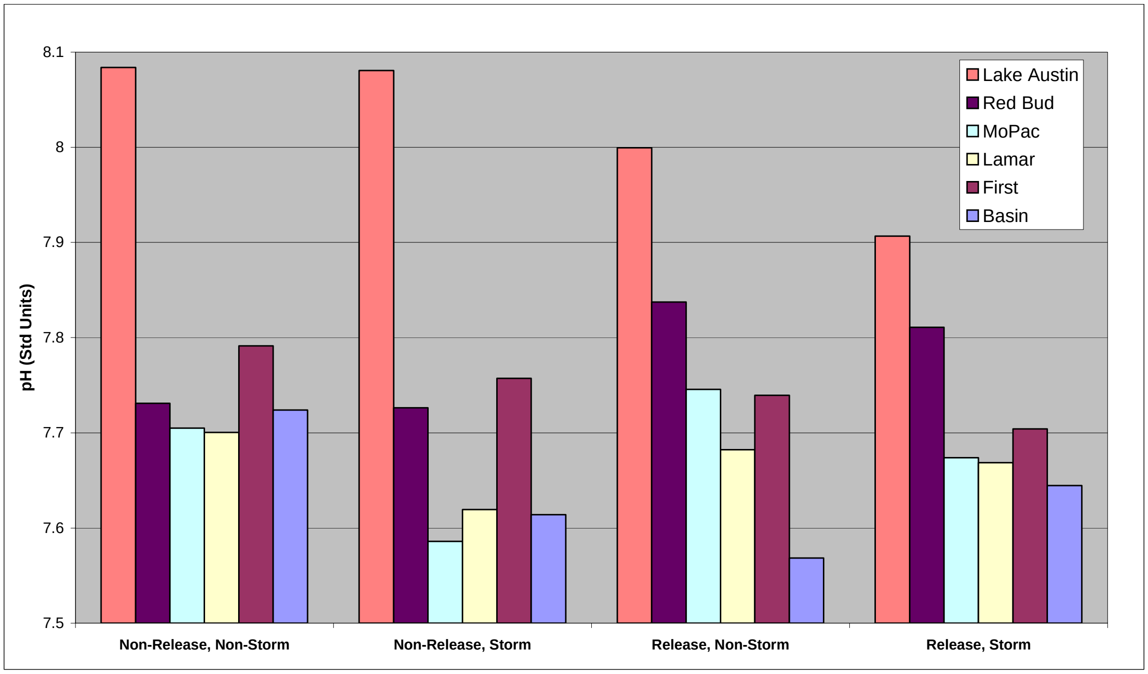
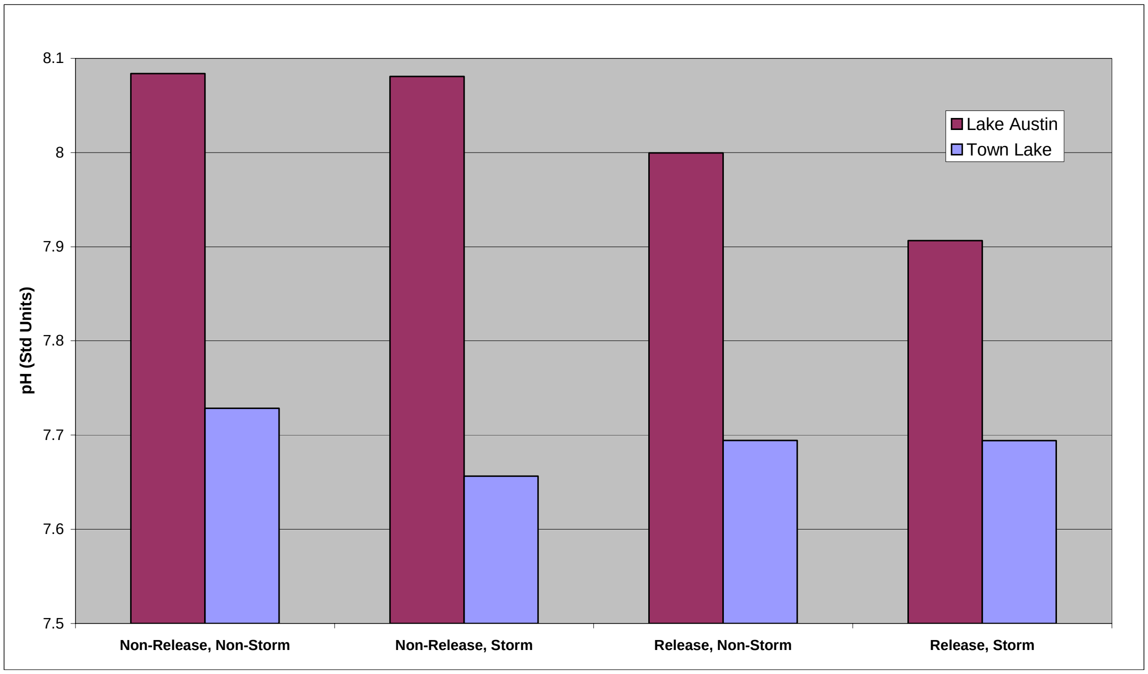


Figure 4.161 Mean Watershed pH by Season and Flow Type, All Depths



Water temperature in Town Lake exhibits generally increasing longitudinal trends from upstream to downstream sites during all storm and release conditions (Figure 4.162). During the winter non-release season, average water temperatures at the Basin are significantly higher than all other Town Lake sites in both storm and non-storm flow conditions. No other statistically significant difference in average water temperature is exhibited between any Town Lake sites during non-release in any flow condition. Average Town Lake water temperature is significantly warmer than Lake Austin during all storm and release conditions (Figure 4.163), most likely due to the reduced depth of Town Lake relative to Lake Austin.

Figure 4.162 Mean Site Water Temperature by Season and Flow Type, All Depths

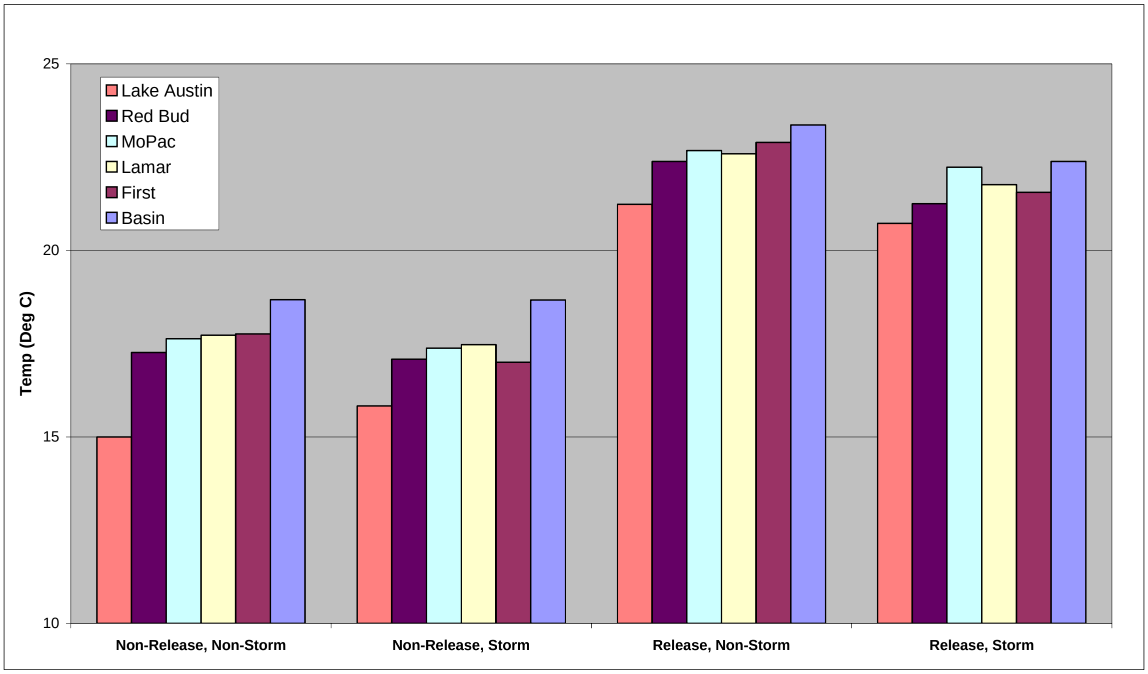
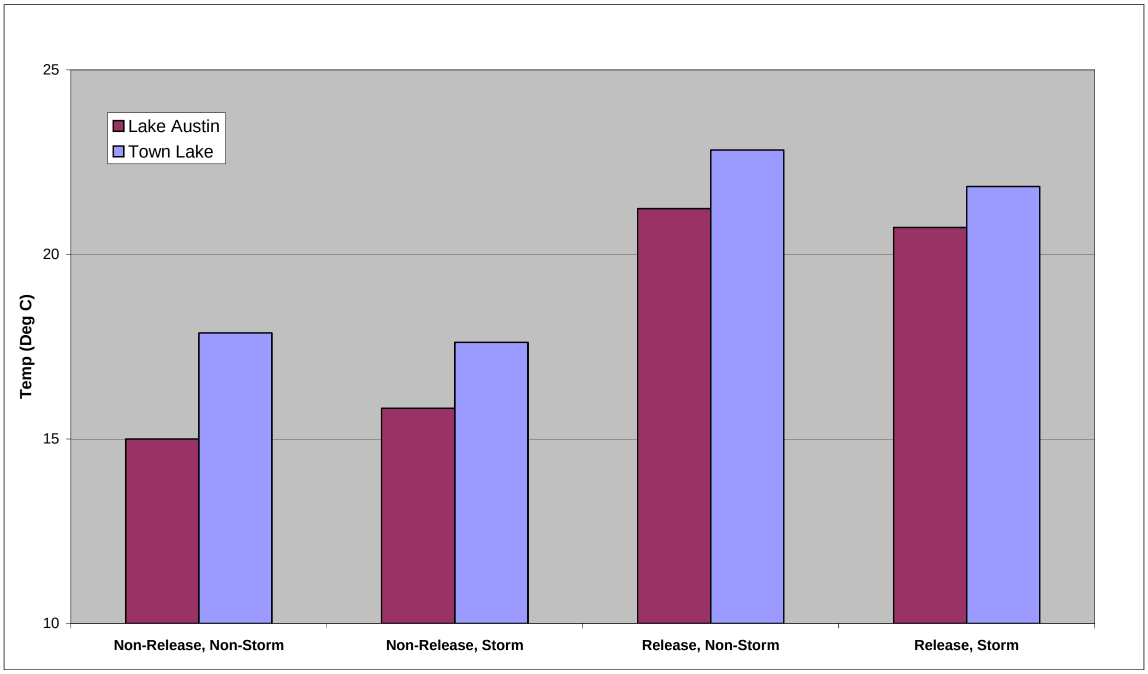


Figure 4.163 Water Temperature Watershed Averages for All Depths by Season and Flow Type



4.6.3 Storm and Release Conditions

Within Town Lake, average non-release DO levels are significantly greater than release averages at both surface and bottom depths during storm and non-storm flow conditions when data from all sites are aggregated for analysis. At the surface, average Town Lake DO levels are significantly higher during non-storm flow conditions than storm flows during both release and non-release seasons, although no difference at bottom depths between storm and non-storm flow average DO levels occurred in either season.

During non-release conditions, non-storm flow in Town Lake exhibits pH levels that are more basic than average storm flow levels at both surface and bottom depths. Although no statistically significant difference occurred between storm and non-storm pH levels in Town Lake at the surface during release, release bottom depths exhibit significantly higher pH levels in storm flow than non-storm flow conditions. Comparison of pH levels between seasons reveals that although no difference occurred between release and non-release at the surface during non-storm flow conditions, bottom pH levels are significantly more basic during non-release than during release.

Summer release average temperatures in Town Lake are significantly greater than winter non-release averages at both surface and bottom depths during both storm and non-storm flow conditions. During the release season, non-storm temperatures are significantly warmer than storm flow temperature averages at both surface and bottom depths in Town Lake. Although no statistically significant difference was shown between storm and non-storm flow temperatures during the non-release season at the surface of Town Lake, non-storm flow temperatures are significantly warmer at the bottom of Town Lake during non-release.

Both DO and pH are positively correlated with discharge from Tom Miller Dam into Town Lake (Table 4.22). However, Town Lake DO is more strongly correlated with Lake Austin inflows during the release season, while Town Lake pH is more strongly correlated to upstream inputs during non-release. DO (Figure 4.164) and pH (Figure 4.165) data from all sites and depths are plotted versus average daily discharge from Tom Miller Dam. Temperature is inversely related to Lake Austin inflows into Town Lake through Tom Miller

Dam (Figure 4.166), with the strongest negative correlation observed during the release season. The inverse correlation between Town Lake temperature and Lake Austin inflow is expected since Town Lake is shallower than Lake Austin and yields higher average temperatures throughout the year. The positive correlation between Town Lake temperature and Lake Austin discharge through approximately 1,400 ft^3/s of discharge through Tom Miller Dam is unexpected, but may be related to seasonal effects.

Table 4.22 Pearson Partial (adjusted for variation with depth) Correlation Coefficients with Mean Daily Discharge from Tom Miller Dam

Parameter	Season	Non-Storm Flow	Storm Flow
Dissolved Oxygen	Non-Release	0.2561	0.2507
	Release	0.3535	0.2714
pH	Non-Release	0.2268	0.1855
	Release	0.0838	0.1402
Water Temperature	Non-Release	-0.1937	-0.2652
	Release	-0.3738	-0.3274

*all correlation coefficients are statistically significant (p<0.0001)

Figure 4.164 Town Lake DO Versus Mean Daily Discharge from Tom Miller Dam

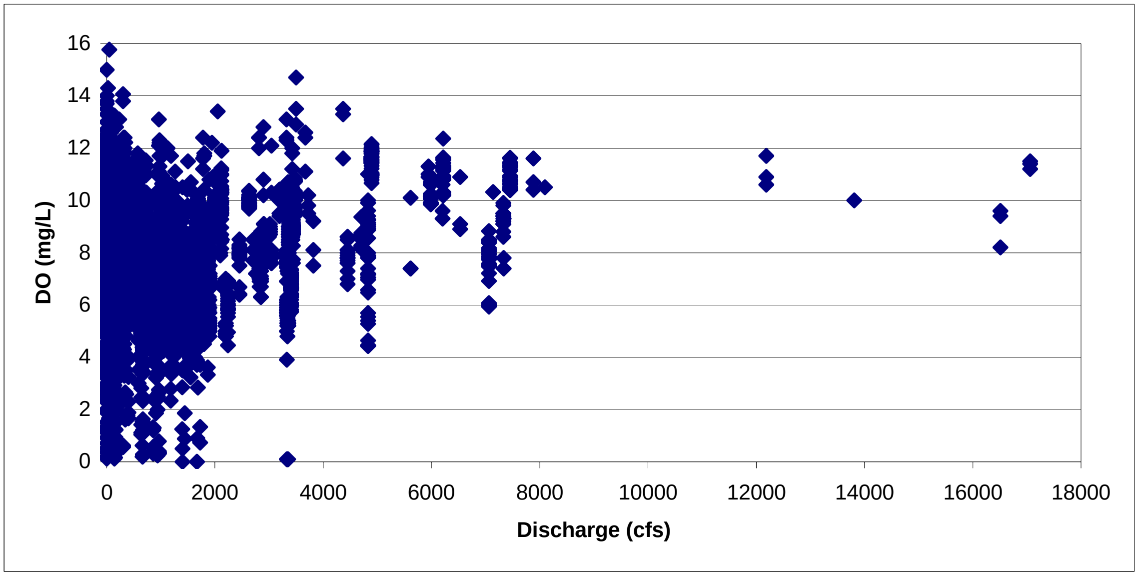


Figure 4.165 Town Lake pH Versus Mean Daily Discharge from Tom Miller Dam

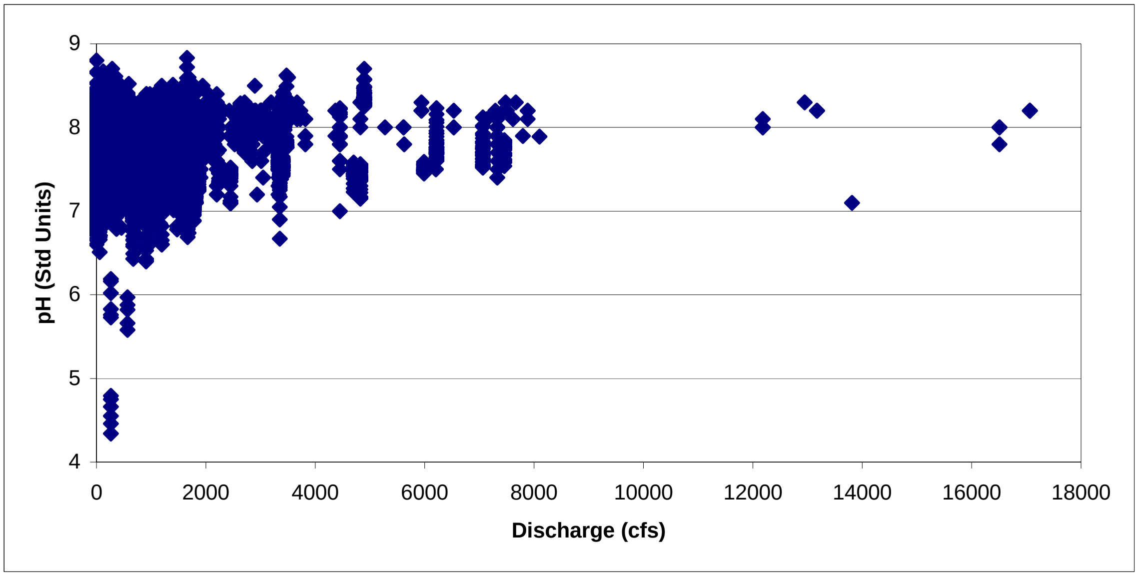
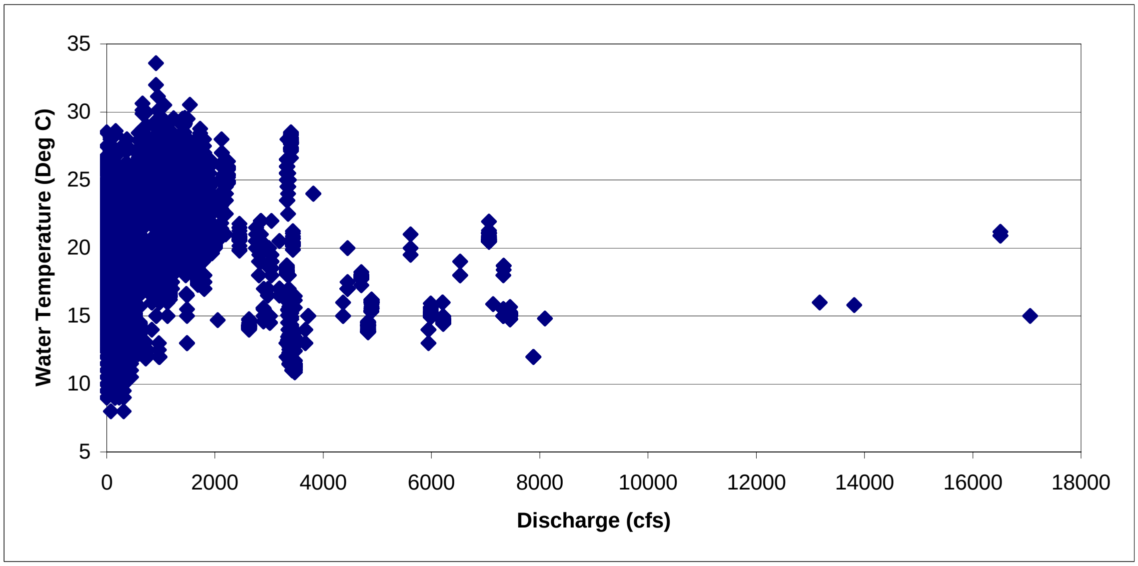


Figure 4.166 Town Lake Water Temperature Versus Mean Daily Discharge from Tom Miller Dam



With depth, Town Lake DO and water temperature values exhibit statistically significant decreasing trends for all storm and release conditions when data from all sites are combined. Note that the primary difference between the storm and non-storm average DO concentrations in Town Lake during non-release is a divergence at the surface (Figure 4.167). During release, the same decrease in surface DO under storm flow conditions is evident, although storm DO values are slightly higher at bottom depths. Average temperature in Town Lake also generally decreases, though slightly, with increasing sample depth (Figure 4.168). However, because DO saturation in water is inversely related to water temperature, the decrease in average DO values cannot be accounted for simply by water temperature variation.

Town Lake temperatures are generally most uniform throughout the lake during the release season, particularly during storm flow (Figure 4.168). Thus, lake turnover is most likely to occur in the late summer release season when temperature gradients are minimized, although historical observations indicate that turnover is rare in Town Lake. During the non-release season, a slight thermocline may potentially occur between 3 and 4 meters below the surface of the lake, as exhibited by the more marked drop in temperature visible near those depths. However, DO averages by season and flow type do not reflect a thermal separation between 3 and 4 meters in depth, and extreme divergence in average DO values for all sites composited for analysis occurs only at absolute bottom depths where organic matter, and the resulting oxygen demand, would be concentrated.

Attempting to detect lake stratification from these generalized plots, particularly from the DO averages (Figure 4.167), is difficult not only due to the large amount of variation accumulated from the data aggregation process, but also due to the natural climatic variation. Average monthly Town Lake and Lake Austin surface water temperatures are strongly correlated to monthly air temperature (Figure 4.169). Monthly average DO and temperature plots by depth are shown for the Basin (Figure 4.170 and 4.171), the Town Lake site most likely to experience low DO values. The lowest Basin DO-depth profiles and highest temperature-depth profiles are observed from June to October when monthly air temperatures are highest. Basin average monthly DO-depth profiles do not correlate with average monthly rainfall, as the month of May, which exhibits maximum average monthly rainfall, yields a moderate DO-depth profile. However, the same months in which Lake Austin inflows are decreasing, from June to November, DO-depth profiles are lowest. No clear and rapid alteration in average temperature with increasing depth was observed in any month to indicate a consistent thermal stratification of the lake. From the temperature-depth profiles, it is possible to theorize that lake turnover is most likely to occur in April and May, the most linear and constant monthly temperature-depth profiles, and lake stratification is most likely in March, October, and November, the months with the largest and most rapid change in temperature with depth. Historical observation, however, indicates that turnover in Town Lake is rare and most likely to occur in late summer after a period of strong stratification followed by a large storm event.

Figure 4.167 Town Lake DO Depth Profile by Season and Flow Type

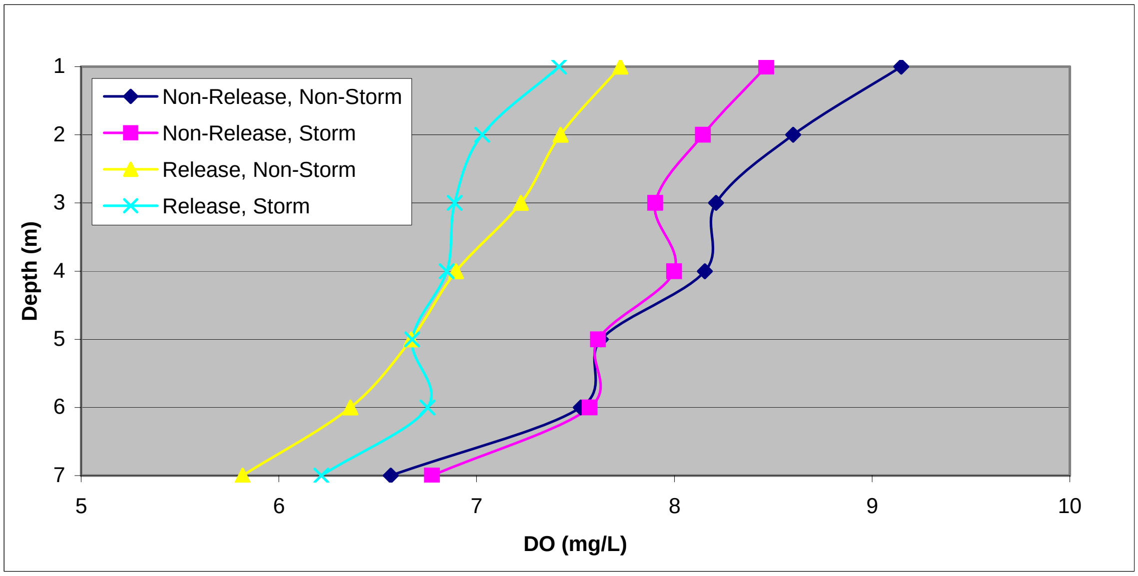


Figure 4.168 Town Lake Water Temperature Depth Profiles

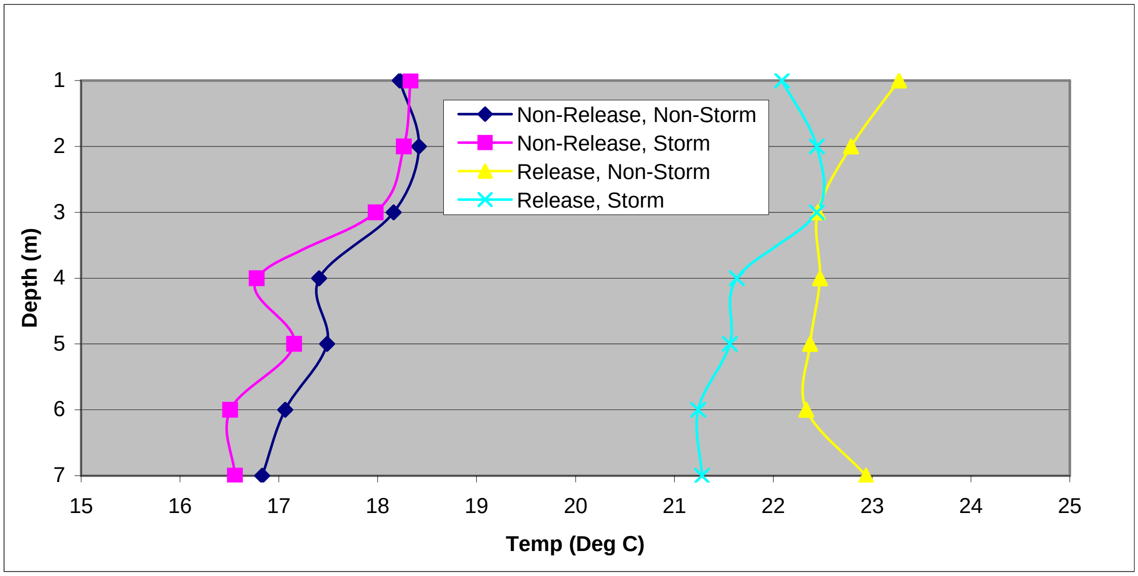


Figure 4.169 Town Lake and Lake Austin Mean Monthly Surface Temperature Versus Mean Monthly Austin Air Temperature

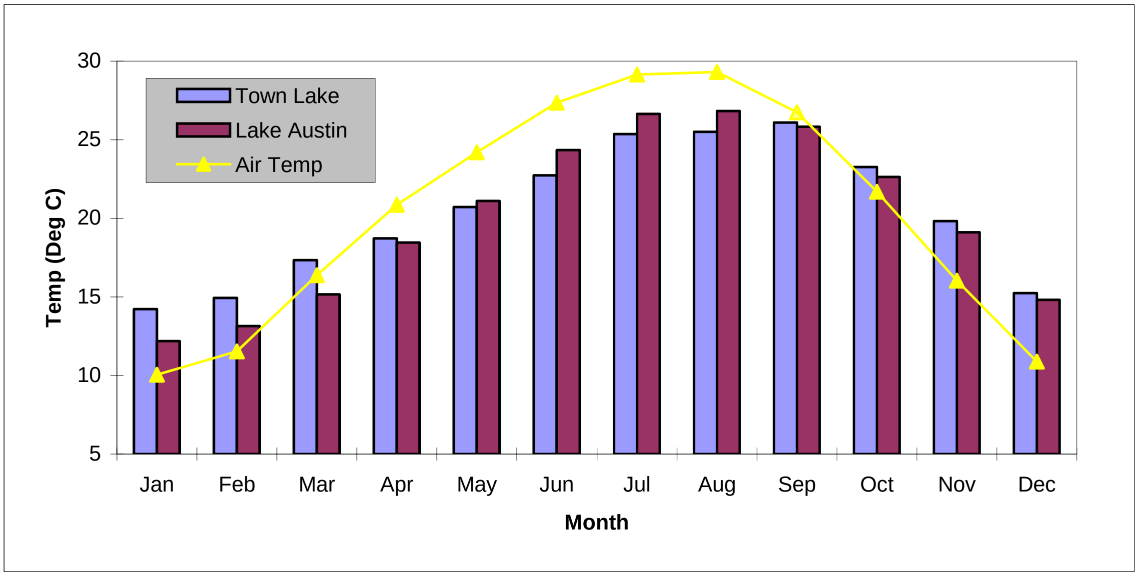
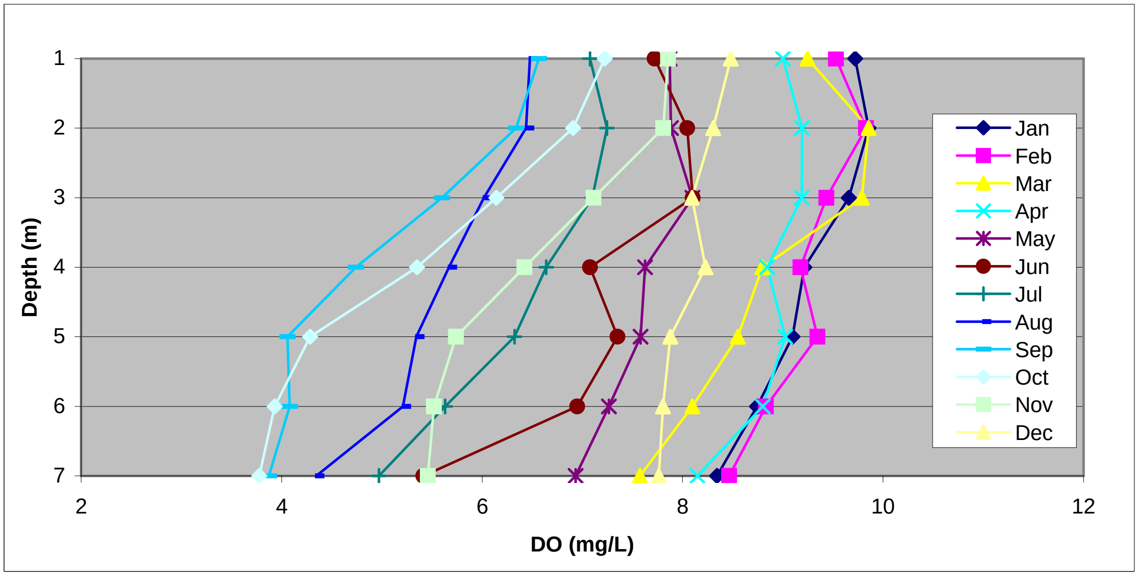


Figure 4.170 Town Lake at Basin Monthly Mean DO Depth Profiles



Hourly mean DO by month for the bottom of the Basin (Figure 4.171) and the surface of the Lamar site (Figure 4.172) were calculated from continuous-monitoring instrumentation. Although little daily variation is present at the bottom of the Basin in any month, a slight increase in mean hourly DO occurs in the evening during July and August. This same general pattern of a slight depression in mean DO during the middle of the day is evident at the surface of the Lamar site, and although this pattern occurs in almost every month for which data exist, it is most pronounced in July and August. For both the Lamar surface and Basin bottom locations, hourly DO mean levels are highest from January to March. However, comparison of Basin bottom and Lamar surface DO levels shows that while DO is higher at the surface of the Lamar site, even when adjusted for temperature (Figure 4.173), typically more variation in DO concentrations between months at the bottom of the Basin is shown through the course of the year.

Figure 4.171 Town Lake Basin Bottom Hourly Mean DO by Month

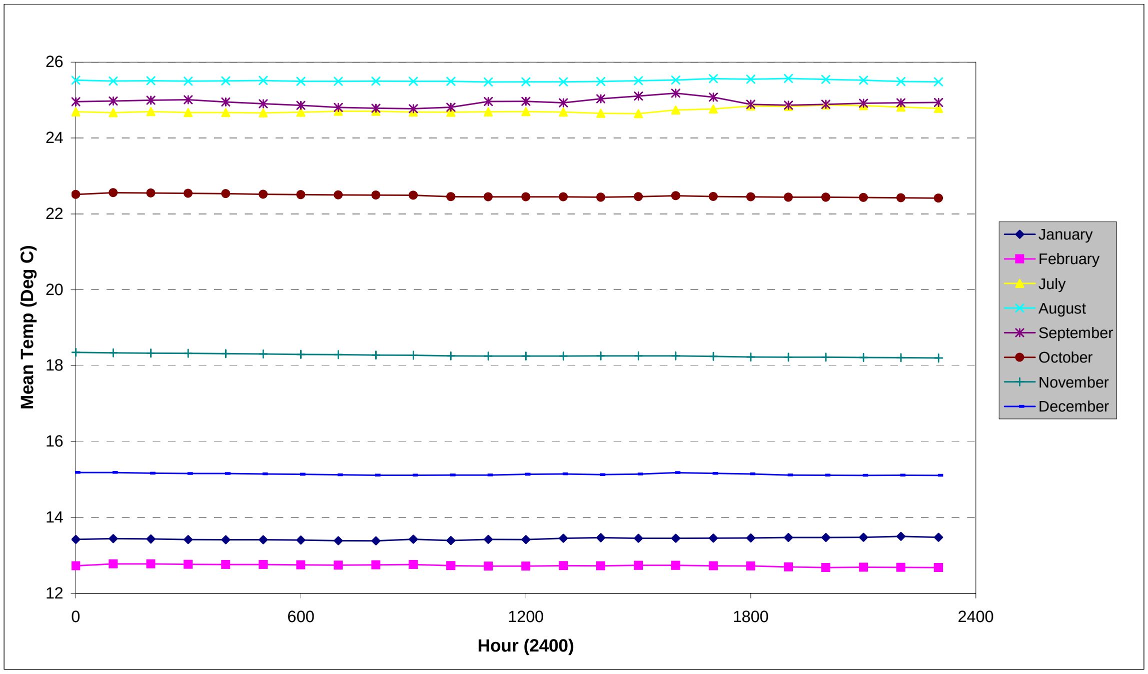


Figure 4.172 Town Lake Lamar Surface Hourly Mean DO by Month

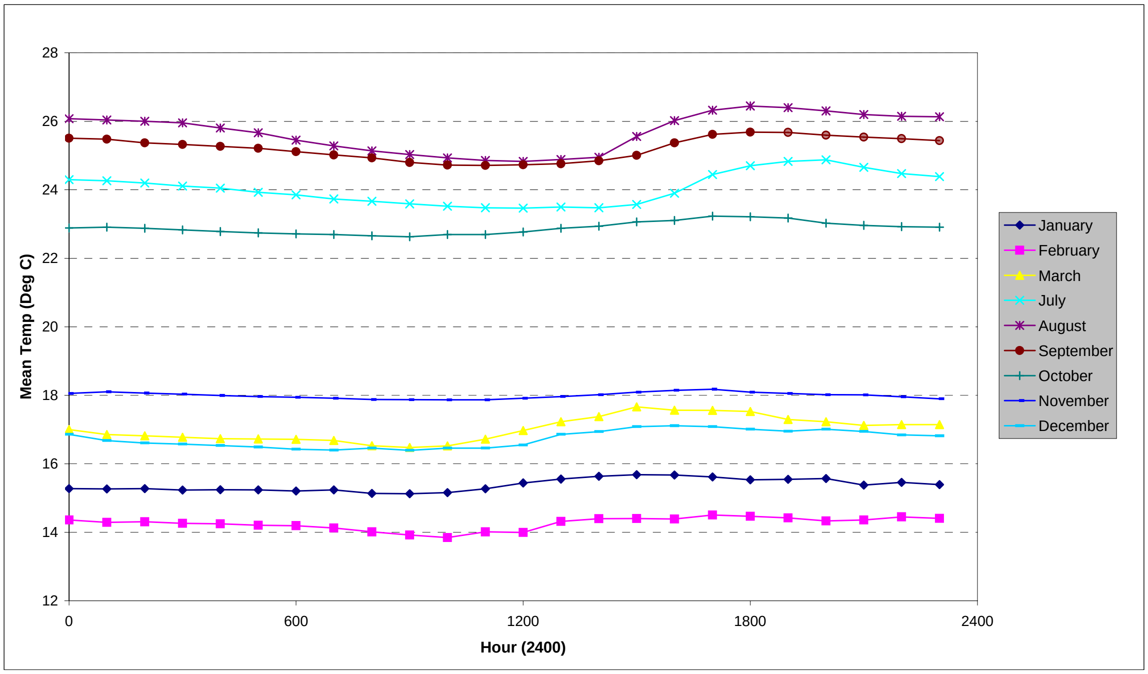
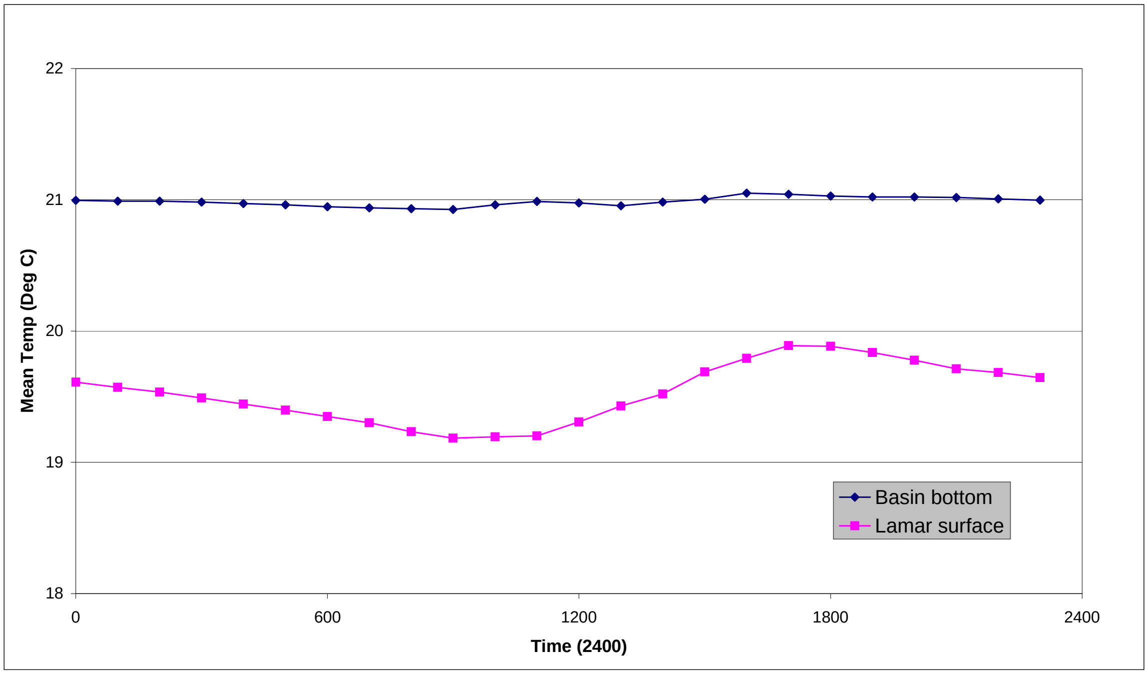


Figure 4.173 Town Lake Hourly Mean DO Percent of Saturation by Site



Even when adjusted for variation in temperature, little statistically significant correlation (Pearson's θ = -0.09) occurred between DO measurements recorded simultaneously at the surface of the Lamar site and bottom of the Basin site by continuous monitoring datasondes (Figure 4.174). Although several series of simultaneous datasonde deployments were made at the Lamar and Basin sites, the October/November 2000 deployment not only serves as a more recent representative of Town Lake conditions, it also highlights the effects of algal growth and flow on Town Lake oxygen levels. The period from mid-October 2000 to the beginning of November 2000 represents an extended period of elevated algal growth in Town Lake (Figure 4.175). While algal respiration is occurring at the surface, Lamar DO percent saturation values exceed even 100 percent. However, decaying algal biomass settling to the bottom of the Basin exerts a strong oxygen demand, driving DO percent saturation values to near zero as actual DO measurements drop below 1 mg/L for more than a week. It is essentially not until a rainfall event greater than 1" in magnitude at the beginning of November (Figure 4.176), which drives Colorado River flows (Figure 4.177) above 8,000 ft^3/s, that the Lamar surface and Basin bottom DO levels stabilize and return to more nominal conditions, clearly underscoring the strong effects of flow on DO within Town Lake.

Figure 4.174 Lamar Surface and Basin Bottom DO Percent Saturation Comparison During Oct/Nov-2000 Datasonde Deployment

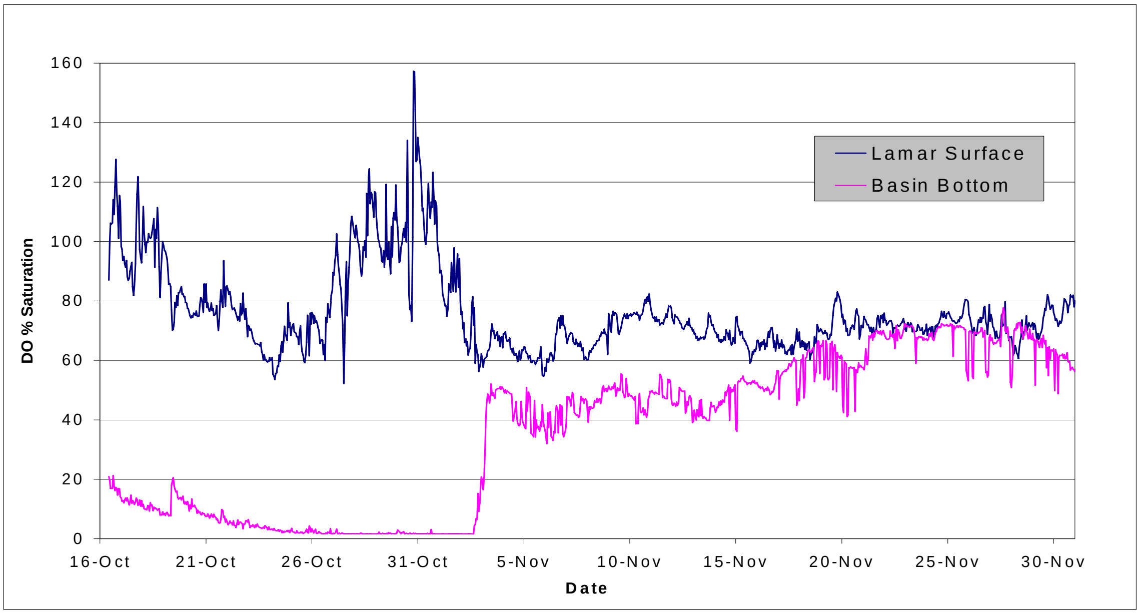


Figure 4.175 Lamar Surface and Basin Bottom DO Levels Versus Plankton Counts Assessed at the Green WTP During Oct/Nov-2000 Datasonde Deployment

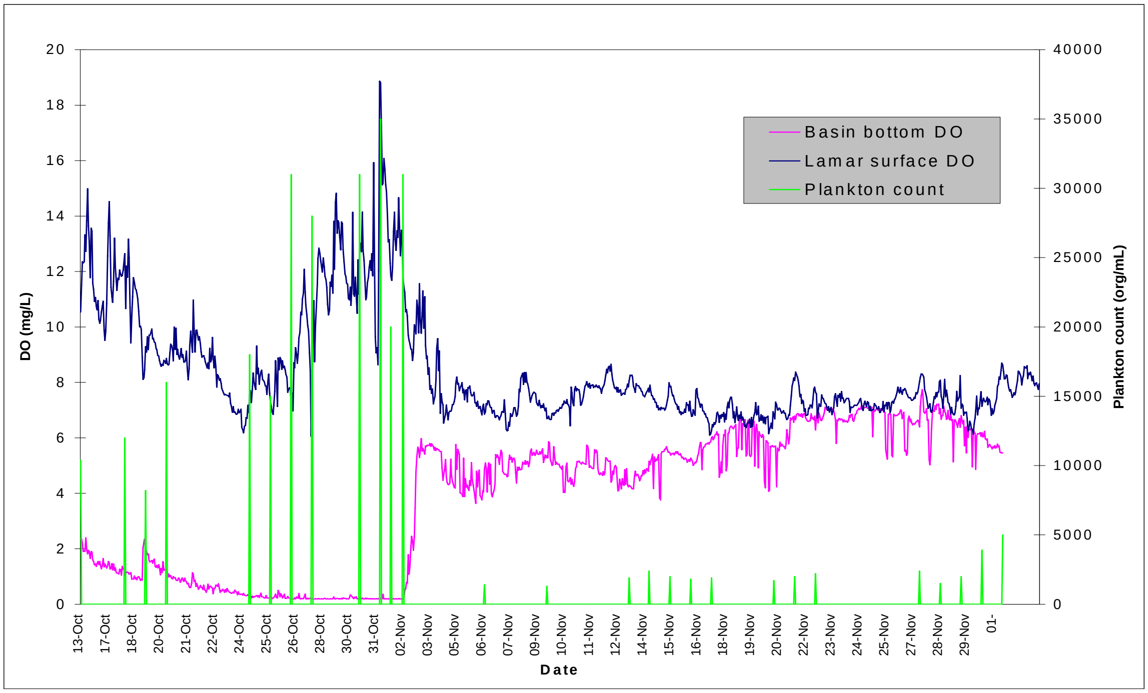


Figure 4.176 Lamar Surface DO Levels Versus Estimated Hourly Rainfall Totals During the Oct/Nov-2000 Datasonde Deployment

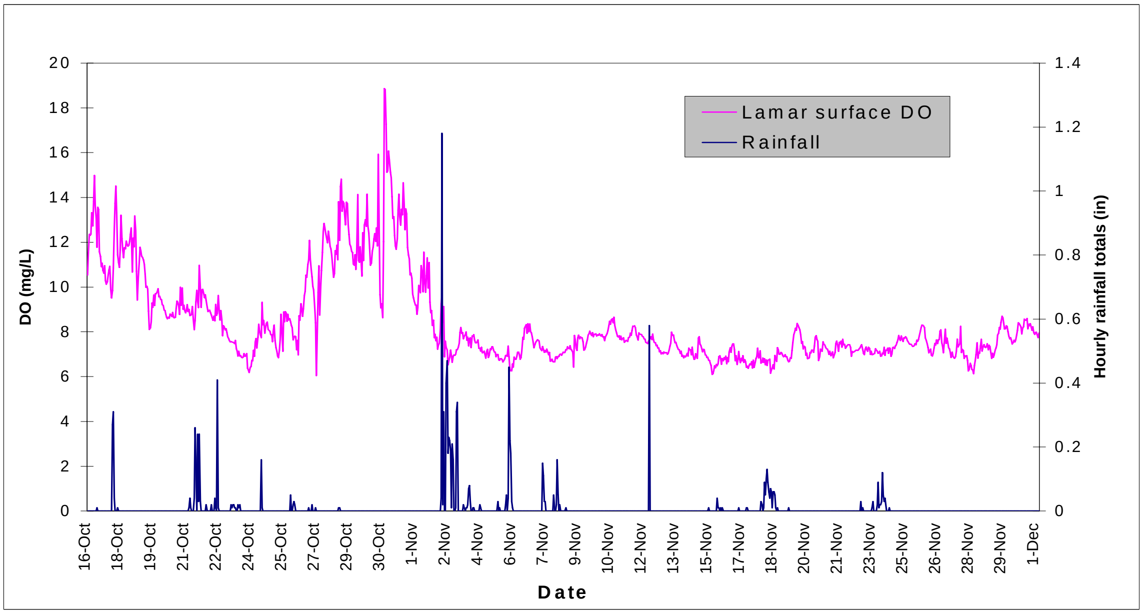
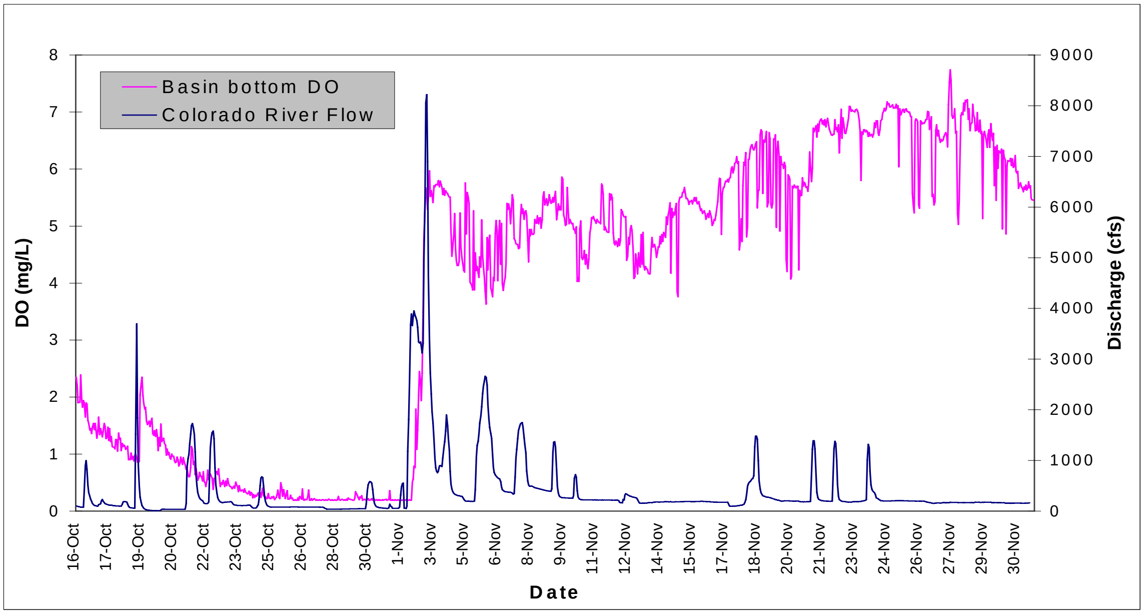
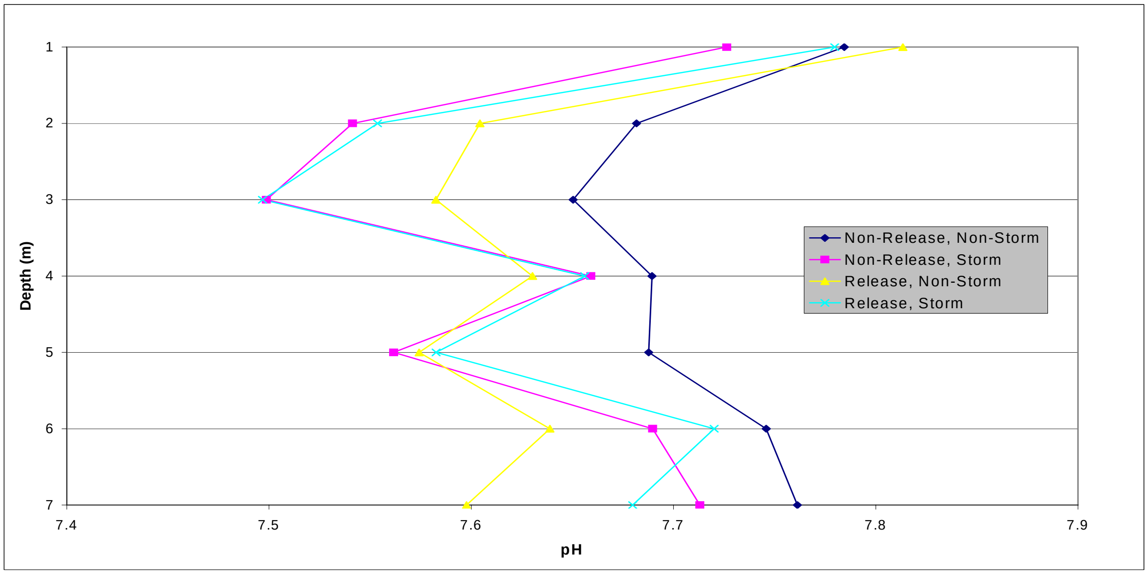


Figure 4.177 Basin Bottom DO Levels Versus Town Lake Flow as Measured by USGS Colorado River Gage at US183 During the Oct/Nov-2000 Datasonde Deployment



Town Lake average pH by sample depth exhibits similar patterns during all storm and release conditions (Figure 4.178). Although storm flow average pH levels fluctuate more than non-storm flow averages, while observing the same generalized pattern of oscillation with depth, the range of total variation is less than 0.3 pH units and does not approach TNRCC water quality standards on either basic or acidic levels.

Figure 4.178 Town Lake pH Depth Profiles by Season and Flow Type



Average monthly DO (Figure 4.179) and water temperatures (Figure 4.180) at surface and bottom depths are presented for Town Lake. The strong inverse correlation between DO and water temperature would suggest that temperature is a primary factor in Town Lake oxygen levels. Minimal DO levels, particularly at bottom depths, occur during September, when both surface and bottom temperature averages are at a maximum.

Figure 4.179 Town Lake Mean Monthly Surface and Bottom DO

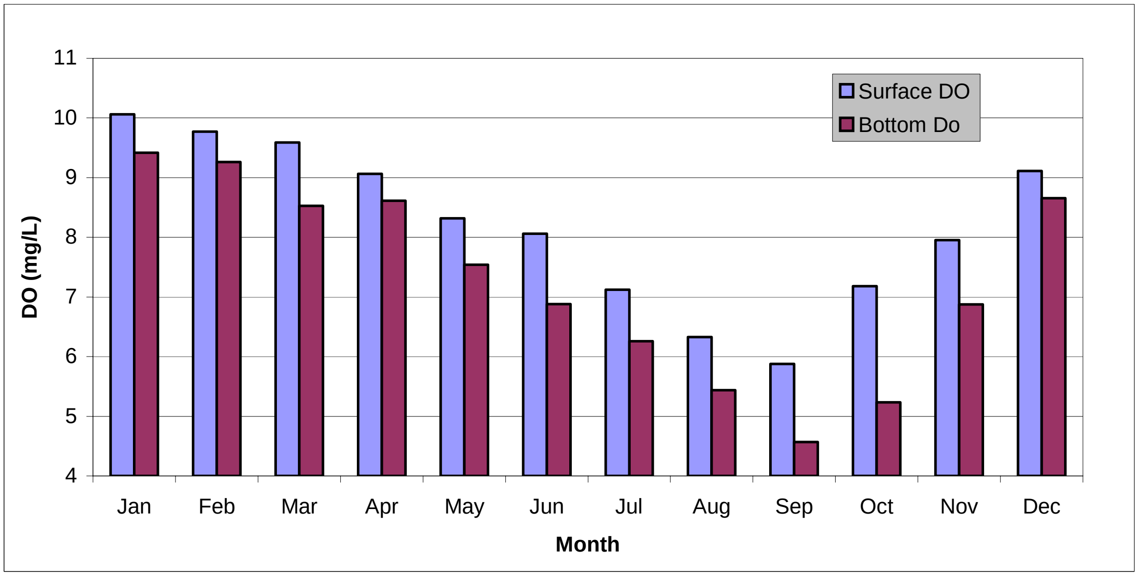
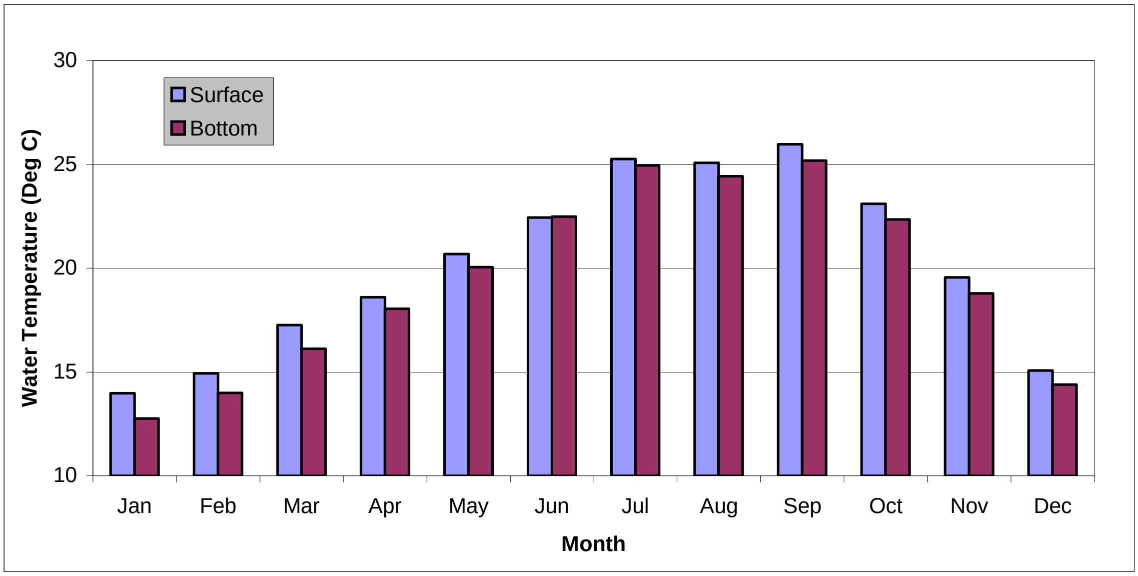
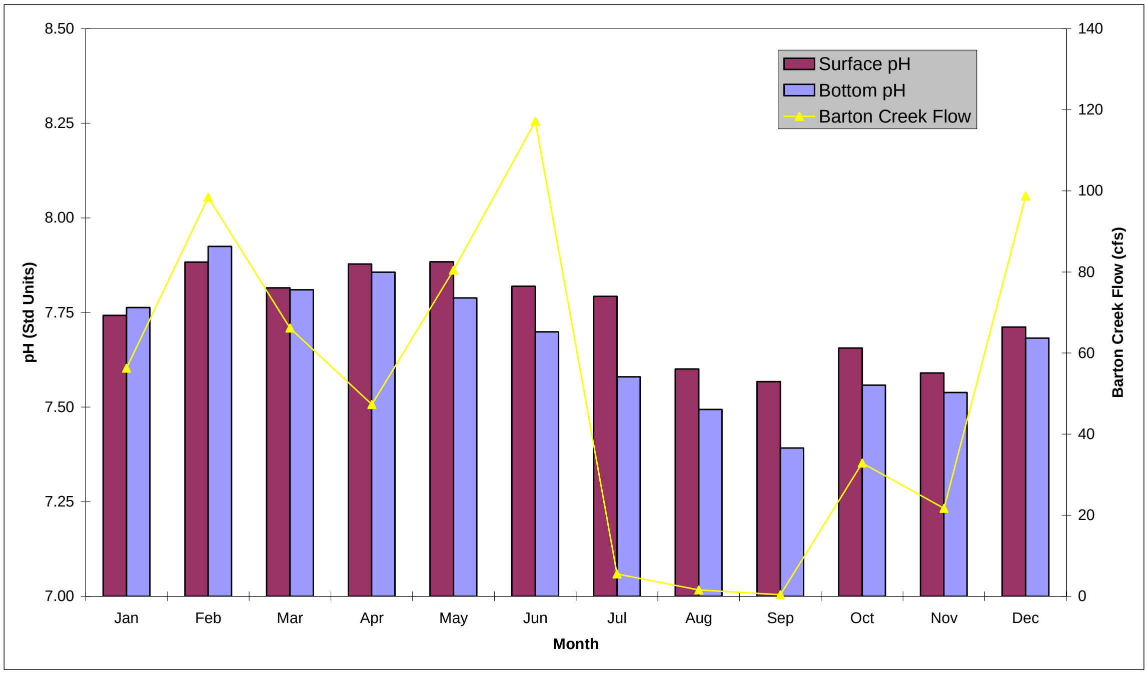


Figure 4.180 Town Lake Mean Monthly Water Temperature, by Depth



Average monthly Town Lake pH levels are compared to Town Lake inflow (Figure 4.181). Although partial similarities exist in certain segments of the year with Barton Creek and Lake Austin inflows, both of which are typically more alkaline than average conditions in Town Lake, the general pattern of variation in monthly lake pH cannot be explained by any single flow variable. However, little total variation occurred in monthly pH averages and little deviation between surface and bottom averages was shown, particularly during winter non-release months when Town Lake is most separated from Lake Austin waters. Minimum average pH levels occur in September, when average monthly temperatures are at a maximum and average monthly DO levels at a minimum.

Figure 4.181 Town Lake Mean Monthly pH with Mean Monthly Barton Creek Flows as Measured by the USGS Gage at Loop 360



Continuous monitoring data show fluctuations between months in daily pH patterns within Town Lake at the surface of the Lamar site (Figure 4.182) and the bottom of the Basin site (Figure 4.183). Although little overall change in pH throughout the day was observed at the Basin, mean pH at the surface of Lamar yields highly variable patterns between months with maximum daily variation occurring in the months of July, August, and September, when pH values drop to daily minimums around noon. During the winter month of January, daily pH patterns also yield a maximum around noon. Correlation analysis for pH values measured simultaneously at the bottom of the Basin and the surface of Lamar show that no statistically significant correlation in pH values exists between the two locations.

Figure 4.182 Town Lake Basin Bottom Mean Hourly pH by Month

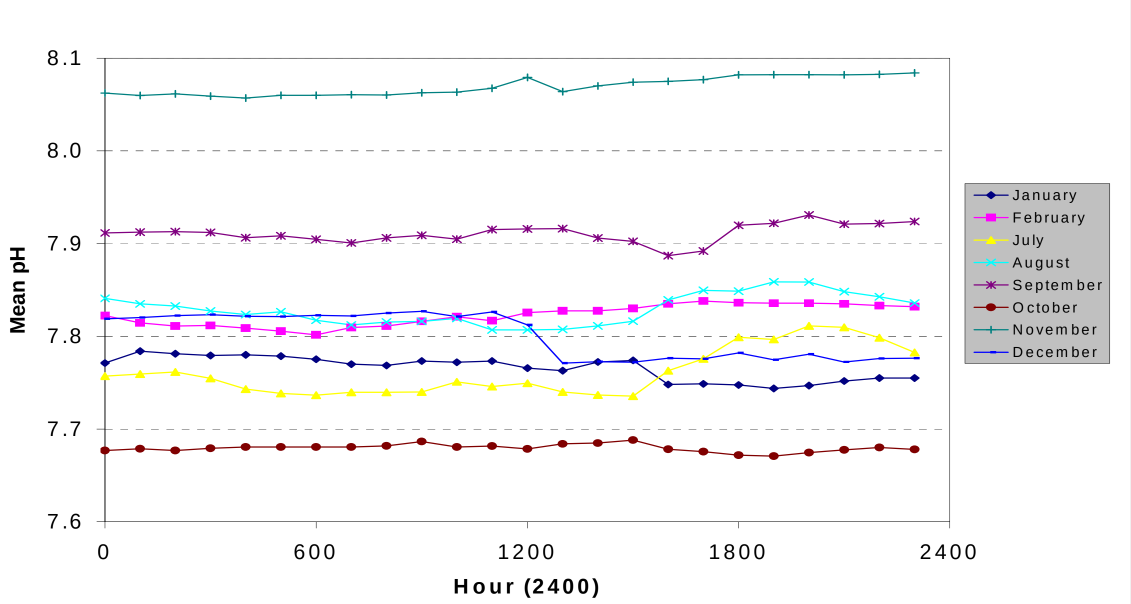
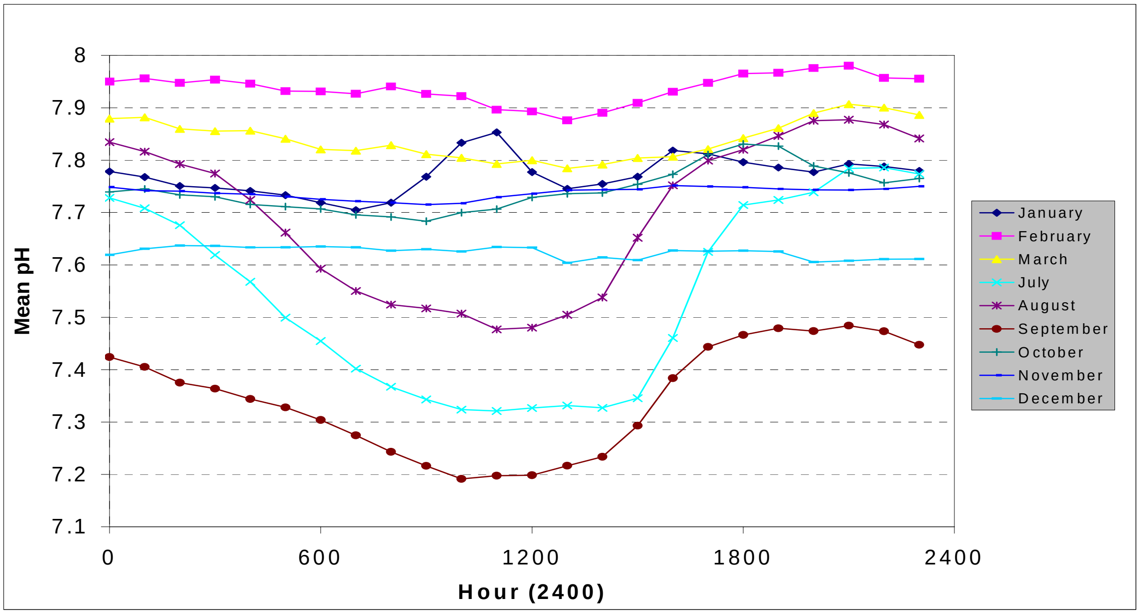


Figure 4.183 Town Lake Lamar Surface Hourly Mean pH by Month



Despite an initial depletion of DO levels in Town Lake during large storm events (≥ 0.5") as oxygen is consumed in the degradation of organic materials brought into the lake by storm run-off (Figure 4.184), DO in Town Lake during non-release actually increases at the lake's surface, potentially due to respiration by an expanding phytoplankton population feeding on storm-introduced nutrients. Although surface DO concentrations rise, the divergence between surface and bottom average DO concentrations is evident. If surface DO concentrations are increasing because of algal growth where light penetration is greatest, then DO at depth would decrease as dead algal matter settles to the bottom of Town Lake, where light penetration is minimal and algal growth cannot occur, exerting an oxygen demand. Surface and bottom average DO concentrations following storm events during the release season are in general more similar (Figure 4.185), potentially due to stronger mixing from increased flows in the lake. Release DO concentrations, although initially not as great as non-release DO immediately following the storm event, appear more cyclic in nature.

Figure 4.184 Town Lake DO Following Large Storm Events During Non-Release

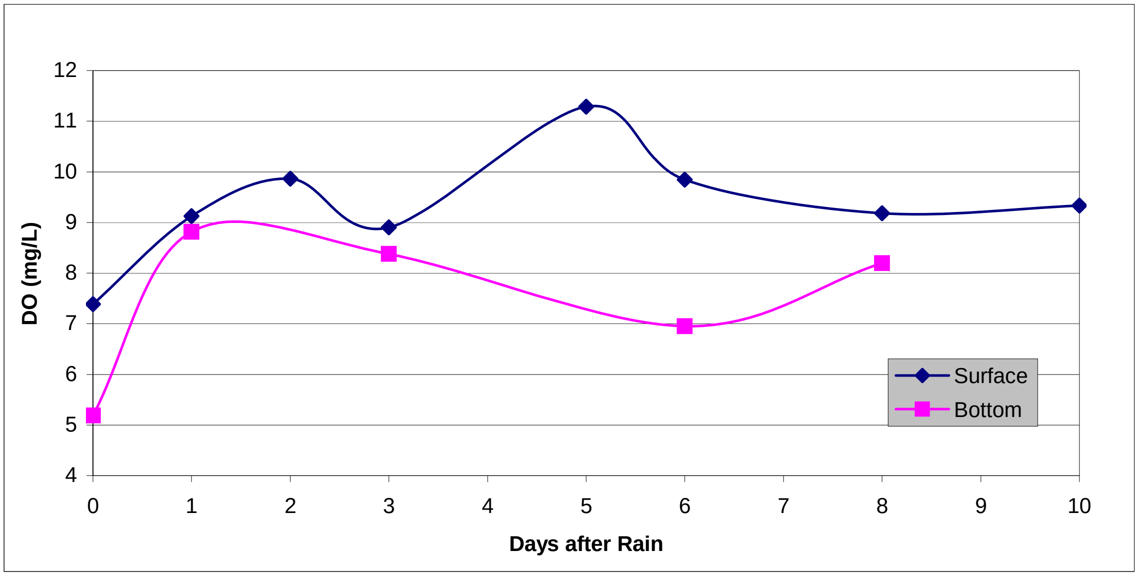
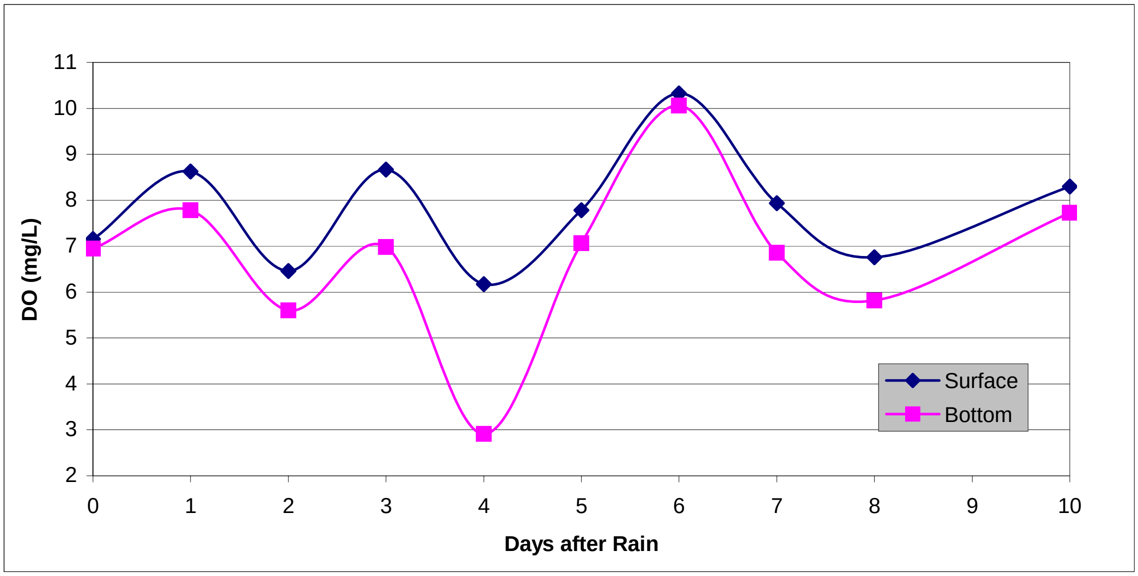


Figure 4.185 Town Lake DO Following Large Storm Events During Release

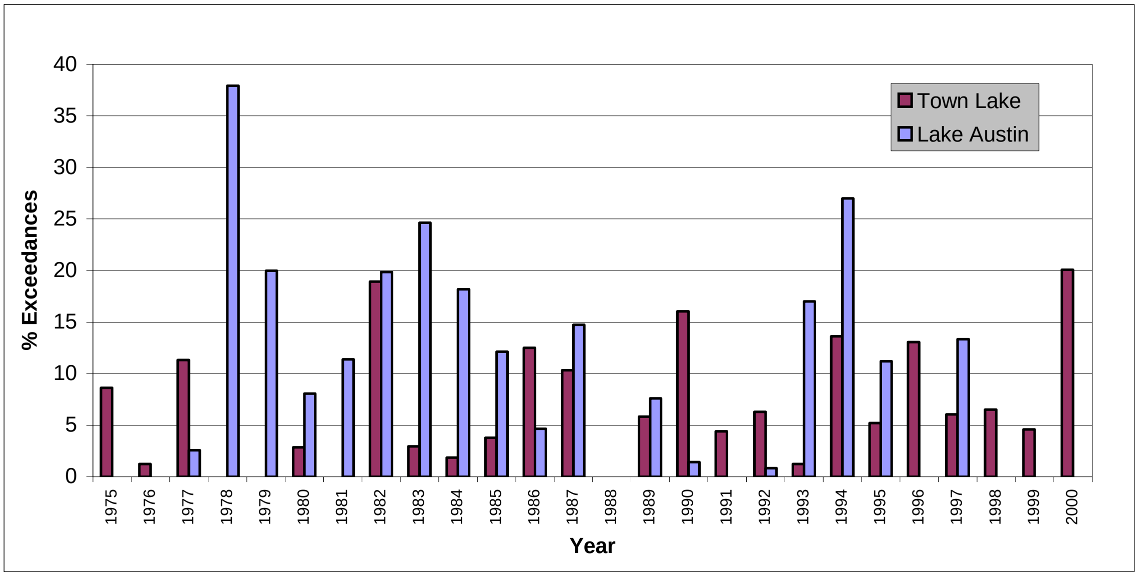


4.6.4 Concern Status

Town Lake surface DO measurements have dropped below the 5 mg/L water quality standard numerous times since 1975 (Figure 4.186). Note that in every year since 1989, at least 1 percent or more of surface Town Lake samples have been below 5 mg/L, with the maximum percentage of Town Lake samples exceeding the screening criteria actually occurring in 2000.

Recorded dissolved oxygen levels in Town Lake have dropped below 1 mg/L on 61 occasions since 1975, with extremely low DO values recorded from the bottom of the Lamar and Basin sites even as recently as the fall of 2000. DO values have actually been greater than or equal to 15 mg/L in Town Lake on two occasions, both during storm flow conditions at the surface.

Figure 4.186 Surface DO Annual Percentage of Samples Exceeding TNRCC Standards by Watershed



Town Lake surface pH levels have dropped below TNRCC water quality standards of 6.5 in only three years since 1975. In 1995, approximately 2.5 percent of the 679 samples were below 6.5, and fewer than 1 percent of total samples in 1996 and 1997 were below the lower screening criteria. In no sample has Town Lake surface pH ever exceeded the upper 9.5 screening criteria. No surface Lake Austin pH value, as measured by the City of Austin or USGS, has ever exceeded either the upper or lower screening criteria.

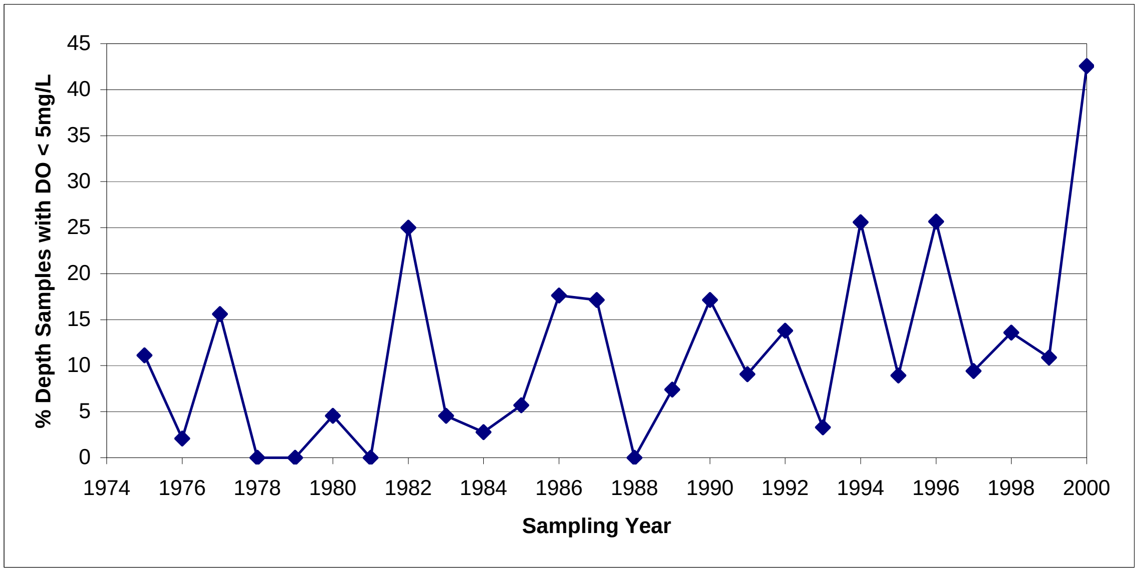
Although pH levels in Town Lake have never exceeded 9, the maximum basic Town Lake pH value of 8.83 was measured at the bottom of the MoPac site during non-storm flow conditions in May 1996 by COA-ERM. The most acidic pH measurements recorded in Town Lake were also made at the MoPac site with all depths exhibiting pH values ranging from 4.34 to 4.79 during non-storm flow on 15 October 1995.

Only one recorded measurement of Town Lake surface water temperature since 1975 has exceeded the 90°F (32.2 °C) TNRCC water quality standard criteria, when a temperature of 91.4°F (33 °C) was recorded during non-storm flow conditions at the Basin on 17 September 1997.

4.6.5 Temporal Patterns

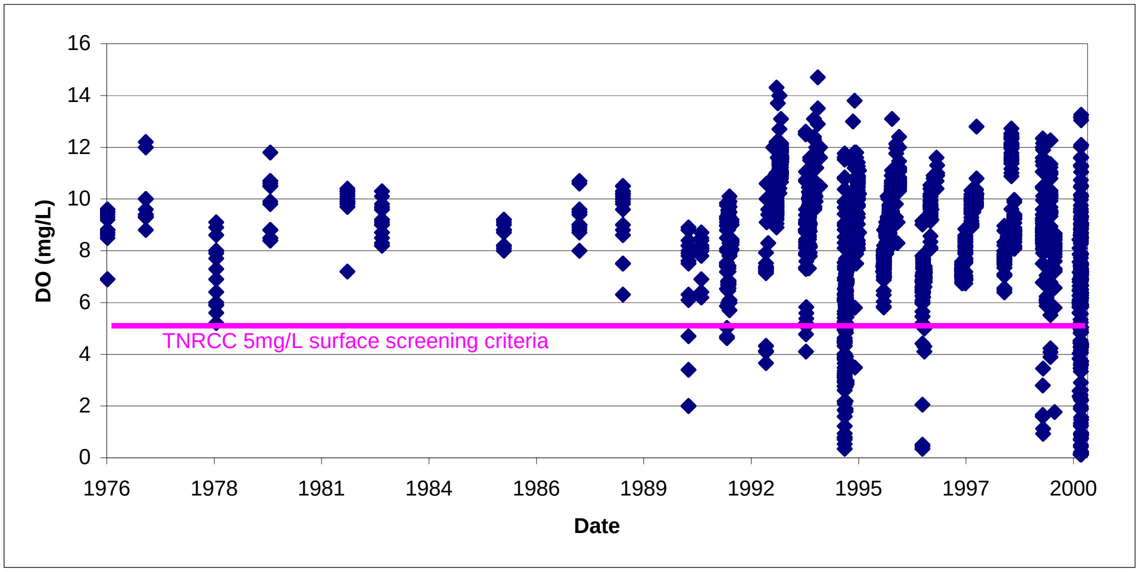
Analysis of average DO levels in Town Lake before and after institution of the minimum low-flow policy by the LCRA in 1991 indicates that while no significant difference in average DO concentrations is evident during non-release, non-storm flows at the surface of Town Lake before and after 1991, bottom DO levels are actually significantly greater before the low-flow policy was undertaken by the LCRA. However, oxygen depletion at lower depths is occurring more frequently with time, which could result in higher pre-1991 DO concentrations at depth (Figure 4.187). Thus, potential improvements in Town Lake non-release DO resulting from the institution of the minimum low-flow policy may be offset by degradation in Town Lake DO levels over time.

Figure 4.187 Frequency of Town Lake Bottom Samples with DO Values Below 5 mg/L



Town Lake non-release DO values exhibit overall significantly decreasing (worsening) trends over time at surface and bottom depths in both storm and non-storm flow conditions. This statistically significant decrease is potentially driven by an increase in the frequency of lower DO values sampled over time (Figure 4.188). At the present rate of decrease, Town Lake mean DO levels during non-release non-storm flow would approach the TNRCC water quality standard of 5 mg/L in approximately 50 years. Analysis of Town Lake DO values at depth reveal an increasing frequency of samples dropping below 5 mg/L over time from 1975 to 2000. Regression analysis of this data yields a statistically significant ($p = 0.0129$, $r^2 = 0.2270$) increasing trend in frequency of occurrence of low DO values at depth in Town Lake for release and non-release periods combined for analysis. Analysis of Town Lake non-release DO data at the site level in non-storm flow conditions yields statistically significant decreasing trends at the bottom of all five Town Lake sites as well as at the surface of the Lamar, MoPac, and Red Bud sites.

Figure 4.188 Town Lake DO During Non-Release, Non-Storm Flow, All Sites and Depths



Continuous monitoring data at the bottom of the Basin also indicate increasing deficits of DO in Town Lake. Not only is the frequency of low DO values increasing at depth in the lower end of Town Lake (Figure 4.189), the amount of time in which the bottom of the Basin is near anoxic levels is increasing as well (Figure 4.190). The frequency of continuous-monitoring DO values less than 4 mg/L may also be increasing at the surface of the Lamar site (Figure 4.191).

Figure 4.189 Town Lake Basin Bottom Frequency of DO Measurements Less Than Specified Levels by Instrument Deployment with Mean Flow in Period as Measured by USGS Colorado River Gage at U.S. 183 (error bars indicate minimum flow in period)

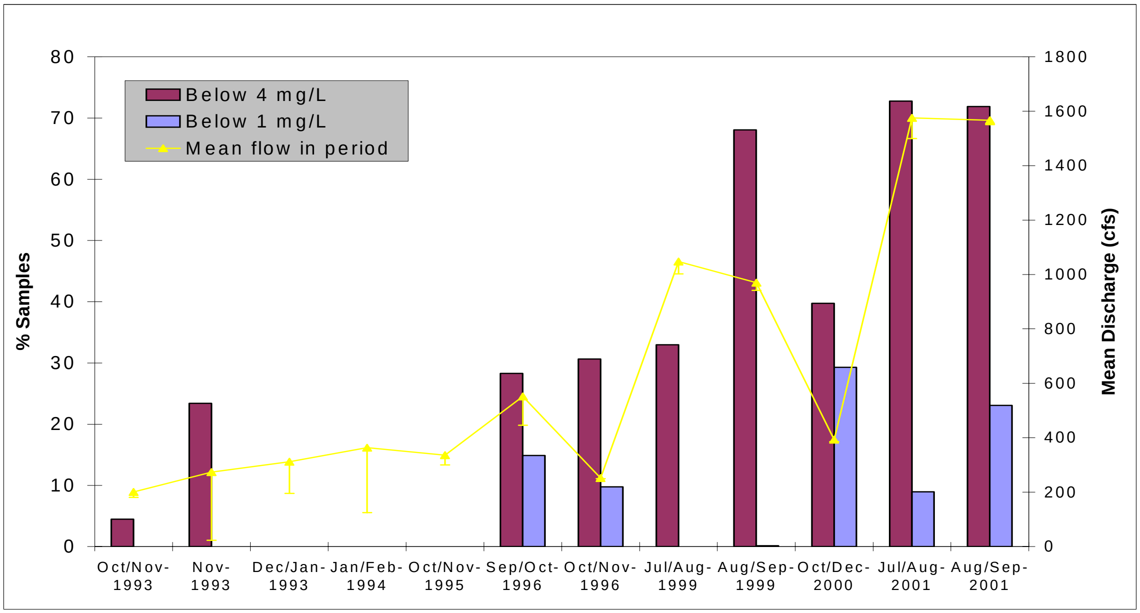


Figure 4.190 Maximum Number of Consecutive Hours Below Specified DO Levels at Basin Bottom by Instrument Deployment with Mean Flow in Period as Measured by USGS Colorado River Gage at U.S. 183 (error bars indicate minimum flow in period)

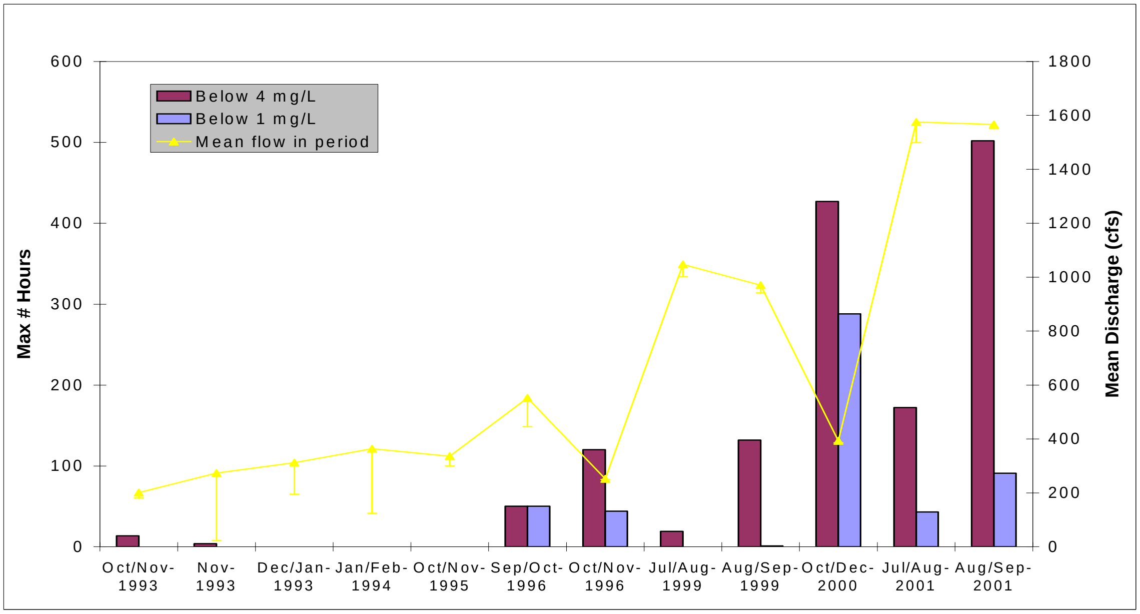
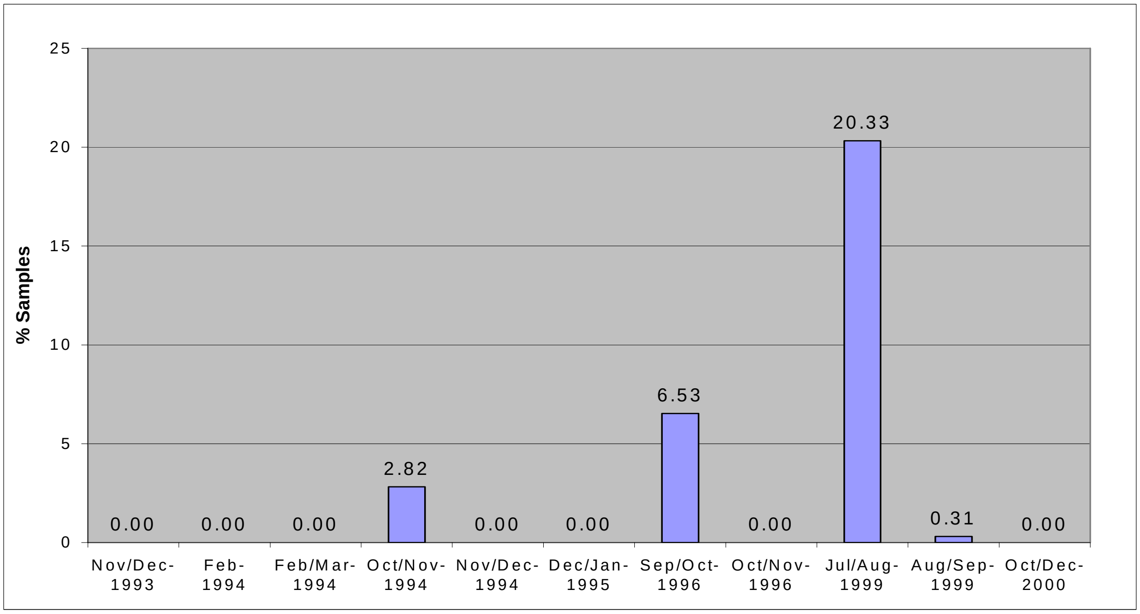


Figure 4.191 Town Lake Lamar Surface Frequency of Continuous Monitoring DO Measurements <4 mg/L by Deployment



Despite the significantly decreasing trends in DO during non-release, non-storm flow conditions, DO concentrations in release at both surface and bottom depths yield significantly increasing trends over time for all sites combined in analyses (Figure 4.192). Not only is there an increase in low DO values during release, but an increase in high DO values occurs with time. Analysis of Town Lake non-storm flow data at the site level during the release seasons reveals statistically significant increasing trends at the surface of the Basin, the surface and bottom of First Street, and the bottom of Red Bud.

However, Town Lake DO concentrations during storm flow conditions exhibit statistically significant decreasing temporal trends for both release and non-release seasons at surface and bottom depths (Figure 4.193).

Figure 4.192 Town Lake DO During Release, Non-Storm Flow, All Sites and Depths

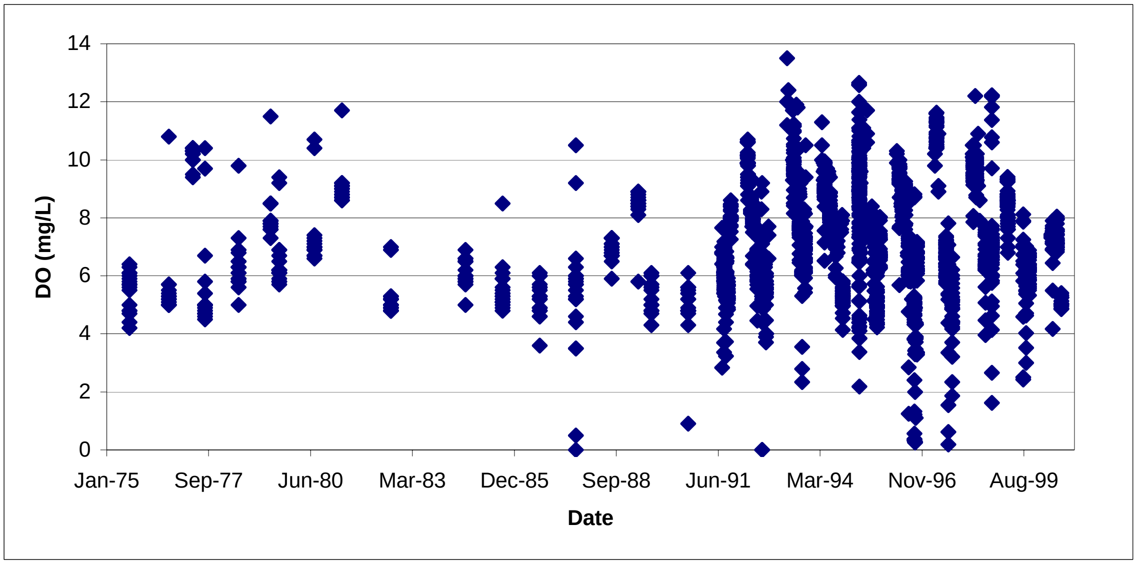
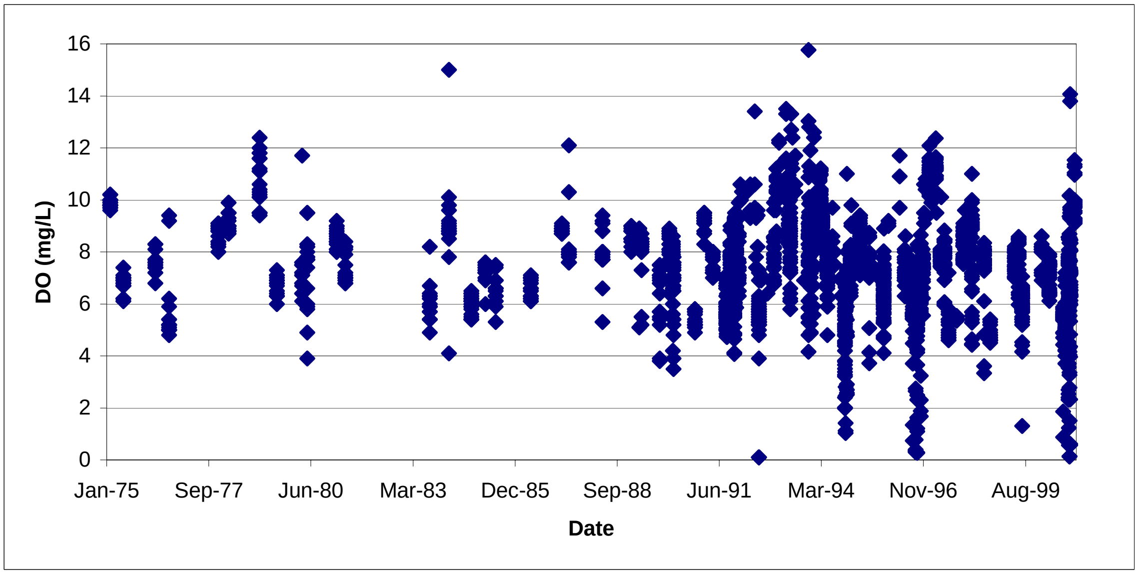
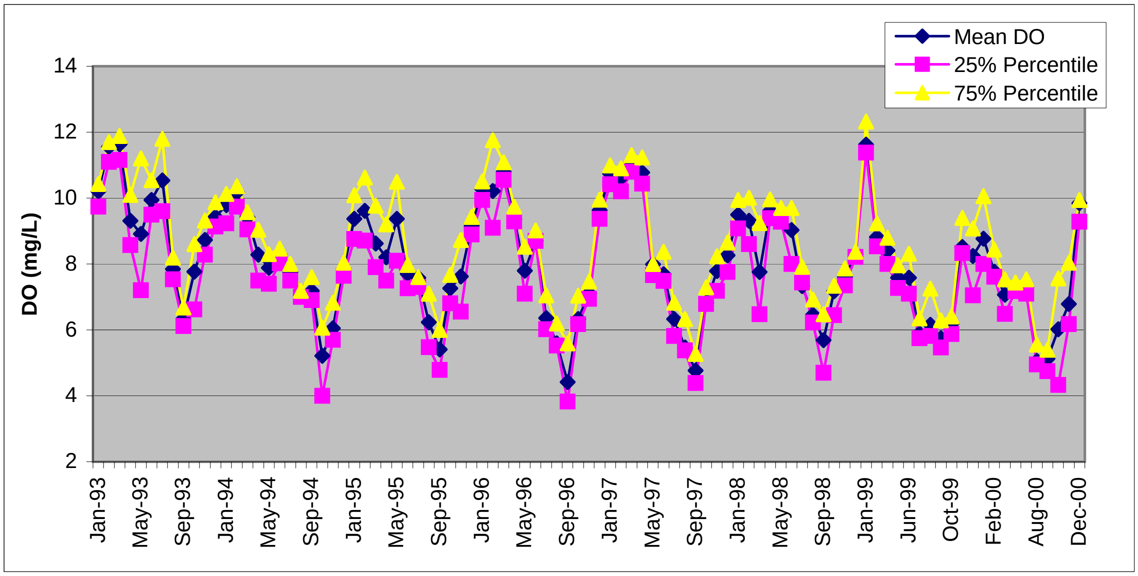


Figure 4.193 Town Lake DO During Storm Flow, All Sites and Depths



In order to assess an overall temporal trend in Town Lake DO concentrations, average monthly DO values for all sites and depths from 1993 to 2000 were assessed (Figure 4.194). The limited time period was employed to yield a more consistent dataset. The overall general decline in Town Lake DO values, though slight and still subject to strong seasonal variation, is clearly evident.

Figure 4.194 Town Lake Monthly DO Summary by Year, All Sites and Depths (1993-2000)



Town Lake water temperatures yield statistically significant increasing trends at both surface and bottom depths during the non-release season in storm and non-storm flows when data from all sites are combined for analysis (Figure 4.195). Although storm flow temperatures are also significantly increasing during the release season, no statistically significant increasing temporal trend occurred during release, non-storm flows. Despite a large amount of seasonal variation, the slightly increasing trend in temperature values is evident. In order to better clarify temporal trends in Town Lake water temperatures, monthly average surface and bottom temperatures were calculated by year (Figure 4.196). As seen in temperature scatter plots, monthly averages exhibit an overall slight increase over time in Town Lake.

Figure 4.195 Town Lake Water Temperature, All Sites and Depths

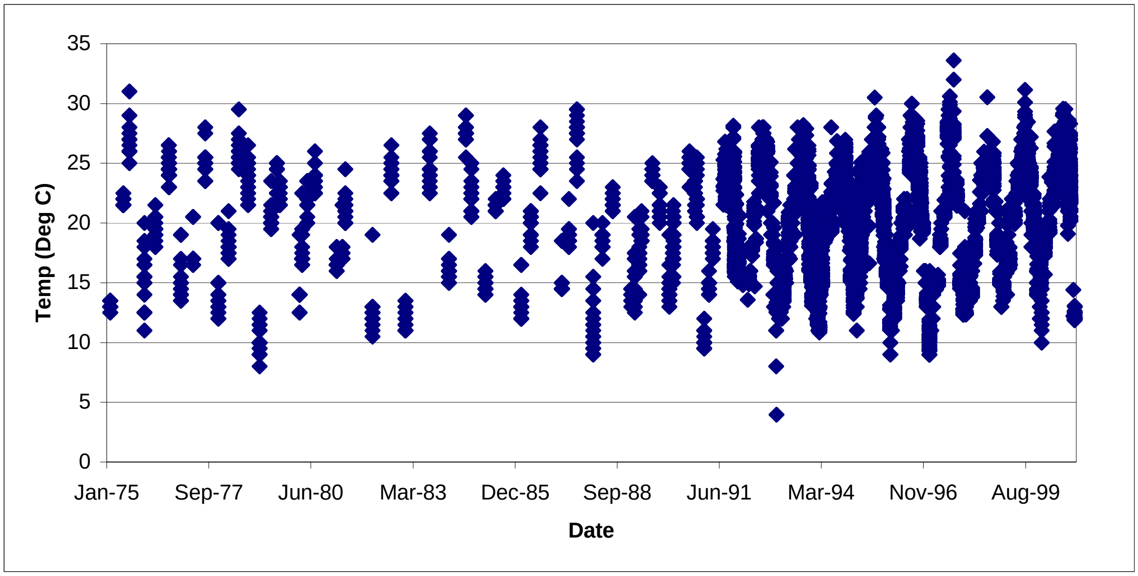
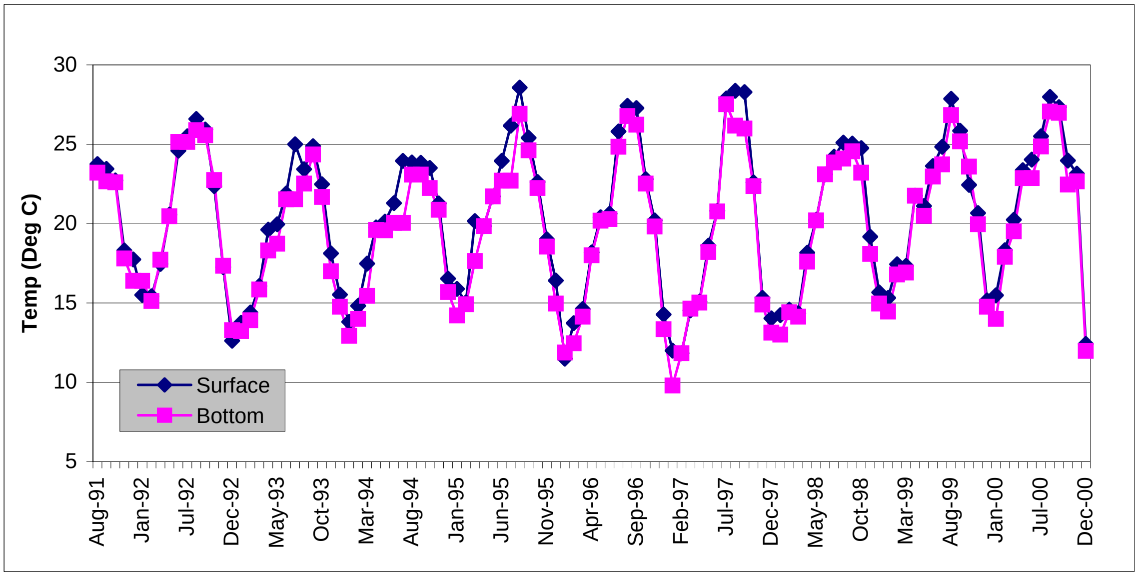


Figure 4.196 Town Lake Mean Monthly Water Temperature by Year, All Sites



Mean hourly temperatures by month were calculated from continuous monitoring data for the bottom of the Basin site (Figure 4.197) and the surface of the Lamar site (Figure 4.198). Although almost no mean daily temperature variation at the bottom of the Basin was observed for any given month, the variation between months is clear, with maximum measured temperatures recorded in the months July, August, and September. Monthly variations in daily temperature at the surface of the Lamar site from continuous monitoring data present two distinct seasonal groupings, although perceptible daily temperature fluctuations appear most notably in July, August, and September, when water temperature basically decreases from midnight to noon and then increases from noon to midnight.

Figure 4.197 Town Lake Basin Bottom Mean Hourly Temperature by Month

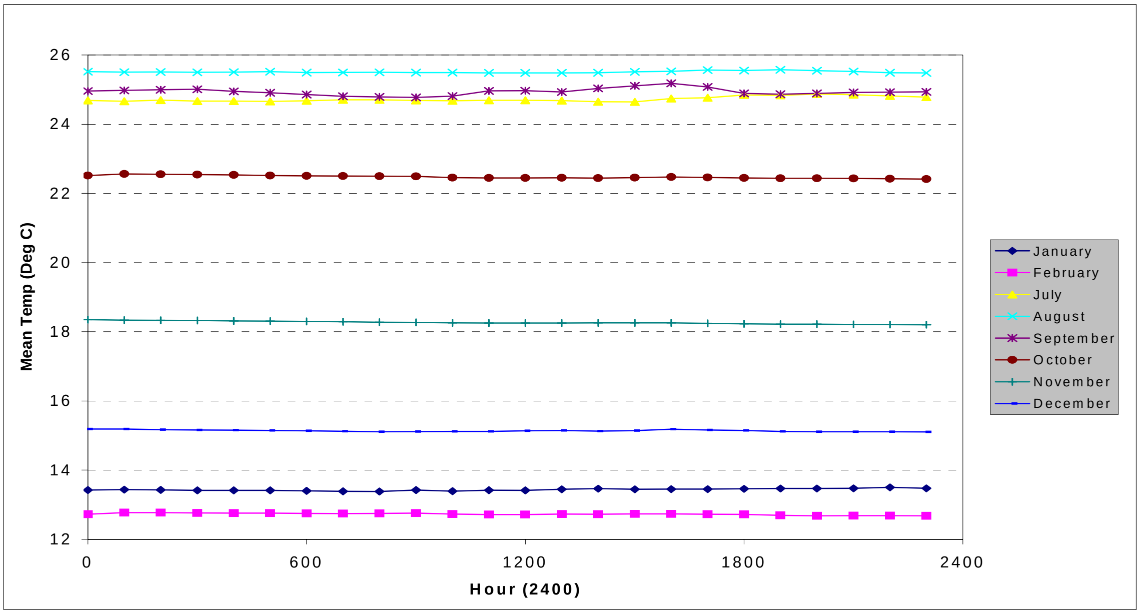
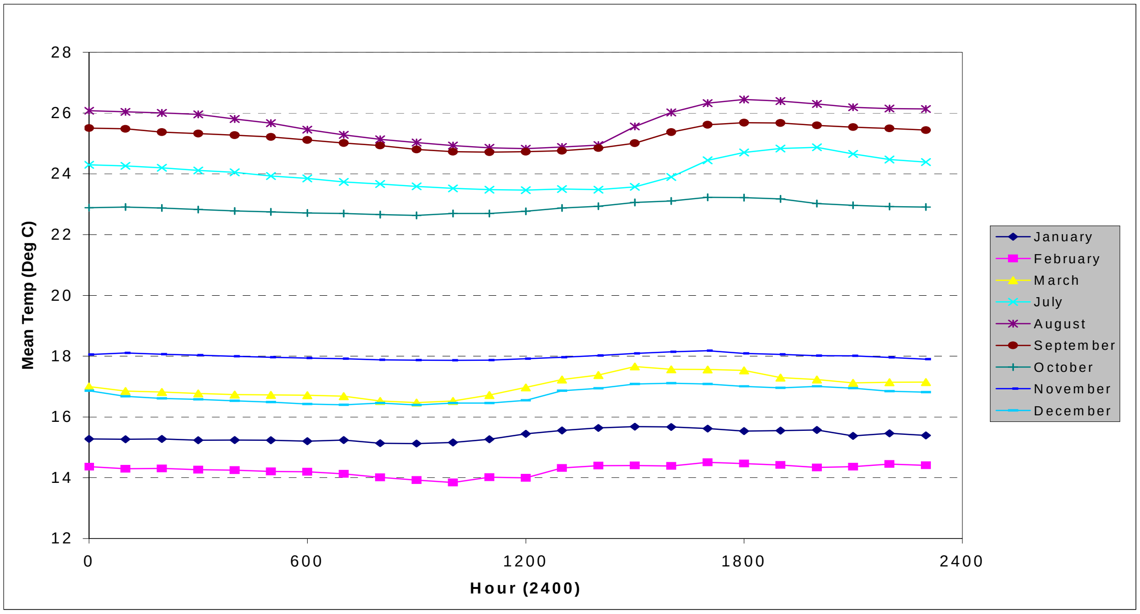


Figure 4.198 Town Lake Lamar Surface Hourly Mean Water Temperature by Month



Town Lake release pH values at surface depths are significantly increasing over time during both storm and non-storm flow conditions when data from all sites are composited for analyses (Figure 4.199). This increase is slight and does not approach either TNRCC segment-specific water quality standard. No temporal trends in surface pH values are evident during non-release. During the non-release season, however, Town Lake bottom pH values exhibit significant decreasing trends over time in both storm and non-storm flow conditions (Figure 4.200).

Figure 4.199 Town Lake Surface pH During Release, All Sites

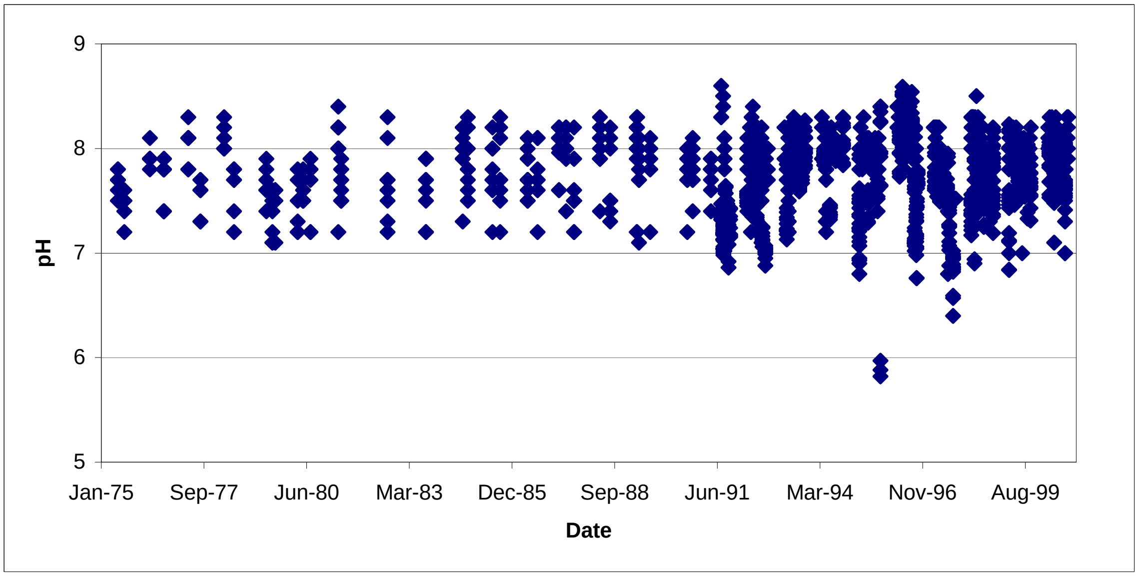
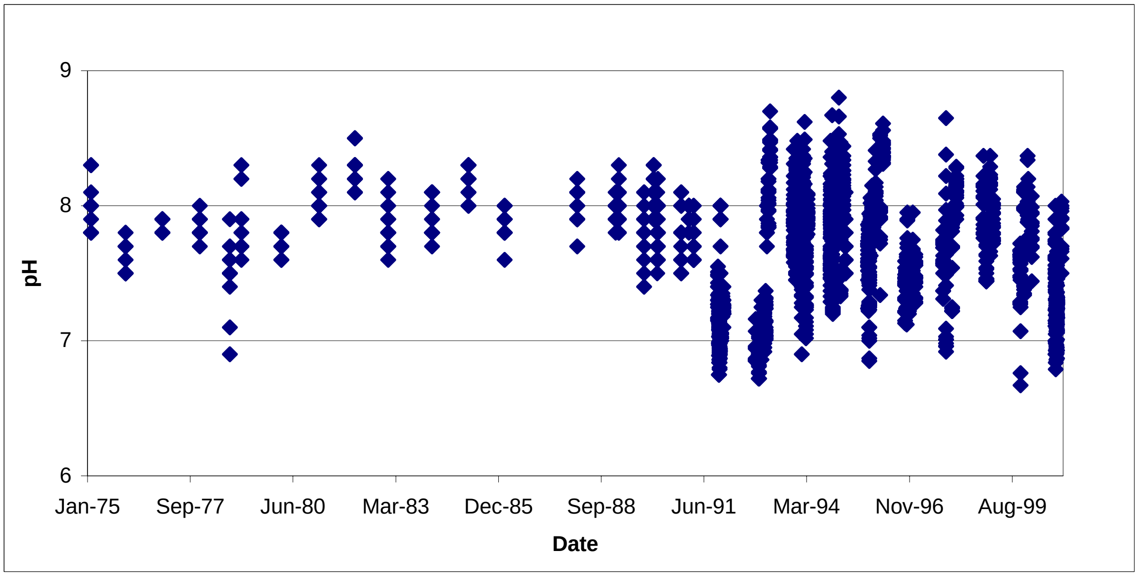


Figure 4.200 Town Lake Bottom pH During Non-Release, All Sites



4.6.6 Monitoring Recommendations

Sample frequency analysis was conducted for Town Lake physical parameters to assess potential modifications to sampling procedures (Table 4.23). Minimum significant detectable differences in mean watershed concentrations were estimated as numeric values and percentages of current means and based on projections of current sampling rates into the next one- and five-year periods.

Table 4.23 Minimum Significant Detectable Difference in Watershed Mean Physical Parameter Values (as a value and percentage of current means) if Sampling Continued at Current Rates Over Specified Time Periods

Param (mg/L)	**Non-Release**				**Release**			
	Non-Storm		**Storm**		**Non-Storm**		**Storm**	
	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 1 yr
DO	0.585 (7)	0.261 (3)	0.498 (6)	0.222 (3)	0.498 (7)	0.222 (3)	0.457 (7)	0.204 (3)
Temp (°C)	1.037 (6)	0.462 (3)	1.051 (6)	0.468 (3)	0.874 (4)	0.39 (2)	0.914 (4)	0.407 (2)
pH	0.106 (1)	0.047 (1)	0.093 (1)	0.042 (1)	0.100 (1)	0.045 (1)	0.085 (1)	0.038 (0)

Note that all physical parameters have been well-characterized in Town Lake, based on the low percentage change in current mean values that could be significantly detected after only one year. This is most likely due to the intensive sampling efforts employed to obtain depth profile information. Although this would provide a good opportunity for reducing sampling efforts, the physical changes that may be occurring in the lake and the need for data in model inputs may require the extension of current sampling protocols.

4.7 Chlorophyll-*a*

Chlorophyll-*a* is the green pigment contained in the chloroplasts of plants which directly interacts with sunlight, converting solar energy to chemical energy in the process of photosynthesis (Campbell 1993). Numerous studies have documented relationships between chlorophyll-*a* concentrations in reservoirs and the quantity of the phytoplankton community (Mierstchin and Armstrong 1986).

The TNRCC (2000) screening criteria for freshwater reservoirs to identify water quality concerns for chlorophyll-*a* is 11.6 μg/L.

4.7.1 Summary of Results

Figure 4.201 presents a graphical summary of Town Lake chlorophyll-*a* data analysis. Although Lake Austin exhibits higher mean plankton counts than Town Lake, Town Lake mean chlorophyll-*a* levels are higher because of the enormous spikes in concentration during the algae blooms on Town Lake. However, Lake Austin exhibits higher median chlorophyll-*a* values.

Despite higher levels of chlorophyll-*a* under normal conditions in Lake Austin, Town Lake chlorophyll-*a* is inversely related to Lake Austin discharge into Town Lake. This pattern most likely is because chlorophyll-*a* exhibits higher mean non-storm flow concentrations than storm concentrations and algae blooms are most likely to occur during the non-release season.

Chlorophyll-*a* (particularly during non-release) displays increasing longitudinal patterns in concentration from upstream to downstream sites, potentially due to urban runoff and Barton Creek nutrient loading that would feed the growth of algae within Town Lake.

The concentrations of chlorophyll-*a* leaving Town Lake are greater than the initial concentrations entering Town Lake from Lake Austin, possibly impacting the Colorado River.

Chlorophyll-*a* concentrations during non-release are increasing over time during both storm and non-storm flow conditions, with mean Town Lake concentrations approaching the TNRCC screening criteria in approximately 30 years if the current rate of increase does not change.

Comparison of data in Town Lake to 2000 TNRCC screening criteria in water reveals that Town Lake is of “no concern” chlorophyll-*a*. However, Town Lake has exceeded TNRCC criteria for chlorophyll-*a* in six of the last seven years in at least 5 percent of samples.

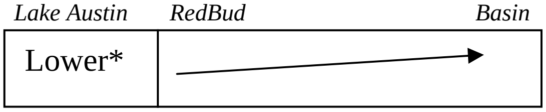
The increasing trend in Town Lake chlorophyll-*a* (and similar decreasing trend in Secchi disk depths) observed during the non-release season offers opportunities for additional monitoring to better assess the nature of chlorophyll-*a* changes in Town Lake. Design of algae community surveys may be necessary to address this need.

Figure 4.201 Graphical Summary of Town Lake Chlorophyll-*a*

SPATIAL

Location

Town Lake vs. Lake Austin



*Lower average chl-a levels

Downstream →

Depth

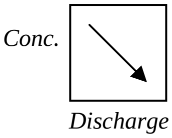
Surface

No chl-a samples at depth

Bottom

Conc →

FLOW/SEASONALITY



Storm flows highest in:	*Non-Storm flows highest in:*	*Max conc. in:*
Non-Release	Non-Release	NR, NS

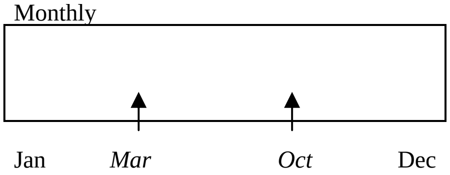
Post-Storm

NR

R

0 3 # Days after Storm

Monthly

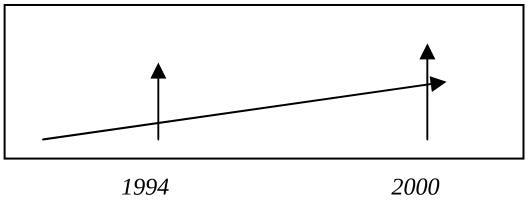


TEMPORAL

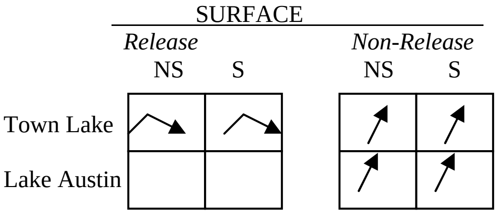
Annual % Exceedance of TNRCC Criteria

No Concern

Overall temporal trend



Temporal



*break-point in 1995

Comments:

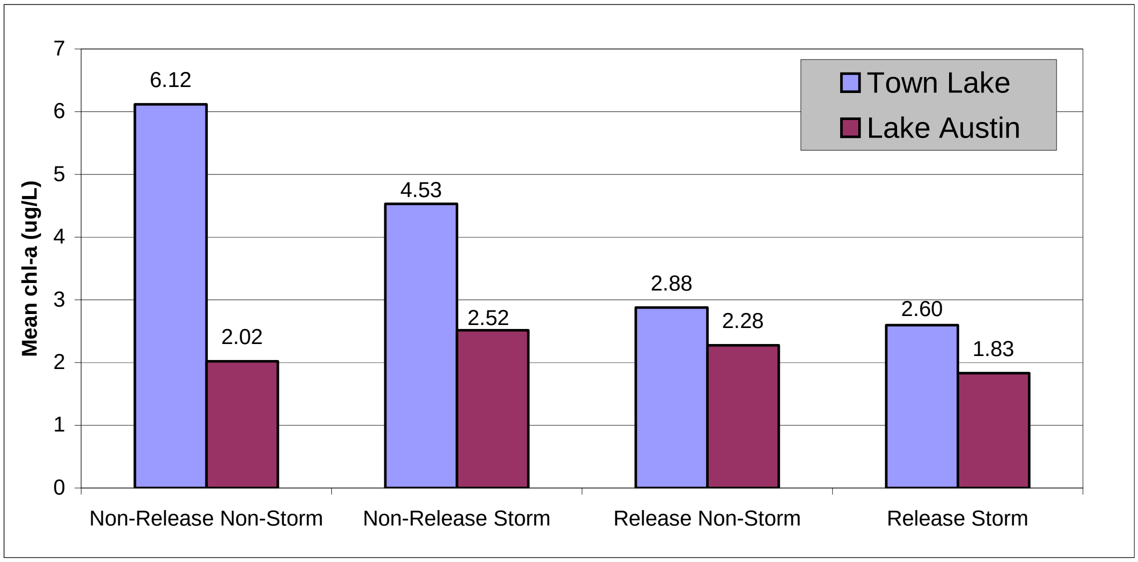
Although Town Lake exhibits higher mean chlorophyll-a concentrations due to extremely large spikes in chlorophyll-a during algae blooms, Lake Austin maintains a higher median chlorophyll-a level. Mean monthly chlorophyll-a is at a maximum during flow transitions between the release and non-release seasons due to reduced flows and higher temperatures.

NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

4.7.2 Spatial Distribution

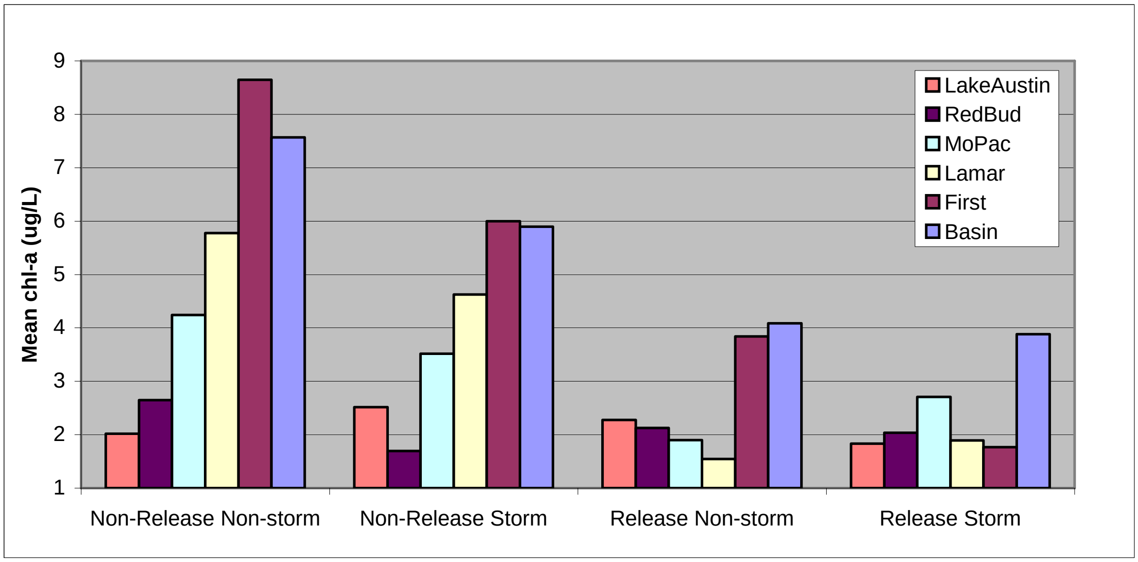
Town Lake chlorophyll-*a* mean concentrations are significantly greater than Lake Austin concentrations during all storm and release conditions except release, non-storm flow periods (Figure 4.202). However, median chlorophyll-*a* concentrations are greater in Lake Austin than Town Lake. Within Town Lake, non-release mean chlorophyll-*a* concentrations are significantly greater than release concentrations during both storm and non-storm flows.

Figure 4.202 Mean Watershed Chlorophyll-*a* Values by Season and Flow Type



Analyses of average site chlorophyll-*a* concentrations (Figure 4.203) yield opposite patterns under non-storm flow conditions between the release and non-release seasons. During winter non-release months, non-storm chlorophyll-*a* concentrations generally increase from upstream to downstream sites. During non-storm, release periods, however, chlorophyll-*a* concentrations decrease from Red Bud to Lamar, but remain elevated at the First Street and Basin sites. Concentrations at the most-downstream Basin site are significantly greater than chlorophyll-*a* concentrations at the most-upstream Red Bud site in all release and storm conditions.

Figure 4.203 Mean Site Chlorophyll-*a* Values by Season and Flow Type



Estimation of depth profiles in Town Lake for chlorophyll-*a* are impractical, as only surface data have been collected since 1996. However, existing data indicate that Town Lake mean surface chlorophyll-*a* is significantly greater than bottom concentrations during all storm and release conditions except release, storm flows when the waters of Town Lake are hypothetically more mixed and chlorophyll-*a* concentrations are at a general minimum.

4.7.3. Storm and Release Conditions

Mean monthly chlorophyll-*a* averages (Figure 4.204) exhibit sharp peaks during non-storm flow conditions in March and October when flow is reduced and temperatures are elevated (for the non-release season). Correlation analyses further illustrate the influences of flow through Town Lake on chlorophyll-*a* concentrations as significant inverse correlation is observed in all release and flow conditions (Table 4.24).

Figure 4.204 Town Lake Monthly Mean Chlorophyll-*a* Levels by Flow Type

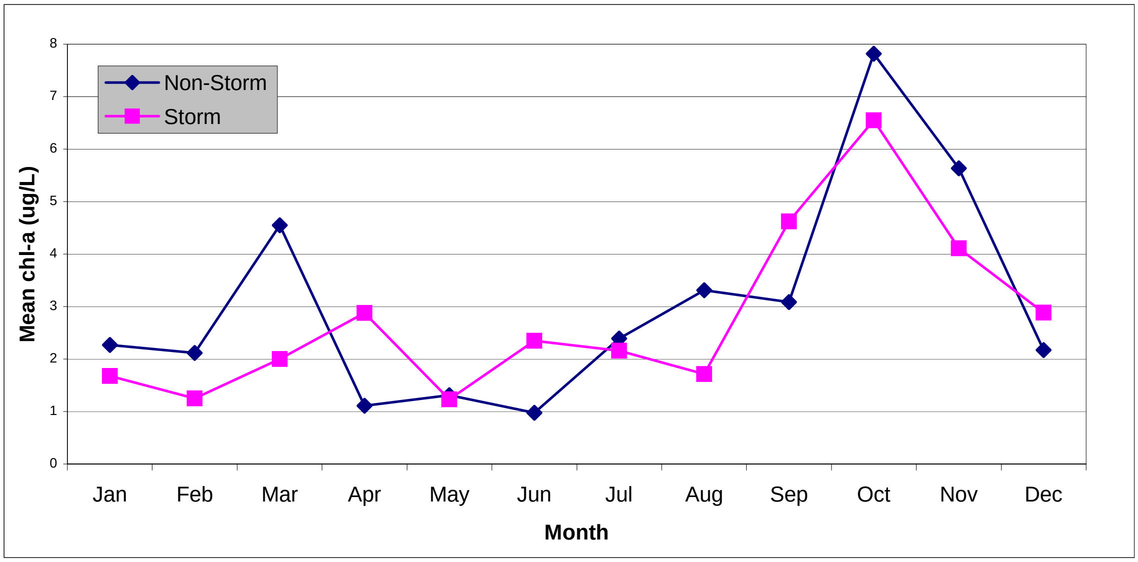


Table 4.24 Spearman Partial (with depth) Correlation Coefficients of Town Lake Chlorophyll-*a* versus Total Discharge from Tom Miller Dam

Non-Release		Release	
Non-Storm	**Storm**	**Non-Storm**	**Storm**
-0.2286 (<0.0001)	-0.3447 (<0.0001)	-0.3121 (<0.0001)	-0.1378 (0.0417)

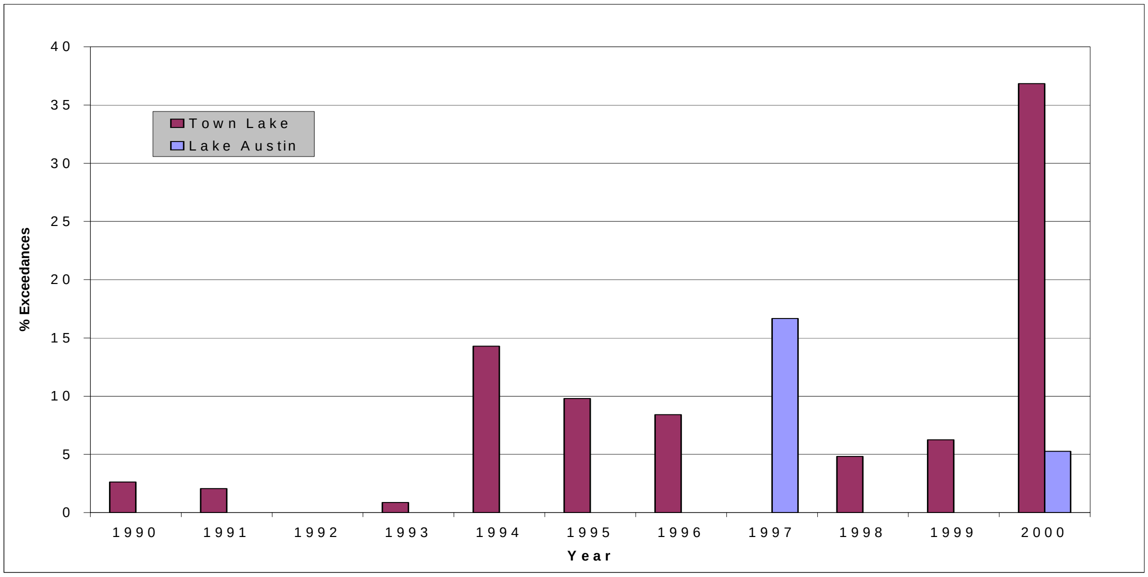
*associated probability that coefficients not equal 0 given in parentheses.

4.7.4 Concern Status

The maximum recorded chlorophyll-*a* concentration in Town Lake of 66 μg/L was recorded on 30 October 2000 during an extended algae bloom at the First Street site. Chlorophyll-*a* values above 50 μg/L were observed at both the First Street and Lamar sites for four days during this algae bloom. The last time measured Town Lake chlorophyll-*a* values exceeded even 35 μg/L was in October 1994.

Although Lake Austin typically maintains higher median chlorophyll-*a* values, available data show exceedances of the 2000 TNRCC screening criteria of 11.6 μg/L in only two years since 1983. Town Lake chlorophyll-*a* data, however, have shown at least one exceedance in none of the last 12 years and even show Town Lake as being "of concern" for chlorophyll-*a* in 2000 (Figure 4.205). The surge in chlorophyll-*a* exceedances in 2000 is most likely due to increased sampling related to an extended algae bloom. Although chlorophyll-*a* data reveal a statistically significant increase (p=0.0496) of percent exceedances in Town Lake, this temporal trend becomes non-significant (p=0.2516) when data from the year 2000 are excluded.

Figure 4.205 Percentage of Chlorophyll-*a* Samples Exceeding TNRCC Screening Criteria by Sampling Year and Watershed



4.7.5 Temporal Patterns

Despite a strong peak in chlorophyll-*a* values in October 1994, followed by decreasing chlorophyll-*a* values through the summer of 1998, overall Town Lake non-release chlorophyll-*a* concentrations are increasing significantly over time during both storm and non-storm flow conditions (Figure 4.206), primarily due to the extreme values observed during October 2000. Thus, it would appear that despite a period of several non-release seasons from 1995 through 1998 in which chlorophyll-*a* concentrations were decreasing, recent levels could be on the rise once again. If the algae bloom sampling event is excluded from analysis, regression statistics reveal that mean Town Lake chlorophyll-*a* concentrations would reach the TNRCC (2000) screening criteria of 11.6 μg/L in approximately 30 years, assuming that the rate of increase remains constant. Lake Austin chlorophyll-*a* concentrations also yield a significant overall increasing temporal trend during the non-release season, and similar patterns are observed in analyses of chlorophyll-*a* concentrations at individual sites. Significantly increasing temporal trends were observed in chlorophyll-*a* at all sites during non-release in both storm and non-storm flow conditions.

Town Lake chlorophyll-*a* concentrations during the release period (Figure 4.207) show a strong peak in March 1995 followed by decreasing values through the end of the data period of this report. Note that March is typically the month of flow transition from release to non-release. Analysis of Town Lake chlorophyll-*a* at individual sites during release yields the same pattern of rising to a peak followed by a decline, with statistically significant overall increasing trends observed only at the Lamar and Red Bud sites during release, non-storm flows. However, the more upstream sites exhibit peak chlorophyll-*a* concentrations at later dates than downstream sites. Release concentrations at the Basin peak in 1995, Lamar chlorophyll-*a* peaks in 1996 and Red Bud peaks in 1997.

Figure 4.206 Town Lake Surface Chlorophyll-*a* During Non-Release by Flow Type

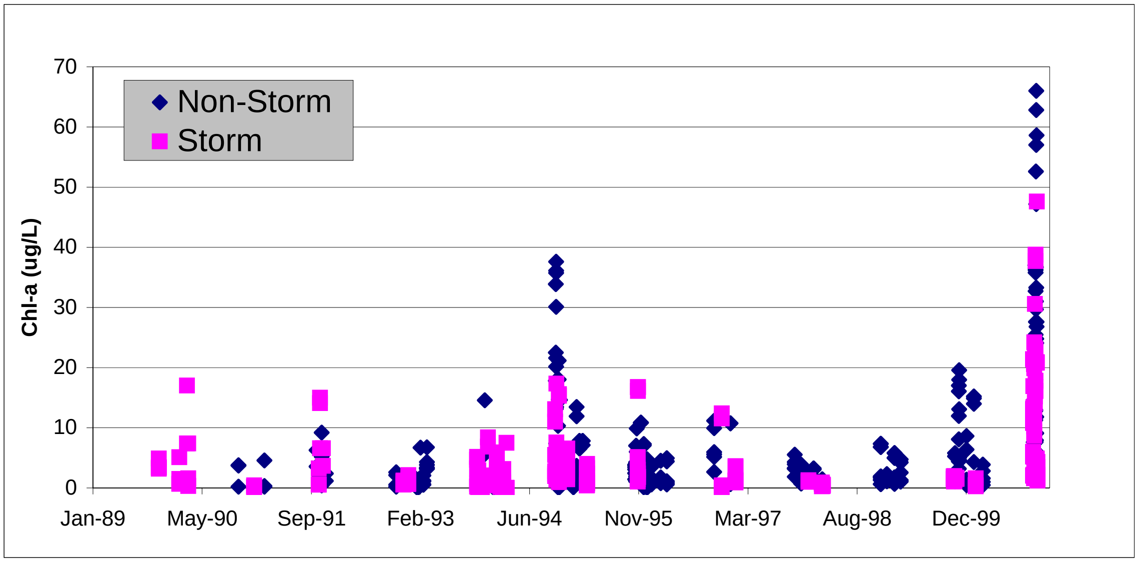
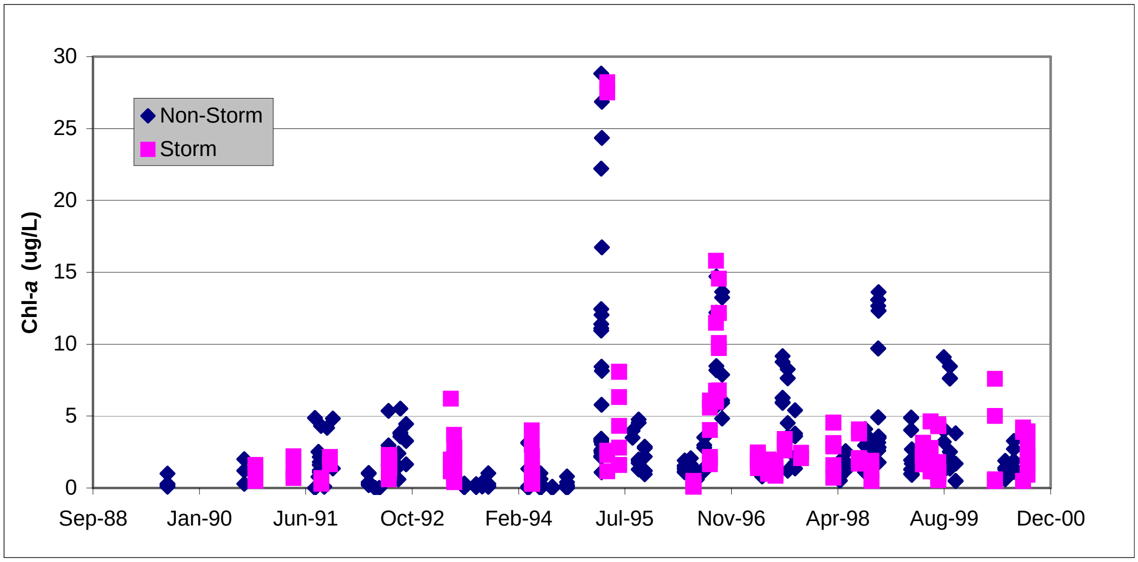


Figure 4.207 Town Lake Surface Chlorophyll-*a* During Release by Flow Type



4.7.6 Monitoring Recommendations

Sample frequency analysis for chlorophyll-a in Town Lake using estimated summary statistics and projecting current sampling rates into the future for the next one- and five-year periods was conducted (Table 4.25). Increased variation is evident during the non-release season in both storm and non-storm flows. Due to the potentially increasing trends in chlorophyll-a concentrations during non-release and the high variability in results, little opportunity exists for a reduction in current monitoring.

Table 4.25 Minimum Significant Detectable Difference in Watershed Mean Chlorophyll-*a* (as a value and percentage of current mean) if Sampling Continued at Current Rates Over Specified Time Periods

PARAM (µg/L)	**Non-Release**				**Release**			
	Non-Storm		**Storm**		**Non-Storm**		**Storm**	
	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 1 yr
Chl-*a*	5.220 (85)	2.303 (38)	3.538 (78)	1.561 (34)	1.964 (68)	0.867 (30)	1.779 (68)	0.785 (30)

4.8 Dissolved Metals

Although the USGS has monitored numerous metals in Town Lake water since 1975, only dissolved copper and dissolved lead have sufficient data sets for trend and comparison analysis across the period of record for this report.

Humans require small amounts of copper for normal metabolic processes. Copper is also one of the most important commercial metals due to its unique physical properties. Though naturally occurring, high concentrations of copper produce harmful environmental impacts on plants, invertebrates, and fish. The typical source of dissolved copper, more likely to pose hazards to human health than other forms of copper, which are tightly bound to inorganic materials, is corrosion of copper water pipes. Because of the human liver’s ability to effectively process copper, the impacts on aquatic life from excessive copper are typically of greater concern in natural waters (USEPA 1984).

Lead, similar to copper, is also a naturally occurring element in the environment. However, elevated lead levels in water typically result from the combustion of fossil fuels or corrosion of water pipes. Lead, unlike copper, has no beneficial effects on the human body and actually accumulates over time, resulting in damage to the nervous system, blood and reproductive organs, particularly in children. Lead in drinking water typically contributes less than 20 percent of total lead exposure, although lead also poses toxic effects to aquatic organisms (USEPA 1993).

TNRCC (2000) water quality standards for specific metals in freshwater reservoirs to protect aquatic life are based on calculations that employ segment-specific average hardness values. The contaminant level at which an immediate toxic effect on aquatic life occurs is listed as the acute criteria, and the contaminant level for which exposure over time would result in toxic effects on aquatic life is listed as the chronic criteria (Table 4.26). The Town Lake acute and chronic standards were calculated using the 246 mg/L as $CaCO_3$ average hardness value published in Implementation of TNRCC Standards via Permitting (TNRCC 1995).

Table 4.26 Town Lake TNRCC Dissolved Metal Water Quality Standards

Parameter	Acute Criteria (μg/L)	Chronic Criteria (μg/L)
Copper, Dissolved	43	27
Lead, Dissolved	228	8

4.8.1 Summary of Results

Figures 4.208 and 4.209 present graphical summaries of dissolved metals in Town Lake. Dissolved metals exhibit generally inverse relationships in Town Lake with discharge from Tom Miller Dam.

Town Lake appears to be increasing the concentrations of dissolved copper from initial concentrations upon entrance to Town Lake from Lake Austin, possibly impacting the Colorado River.

Dissolved copper appears to be increasing in Town Lake over time during release, storm flow conditions, although at present rates of increase it would be approximately 40 years before mean levels reached TNRCC chronic screening criteria. Town Lake concentrations of dissolved lead, however, appear to be improving over time during the recent past.

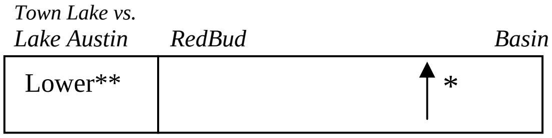
Comparison of data in Town Lake to 2000 TNRCC screening criteria in water reveal that Town Lake is of “no concern” for dissolved copper and dissolved lead, according to official assessment methodologies.

The decreasing temporal trend and low concentrations relative to TNRCC standards suggest a reduction in dissolved lead sampling to as little as one sample per year at each of two sites. The increasing temporal trend in dissolved copper concentrations in Town Lake, though slight and still well below TNRCC screening criteria, in combination with the potential for cupric herbicide application in Lake Austin for the control of nuisance aquatic macrophytes, suggests that at the least no reduction in dissolved copper sampling occurs at this time.

Figure 4.208 Graphical Summary of Town Lake Dissolved Copper

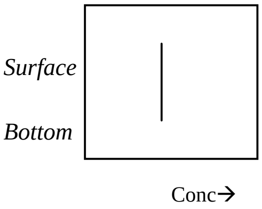
SPATIAL

Location

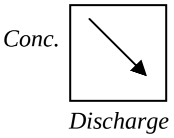


*Basin sig. higher in NR
**No difference b/n wsheds in storm flows

Depth



FLOW/SEASONALITY

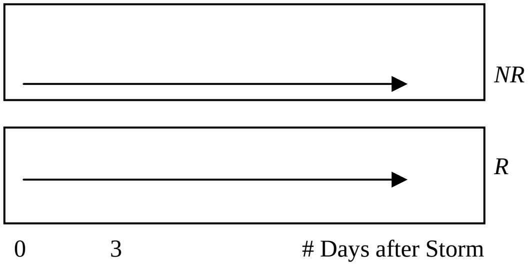


Storm flows highest in: Non-Release

Non-Storm flows highest in: Non-Release

Max conc. in: NR, NS

Post-Storm



Monthly

Lack of data to calculate reasonable estimates for monthly means

Jan Dec

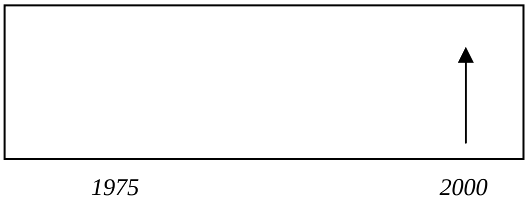
TEMPORAL

Annual % Exceedance of TNRCC Criteria

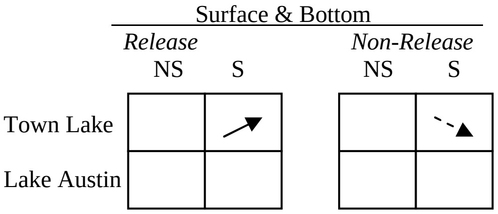
No exceedances of acute or chronic criteria

1975 *2000*

Overall temporal trend



Temporal Regression



NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

Comments:

Max concentrations observed at the Basin. No clear site or watershed differences during release. Strange elevated values in most recent (2000) sampling. No NR, NS data since 1992. Sharp and significant increase in release, storm concentrations from 1996 – 2000. Potential application of cupric herbicide in Lake Austin for control of hydrilla provides opportunity for additional monitoring.

Figure 4.209 Graphical Summary of Town Lake Dissolved Lead Analyses

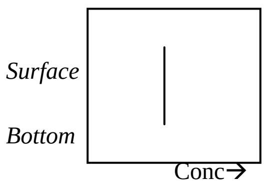
SPATIAL

Location

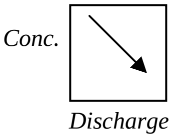
Town Lake vs. Lake Austin	*RedBud*	*Basin*
?*	No site diff.	

*LA sig. greater during R, NS, but no diff in NR, S.

Depth

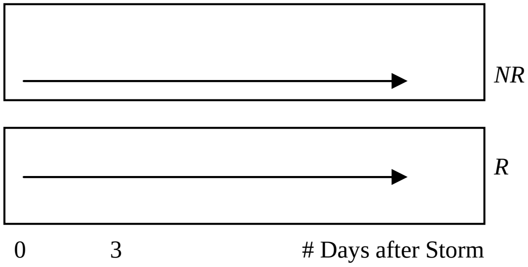


FLOW/SEASONALITY



Storm flows highest in:	*Non-Storm flows highest in:*	*Max conc. in:*
Non-Release	No diff.	NR, S

Post-Storm



Monthly

Not enough data to reasonably estimate monthly means

Jan Dec

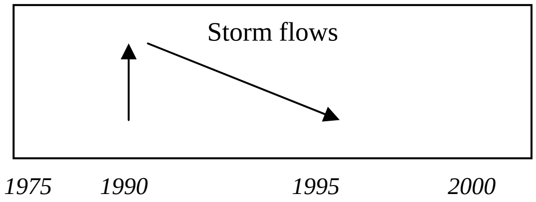
TEMPORAL

Annual % Exceedance of TNRCC Criteria

No exceedances of acute criteria.
Chronic criteria exceeding at surface only in 1990 and 1991.

Time →

Overall temporal trend



Temporal Regression

SURFACE & Bottom

	Release NS	*Release* S	*Non-Release* NS	*Non-Release* S
Town Lake		↘		↘
Lake Austin				

Time →

Comments:

No clear site differences. Lake Austin concentrations sig. greater than Town Lake during release, non-storm, but significantly less during release, storms.

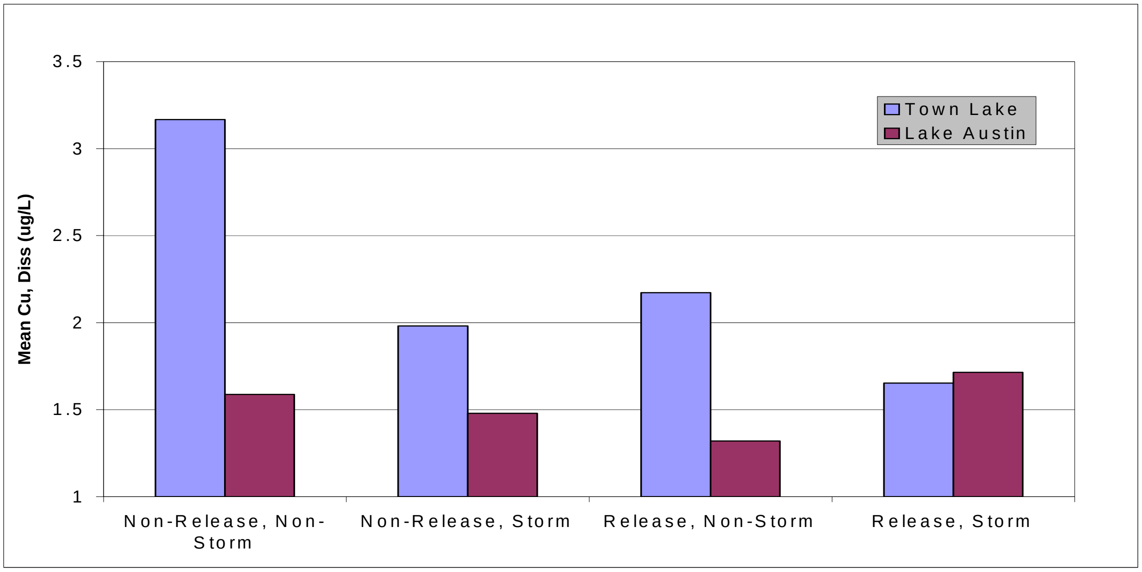
NR = Non-Release R = Release
NS = Non-Storm S = Storm
Blank cells indicate no statistically significant pattern

4.8.2 Spatial Distribution

Due to a modification in sampling protocol by the USGS, no non-release, non-storm dissolved copper or lead data were obtained after 1992 in Town Lake and no Lake Austin measurements of dissolved lead during non-release, storm flow conditions.

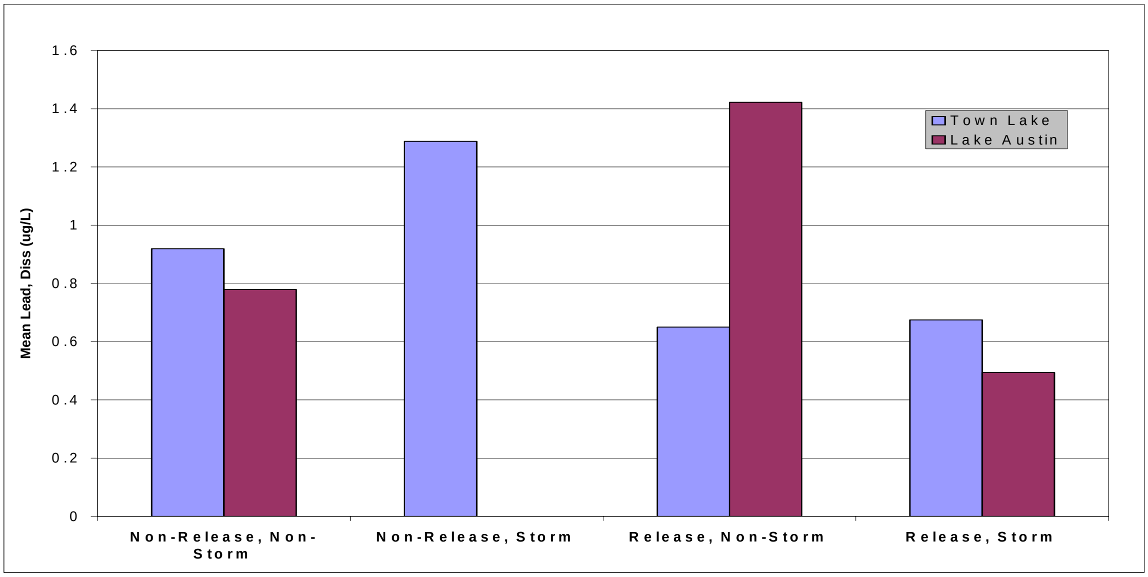
Mean Town Lake dissolved copper concentrations are significantly greater than mean Lake Austin concentrations during non-storm conditions in both release and non-release seasons (Figure 4.210). Although no clear patterns occur in mean site dissolved copper levels during release, the Basin does exhibit significantly higher average dissolved copper during non-release, storm flow conditions.

Figure 4.210 Mean Dissolved Copper Watershed Concentrations by Season and Flow Type



Mean Town Lake dissolved lead concentrations are significantly higher than Lake Austin during storm flow conditions in release, although Lake Austin exhibits higher mean dissolved lead levels during non-storm flow conditions in release (Figure 4.211). Mean dissolved lead measurements also exhibit no significant differences between Town Lake sites in any storm or release condition for which data exist.

Figure 4.211 Mean Dissolved Lead for All Sites and Depths by Watershed



No clear depth patterns were determined in either dissolved copper or lead concentrations in Town Lake, and no statistically significant difference exists between average Town Lake surface and bottom copper or lead measurements for any storm or release condition.

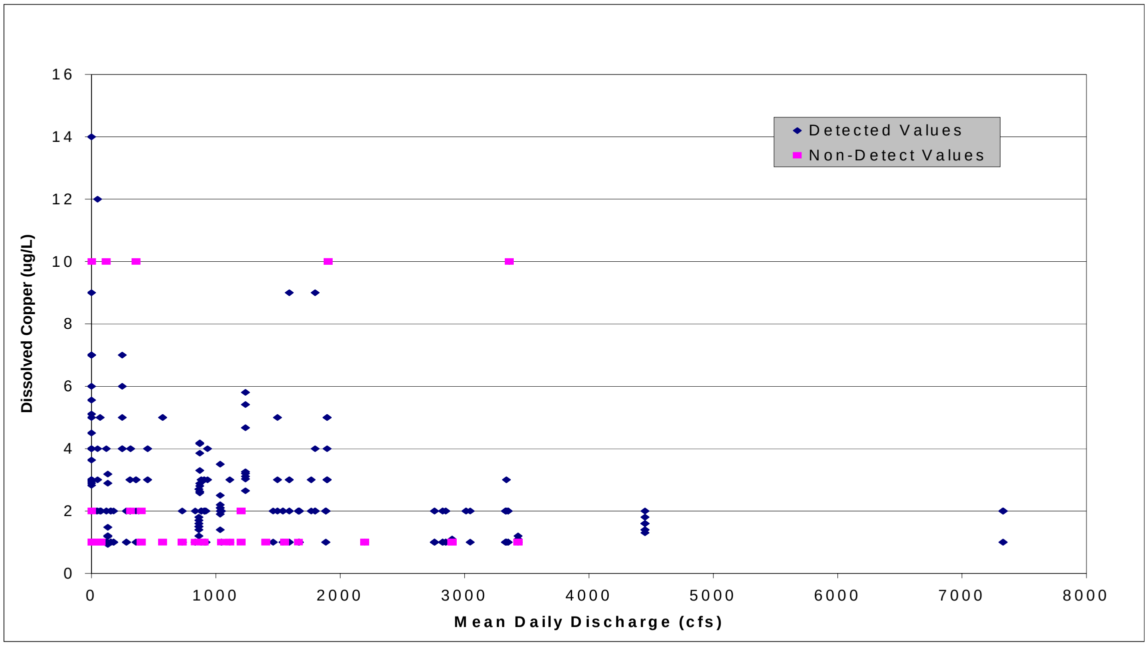
4.8.3 Storm and Release Conditions

Non-release conditions yield significantly higher dissolved copper concentrations than release in both storm and non-storm flows. However, no statistically significant difference occurred between storm and non-storm flow mean dissolved copper levels during either the release or non-release seasons.

Storm flow impacts in Town Lake, as measured by dissolved lead concentrations, are significantly greater in non-release than release conditions, with maximum Town Lake average dissolved lead concentrations observed during non-release, storm flow conditions.

When all available data are combined for analysis, dissolved copper concentrations are significantly and inversely related to total daily discharge from Tom Miller Dam into Town Lake, as expected from the lower observed mean concentrations observed in Lake Austin (Figure 4.212). Lead data, when ranked for analysis purposes due to non-detect data points, also reveal a significant inverse relationship with flows through Town Lake, although the slope of the decrease is small, indicating no strong connection between dissolved lead in Town Lake and flows through the dam.

Figure 4.212 Town Lake Dissolved Copper versus Mean Daily Discharge From Tom Miller Dam



No clear trends in dissolved lead or dissolved copper concentrations in the days following storm events are evident in Town Lake data during either the release or non-release seasons when data from all sites and depths are combined for analysis.

4.8.4 Concern Status

Dissolved lead and dissolved copper concentrations do not pose a concern to the protection of aquatic life in Town Lake as assessed by TNRCC screening methodology.

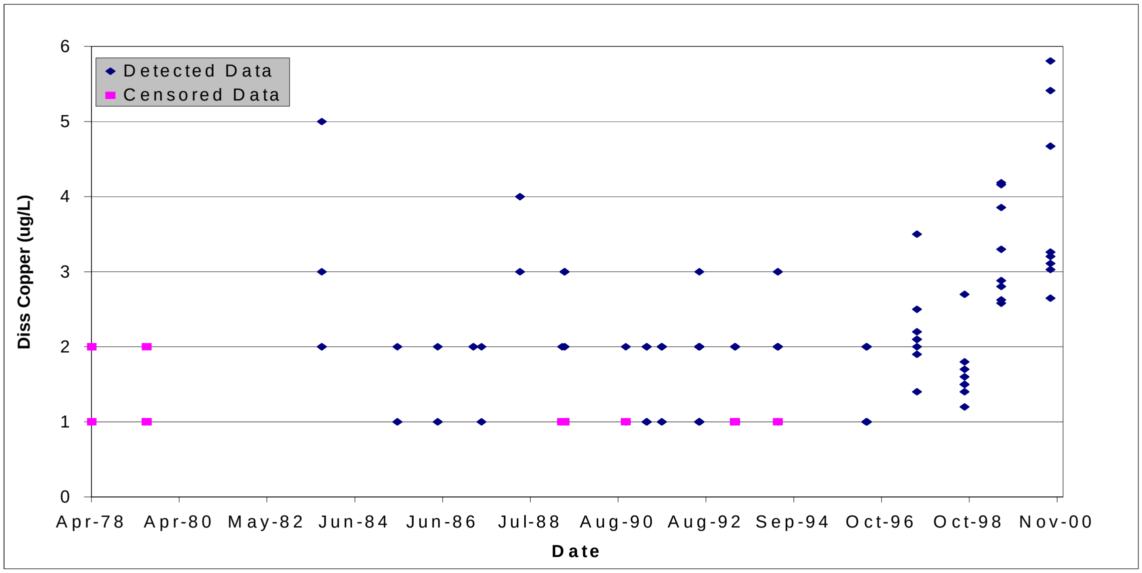
No sample in Town Lake for dissolved copper has exceeded either the TNRCC 2000 acute or toxic criteria in any year since 1975 at any depth or any site. No sample in Town Lake for dissolved lead has ever exceeded the TNRCC 2000 acute criteria in any year since 1975 at any depth or site. Four Town Lake surface samples have exceeded the chronic criteria since 1975, although the last exceedance of the chronic criteria occurred in February 1991, when a concentration of 11 µg/L was recorded at Red Bud.

4.8.5 Temporal Patterns

Both dissolved lead and dissolved copper yield significantly higher mean concentrations in the period before 1992 when the minimum low flow policy was instituted by the LCRA during non-release, storm flow conditions. However, the institution of the low flow policy would not be expected to have any major impact on dissolved lead or dissolved copper concentrations in Town Lake.

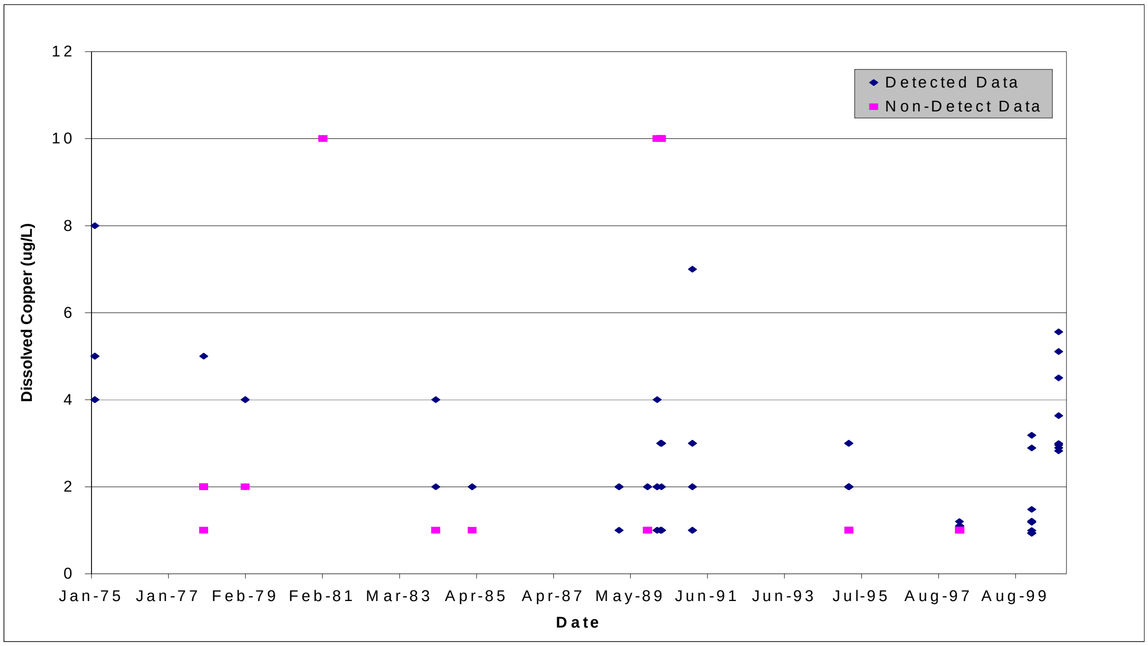
Dissolved copper concentrations in Town Lake exhibit a statistically significant increasing trend over time during release, storm flow conditions, at all monitored locations (Figure 4.213). However, even at the abrupt rate of increase in dissolved copper concentrations observed from 1996 to 2000, it would be approximately 40 years before Town Lake release, storm flow mean dissolved copper concentrations were at chronic screening criteria levels.

Figure 4.213 Town Lake Dissolved Copper During Release, Storm Flow, All Sites and Depths



During non-release storm flow conditions, however, Town Lake dissolved copper yield no clear trend over time (Figure 4.214). The same elevated dissolved copper level observed in release storms during 2000 are also evident in non-release storm copper levels.

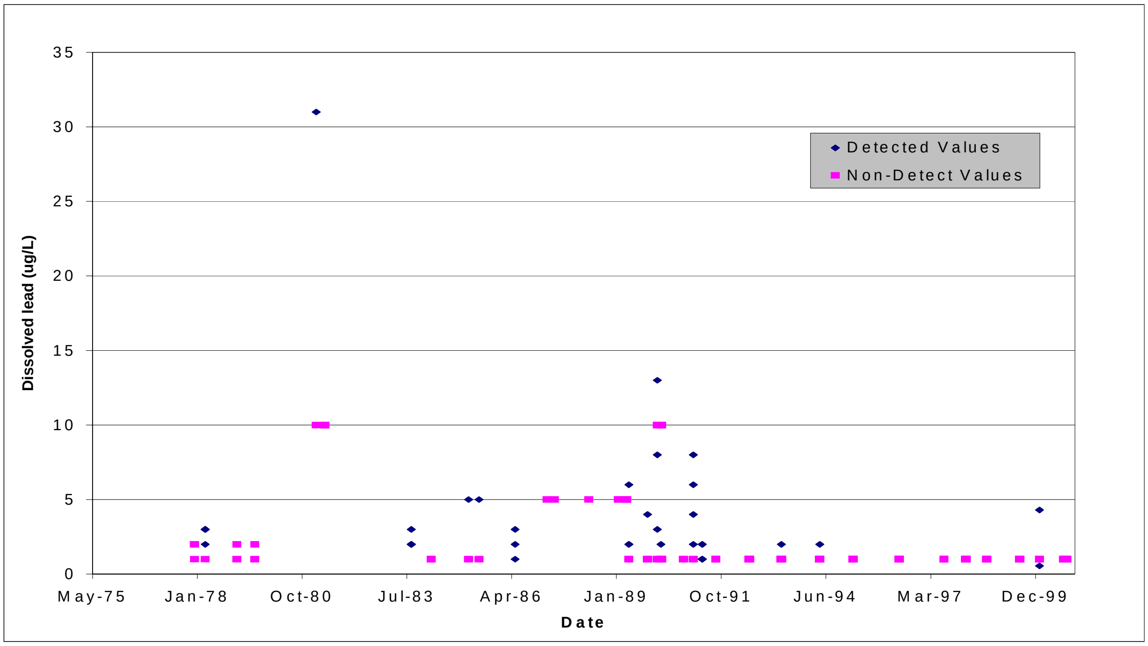
Figure 4.214 Town Lake Dissolved Copper During Non-Release, Storm Flow, All Sites and Depths



No clear statistical trends in dissolved copper concentrations within Town Lake during non-storm conditions are evident (note that no non-release non-storm data exist after 1992 for dissolved copper), although when data are aggregated for all sites and depths, a graphically decreasing trend was observed in non-storm dissolved copper levels in Town Lake.

Dissolved lead concentrations in Town Lake under storm flow conditions in both release and non-release exhibit statistically significant decreasing trends over time (Figure 4.215), with only one detected value measured since 1996. No clear trend is evident in Town Lake dissolved lead concentrations over time during non-storm conditions.

Figure 4.215 Town Lake Dissolved Lead During Storm Flow, All Sites and Depths



4.8.6 Monitoring Recommendations

Sample frequency analysis of Town Lake dissolved metals was conducted using current estimates of summary statistics and rates of sampling projected into the future (Table 4.27).

Table 4.27 Minimum Significant Detectable Difference in Watershed Mean Metals Concentrations (as a value and percentage of current mean) if Sampling Continued at Current Rates Over Specified Time Periods

PARAM (mg/L)	**Non-Release**				**Release**			
	Non-Storm		**Storm**		**Non-Storm**		**Storm**	
	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 5 yr	Min diff after 1 yr	Min diff after 1 yr
Cu, Diss.	3.798 (120)	1.544 (49)	2.251 (114)	0.915 (46)	2.663 (123)	1.082 (50)	1.316 (80)	0.535 (32)
Pb, Diss	2.517 (274)	1.023 (111)	4.787 (372)	1.946 (151)	1.712 (263)	0.696 (107)	1.131 (168)	0.460 (68)

Although a large amount of variation in lead values exists, the observed decreasing temporal trend and lack of exceedance of TNRCC screening criteria in the nine years from 1991 to 2000 do not suggest that additional lead monitoring should be performed on Town Lake. If current sampling rates were reduced to more of a periodic screening process, where two sites were sampled once per year for five years, mean watershed differences of greater than or equal to approximately 2 μg/L would be detectable and would still provide the opportunity to assess the impacts of dissolved lead on the aquatic life of Town Lake.

However, the increasing temporal trend, though slight, in dissolved copper values in Town Lake, in combination with the potential application of cupric herbicide in Lake Austin for the control of nuisance exotic macrophytes, would suggest that no reduction in dissolved copper monitoring should be made at this time.

4.9 Conclusions

The analysis of surface water chemistry in Town Lake does not lead to any single conclusion about the relative health of the lake during the period since the previous Town Lake Study was completed. The detailed review of the data provided in this section was necessary to discern patterns or lack thereof related to release conditions, stormwater influences, development patterns, localized sources of pollution, or other human impacts. Most of the statistically significant changes documented in water quality through monitoring of conventional pollutants have been relatively minor in effective magnitude, but may be precursors of more rapid change in future monitoring periods. The water quality impacts from Austin's urbanized landscape were observed ten years ago, and now some evidence of degradation over time is seen when examining the extended period of monitoring data. Summarizing and synthesizing this detailed information leads to the following major conclusions:

Hydrology - The flow rates in Town Lake have increased during non-release periods, primarily due to the minimum release policy negotiated with LCRA by the City of Austin in 1992. This policy has had collateral benefits to many water quality parameters. Increases in minimum release could potentially be an effective non-structural best management practice were it found to be feasible from a water supply and water rights standpoint. This should be included in water planning negotiated through LCRA and the Texas Water Development Board.

Nutrients - All nutrient parameters were tracked closely over this period and some were found to be increasing while others were decreasing under specific storm and release conditions. Overall, the trends and magnitude of the nutrient levels in Town Lake were inconclusive, and continued tracking will be necessary for timely responses to be made. Many of these parameters were found to have benefited from the minimum flow policy of 1992 with significantly higher means in ammonia, TKN, and orthophosphorus prior to its initiation under release conditions. Although orthophosphorus is decreasing over time under all conditions, a pattern corresponding to seasonal fertilizer applications indicates a potential nonstructural best management practice that may be effective, were levels to become problematic.

Solids, Salts, and Clarity - Clarity of water in Town Lake exhibits contrary trends depending on release condition, but is improving during storm conditions, which is reflective both of Lake Austin influences and, potentially, City attention to sediment controls. Conductivity, dissolved salts, and solids also indicate mixed results. Pre-1992 conductivity levels are significantly greater than post-1992 levels in both release and non-release seasons. Both calcium and alkalinity exhibit significantly higher mean Town Lake levels during non-release prior to 1992, while total chloride, sulfate, and magnesium exhibit significantly higher concentrations after 1992. Ionic composition of Town Lake water may be impacted by larger events moving through the Colorado River, as both increases and decreases have been observed in past periods:

- Despite periods of apparent increasing historical conductivity in Town Lake during the non-release season, such as that observed from approximately 1984 to 1990, a significant overall decreasing temporal trend in both storm and non-storm flow conditions was shown when data from all sites was composited during the non-release season at both surface and bottom depths Although Town Lake experienced decreasing conductivity throughout the later half of the 1990s during non-release, a sharp spike in conductivity values was observed in the fall and winter of 2000.
- Chloride concentrations do not show a statistically significant trend, but during any release or flow condition, a pattern emerges in which non-storm chloride concentrations increase sharply from approximately 1992 to 1997, surpassing the 60 mg/L TNRCC

screening criteria, then decline sharply through 2000. A nearly identical pattern is evident in non-storm total sulfate and sodium concentrations in Town Lake in both release and non-release seasons. Although strong fluctuations occur in total sulfate concentrations with time, a statistically significant increasing trend in overall concentration over time does exist during non-release, non-storm flows. Conversely, a significant decreasing overall temporal trend is found in non-storm, release total sulfate and sodium concentrations for all sites combined.

Bacteria - No statistically significant temporal trends occur in overall Town Lake fecal coliform concentrations during either the non-release season in non-storm or storm flows by site, or for all stations combined. Average Town Lake fecal coliform levels are significantly greater than average Lake Austin concentrations for all release and flow conditions. Fecal coliform levels during non-release, non-storm flow are significantly greater before 1992, indicating a potential benefit to Town Lake from the minimum flow policy instituted by LCRA in 1991. Non-storm, release fecal coliform levels, however, are significantly higher in post-1992 data. No statistically significant difference was indicated between pre- and post-1992 concentrations during storm flow in either the release or non-release season.

Dissolved Oxygen and Physical Parameters - The frequency and duration of near-anoxic conditions at the bottom of the Basin are increasing over time, and DO levels are showing decreasing trends during non-release in both storm and non-storm flow conditions. At the present rate of decrease (not considering the large amount of both daily and seasonal variation), mean Town Lake DO during non-release, non-storm conditions would approach the 5mg/L screening criteria in approximately 50 years. Although not currently a problem in Town Lake, according to TNRCC assessment methodology, decreases in DO indicate a potential for additional “concern” status in the future due to DO impairment. Analysis of Town Lake non-release DO data at the site level in non-storm flow conditions yields statistically significant decreasing trends at the bottom of all five Town Lake sites as well as at the surface of the Lamar, MoPac, and Red Bud sites. Slight, but significant, increasing trends are observed during some of the specific storm and flow conditions for temperature as well; however, pH shows no clear pattern.

Chlorophyll-a and Trophic Status - Eutrophic levels are observed at some time during most years. Some of the water quality parameters measured seem to indicate the potential for worsening algae conditions, but not consistently for similar parameters. Chlorophyll-*a* concentrations during non-release are increasing over time during both storm and non-storm flow conditions. Using TNRCC screening levels (TNRCC 2002), Town Lake has exceeded criteria for chlorophyll-a in six of the last seven years in at least 5 percent of samples, and trends would indicate exceedance of concern to the state in about 30 years. Unfortunately, the location of the highest algal levels coincides with the location of the drinking water intake.

Dissolved metals - Slight, but significant, increasing trends are observed during some of the specific storm and flow conditions for dissolved copper. However, dissolved lead appears to be improving during the recent past. Other metals were either below detection or too few data points existed to evaluate.

5.0 TOWN LAKE ALGAE BLOOMS

Algae blooms are highly visible, problematic water quality events in Town Lake as identified in both the Town Lake Report (COA 1992b) and the Watershed Protection Master Plan (COA 2001). The initial goal for this water quality problem was to reduce the number of major blooms to one per year. In retrospect, some of the initial Town Lake goals, such as this one, were unattainable. COA has only limited jurisdiction over the majority of the watershed areas contributing runoff to the upstream reservoirs. Nitrate concentrations in Barton Springs are unlikely to decrease, as development is expected to increase in the contributing and recharge zones for the Barton Springs segment of the Edwards Aquifer. With these complications in mind, the goals were revised through the master planning process. The Citywide Master Plan (COA 2001) set a new goal to maintain Town Lake's Designated Use support status as specified in the TCEQ Texas Surface Water Quality Standards (30 TAC 307). To support this broader goal, an objective was defined to maintain the current status in terms of the frequency and magnitude of algae blooms. Because of the complexity inherent in achieving this objective, several intermediate, measurable objectives were outlined in 1992 and revised in the Master Plan. Current watershed-specific objectives include the reduction of loads from urban watersheds, maintenance of existing loads from Barton Creek, and reduction in the rate of increase in loads from Lake Austin. From the model projections described in Volume II of this document, meeting these objectives is predicted (within the limitations inherent in modeling such dynamic biological events) to maintain current algae bloom frequency and magnitude.

5.1 Algae Bloom Sampling

The monitoring program for Town Lake was designed to assess progress in reaching specific water quality goals as well as the general water quality objectives, which were developed in the Town Lake Water Quality Alternatives Study (COA 1992b). Sampling efforts are designed to provide an ongoing assessment of trends or patterns in the number, duration, location, and magnitude of algae blooms. The historic algae bloom sampling protocol is described below in Figure 5.1. Storm sampling is included, since storm runoff may provide the necessary nutrients to trigger blooms. The algae bloom sampling protocol maintained the routine algae count sampling until 2005, when bloom and storm sampling began being restricted to once every five years. Sampling will no longer occur at the Lamar Boulevard bridge. The continuous monitoring at the surface will take place at the First Street bridge.

Figure 5.1 Algae Bloom Sampling Protocol

Sampling Collection and Analysis Protocols:

- **Routine algae count sampling** - Surface water samples analyzed for planktonic algae density by water treatment plants.
  Sites: Green (GWTP), Ullrich and Davis Water Treatment Plant intake areas.
  Frequency: GWTP – every week day
  Ullrich and Davis – 2 or 3 times per week.

- **Bloom and storm sampling -** Intensive sampling triggered by either a storm or by algae counts > 10,000 at GWTP. Surface water sampling will begin following the fall decrease in dam releases to a minimal level (usually in mid-October). Samples will be either the full Town Lake run without fecal samples (see the description of sites and parameters in Chapter 2) or a reduced set of surface-only samples and parameters taken at bridge sites.
  Storm event frequency:
  Day of the storm – Bridge samples taken.
  Day after the storm - A complete Town Lake run.
  Continued sampling daily until either algae counts go over 10,000 or it becomes apparent that a bloom is not going to occur – Town Lake runs weekdays; bridge samples weekends.
  High algae count frequency (>10,000 at GWTP):
  First day where count > 10,000 - Bridge samples taken.
  Continued sampling until count < 10,000 - Town Lake runs daily.
  Bridge sample sites: First, Lamar, Redbud and Walsh boat ramp in Lake Austin
  Bridge parameters: temperature, turbidity, total phosphorus, dissolved orthophosphorus, TKN, ammonia, nitrate+nitrite, and chlorophyll-*a*.

- **Continuous Monitoring**: DataSonde units are placed: 1) at depth in the Basin near Longhorn Dam and 2) at the surface at Lamar bridge from mid Oct. – mid Nov. to monitor fluctuations due to algae blooms. This will allow staff to continuously monitor changes in dissolved oxygen levels resulting from diel cycles of algae photosynthesis and respiration, senescing and decomposing algae blooms, transient storm inflows of organic matter and other oxygen-demanding pollutants from urban tributaries, and variation in flows from upstream releases.

- **Weather Data** – Daily air temperature, cloud cover, and wind speed data will be obtained from the National Weather Service for the airport location.

5.1.1 Algae Bloom Events

Algal densities in Town Lake in excess of 10,000 cells/mL were historically considered a bloom (COA 1992b). This definition was partially arbitrary. To more closely relate the COA definition of algal blooms to lake trophic status, this number has been refined. Literature values (Olem 1990) for the relationship between trophic state, chlorophyll *a* concentrations, and algal counts are shown in Table 5.1.

Table 5.1 Relationship between Phytoplankton Measures and Trophic State

Trophic state	oligotrophic	mesotrophic	eutrophic	“high algae” appearance	hyper-eutrophic
chlorophyll *a* (µg/L)	<4	4-10	10-25	approx. 17	>25
algae counts (cells/mL)	<2,000	2,000-15,000	>15,000		

These literature values indicate that the count level used by COA for blooms could be as high as 15,000 rather than 10,000. Based on 15,000 cells/mL, Town Lake has averaged between one and two blooms per year in recent years. The major bloom periods have been in late fall. Table 5.2 shows the number of blooms per year and the time of year during which the blooms occurred in recent years.

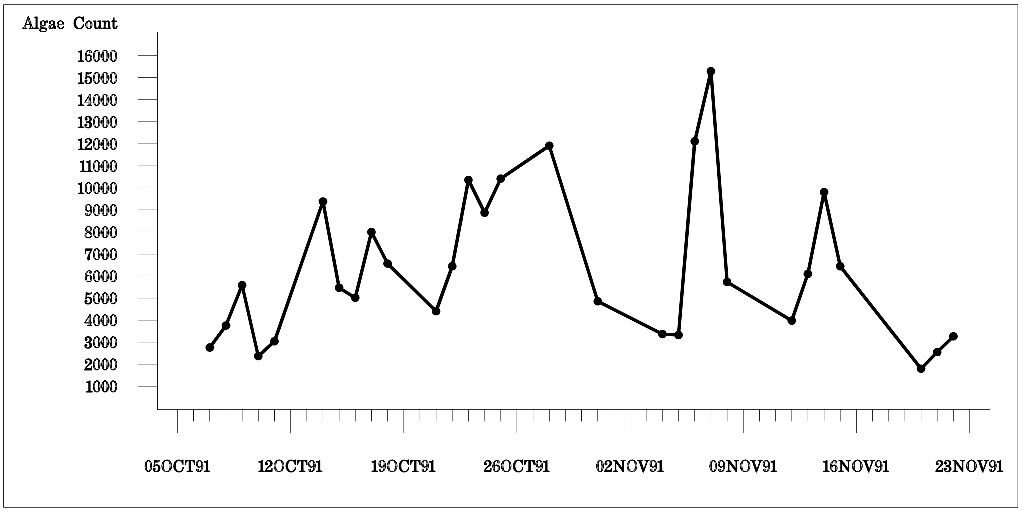
Table 5.2 Number of Algae Blooms per Year

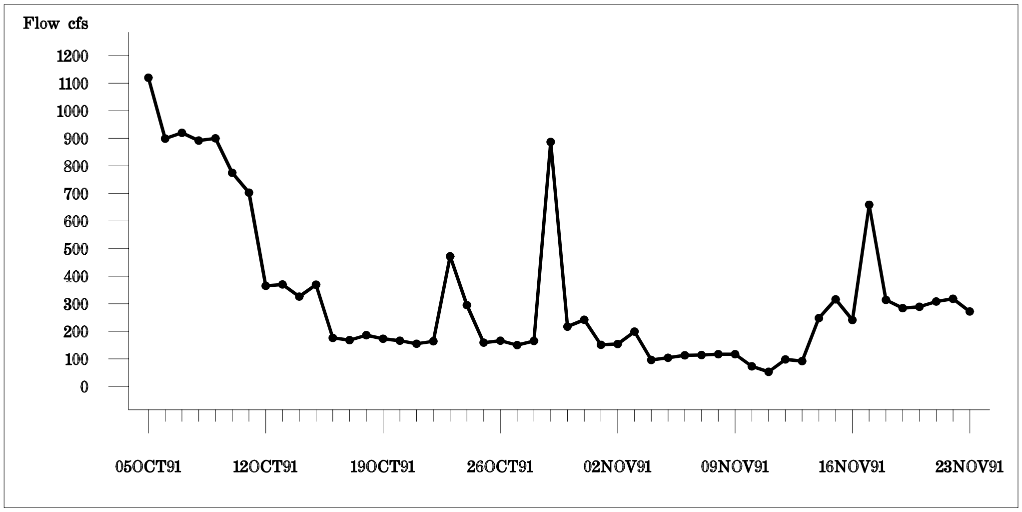
Year	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Number of Blooms	3	1	0	2	2	2	0	0	0	1	1
Bloom Periods	Spring Fall	Fall		Sum. Fall	Fall	Spring Fall				Sum.	Fall

5.1.2 Monitoring Event Results

Because algae counts are taken much more frequently then chlorophyll *a* concentrations (due to laboratory expense and analysis delivery time), blooms are determined initially from the counts. Sampling that succeeded in tracking all or part of a boom period occurred six times: during the fall of 1991, 1993, 1994, 1995, and 2000, and spring 1995. Data from these six periods are presented below, in Figures 5.2 through 5.7. For each event, parameters are presented first which either remain fairly constant over the length of the lake or which have been measured in only one location. These variables are flow, rainfall, water temperature, and the algal count. Then parameters that differ from one segment of the lake to another are plotted in subsequent figures. In many cases, extended periods occur between sampling dates. Sample data points are connected using linear interpolation, but in actuality the parameter levels may have varied significantly between samples. Flow, precipitation, temperature, light (secchi disk depth), and nutrients are the driving variables; dissolved oxygen, chlorophyll *a* and the algal count are the response variables. In each plot, the response variables are plotted first, followed by the driving variables.

Figure 5.2a Fall 1991 Bloom Data





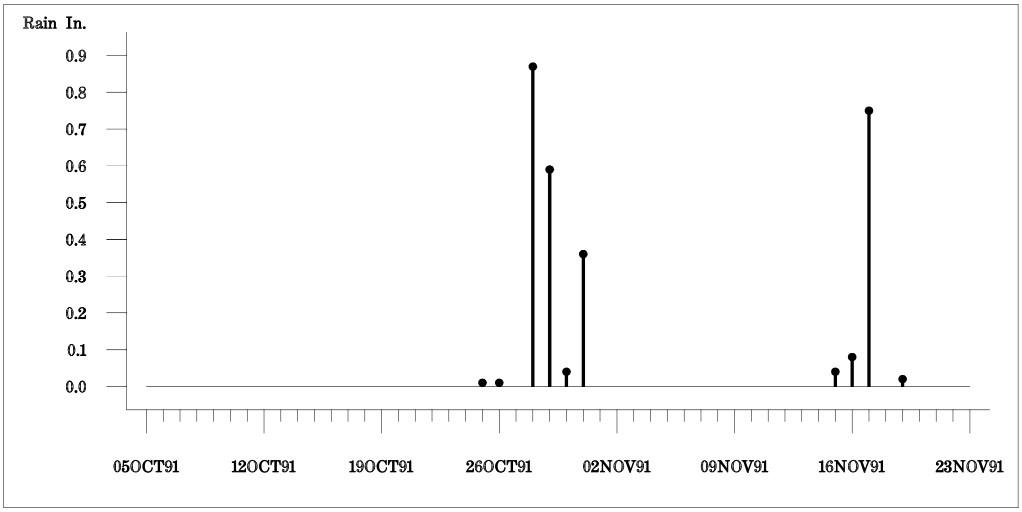


Figure 5.2b Fall 1991 Bloom Data (continued)

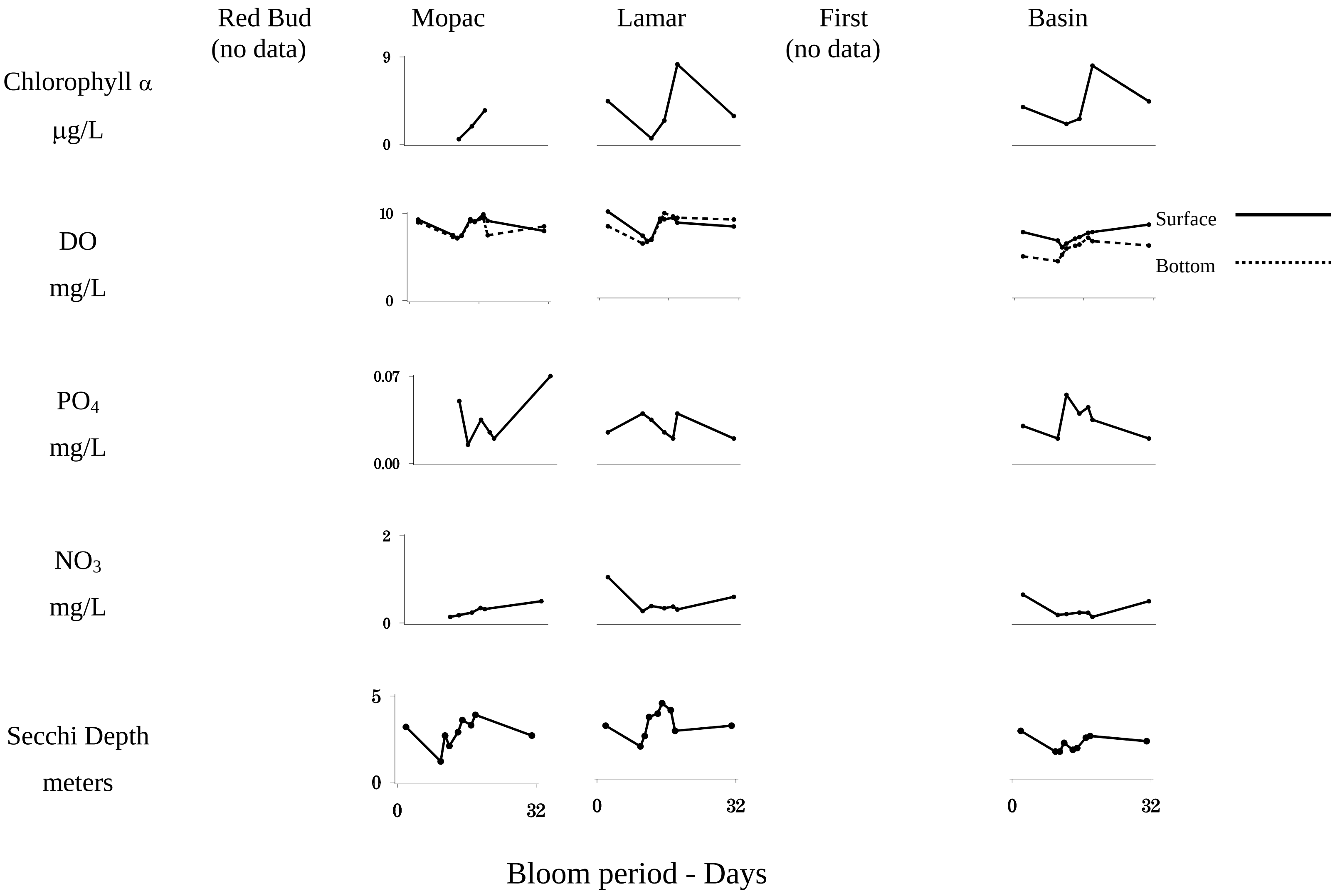


Figure 5.3a Fall 1993 Bloom Data

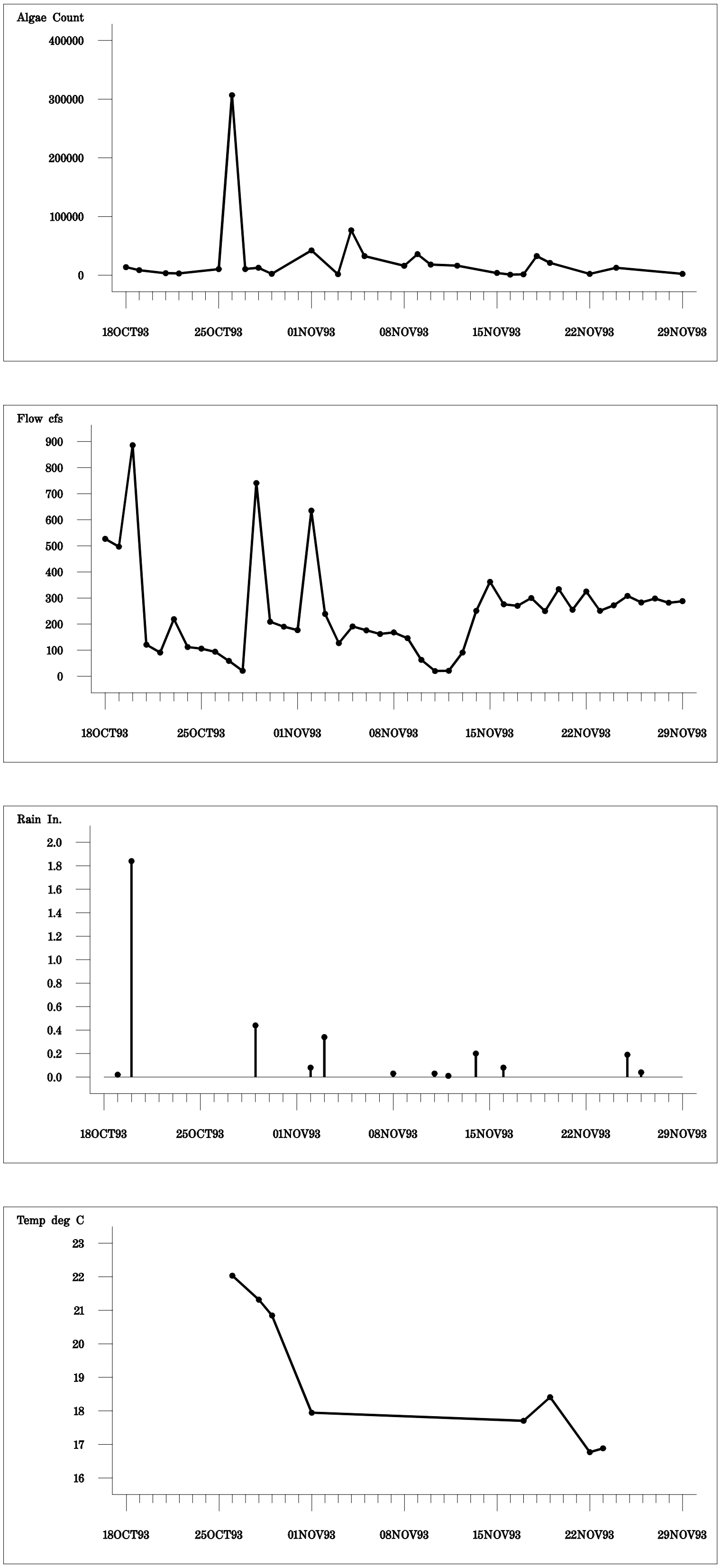


Figure 5.3b Fall 1993 Bloom Data (continued)

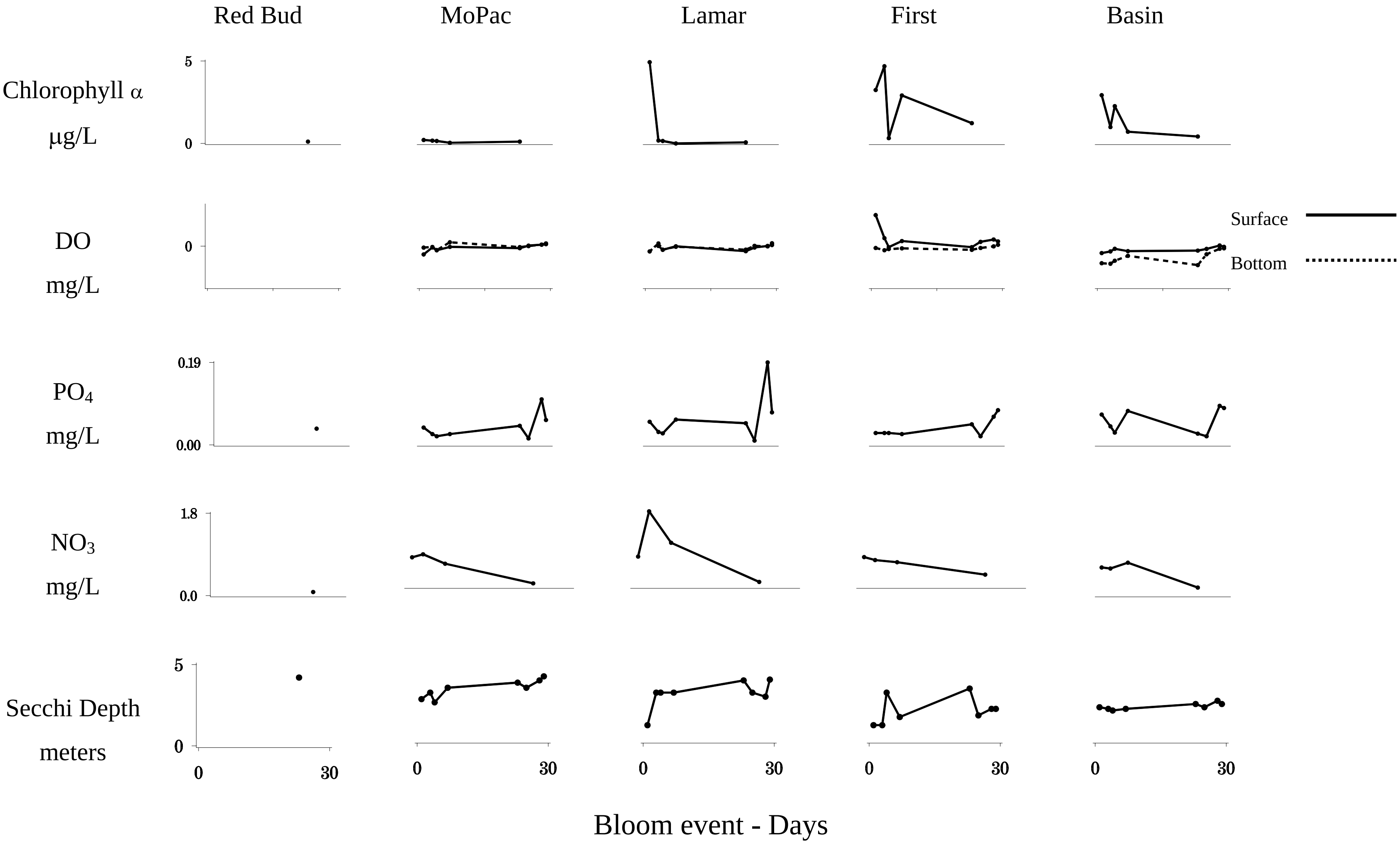


Figure 5.4a Fall 1994 Bloom Data

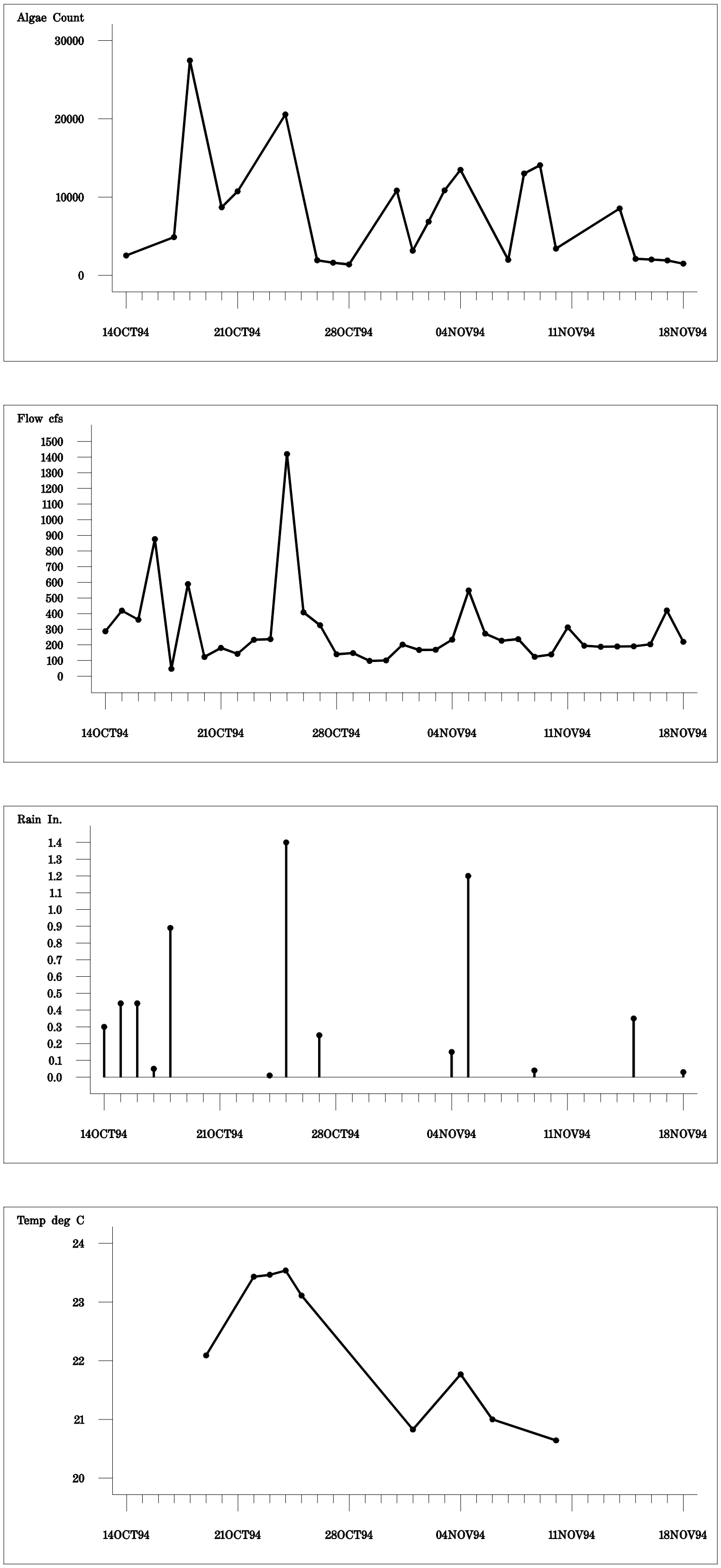


Figure 5.4b Fall 1994 Bloom Data (continued)

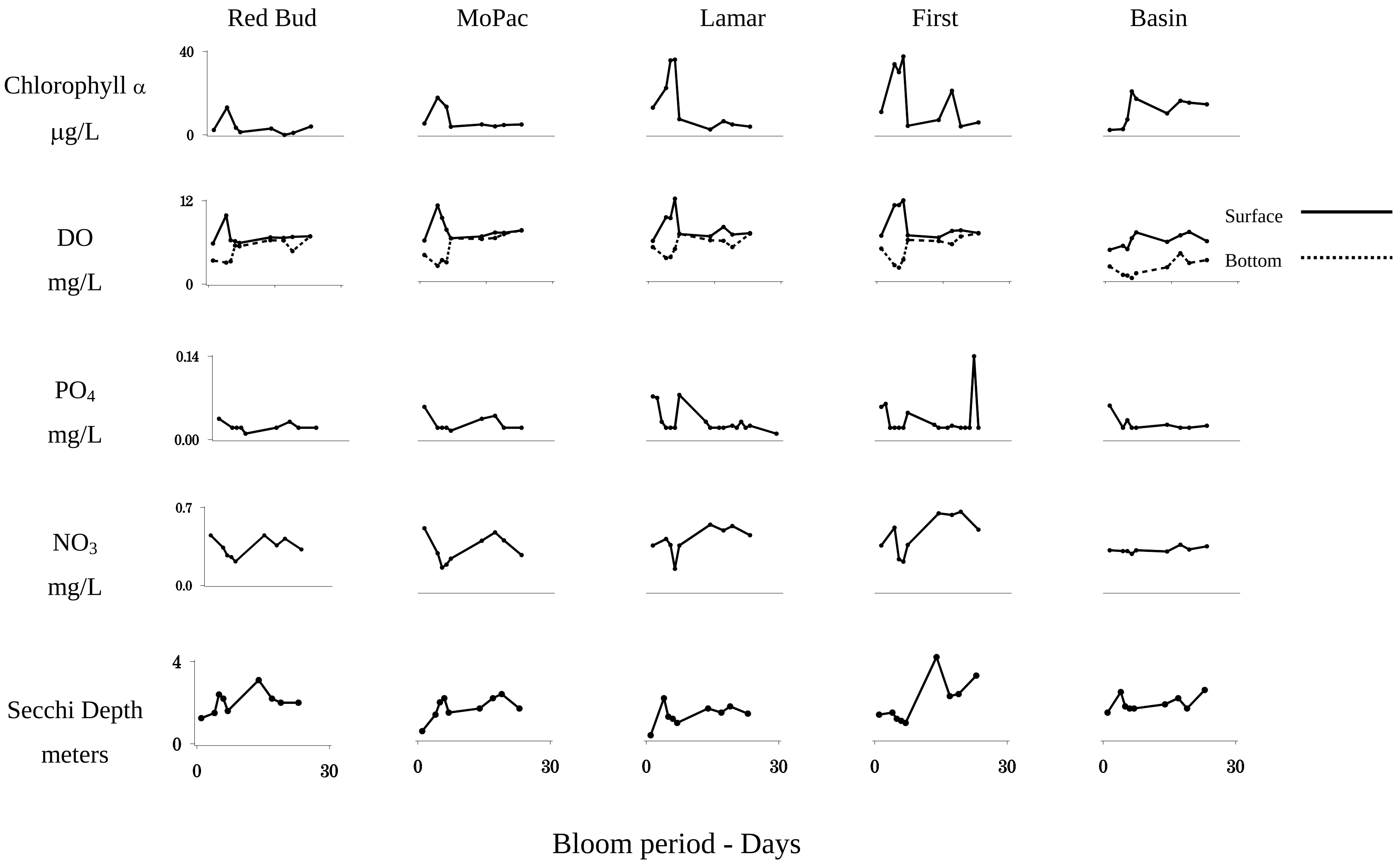


Figure 5.5a Spring 1995 Bloom Data

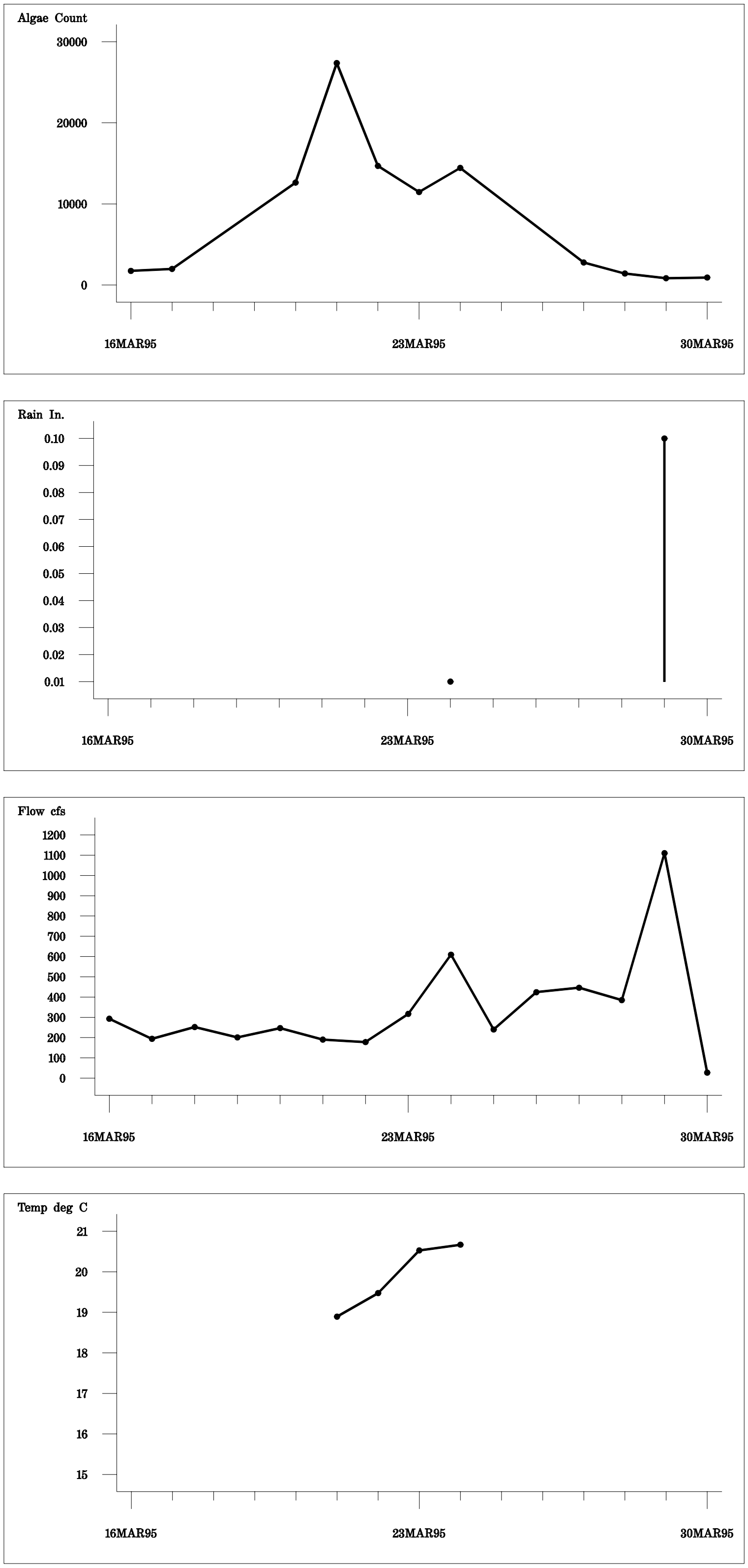


Figure 5.5b Spring 1995 Bloom Data (continued)

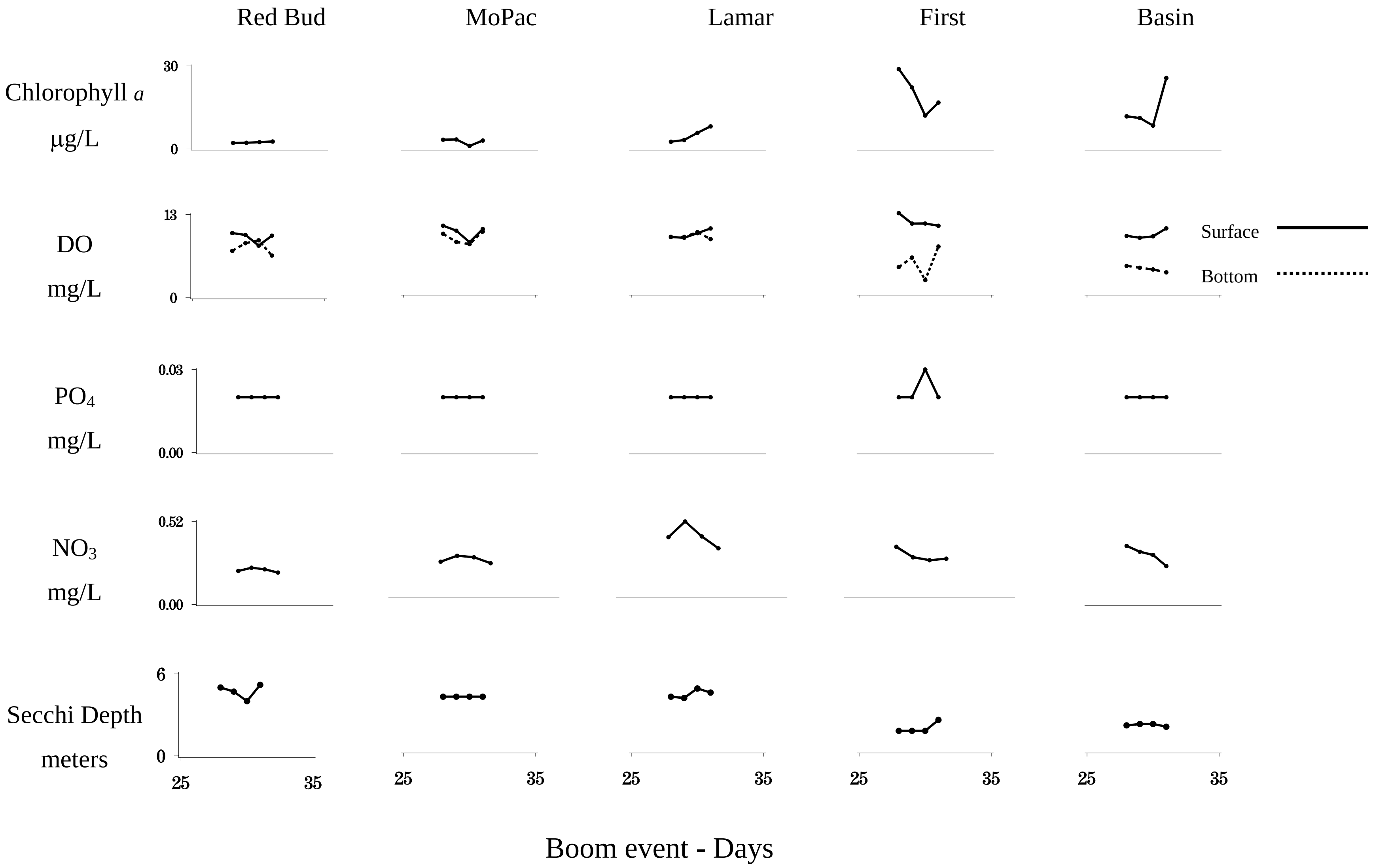


Figure 5.6a Fall 1995 Bloom Data

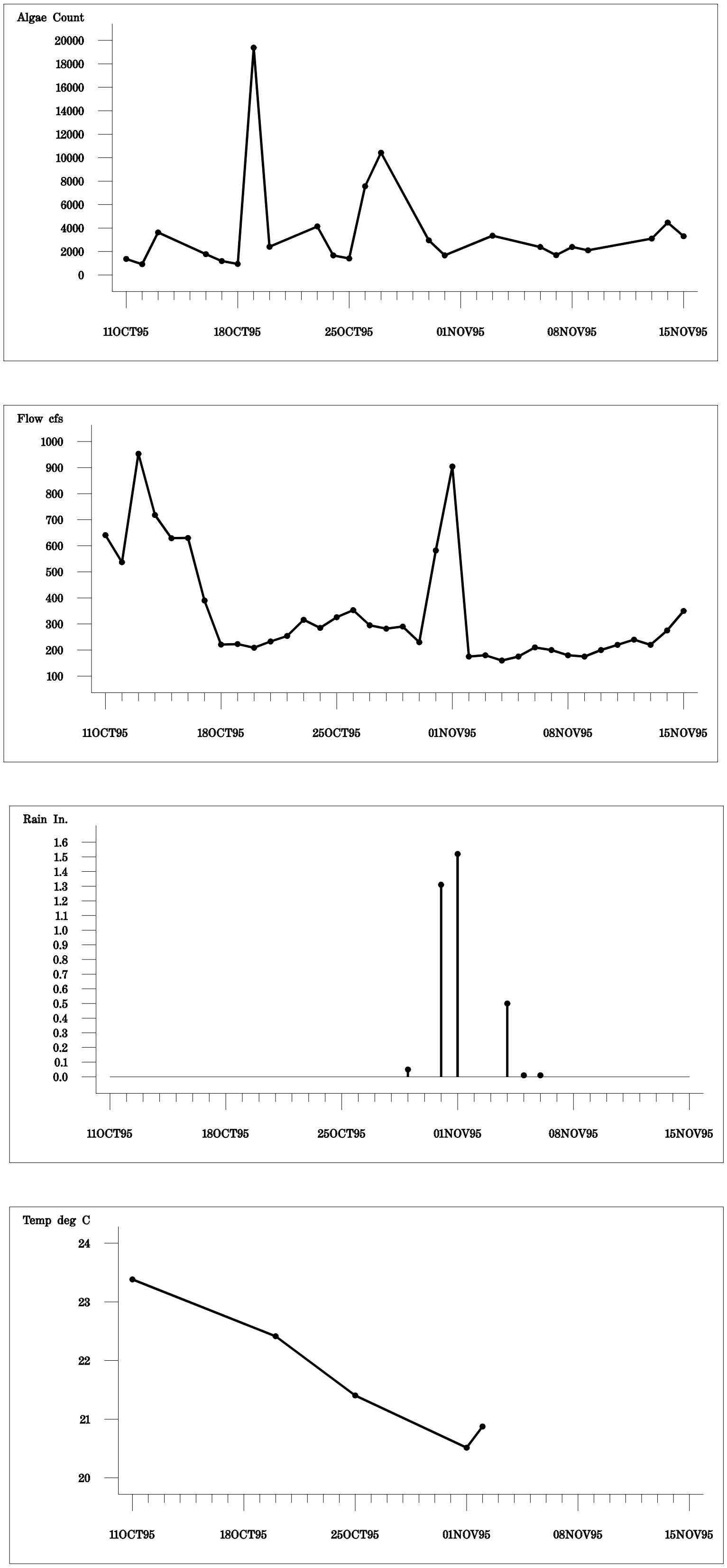


Figure 5.6b Fall 1995 Bloom Data (continued)

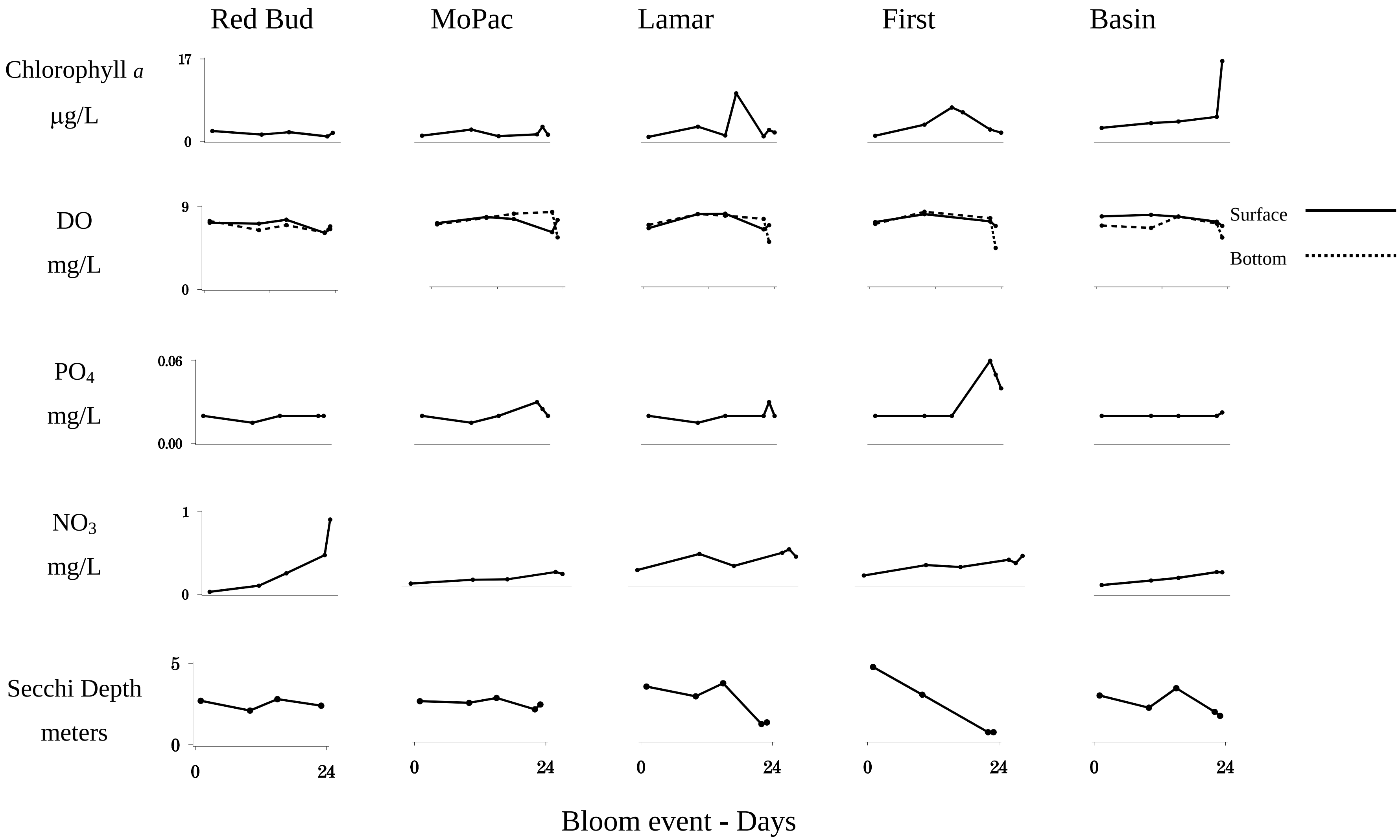


Figure 5.7a Fall 2000 Bloom Data

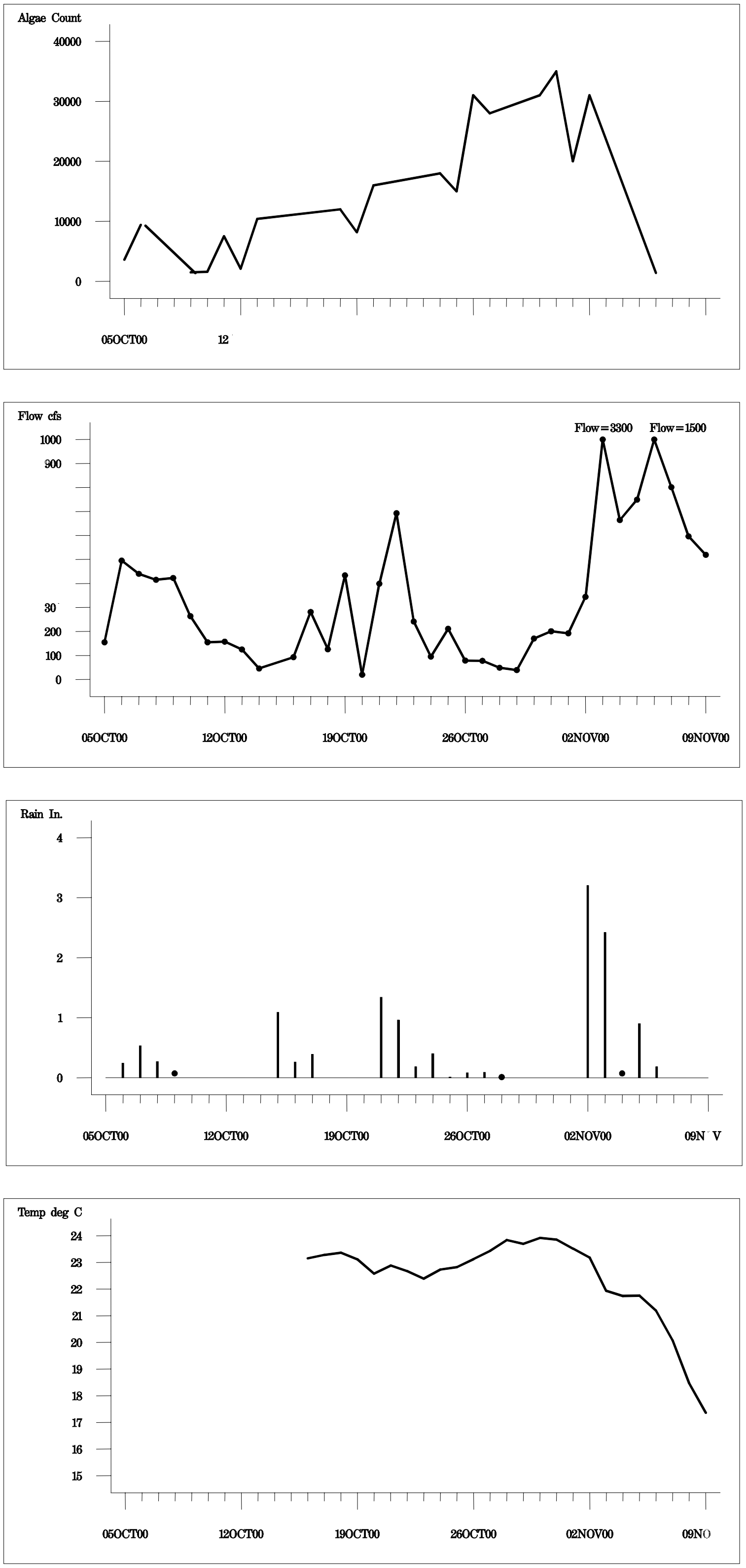
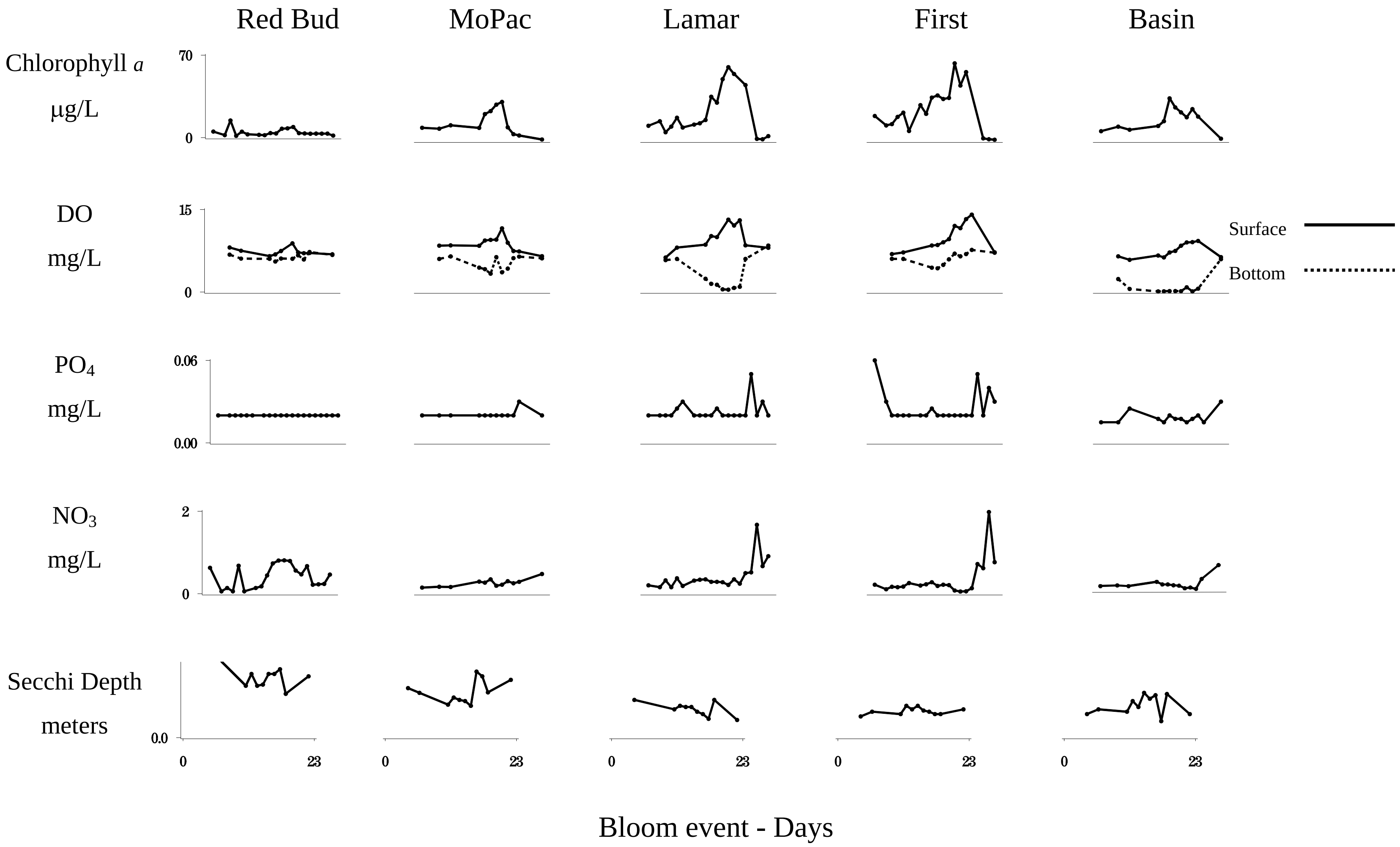


Figure 5.7b Fall 2000 Bloom Data (continued)



The algae blooms that were monitored occurred mostly in the fall; only one was in the spring. This is a roughly representative sample, as can be seen from the frequency of dates with counts greater than 15,000 since COA began algal counts in 1987.

Table 5.3 Frequency of Algae Blooms by Month

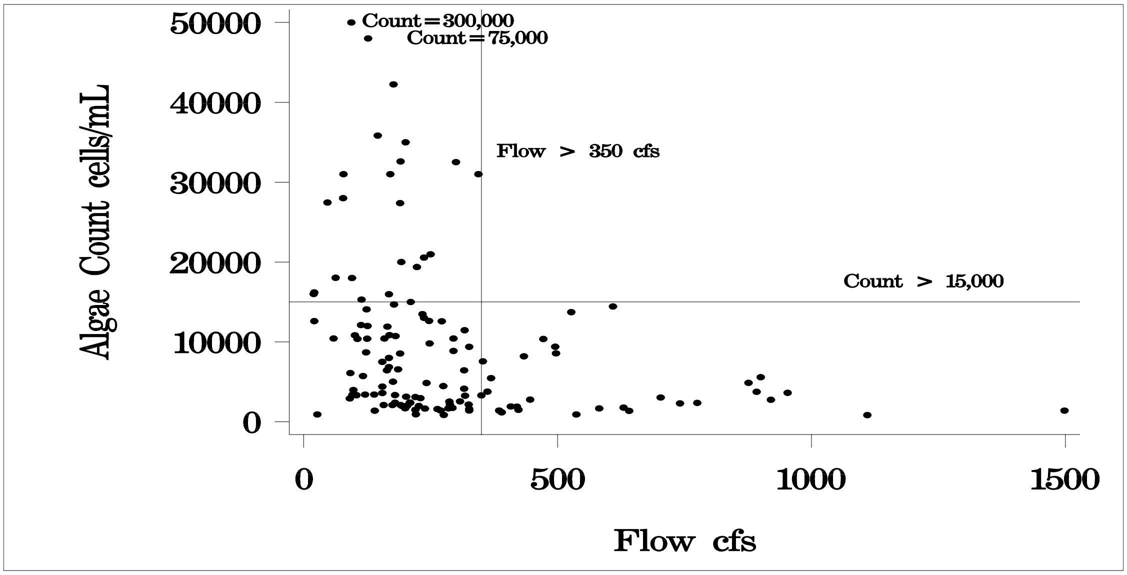
Month	October	November	March	June	August
Number of Days with Algae Counts > 15,000 cells/mL	13	18	2	1	1

The maximum algal count during the sampled booms was typically between 15,000 and 35,000 cells/mL. In 1993, however, the counts exceeded 300,000 cells/mL for one day. Such elevated counts do not ordinarily last long. One- or two-day blooms are typical, although counts may drop, only to go back up soon thereafter. Usually, the increase in counts is abrupt. However, gradual increases and extended periods with elevated counts do occur. An example of a gradual increase started on November 1, 1994. During fall 2000, the counts increased gradually and remained high for a two-week period. This was twice as long as the previous longest period of elevated counts. It is unknown whether the pattern of blooms in the lake is changing or sampling has been insufficient to determine the variety of blooms likely to occur in Town Lake. Frequently, gaps in the data occur and the subsequent changes are unknown. Since algal counts can change so rapidly, any extrapolation between sampling dates is tenuous. The same could be said for many other parameters during blooms and storms. Nutrient, light and temperature levels also may change abruptly.

Substantial rainfall several days prior to a bloom occurs several times: in fall 1991, 1993, and 1994. Rainfall may introduce enough additional nutrients into the lake to produce a bloom. However, rainfall is not necessary, as blooms occurred without the impetus of a storm in both the spring and fall of 1995. Notice that when blooms do occur in association with rainfall, the maximum algal count is several days after the storm. Indeed, a substantial storm associated with a cold front will typically cut short a bloom if one is in progress, since storms are typically associated with decreases in light and temperature, which algae need for optimal growth. Storms that terminated blooms occurred on October 29, 1991, October 27, 1993, October 25, 1994, and November 2, 2000. Blooms may end without a storm (see October 20, 1995) and blooms may continue (see fall 2000) throughout periods with light rainfall not associated with a strong cold front.

Algal blooms are primarily associated with the lower flows and increased residence times of the non-release season. Daily flow is compared to the algal count during the six bloom periods in Figure 5.8. All blooms occurred at flows of 350 ft^3/s or less. October 12, 1991, and October 18, 1995, are examples of blooms occurring as soon as the flow decreases following the end of the rice-growing season. Blooms that started during periods of steady low flow are seen on November 7, 1991, and March 24, 1995. Increases in flow may coincide with the end of blooms. Increases in flow during the non-release season are usually the result of storms, so decreased residence time, combined with decreased temperature and light, are conjectured factors.

Figure 5.8 Algae and Flow Relationship



Algal blooms typically occur during the warmer months of the non-release season. The cooler months (December, January, and February) have not had any blooms. Most blooms have occurred with water temperatures in the 20s (°C). However, blooms can occur at stable temperatures of 17 to 18 °C (November 7, 1991). COA has not tracked any blooms at water temperatures less than 17 °C, and this may be a threshold temperature. Additionally, a sudden decrease in water temperature usually coincides with decreases in algal counts if the counts were elevated.

The correlation between the daily algal counts and the chlorophyll *a* levels is not as good as might be expected. However, the sites and sampling times are different, and the algal count can not differentiate between live and dead cells, which may obscure this correlation. The chlorophyll *a* concentrations during blooms are lower at the upper end of the lake, Red Bud and MoPac, and higher in the middle and lower part of the lake, from Lamar to the Basin. Apparently, conditions are better-suited for algal growth in the middle and downstream end of the lake. Maximum chlorophyll *a* concentrations have been increasing over time. Maximum chlorophyll *a* concentrations ranged from 5 to 8 μg/L in 1991 and 1993, from 25 to 38 μg/L in 1994 and 1995, and reached 66 μg/L in 2000. This pattern is not matched by the peak algal counts, although it is closer to the monthly median count pattern. The highest counts were detected in 1993. The maximum monthly median count occurred in 2000, with the second-highest monthly median in 1993.

At times, no apparent changes in DO levels are observed due to algal blooms. Major responses in DO were not observed in fall 1995. At other times, COA has measured large differences in surface and bottom DO during a bloom. Fall 1994, spring 1995 and fall 2000 are examples of this phenomenon. Surface DO increases and bottom DO falls to near zero. The highest surface DO is observed at Lamar and First Street, and the lowest bottom DO is usually found at the Basin, but may be observed at Lamar as well. The maximum measured DO from surface grab samples was 18.5 mg/L at Lamar in 1993. Large changes in DO levels coincide with maximum chlorophyll *a* levels (fall

1994 and fall 2000). A potentially related die-off of clams was also investigated in summer 1996. Documentation of this event is presented in a subsequent chapter.

The relationship of orthophosphorus concentrations to chlorophyll *a* levels is not always clear (see fall 1991 and 1993). When a correlation is present between the two, the strongest pattern is usually observed at First Street or Lamar. An increase in PO4 concentrations may occur following the end of a bloom. This can be seen in both spring and fall 1995 at First as well as during fall 1994. However, a very clear, very strong pattern is apparent in fall 1994 in the following sequence; 1) orthophosphorus increases following a storm, 2) an algal bloom commences, 3) chlorophyll *a* levels increase abruptly with a simultaneous drop in orthophosphorus concentrations to below the detection limit, 4) the bloom is ended by a second storm, and 5) chlorophyll *a* levels decrease abruptly with a simultaneous jump in orthophosphorus concentrations (Section 4). A similar pattern is observed in fall 2000 at First Street.

Nitrate is similar to orthophosphorus in that the relationship of nitrate to chlorophyll *a* levels is unclear except during the 1994 and 2000 blooms. No relationship is apparent during the spring and fall of 1995. In fall 1991, nitrate concentrations decrease during the bloom whereas during fall 1993, the nitrate concentrations increase as chlorophyll *a* increases. During the 1994 bloom, nitrate levels decrease gradually while chlorophyll *a* levels increase. Unlike orthophosphorus, the nitrate levels do not drop to the detection limit. When the bloom ends, chlorophyll *a* levels decrease while nitrate concentrations increase. This pattern holds for all but the very downstream segment of the lake. In the basin, nitrate concentration remains fairly constant, showing no relationship to chlorophyll *a* levels. In 2000, nitrate levels remained low after the decrease in inflows from Lake Austin, instead of increasing following the increased percentage of lake inflow from Barton Springs with its high nitrate levels. Then, when the bloom ends, chlorophyll *a* levels decrease while nitrate concentrations increase abruptly.

The secchi disk depths provide an estimate of the amount of light available for phytoplankton growth. Greater secchi disk depths indicate greater visibility and light availability. The water is frequently clear during the start of a bloom, with a decrease in visibility at the height of the bloom. This pattern can be seen at First Street during fall 1991, and at all sites except First Street during fall 1994. As with the other parameters, however, this relationship is not always apparent. The correlation between light and chlorophyll *a* is unclear during fall 1993, and no signal at all was present during 1995. During the bloom in fall 2000, the relationship between light and chlorophyll *a* is confused by frequent mild rainstorms that likely increased the turbidity of the lake water.

5.2 Time Trends, Trophic Levels and Seasonal Patterns

Time trends, lake trophic levels and seasonal patterns in algal counts and chlorophyll *a* were also analyzed.

5.2.1 Algal Counts

The seasonal pattern in algal counts is shown in Figure 5.9. Scattered peaks occur throughout the year, but the majority of the peaks are during the fall. Increases in counts to bloom levels are usually abrupt; the blooms do not last long, and the counts drop quickly back to baseline levels. During the current monitoring period, Town Lake has experienced both higher maximum algal cell counts during blooms and longer periods with mid-level counts than before.

During the summer of 1996, an anomalous event occurred with counts increasing above baseline, but not to bloom levels, and remaining elevated for several weeks. During this period, bottom DO levels fell to near zero and a clam kill occurred (Section 6). The bloom in the fall of 2000 was also atypical, with gradually increasing counts that remained high for two weeks. The majority of the year the counts oscillate between oligotrophic and mesotrophic levels. Eutrophic levels are rare except during the fall. Monthly median counts, which are more representative of lake trophic status than daily counts, are displayed in Figure 5.10. Lake Austin counts are also plotted since it is the primary external source of algae to Town Lake. Lake Austin counts are typically higher than those in Town Lake, although Lake Austin counts did not exceed the 15,000 bloom level until 1997, and the maximum count from Lake Austin, in July 1999, was only 22,000.

Figure 5.9 Seasonal Pattern in Algal Counts

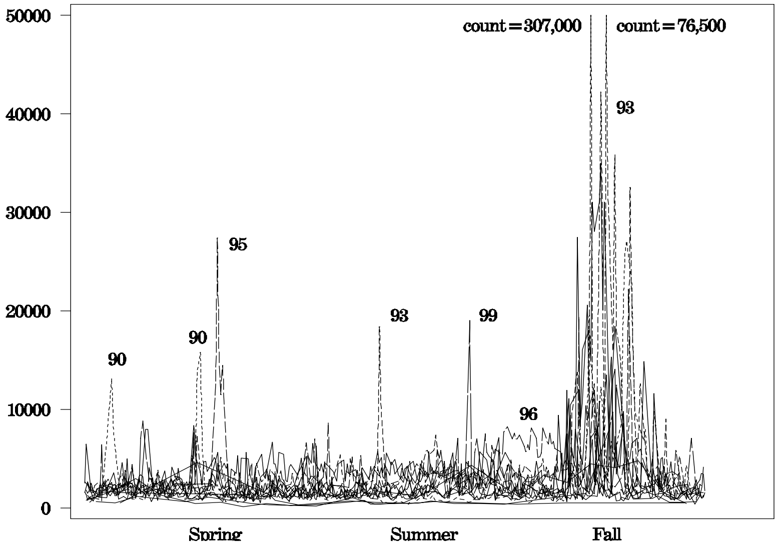
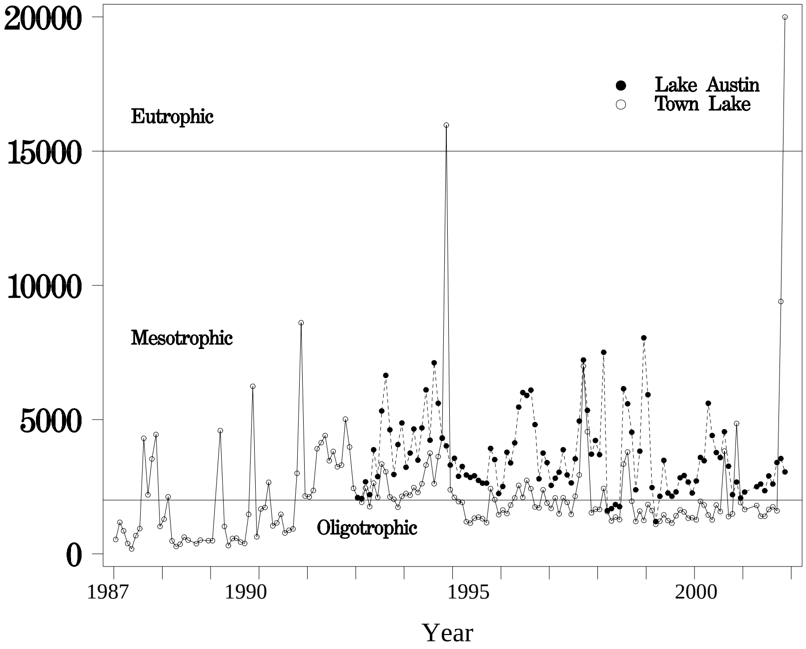
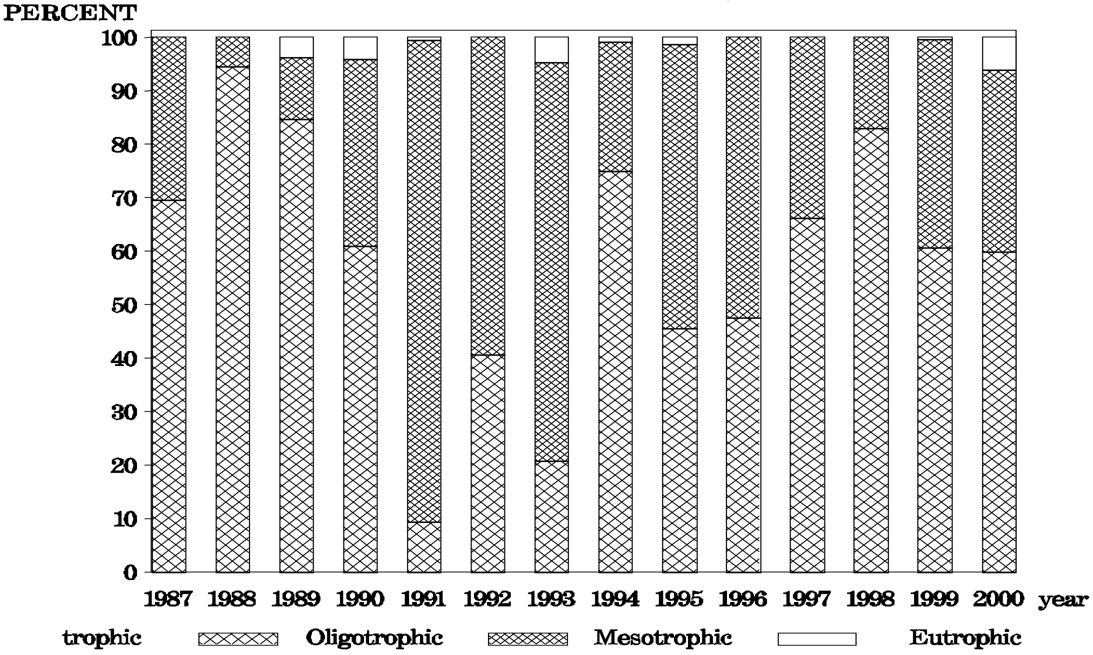


Figure 5.10 Monthly Median Counts



Town Lake median counts were usually in the oligotrophic region prior to 1990. From the fall of 1991 through the spring of 1994 the median counts remained predominantly in the mesotrophic region. Monthly median counts were in the eutrophic range only during the fall of 1993. In recent years the median counts have oscillated between oligotrophic and mesotrophic levels. Figure 5.11 shows the percentage of the time Town Lake has been in each trophic category during the last 14 years. While variation occurs from year to year, no obvious trend or a decisive change in the trophic level status of Town Lake has been documented during the past decade and a half.

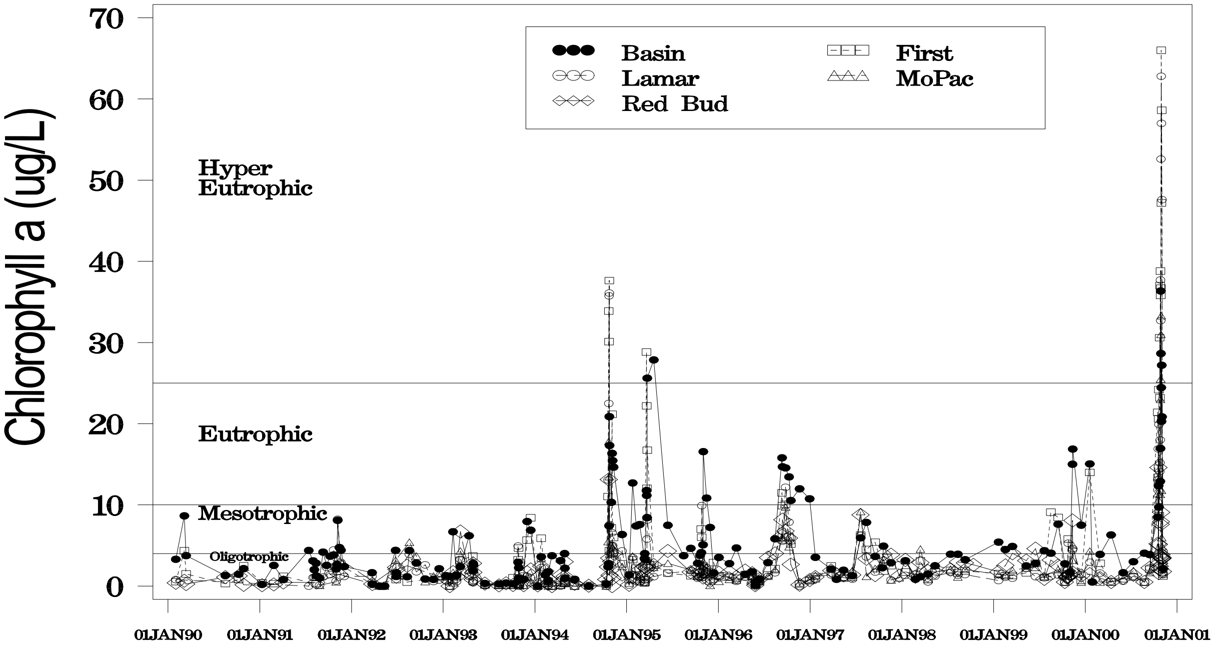
Figure 5.11 Percentage of Time on an Annual Basis in the Three Trophic Levels, Calculated from Town Lake Algal Counts



5.2.2 Chlorophyll a

The seasonal patterns exhibited by chlorophyll *a* are similar to those for the algal counts. Maximum chlorophyll *a* concentrations ranged from 5 to 8 µg/L in 1991 and 1993, from 25 to 38 µg/L in 1994 and 1995, and reached 66 µg/L in 2000, as seen in Figure 5.12. The lake's trophic status, as determined by chlorophyll *a* concentrations, is mostly oligotrophic. During the spring and fall the lake may be mesotrophic or eutrophic. Incursions into the hyper-eutrophic region were observed in 1994, 1995, and 2000. The lake is not uniform in this regard; Red Bud and MoPac rarely reach either mesotrophic or eutrophic levels and never become highly eutrophic. The basin, First Street and Lamar typically have higher chlorophyll *a* concentrations during the bloom seasons.

Figure 5.12 Chlorophyll *a* Concentrations in Town Lake (1990-2000)



5.3 Conclusions

It is difficult to predict and sample algae blooms. Indicator algae counts may not be made or checked in time for rapid response sampling at the beginning of the bloom. Continuous daily sampling also presents logistical problems when resources are limited. Important relationships may be missed with interrupted sampling and rapidly changing parameter level. Continuous daily sampling was instituted in the fall of 1996, after summer algae counts had been high, to provide complete bloom coverage. That fall, however, no blooms occurred.

The largest amount of information was gained from sampling the 1994 bloom period. This was a very strong bloom and it was sampled more consistently than other bloom periods had been sampled. It is not clear, however, if the same relationships exist during weak blooms. In addition, the bloom in the fall of 2000 was quite different from the usual bloom pattern. It is unknown whether the pattern of blooms in the lake is changing or sampling has been insufficient to determine the variety of blooms seen in Town Lake.

Conditions conducive to algae blooms were characterized during sampling attempts. Important preceding conditions for a bloom include ample light, warm temperatures, and low flows. Calm, clear, warm days just after the fall decrease in river flow were the most likely to result in a bloom. In the fall, blooms usually ended with the arrival of a cold front and the accompanying increase in wind, cloud cover, and turbidity due to storm runoff, and the decrease in temperature.

Town Lake’s trophic status can be viewed as wavering between oligotrophic and mesotrophic most of the year. However, eutrophic levels are observed at some time during most years. The location of the highest algae levels in Town Lake unfortunately coincides with the location of the drinking water intake. Lake Austin may be changing its patterns of algal levels, and any changes may have an effect on Town Lake as well. Thus the forecast for Town Lake is unclear. Evaluation of future conditions are discussed further in the modeling sections.

5.4 Recommendations

It is difficult to recommend a monitoring policy. However, it would be advantageous to consistently monitor an additional bloom in order to validate the water quality model of Town Lake (Section 4). It would also be appropriate to continue monitoring changes in the severity of Town Lake blooms. In order to determine severity, sampling needs to be done in addition to the daily algal count. Therefore, it is recommended that the current sampling policy be maintained.

6.0 CLAM KILL

Environmental conditions severe enough to produce major clam kills in Town Lake are rare. During the period covered by this report (1991-2000) only one clam kill was observed. During a routine monthly sampling run on September 11, 1996, dead clams (*Corbicula*) were found floating on the surface of Town Lake. A clam kill had never been documented on Town Lake, and further investigation was deemed necessary to determine the cause.

6.1 Data Collection

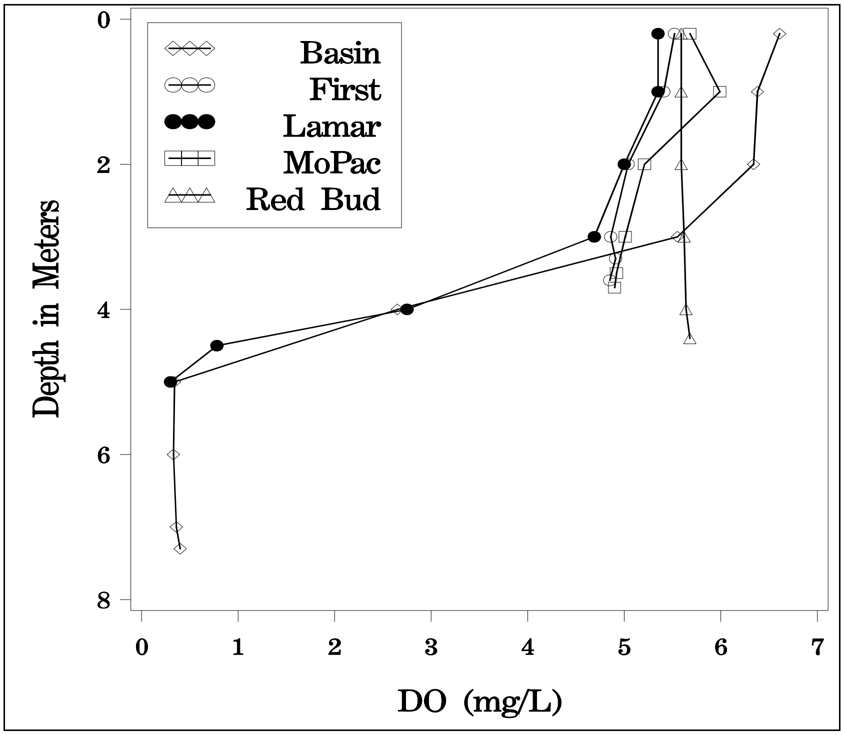
The *Corbicula* bodies were found primarily from the Lamar bridge downstream to Longhorn Dam on September 11, 1996. No clams were found floating with their shells still intact. The routine sampling run was repeated two days later on September 13, 1996, confirming the clam kill and the associated environmental conditions. The Texas Parks and Wildlife Department Kills and Spills Team was contacted and clams were collected on September 18, 1996, from the bottom sediment at Lamar and First Street for histological examination. Dredge samples for clams were not taken at the Basin. Water quality samples were taken from the Basin to Lamar. Flow, rainfall and algal count patterns prior to and during the clam kill were also investigated. Data from Lake Austin, collected by LCRA on September 14, 1996, were also examined.

6.2 Data Analysis: Low DO Implicated in the Clam Kill

Dredge samples from Lamar on September 18, 1996, revealed that only 25 percent of the shells contained living clams. At First Street approximately 90 percent of the shells contained living clams. An open shell with the body still intact was found at Lamar, indicating that the clam died at this location and had not yet ascended to the surface. The histopathology report on the collected clams stated that no significant diagnostic lesions were evident histologically in these animals to account for their deaths, and that death may have been associated with poor water quality or other environmental factors.

Most water quality parameters routinely collected on Town Lake were within normal limits and at levels adequate to support aquatic life. Exceptions were dissolved oxygen and ammonia. Ammonia, which is typically near detection, was 0.52 mg/L at Lamar at depth two days after the clam kill was noticed. Ammonia levels were not high on the day the kill was first noticed. This isolated high value may be a result of the clam kill rather than a cause. Bottom dissolved oxygen levels on September 11, 1996, the day the kill was first noticed, were very low at Lamar and in the Basin but not in the rest of the lake (Figure 6.1). On September 18, 1996, bottom DO was 0.25 mg/L at Lamar, where 75 percent of the clams were dead. At First Street, where only 10 percent of clams were dead, the bottom DO was 3.4 mg/L. Town Lake DO levels are typically much higher than this, ranging between 6 and 10 mg/L. Dead clams were also observed in Lake Austin at the only location with anoxic conditions at depth.

Figure 6.1 DO Profiles in Town Lake on September 11, 1996



Dr. Robert McMahan of the University of Texas-Arlington Biology Department, an expert on mollusk biology, was contacted for information on *Corbicula*. He stated that *Corbicula* are extremely susceptible to die-off due to low DO. He also noted that August to September is the *Corbicula* reproductive season, when they are more vulnerable to environmental stress.

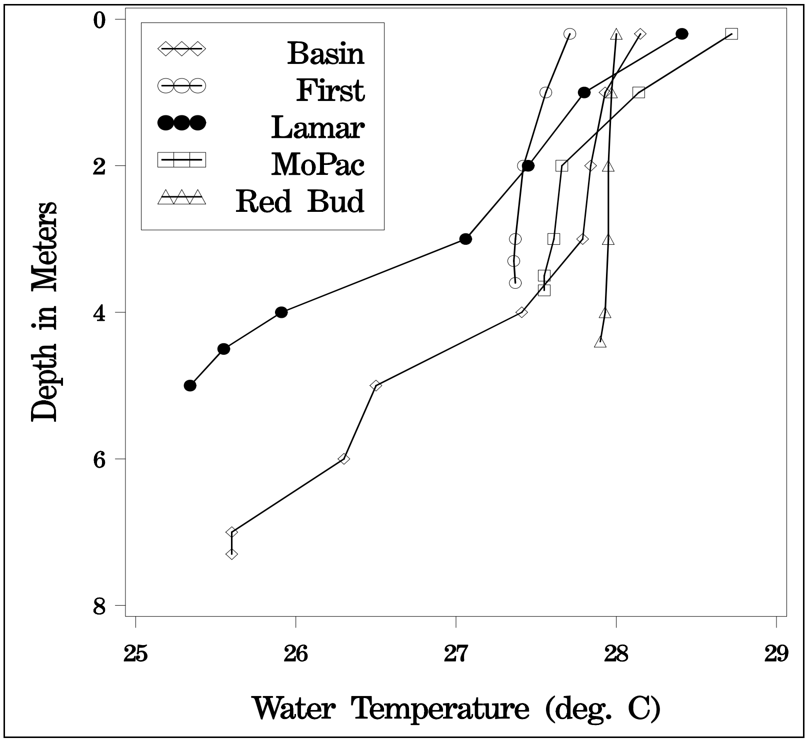
Information on the aerial extent and duration of the low DO levels in Town Lake is incomplete. In the Basin, a Datasonde was deployed at depth from August 14, 1996, to September 11, 1996. Bottom DO levels dropped below 1 mg/L on August 29 and fell to approximately 0 mg/L from September 5 through the end of the Datasonde deployment. The extent of the anoxic zone during the clam kill is not known. However, on September 25, 1996, measurements were taken to ascertain the extent of low DO levels. Bottom DO concentrations were 0.28 mg/L in the Basin. Near Fiesta Gardens, on the northern shore of the lower end of the lake, the levels were 2.1 mg/L. Upstream at the IH-35 bridge over Town Lake, however, the concentration at depth was 4.3 mg/L. These results indicate that anoxic levels were confined to the Basin. At Lamar, DO was low following the kill, as samples taken at depth on September 11, 13 and 18 were 0.3, 1.2 and 0.25 mg/L respectively. On September 18, 1996, a week after the clam kill, the low bottom DO levels extended approximately 1,000 feet upstream from the Lamar site.

6.3 Data Analysis: Possible Causes for the Low DO

Potential causes of the abnormally low DO include an influx of organic debris and nutrients in stormwater, subsequent algal growth and atypically low releases from Tom Miller Dam. An extended dry period in 1996 in the Austin area ended with substantial rains in late August. Total average rainfall from August 19 to August 31, 1996, was 7 inches. A considerable quantity of organic material may have been washed into the lake, consuming oxygen as it decomposed.

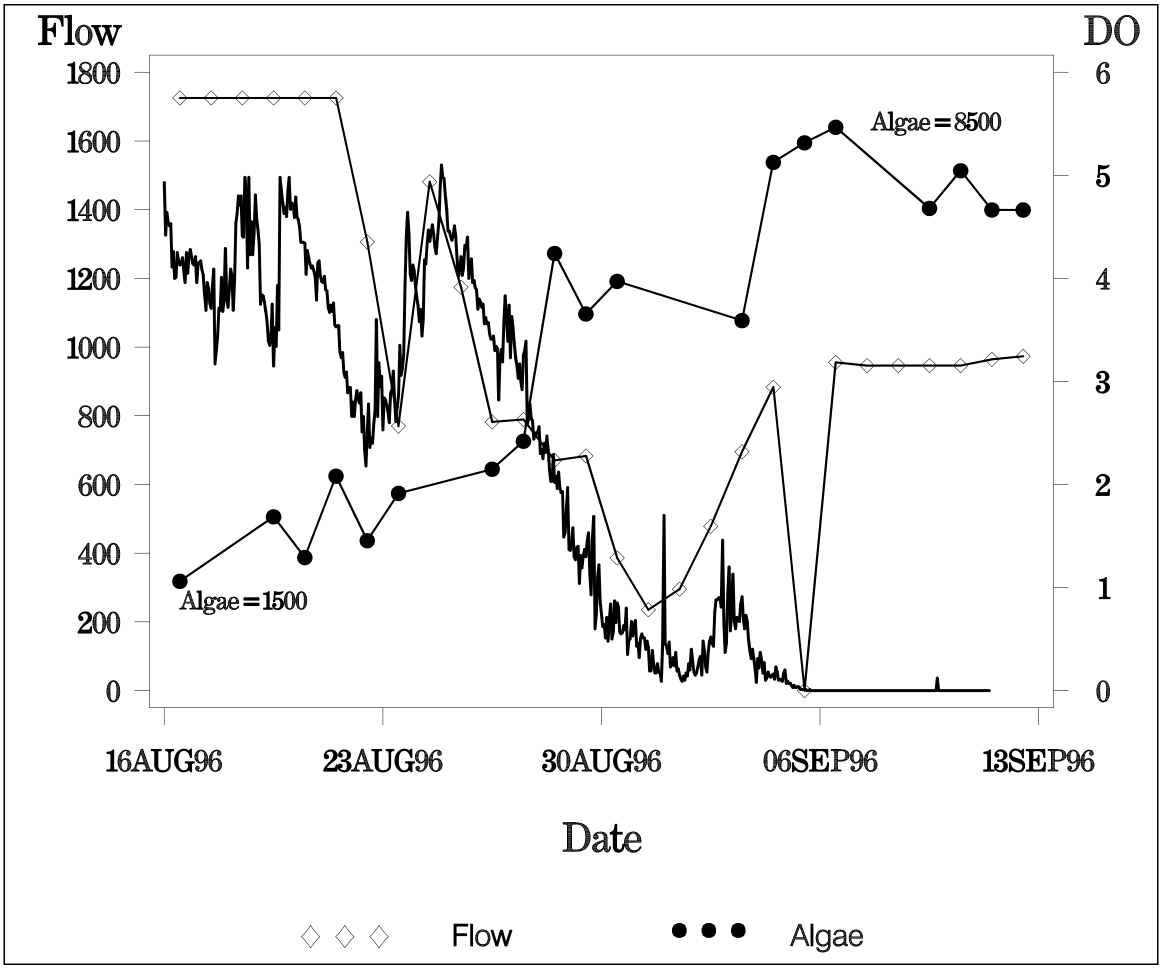
With the rainfall, the LCRA substantially reduced releases from Tom Miller Dam. Daily average flows were reduced gradually from 1,725 ft^3/s on August 21, 1996, to 235 ft^3/s on August 31, with gradually increasing flows to 946 ft^3/s by September 7, 1996. During periods of low flow the lake is not as well mixed as it is during high-flow conditions. However, the lake should not be viewed as completely thermally stratified. The shape of the temperature profiles (Figure 6.2) and the maximum difference of 3 °C between surface and bottom temperatures indicate that thermal resistance to mixing was not high. While the lake is not strongly stratified, days or even weeks may go by without complete mixing within the lake. The Basin is the deepest portion of the lake and thus the least likely to be well mixed. At Lamar, cold water inflows from Barton Springs (via Barton Creek), combined with a depression in the lake bottom, result in a pocket of water that is also not easily mixed. These are the locations where DO is typically the lowest and clam kills are likely to happen.

Figure 6.2 Temperature Profiles in Town Lake on September 11, 1996



Elevated algal counts were also seen during the period of the clam kill. By August 28, 1996, algal counts had increased from typical summer levels of less than 2,000 cells to approximately 6,000 cells. Instead of rapidly decreasing in a typical fashion, the counts remained elevated during all of September 1996. Chlorophyll-a levels on September 11, 1996, were in the eutrophic range. Elevated counts in Town Lake are associated with decreases in bottom DO levels. Dead algae settle to the bottom of the lake and consume oxygen as they decompose. Those portions of the lake that are not well mixed can become anoxic.

Figure 6.3 DO at the Basin Bottom, Green Water Treatment Plan Algae Counts and Tom Miller Dam Releases



6.4 Conclusion

Through cooperation with Texas Parks and Wildlife and the University of Texas, the cause of death was determined to be low DO levels caused by low flow through the lake and high levels of organic matter decomposition. Discussion of DO in the lake, which would be related to the likelihood of reoccurrence of a major clam kill, is provided in Section 4.

7.0 TOWN LAKE SPRINGS

Several large springs discharge from the Barton Springs segment of the Edwards Aquifer (BSEA) directly into Town Lake or into Barton Creek within one mile of the lake. These springs include Barton Springs, the fourth-largest spring in the State of Texas (Brune 1981), and its associated outlets of Eliza, Old Mill, Upper Barton, and High Barton springs, as well as Cold Springs, which discharges directly into the lake.

7.1 Spring Hydrology

The main outlet of Barton Springs has the highest flow rate and is the primary discharge point from the BSEA. Flow measurements indicate that springs upstream of Barton Springs Pool, primarily Upper Barton, contribute approximately 3 percent of total discharge, whereas Old Mill contributes approximately 13 percent and Eliza approximately 6 percent with the remaining 78 percent discharge from the main springs in Barton Springs Pool. The contribution from each spring may change with changing aquifer water levels. Upper and High Barton generally discharge approximately 1.5 ft^3/s or less. Cold Springs discharge is difficult to gauge or estimate because of multiple outlets from thick alluvial bank sediments and possible submerged outlets. Field measurements of Cold Springs were made in 1997, when Barton Springs was discharging 83 ft^3/s and Barton Creek flow at Lost Creek Boulevard was 2.5 ft^3/s. Under these conditions a 4.5 ft^3/s discharge was measured at Cold Springs with an estimated one-third to one-half of the discharge not measurable; therefore, the total was estimated to be from 6.0 to 6.8 ft^3/s. This estimate was approximately 7 to 8 percent of Barton Springs discharge at the time of measurement.

Discharge from all these springs is related to the amount of recharge entering the aquifer through creek beds and uplands in the aquifer recharge zone. Upper and High Barton discharge only under higher than normal discharge conditions at the other springs because they are located at higher water table outlets. High Barton only discharges when cumulative Barton Springs discharge is greater than about 98 ft^3/s. Upper Barton continues to discharge as long as cumulative discharge from Barton Springs is greater than approximately 50 ft^3/s. Water from groundwater seepage continues to pool in Barton

Creek at Barton Springs discharges of greater than 32 ft^3/s. Records do not indicate that the other springs cease to flow under drought conditions, although the cumulative discharge during the drought of record in 1956 was only 9.6 ft^3/s (USGS 1999).

The discharge through Town Lake varies not only with rainfall conditions, but also with dam operations, as discussed in Section 3. Under release conditions, the median discharge from Tom Miller Dam is 1,478.5 ft^3/s (Table 3.2). Under non-release conditions, the median discharge from Tom Miller Dam drops to 98 ft^3/s. With an average flow of 53 ft^3/s, Barton Springs may contribute more than half of the flow into the lake under non-release conditions. Therefore, under non-release conditions the springs may have a substantial impact on the flow and the water quality in Town Lake.

7.2 Water Quality

Data in this section updates information discussed in the COA Barton Creek Report (1997). Data discussed in this report covers the period between July 1978 and May 1998. Barton Springs has far more chemistry and flow data than any other spring in the Austin area. A small amount of data is available for Cold Springs, primarily from COA sources. No chemistry data from Eliza, Old Mill, Upper Barton, or High Barton were available prior to initial COA data collection in 1994. High Barton has insufficient data for detailed statistical analysis, although existing chemistry data is very similar to Upper Barton.

7.2.1 Average Chemistry of the Springs

Although the chemistry of these six springs is similar, each has distinct, and sometimes unique, differences (Table 7.1). Upper Barton has the highest mean temperature over the study period, 21.38 °C, whereas Cold has the lowest, 20.28 °C. The mean temperature of Barton Springs, based on over four years of nearly continuous measurements, is 21.2 °C (70.2 °F), not 68 °F as is commonly believed. Mean conductivity is greatest at Old Mill (819.2 µS/cm) and lowest at Cold (569 µS/cm). Mean pH is greatest in Old Mill (7.23) and lowest in Upper Barton (7.14). Upper Barton has the highest mean nitrate concentrations of 2.33 mg/L and concentrations are lowest in Eliza at 1.16 mg/L, closely followed by Cold at 1.18 mg/L. Barton Springs mean nitrate concentration over the same time period, not adjusted for discharge stage, was 1.32 mg/L. Baseflow mean fecal coliform values are greatest in Upper Barton with 18.5 cfu/100mL and lowest in Old Mill with 2 cfu/100mL. Ion enrichment patterns closely follow conductivity trends, with Old Mill usually having the greatest ion concentrations and Cold having the lowest ion concentrations. Exceptions with this trend are all associated with Upper Barton, which has the greatest concentrations of calcium and alkalinity and the lowest sodium concentration.

Table 7.1 Water Quality Averages for the Barton-Related Springs

	Barton Springs	**Cold Springs**	**Eliza Springs**	**Old Mill Springs**	**Upper Barton Springs**
Period of Record	**1978-1998**	**1989-1998**	**1995-1998**	**1994-1998**	**1997-1998**
Temperature (°C)	21.13	20.28	21.04	21.14	21.38
Turbidity (NTU)	2.01	2.52	2.25	1.38	3.44
TSS (mg/L)	3.29	0.83	1.86	0.79	3.99
Organic Carbon (mg/L)	1.36	3.17	1.94	2.99	4.35
Fecal coliform (cfu/100mL)	9.50	4.00	3.00	2.00	18.50
Fecal streptococcus (cfu/100mL)	59.60	29.70	32.70	20.00	61.50
Orthophosphorous (mg/L)	0.01	0.02	0.01	0.01	0.02
Nitrate+Nitrite-N (mg/L)	1.32	1.18	1.16	1.21	2.33
Ammonia-N (mg/L)	0.04	0.03	0.01	0.02	0.02
TKN (mg/L)	0.38	0.11	0.12	0.11	0.14
Phosphorous-P (mg/L)	0.05	0.04	0.04	0.05	0.02
pH	7.17	7.16	7.19	7.23	7.14
Conductivity (μS/cm)	631.46	569.04	668.90	819.18	646.2
TDS (mg/L)	354.59	229.75	411.83	397.00	520.5
Calcium (mg/L)	84.84	77.28	85.69	85.89	92.47
Magnesium (mg/L)	20.99	20.68	20.88	23.36	22.43
Sodium (mg/L)	17.97	10.52	18.29	38.95	10.10
Chloride (mg/L)	31.38	18.08	31.45	63.49	22.24
Sulfate (mg/L)	31.83	27.79	34.08	53.38	32.40
Potassium (mg/L)	1.65	1.07	1.28	1.89	1.13
Fluoride (mg/L)	0.21	0.19	0.16	0.21	0.13
Alkalinity (mg/L)	257.24	248.25	260.45	258.08	281.0

Lower constituent concentrations in Cold Springs may be due to a shorter water residence time in the aquifer (see discussion in 7.3), especially when Barton Creek is flowing across the Recharge Zone. Higher ionic concentrations in Old Mill are probably due to contributions of water from the bad water line, where potentially long water residence time allows for greater water-rock interactions. Elevated concentrations of nitrate, bacteria, and TSS may be due to a smaller contributing area (BSEACD 2002) that is more heavily developed with less dilution of cleaner water from the Contributing Zone.

7.2.2 Water Chemistry Variations

Given the dependency of these springs on recharge for their flow (discharge), it is not surprising that the chemistry of the springs varies with recharge and discharge volumes. Conductivity and discharge have a clear negative relationship in Barton, Eliza, and Old Mill (Figure 7.1). When spring discharge is high, conductivity tends to be low in these springs. No relationship exists between discharge and conductivity in Upper Barton Spring, most likely because it flows only during normal and high discharge conditions. Cold Springs may demonstrate a slight relationship to Barton Creek flow at Lost Creek, as conductivity tends to be lower when flows measured at Lost Creek are higher.

In general, these springs yield a negative relationship between discharge and nitrate concentrations (Figure 7.2). Flow in Barton Creek, as measured at the Lost Creek gage, also may affect nitrate concentrations in Cold Springs, with data yielding a negative relationship between flow and nitrate concentrations. When creek flow is below 10 ft^3/s, nitrate concentrations in Cold Springs average 1.59 mg/L. When creek flow is greater than 10 ft^3/s, however, the average nitrate concentrations are lowered to 0.76 mg/L.

Discharge rate has a dependable effect on nitrate concentrations in Barton Springs, as previously stated. Data collected between 1996 and 1998 indicate average nitrate concentrations of 1.48 mg/L under low-flow discharge conditions (defined as Barton Springs discharge less than 35 ft^3/s). The average nitrate concentration under normal discharge conditions (defined as Barton Springs discharge between 35 and 60 ft^3/s) is 1.38 mg/L and, under high discharge conditions (defined as Barton Springs discharge greater than 60 ft^3/s), Barton Springs mean nitrate falls to 1.25 mg/L.

Figure 7.1 Relationship Between Discharge and Conductivity in Barton Springs

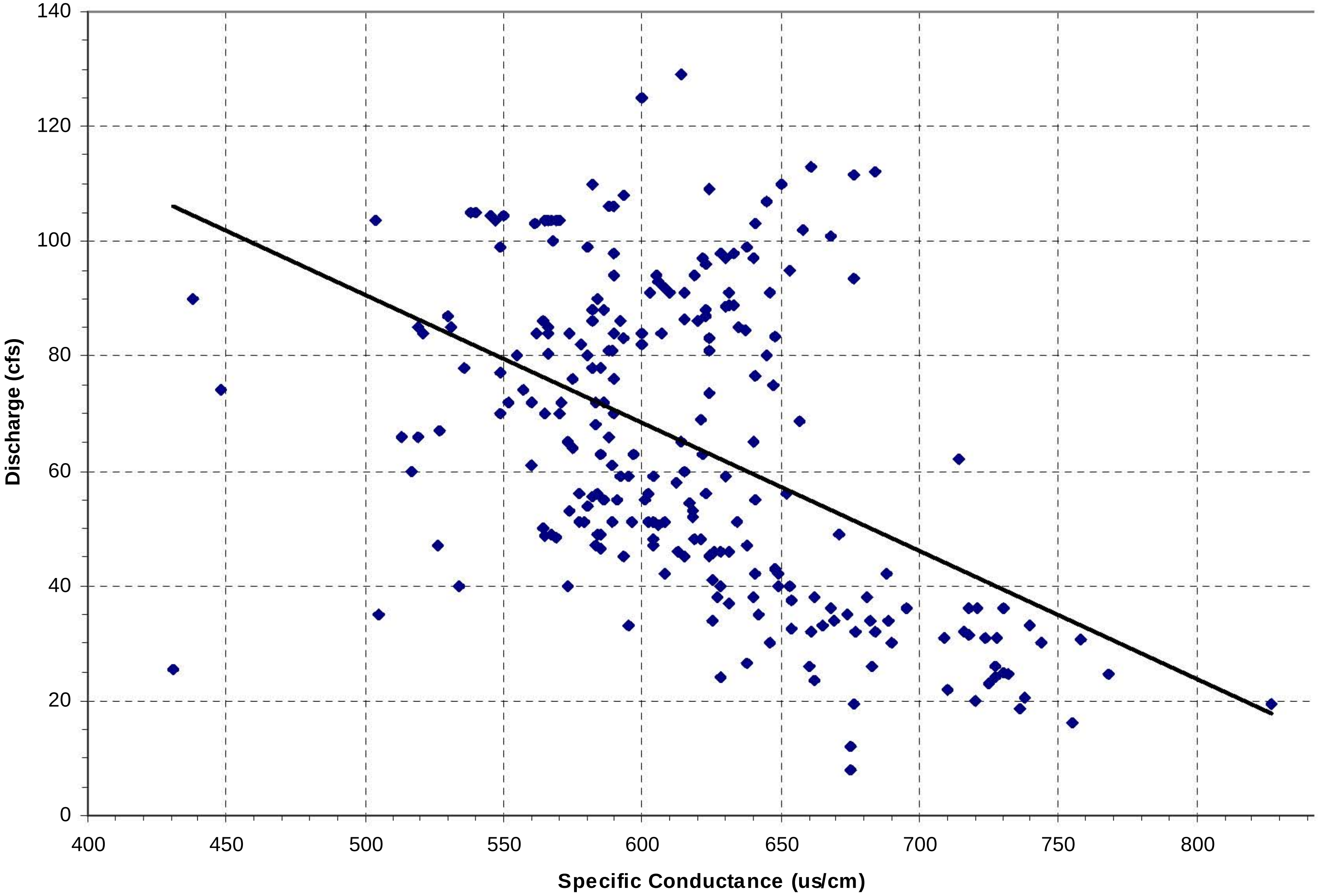
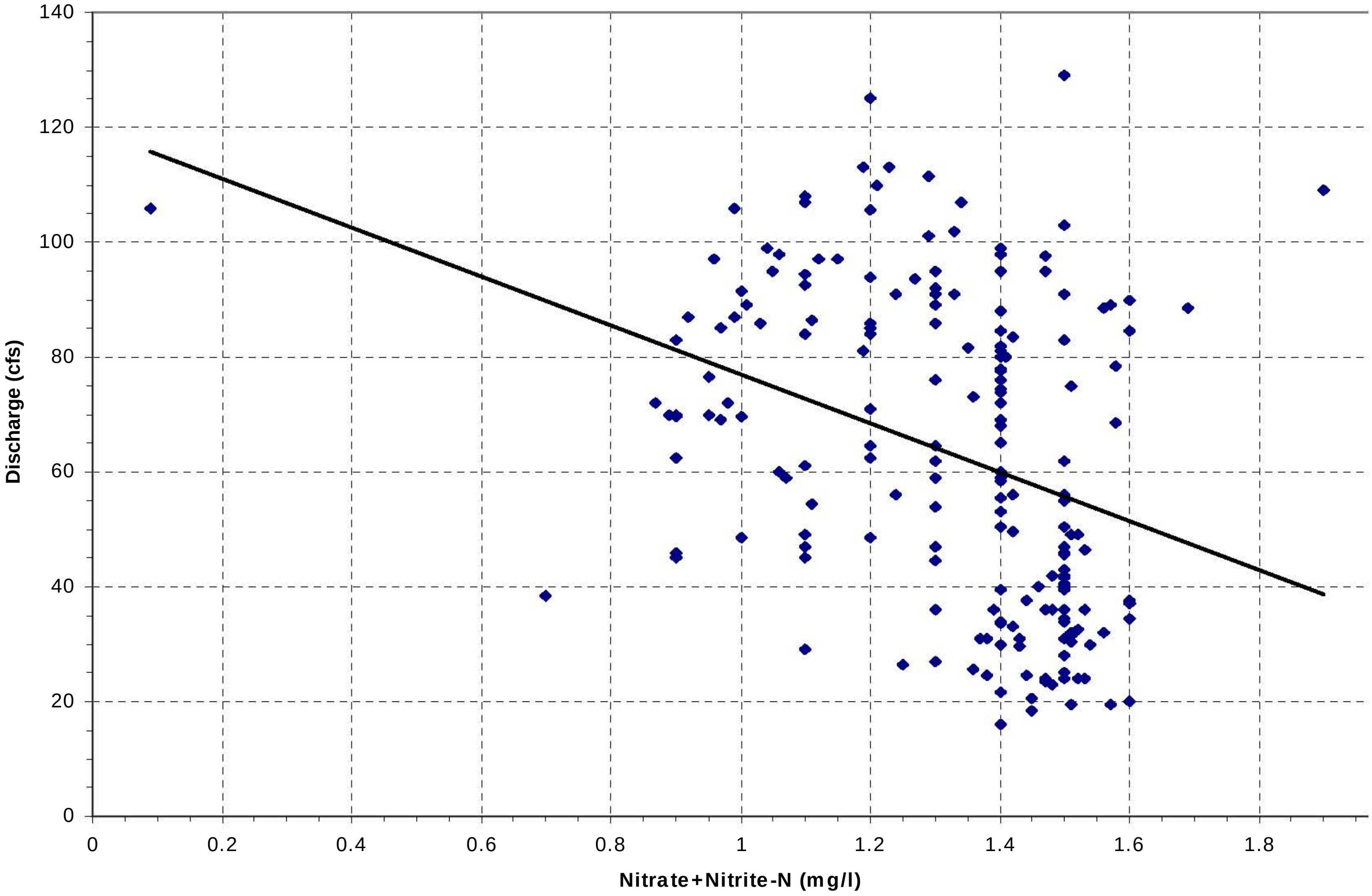


Figure 7.2 Relationship Between Discharge and Nitrate in Barton Springs



These data are comparable to samples collected in the late 1970s and early 1980s, indicating no noticeable change in nitrate concentrations in Barton Springs baseflow over this period of time (Table 7.2). A more recent analysis, including data into 2000 (COA 2000), indicates a statistically significant difference in nitrate, with concentrations over 1.6 mg/L during drought conditions in 2000 compared to 1.5 mg/L during a drought in 1996.

Table 7.2 Barton Springs Discharge and Nitrate

Discharge Stage (ft^3/s)	**Nitrate (mg/L)**	**Source and Sample Size**
	USGS 1978-81	
BS < 35	1.38	n=5
35 < BS < 60	1.36	n=24
60 < BS	1.25	n=28
	COA/WPD 1996-98	
BS < 35	1.48	n=17
35 < BS < 60	1.38	n=13
60 < BS	1.25	n=31

Continuous data recorders in Barton Springs have tracked variations in physical properties of water from Barton Springs since 1994. These data show natural variations in temperature and conductivity that are caused by large recharge events and variations in discharge rate. The average temperature of Barton Springs discharge water as measured by the data loggers (Figure 7.3), for example, has been approximately 21.2 °C (70.1 °F) rather than 20.0 °C (68 °F) as commonly believed. Maximum temperature in Barton Springs was 22.4 °C (72.4 °F) and the minimum temperature was 18.9 °C (66 °F). Conductivity has averaged 648 μs/cm with a maximum of approximately 850 μs/cm following pool drawdowns and a minimum of approximately 500 μs/cm following large recharge events (Figure 7.4).

Data also document the onset of chemical changes following rain events. Runoff from rains can begin affecting conductivity within Barton Springs in as little as six hours, with dramatic changes beginning approximately 12 hours after rains begin.

Figure 7.3 Barton Springs Temperature (Feb 1993 – July 1999)

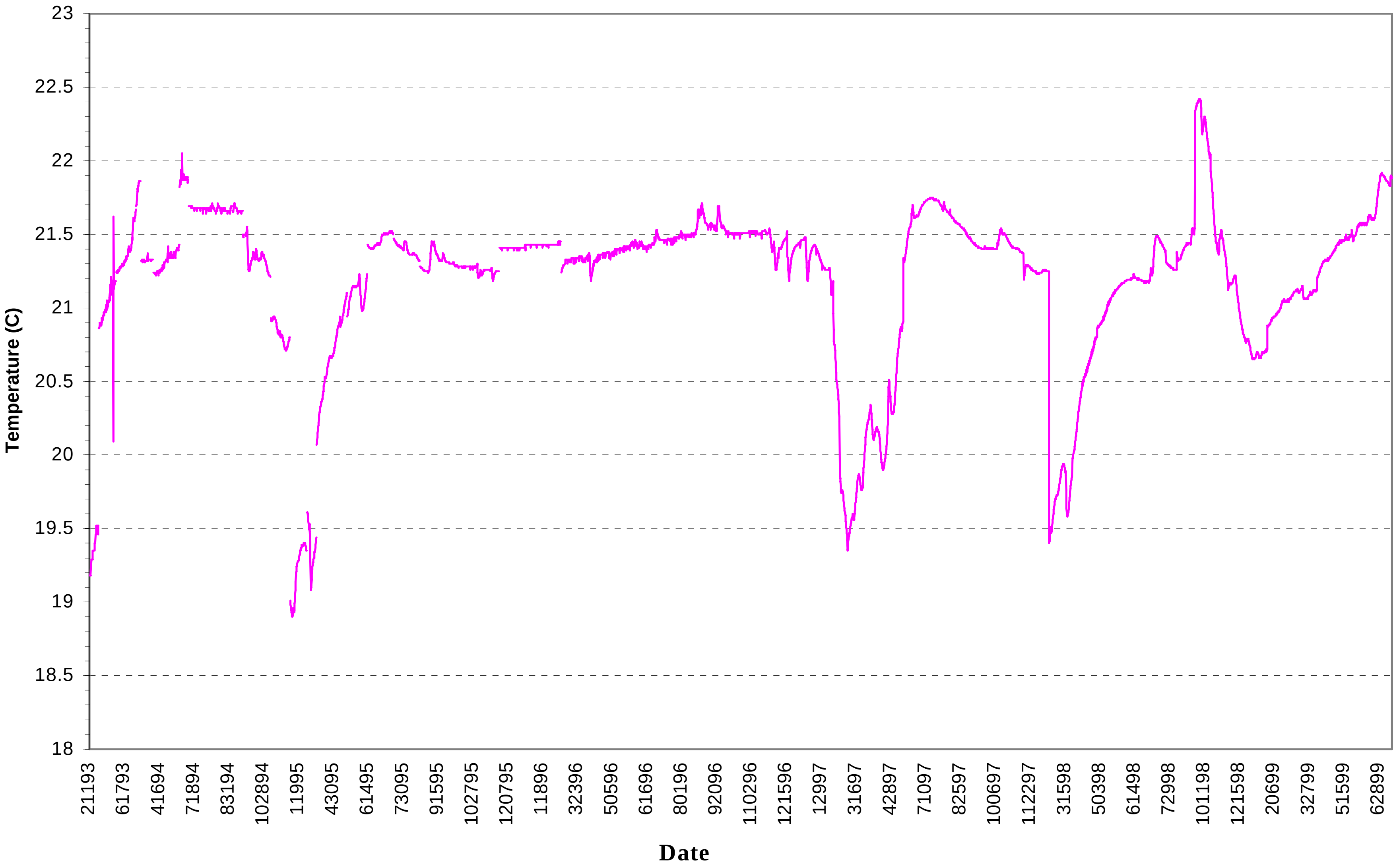


Figure 7.4 Barton Springs Conductivity (Feb 1993 – July 1999)

These data illustrate the rapid rate of recharge and groundwater migration in the Barton Springs segment of the Edwards Aquifer that is being confirmed in tracing studies conducted by the Barton Springs/Edwards Aquifer Conservation District and COA.

Data recorders have also been placed in Old Mill and Upper Barton springs to compare with Barton Springs data following pool drawdowns and rain events. Upper Barton appears to have a similar response to rain events as Barton, although the response is more intense with greater changes in the measured parameters. In March 1999, with Barton Springs discharge measuring 90 ft^3/s, a 1.5-inch rain caused a 26 μs/cm drop (-4.3 percent) in conductivity in Barton Springs whereas the same storm event resulted in a 253 μs/cm drop (-38.5 percent) in conductivity at Upper Barton Springs (Figure 7.5). Another storm event of 1.1 inches in the same month lowered conductivity by 11 μs/cm (-2 percent) in Barton Springs and 125 μs/cm (-19 percent) in Upper Barton Springs. A similar difference exists between Barton and Old Mill Springs, although Old Mill appears to have a less-intense response to rain events than Barton Springs. In November 1998, for example, a 1.5-inch rain with a Barton Springs discharge of 102 ft^3/s, caused a 53 μs/cm drop (-8 percent) in Barton Springs conductivity, whereas the same storm event resulted in a 26 μs/cm drop (-3.7 percent) in Old Mill conductivity (Figure 7.6).

During pool drawdowns, a characteristic conductivity spike has been noted in Barton Springs (COA 1997). A similar spike occurs at Old Mill and Eliza springs at approximately the same time. This suggests that these springs are receiving water from inter-connected aquifer conducts although differences in arrival times may reflect the complexity of these conduits. Conductivity spikes associated with pool drawdowns have not been observed in Upper Barton. However, changes in water depth and slight variations in DO and conductivity indicate occurrences of chemical changes to the discharge water that are related to the pool drawdown. The conduits feeding Upper Barton may not be connected to the same conduits as Barton, Eliza and Old Mill, or the conduits are connected farther from the source of the high conductivity water (i.e. the spike water is not reaching Upper Barton).

Figure 7.5 Barton and Upper Barton Springs Conductivity in Response to Rain

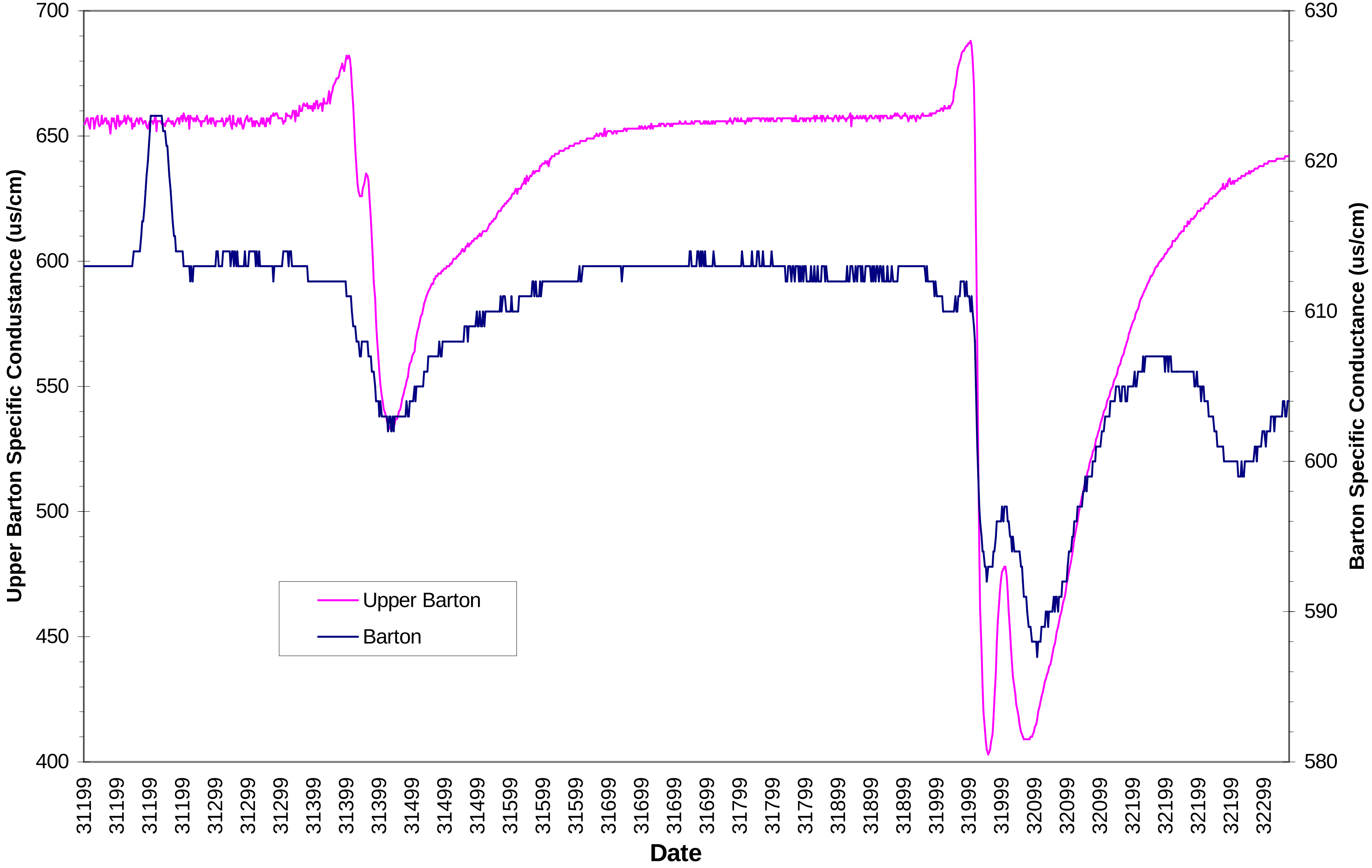
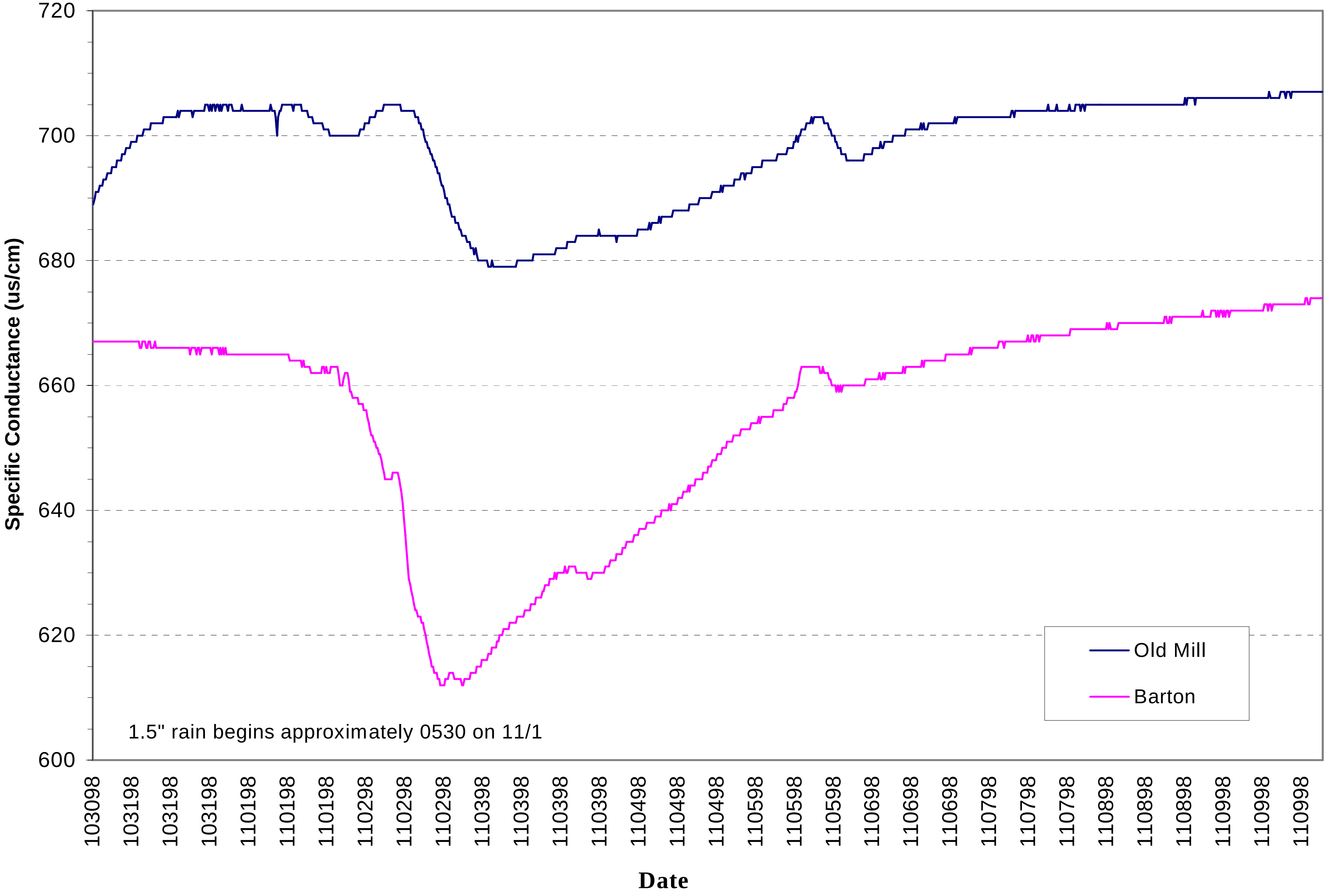


Figure 7.6 Barton and Old Mill Springs Conductivity in Response to Rain



7.2.3 Influence on Town Lake

The sections above clearly illustrate that at the time of highest flows, the concentrations in the springs would be closest to the average stormwater runoff chemistry entering Town Lake. Under non-release conditions, however, the influence of these large springs may elevate the nutrients and ions in the lake. Tables 7.3a and 7.3b below show average values of Barton Springs compared to Town Lake chemistry values from upstream to downstream in Town Lake.

Table 7.3a Release Condition Mean Water Chemistry Comparison, Storm and Non-Storm Conditions Combined

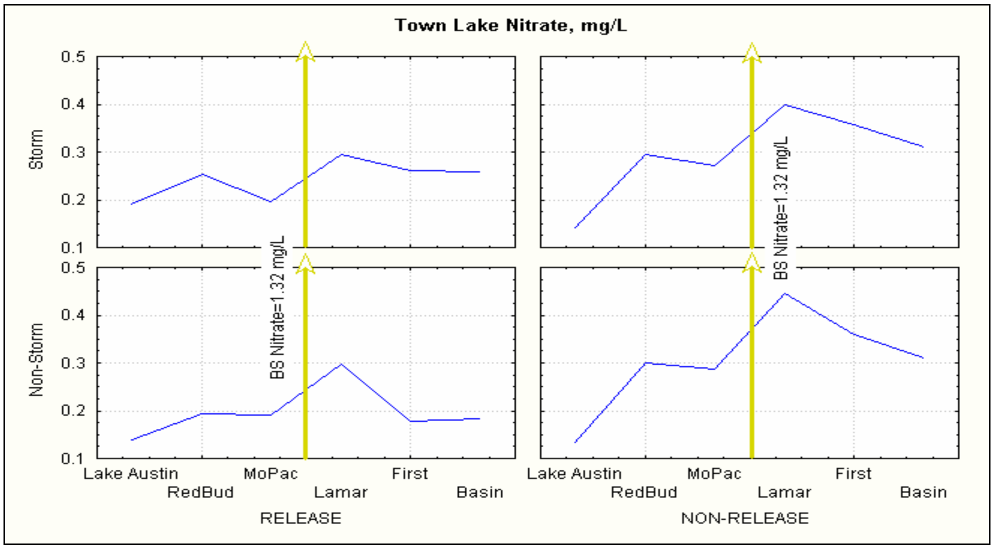
Parameter	units	Lake Austin	Red Bud	MoPac	Barton Springs	Lamar	First	Basin
Temperature	°C	21.0	22.0	22.5	**21.3**	22.3	22.2	23.0
TOC	mg/L	3.6	3.6	3.2	**1.4**	3.6	4.0	5.1
TSS	mg/L	8.7	6.9	2.6	**3.3**	6.9	12.6	8.7
Fecal coliform (**Non-Storm**)	cfu/100mL	11.4	14.6	166.4	**9.5 (averaged)**	128.6	157.6	106.3
Fecal coliform, (**Storm)**	cfu/100mL	242.5	89.6	251.5		991.2	7468.3	1685.4
Ammonia	mg/L	0.04	0.03	0.06	**0.04**	0.06	0.05	0.08
Nitrate	mg/L	0.16	0.22	0.19	**1.32**	0.30	0.21	0.21
TKN	mg/L	0.42	0.33	0.29	**0.38**	0.34	0.35	0.40
Orthophosphorus	mg/L	0.01	0.02	0.03	**0.01**	0.03	0.02	0.03
Phosphorus	mg/L	0.02	0.02	0.04	**0.05**	0.03	0.04	0.04
pH	SU	7.96	7.83	7.72	**7.17**	7.68	7.72	7.60
Conductivity	µS/cm	570.9	548.3	568.5	**631.5**	584.5	528.9	588.7
Alkalinity	mg/L	157.6	158.9	163.8	**257.2**	166.8	161.5	161.2
Chloride	mg/L	55.0	50.2	49.7	**31.4**	47.6	41.7	45.2
Sulfate	mg/L	36.4	33.6	32.6	**31.8**	32.3	28.3	31.9

Table 7.3b Mean Water Chemistry During Non-Release, Storm and Non-Storm Conditions Combined

Parameter	**units**	**Lake Austin**	**Red Bud**	**MoPac**	**Barton Springs**	**Lamar**	**First**	**Basin**
Temperature	°C	15.3	17.2	17.5	**21.3**	17.6	17.4	18.4
TOC	mg/L	3.4	3.5	3.0	**1.4**	3.0	4.3	3.7
TSS	mg/L	5.2	2.5	2.6	**3.3**	6.0	17.0	5.7
Fecal coliform (**Non-Storm**)	cfu/100mL	19	15	115	**9.5 (averaged)**	149	128	61
Fecal coliform, (**Storm**)	cfu/100mL	80	105	460		1,190	4,829	1,156
Ammonia	mg/L	0.04	0.05	0.05	**0.04**	0.05	0.06	0.07
Nitrate	mg/L	0.14	0.30	0.28	**1.32**	0.43	0.36	0.31
TKN	mg/L	0.47	0.31	0.32	**0.38**	0.36	0.37	0.39
Orthophosphorus	mg/L	0.01	0.02	0.03	**0.01**	0.03	0.03	0.03
Phosphorus	mg/L	0.04	0.02	0.04	**0.05**	0.04	0.05	0.05
pH	SU	8.08	7.73	7.66	**7.17**	7.67	7.78	7.68
Conductivity	µS/cm	577	566	567	**631.5**	580	547	562
Alkalinity	mg/L	162	173	188	**257.2**	197	185	181
Chloride	mg/L	56.1	50.1	48.2	**31.4**	43.7	38.2	41.9
Sulfate	mg/L	38.4	35.6	35.9	**31.8**	33.9	30.2	33.4

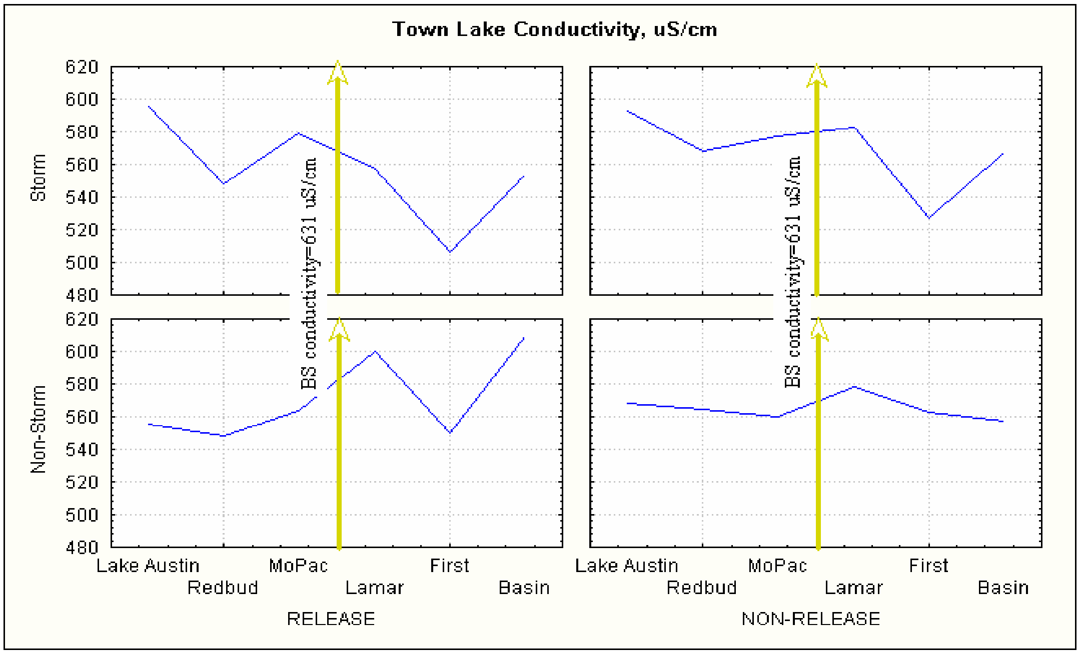
Under non-release conditions, impacts from the springs can be observed within Town Lake. The input of high levels of nitrate (1.32 mg/L) from Barton Springs correlates with increases in nitrates at the Lamar site within Town Lake (Figure 7.7). Downstream of Lamar, nitrate levels decrease as either lower levels of nitrate are input to the lake or nitrogen is consumed by aquatic plants. This pattern is seen under all release and storm conditions for nitrate, although the impact of groundwater input for other nitrogen species in Town Lake is not clear.

Figure 7.7 Barton Springs Influence on Town Lake Nitrate Concentration



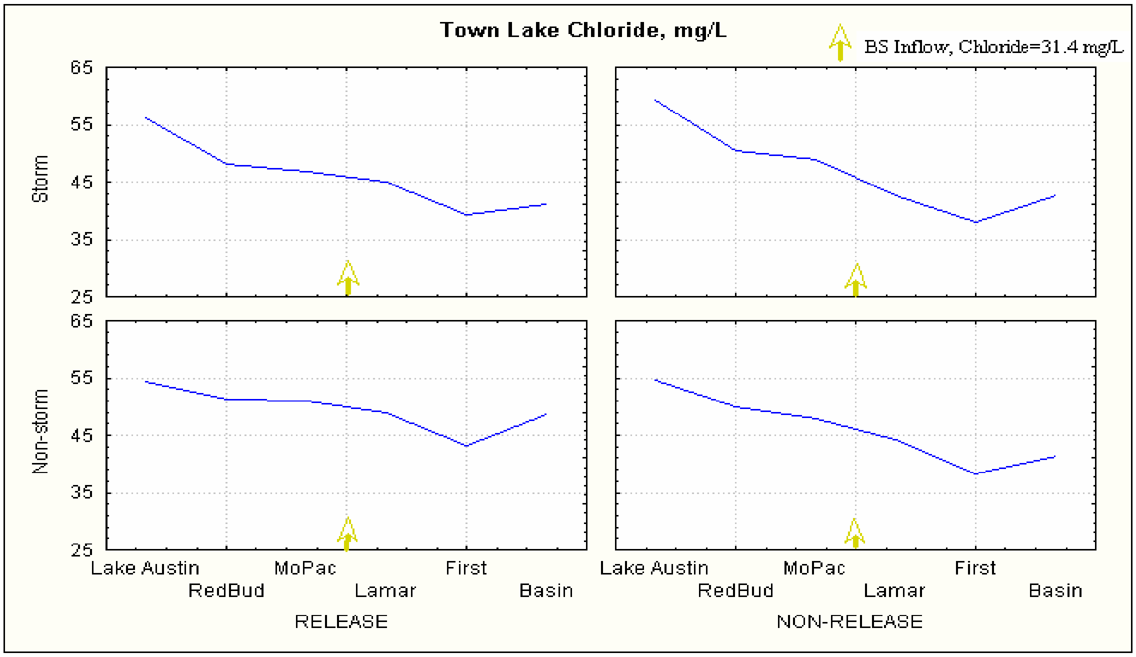
Influences on conductivity and alkalinity are clearly apparent (Figure 7.8), as conductivity rises between MoPac and Lamar under most conditions. It subsequently declines at First Street as other inflows dilute the impact or conductivity is lost through chemical reactions. Under release conditions during storm flow, the increase is not apparent and is perhaps diluted by the large inflows from Lake Austin and the urban tributaries. The lowest levels of conductivity are seen under storm conditions at First Street, where urban runoff transported to Town Lake from Shoal Creek may provide a large volume of water with low conductivity.

Figure 7.8 Barton Springs Influence on Town Lake Conductivity



As chlorides and sulfates show a decline throughout the lake before the Basin, the lesser values at Lamar can not be attributed solely to the lower levels entering with Barton Springs inflows (Figure 7.9). A further discussion of chlorides and sulfates in the lake and changes over time is found in Section 4.

Figure 7.9 Barton Springs Influence on Town Lake Chloride Concentration



Overall, the flows from the large springs leading to Town Lake, in particular Barton Springs, influence the chemistry of the lake itself even under conditions of higher flows. Thus, changes within the springs themselves can substantially impact this receiving water and must be considered when devising strategies to maintain or improve the conditions of the lake.

7.3 Ground Water Tracing

Results from five traces conducted by the BSEACD and COA (Hauwert et al 2001) in Barton Creek indicate that recharge in the creek from approximately Loop 360 westward to the upstream edge of the recharge zone discharges from Cold Springs along Town Lake and not Barton Springs, as commonly believed. A trace in Barton Creek downstream of Loop 360 discharged from Barton Springs. In addition, traces in Williamson Creek indicated that the western end of the recharge zone in that watershed also recharges water that discharges from Cold Springs. A trace near the eastern edge discharged from Upper Barton Springs. Two traces in 1999 in the Slaughter Creek watershed discharged from Barton Springs. Travel times as indicated by the tracing can vary by nearly 10 times. For example, a trace in low flow conditions (Barton Springs discharge was less than 35 ft^3/s) reached Cold Springs in approximately five days, traveling around 0.5 miles per day. A trace from the same feature under high flow conditions (Barton Springs discharge was over 100 ft^3/s) reached Cold Springs in less than 20 hours, traveling around 4.5 miles per day. Similar travel rates are being documented for Barton Springs from other parts of the Recharge Zone. Results document connections between specific recharge features in the Bear and Onion Creek watersheds and Barton Springs. Travel times from these watersheds to Barton Springs range from 14-16 days from Barber Falls in lower Onion Creek, 22 days from Crooked Oak Cave in upper Onion Creek and 36 to 43 days from Marbridge Sink in lower Bear Creek (Hauwert et al 2001). Monitoring to detect a trace from the Blanco River is continuing.

These rapid travel times again emphasize the consideration that must be placed on these springs when examining the status of Town Lake. Rapid transit times may also mean high vulnerability of the receiving water from spills in the Recharge Zone with little opportunity for attenuation of contaminants occurring by overland flow or soil infiltration.

7.4 Conclusions

The following conclusions with respect to groundwater impacts on Town Lake were derived from data collected during this monitoring period:

- Hydrology of Barton and Cold springs in integrally related to Town Lake conditions as demonstrated by water level and discharge monitoring combined with water chemistry analysis.
- Generally, concentrations of ions decrease with increasing flow both in Barton Springs discharges and in Town Lake conditions.
- High nitrate and conductivity discharges from Barton Springs can be observed in Town Lake primarily during non-release conditions, indicating that watershed protection in the contributing and recharge zone is an important factor in Town Lake management.
- Tracing studies have documented short travel times in the Barton Springs segment of the Edwards Aquifer and helped define the contributing watershed boundaries of Barton and Cold springs.

8.0 SEDIMENT ACCUMULATION AND PLANT COVER

Tracking the accumulation of sediment and composition of macrophytes and benthic algae in Town Lake is an important part of COA assessment of trends in the lake. Macrophytes provide numerous benefits to an aquatic ecosystem, including oxygen production and silt entrainment as well as spawning habitat and refugia for fish and other aquatic organisms. Build-up of sediments or nuisance levels of algae or macrophytes, however, can reduce the effective capacity of the lake, create boating hazards, degrade aquatic wildlife habitat and diminish the diversity of aquatic life in the lake. The 1992 Town Lake Report (COA 1992) established a goal to reduce urban sediment load by 50 percent. One of the concerns prompting this goal at that time was the potential loss of volume in the lake with accumulated sediment. As discussed in previous sections, the Watershed Protection Master Plan (COA 2001b) established new goals to support beneficial uses for the lake. As with nutrients, the sub-goal for sedimentation was revised to "maintain existing loads discharged to Town Lake." This sub-goal should enable the lake to maintain the current conditions, as described in the following section, so that long-term net accumulation does not occur.

8.1 Methods

City staff has made measurements of sediment accumulation on the bottom of Town Lake by comparing the depth across the lake along six bathymetry transects over time. These transects represent both upper and lower reaches of Town Lake. In addition to these measurements, aerial photos taken as far back as 1951 were examined at the Texas Natural Resource Information Service (TNRIS) to visually compare the size of delta formations in Town Lake at the mouths of several contributing creeks.

At the same time that City staff measured sediment accumulation along lake transects, the percent cover of aquatic macrophytes, algae, and sediment was recorded. This aspect of the survey focused on identifying the common plant species and substrate composition beneath Town Lake and scouting for the presence of an undesirable invasive species, *Hydrilla verticillata*. Hydrilla populations have been discovered upstream in Lake Travis and more recently in Lake Austin. Rapid control measures are necessary to limit infestation, since

Hydrilla displaces native aquatic species and chokes out many recreational uses in an invaded lake.

New methods have recently been developed to create more accurate bathymetric maps in order to compare overall lake volumes over time, thereby enabling more accurate comparison of sedimentation rates. In 1999, the City contracted the Texas Water Development Board (TWDB) to perform a survey of Town Lake and Lake Austin using a combination of sonar and satellite global positioning. The City also contracted with USGS in 1999 to collect a sediment core from Town Lake to determine the historic sedimentation rates dating back to the reservoir's creation. Additionally, the sediment core from Town Lake was used to evaluate historic pollution rates by analyzing adsorption of various pollutants in sediments from different time periods (Section 9).

8.2 Changes in Lake Depth

Calculating depositional rates or net accumulation rates throughout a riverine lake, like Town Lake, is difficult. In fact, regular scouring in the upper portions of this relatively shallow lake occurs, maintaining a long-term equilibrium between tributary inputs and transport into the mainstem Colorado (COA 1992a). A large scouring event in December 1991, referred to locally as the 1991 Christmas flood, virtually removed the deltas from the mouths of creeks feeding Town Lake. Deltas have also receded following several other large storm events requiring heavy releases from Tom Miller and Longhorn dams. One area in Town Lake where fine sediment has deposited and slowly accumulated is in the backwater portion of the downstream basin on the south side of the lake. This area was used by the USGS to pull cores for temporal comparisons of toxic accumulation in sediments.

8.2.1 Aerial Photography of Delta Areas

COA staff examined aerial photographs of Town Lake at TNRIS to determine if long-term sediment accumulation could be seen by comparing the size of delta formations at the mouths of several urban creeks including Johnson, Barton, Shoal, Waller, and East Bouldin. Aerials from 1951, 1980, 1986, 1990, 1993, 1995, and 1997 were compared. Although no quantitative assessment could be made, no incremental delta buildups were detected. In fact, deltas were visible in all aerials and appeared to expand and shrink somewhat in a random manner chronologically, indicating that an equilibrium was being kept over the long term through steady deposition and periodic scouring.

8.2.2 USGS Basin Core

The lower portion of Town Lake, especially the basin area, may be more susceptible to long-term sediment accumulation. The 1992 COA Town Lake Study (COA 1992) estimated that in the absence of scouring flows, coarse sediment material may accumulate at a rate of 1.8 inches/year and fine sediments may accumulate at a rate of 1.08 inches/year. Therefore, depending on the sediment density, accumulation is probably somewhere in this range. Previous local sediment accumulation in the basin is documented by the necessity for dredging partly obstructed water intakes to Holly Power Plant in 1982 (COA 1992a). The USGS, therefore, selected this area to collect a sediment core. The core was collected in a backwater portion of the downstream basin on the south side of the lake. This is one of the few areas in Town Lake where fine sediment has consistently accumulated. The location was selected to obtain a core sample with the most complete historic profile of the pollutants in the lake. When the USGS calculated an accumulation rate 0.98 inches/year from the core, it gave a close confirmation of the fine sediment deposition rate estimated in the 1992 Town Lake Report (Van Meter 2000).


USGS Town Lake Core

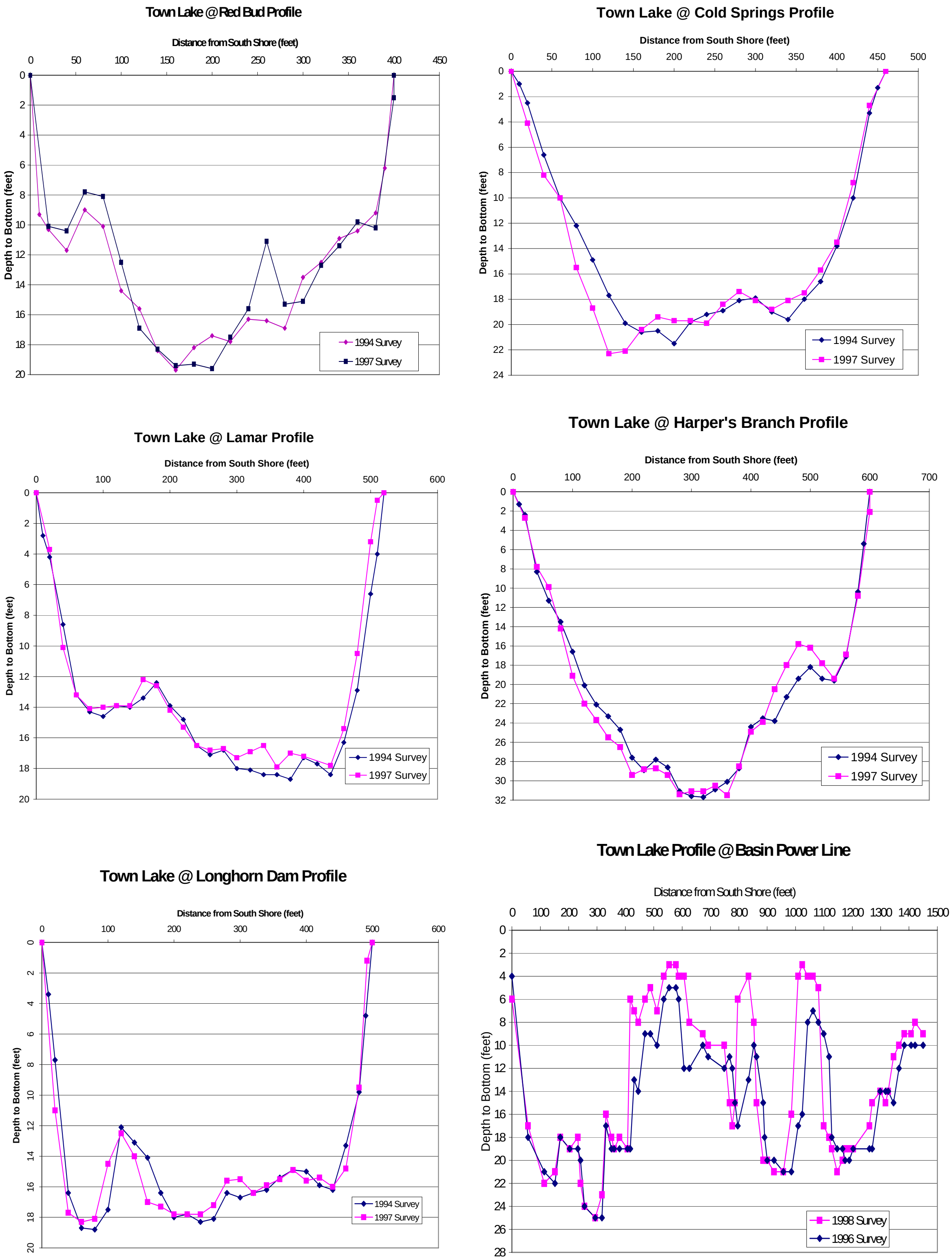
8.2.3 COA Transects

Beginning in 1994, COA staff tracked the actual amount of sediment accumulation along lateral transects across Town Lake. The original survey included six transects: downstream of Red Bud, downstream of Cold Springs, upstream of Lamar Boulevard, downstream of IH-35 at the mouth of Harper's Branch, just upstream of Longhorn Dam, and across the basin of Town Lake (under the transmission power lines from Holly Power Plant to Longhorn Shores at Pleasant Valley District Park). Five transects were assessed in 1994 and 1997 by taking depth measurements every 20 feet with a sounding line. Rebar was driven into opposite banks at each transect, and nylon rope was strung across the lake and attached to the rebar. Divers held the sounding line on the bottom of the lake while staff on board a boat recorded the depth at each 20-foot interval. A sixth transect, located under the power lines in the basin, was assessed using an electronic fathometer in 1994, 1996, and 1998. All of these transects were measured again in 1999 and compared to earlier COA measurements as part of the TWDB volumetric survey and report.

After correcting for differences in lake levels between the 1994 and 1997 surveys, some differences in the lake's bottom profile were detected at each of the six transects measured (Figure 8.1). The transect downstream of Red Bud measured an overall average accumulation of 0.4 feet of sediment, or 0.13 feet annually. Moving downstream, the transect below Cold Springs measured an average loss of 0.38 feet of sediment over three years, or -0.13 feet annually. The transect just upstream of Lamar measured an average 0.39 feet accumulation of sediment, or 0.13 annually. The transect below Harper's Branch measured an average accumulation of 0.01 feet over the three years and 0.003 feet annually. The transect directly upstream of Longhorn Dam measured an average 0.12 feet decrease in sediment, or -0.04 feet annually. Overall, these five transects best represent areas of the lake where equilibrium between deposition and scouring is maintained over time. Comparisons in depth among these five transects over three years indicate 0.09 feet accumulation in sediment annually throughout most of the lake during this time period. However, the middle of the basin, represented by the power line transect, is where large populations of yellow stargrass (*Heteranthera dubia*) cover mounds of accumulated sediment (see photo).

Town Lake Basin

Figure 8.1
Town Lake Depth Profiles



The best transect for measuring accumulation of sediment in the basin of Town Lake is located under the transmission power lines from Holly Power Plant to Longhorn Shores at Pleasant Valley District Park. Because of its long length (more than 1,000 feet), this transect's profile was measured using an electronic fathometer rather than a measured rope and sounding line. Depth profiles along the power line transect were recorded on three separate occasions: October 1994, February 1996 and June 1998. The profile recorded in October 1994 was difficult to interpret because of major interference from stargrass growth in the middle of the transect. Following the 1994 survey, COA concluded that the best time to record the power line transect's profile was during the winter, when the stargrass is dormant. Therefore, a second profile was recorded in February 1996, and this recording was free of interference. A third profile was recorded in June 1998 for comparison purposes in this report, and some stargrass interference was encountered. However, the readout was clear enough to indicate significant sediment deposition had occurred since 1996 (Figure 8.1). Fathometer profiles recorded between February 1996 and June 1998 indicate an average of 1.51 feet of sediment accumulation along this transect at various points, particularly at the peaks of sediment mounds. The same sediment peaks measuring 8 and 10 feet in depth in 1996 measured only 4 and 6 foot depths, respectively, in 1998. The TWDB assessed the same power line transect in 1999 and reported depths were very close to the same depths as the 1996 survey. Therefore, the scouring storm event of October 1998 may have reduced the deposition that occurred between the 1996 and 1998 surveys.

Although stargrass obscured the 1994 profile throughout the middle of the power line transect, the north end of the transect was free of stargrass, providing a decent profile of the bottom for the last 400 feet. This proved useful when comparing the 1994 and 1996 profiles, because a new sediment peak appeared in 1996 within the 400 feet where no peak was present in 1994. The same peak also appeared in the 1998 survey and had grown in height around the 700 foot mark (Figure 8.1, Profile @ Basin Power Line). COA staff dove along the power line transect after the 1998 survey to investigate the composition of all the fathometry profiled deposits. The fathometry peaks were indeed sediment mounds, and the bases of these mounds were composed of river cobble, presumably deposited out in front of Longhorn Dam during large flood events. The upper portions of the mounds were composed of fine sediment deposits that support dense columns of stargrass**.** The appearance of the new mound near the 700-foot mark may have occurred on May 29, 1995 (between the 1994 and 1996 surveys), when a large discharge of 22,000 cfs was recorded at Longhorn Dam.

Overall, the City of Austin's transects indicate deposition and scouring events for sediment both throughout the lake and in the basin.

8.2.4 Volumetric Survey, 1999

The TWDB conducted the most recent volumetric survey of Town Lake between March and July of 1999. The TWDB employed technological advances by combining a differential global positioning system (GPS), depth sounding and geographical information system technology to create a digital model of the reservoir's bathymetry. This underwater mapping system has provided the best estimate of Town Lake's volume and overall lake bottom topography to date. COA transects measured manually with a sounding line, though extremely accurate, represent only six transects whereas the TWDB's latest survey includes more than 130 transects. It is noteworthy that a comparison of the same six transects between City data and TWDB data indicates little or no change in volume between 1994 and 1999. The 1999 TWDB survey indicates Town Lake covers 469 surface acres, has a 17-mile-long shoreline and holds a total volume of 6,596 acre-feet at an elevation of 429.0 feet. The deepest point, 35.88 feet, is located approximately 37 feet upstream from the center of Longhorn Dam. Comparisons between the 1999 TWDB survey and other bathymetric surveys of Town Lake are mixed. A 1960 survey (COA 1984) showed the lake's volume to be 2,615 acre-feet less than the 1999 survey, and a more complete survey in 1991 (Armstrong 1991) found the volume to be 967 acre-feet less than the 1999 survey. However, a 1992 survey (COA 1992) found the volume to be 536 acre-feet more than the 1999 survey, including eight additional surface acres. Since methodology has improved, the latest survey is believed to be the most accurate and it is recommended that the same methodology be used in five to ten years to make future comparisons.

As methods have varied, it is difficult to determine a net sedimentation rate for Town Lake. Overall, the transects and volumetric survey seem to indicate no net sedimentation in the lake system despite fluctuations in depth profiles over time. However, the basin USGS core seems to indicate that a minimal amount of fine sediment is accumulating in the basin, at least in specific locales.

8.3 Macrophyte Cover Mapping

Divers recorded the coverage of aquatic plants and unvegetated substrate composition (Table 8.1) while measuring depths with the sounding line along five of the transects previously discussed, excluding the power line transect. Just as these five transects represent Town Lake in equilibrium, these same transects represent the plant community and substrate composition throughout the majority of the stable riverine portion of the lake. As the boat stopped every 20 feet along each transect to record the lake's depth, time was allowed for divers to tabulate what covered the bottom of the lake in one-foot increments. Based on visual observations, vegetation at the mouth of Barton Creek and on the sediment mounds in the basin under the power lines is considerably denser than other areas in Town Lake. These two areas were not included as transects, although the vegetation growing to the surface could be easily observed from the boat.

Most of the filamentous algae in Town Lake are green algae of the genus *Vaucheria* growing from bottom sediments. These non-septate, branching, green algae are commonly found growing in unpolluted water on reservoir walls (Palmer 1959). At times, a dense community of *Vaucheria* algae species made the lake bottom look like the top of a giant pool table, giving significance to the algae's common name – "green felt." Some decline in the coverage of *Vaucheria* has been measured in Town Lake, both upstream and downstream of Shoal Creek. The original coverage upstream of Shoal Creek, measured in 1991(before a significant flood event that winter) was 50 percent, as compared to 38.84 percent coverage in 1994, and 13.07 percent coverage in 1997. Underwater transects were not made below Shoal Creek in 1991, but *Vaucheria* covered 25.94 percent upstream of Shoal Creek in 1994 and 9.07 percent in 1997.

The most widespread submerged aquatic plant in Town Lake is Eurasian water milfoil, *Myriophyllum spicatum*. This plant is regarded as a nuisance by some users of Lake Austin (upstream of Town Lake), where it is controlled by periodic drawdowns. Fishermen consider milfoil good fish habitat, and widespread coverage of milfoil may deter the spread of the submerged and more aggressive hydrilla. Milfoil is not considered a problem in Town Lake, but it does dominate in some areas, especially near the mouth of Barton Creek. Since swimming and motor boating are prohibited on Town Lake, milfoil is not likely to be considered a nuisance. Some decline in milfoil coverage has been measured upstream of Shoal Creek: 14.42 percent in 1991, 13.19 percent in 1994 and 0.58 percent in 1997. Milfoil coverage below Shoal Creek has not changed substantially since 1991. Although considered a nuisance by swimmers and boaters in Lake Austin, milfoil plays a valuable wildlife habitat role by providing cover, food, and oxygen for young fish in Town Lake.

Just as the power line transect in the basin represents an area of increased sediment deposition, the same transect represents an area of the lake where aquatic plant growth is accentuated. An extensive population of yellow stargrass, *Heteranthera dubia*, grows in the basin of Town Lake, mostly along the power line transect on top of sediment mounds. Although coverage along the power line transect is not represented in Table 8.1, stargrass coverage along this transect has been greater than 50 percent in any given year since 1990. These dominating populations of stargrass are dense and leafy in the middle of the basin, growing from the bottom of the reservoir to the surface. By diving the stargrass beds, COA staff observed the importance of this habitat in supporting a host of macro-fauna, including large bass, gar, and carp, seen cruising the periphery of the stargrass stands. Schools of minnows navigated a forest of stargrass plants while large crayfish patrolled the bottoms. As long as the sediment deposits supporting these stargrass communities do not cause a danger to the community, it is recommended that the vegetation be preserved for aquatic habitat and as a vegetated water quality filter. The stargrass aids water quality by catching sediment as it reaches the basin.

The coverage of aquatic plants and algae generally decreased from 1991 to 1997 along the five transects considered in equilibrium from sediment deposition (Table 8.1). The percentage of exposed sediment increased over the same period along these five transects, although depth profiles did not change substantially. These results suggest that scouring events have occurred frequently enough during this six-year period to keep vegetation from fully reestablishing itself on exposed sediment deposits. Some differences in macrophyte and algae composition may be attributed to short-term fluctuations in coverage, or differences in months the transects were surveyed (August 1991, October 1994, November 1997), but the results generally indicate a fairly diverse community of macrophytes and a predominance of *Vaucheria sp*. In addition to the species listed in Table 8.1, TPWD inventoried these additional species in their vegetation surveys: smart weed, chara, water willow, and water hyacinth. Although water hyacinth is an invasive exotic plant that can cause serious problems, it has been very limited in coverage and is not of concern at this time.

Table 8.1 Coverage of Macrophytes, Macro-Algae and Sediment Occurring in Town Lake During 1994 and 1997 Surveys

Species	**Coverage (acres)**		**% of Area Occupied**	
	1994	**1997**	**1994**	**1997**
Upstream of Shoal Creek				
Eurasian water milfoil - *Myriophyllum spicatum*	25.19	1.11	13.19	0.58
Elephant ears - *Colocasia esculenta*	0.28	0	0.14	0
Arrowhead - *Sagittaria sp.*	2.77	0	1.45	0
Bulrush - *Scirpus sp.*	0.83	0	0.43	0
Green felt algae - *Vaucheria sp.*	74.19	24.96	38.84	13.07
Blue-green algae	1.94	2.92	1.01	1.53
Unvegetated Sediment	40.83	66.35	21.38	34.74
Other substrates: silt, sand, pebble, cobble, boulder, bedrock, clam shells	44.98	95.63	24.55	50.07
Downstream of Shoal Creek				
Eurasian water milfoil - *Myriophyllum spicatum*	3.76	3.92	1.32	1.37
Elephant ears - *Colocasia esculenta*	0.5	0.26	0.18	0.09
Yellow stargrass - *Heteranthera dubia*	2.01	0	0.7	0
Water hyacinth - *Eichornia crassipes*	0.5	0	0.18	0
Duckweed - *Lemna minor*	0.5	0	0.18	0
Green felt algae - *Vaucheria sp.*	189.66	25.94	66.32	9.07
Blue-green algae	3.01	8.64	1.05	3.02
Unvegetated Sediment	60.96	69.41	21.32	24.27
Other substrates: silt, sand, pebble, cobble, boulder, bedrock, clam shells	25.09	177.83	8.77	62.18

The invasive exotic plant hydrilla was not encountered along the five transects (or in any TPWD survey) in spite of a substantial hydrilla infestation in Lake Austin. Twenty-three (23) acres were first documented in Lake Austin in 1999 by TPWD, and the plant coverage had increased to 320 acres by May 2002. A major flood event in July 2002 moved more than 100 acres of hydrilla out of Lake Austin into Town Lake and the Colorado River downstream. To date, hydrilla is not established in either Town Lake or the river, but COA conducts periodic checks of the lake to ensure early detection.

While the presence and density of plant communities on Town Lake are dynamic, controlled in part by seasons and scouring events, the overall acreage of macrophytes in the lake is very limited. According to vegetation surveys, macrophyte coverage ranged from 1.2 percent to 2.3 percent between 1993 and 1999. (TPWD 1994; TPWD 1997; TPWD 2000).

This limited macrophyte coverage is of concern, not only for the direct impacts on the lake ecosystem, but also for the increased potential for hydrilla to establish in the unvegetated areas of the lake. COA is currently working to control Lake Austin hydrilla through an integrated plan (using lake draw-downs, sterile grass carp and harvesting) developed with TPWD, LCRA and a citizen group. An important next step is establishing substantial populations of native plants in Lake Austin (post-hydrilla control), and in Town Lake as a preventive measure. Initial efforts in this joint project between COA and the Lewisville Aquatic Ecosystem Research Facility (LAERF) under the U.S. Army Corps of Engineers are currently underway.

8.4 Plans For Future Monitoring

Bathymetric maps can now be generated by the TWDB using a boat equipped with a computer-coordinated GPS and sonar depth location system. Multiple transects, positioning hundreds of depths, can be profiled throughout the lake to generate a two-foot contour map of the bottom of Town Lake. The volume of the reservoir can then be calculated and compared with historic volumes (calculated using older methods) or future volumes (calculated using the new GPS method). Town Lake was GPS mapped in 1999 using this methodology. The volume and transect profiles derived from this map will be compared with future volumes, generated by the TWDB approximately every five to ten years.

Manual measurement of bathymetry through diving has been replaced in most monitoring programs by fathometry. This method is more time- and cost-efficient and provides better overall coverage of water bodies. For this reason, the routine transect diving conducted by COA staff has been discontinued. Since the COA transects will no longer be profiled with a sounding line for sediment deposition, the measurement of percentage cover of aquatic vegetation and substrate composition along these transects will be discontinued. Instead, the TPWD annual vegetation surveys will be tracked for macrophyte community changes. COA will continue periodic checks for hydrilla and other invasive species in conjunction with other routine monitoring. Additionally, COA will monitor vegetation (founder colonies and existing plants) as needed for the LAERF restoration project.

8.5 Conclusions

Most sediment accumulates in Town Lake at the basin under the power lines, based on comparisons of transects measured by COA over time across various parts of lake using sounding lines and fathometers. Fathometer transects in the basin indicate that a large new mound of sediment was deposited between 1994 and 1996 and about 1.51 feet of sediment accumulated under the power lines between February 1996 and June 1998. The TWDB volumetric survey of Town Lake conducted between March and July of 1999, however, found about the same sediment buildup as COA staff measured in 1996. These findings indicate that major releases triggered by large storm events like the one in October 1998 may have scoured some of the coarser sediment from the accumulation zone under the power lines in the basin back to 1996 levels. Nevertheless, certain pockets in the southern backwater portions of the basin, where the USGS core was taken, may accumulate and hold finer sediments.

Other common sediment build-ups are observed as deltas at the mouths of the major creeks feeding Town Lake. These deltas are periodically reduced, sometimes substantially, by major releases from large storm events. This conclusion is based on review of aerial photos taken over Town Lake from 1951 through 1997 and visual observations made by COA staff since 1990. The TWDB 1999 survey verified that the first five transects measured by COA staff since 1994 above the basin were very similar in profile. Most of the lake upstream of the basin is not believed to be a depositional area, except at the mouths of contributing creeks. The TWDB calculated slightly less volume and area in 1999 than previous lake volume and area estimates made by COA staff in 1992. This may be due to the more accurate mapping methods used by the TWDB and the more detailed measurements taken in the basin and at the mouths of the contributing creeks. COA plans to repeat the TWDB survey every five to ten years for the most accurate estimates of the lake's future volume changes.

The presence of the invasive, lake-choking hydrilla species has not been detected in Town Lake even though this aggressive invader is now well-established in Lake Austin. The most common submerged plants in Town Lake are milfoil, with densest populations occurring at the mouth of Barton Creek, and yellow stargrass, forming an underwater forest on sediment deposits in the basin under the power lines. Both of these plant communities are regarded as good habitat for fish and good fishing areas by anglers. The most common filamentous algae is green felt (*Vaucheria sp*.), whose name is fitting for the "pool table" appearance it can give the bottom of Town Lake. Except for dense submerged aquatic plant communities growing at the mouth of Barton Creek and on sediment bars in the basin, the coverage of both submerged aquatic plants and algae generally decreased from 1991 to 1997 along the five transects considered in equilibrium from sediment deposition. TPWD surveys also indicate a very minimal amount of vegetation on Town Lake leaving large areas of the lake open to infestation by hydrilla. COA is working with the U.S. Army Corps of Engineers to remedy this concern by establishing native plants in the lake.

9.0 SEDIMENT QUALITY

The accumulation of sediment in Town Lake was discussed in Section 8. In addition to causing increased turbidity and potential filling of the river basin, sediments are an important storage compartment for many toxins released into surface waters. Because of their ability to sequester toxic compounds, sediments can reflect water quality and record the effects of anthropogenic emissions. As these toxins move through the water column and settle on the bottom, fish and other aquatic life may be exposed to them both through suspended sediments and in the benthic habitat. Because of these impacts and observed toxins in fish tissue (Section 10), the 1992 Town Lake Report (COA 1992a) set a goal of reducing the toxin concentrations in sediment by 50 percent.

The recently adopted Watershed Protection Master Plan (COA 2001b) set new goals in terms of maintaining the beneficial uses of the lake. A beneficial use affected by the toxins associated with the sediment is Aquatic Life Support (ALS), in terms of benthic and fish populations. To assess impacts to the benthic populations for this report, sediment concentrations are compared to two sets of sediment quality guidelines (SQGs) from a recent evaluation of guidelines for freshwater ecosystems and those used by TNRCC. Fish accumulate toxins through water, plant, and sediment pathways. Thus, their health and the use of the water body for fishing may be negatively impacted by these toxins. The fish tissue concentrations of the toxins and fish consumption advisories are discussed in Section 10.

The Watershed Protection Master Plan (COA 2001b) also used a sub-goal to address the continued input to the lake rather than the level of toxins. The overall goal for toxic sediments was “to maintain existing toxic loads being discharged to Town Lake, represented by total organic carbon (TOC), chemical oxygen demand (COD), copper, lead, and zinc loads, as well as by the Spills Risk Index.” This goal will be assessed in future years to gauge the success of the Master Plan programs.

Several groups of toxins are frequently present in sediments either due to their stability when adsorbed or their high level of use in the environment (Table 9.1). The sampling and sampling results for these toxins in sediments will be discussed in the following sections.

Table 9.1 Sediment Toxins for Analysis

Pollutant	Toxicity Characteristics	Sources	Remarks
Pesticides: Generally chlorinated hydrocarbons	Readily assimilated by aquatic animals, fat-soluble, concentrated through the food chain (biomagnified), persistent in soil and sediments	Direct application to farm and forest lands, runoff from lawns and gardens, urban runoff, discharge in industrial wastewater.	Seven chlorinated hydrocarbon pesticides already restricted by USEPA: aldrin, dieldrin, DDT, DDD, endrin, heptachlor, lindane and chlordane.
Polychlorinated Biphenyls (PCBs):	Readily assimilated by aquatic animals, fat-soluble, subject to biomagnification, persistent, chemically similar to the chlorinated hydrocarbons	Used in electrical capacitors and transformers, paints, plastics, insecticides, other industrial products. Municipal and industrial waste discharges disposed in dumps and landfills.	TOSCA ban on production after 6/1/79 but will persist in sediments; restrictions on many freshwater fisheries as result of PCB pollution.
Metals: antimony, arsenic, beryllium, cadmium, copper, lead, mercury, nickel, selenium, silver, thallium and zinc	Not biodegradable, persistent in sediments, toxic in solution, subject to biomagnification.	Industrial discharges, mining activity, urban runoff, erosion of metal-rich soil, certain agricultural uses (e.g., mercury as a fungicide). Many metals may be associated with vehicle use.	Incomplete combustion of fossil fuels; vehicle exhaust and incomplete atmospheric deposition of vapors: arsenic and cadmium. Corrosion of alloys and plated surfaces; spillage of brake fluid: chromium and cadmium. Coolant, brake fluid, motor oil and gasoline: copper, lead, and nickel. Component of automobile tires: zinc.
Polycyclic Aromatic Hydrocarbons (PAHs):	Carcinogenic in animals and indirectly linked to cancer in humans; not persistent and are biodegradable, although bioaccumulation can occur	Used as dye-stuffs, chemical intermediates, pesticides, herbicides, motor fuels and oils. Fossil fuels (use, spills and production), incomplete combustion of hydrocarbons.	More work is needed on the aquatic toxicity of these compounds;

Modified from: (CEQ 1978)

9.1 Sediment Sampling

Many entities have collected sediment samples from Town Lake at many different sites, and these samples have been analyzed at several different laboratories over the period of record. The 1992 Town Lake Study (COA 1992a) included data from 1981 through 1990 (Table 9.2). An additional sampling effort undertaken as part of that study involved sampling for heavy metals and organic pollutants in sediments at areas where worst-case accumulation of past contamination would likely be present: tributary mouth deposits. Sampling sites included the mouths of all nine Town Lake tributaries. For comparative purposes, the mouth of an unnamed, undeveloped tributary within the Lake Austin watershed (12.1 miles upstream of Tom Miller Dam) and a downstream site on the mainstem of the Colorado River (0.7 miles down stream of Longhorn Dam) were sampled as well.

In addition to the data analyzed for the Town Lake Study (COA 1992a), some additional historical data were identified and included in this report (Table 9.2). Table 9.2 also cites sampling that has occurred since the Town Lake Study (1992-2000), incorporating primarily the ongoing cooperative monitoring program with the USGS and sampling efforts by the City itself. The Lower Colorado River Authority (LCRA) also conducted one sampling event in June 1994.

Table 9.2 Town Lake Sediment Data

Sampling Dates	Reference
Town Lake Study Data (1981-1991)	
March 1, 1981	Final Report of the National Urban Runoff Program (NURP) in Austin, Texas (City of Austin and Engineering Science,1983)
May 14, 1985	Sampling for study on "Effects of Urbanization on Toxic Organics Concentrations in Lake Austin and Town Lake, Texas" (Wallace and Armstrong 1986)
1987-1991	COA/USGS annual sediment monitoring data
February 1, 1988	The Lower Colorado River Pesticides Study: Pesticide and Heavy Metal Residues in Surface Water, Sediment, and Fish Tissue (Clear Clean Colorado (CCC) et al. 1990)
June 6, 1990	Texas Water Commission (TWC), unpublished data 1990
September 25-27, 1991	City of Austin Clean Lakes Study, creek mouths
Additional Historical Data (1980-1991)	
November 5, 1980	Texas Natural Resource Conservation Commission (current name), lab not known. Data obtained from TNRCC database.
August 8, 1981	Texas Natural Resource Conservation Commission (current name), lab not known. Data obtained from TNRCC database.
May 1, 1982	Environmental Resources Management data, laboratory not known. Referenced in Wallace and Armstrong (1986).
February 1, 1988	The Lower Colorado River Pesticides Study: Pesticide and Heavy Metal Residues in Surface Water, Sediment, and Fish Tissue (Clear Clean Colorado (CCC) et al. 1990), additional data from low flow sampling analyzed at the Texas Department of Agriculture – Pesticide laboratories
May 15, 1990	Texas Water Commission (TWC), unpublished data 1990
Recent Town Lake Sediment Sampling (1992-2000)	
February 1, 1988	The Lower Colorado River Pesticides Study: Pesticide and Heavy Metal Residues in Surface Water, Sediment, and Fish Tissue (Clear Clean Colorado (CCC) et al. 1990)
June 6, 1990	Texas Water Commission (TWC), unpublished data 1990
September 25-27, 1991	City of Austin Clean Lakes Study, creek mouths
1992-2000	Ongoing sampling, Environmental Resources Management Division, City of Austin
1992-2000	COA/USGS annual sediment monitoring data

9.1.1 Sampling Techniques

Table 9.3 cites the specific sampling dates for Town Lake sediment sampling during the recent sampling period, 1992-2000. The data from other sources were obtained directly from those agencies. Ongoing long-term sampling at four sites is provided by the USGS. COA provides additional sampling for particular data needs. Recently, COA has sampled two additional sites annually (MoPac and Red Bud). The methods for sampling conducted by the City of Austin are described below. In addition to sediment sampling in Town Lake itself, the City has collected sediment from the mouths of creeks for the Environmental Integrity Index (COA 1997b), deposited sediment within creek beds, and captured sediment within water quality control structures. Characteristics of these other sediment may give an indication of the source of contaminants associated with sediments within Town Lake.

Table 9.3 Town Lake Sediment Sampling

Sampling Dates	Sampling Agency	Laboratory
May 14, 1992	COA/ERM	LCRA
August 5, 1992	USGS	USGS
June 15, 1993	USGS	USGS
May 18-19, 1994	COA/ERM	NDRC
June 23, 1994	LCRA	LCRA
June 29, 1994	TWC	Unknown
August 11, 1994	USGS	USGS
July 18, 1995	USGS	USGS
July 10, 1996	TWC	Unknown
August 6, 1996	USGS	USGS
August 20, 1997	USGS	USGS
May 19, 1998	USGS	USGS
June 30, 1998	COA/ERM (2 sites)	LCRA
October 13, 1999	USGS	USGS
July 5, 2000	USGS	USGS
September 14,2000	COA/ERM (2 sites)	LCRA

The following paragraphs describe sampling for different types of sediment sites. All sediment methods comply with the TNRCC Surface Water Quality Monitoring (SWQM) Procedures Manual (TNRCC 1999), including sampling equipment, sample collection, preservation, and holding times.

COA staff has continued to collect samples from the deposited sediments within Town Lake when USGS sampling is not conducted or associated with other studies. Sediment samples within Town Lake itself are collected with a dredge at designated locations along the lake, centrally located between the two banks. Each sample is a composite of several grab samples; sampling by the City of Austin includes at least three to four grabs taken from the surface sediments. At creek mouths (within the sediment delta), samples were taken in backwater areas near the creek mouths, where fine sediments had accumulated.

Creek sediment samples have primarily been collected with shallow overlying water or from moist deposited sediments. Sampling locations near creek mouths are described in the EII report (COA 1997). All samples are composited from a minimum of three grab samples at each site. The sample is collected from deposited sediments using a Teflon-coated scoop or small plastic scoop; the use of a scoop is essential to obtain sediment from creek beds with large cobble/boulder substrate.

The method for collecting sediment from water quality control structures is dependent on the presence of filter media, the study objectives, and the physical characteristics of the structure. Much of the data obtained from these structures were collected during a grant study examining the control of toxic sediment with Best Management Practices (BMPs). This grant included the collection of sediment by grab sampling and in sediment traps for analysis at the grant-approved laboratories (COA 1998). The method for sediment sampling was described in detail in that report. All composite samples were collected according to the TNRCC SWQM Procedures Manual (TNRCC 1999) and as described above for lake and creek sediments.

Sediment traps were placed in two ponds and consisted of glass containers that were either: 1) sealed, labeled, iced, and transported directly to the laboratory or 2) composited into sediment jars for submittal to the laboratory. Water quality control structures with filter media were sampled in a different manner. Inlet filters were sampled by using a Teflon-coated scoop to remove material from an inlet filter, or set of filters, within close proximity. Samples taken in filtration ponds consisted of compositing multiple grab samples from sediment deposited directly on the filter media (sand). Finally, samples in water quality control structures with overlying water were taken as described for Town Lake sediments.

9.1.2 Laboratory Analyses

Recent sediment analyses were performed at several laboratories. All USGS sediment analyses are performed at the USGS laboratory. LCRA samples and some samples collected by COA were performed by the LCRA Environmental Laboratory. One Town Lake sampling event and much of the water quality control structure data were submitted to ITS Laboratories, formerly known as NDRC. Pesticides for the grant study (COA 1998) were analyzed at the Texas A&M Geochemical Environmental Research Group (GERG) laboratory.

The comparability of data used within this report is determined by the commitment of any contracted laboratory staff to use only approved analytical methods. These methods have specified units in which the results are to be reported. Projects undertaken by COA employ methods and techniques that have been determined to produce measurement data of a known and verifiable quality and that are of quality sufficient to meet the overall objectives of each program. The contract laboratories have committed to using only approved methods when performing analyses on samples. In some cases, for example, the cooperative monitoring program with USGS and the Contaminated Sediment Grant, analyses by methods other than standard EPA methods are implemented. This can be done for specific purposes such as the detection of pesticides in sediments below standard EPA method detection limits. Results considered from other studies have used EPA-approved methods for all the included parameters.

The use of approved methods alone does not assure quality data. Therefore, COA has established procedures to verify the degree of quality actually attained on real environmental samples. These procedures are internal quality control checks and the database data approval process (Section 1.3.3).

9.2 Data Evaluation

Sediment chemical concentrations for this report were examined with relation to screening levels as described in the following section. Data were analyzed for temporal trends, and spatial variations were observed. The constituents examined for the report were primarily the toxic metals and organics.

Several methods are currently available for evaluating potential aquatic impacts of sediments on benthic species. The sediment chemistry screening values used in these methods are not regulatory criteria, site-specific cleanup standards, or remediation goals. Sediment chemistry screening values are reference values above which a sediment ecotoxicological assessment might indicate a potential threat to aquatic life. Two sets of sediment quality guidelines (SQGs) were selected for evaluating data in this report. Most of them were developed from data relating the incidence of adverse biological effects to sediment concentrations using paired field and laboratory data. The 85th percentile for Texas uses the frequency of observation of concentrations from a statewide database. Parameters selected in Tables 9.4 and 9.5, discussed below, were selected based on concerns for Town Lake.

MacDonald et al (2000) developed consensus-based guidelines for freshwater ecosystems. This approach used many of the same criteria (derived from paired field and laboratory data) used by USEPA for a nationwide assessment of sediments (EPA 1999). The consensus-based guideline development used the incidence of measured toxicity from paired sediment chemistry and toxicity testing from various locations in the United States. The paper concluded that the newly developed Threshold Effect Concentration (TEC) and a Probable Effect Concentration (PEC) provide a reliable basis for assessing sediment quality conditions in freshwater ecosystems. These may be the most up-to-date criteria and the most applicable for freshwater systems (Table 9.4).

TNRCC evaluates concerns for sediment toxin levels in the state by assessing the percentage site sediment chemistry data that exceed either of two criteria. These criteria are the 85th percentile (based on measured values statewide), and the Probable Effects Level

(PEL) developed for the Florida Department of Environmental Protection (MacDonald 1994). These criteria for freshwater reservoirs are shown in Table 9.5.

Table 9.4 Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems (MacDonald et al 2000)

Substance	Consensus-Based TEC	Consensus-Based PEC
Metals (in mg/kg dry weight)		
Arsenic	9.79	33.0
Cadmium	0.99	4.98
Chromium	43.4	111
Copper	31.6	149
Lead	35.8	128
Mercury	0.18	1.06
Nickel	22.7	48.6
Zinc	121	459
Semivolatile organics(in ug/kg dry weight)		
Fluoranthene	423	2230
Pyrene	195	1520
Total PAHs	1,610	22,800
Polychlorinated biphenyls (in ug/kg dry weight)		
Total PCBs	59.8	676
Organochlorine pesticides (in ug/kg dry weight)		
Chlordane	3.24	17.6
Dieldrin	1.90	61.8
Sum DDD	4.88	28.0
Sum DDE	3.16	31.3
Sum DDT	4.16	62.9
Total DDTs	5.28	572
Endrin	2.22	207
Heptachlor epoxide	2.47	16.0
Lindane (gamma-BHC)	2.37	4.99

Table 9.5 Screening Levels for Organic Substances in Sediment (from TNRCC 2001, Table 20)

Substance	Probable Effect Level	85th Percentile for Reservoirs
Metals (in mg/kg dry weight)		
Arsenic	17.0	32.7
Cadmium	3.53	0.73
Chromium	90.0	51.3
Copper	197.0	26.8
Lead	91.3	34.8
Mercury	0.486	0.169
Nickel	35.9	33.5
Silver		0.87
Zinc	315.0	143.0
Semi-volatile organics(in ug/kg dry weight)		
Bis (2-ethylhexyl)phthalate		2400.0
3,4-benzofluoranthene	782.0	2400.0
Flouranthene	2355.0	2400.0
Pyrene	875.0	2400.0
Oil and Grease		7180.0
Polychlorinated biphenyls (in ug/kg dry weight)		
Total PCBs	277.0	234.5
Organochlorine pesticides (in ug/kg dry weight)		
Aldrin		34.05
Chlordane	8.9	172.5
Dieldrin	6.67	26.68
Sum DDD		35.9
Sum DDE		35.9
Sum DDT		34.75
Diazinon		160.5

9.3 Results

Sediment sampling typically focuses on toxins that are sequestered in the sedimentary environment. Additional parameters are analyzed (although parameter groups are study specific) and the data are available in the COA database. Support parameters are almost always analyzed and are used for interpretation of the data. These parameters describe the sediment matrix sampled and factors that affect the adsorption of toxins such as percentage moisture, grain size distribution, Acid Volatile Sulfide (AVS) content, and TOC. Other parameters such as nutrients may also be examined. For this report, however, the focus will be on the toxins identified. These parameters have been grouped by characteristics: the pesticides, metals and other organics including polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). The results for the primary group of toxic constituents are described below for both historic and recent sediment sampling.

9.3.1 Metals

Many metals are found as elements in rock minerals and in natural waters. Copper, nickel, and zinc are fairly common due to their abundance in crustal rocks. Though naturally occurring, many of these metals exhibit harmful environmental impacts on plants, invertebrates, and fish at high concentrations. Selected metals were sampled that are associated with anthropogenic sources and considered to be at levels that may be frequently detected or of concern. Each is described in the following section.

9.3.1.1 Anthropogenic Sources

Discussed below are anthropogenic sources of various metals that may cause elevated levels over natural background levels (Hem 1985).

Aluminum metal is light in weight and silvery-white in appearance. The most familiar forms of aluminum are in beverage cans, pots and pans, airplanes, siding, roofing, and foil. Aluminum compounds are used in many diverse and important industrial applications such as alums in water-treatment and alumina in abrasives and furnace linings. Aluminum compounds are found in consumer products such as antacids, astringents, buffered aspirin, food additives, and antiperspirants. Powdered aluminum metal is often used in explosives and fireworks. High levels in the environment can be caused by the mining and processing of its ores and by the production of aluminum metal, alloys, and compounds. Small amounts of aluminum are released into the environment from coal-fired power plants and incinerators. Aluminum particles released from power plants and other combustion processes are usually attached to very small particles. Aluminum contained in wind-borne soil is generally found in larger particles. These particles settle to the ground or are washed out of the air by rain. Aluminum that is attached to very small particles may stay in the air for many days. Most aluminum will ultimately end up in the soil or sediment.

Arsenic has been used as a component of pesticides and thus may enter streams through waste disposal or agricultural drainage. An important factor in the natural circulation of arsenic is the volatility of the element and some of its compounds.

Cadmium and zinc have some similarities, but cadmium is much less abundant. Cadmium is used for electroplating, for pigments, as a stabilizer for PVC plastic, in batteries, and in fluorescent and video tubes. Cadmium has a tendency to enter the atmosphere through vaporization at high temperatures. Cadmium may therefore be liberated to the environment in metallurgical processes and in the combustion of fossil fuel.

Copper may be dissolved from water pipes and plumbing fixtures. Copper salts are sometimes used to suppress the growth of algae in water supply reservoirs and ponds.

Chromium occurs naturally in the earth's crust. It is a metal used mainly for making steel and other alloys. Chromium compounds are used for chrome plating, manufacture of dyes and pigments, leather tanning, and wood preserving. Smaller amounts are used in drilling muds, rust and corrosion inhibitors, textiles, and toner for copy machines. Chromium is also used in cooling waters, fungicides, and in cement. Although many of the industrial sources are not present in Austin, other potential sources are present, including the wearing down of asbestos brake linings from automobiles, exhaust emission from automotive catalytic converters, and emissions from cooling towers that use chromium compounds as rust inhibitors.

Lead has been used in various forms since pre-Roman times but has been most extensively dispersed during the mid 20th century by the burning of leaded motor fuel. Regulation of automobile exhaust emissions in the Unites States substantially decreased this source of lead aerosols during the 1970s and 1980s. Large amounts also are released in the smelting of ores and burning of coal and lead has a long history of use in water pipes.

Mercury was recognized as an environmental pollutant of potential significance during the late 1960s and 1970s, and steps were taken to curtail uses that had allowed it to enter natural water and sediments. Organomercuric compounds were widely used as biocides for treatment of seed grain and in various other applications until these uses were banned in the 1960s. Various cultural uses of mercury and its release into the atmosphere in smelting and fossil-fuel combustion have probably raised the general background level of this element in the environment substantially above its pre-industrial status. Even though the element is rare, it may be widely dispersed due to a natural tendency to volatilize.

Nickel, combined with other elements, is natural in the earth's crust. Most nickel is used to make stainless steel. Nickel is released into the atmosphere by oil- and coal-burning power plants. Nickel oxide has been identified in residual fuel oil and in atmospheric emissions from nickel refineries.

Silver is a rare element that occurs naturally in ores. Important sources of atmospheric silver from human activities include the processing of ores, steel reining, cement manufacture, fossil fuel combustion, municipal waste incineration, and cloud seeding. The major source of release to surface waters is effluent from photographic processing. Sewage treatment plants and urban runoff are additional sources to surface waters.

Zinc is fairly common due to its natural and anthropogenic sources, but it tends to be substantially more soluble than the metals listed above. Zinc is widely used in metallurgy, as a constituent of brass and bronze, and for galvanizing. It is also used extensively as a white pigment in paint and rubber. These applications tend to disperse the element widely into the environment, and its availability for solution in water has been greatly enhanced by modern industrial civilization. A study by Robert Pitt et al (1996) indicated that roof runoff had the highest concentrations of zinc, and that zinc was the exception for metals by being mostly associated with the dissolved sample portion.

9.3.2 Concern Status

The results for samples analyzed for metals in Town Lake sediments are displayed in Table 9.6. Although aluminum does not have available screening criteria at this time, it is included in the table.

Many samples for some metals had concentrations that exceeded at least one SQG (typically either the 85th percentile or the TEC for metals is the lowest). These metals included cadmium, copper, and lead. Levels for zinc were also high, but zinc is not as toxic at low levels as other metals (it has the highest screening levels) so only a few samples were above effects levels. Few samples exceeded the PEC and an even smaller number of samples in excess of the PEC were within the last 10 years of sampling data. For the period from 1991 to 2000, lead and cadmium in sediments would be of concern using TNRCC methodology for assessing sediment concerns (TNRCC 2000). Downstream sites had more levels of concern for lead and more metals that exceeded criteria (Figure 9.1).

Concentrations in sediments collected near creek mouths and in the tributary deltas were also examined to characterize sediments entering Town Lake. Most creeks also had high metal values. Although they had values as high as those found in the lake, overall Town Lake sites had more levels exceeding effects levels (Figure 9.2).

Table 9.6 Metals in Town Lake Sediments

	ARSENIC	CADMIUM*	CHROMIUM	COPPER*	LEAD*	MERCURY	NICKEL*	SILVER	ZINC*
	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG
Consensus-Based Sediment Quality Guidelins									
TEC	9.79	0.99	43.4	31.6	35.8	0.18	22.7		121
PEC	33.0	4.98	111	149	128	1.06	48.6		459
TNRCC Screening Criteria for Freshwater Reservoirs (TNRCC 2002)									
PEL	17.0	3.53	90.0	197.0	91.3	0.486	35.9		315.0
85th percentile	32.7	0.73	51.3	26.8	34.8	0.169	33.5	0.87	143.0
Town Lake @ Red Bud Isle (EC)									
1-Feb-88	6.7	< 2.30	17.0	. .	65.7	< 0.260	. .	< 2.30	. .
1-Jul-88	2.9	< 1.09	9.2	. .	42.0	< 0.560	. .	< 1.09	. .
14-May-92	. .	. .	3.5	< 2.5	43.1	. .	. .	. .	47
19-May-94	1.2	4.60	< 12.0	. .	13.7	< 0.900	. .	. .	32
30-Jun-98	< 3.0	3.16	13.7	10.6	16.1	< 0.185	9.4	< 0.60	45
14-Sep-00	7.4	<J 0.14	4.3	6.6	19.1	< 0.270	6.8	<J 0.20	410
Town Lake @ Mopac Bridge									
1-Mar-81	5.8	4.10	. .	19.0	120.0	0.780	. .	. .	75
1-Mar-81	12.50	0.08	. .	17.0	49.0	0.050	. .	. .	69
1-Mar-81	17.40	3.70	. .	21.0	136.0	1.300	. .	. .	101
23-Aug-90	6.8	< 1.00	19.0	14.0	46.0	0.102	15.0	< 1.00	75
28-Sep-90	4.0	6.00	11.3	8.8	< 1.0	0.010	10.3	< 1.00	33
28-Feb-91	7.0	2.00	6.0	10.0	40.0	0.030	. .	. .	50
5-Aug-92	16.00	2.00	8.0	10.0	60.0	0.040	. .	. .	50
15-Jun-93	5.0	2.00	20.0	10.0	100.0	0.050	. .	. .	80
19-May-94	6.0	7.00	< 17.0	. .	25.0	< 1.200	. .	. .	80
11-Aug-94	6.0	2.00	9.0	20.0	50.0	0.020	. .	. .	70
30-Jun-98	< 3.0	2.27	8.2	6.5	12.3	< 0.100	6.8	< 0.60	32
14-Sep-00	6.0	0.18	5.5	9.9	13.4	< 0.244	. 9.8	<J 0.18	49
Town Lake @ Lamar (DC)									
28-Feb-91	6.0	5.00	6.0	20.0	50.0	0.040	. .	. .	40
5-Aug-92	10.0	3.00	5.0	9.0	70.0	0.030	. .	. .	30
15-Jun-93	7.0	2.00	2.0	3.0	20.0	0.030	. .	. .	20
11-Aug-94	4.0	2.00	3.0	6.0	60.0	0.020	. .	. .	30
18-Jul-95	6.0	2.00	5.0	6.0	60.0	0.040	. .	. .	30
6-Aug-96	7.0	< 1.00	2.0	19.0	70.0	0.050	. .	. .	48
20-Aug-97	4.4	1.40	15.0	17.0	101.0	0.040	. .	. .	74
19-May-98	5.0	1.00	3.0	12.0	55.0	0.070			343
13-Oct-99	2.9	0.22	6.1	12.5	30.9	0.024			31
5-Jul-00	1.8	0.20	6.3	13.6	71.7	0.027			46
Town Lake @ 1st St (CC)									
1-Mar-81	0.4	1.90	. .	26.0	123.0	0.370	. .	. .	101
1-Mar-81	5.1	3.20	. .	24.0	158.0	0.180	. .	. .	100
1-Mar-81	11.8	0.90	. .	27.0	109.0	0.350	. .	. .	117
26-Jan-89	5.0	3.00	10.0	26.0	70.0	0.130	. .	. .	110
27-Feb-89	3.0	< 10.00	20.0	30.0	< 100.0	0.160	. .	. .	150
12-Apr-89	16.0	2.00	10.0	26.0	70.0	0.120	. .	. .	100
14-Apr-89	9.0	3.00	9.0	46.0	50.0	0.220	. .	. .	170
5-May-89	6.0	2.00	20.0	30.0	70.0	0.110	. .	. .	120
21-Aug-89	10.0	< 10.00	20.0	30.0	40.0	0.090	. .	. .	120
30-Oct-89	6.0	2.00	20.0	25.0	60.0	0.090	. .	. .	110
1-Feb-90	8.0	< 1.00	9.0	20.0	20.0	0.100	. .	. .	100
7-Mar-90	6.0	2.00	8.0	30.0	80.0	0.100	. .	. .	110
14-Mar-90	16.0	2.00	20.0	35.0	90.0	0.100	. .	. .	130
17-Aug-90	9.0	3.00	10.0	32.0	120.0	0.120	. .	. .	110
9-Oct-90	9.0	4.00	< 10.0	35.0	120.0	0.400	. .	. .	110
28-Feb-91	8.0	4.00	9.0	20.0	80.0	0.060	. .	. .	80
5-Aug-92	15.0	3.00	5.0	10.0	60.0	0.060	. .	. .	70
15-Jun-93	8.0	2.00	8.0	20.0	70.0	0.050	. .	. .	130
11-Aug-94	10.0	2.00	5.0	20.0	70.0	0.030	. .	. .	100
18-Jul-95	8.0	2.00	8.0	10.0	70.0	0.120	. .	. .	110
6-Aug-96	8.0	1.00	5.0	25.0	70.0	0.040	. .	. .	140
20-Aug-97	4.7	2.00	10.0	24.0	98.0	0.070	. .	. .	69
19-May-98	7.0	2.00	5.0	17.0	62.0	0.060			288
13-Oct-99	4.4	0.41	7.9	16.7		0.038			77
5-Jul-00	3.7	0.52	10.3	27.5	69.3	0.059			120

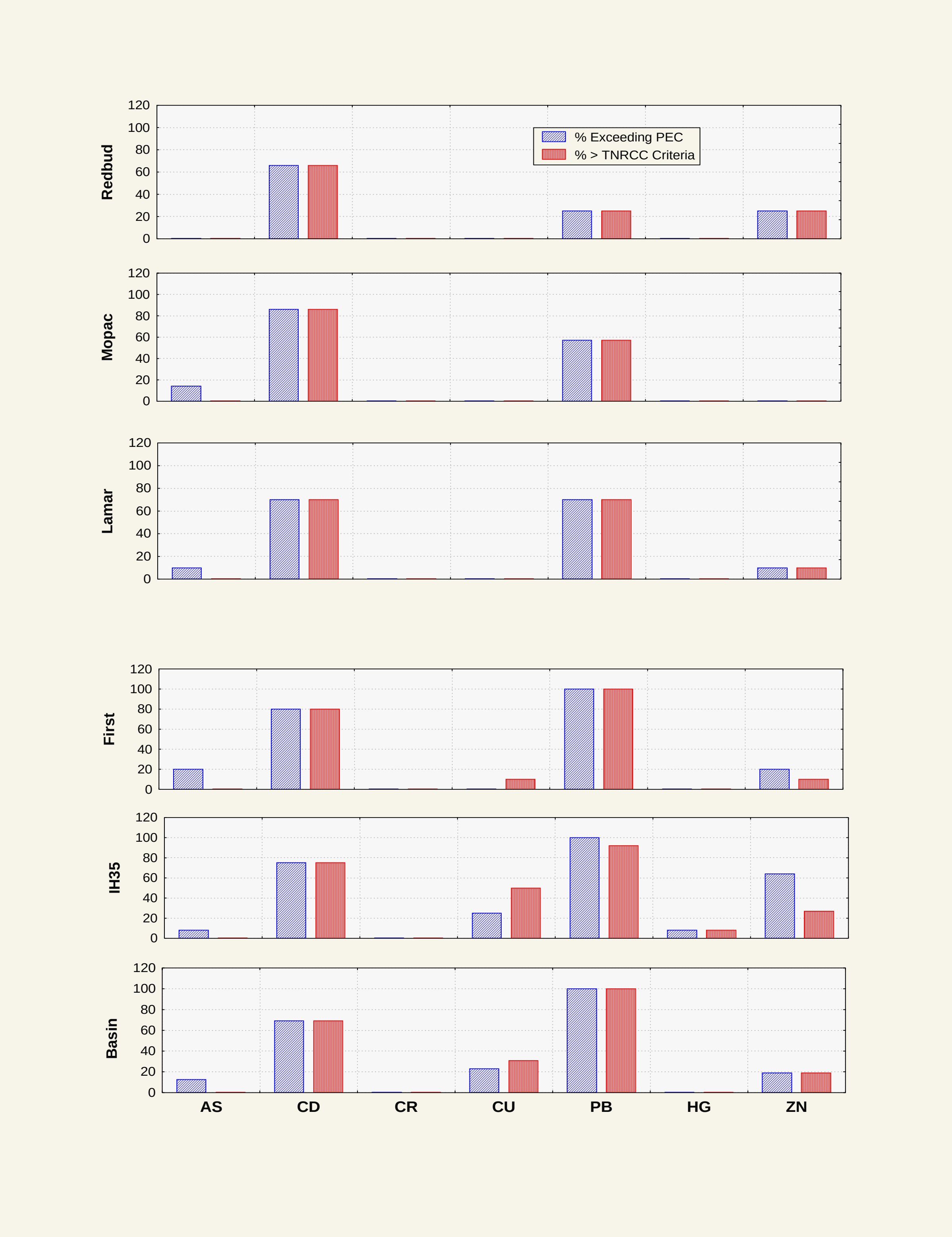
Table 9.6 Metals (cont.)

	ARSENIC	CADMIUM*	CHROMIUM	COPPER*	LEAD*	MERCURY	NICKEL*	SILVER	ZINC*
	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG
Consensus-Based Sediment Quality Guidelins									
TEC	**9.79**	**0.99**	**43.4**	**31.6**	**35.8**	**0.18**	**22.7**		**121**
PEC	**33.0**	**4.98**	**111**	**149**	**128**	**1.06**	**48.6**		**459**
TNRCC Screening Criteria for Freshwater Reservoirs (TNRCC 2002)									
PEL	**17.0**	**3.53**	**90.0**	**197.0**	**91.3**	**0.486**	**35.9**		**315.0**
85th percentile	**32.7**	**0.73**	**51.3**	**26.8**	**34.8**	**0.169**	**33.5**	**0.87**	**143.0**
Town Lake @ Congress Avenue Bridge									
1-Feb-88	4.0	< 0.90	15.9	. .	48.2	. .	. .	< 0.90	. .
1-Jul-88	2.4	< 0.72	11.6	. .	43.5	< 0.480	. .	< 0.72	. .
11-Aug-89	5.4	< 0.50	16.0	18.0	50.0	0.073	16.0	. .	79
6-Jun-90	7.0	1.20	18.0	24.0	74.0	0.134	14.0	< 1.00	114
23-Aug-90	4.5	0.46	17.0	21.0	65.0	0.100	13.0	< 1.00	98
28-Sep-90	8.2	7.50	15.4	25.3	70.1	0.030	16.7	< 1.00	113
14-May-92	. .	. .	15.5	20.5	88.5	.	. .	. .	79
14-May-92	15.0	3.00	6.0	14.0	80.0	0.080	. .	. .	47
18-May-94	4.8	0.60	30.8	. .	49.9	< 0.900	. .	. .	94
Town Lake @ IH35 (BC)									
6-Jun-90	5.9	0.94	25.0	24.0	89.0	0.182	15.0	< 1.00	124
23-Aug-90	3.2	0.64	27.0	26.0	80.0	0.124	17.0	< 1.00	128
28-Sep-90	6.9	8.10	23.6	28.5	89.3	0.090	126.0	< 1.00	< 1
28-Feb-91	7.0	3.00	10.0	30.0	120.0	0.080	. .	. .	140
5-Aug-92	11.0	3.00	10.0	20.0	130.0	0.090	. .	. .	80
15-Jun-93	7.0	2.00	10.0	20.0	80.0	0.080	. .	. .	120
18-May-94	< 7.0	0.50	34.0	. .	96.0	< 1.300	. .	. .	153
23-Jun-94	1.1	1.36	20.2	35.6	67.8	< 0.500	14.5	0.23	. .
11-Aug-94	6.0	2.00	10.0	30.0	170.0	0.140	. .	. .	120
18-Jul-95	6.0	2.00	10.0	20.0	100.0	0.090	. .	. .	130
6-Aug-96	6.0	2.00	3.0	39.0	90.0	0.090	. .	. .	190
20-Aug-97	4.7	2.00	21.0	28.0	102.0	0.060	. .	. .	155
19-May-98	5.0	1.00	7.0	15.0	118.0	0.320			243
13-Oct-99	3.3	0.34	4.2	12.9	40.2	0.046			60
5-Jul-00	3.1	0.54	10.5	36.9	71.2	0.067			132
Town Lake @ Basin (AC)									
1-Mar-81	11.3	3.30	. .	36.0	148.0	0.080	. .	. .	111
1-Mar-81	10.3	2.60	. .	35.0	150.0	1.500	. .	. .	107
1-Mar-81	9.7	3.10	. .	50.0	183.0	0.120	. .	. .	143
1-May-82	. .	. .	. .	. .	91.0	. .	. .	. .	13
18-Mar-87	10.0	2.00	20.0	30.0	100.0	0.150	. .	. .	80
26-May-87	8.0	3.00	110.0	38.0	100.0	1.300	. .	. .	100
10-Aug-87	8.0	2.00	330.0	16.0	70.0	0.710	. .	. .	70
19-Jan-88	5.0	2.00	<B 10.0	10.0	60.0	< 0.100	. .	. .	50
1-Feb-88	1.0	< 0.60	2.1	.	3.5	< 0.070	. .	< 0.60	. .
19-Apr-88	9.0	2.00	10.0	18.0	20.0	< 0.100	. .	. .	60
1-Jul-88	1.3	< 0.66	3.0	.	7.6	< 0.450	. .	< 0.66	. .
27-Jul-88	1.0	2.00	10.0	20.0	60.0	< 0.010	. .	. .	80
11-Aug-89	4.4	< 0.40	15.0	22.0	57.0	0.120	16.0	. .	65
6-Jun-90	6.0	0.51	19.0	25.0	106.0	0.272	13.0	< 1.00	89
23-Aug-90	3.8	0.49	22.0	31.0	101.0	0.156	14.0	1.30	85
28-Sep-90	6.9	7.80	22.8	5.0	107.0	0.060	19.9	< 1.00	111
28-Feb-91	6.0	4.00	5.0		50.0	0.110	. .	. .	40
14-May-92	.	. .	16.5	25.9	110.5	. .	. .	. .	95
14-May-92	13.0	3.00	8.0	19.0	70.0	0.010	. .	. .	61
5-Aug-92	14.0	3.00	7.0	20.0	50.0	0.070	. .	. .	60
15-Jun-93	6.0	2.00	8.0	20.0	50.0	0.060	. .	. .	70
18-May-94	6.9	0.40	27.4	. .	57.3	< 1.100	. .	. .	81
18-May-94	< 6.3	0.50	41.9	. .	64.4	< 1.300	. .	. .	83
18-May-94	< 6.1	< 0.20	< 0.5	. .	64.2	< 1.200	. .	. .	91
23-Jun-94	1.1	1.36	20.2	35.6	67.8	< 0.500	14.5	0.23	. .
11-Aug-94	7.0	2.00	6.0	20.0	70.0	0.040	. .	. .	80
18-Jul-95	5.0	2.00	7.0	10.0	60.0	0.060	. .	. .	50

Table 9.6 Metals (cont.)

Consensus-Based Sediment Quality Guidelins									
TEC	**9.79**	**0.99**	**43.4**	**31.6**	**35.8**	**0.18**	**22.7**		**121**
PEC	**33.0**	**4.98**	**111**	**149**	**128**	**1.06**	**48.6**		**459**
TNRCC Screening Criteria for Freshwater Reservoirs (TNRCC 2002)									
PEL	**17.0**	**3.53**	**90.0**	**197.0**	**91.3**	**0.486**	**35.9**		**315.0**
85th percentile	**32.7**	**0.73**	**51.3**	**26.8**	**34.8**	**0.169**	**33.5**	**0.87**	**143.0**
Town Lake @ Basin (AC)									
18-Jul-95	5.0	2.00	7.0	10.0	60.0	0.060	. .	. .	50
10-Jul-96	< 3.5	2.04	23.6	80.8	70.2	< 0.080	22.9	< 0.70	159
6-Aug-96	5.0	3.00	2.0	48.0	120.0	0.060	. .	. .	230
20-Aug-97	5.1	1.80	15.0	24.0	62.0	0.050	. .	. .	87
19-May-98	6.0	1.00	4.0	18.0	57.0	0.070			523
13-Oct-99	3.9	0.40	7.4	< 2.0	43.0	0.049			62
5-Jul-00	3.4	0.05	9.6	31.2	57.8	0.064			89

Figure 9.1 Percentage of Sediment Concentrations Over Sediment Quality Guidelines



9.3.3 Spatial Patterns

Some metals showed a fairly strong spatial pattern through the lake. Data from 1991 to 2000 for Town Lake mainstem sites and tributary mouths are shown in Figure 9.2 for selected metals. These data are displayed from upstream to downstream. In the graphs, the medians at only the mainstem sites are displayed with a heavy dash mark illustrating the changes through the lake. The data from the mouth sites illustrate the types of sediment being introduced from the tributaries. The sites are designated as mainstem with the “TL” prefix (Town Lake) or creek sites with no medians displayed. Figure 9.3 displays a schematic of the position of these sites relative to each other.

Nickel and silver had insufficient data to examine spatial distribution. Additionally, mercury was not examined spatially, as detected mercury concentrations were primarily below 0.1 mg/Kg while detection limits (more than 40 percent of the data were below detection levels) were greater than 0.1 mg/Kg.

Zinc demonstrates the most marked spatial patterns. The median concentration was low at MoPac, increased and First Street and Congress, reached a maximum at IH-35 and then dropped slightly at the Basin. The highest concentrations for all metals are generally found at First Street, Congress, or IH-35. The Basin concentrations generally remain high but drop below those at First/Congress and IH-35, perhaps due to more erosive sediments at larger quantities of sediments found at the Basin. Other metals, particularly those with more data reported below detection limits such as mercury and cadmium, did not demonstrate spatial variability.

Generally, the median values in the mainstem of the lake were higher than those at the creek mouths with some elevated values seen, primarily at the Waller Creek mouth. This may simply be due to the movement of a greater portion of fine sediments to the receiving water body, or it may indicate unmonitored sources such as the areas along Town Lake that drain directly into the lake without entering a creek system. One large area between the mouths of Shoal and Waller creeks encompasses the heart of downtown for several city blocks on either side of Congress Avenue, extending up to the State Capitol. This area enters the storm sewer system and drains directly into the lake. Inputs from this area could account for the increases seen in some constituents at First Street and Congress bridges and at IH-35. These inputs could be similar to some of the elevated values seen in sediments from the Waller Creek mouth, for example, for lead and zinc. Sediment captured in water quality control structures, discussed below, also demonstrate levels that may be transported to the lake during storm events.

Aluminum demonstrated an atypical pattern, with a few measurements from creek mouth sediment that were higher than those found in the lake. Aluminum and cadmium also showed higher medians at Red Bud, near the head of the lake, with limited data. Aluminum, cadmium, and chromium did not, therefore, show the same spatial patterns as other metals, although they did have the typical increase in medians from Lamar to IH-35. Overall, sediment metals reflect the input of pollutants with urban creek sediments along the lake.

Through various projects, sediment captured in structural controls such as ponds have also been intermittently sampled and analyzed. These data provide some information on the source and runoff characteristics for toxins. Although sediments from several control structures around the City have been analyzed for metals, relative few samples were available at each site. Figures 9.4 through 9.9 display the median concentrations of selected metals in sediments sampled since the Town Lake Report (1991-2000). The data were restricted primarily to sites that had at least three measurements during the last 10 years.

Figure 9.2 Sediment Metal Concentrations by Site

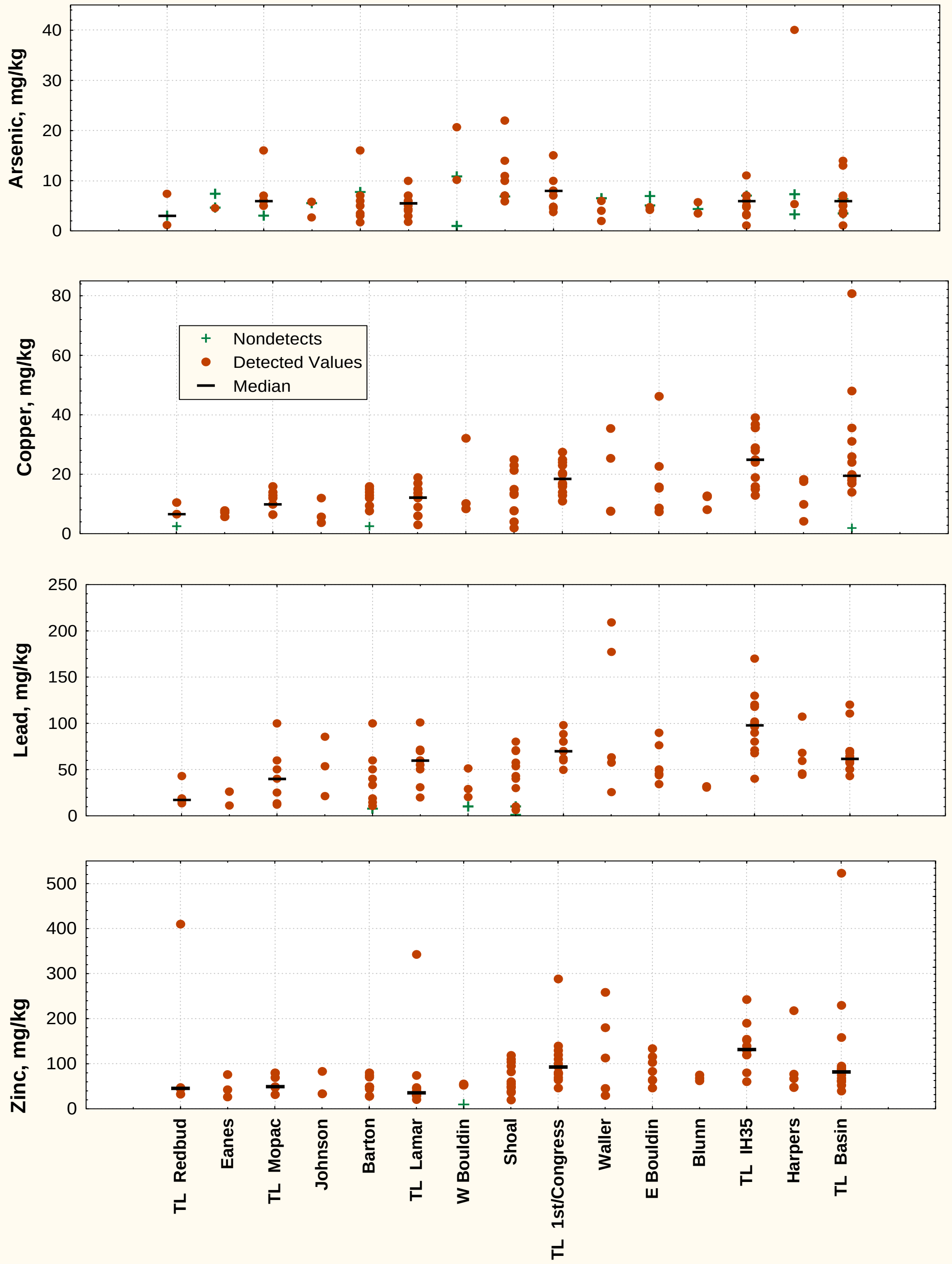
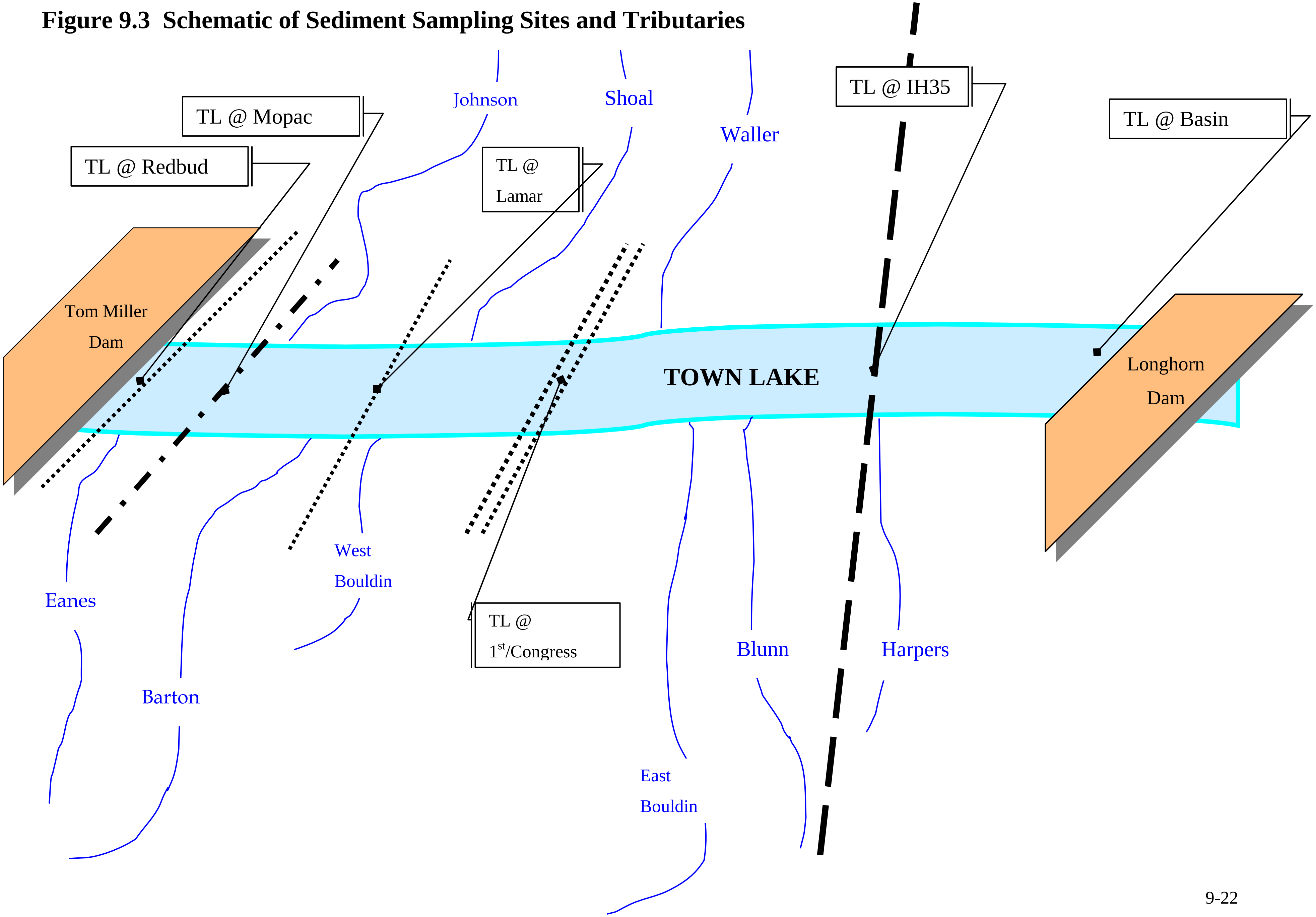
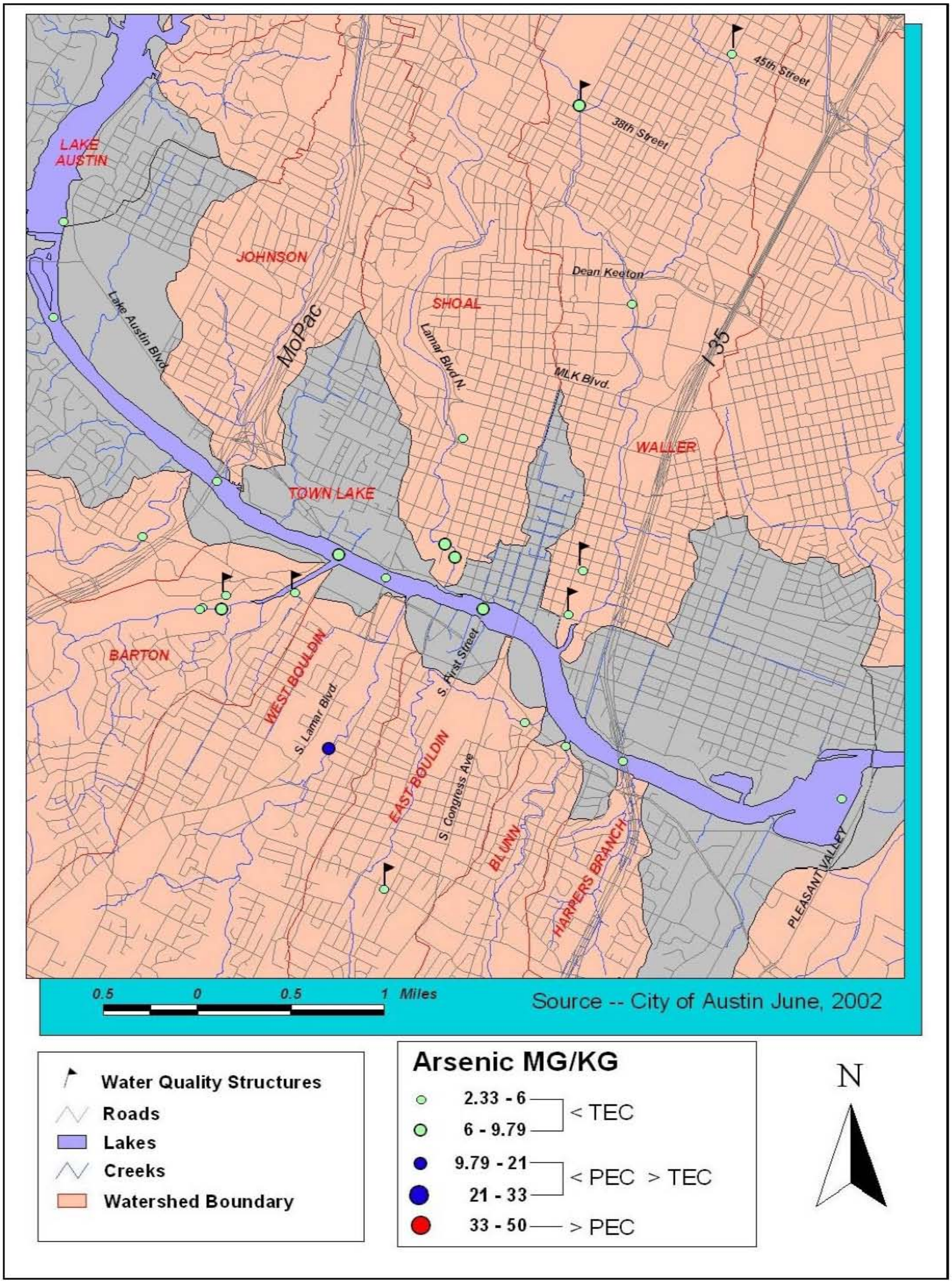


Figure 9.3 Schematic of Sediment Sampling Sites and Tributaries



As expected, the sediments from structural water quality controls generally had higher values than were seen in either the creeks or the lake. Sediments from some control structures had median cadmium, copper, lead, and zinc levels exceeding PECs. Sediments captured by the controls tested are primarily from upland runoff, while creek and lake sediments contain a large component contributed from erosion of relatively clean bank sediments. Levels in the creeks themselves vary widely, but usually within the range of lake sediments. This may reflect the contribution of erosive sediment or indicate that fine-grained sediments are transported to the lake rather than settling in the creeks. The high values in the captured sediments indicate both that pollutants are still contained in runoff from our urban areas, and that the water quality controls are effectively capturing them. The City, however, has many areas that were constructed before controls were required or where, within the urban watersheds, developers may select to pay a fee rather than construct on-site controls.

Figure 9.4 Median Arsenic in Sediment (1991–2000)



Source -- City of Austin June, 2002

Figure 9.5 Median Cadmium in Sediment (1991—2000)

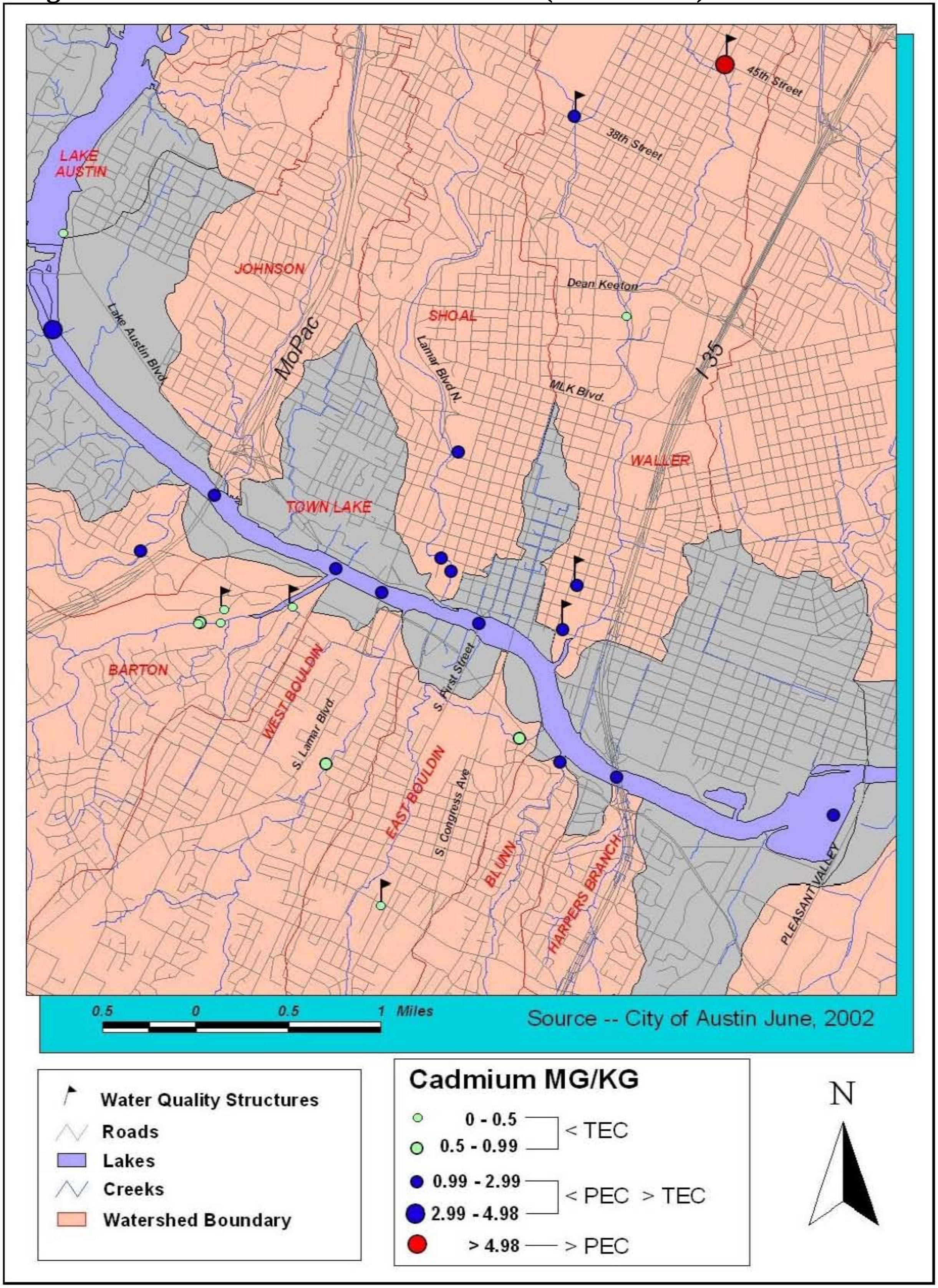
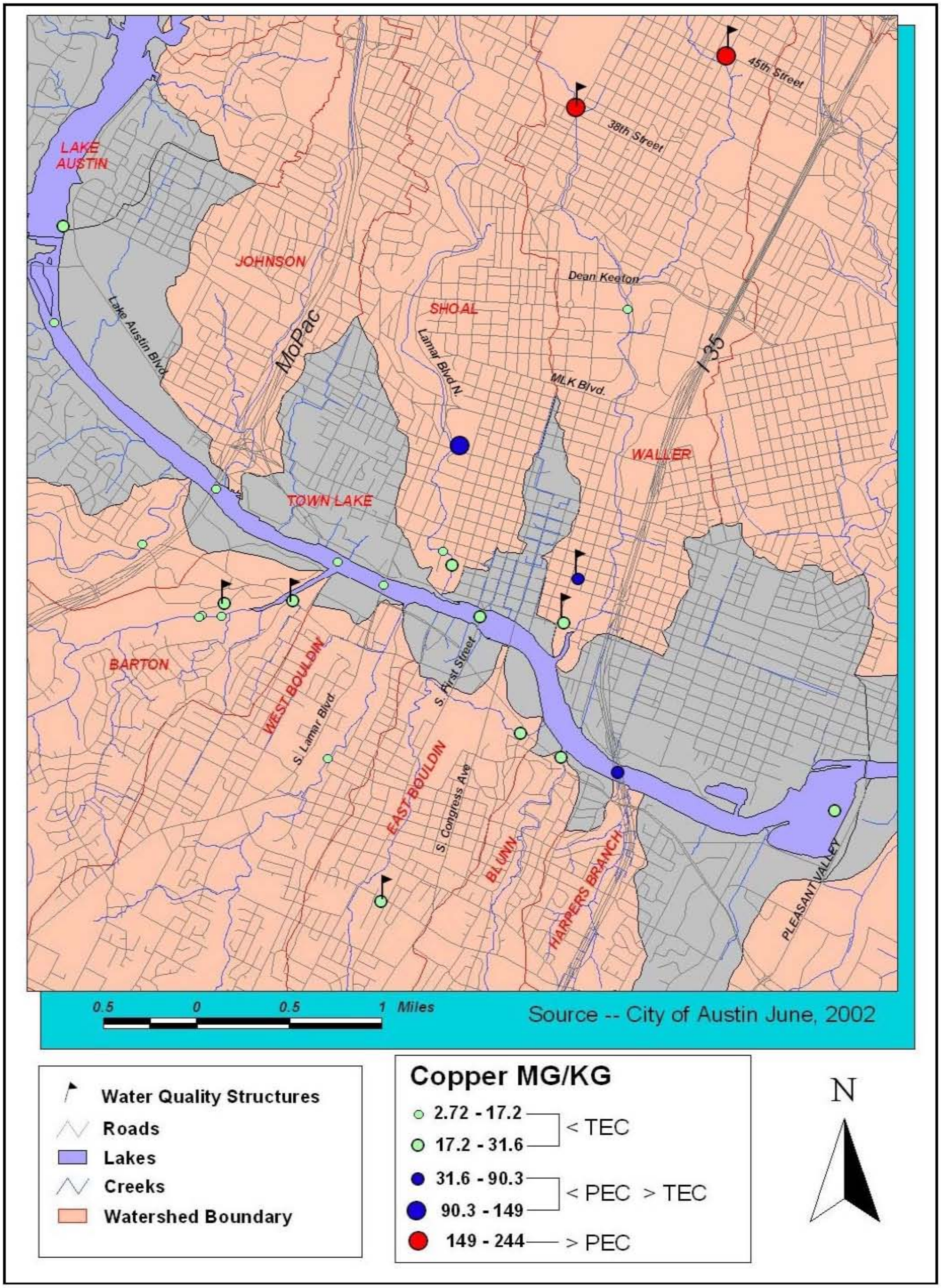
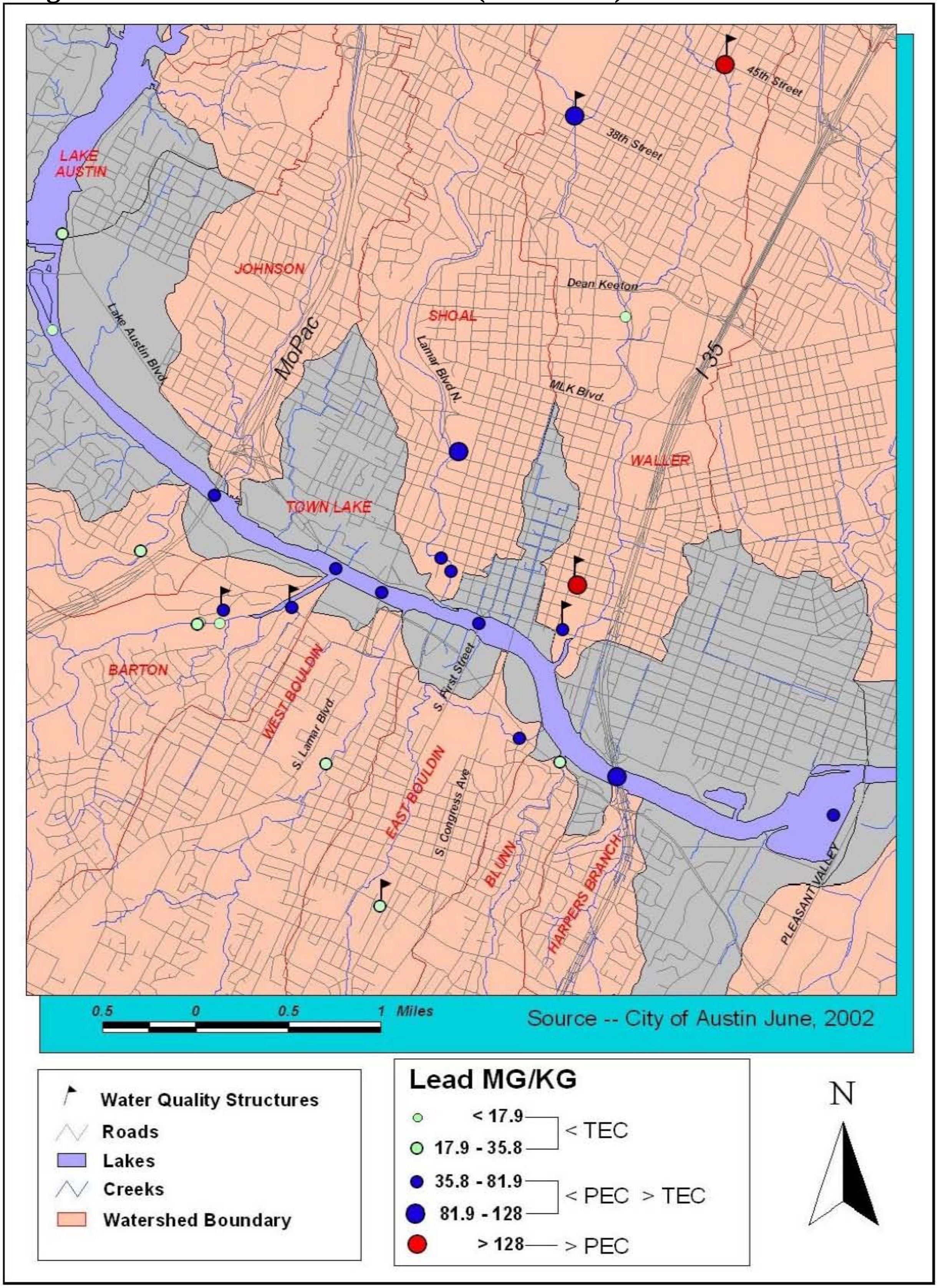


Figure 9.6 Median Copper in Sediment (1991–2000)



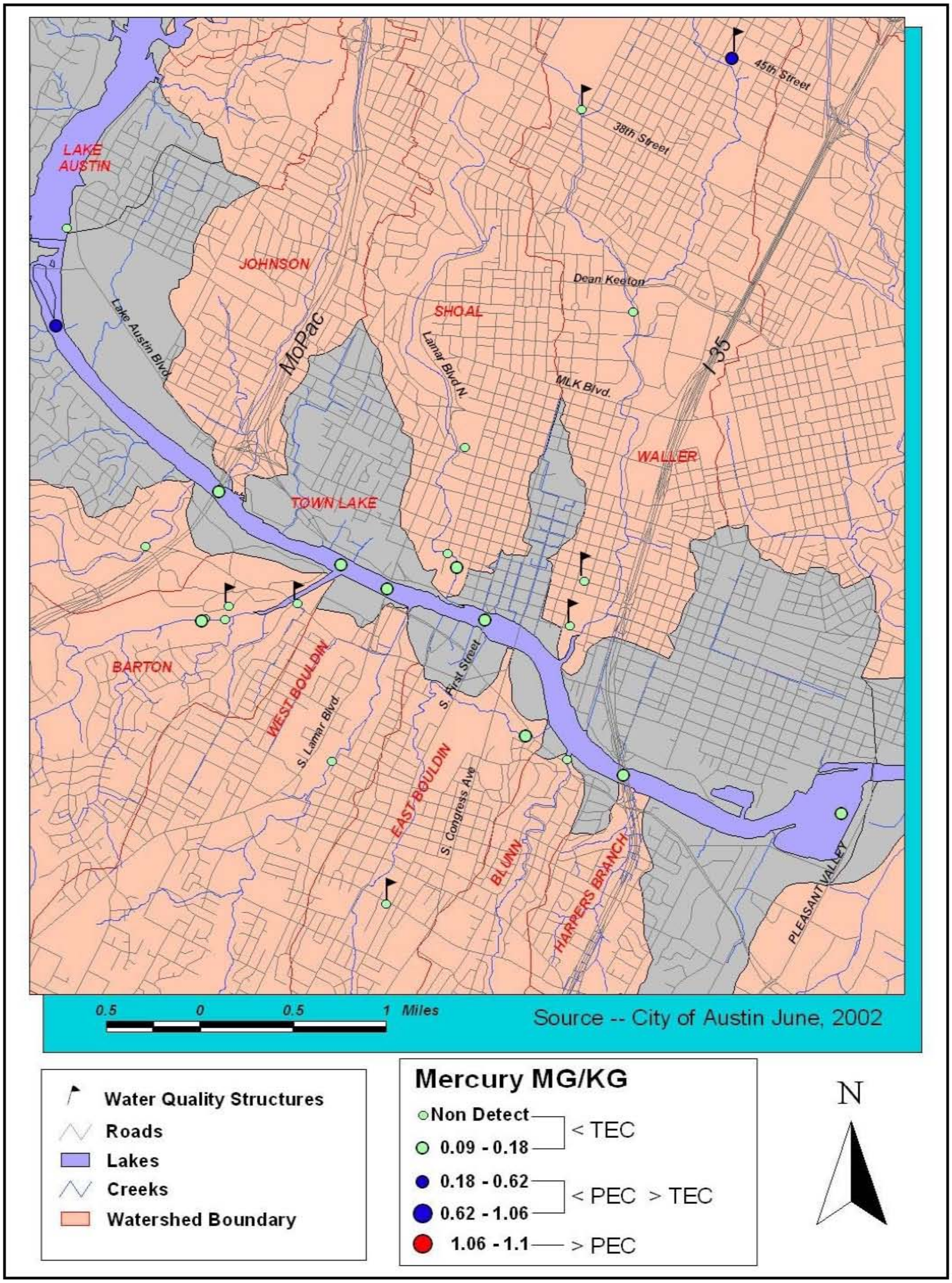
Source -- City of Austin June, 2002

Figure 9.7 Median Lead in Sediment (1991–2000)



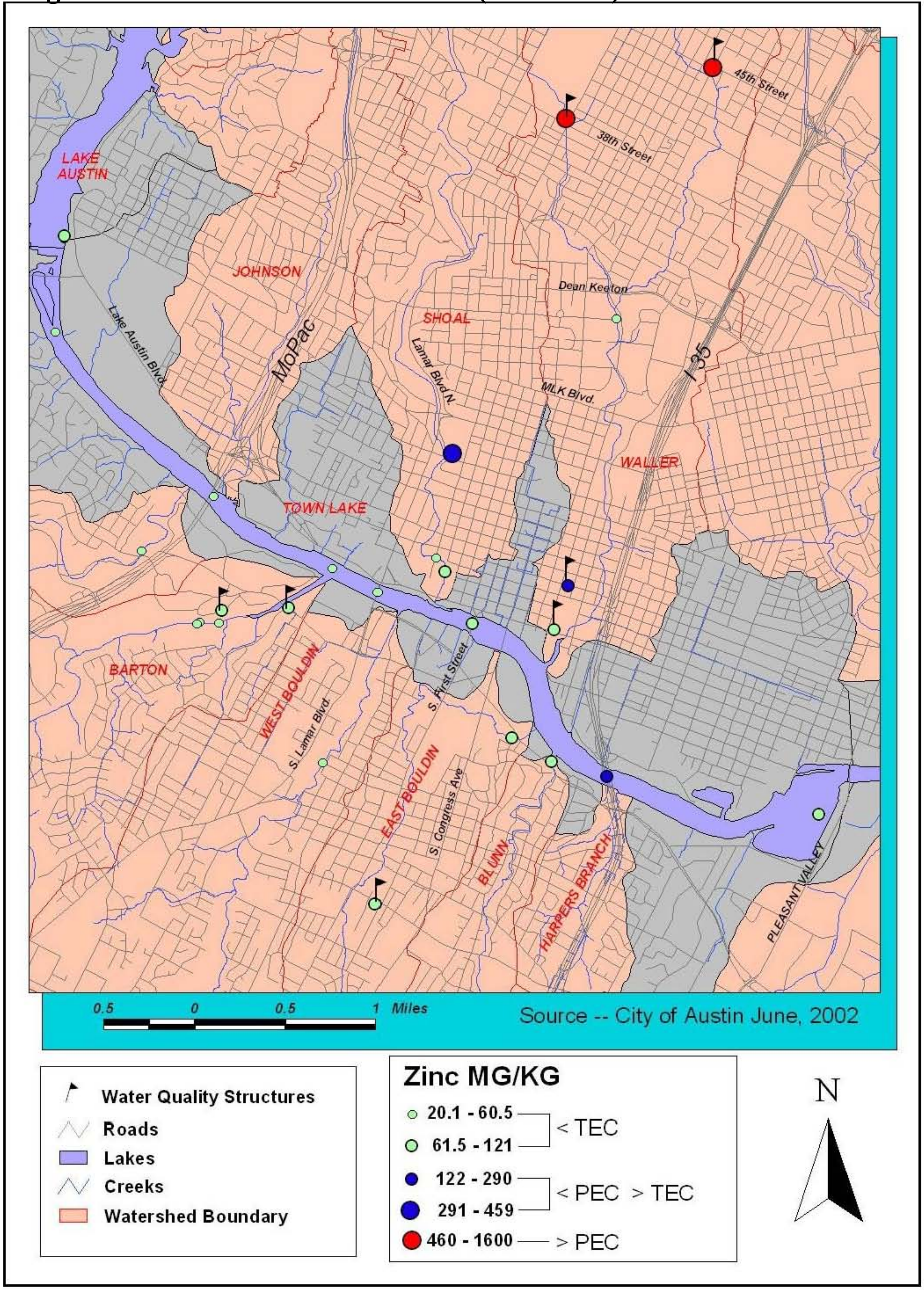
Source -- City of Austin June, 2002

Figure 9.8 Median Mercury in Sediment (1991–2000)



Source -- City of Austin June, 2002

Figure 9.9 Median Zinc in Sediment (1991-2000)



Source -- City of Austin June, 2002

City-wide plots show lower median concentrations in Lake Austin sediments than in Town Lake, indicating that the urban watersheds are the primary contributors of these pollutants. Although spatial patterns and trends were discussed above, phenomena within the lake itself are not well documented. The lake sediments are also impacted by severe flood events that may re-suspend and flush recent sediments downstream, while exposing older sediments.

9.3.4 Temporal Changes

Metals in Town Lake sediments were examined for trends over time. Most metals demonstrated a slight decreasing trend in sediment concentrations over the period of record. Table 9.7 presents a summary of metals with significant linear trends with time. For the first analyses of concentrations and ranks of concentrations, all dates and sites were combined into one data set. Ranked concentrations were examined because for many parameters, the assumptions of normally distributed residuals of a linear regression were better than for the raw data. Where the assumptions were good, they generally supported the results found with the ranked data. Most of the metals demonstrated significant decreasing trends with both raw and ranked data.

Additional data analyses included trend analyses for the period 1991 to 2000 (examined to look for trends during a period with more consistent sampling and lab methods), and trend analyses using data only from the most downstream site, the Basin, where sediment deposition is the most consistent. Arsenic and cadmium, however, were the only metals that showed trends with the smaller data sets. A decreasing trend was observed for both metals within only the last 10 years of data and only when the data were restricted to concentrations at the Basin. Fluxes in individual metals occurred during the period of record, but the elevated years differed for different constituents, precluding the examination of temporal events such as flooding to explain those fluxes.

Finally, results for aluminum and zinc were inconsistent with the other metals, with both yielding some indications of increases over time. Aluminum showed this increase for both the full data set and the last 10 years, but not at the Basin. Zinc showed an increasing trend only for the last 10 years of data.

Table 9.7 Significant, Decreasing Linear Trends with Time

Metal	***Trend in Concentrations***	***Trend in Rank of Concentrations***	***Sig. during 1991-2000***	***Sig. at Basin only***
Decreasing Trends				
Arsenic	**S**	**S**	**S**	**S**
Cadmium	*S*	**S**	**S**	ranked data only
Chromium	*S*	**S**	-	-
Copper	**S**	**S**	-	-
Lead	**S**	**S**	-	-
Mercury	*S*	**S**	-	-
Increasing Trends				
Aluminum	**-**	**S**	-	-
Zinc	*S*	-	**S**	**S**

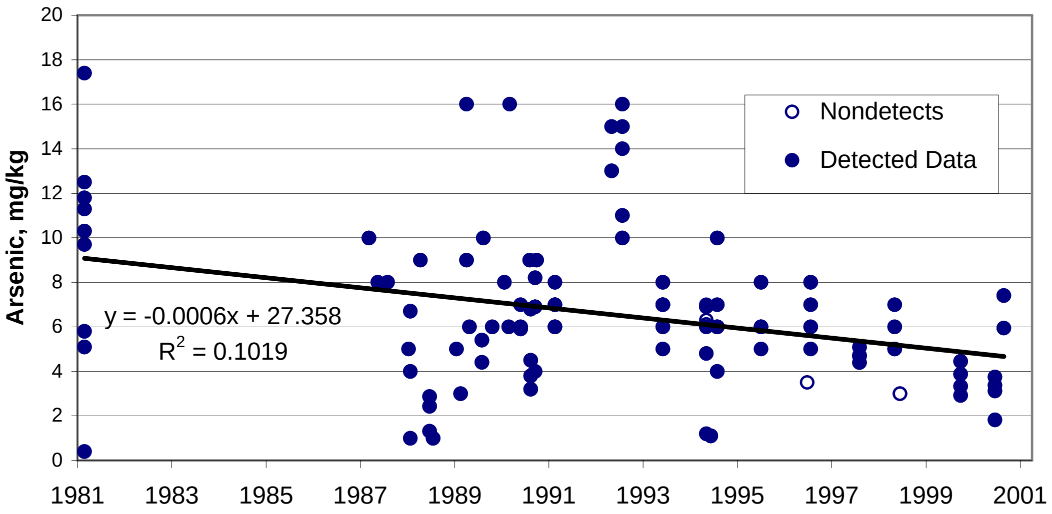
S - significant decreasing linear trend

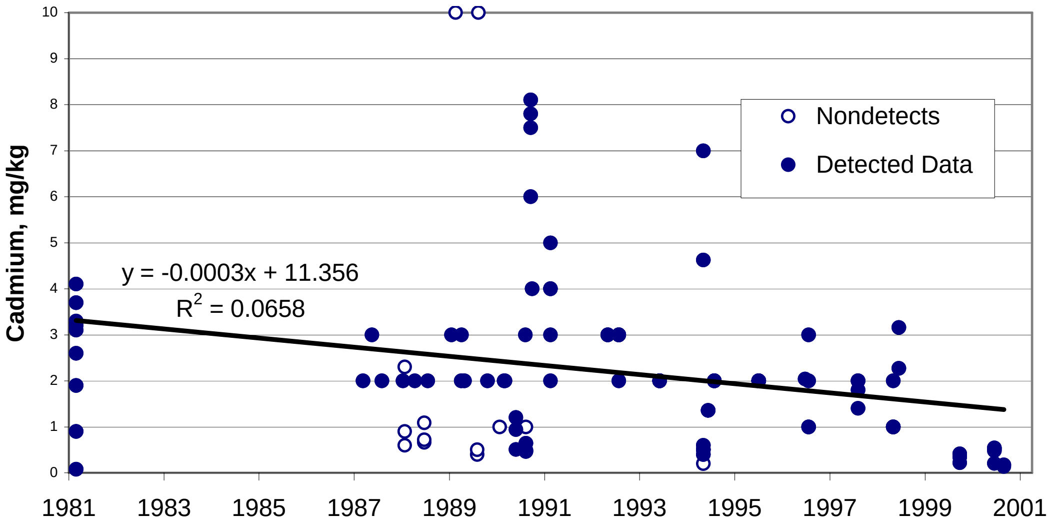
S **–** significant decreasing trend but residuals did not have a normal distribution

- indicates no statistically significant trend over time

The figures for each metal in the section below will show the concentrations (rather than the ranks) and the linear regression line if the regression was significant. Arsenic and cadmium (Figure 9.10) both show significant decreasing trends for all the data combined and for the Basin alone. Although the trends are significant, the r^2 values are low, indicating much variation in the data due to other factors. This is expected in sediment data as the amount of fine particles and organic material alone may determine to some extent the amount of metals sequestered. In addition to the difficulty in replicating exact site and depths for grab samples obtained in a lake, strong flows redistribute sediment periodically along the bottom of the lake.

Figure 9.10 Arsenic and Cadmium for All Town Lake Sites





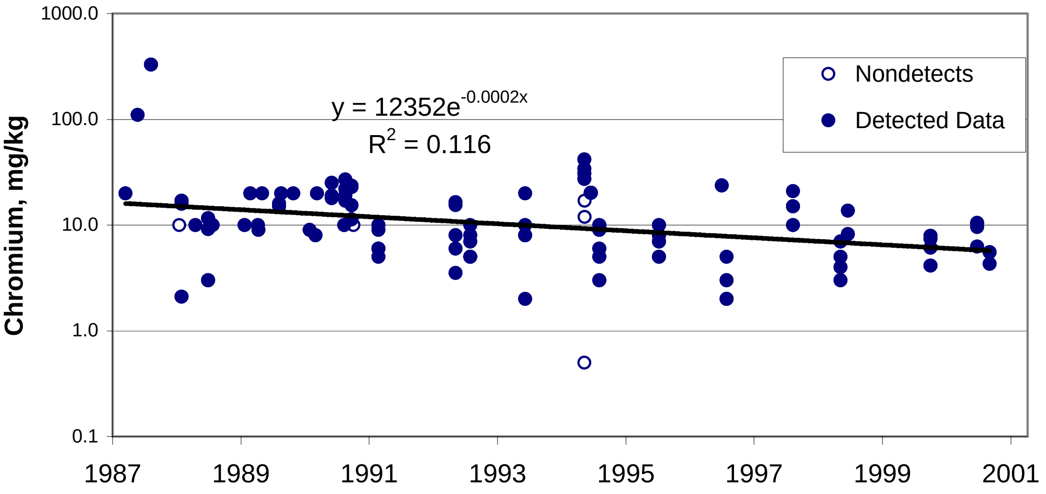
Arsenic and cadmium showed decreasing trends for the period 1991 to 2000. Table 9.8 below shows the change in sediment concentrations over the period of record for each parameter and for the period 1991 to 2000, derived from the regression lines. The rate of change for arsenic and cadmium was higher over the last 10 years than over the period of record. Nonlinear regressions, however, had lower r^2 values and the rate of change seems to be driven by high values in the early 1990s.

Table 9.8 Slope of Significant Trends with Time

Metal	**Period of Data Record**	***For entire period of record (14-20 years)***	***Recent 10-year period (1991-2000)***
		Size of increase or decrease in mg/kg (**Annual** percent change)	
Decreasing Trends			
Arsenic	1981 - 2000	-4.38 (-2.3%)	-5.84 (-5.6%)
Cadmium	1981 - 2000	-2.19 (-4.4%)	-2.92 (-17.8%)
Chromium	1987 - 2000	-13.74 (-4.6%)	-
Copper	1981 - 2000	-10.23 (-1.8%)	-
Lead	1981 - 2000	-37.98 (-2.1%)	-
Mercury	1981 - 2000	-0.37 (-6.1%)	-
Increasing Trends			
Zinc	1981 - 2000	74.5 (6.4%)	104.45 (17.9%)

Other metals showing decreases over time included chromium, copper, lead, and mercury (Figures 9.11 and 9.12). All of these metals showed significant decreasing trends. However, none had significant trends for the last 10 years of data. This could indicate that insufficient data were available for the 10-year period with the high variability to find the trend significant or that a more rapid decrease in earlier years occurred followed by a period with little change. Chromium seems to demonstrate this pattern as a nonlinear fit (shown on a log scale in Figure 9.11) has a higher r^2 than a linear regression. The other metals, however, do not demonstrate this pattern as nonlinear regressions provided poorer fits.

Figure 9.11 Chromium and Copper for All Town Lake Sites



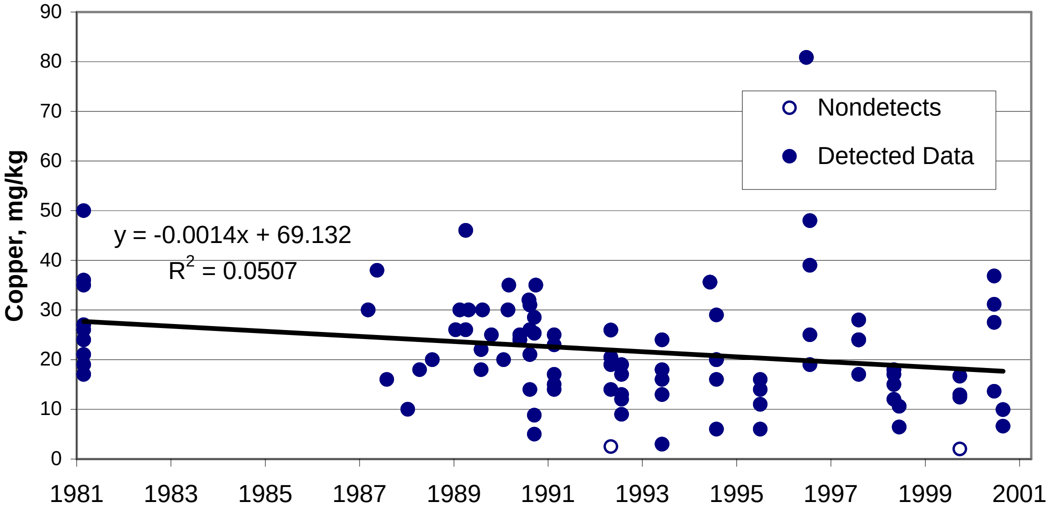
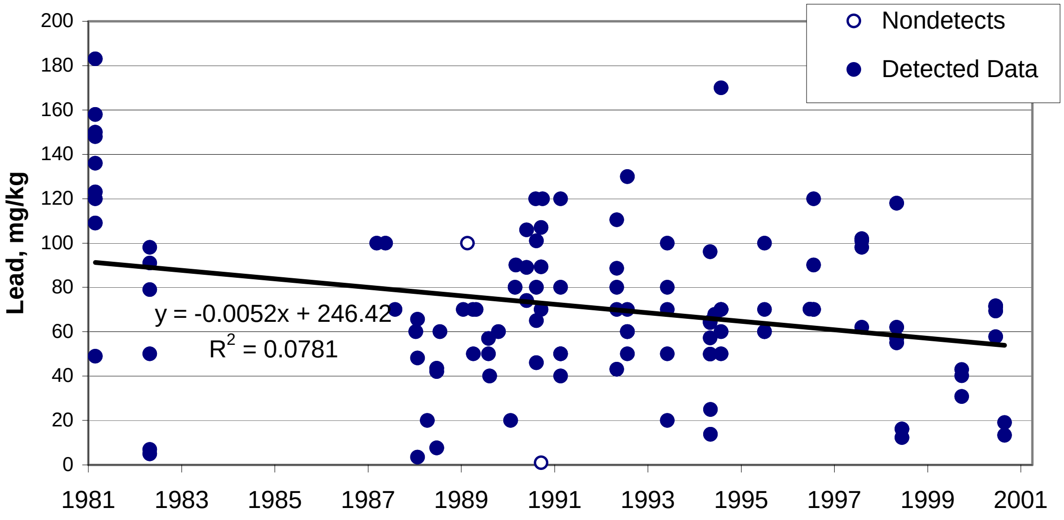
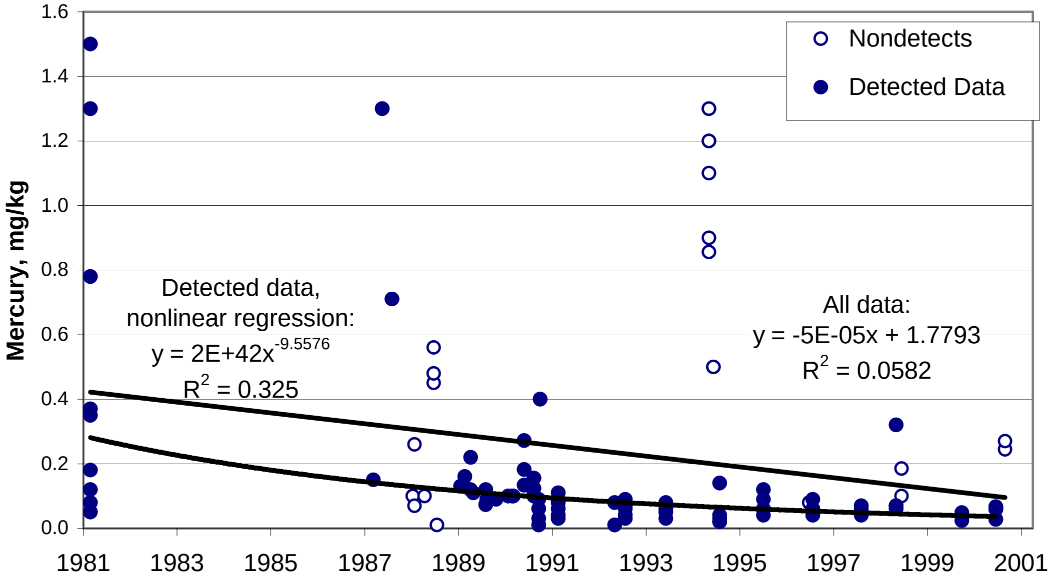


Figure 9.12 Lead and Mercury for All Town Lake Sites





Mercury showed the strongest trend within the detected data (with a nonlinear regression, r^2=0.325, Figure 9.12), primarily because the only values above 0.4 mg/L were in earlier years (1981 and 1987).

A decrease over time in metal concentrations in receiving water bodies might be expected due to new laws governing discharge and controls for non-point source pollution. At the same time, however, the population of Austin has increased from approximately 349,513 in 1981 to 656,562 in 2000, an 88 percent increase in 20 years (Figure 9.13). As the population increases, the load of pollutants to Town Lake associated with increased traffic volumes would be expected to increase. The water quality controls implemented by COA may have prevented or captured some of this increased pollutant load. Additionally, the change to unleaded gasoline may not be accounted for completely.

The net result of these changes in the watersheds and loads to Town Lake might be only slight trends as seen in the data. The impacts from these combined factors are not easy to predict and management measures may be able to offset only some of the pollutant-loading increases as urbanization continues.

To examine whether increases related to population growth may be obscuring other trends, metal concentrations normalized to population over the time could be examined. With the slight declining trends already demonstrated and the dramatic increase in population, only improved relationships would be expected to be found. Therefore, only those metals, zinc and aluminum, without significant trends and with some indication of an increase, were examined. With the normalization (Figure 9.14), any increasing trends were no longer significant. For these two metals, then, any increase may be a result of an increase in sources that are increasing in a similar manner through time such as population, traffic, and impervious cover.

Figure 9.13 Population Changes in Austin and Surrounding Area

(COA Demographer, Department of Planning, COA, January 2000)

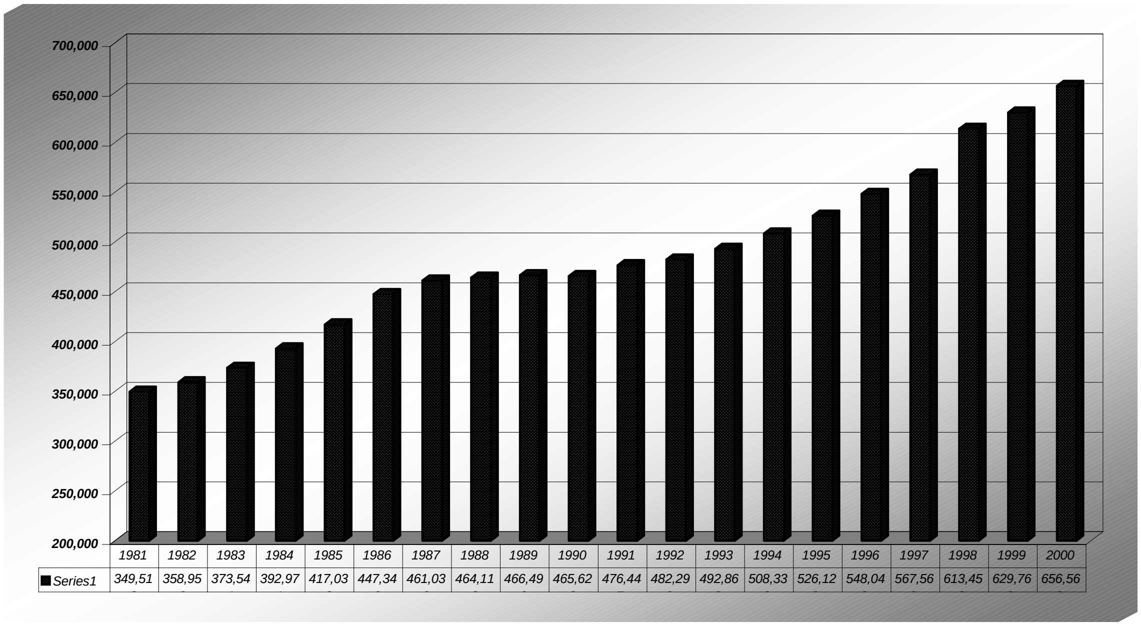
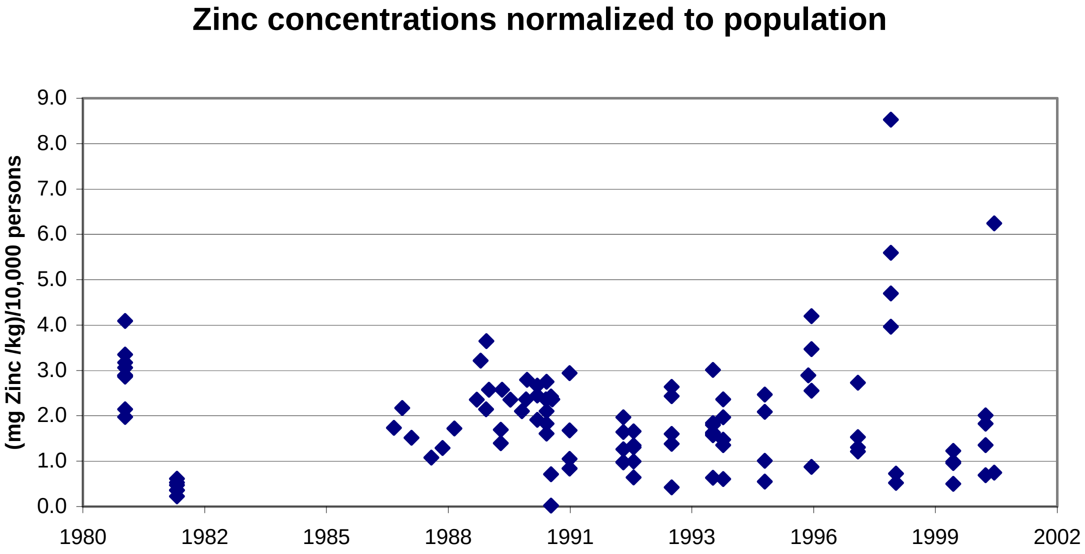
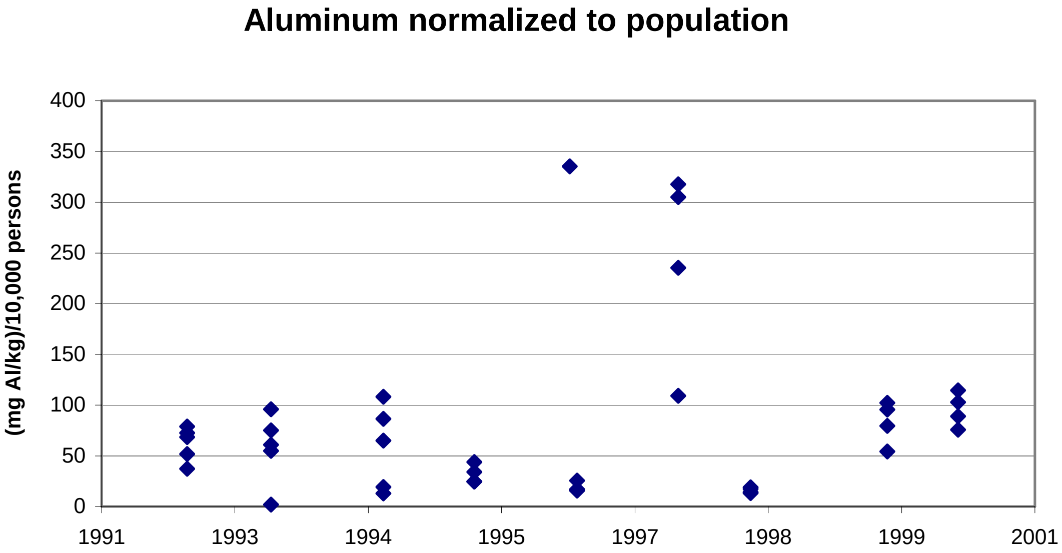


Figure 9.14 Zinc and Aluminum Concentrations Normalized to Population in 10,000 Persons





In general, an overall decrease for most metals over 20 years is demonstrated. For many of these metals, the very elevated data in the 1980s, followed by a gap in data, may tend to drive observed trends. This decrease may reflect the removal of older sediments deposited before advent of many source controls such as use of unleaded gasoline and control of used oil disposal. Continued tracking of these parameters at fewer sites will demonstrate if decreasing trends continue. In addition, the rates of decrease are encouraging and, if continued, would drop the levels of metals below levels of concern in 10 to 20 years.

9.3.5 Pesticides

Concentration data for pesticides in sediments consisted primarily of data for the chlorinated hydrocarbon pesticides, including chlordane and DDT (Table 9.9). Limited testing was done for organo-phosphorus pesticides, but these were rarely found above detection limits, probably due to their faster degradation rates.

9.3.5.1 Anthropogenic Sources

Chlorinated pesticides were used for various pest-control purposes. Although most of these products have been restricted, the more persistent ones will be discussed below. Following restrictions on chlorinated pesticides, organo-phosphorus pesticides became more widely used as they were believed to be less persistent.

Chlordane was widely used in the U.S. prior to 1983 for control of pests on vegetables, fruits, lawns, and roadsides. It was applied directly to soil or foliage to control a wide variety of insect pests including nematodes, termites, cutworms, and chiggers. After July 1, 1983, the only approved use for chlordane in the U.S. was for underground termite control. As of April 14, 1988, all commercial use of chlordane in the U.S. has been cancelled, but is still permitted for fire ant control in power transformers. Chlordane has been detected in most environmental media, and one study of soil samples around 30 houses treated with chlordane showed that mean reside levels ranged from 22 to 2,540 ppm (Delaplane and LaFarge 1990). If released into water, chlordane is very persistent in the adsorbed state. When organo-chlorine pesticides were detected in Town Lake sediments, they almost invariably exceeded effects levels. This is true in part because they have a high toxicity with very low effects levels frequently below detection limits available at the laboratories.

DDT is another chlorinated hydrocarbon pesticide widely used before being banned in the U.S. in 1972. During the period when DDT was widely used, large portions were released into the air from agricultural or vector-control applications. DDD and DDE were impurities in DDT formed during the breakdown of DDT. DDT and DDD breakdown products preferentially bind to soil and sediment and persist for long periods of time. DDE persists even longer.

Dieldrin is another of the persistent organo-chlorine pesticides found in many media in most nationwide programs (Nowell et al 1999). Dieldrin may come from introduction of either aldrin, or dieldrin as aldrin, which is rapidly metabolized to dieldrin. From 1950 to 1970, aldrin and dieldrin were popular pesticides for crops such as corn and cotton. Because of concerns about damage to the environment and the potential harm to human health, EPA banned all uses of aldrin and dieldrin in 1974 except to control termites. In 1987, EPA banned all uses.

Diazinon is the common name of an organo-phosphorus insecticide that has been used to control pest insects in soil, on ornamental plants, and on fruit and vegetable field crops. It has also been used to control household pests such as flies, fleas, and cockroaches. This chemical is manufactured and does not occur naturally in the environment. Diazinon was one of the three organo-phosphorus pesticides most frequently detected and at highest concentrations in USGS National Ambient Water Quality Assessment (NAWQA) program (USGS 2000). In 2000, EPA announced an agreement to phase out diazinon for indoor uses beginning in March 2001, and for all lawn, garden, and turf uses by December 2003.

Table 9.9 Town Lake Sediment Pesticide Concentrations and SQGs

SITE and SAMPLING DATE	ALDRIN	CHLORDANE or TECHNICAL CHLORDANE (ALL ISOMERS)	DDD	DDE	DDT	Total DDTs	DIAZINON	DIELDRIN
.	UG/KG	UG/KG	UG/KG	UG/KG	UG/KG	UG/KG	UG/KG	UG/KG
Consensus-Based Sediment Quality Guidelins								
TEC		**3.24**	**4.88**	**3.16**	**4.16**	**5.28**		**1.9**
PEC		**17.6**	**28.0**	**31.3**	**62.9**	**572**		**61.8**
TNRCC Screening Criteria for Freshwater Reservoirs (TNRCC 2000)								
PEL		**8.9**			**4450**			
85th percentile	**34.05**	**172.5**	**35.9**	**35.9**	**34.75**		**160.5**	**26.68**
Town Lake @ Red Bud Isle (EC)								
1-Feb-88	. .	. .	. .	24.0	. .	24.0	. .	. .
1-Jul-88	. .	. .	. 52.0	411.0	. 150.0	613.0	. .	. .
14-May-92	< 253	< 1000.0	< 253.0	< 253.0	< 253.0		. .	< 253.0
14-May-92	. .	. 32.0	< 7.0	20.0	. 12.0	32.0	. .	. .
19-May-94	< 46	< 161.0	< 127.0	< 46.0	< 137.0		< 1712.0	< 22.0
30-Jun-98							< 289.5	
14-Sep-00	< 13.5	< 135.0	< 13.5	< 13.5	< 13.5			< 135.0
Town Lake @ Mopac Bridge								
1-Mar-81	. .	. .	. 5.0	24.0	. 5.0	34.0	. 100.0	. .
1-Mar-81	. .	. .	. 96.0	91.0	. 124.0	311.0	. 100.0	. .
1-Mar-81	. .	. .	. 97.0	92.0	. 92.0	281.0	. 100.0	. .
15-May-90	< 1	< 6.0	< 6.0	< 3.0	< 6.0		< 5.0	< 2.0
23-Aug-90	< 1	< 6.0	< 6.0	< 3.0	< 6.0		< 5.0	< 2.0
28-Sep-90	< 27	< 93.0	< 73.0	< 26.0	< 80.0		< 400.0	< 13.0
28-Feb-91	. .	. 28.0	. 9.0	11.0	. 15.0	35.0	. .	. 28.0
28-Feb-91	< 1	18.0	5.8	12.0	5.6	23.4	. .	1.8
5-Aug-92	. 3	. 125.0	. 66.0	97.0	. 9.0	172.0	. .	. .
5-Aug-92	< 0.1	71.0	46.0	79.0	17.0	142.0	. .	0.7
15-Jun-93	< 0.1	140.0	69.0	100.0	9.9	178.9	. .	4.3
19-May-94	< 65	< 226.0	< 178.0	< 65.0	< 192.0		< 2404.0	< 31.0
11-Aug-94	< 0.2	12.0	7.0	10.0	4.0	21.0	. .	6.2
30-Jun-98							< 190.3	< 190.3
14-Sep-00	< 12.2	< 122.0	< 12.2	< 12.2	< 12.2		. .	< 12.2
Town Lake @ Lamar (DC)								
28-Feb-91	. 8	. 40.0	. 12.0	26.0	. 18.0	56.0	. .	. 4.0
28-Feb-91	< 10	32.0	8.8	19.0	3.4	31.2	. .	2.0
5-Aug-92	. .	. 30.0	. .	19.0	. 23.0	42.0	. .	. .
5-Aug-92	< 0.1	22.0	< 0.1	11.0	41.0	52.0	. .	0.1
15-Jun-93	< 0.1	19.0	8.1	11.0	1.3	20.4	. .	0.9
11-Aug-94	< 0.1	5.0	4.0	7.7	0.7	12.4	. .	0.5
18-Jul-95	< 0.1	16.0	6.8	13.0	2.3	22.1	. .	0.8
6-Aug-96	< 0.1	3.0	3.8	7.5	0.1	11.4	. .	< 0.2
20-Aug-97	< 0.2	18.0	7.6	21.0	1.7	30.3	. .	1.0
19-May-98	< 0.2	3.4	E 4.4	12.0	< 0.5	16.4		< 0.2
13-Oct-99	< 0.2	4.4	2.1	7.8	0.5	10.4		0.3
5-Jul-00	< 0.42	7.2	E 4.3	E 20.0	E 1.4	25.7		E 0.5
Town Lake @ 1st St (CC)								
1-Mar-81	. .	. .	. 35.0	47.0	. 43.0	125.0	. 100.0	. .
1-Mar-81	. .	. .	. 31.0	56.0	. 37.0	124.0	. 100.0	. .
1-Mar-81	. .	. .	. 45.0	71.0	. 79.0	195.0	. 100.0	. .
28-Feb-91	. .	. 94.0	. 14.0	29.0	. .	43.0	. .	. 3.0
28-Feb-91	< 1	110.0	22.0	42.0	13.0	77.0	. .	3.9
5-Aug-92	. 6	. 74.0	< 19.0	34.0	. 13.0	47.0	. .	. 5.0
5-Aug-92	0.5	100.0	12.0	31.0	1.6	44.6	. .	1.6
15-Jun-93	< 0.1	32.0	9.5	23.0	5.9	38.4	. .	2.4
11-Aug-94	< 0.3	19.0	6.8	8.9	2.0	17.7	. .	2.4
18-Jul-95	< 0.1	100.0	26.0	44.0	9.3	79.3	. .	5.1
6-Aug-96	< 0.4	34.0	6.8	12.0	1.4	20.2	. .	3.4
20-Aug-97	< 0.2	9.2	21.0	30.0	0.7	51.7	. .	0.3
19-May-98	< 0.9	92.0	E 16.0	E 37.0	E 12.0	65.0		9.6
13-Oct-99	1.1	74.0	20.0	44.0	12.0	76.0		5.6
5-Jul-00	< 0.42	41.0	E 5.6	E 37.0	E 4.8	47.4		E 3.6

Table 9.9 Town Lake Sediment Pesticide Concentrations and SQGs (cont.)

SITE and SAMPLING DATE	ALDRIN	CHLORDANE or TECHNICAL CHLORDANE (ALL ISOMERS)	DDD	DDE	DDT	Total DDTs	DIAZINON	DIELDRIN
.	UG/KG	UG/KG	UG/KG	UG/KG	UG/KG	UG/KG	UG/KG	UG/KG
Consensus-Based Sediment Quality Guidelins								
TEC		**3.24**	**4.88**	**3.16**	**4.16**	**5.28**		**1.9**
PEC		**17.6**	**28.0**	**31.3**	**62.9**	**572**		**61.8**
TNRCC Screening Criteria for Freshwater Reservoirs (TNRCC 2000)								
PEL		**8.9**			**4450**			
85th percentile	**34.05**	**172.5**	**35.9**	**35.9**	**34.75**		**160.5**	**26.68**
Town Lake @ Congress Avenue Bridge								
1-Feb-88	. .	. .	. .	31.0	. 9.0	40.0	. .	. .
1-Jul-88	. .	. 140.0	. 50.0	60.0	. 36.0	146.0	. .	. .
11-Aug-89	< 1	< 6.0	< 6.0	< 3.0	< 6.0		< 5.0	< 2.0
6-Jun-90	< 1	< 6.0	< 6.0	< 3.0	< 6.0		< 5.0	< 2.0
23-Aug-90	< 1	. 110.0	< 6.0	10.0	< 6.0	10.0	< 5.0	< 2.0
28-Sep-90	< 27	< 93.0	< 73.0	< 26.0	< 80.0		< 400.0	< 13.0
14-May-92	< 176	< 1000.0	< 176.0	< 176.0	< 176.0		. .	< 176.0
14-May-92	. .	. 26.0	< 117.0	39.0	. 6.0	45.0	. .	. .
18-May-94	< 50	< 173.0	< 136.0	< 50.0	< 147.0		< 184.0	< 24.0
Town Lake @ IH35 (BC)								
15-May-90	. .	< 6.0	< 6.0	< 3.0	< 6.0		. .	. .
6-Jun-90	< 1	< 6.0	< 6.0	< 3.0	< 6.0		< 5.0	< 2.0
23-Aug-90	< 1	. 90.0	< 6.0	50.0	< 6.0	50.0	< 5.0	< 2.0
28-Sep-90	< 2.7	< 9.3	< 7.3	< 2.6	< 8.0		< 400.0	< 1.3
28-Feb-91	. 11	. 76.0	. 24.0	64.0	. .	88.0	. .	. 4.0
28-Feb-91	< 0.1	93.0	53.0	< 40.0	38.0	91.0	. .	4.9
5-Aug-92	. 2	. 49.0	. 32.0	54.0	. 10.0	96.0	. .	. .
5-Aug-92	< 0.1	40.0	33.0	48.0	6.1	87.1	. .	0.7
15-Jun-93	< 0.1	27.0	11.0	17.0	3.8	31.8	. .	1.7
18-May-94	< 5	< 25.0	< 20.0	30.0	< 21.0	21.0	< 264.0	< 3.0
23-Jun-94	. .	. .	. .	. .	96.8	96.8	. .	< 10.0
11-Aug-94	<A 0.3	16.0	28.0	21.0	22.0	71.0	. .	0.5
18-Jul-95	<A 0.2	40.0	22.0	23.0	5.6	50.6	. .	1.9
6-Aug-96	< 0.2	16.0	7.8	14.0	1.0	22.8	. .	0.8
20-Aug-97	< 0.5	67.0	44.0	66.0	7.3	117.3	. .	4.7
19-May-98	< 0.2	30.0	E 38.0	84.0	E 3.5	125.5		0.9
13-Oct-99	0.21	36.0	78.0	124.0	28.0	230.0		2.1
5-Jul-00	< 0.42	18.0	E 4.4	E 30.0	E 3.2	37.6		< 0.2
Town Lake @ Basin (AC)								
5-Nov-80	< 0.5	23.0	76.0	89.0	28.0	193.0	< 5.0	< 2.0
1-Mar-81	. .	. .	. 35.0	46.0	. 13.0	94.0	. 100.0	. .
1-Mar-81	. .	. .	. 63.0	58.0	. 19.0	140.0	. 100.0	. .
1-Mar-81	. .	. .	. 5.0	5.0	. 5.0	15.0	. 100.0	. .
8-Aug-81	< 5	380.0	690.0	480.0	380.0	1550.0	. .	3.9
1-May-82	. .	. .	35.0	19.0	6.0	60.0	. .	. .
14-May-85	. .	. .	. .	210.1	. .	210.1	. .	. .
1-Jul-88	. .	. .	. .	2.0	. .	2.0	. .	. .
11-Aug-89	< 1	80.0	50.0	50.0	20.0	120.0	< 5.0	< 2.0
15-May-90	< 1	. 120.0	< 6.0	90.0	. .	90.0	< 5.0	< 2.0
6-Jun-90	< 1	< 6.0	< 6.0	< 3.0	< 6.0		< 5.0	< 2.0
23-Aug-90	. .	. 120.0	. 40.0	90.0	. .	130.0	. .	. .
28-Sep-90	< 2.7	< 9.3	< 7.3	< 2.6	< 8.0		< 400.0	< 1.3
28-Feb-91	. 2	. 55.0	. 18.0	45.0	. .	63.0	. .	. 2.0
28-Feb-91	< 0.1	32.0	20.0	27.0	5.1	52.1	. .	1.5
14-May-92	< 240	< 1000.0	< 240.0	< 240.0	. .		. .	< 240.0
14-May-92	< 0.1	. 32.0	< 20.0	35.0	. .	35.0	. .	. 0.5
14-May-92	. 3	. 35.0	< 22.0	37.0	. .	37.0	. .	. .
5-Aug-92	. 3	. 46.0	. 13.0	27.0	. .	40.0	. .	. .
5-Aug-92	< 0.1	35.0	15.0	25.0	0.3	40.3	. .	0.7
15-Jun-93	< 0.1	38.0	23.0	32.0	3.0	58.0	. .	1.3
18-May-94	< 6	< 20.8	< 16.4	13.0	< 18.0	13.0	< 221.0	< 2.9
18-May-94	< 6.8	< 23.6	< 18.5	12.0	< 20.0	12.0	< 251.0	< 3.3
18-May-94	< 6.5	< 22.8	< 17.9	15.3	< 19.0	15.3	< 242.0	< 3.1
23-Jun-94	. .	. .	. .	. .	. .		. .	< 10.0
29-Jun-94	< 22	< 108.0	106.0	274.0	300.0	680.0	. .	< 22.0
11-Aug-94	< 0.2	10.0	5.0	7.7	1.2	13.9	. .	0.3

Table 9.9 Town Lake Sediment Pesticide Concentrations and SQGs (cont.)

Consensus-Based Sediment Quality Guidelins								
TEC		**3.24**	**4.88**	**3.16**	**4.16**	**5.28**		**1.9**
PEC		**17.6**	**28.0**	**31.3**	**62.9**	**572**		**61.8**
TNRCC Screening Criteria for Freshwater Reservoirs (TNRCC 2000)								
PEL		**8.9**			**4450**			
85th percentile	**34.05**	**172.5**	**35.9**	**35.9**	**34.75**		**160.5**	**26.68**
18-Jul-95	< 0.2	34.0	17.0	29.0	3.7	49.7	. .	1.2
10-Jul-96	< 23.4	< 93.6	< 46.8	153.0	57.2	210.2	< 50.0	< 23.4
6-Aug-96	< 0.2	21.0	8.3	19.0	0.3	27.6	. .	1.3
20-Aug-97	< 0.3	33.0	18.0	32.0	2.5	52.5	. .	1.9
19-May-98	< 0.3	26.0	E 11.0	21.0	E 12.0	44.0		1.5
13-Oct-99	< 0.2	21.0	12.0	28.0	1.5	41.5		0.7
5-Jul-00	< 0.42	18.0	E 10.0	E 27.0	E 2.0	39.0		E 0.8

9.3.5.2 Concern Status

Most forms of DDT had some exceedances of upper screening levels, primarily for historic data. DDE, which is a breakdown product and persists longest, showed the most exceedances. Most detected chlordane values exceeded the PEL (TNRCC criteria) and the PEC. Chlordane was not detected at as many sites, perhaps because its degradation rate is somewhat faster than the degradation rates of DDT and its isomers. Fact sheets from the ARS (ARS 1999) provide a range of field dissipation half-life values for these pesticides. The half-life for chlordane ranges from 283 to 1,387 days (mean half-life of 3.3 years under field conditions (USEPA 1999), while DDT's half-lives ranges from 239 days to 15 years. In addition, DDD and DDE, each with a half-life similar to DDT, degrade to DDE. All of these isomers are included in the total DDT value.

The other chlorinated hydrocarbon pesticides occurred at lower levels. Aldrin was detected only in 1991 and 1992 at levels of 11 μg/kg and lower. Dieldrin was detected more frequently, but had only one value exceeding the 85th percentile in 1991. The TEC for many organo-chlorine compounds is close enough to the detection limits that most detected values exceed this lower threshold (Figure 9.15). As mentioned previously, limited sampling has been performed for organo-phosphorus pesticides. One of these, diazinon, is included in Table 9.9 to demonstrate the scarcity of data as well as the fact that detection limits were frequently higher than detected values for the organo-chlorine pesticides. Only in 1981 did the USGS report detected levels of diazinon; however, the constant reported value of 100 μg/kg at all sites indicates that the levels were probably at or near detection limits.

Concentrations in sediments collected near creek mouths and in the tributary deltas were also examined for pesticide concentrations to characterize sediments entering Town Lake. Some creek bed sediments also had high pesticide values and these will be discussed in the following section, but many of the sample dates had higher detection limits than for Town Lake sediments, which were sampled on different dates.

9.3.5.3 Spatial Distribution

Median values are difficult to interpret in plots of Town Lake mainstem and creek mouth sediments from upstream to downstream because of the high detection level values frequently observed. Figures 9.16a and 9.16b display pesticides in creek mouths and Town Lake, with non-detect values reported at levels above a legible scale for the graph being reduced and set to the highest value on the scale. These non-detects were frequently much higher than even the highest detected values. Again, high variability was observed in the pesticides.

Figure 9.15 Percent of Measurements Exceeding SQGs

Figure 9.16 Town Lake and Creek Mouth Sediment Pesticide Concentrations

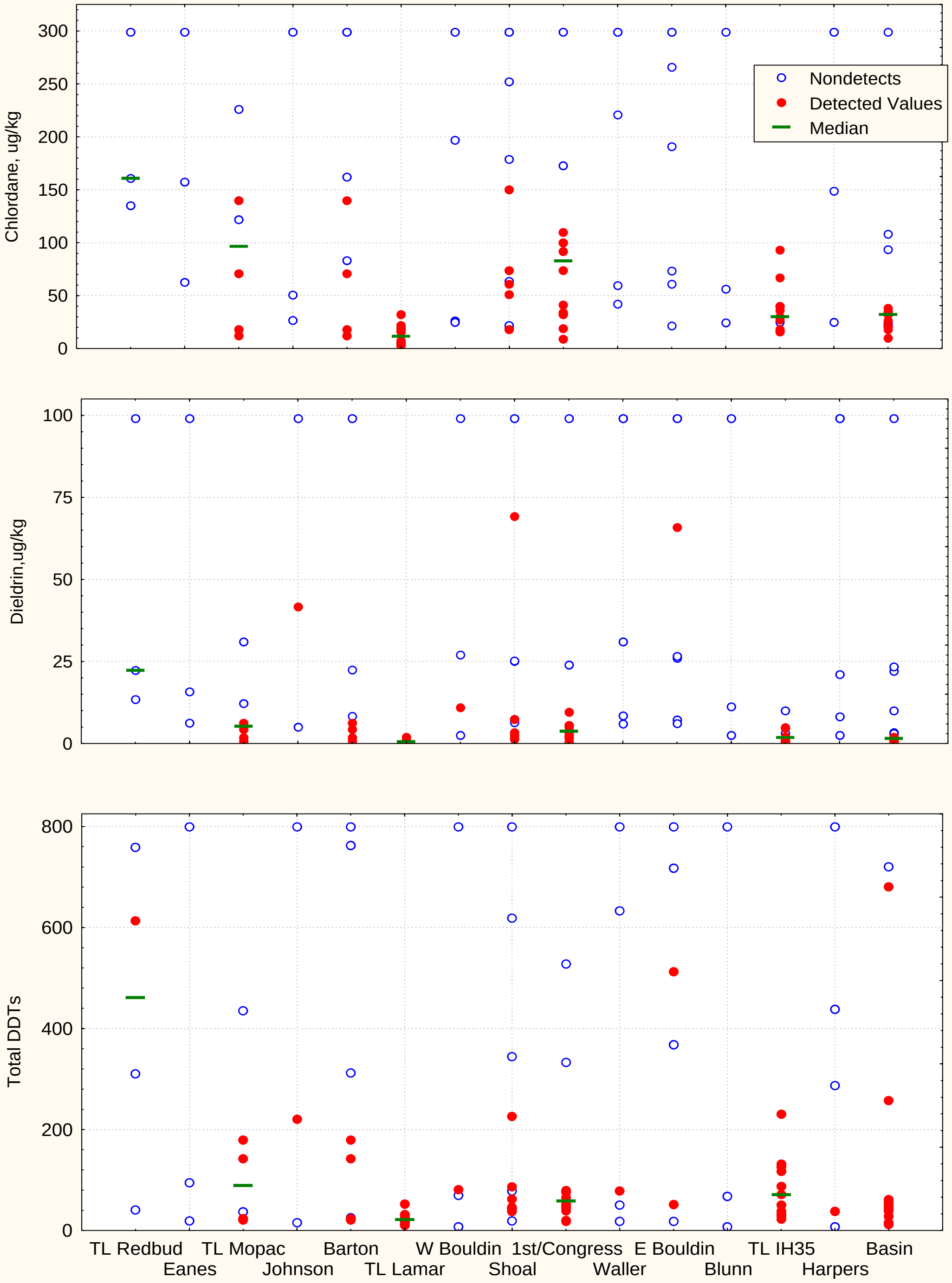
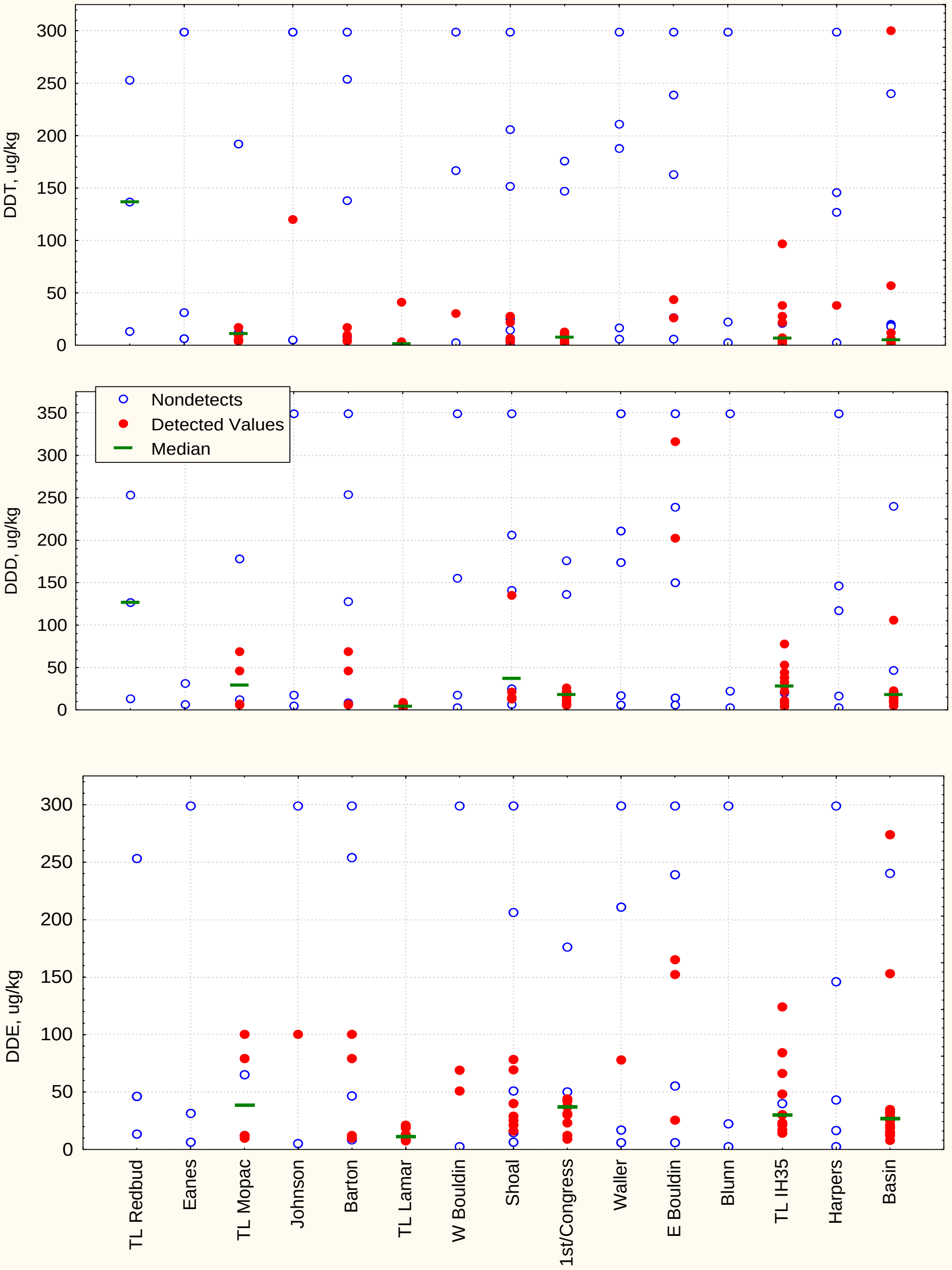


Figure 9.16 Town Lake and Creek Mouth Sediment Pesticide Concentrations (cont.)



While a strong spatial pattern is not clearly evident (Figure 9.16), the overall site differences for organo-chlorine pesticides are similar to those observed for metals with a drop in concentrations at the Lamar site and higher values at First Street/Congress and IH-35. Similar to metals, the median values in the lake were usually higher than at the creek mouths. Some of the measurements at Shoal, which enters above First Street/Congress, and East Bouldin, which enters above IH-35, yielded the most elevated values for many of these pesticides. It is also apparent that DDT is not as prevalent as its degradation products, DDD and DDE (Figure 9.16).

The lack of detections of pesticides in some creek sediments may not definitively indicate their absence. Figures 9.17 and 9.18 present the median values for total DDTs and chlordane over the period from 1991 to 1998. The sites displayed include those in Town Lake, creeks in central Austin and structural Best Management Practices. As seen in the figures, the pesticides were present in sediments captured by water quality controls in most of these creek watersheds. Potentially, the grain size present in the creek mouth samples, the amount of the fine sediment that is transported directly to the lake or the relative amount of bank sediments diluting the creek mouth samples may be factors in the presence or absence of these pesticides.

Pesticides could also be coming from upstream. However, only one sediment sample from Lake Austin was analyzed for pesticides on January 30, 1995, and all pesticide concentrations in that sample were below detection limits.

9.3.5.4 Temporal Patterns

The use of organo-chlorine pesticides has been banned. However, their slow degradation rate is reflected in their persistence in the environment. Decreasing values over time for all of these pesticides were statistically significant, with the exception of dieldrin, which had insufficient detected data for a regression analysis. The regressions and plots in the section used all mainstem data, with data from May 14, 1992, and May 19, 1994, removed. May 14, 1992, was a screening study by USGS and data collected on May 19, 1994, was analyzed at NDRC. Laboratory data on both of the dates consisted primarily of non-detect values with extremely high detection limits.

Figure 9.17 Median Chlordane in Sediment (1991–2000)

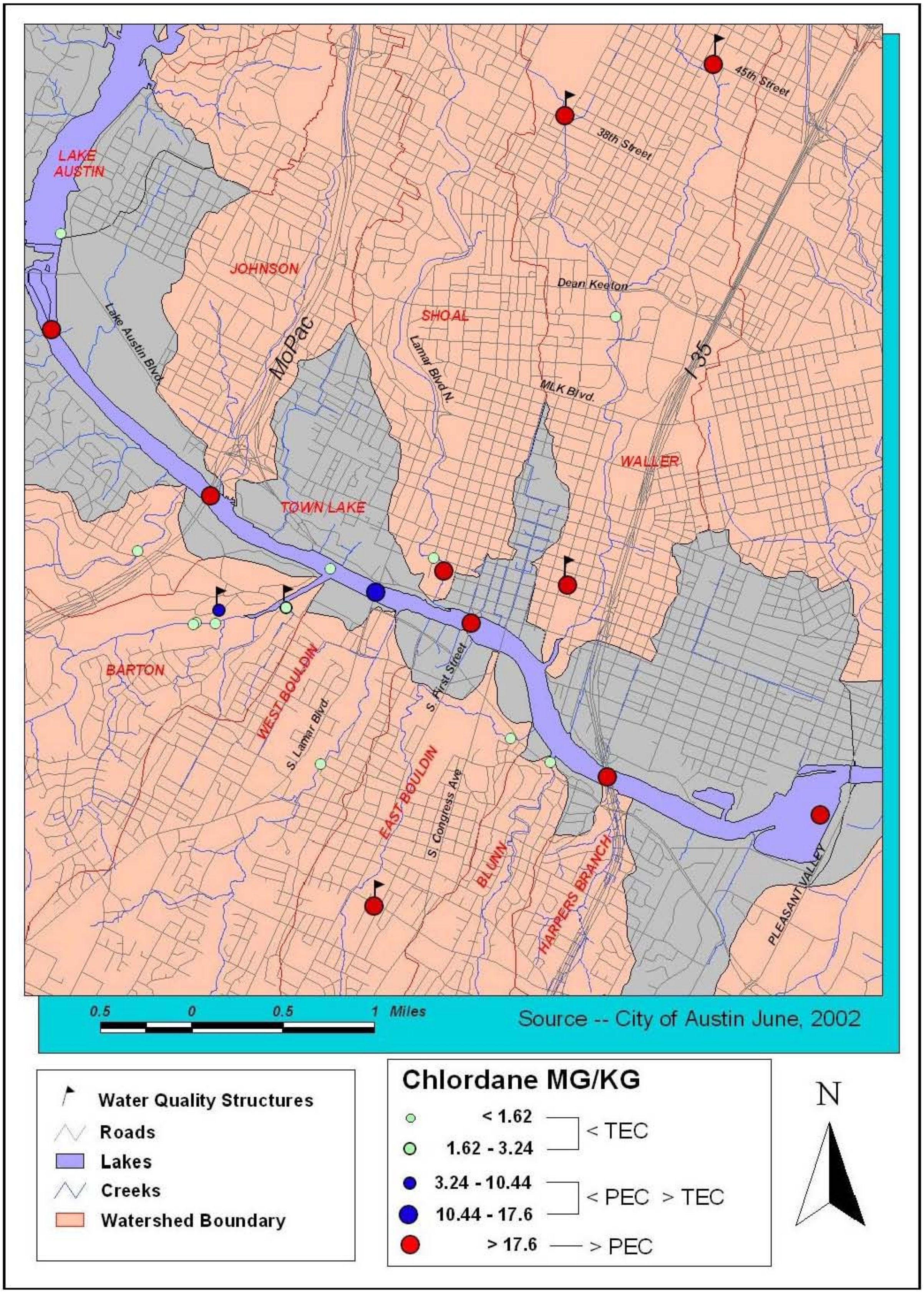
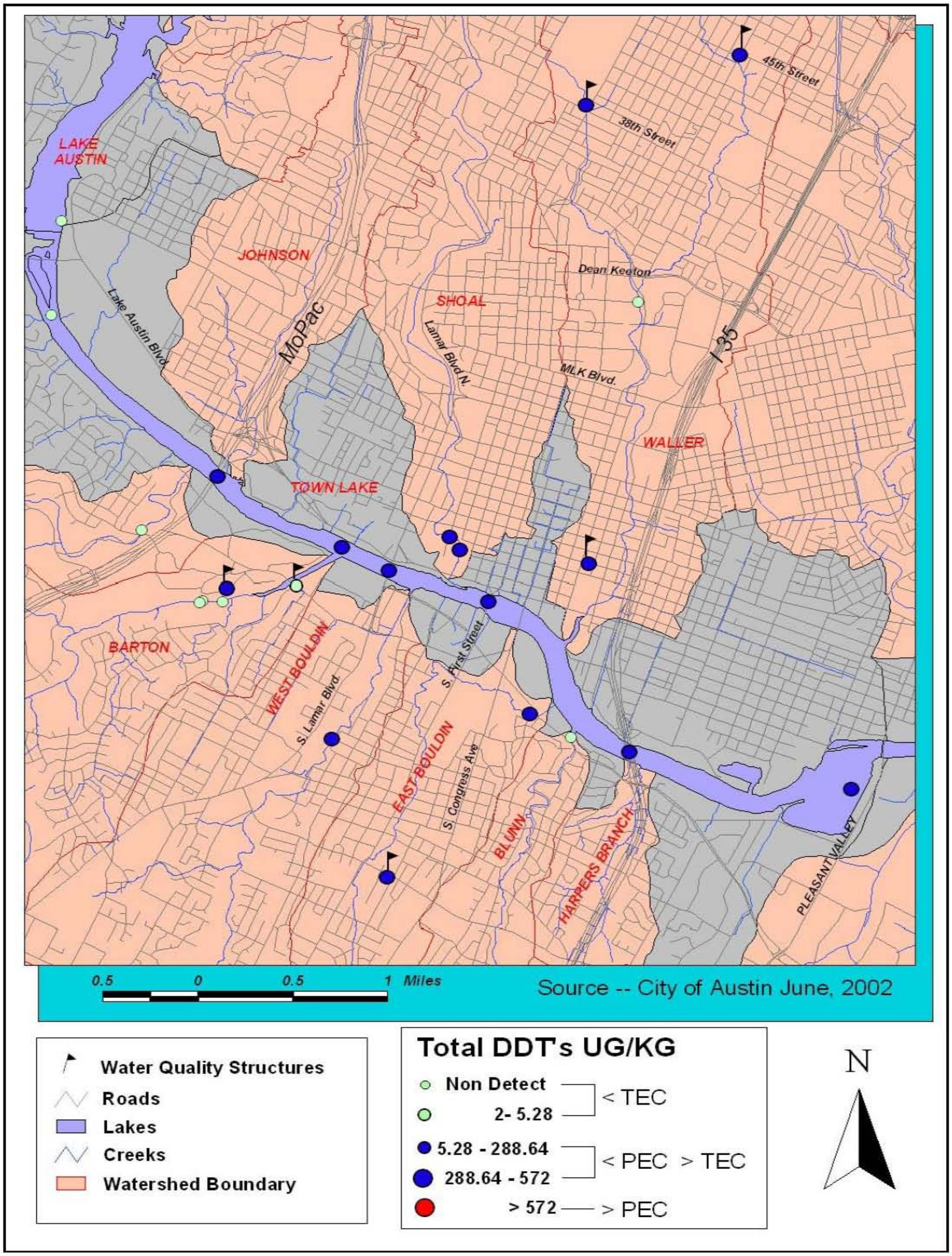


Figure 9.18 Median DDTs in Sediment (1991–2000)



Source -- City of Austin June, 2002

Figure 9.19 displays total DDTs (the sum of the isomers), dieldrin and chlordane. Figure 9.20 shows the trends for the DDT isomers. The decreasing trends for chlordane and total DDTs were significant. These decreasing trends are expected, as no new inputs of these pesticides are occurring into our surface water systems.

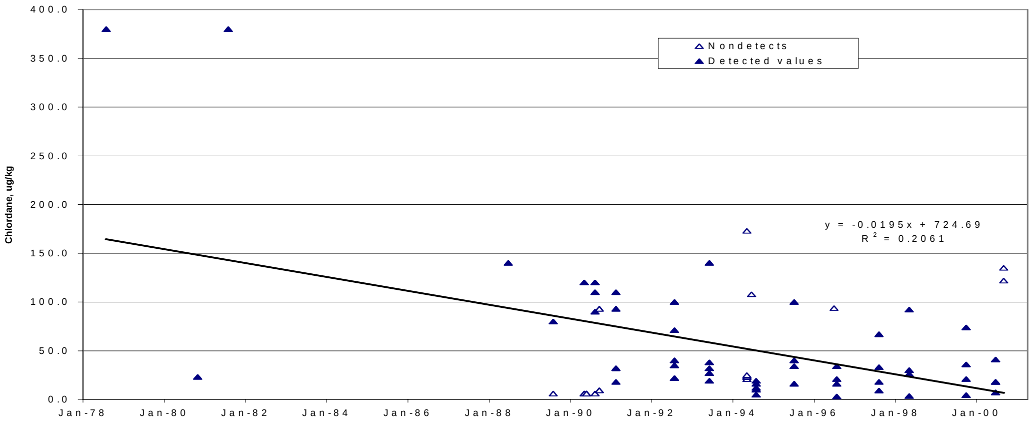
The values of DDT, the primary isomer (which transforms to DDD and then DDE), shows the most values in the lower range (0.1-1 μg/kg) in recent years. This is expected, as DDD and DDE, although degrading, are also generated with the breakdown of DDT. This decreasing trend reflects not only the degradation of these pesticides in resident sediments of Town Lake, but also contributions of the pesticides adsorbed to sediments transported from upstream and surrounding watershed surfaces. These pesticides continue to be identified in sediments washed off our urban lands as discussed in the previous section on the spatial distributions (Figures 9.17 and 9.18).

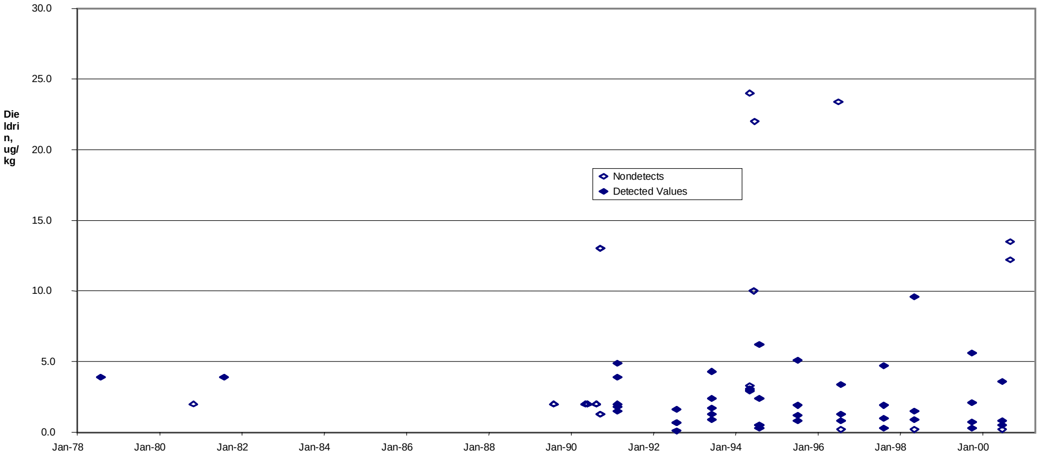
In summary, although organo-chlorine pesticides are no longer in use, their persistence in the environment is reflected not only in Town Lake concentrations, but high concentrations found in sediments captured by water quality control structures in recent years. DDT levels in some creek mouths and creek sediments were elevated (West Bouldin, East Bouldin and Shoal), while chlordane medians were below detection limits.

In Figures 9.17 and 9.18, pesticide levels are highest in the BMPs and in Town Lake. Contrary to that seen for metals, the contribution of the eroded sediments does not seem to dilute the sediments in the receiving water substantially. Most site median levels in the lake are higher than the median concentrations at creek mouths. As discussed above, all the lake processes are not well documented, and exposure of older sediments or pesticide association with finer grained sediments may be causative factors in this difference between metal and pesticide distributions.

Both chlordane and DDT show some indications of a decrease over time, but continue to be detected at levels of concern. The organo-phosphorus pesticides, however, were rarely detected. This may be because their degradation rates are much faster. For example, the degradation rate for diazinon in soil is given as 39 days in aerobic soils and 14 in anaerobic soils (field dissipation half-life values range from 2.8 to 54 days, ARS 1999). However, Pitt et al (1994) state that “organo-phosphate pesticides are less persistent than organo-chlorine pesticides,” and hypothesize that because they are not strongly adsorbed by the sediment they are likely to leach into the vadose zone and the groundwater.

Figure 9.19 Total DDTs in Town Lake Sediments





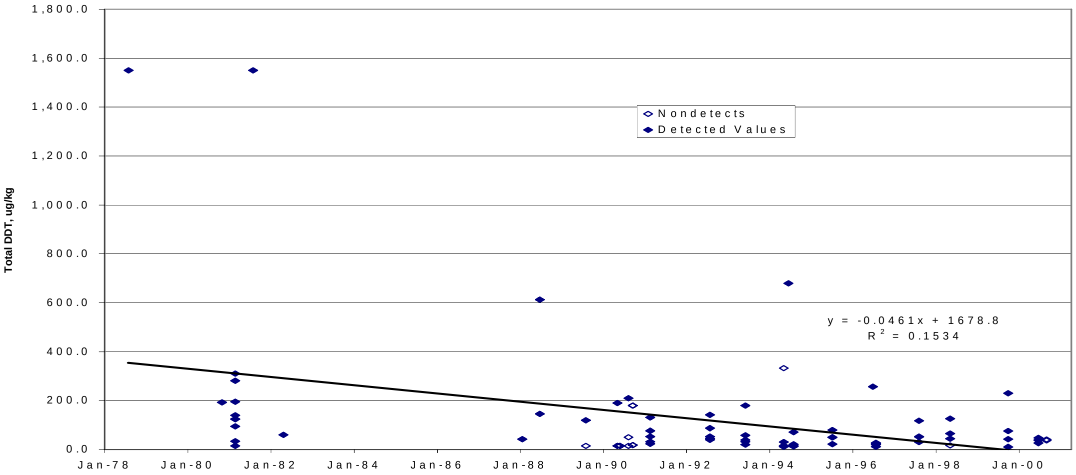
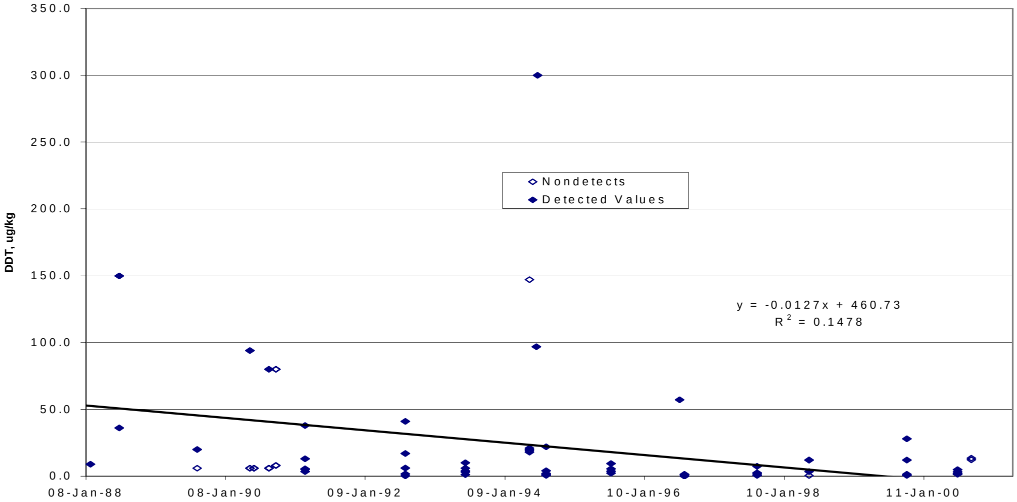
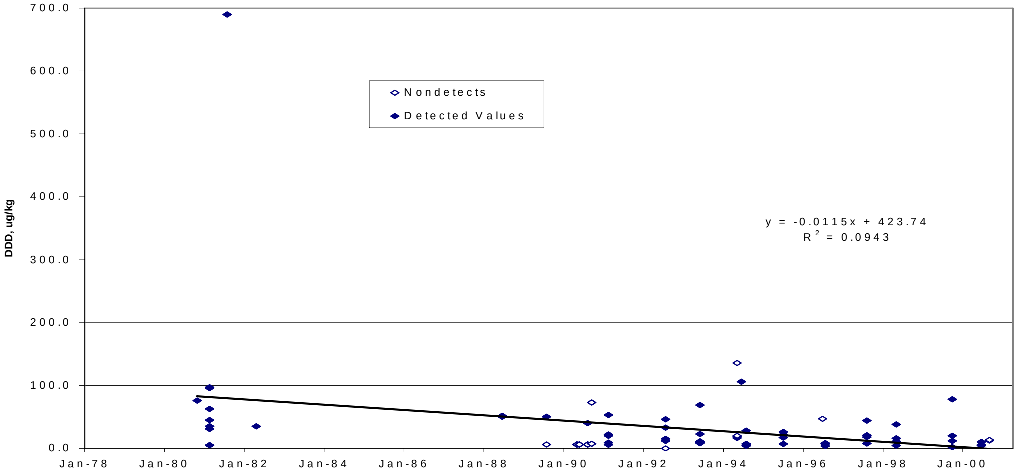
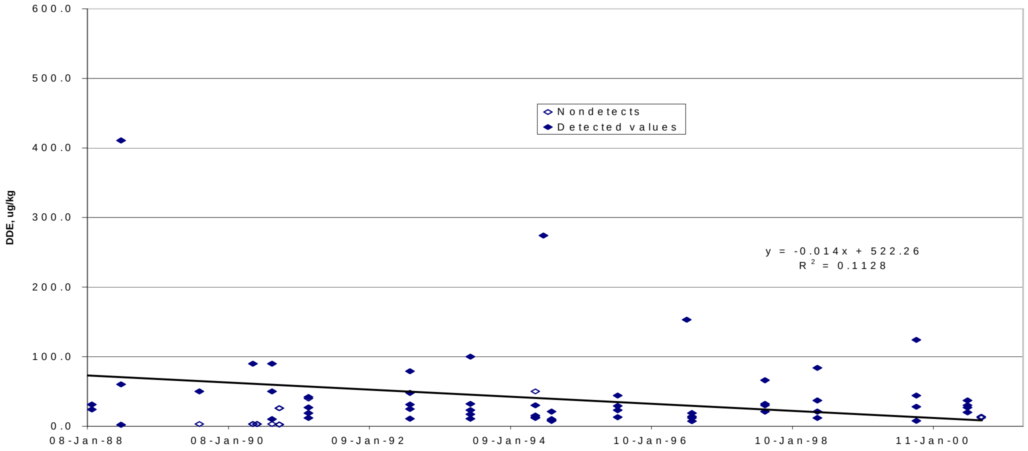


Figure 9.20 Trends for the DDT Isomers in Town Lake Sediments







9.3.6 Other Organics (PAHs and PCBs)

Besides pesticides, many synthetic organic materials are being produced for various purposes and generated as the by-products of other processes (such as the refining of gasoline and oils). End uses of many of these products tend to disperse them in the environment. Of these compounds, some are more volatile and are not commonly seen in the aqueous or solid environmental media unless near an industrial source. Other compounds adsorb strongly to sediments, or are less volatile and more likely to be found in Austin area sediment data including PCBs and polycyclic aromatic hydrocarbons (PAHs). Both PCBs and PAHs will be discussed here, although they differ greatly in deposition and transport in the environment. PAHs are semi-volatile organics covering a wide range of molecular weights often with a petroleum source. They range in persistence although the heavier molecular weight compounds in this group typically degrade more slowly. PCBs, as well as the organo-chlorines fall into the class of halogenated organics that are among the more stable species in water. PCBs were purposely designed to be chemically inert in transformer oils. Therefore the presence of oil and grease from petroleum sources may indicate potential for either of these compounds to be present.

9.3.6.1 Anthropogenic Sources

Sources of these constituents were summarized and described in Table 9.1.

PAHs have not only been identified as a problem in deposited sediments, they have been associated with suspended particulates (Norton 1998). Comparison of high and low molecular weight PAHs may indicate that weathering processes have taken place.

The manufacture and use of PCBs in new products stopped in the U.S. in October 1977. Sources include many older transformers and capacitors, which have lifetimes of 30 years or more and still contain fluids made with PCBs. Old fluorescent lighting fixtures may contain PCBs as well.

9.3.6.2 Concern Status

Analysis for semi-volatiles in sediment in Town Lake itself is very limited, with at most four sample results at any one site location. The oldest data are for a few individual PAH compounds analyzed by the University of Texas at the Basin and IH-35. Unlike metals and pesticides, total PAHs have been identified above detection limits in Town Lake sediments only at the Basin. However, sediment collected from many of the deltas of the urban creeks leading to Town Lake had values over effects levels, primarily over the lower TEC. Table 9.10 below shows total PAHs measured in Town Lake and at creek mouths.

The USGS collected a sediment core in 1998 from the Basin to look at historic trends. A significant finding was an increase in PAHs through the core, corresponding to increased traffic loads in Austin (Figure 9.23). The values at the top of the core are also above the TEC for this core taken at the Basin and indicate that Town Lake sediments may have similar concentrations to those found at creek mouths. If the increase continues, problems associated with this newer contaminant may replace those seen with organo-chlorine pesticides in the past. Analysis for PAHs has been added to routine sediment analysis in Town Lake, including any conducted by the USGS.

Table 9.10 Total PAHs in Town Lake and Tributary Delta Sediments

	Total PAHs, ug/kg	
Tom Miller Dam		
30-Jan-95	<	1,165
Town Lake @ Red Bud Isle (EC)		
19-May-94	<	565
30-Jun-98	<	6,384
14-Sep-00	<	1,350
Town Lake @ Mopac Bridge		
19-May-94	<	793
30-Jun-98	<	3,974
14-Sep-00	<	1,220
Tributary: Johnson Creek delta		
26-Sep-91	<	1,600
Tributary: Barton Creek delta		
25-Sep-91	<	2,100
19-May-94		12,084
Tributary: West Bouldin delta		
26-Sep-91		8,300
Tributary: Shoal Creek delta		
26-Sep-91	<	4,300
19-May-94		14,353
Town Lake @ Congress		
18-May-94	<	3,039
Tributary: Waller Creek delta		
26-Sep-91		**36,000**
19-May-94		14,363
Tributary: East Bouldin delta		
26-Sep-91		14,100
19-May-94	<	3,354
21-Nov-94		8,568
20-Apr-95		**40,297**
Tributary: Blunn Creek @ Riverside		
11-Jul-96		9,720
07-Jul-00		8,287
Tributary: Harpers Branch delta		
26-Sep-91		16,900
19-May-94	<	2,616
Town Lake @ IH35 (BC)		
18-May-94	<	4,354
Town Lake @ Basin (AC)		
Median 18-May-94		877
10-Jul-96	<	2,183

Consensus-Based Sediment Quality Guidelines	
TEC	**1,610**
PEC	**22,800**

Although many values for PCBs in Town Lake sediments are less than detection limit, they are still at levels above lower screening levels on many occasions. No analysis for PCBs was performed between 1980 and 1989, and some of the highest values were documented in 1997 at First Street and IH-35, so no trend is evident. Additional sampling is needed to verify the high 1997 levels. At First Street and IH-35, high levels were found in other years as well (Table 9.11). The majority of samples at those sites exceeded lower screening levels.

Oil and grease have not been recently sampled in Town Lake. Sparse data historically indicates that some elevated values were seen (Table 9.11). Since TNRCC has developed some criteria for sediment concerns for oil and grease, future sampling of lake sediments will include laboratory analysis for oil and grease. Oil and grease will not be discussed in the following sections, as insufficient data exist for any analyses.

9.3.6.3 Spatial Distribution

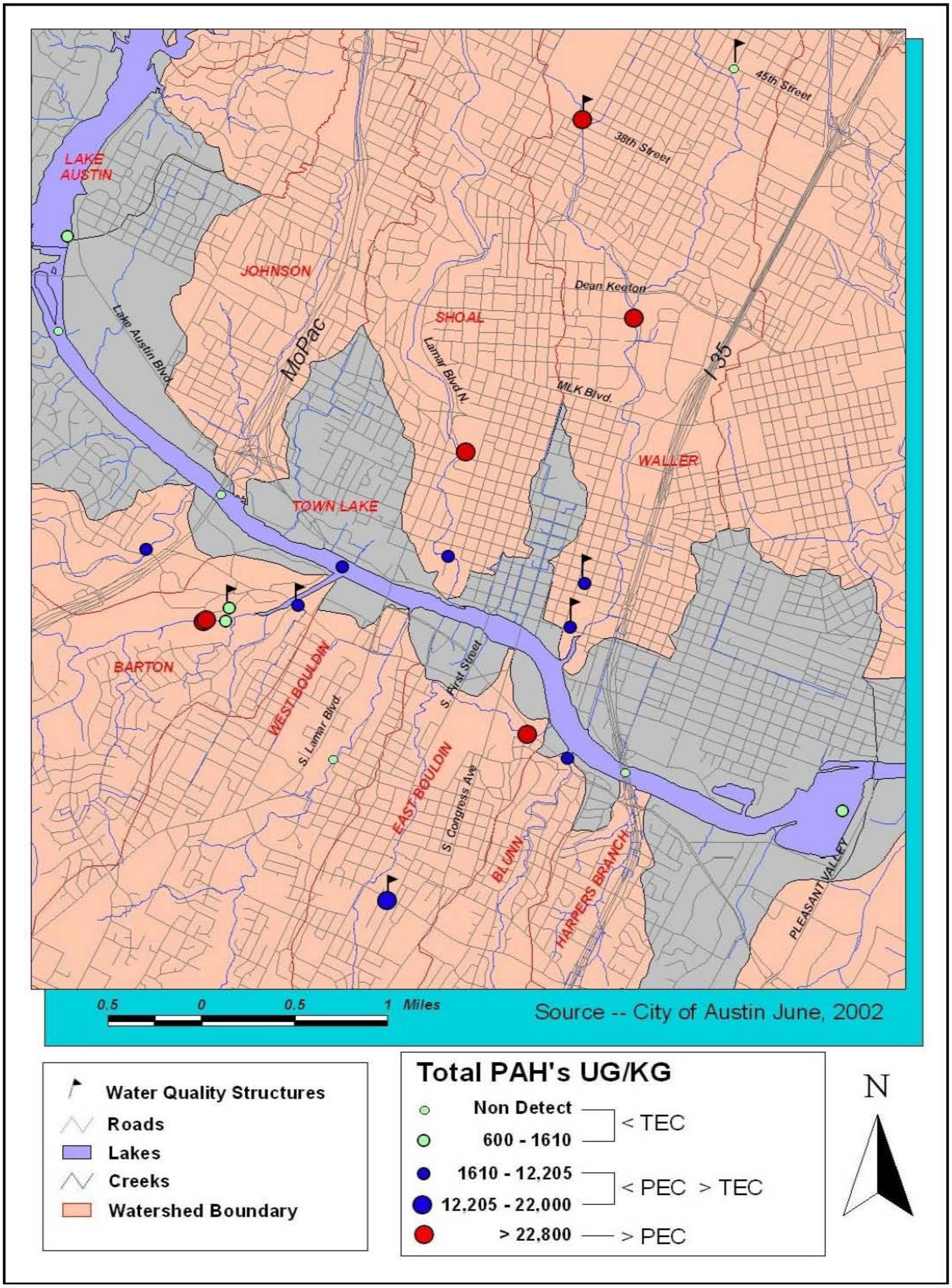
Insufficient data are available for PAHs to examine temporal or spatial trends. However, Figure 9.21 displays the median values for all PAHs in adjacent Town Lake watershed areas in addition to the Town Lake sites themselves. In recent years, PAHs in sediments at levels over biological effects levels (>PECs) have been found in both water quality control structures and in a few creeks and tributaries. Although the levels in the lake itself are not elevated to levels of concern, as these sediments move to the lake they may reach levels of concern.

Table 9.11 Oil and Grease in Town Lake Sediments

	OIL AND GREASE MG/KG	PCBs UG/KG
Consensus-Based Sediment Quality Guidelins		
TEC		**59.8**
PEC		**676**
TNRCC Screening Criteria for Freshwater Reservoirs (TNRCC 2002)		
PEL		**234.5**
85th percentile	**7,180**	**277**
Town Lake @ Congress Avenue Bridge		
11-Aug-89	. .	< 20
06-Jun-90	. .	< 20
23-Aug-90	< 50	< 20
28-Sep-90	133,000	. .
14-May-92	. .	< 180
Town Lake @ IH35 (BC)		
06-Jun-90	. .	< 20
23-Aug-90	150	< 20
28-Sep-90	49,000	. .
28-Feb-91	. .	28
05-Aug-92	. .	10
15-Jun-93	. .	22
23-Jun-94	. .	< 100
11-Aug-94	. .	31
18-Jul-95	. .	23
06-Aug-96	. .	12
20-Aug-97	. .	58
19-May-98	. .	140
13-Oct-99	. .	30
05-Jul-00	. .	18
Town Lake @ Red Bud Isle (EC)		
14-May-92	. .	< 250
30-Jun-98	415	. .
14-Sep-00	. .	< 140
Town Lake @ Mopac Bridge		
15-May-90	. .	< 20
23-Aug-90	280	< 20
28-Sep-90	47,000	. .
28-Feb-91	. .	13
05-Aug-92	. .	5
15-Jun-93	. .	31
11-Aug-94	. .	19
30-Jun-98	35	. .
14-Sep-00	. .	< 120

	OIL AND GREASE MG/KG	PCBs UG/KG
Consensus-Based Sediment Quality Guidelins		
TEC		**59.8**
PEC		**676**
TNRCC Screening Criteria for Freshwater Reservoirs (TNRCC 2002)		
PEL		**234.5**
85th percentile	**7,180**	**277**
Town Lake @ Lamar (DC)		
28-Feb-91	. .	9
05-Aug-92	. .	2
15-Jun-93	. .	12
11-Aug-94	. .	5
18-Jul-95	. .	12
06-Aug-96	. .	25
20-Aug-97	. .	20
19-May-98	. .	65
13-Oct-99	. .	14
05-Jul-00	. .	14
Town Lake @ 1st St (CC)		
28-Feb-91	. .	25
05-Aug-92	. .	9
15-Jun-93	. .	22
11-Aug-94	. .	13
18-Jul-95	. .	27
06-Aug-96	. .	9
20-Aug-97	. .	110
19-May-98	. .	34
13-Oct-99	. .	34
05-Jul-00	. .	26
Town Lake @ Basin (AC)		
08-Aug-78	. .	< 100
05-Nov-80	. .	45
08-Aug-81	. .	< 100
11-Aug-89	. .	< 20
15-May-90	. .	< 20
06-Jun-90	. .	< 20
23-Aug-90	150	. .
28-Sep-90	97,000	. .
28-Feb-91	. .	17
median 14-May-92	. .	< 125
05-Aug-92	. .	< 3
15-Jun-93	. .	28
29-Jun-94	. .	< 216
11-Aug-94	. .	13
18-Jul-95	. .	27
10-Jul-96	. 1,727	< 234
06-Aug-96	. .	15
20-Aug-97	. .	29
19-May-98	. .	24
13-Oct-99	. .	17
05-Jul-00	. .	22

Figure 9.21 Median PAHs in Sediment (1991-2000)

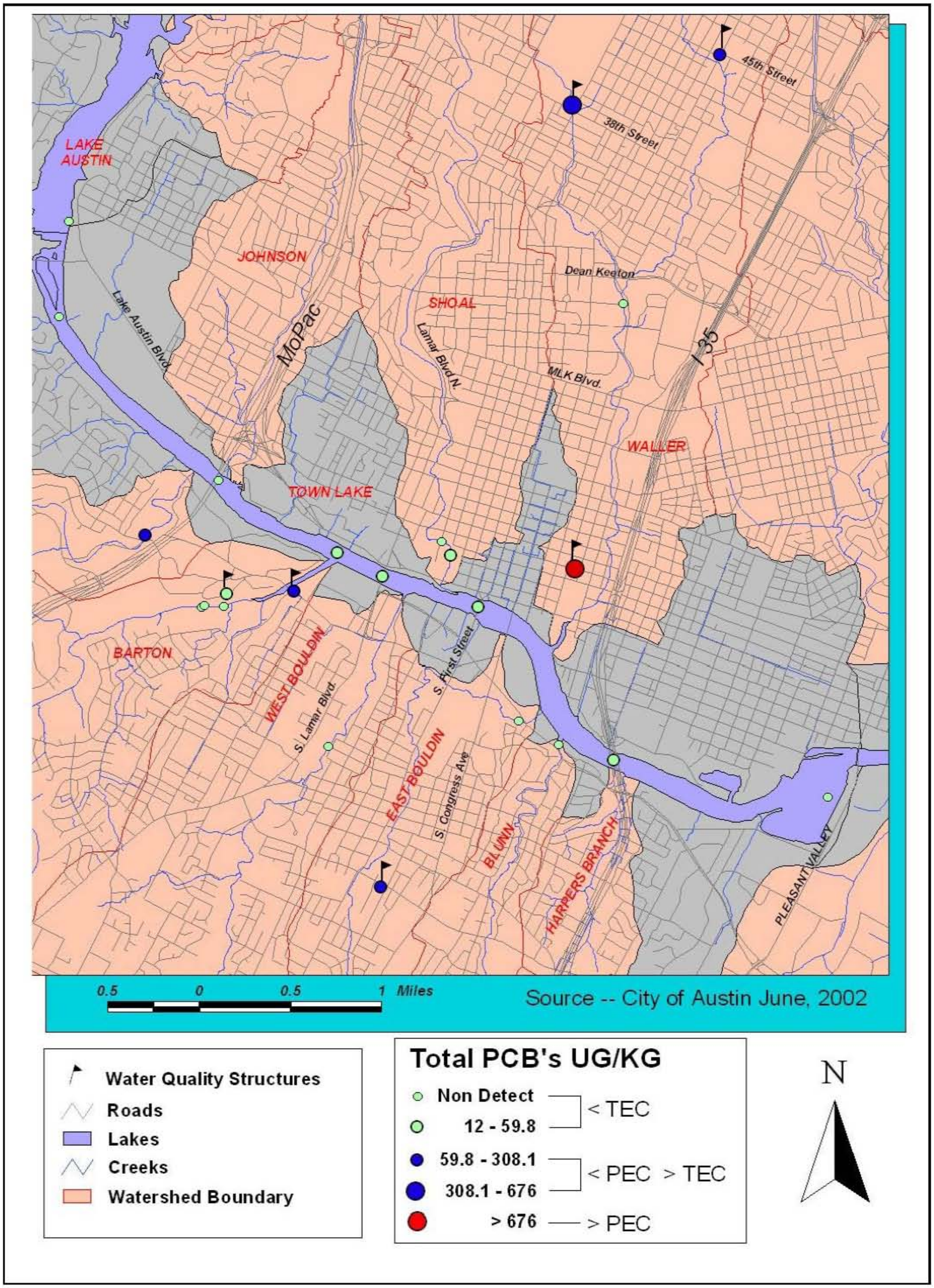


Source -- City of Austin June, 2002

For most creeks, few samples of PAHs in sediment have been taken, and nearly all were taken within the last 10 years. Most creeks showed detectable levels of the PAHs for at least half of the samples. It must also be noted that the detection limits, where non-detects were noted, were frequently more than detected values reported on different sample dates. Therefore, no assurance is provided that the sediments sampled when non-detects were reported actually had lower concentrations than reported values on other dates. Several creek locations have documented high contaminant levels as part of a study that performed screening analyses for high PAHs in selected urban areas.

Analysis of citywide distribution of PCBs indicates that median values above detection limits were seen only in BMPs, where they were the highest, and in Town Lake sediments (Figure 9.22). PCBs are apparently still at levels of concern and still being input into the receiving water system. However, the much lower values of PCBs found in Town Lake sediments raise the question of their different movement from that of the organo-chlorine pesticides. Organo-chlorine pesticides were also used historically before production was banned. The continued residence of the pesticides in the lake, however, precludes the explanation for reduced PCBs from dilution with erosive sediments.

Figure 9.22 Median Total PCBs in Sediment (1991–2000)



9.3.6.4 Temporal Patterns

Insufficient data are available from grab samples to examine temporal trends. However, in 1998, USGS collected a sediment core in 1998 from the Basin area of Town Lake, where scouring was least likely to occur. Approximately one meter of sediment deposited at the site was obtained with the core. Ages of sediment layers in the Town Lake core were assigned on the basis of the cesium-137 profile and core lithology similar to the approach used by Van Metre and others (1997). PAHs, which have not been sampled on an ongoing basis in Town Lake sediment, showed a dramatic increase over the past 20 years based on core results (Figure 9.23).

Figure 9.23 PAHs from Town Lake and Traffic Trends in Austin (USGS 1999)

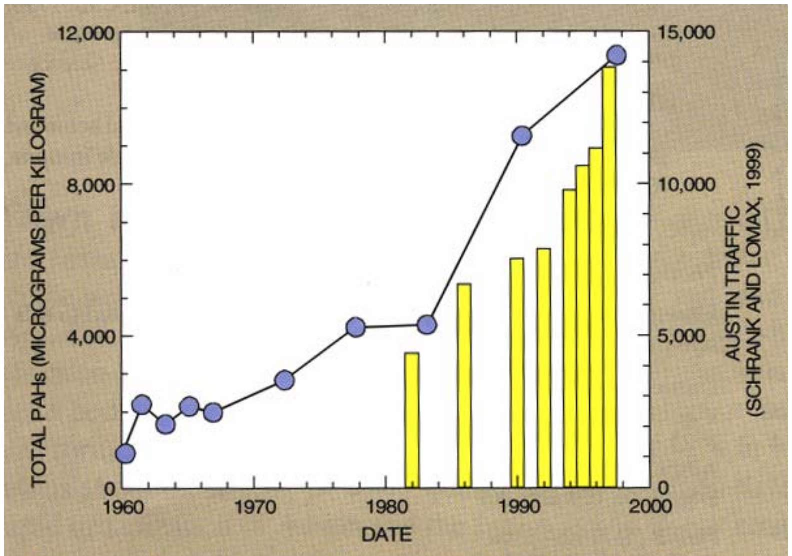


Figure 3. Comparison of Town Lake PAHs and traffic trends.

9.4 Conclusions

These new analyses of Town Lake sediment toxin concentrations confirm some of the analyses conducted in the original Town Lake Study (COA 1992a). Many toxic constituents remain at levels of concern in Town Lake sediments, and continue to move from upland sources to the receiving water body. Some decrease in restricted chemicals may be seen. However, the levels of these restricted constituents are still higher relative to effects level concentrations (TEC) than metals, which are continuing inputs. Furthermore, the spatial trends indicate that sediments in Town Lake increase in toxin levels as the river courses through the City, receiving inputs from runoff and tributaries.

As the City plans new policies and methods to address non-point source pollution problems, the PAHs may arise as a new focus. As sediment investigations continue, more areas are identified that have unexpectedly high levels of PAHs. Although these levels have not yet been representatively sampled in Town Lake sediments, they are of concern in some creeks.

10.0 FISH AND FISH TISSUE

Town Lake supports a diverse and productive fish community. In the 2000 Bass Fishing Forecast for the Austin area, the Texas Parks and Wildlife Department (TPWD) stated that “Town Lake is an outstanding urban bass fishery that should continue to produce many quality bass for Austin anglers”.

As urbanization increases, fish populations in a reservoir may be affected by changes that occur in contributing watersheds. Excessive nutrients may lead to more frequent nuisance algal blooms, which can reduce bottom DO levels. Increased turbidity may also result in a change in the fish community, from visual predators to more olfactory predators which tend to be less desirable, non-game species. Resident fish in a reservoir acquire toxins through bioaccumulation and biomagnification. The toxic contamination may have acute and chronic impacts, effects on the population structure, and physical abnormalities.

COA has not made ongoing assessments of the fish population. However, TPWD has surveyed fish populations on a regular basis (TPWD 1994; TPWD 1997; TPWD 2000). The human health issues associated with elevated levels of probable human carcinogens in the tissues of the resident fish are of concern. Consumption advisories and/or consumption bans have been in effect since 1987 for Town Lake fish, but recently the Texas Department of Health (TDH) lifted the advisory (TDH 1999). Although the advisory was lifted, the fish tissue still contained toxins. Also, sediment concentrations of toxins, a potential source for the toxin levels in fish tissues, continue to be high. This report, therefore, focuses on the examination of trends and patterns of these contaminants in the fish tissues. Previous studies on the Town Lake fish are described in the Town Lake Study (COA 1992a). The collection and analysis details for recent studies are discussed below, followed by an analysis of the data from all the fish tissue studies since 1981.

10.1 Fish Populations

The Town Lake Report (COA 1992a) described fish collected using electrofishing surveys in Town Lake through 1989. Data from TPWD were generated during four additional surveys in 1993, 1998, 1999, and 2000 (Table 10.1).

In addition to surveying the fish present in Town Lake, TPWD may provide stocking of sport fish in the lake. The 1992 Town Lake Report (COA 1992a) provided a summary of stocking from 1966 to 1986. Since 1986, stocking occurred in 1988 (21,209 Kemp's largemouth bass) and in 1998 (161,460 Florida largemouth bass). The dams at each end of Town Lake prevent normal recruitment in Town Lake and the stocking program is seen as the key way to maintain fishable populations of game fish. With these restrictions, an assessment of the natural population may not be appropriate.

Each year that survey data are collected by TPWD, they are published along with a Fisheries Management Plan. The most recent version was published in 2000 (TPWD 2000). The management plan states that the abundance of largemouth bass larger than 14 inches has increased dramatically since 1989. TPWD cites the fish consumption advisory, prohibition of gasoline motors and the implementation of a 14-inch minimum catch length and five-fish daily bag limit in 1986 as factors contributing to the increase. To address concerns that the removal of the consumption advisory would result in over-harvesting of fish, a 14 to 21 inch slot limit was established on September 1, 2000. In conjunction, TPWD will conduct annual electrofishing surveys until 2004. Two other population changes were noted by TPWD. The report stated that a declining Guadalupe bass fishery might be due to the expanding largemouth bass population out-competing Guadalupe bass for limited habitat. In addition, a low density of channel catfish was noted.

Table 10.1 Fish Collected in Electrofishing Surveys in Town Lake (CPUE*)

Common Name	**Species**	**1976**	**1986**	**1988**	**1989**	**1993**	**1996**	**1999**	**2000**
Longnose gar	*Lepisosteus osseus*	1.2	2						
Spotted gar	*Lepisosteus oculatus*	0.6			1		2		
Gizzard shad	*Dorosoma cepedianum*	107.4	17	11		31	33	27	61
Threadfin shad	*Dorosoma petenense*	3.4	12	2		1	4	4	6
Gray Redhorse sucker	*Moxostoma congestum*	5.2	4		13	23	2		
Yellow bullhead	*Ictalurus natalis*		1		1				
Channel Catfish	*Ictaluras punctatus*	4.6	1	1	1				
Flathead Catfish	*Pylodictus oliverus*	0.5	1		1	2	1		
Warmouth	*Lepomis gulosus*	5.8	21	30	32	19	40	15	2
Bluegill sunfish	*Lepomis macrochirus*	37.9	195	298	52	117	210	90	35
Redbreast sunfish	*Lepomis auritus*	120.6	328	400	90	138	84	75	40
Redear sunfish	*Lepomis microlophus*	14.4	27	12	1	26	19	5	10
Longear sunfish	*Lepomis megalotis*	9.2	58	62	28	31	10	6	2
Orangespotted sunfish	*Lepomis humilis*	11.5						21	
Green sunfish	*Lepomis cyanellus*	1.7	5	2	3		5		
Spotted sunfish	*Lepomis punctatus*		185	216	217	66	80	35	43
Largemouth bass	*Micropterus salmoides*	35.0	202	156	129	180	199	255	182
Freshwater drum	*Aplodinotus grunniens*	1.7							
Rio Grand Perch	*Chichlosoma cyanoguttatum*	14.9	18	13	17		4	35	5
Logperch	*Percina caprodes*		14	9	13		3	4	
Mexican tetra	*Astyanax mexicanus*		28	1	4		12	8	6
European Carp	*Cyprinus carpio*		1				5		
River carpsucker	*Carpiodes carpio*						1		
Golden shiner	*Notemigonus chrysoleucas*		24	2					
Sand shiner	*Notropis stramineus*		30						
Blacktail shiner	*Notropis venustus*		7	9		1		17	5
Weed shiner	*Notropis texanus*							10	

Table 10.1 (continued) Fish Collected in Electrofishing Surveys in Town Lake (CPUE*)

Common Name	**Species**	**1976**	**1986**	**1988**	**1989**	**1993**	**1996**	**1999**	**2000**
Blackstripe topminnow	*Zyygonecetes notatus*		3		0				
Inland silversides	*Menidia berllina*		68	36	4		9	78	4
Smallmouth bass	*Micropterus dolomieui*		2		8				
Guadalupe bass	*Micropterus treculi*		25	31	2	50	18	4	7
Darter spp.	*Ethostoma spp.*		1					9	

*CPUE - Catch Per Unit Effort

Other fishing issues addressed by TPWD were the limited angler access to the reservoir, lack of awareness by anglers of the “excellent largemouth bass fishing opportunities on this urban reservoir” and a decline in channel catfish. Management strategies were included to address these issues including:

- discussion with city officials about improving access
- meeting with local angling groups to discuss access needs
- seeking funding to build a fishing pier
- installing angler information signs near public boat ramps
- distributing a Town Lake brochure to promote fishing opportunities
- keeping anglers and news media informed of on-going management activities and fishing opportunities
- depending on availability, stocking channel catfish from 2001 to 2003
- monitoring the success of stocking, and promoting the catfish fishery if successful in establishing it

These management strategies are described fully in the Statewide Freshwater Fisheries Monitoring and Management Program Survey Report for Town Reservoir, 1999 (TPWD 2000). The report states that “with Town Lake located in the heart of downtown Austin, it provides TPWD Inland Fisheries with a unique opportunity to create a showcase fishery within a major Texas metropolitan area.” With the removal of the fish consumption advisory and Town Lake’s present condition as an excellent fishery, the status of the fish population gains importance.

10.2 Recent Fish Tissue Studies and the Fish Consumption Advisory

Fish have been collected and tissue toxins analyzed three times since the Town Lake Study in 1992. In 1994 The Lower Colorado River Authority (LCRA) collected 52 fish from Town Lake between March 30 and April 8. TDH guidelines for fish collection and analysis for edible portions were followed. Six types of fish were collected: largemouth bass, gray redhorse sucker, carp, gizzard shad, redear sunfish and redbreast sunfish. These fish were collected at the Basin, IH-35, First Street and MoPac. Electrofishing was used to collect the fish. The fish fillets were analyzed at the LCRA Environmental Laboratory for pesticides and polychlorinated biphenyls (PCBs) by gas chromatography (EPA method 8080). To analyze chlordane in these samples, a technical chlordane standard was used, and individual isomers were not quantified or reported. Previous studies and other laboratories, specifically the TDH laboratory, may have used different standards and quantification methods for chlordane, as documented in the Town Lake report and as described below for the 1995 sampling effort. Details of the study, including sample preparation methods and analysis results, are included in “Chlordane Levels in Fish from Town Lake: March-April 1994 Survey” by John Trevino, LCRA 1994.

In February 1995, 20 fish were collected from Town Lake by TDH**.** Six types of fish were collected: bass, catfish, carp, gizzard shad, freshwater drum and smallmouth buffalo. These fish were collected at the Basin, Fiesta Gardens, and at IH-35. Electrofishing was used to collect the fish. Fish fillets were analyzed at the LCRA lab for pesticides and metals by gas chromatography (EPA Method 8080). For this sampling event, technical chlordane was not identified, so individual isomer standards were used for calibration and sample results for the individual isomers reported. In July, an additional 10 fish were collected by TDH at Red Bud, Congress and the Basin. The types of fish collected were bass, catfish, carp, and freshwater drum. These fish were analyzed at the TDH lab for pesticides and metals. Fillets from five of the fish previously analyzed at LCRA were reanalyzed at the TDH laboratory. The fillets were analyzed for pesticides and PCBs, also by gas chromatography. The overall method for chlordane analysis at the TDH laboratory, however, differs from that employed at the LCRA laboratory. For the samples submitted to the TDH laboratory, the chlordane analysis was conducted using a technical chlordane standard. Individual isomers were then quantitated and used to determine the total chlordane value reported. The quantitation methods for chlordane in 1995 at the LCRA and TDH laboratories differ not only from each other but also from the method used at the LCRA laboratory in 1994.

The data from this 1995 study indicated that a person eating Town Lake fish would be exposed to several probable human carcinogens simultaneously. These chemicals, chlordane, DDT, DDE, DDD, PCB Aroclor 1260, and hexachlorobenzene, primarily affect the liver. The cumulative lifetime carcinogenic risk for these chemicals was estimated to be 1.1×10^{-4}. This risk level exceeds the TDH criteria for issuance of a fish advisory. The resulting advisory set a consumption limit of one 8-ounce meal of fish from Town Lake per week (TDH 1995).

In September 1998, 14 fish were collected from Town Lake by TDH. Four types of fish were collected: bass, catfish, freshwater drum and smallmouth buffalo. These fish were collected at the Basin, MoPac, and Red Bud by electrofishing. Two of the fish were archived in the TDH freezer and the rest were analyzed at the TDH lab for pesticides, PCBs, volatile organics, semi-volatile organics, and metals. Split samples were taken from two of the fish. If the split samples had the same concentrations, only one number was reported. For parameters with different concentrations in the split samples, both concentrations were reported. The chlordane analysis was conducted using a technical chlordane standard. Individual isomers were then quantified and used to determine the total chlordane value reported.

PCBs, volatile and semi-volatile organic compounds other than pesticides, were not detected in the 1998 fish study samples. Pesticides were detected in all the fish. However, the concentrations of chlordane were lower than in 1995 and were detected in a smaller percentage of the fish. Additionally, the chlordane isomers observed in the samples showed some evidence of degradation. The data from this study indicated that a person eating Town Lake fish would be exposed to several probable human carcinogens simultaneously. These chemicals (chlordane, DDT, DDE and DDD) primarily affect the liver. The cumulative lifetime carcinogenic risk for these chemicals was estimated to be $2.35x10^{-5}$. This risk level is more than four times smaller than the risk estimated in 1995. The decrease in risk is due to both decreases in concentrations and revision by USEPA of the numerical factors used in calculating risk for chlordane. The TDH also calculated non-carcinogenic risk from fish consumption and found the Hazard Index to be acceptable. The overall conclusion of the assessment was that the consumption of fish from Town Lake poses no apparent health hazard. TDH lifted the fish consumption advisory on October 26, 1999 (TDH 1999).

Small quantities of metals were found in several fish, but the levels did not pose a threat to human health using the 1998 EPA reference doses. A new reference dose for mercury was announced by USEPA in January 2001 (USEPA 2001). Using this new reference dose would require a monthly consumption limit from Town Lake fish. However, state criteria have not yet been revised.

10.3 Sampling Information for All Years

Fish were collected from Town Lake between 1981 and 1998 by five different agencies for fish tissue analysis. As with all multi-year, multi-agency studies, the locations, fish varieties, fish size, labs, methods, and measured parameters differed with each collection.

10.3.1 Sampling Variation

Not only were different types of fish caught during each fish tissue study, but the groupings used to examine the data varied (Table 10.2). Common names were used for one grouping and feeding types for another. The feeding types were more useful in the analysis of fish tissue concentrations. The four feeding groups were piscivores (fish that eat other fish), omnivores (fish that eat almost anything), invertivores (fish that feed primarily on benthic macroinvertebrates) and herbivores (fish that eat mostly plankton).

Comparison of Tables 10.1 and 10.2 shows that the percentage of fish in each feeding group was different in the population and in the fish tissue studies. Fish in the herbivore and invertivore groups comprise at least half the population but were sampled minimally or not at all in recent years for the tissue studies.

Table 10.2 Types of Fish in Fish Tissue Studies

Frequency	1981	1985	1987	1990	1994	1995	1998	Total	Fish Group	Feeding Group
Largemouth bass	1		6	17	23	8	4	59	Bass	Piscivore
Smallmouth bass				2				2	Bass	Piscivore
White bass		1				2		3	Bass	Piscivore
Striped bass		2				1		3	Bass	Piscivore
Black bass		14						14	Bass	Piscivore
Flathead catfish				8		7	2	17	Catfish	Piscivore
Channel catfish		2	3	7		2	1	15	Catfish	Omnivore
Blue catfish			3			1	1	5	Catfish	Omnivore
Yellow bullhead			1					1	Catfish	Omnivore
Common carp		11	2	19	6	3		41	Carp	Omnivore
Smallmouth buffalo				1		1	2	4	Carp	Omnivore
Redhorse sucker			6	5	14	5		30	Sucker	Omnivore
Freshwater drum						3	2	5	Other	Omnivore
Gizzard shad		13	6	11	6	2		38	Shad	Herbivore
Rio Grande perch	2	3						5	Other	Invertivore
Redbreastted sunfish	3			2	1			6	Sunfish	Invertivore
Bluegill sunfish	2							2	Sunfish	Invertivore
Redear sunfish	2	5			2			9	Sunfish	Invertivore
Yellow belly sunfish		4						4	Sunfish	Invertivore
Warmouth sunfish		2						2	Sunfish	Invertivore
Long eared sunfish		1						1	Sunfish	Invertivore
Total	10	58	27	72	52	35	12	266		

Figures 10.1 and 10.2 show the number in each fish group for each year and site group. The spotty nature of the sampling both in sites and fish types makes analysis of the data difficult.

Figure 10.1 Fish Feeding Groups

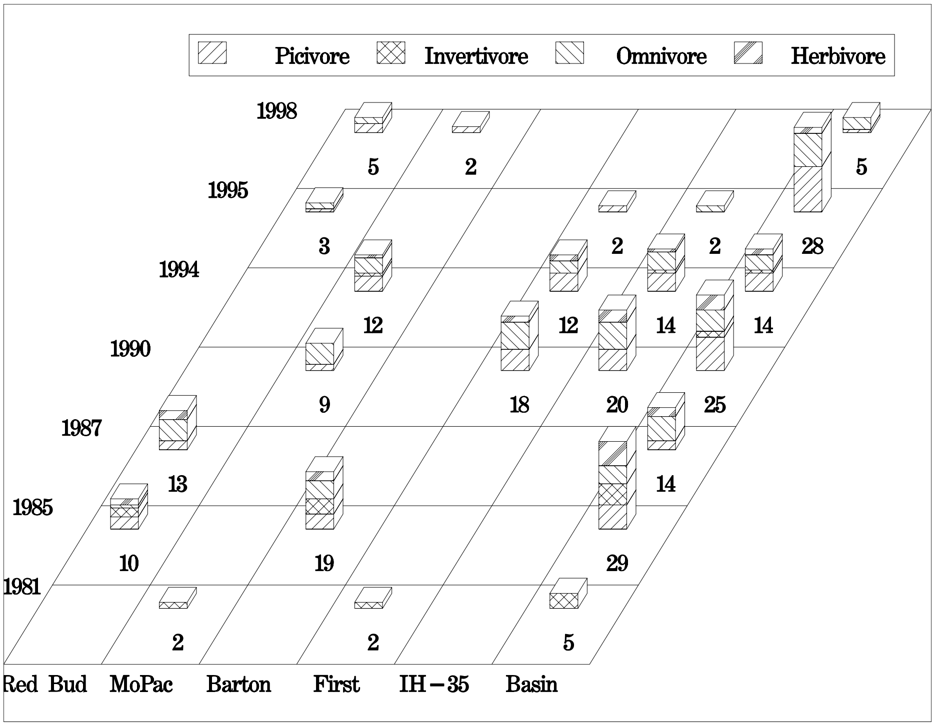
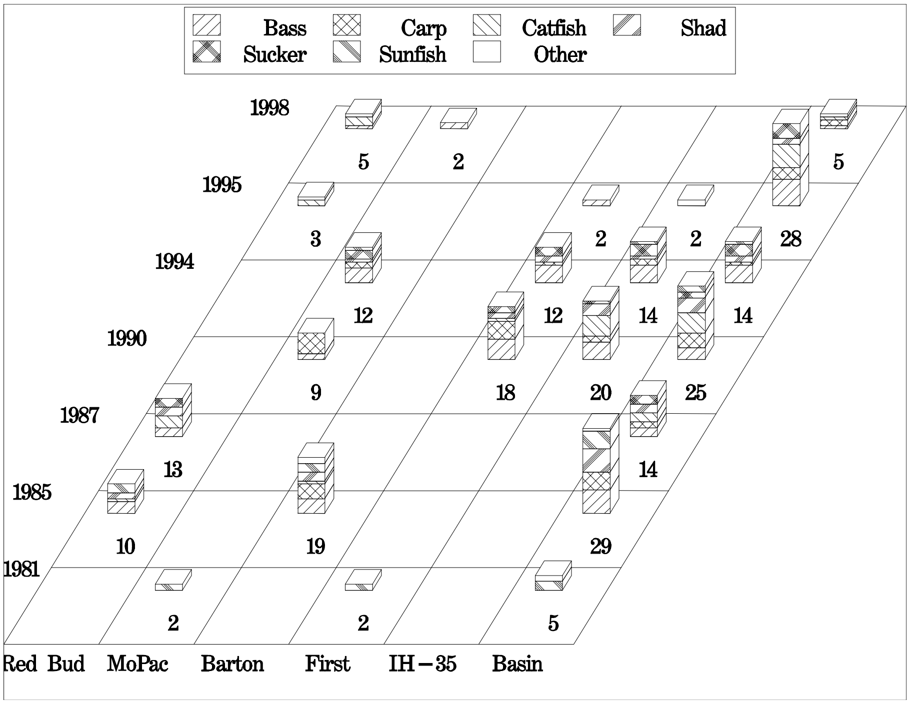


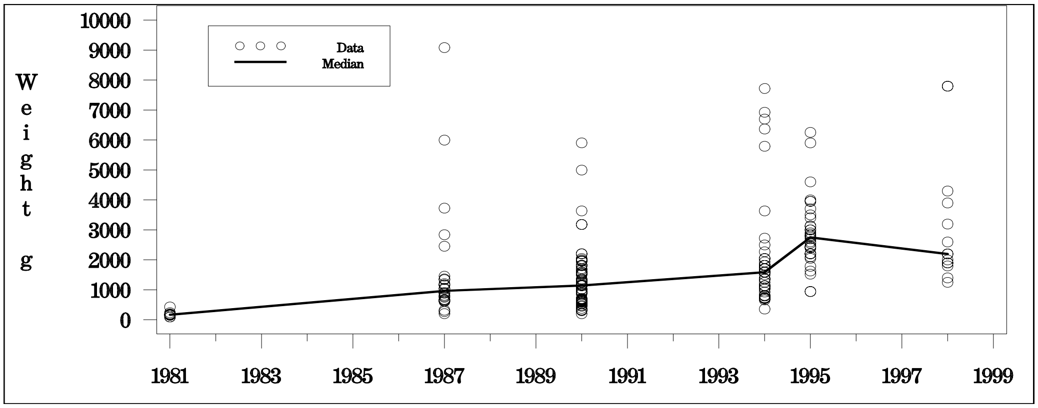
Figure 10.2 Fish Types



The length and weight of the fish caught has been increasing over time (Figure 10.3), except in 1998. The median fish size was smaller in 1998 than in 1995, although the median lengths and weights were larger in 1998 than in 1994. Larger fish tend to be older and have had more time to accumulate toxins. In order to compare fish tissue concentrations from one year to the next, concentration data were normalized by the fish weight. Weights were not measured in 1985, so regression by fish family group was used to estimate the weights from the lengths. Figure 10.4 shows both measured and predicted weights versus lengths for all fish.

Figure 10.3 Sampled Fish Lengths and Weights Over Time

Length



Weight

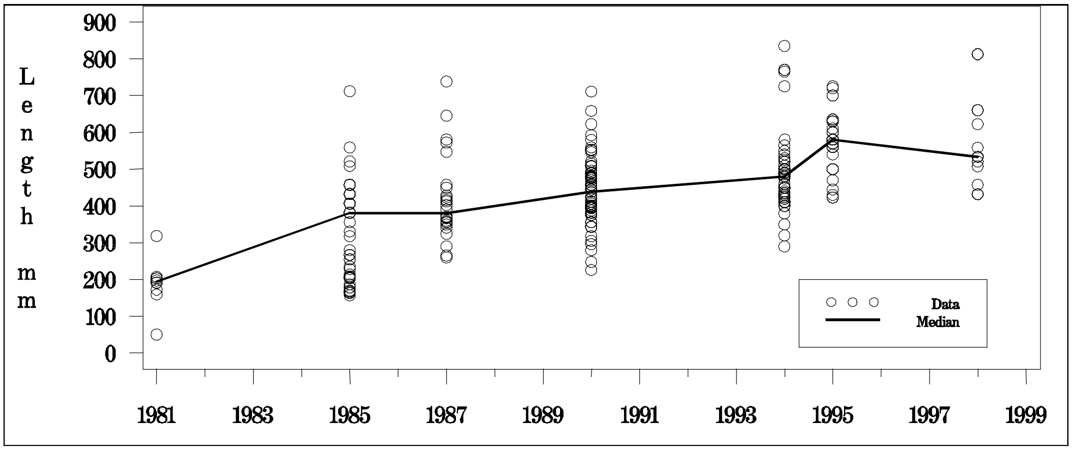


Figure 10.4 Measured and Predicted Fish Weights

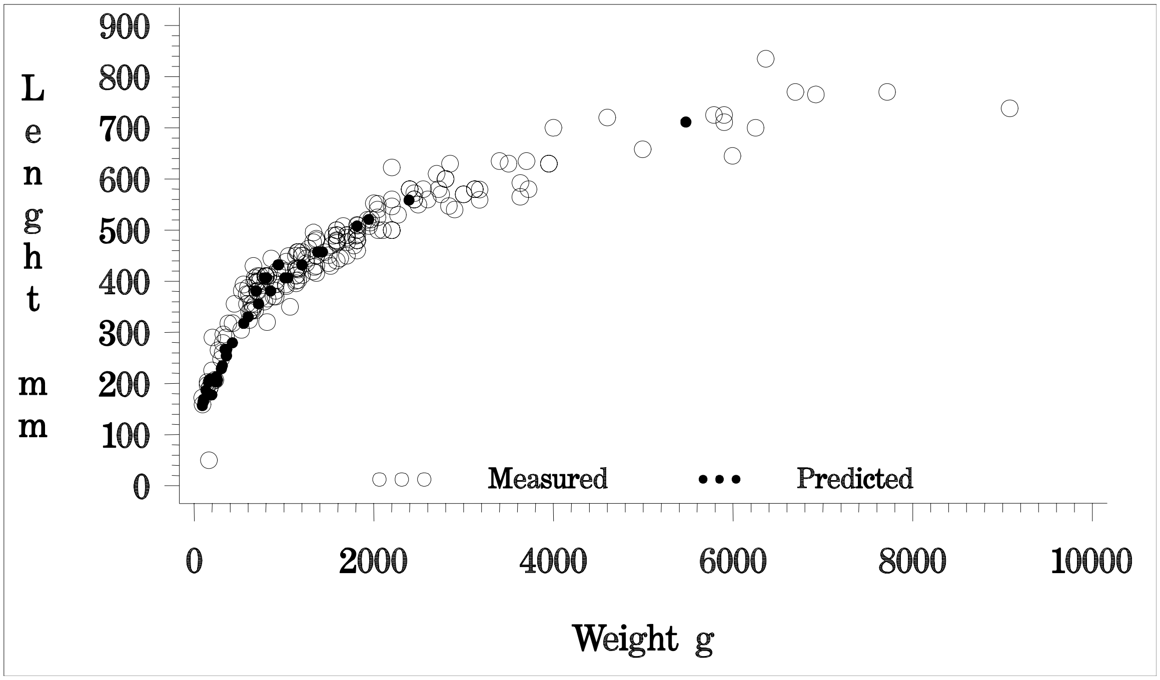


Table 10.3 lists the collection sites, shows the site groupings that were used to look for site differences, and lists the number of fish collected at each site. Sites close to each other relative to other sites were grouped.

Table 10.3 Fish Collection Sites

SITE	Fish Sampling Frequency	GROUPING
Town Lake	1	
Town Lake @ Red Bud Isle (EC)	31	Red Bud
Town Lake @ MoPac Bridge	25	MoPac
Town Lake @ Barton Creek (FC)	19	Barton
Town Lake @ 1st St (CC)	2	First
Town Lake @ Congress Avenue Bridge	32	First
Town Lake @ IH35 (BC)	36	IH-35
Town Lake @ Fiesta Gardens	3	Basin
Town Lake @ Holly Street Power Plant	19	Basin
Town Lake @ Basin (AC)	98	Basin

10.3.2 Laboratories and Analysis Methods

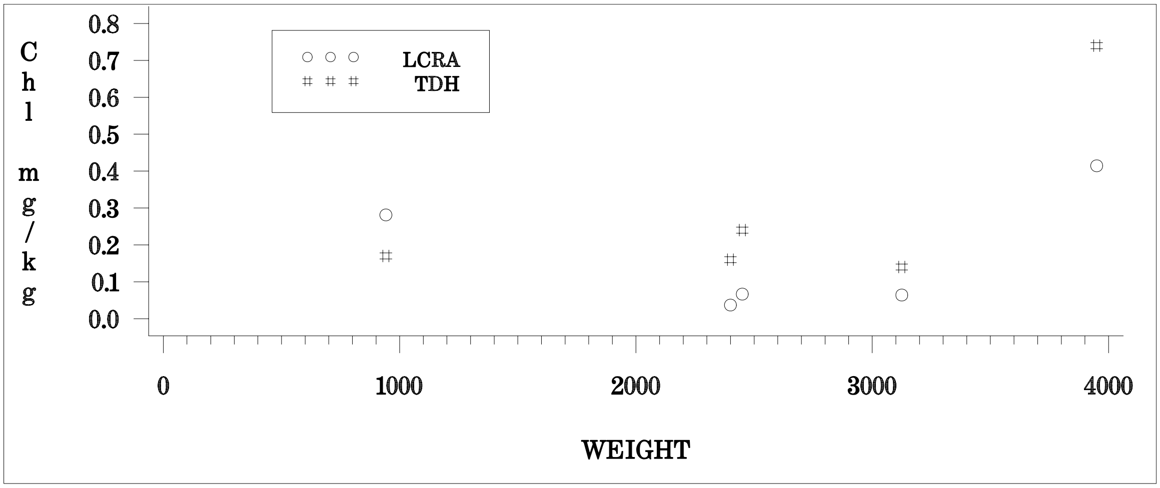
Table 10.4 shows the years during which sampling occurred and the labs at which the fish were analyzed for metals, pesticides, and other parameters. Since 1985 only two labs, LCRA and TDH, have been used.

Table 10.4 Laboratories used for Fish Tissue Analysis

LAB	**YEAR**							
Number of Fish	**1981**	**1985**	**1987**	**1990**	**1994**	**1995**	**1998**	**Total**
LCRA			27	20	52	20		119
Unknown	4							4
TDH		58		52		15	12	137
Harman	6							6
Total	10	58	27	72	52	35	12	266

Analysis methods have changed over time, as have analysis laboratories. Thus, apparent time trends or site differences must be interpreted with caution. Data from five fish collected in 1995 illustrate this problem with interpretation. Tissue samples from these five fish were analyzed at both the LCRA and TDH labs. Although the same gas chromatography analysis method was used for chlordane at both laboratories, the laboratory standards for calibration differed (technical chlordane versus individual isomer standards) as well as quantification of the results. In this case, TDH reported a total chlordane concentration while LCRA reported primary isomers individually. In addition to differences in analysis methods, variations in concentrations may be expected as a result of submitting separate fillets from each fish to each laboratory. Chlordane concentrations versus the weight of the fish for both LCRA and TDH labs were compared (Figure 10.5). The TDH concentrations are higher for four of the five fish. The average concentration of chlordane for these five fish from the LCRA lab is 59 percent of that from the TDH lab. This difference in average chlordane concentrations is enough to make the difference between maintaining the advisory on eating fish from Town Lake or dropping it.

Figure 10.5 LCRA versus TDH Concentrations for 5 Fish



In addition to analysis variations, the parameters requested for analyses varied (Table 10.5). Only metals, organochlorine compounds, and PCBs have been consistently measured. In the metals group only copper, mercury, and zinc have sufficient data above the detection limit for meaningful analysis. The organochlorine compounds with adequate data include chlordane, DDT, DDE, and DDD.

Table 10.5 Parameter Types by Year of Fish Tissue Study

Frequency	1981	1985	1987	1990	1994	1995	1998
ACID-EXTRACTABLE ORGANICS (8270)						x	x
ALCOHOLS/PHENOLS							x
BASE/NEUTRAL EXTRACTABLE ORGANICS (8270)						x	x
HALOGENATED AROMATICS						x	x
HALOGENATED PHENOLS						x	x
HERBICIDE						x	x
METALS	x	x	x	x		x	x
MONOAROMATIC HYDROCARBONS						x	x
ORGANICS						x	x
ORGANOCHLORINE (8080)	x	x	x	x	x	x	x
ORGANOPHOSPHATE (8140)						x	x
PAH						x	x
PCB	x	x		x	x	x	x
PESTICIDE							x
VOLATILE HALOGENATED HYDROCARBONS						x	x
VOLATILE ORGANIC ANALYTES (8240)							x

10.4 Analysis Results

Data for each of the six parameters (chlordane; the sum of DDT, DDD, and DDE; PCBs; copper; mercury; and zinc) were examined in detail. Both normalized and non-normalized concentrations were analyzed. While normalized concentrations are used to investigate changes in tissue concentration over time, the non-normalized concentrations may tell more about the potential doses of toxicants an angler might ingest. The following plots are displayed for each parameter.

- The number of samples by site, year, and feeding group
- Concentrations by year
- The number of samples above and below detection limits by year
- Normalized concentrations by year
- Concentrations by site
- The number of samples above and below detection limits by site
- Normalized concentrations by site

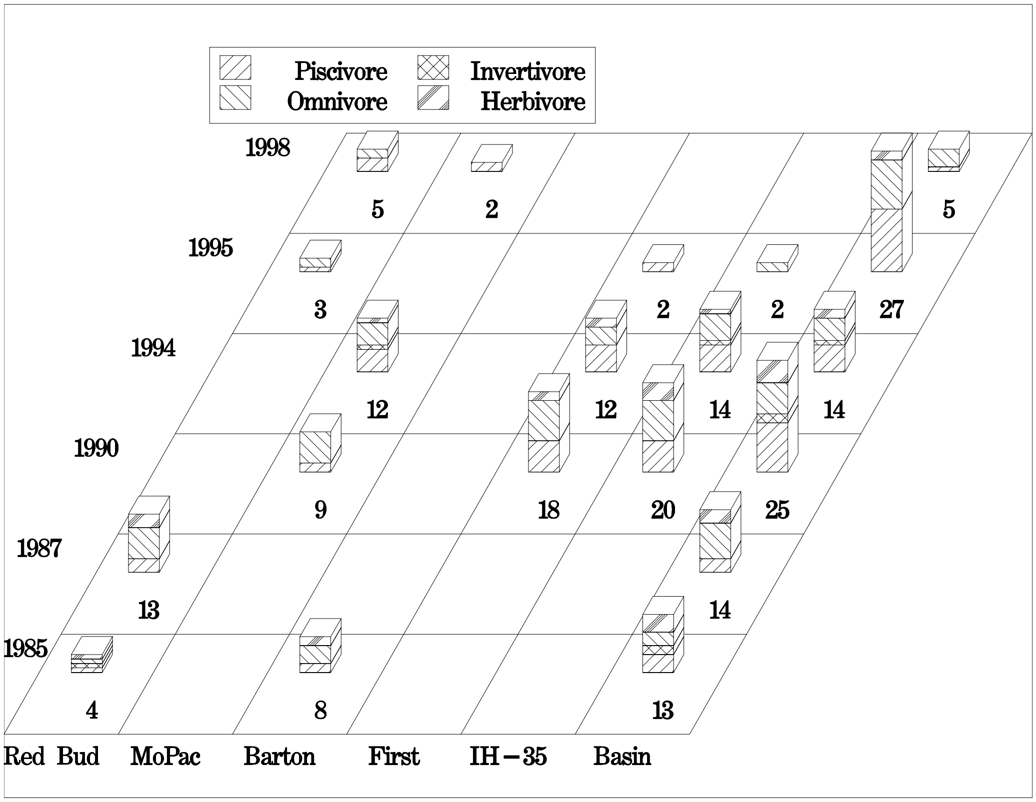
The concentrations for three other metals -- lead, chromium and arsenic -- are also displayed to demonstrate the inadequacy of the data for drawing conclusions about them.

Significant interactions between the varying sites and years make the use of analysis of variance to determine site or year differences inappropriate, and imply a need for care in interpreting the graphs of the data. Plots demonstrating the interaction between location and year are included for one parameter (chlordane).

10.4.1 Chlordane

Examination of the number of chlordane samples for each year, location, and fish feeding group indicates that the data do not represent balanced sampling (Figure 10.6). Fish were sampled at the mouth of Barton Creek only at the beginning of the time period and at MoPac, First Street, and IH-35 only during the last half of the sampling period. Feeding groups were also sampled unevenly. Piscivorous and omnivorous fish feeding groups are fairly well represented but invertivores and herbivores were not caught as often.

Figure 10.6 Total Chlordane in Town Lake Fish and Number of Samples for each Year, Location and Feeding Group (1981-1998)

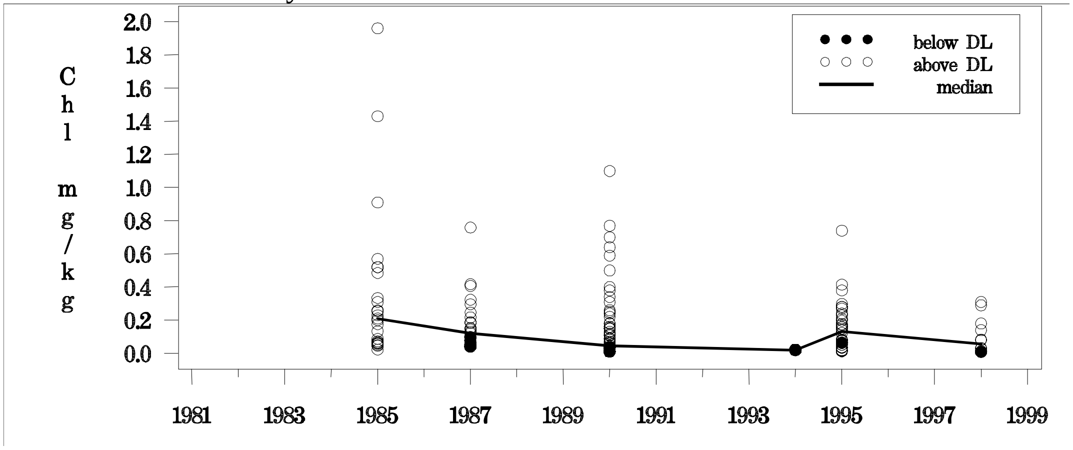


Fifty five percent of the 222 fish tissue concentrations were above the detection limits. These concentrations ranged from 0.0128 to 1.96 ppm. The highest levels were observed in 1985 at the Basin. The majority of the chlordane concentrations were above the detection limit except in 1994, when they were all below detection (Figure 10.7). The maximum detected chlordane concentration in Town Lake fish has been declining, although one of the 12 fish sampled in 1998 (8 percent) still had a concentration above the FDA action level of 0.3 mg/Kg. This decrease has been observed in spite of the increase in length and weight of the captured fish (Figure 10.3). When chlordane concentrations are normalized by weight in order to make the comparison between years more meaningful, the decrease in the maximum normalized concentrations is even stronger.

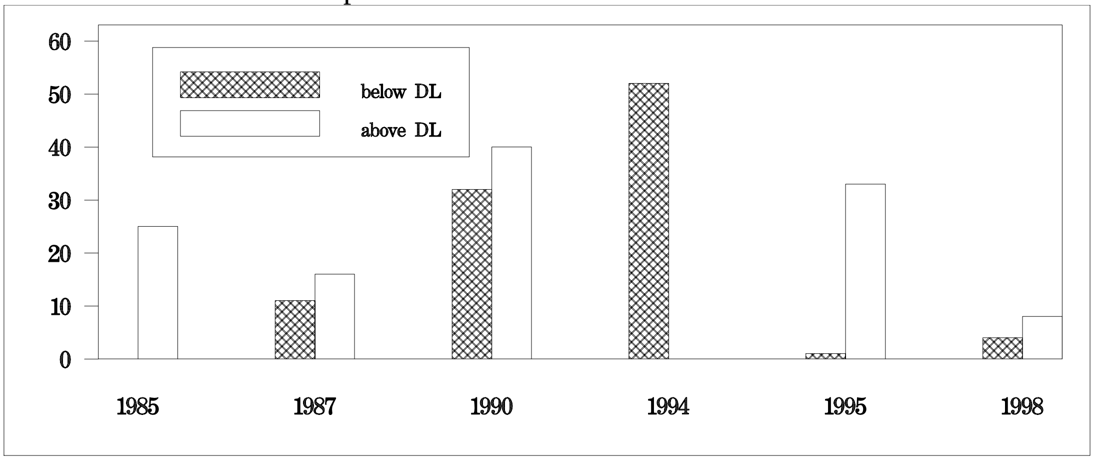
The plot of concentrations versus location indicates apparent location differences. The unbalanced sample design, however, makes interpretation of this data difficult. Fish were caught at the mouth of Barton Creek only during 1985, the first year of sampling, while fish were sampled at MoPac, First Street, and IH-35 only during the later part of the study. Fish were caught at Red Bud at the beginning and end of the time period but not in the middle. The only site at which sampling was done consistently was the Basin. Since concentrations appear to be higher at the beginning of the time period, median concentrations for the Barton site and individual concentrations for the Red Bud and Basin sites may be higher than at the other sites. Plots of the median concentrations for each year and site (Figure 10.7) show interactions between site and year. Thus, no conclusion will be drawn about location differences. Location differences may exist, but they cannot be conclusively demonstrated with the data available. No discussion of the plots of fish concentrations is provided at different locations for the rest of the parameters.

Figure 10.7a Chlordane in Town Lake Fish (1985-1998)

Chlordane by Year



Number of Samples above and below Detection Limit



Normalized Chlordane by Year

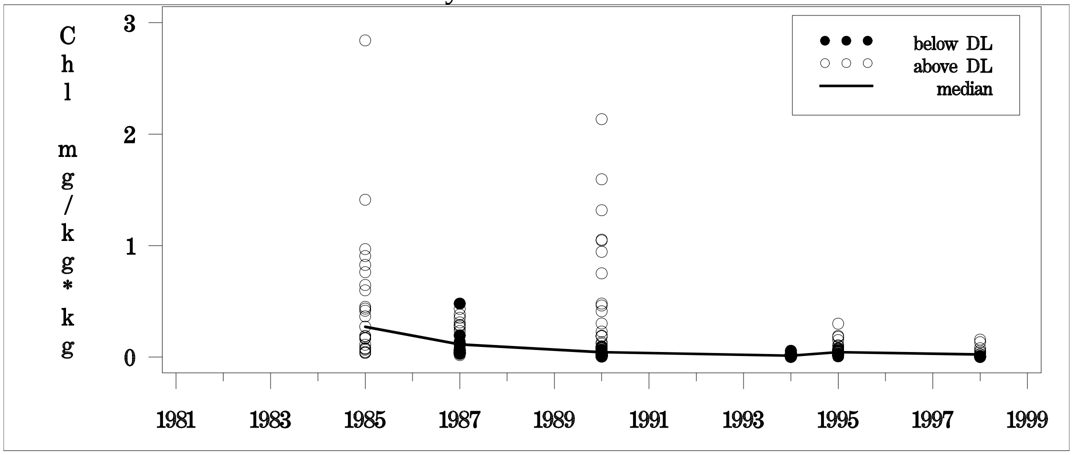
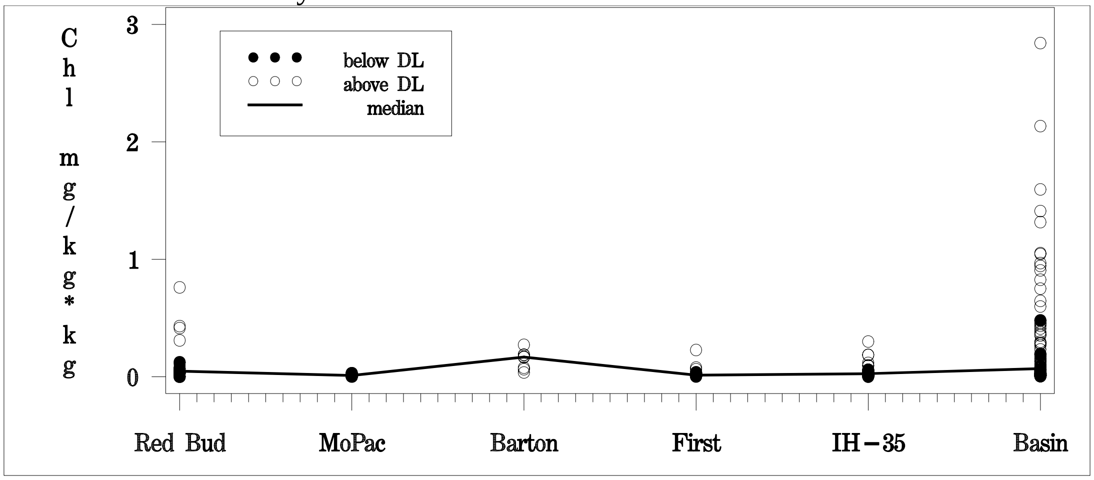
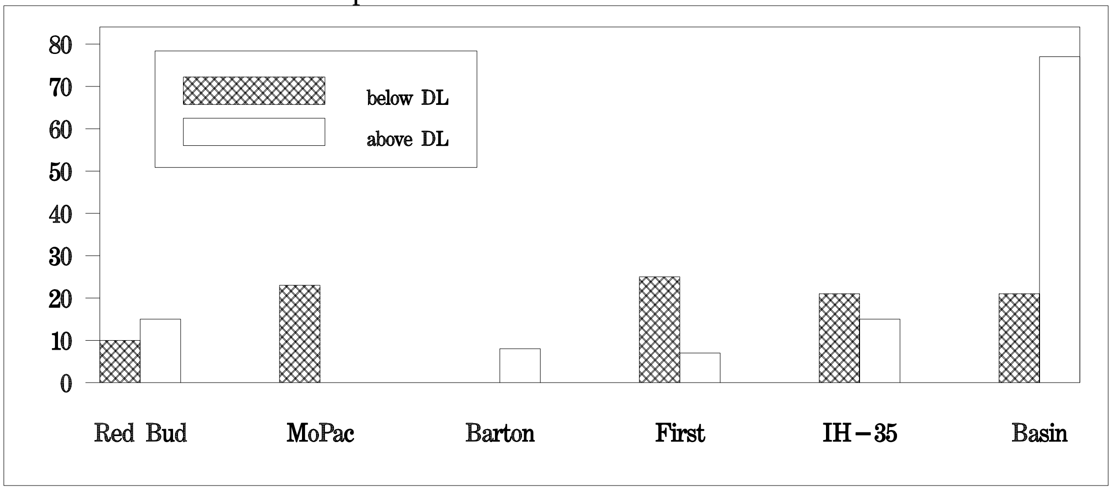


Figure 10.7a (continued) Chlordane in Town Lake Fish (1985-1998)

Chlordane by Location



Number of Samples above and below Detection Limit



Normalized Chlordane by Location

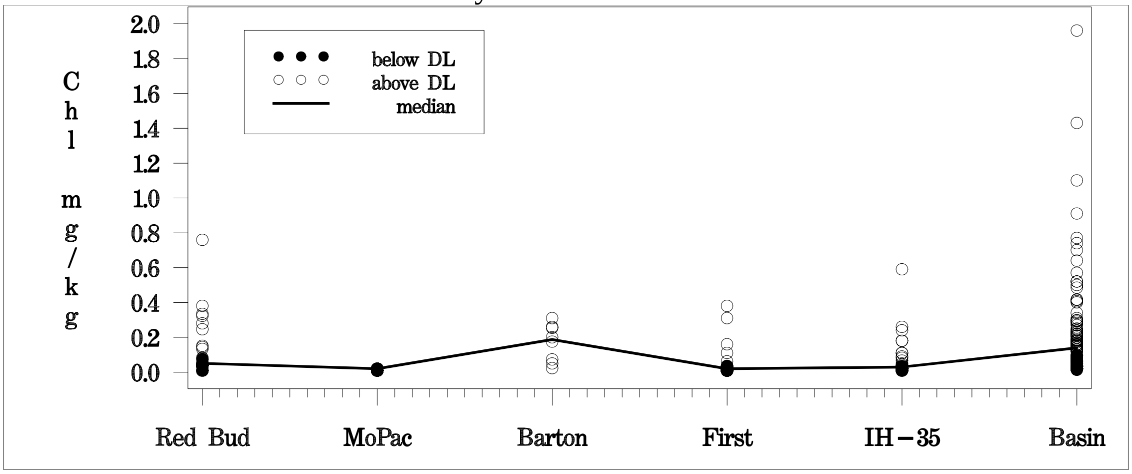
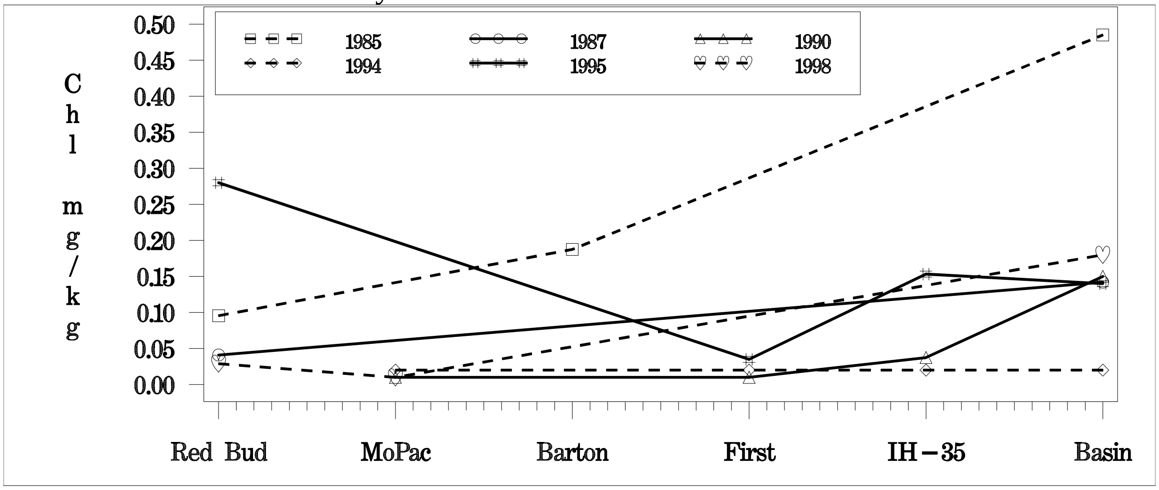
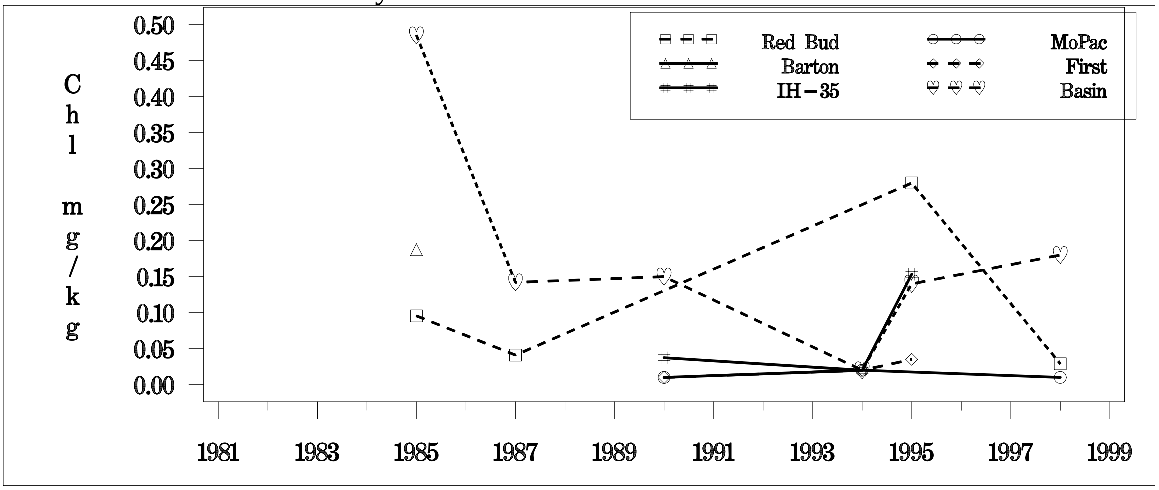


Figure 10.7b Chlordane Concentrations by Location and Year in Town Lake Fish (1985-1998)

Chlordane Medians by Location and Year



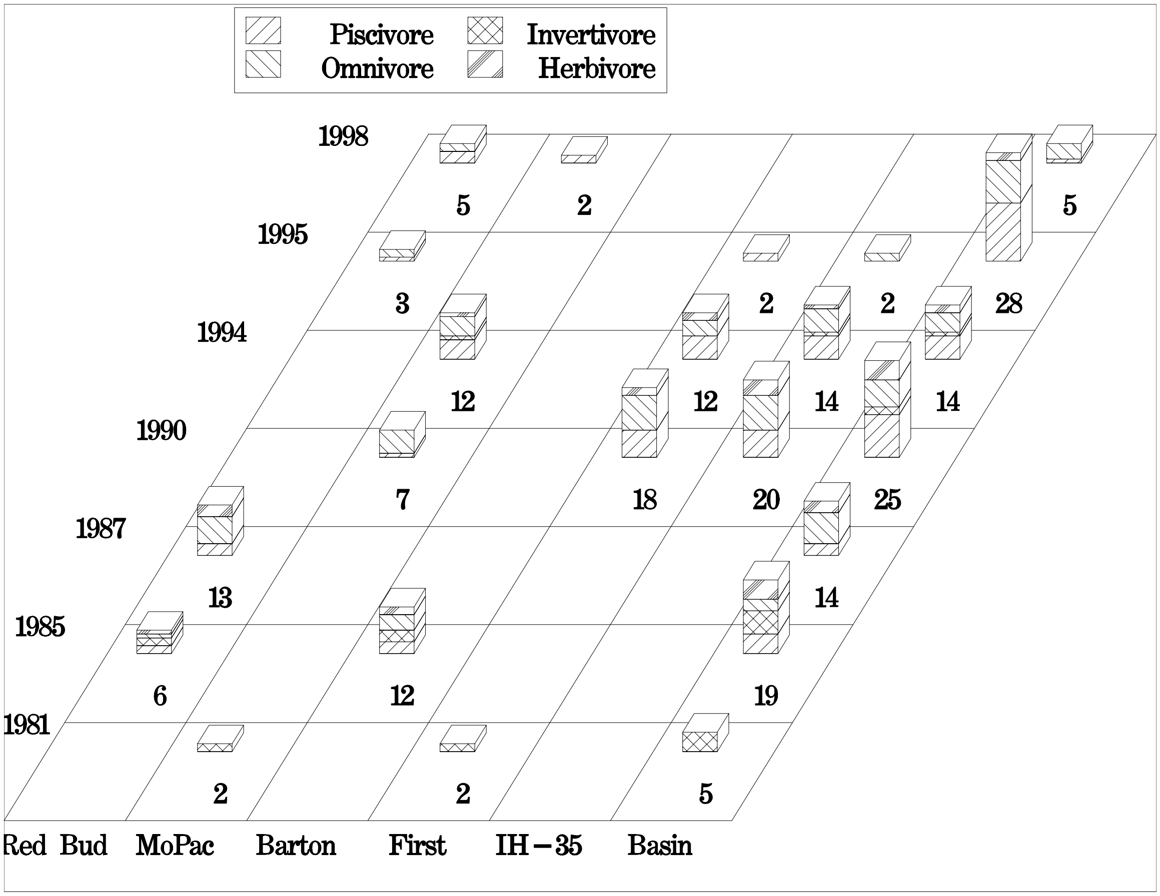
Chlordane Medians by Year and Location



10.4.2 Total DDT

The number of total DDT (calculated as the sum of the concentrations of DDT, DDE, and DDD) samples for each year, location, and fish feeding group were examined (Figure 10.8).

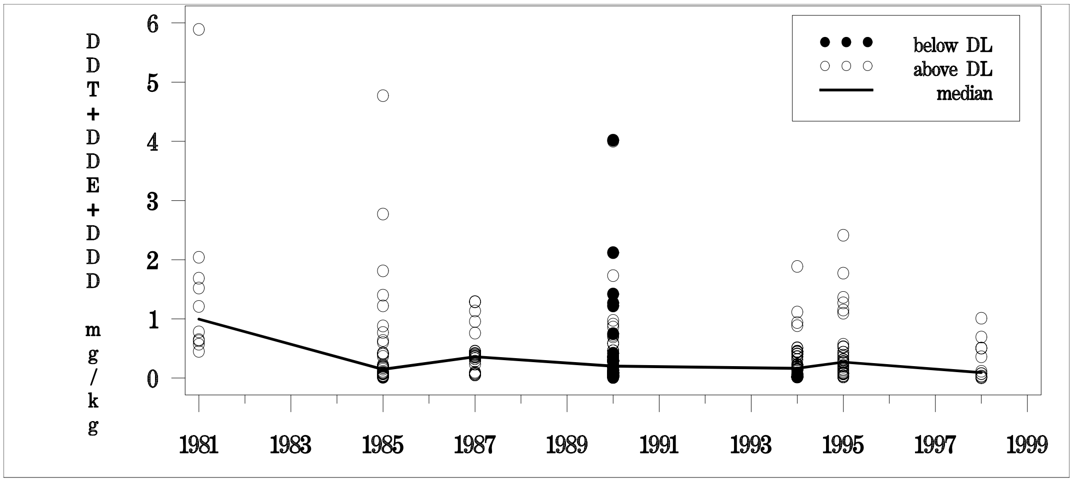
Figure 10.8 Total DDT in Town Lake Fish and Number of Samples for each Year, Location and Feeding Group (1981-1998)



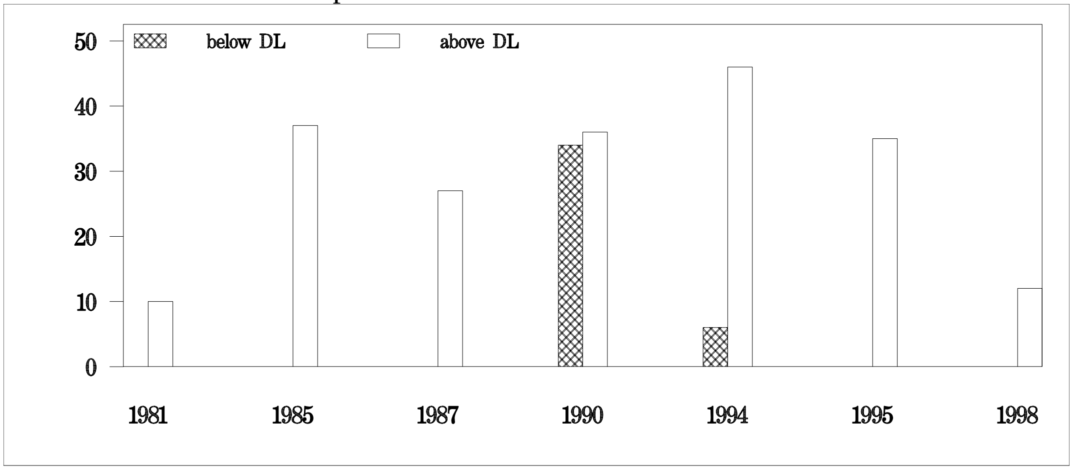
Eighty four percent of the 243 fish tissue concentrations were above the detection limits for DDT, with concentrations ranging from 0.005 to 5.89 ppm. The highest levels were observed in 1981 at the Basin. Before 1990, almost all the fish tissue concentrations of DDT and its derivatives were above the detection limits. After 1990, numerous measurements were observed below detection limits although detection limits were high in some cases (Figure 10.9). The maximum detected total DDT concentration in Town Lake fish has been declining and has been below the FDA action level of 5 mg/Kg in recent years. This decrease has been observed in spite of the increase in the length and weight of the captured fish (Figure 10.3). When the total DDT concentrations are normalized by weight in order to make comparison from between sampling years more meaningful, the decrease in the maximum normalized concentrations is even more pronounced. The predominant form of total DDT in recent samples is DDE, a DDT derivative.

Figure 10.9 Total DDT in Town Lake Fish (1981-1998)

DDT+DDE+DDD by year



Number of Samples above and below Detection Limit



Normalized DDT+DDE+DDD by year

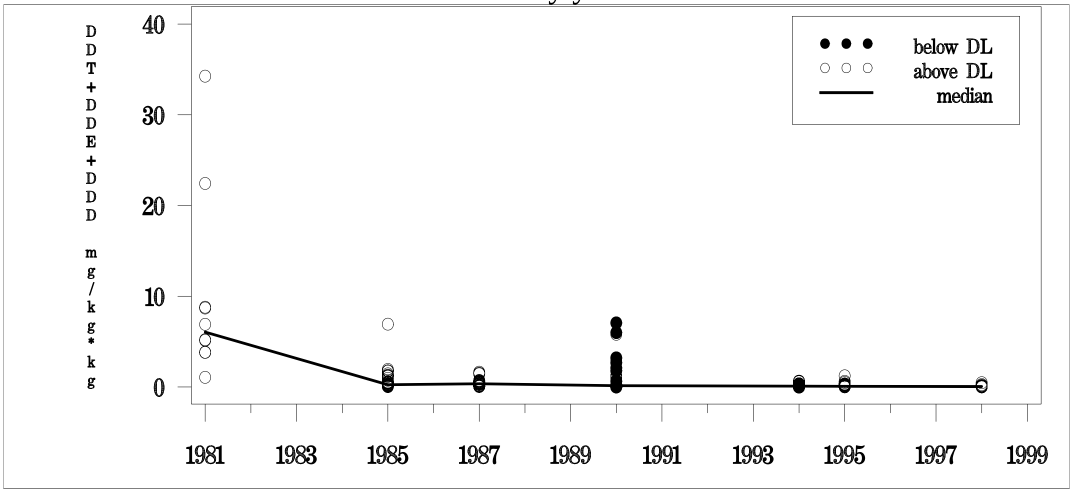
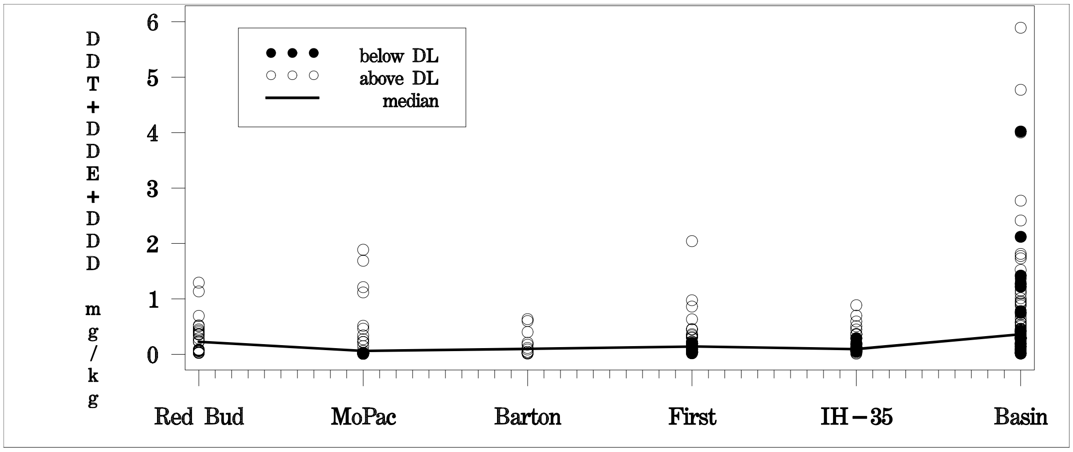
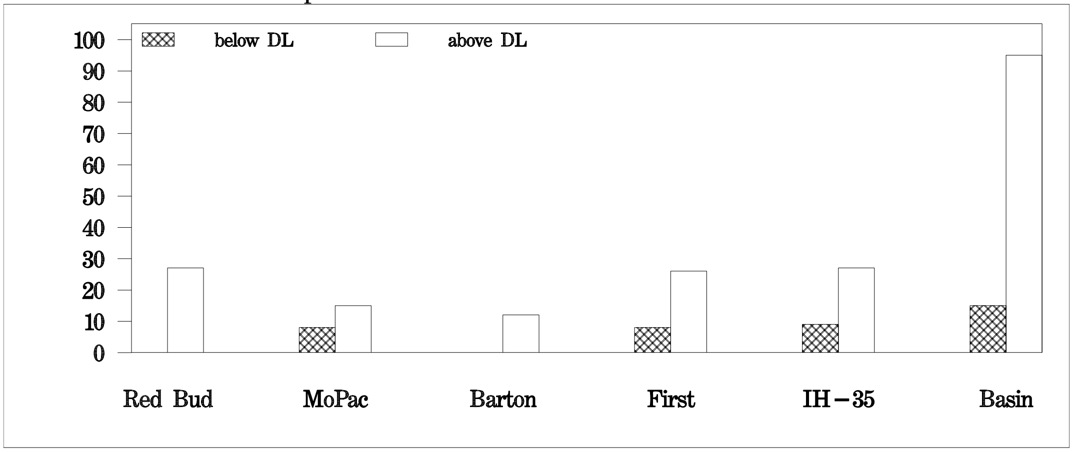


Figure 10.9 (continued) Total DDT in Town Lake Fish (1981-1998)

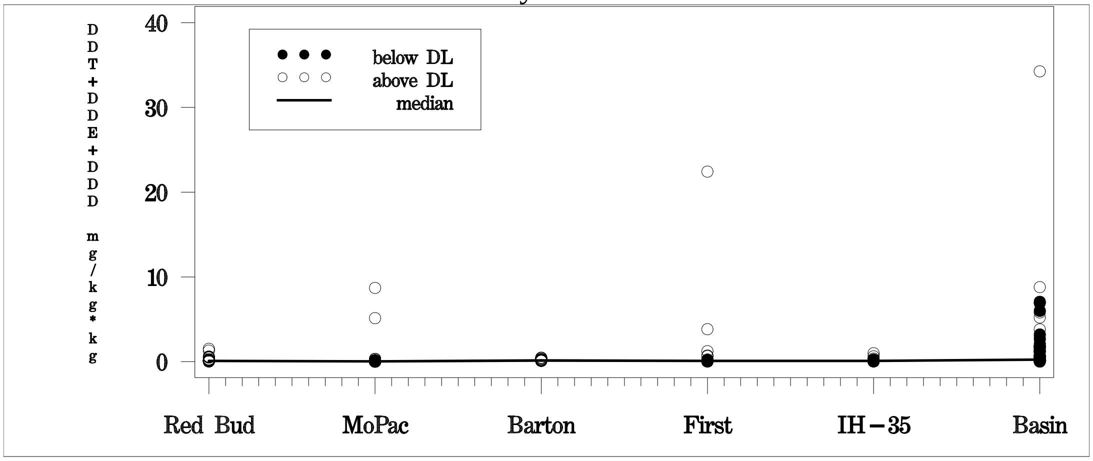
DDT+DDE+DDD by Location



Number of Samples above and below Detection Limit



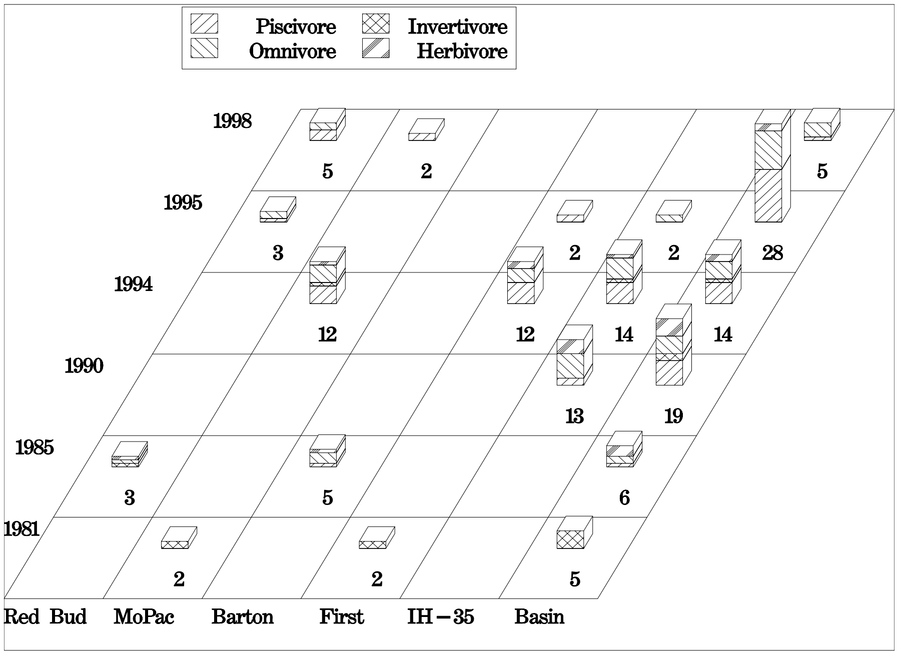
Normalized DDT+DDE+DDD by Location



10.4.3 PCBs

The number of PCB fish tissue samples for each year, location, and fish feeding group were examined (Figure 10.10).

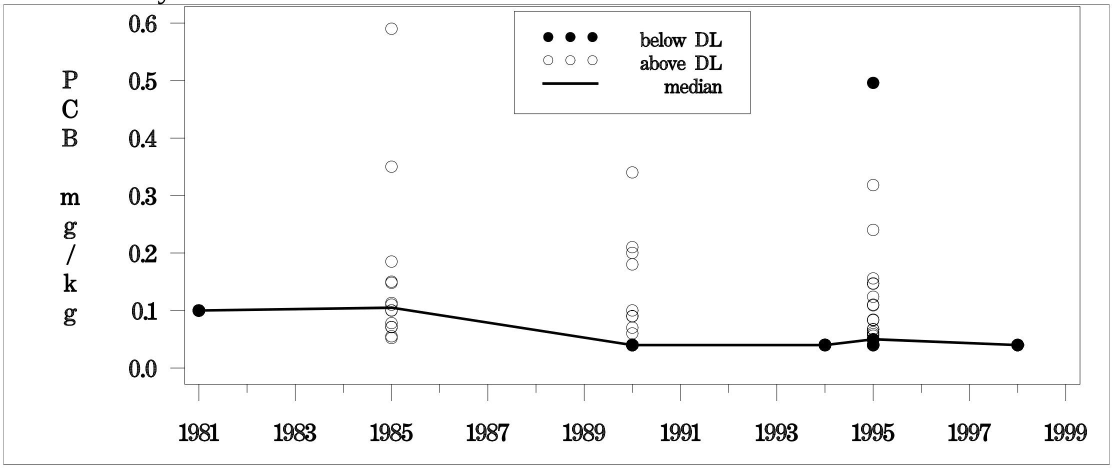
Figure 10.10 PCBs in Town Lake Fish and Number of Samples for Each Year, Location and Feeding Group (1981-1998)



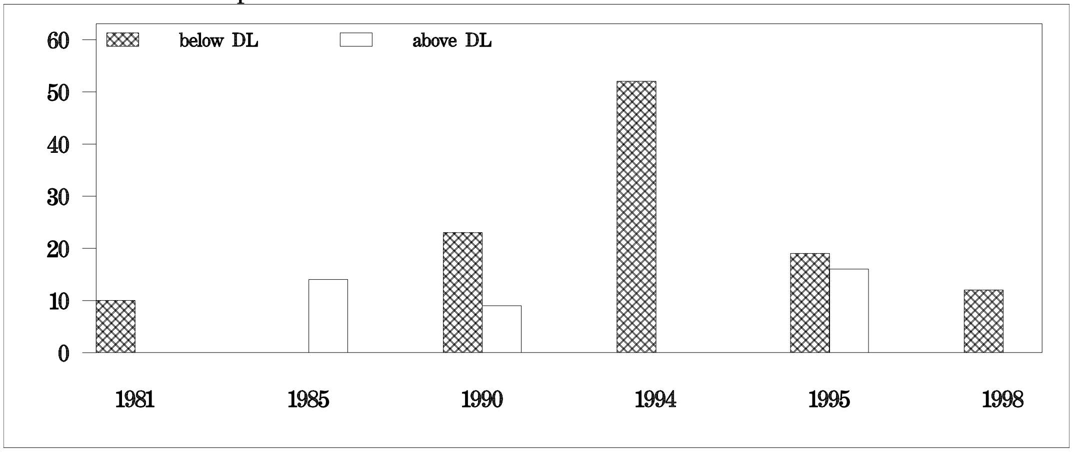
PCB levels above the detection limits were found in Town Lake fish in 1985, 1990, and 1995 (Figure 10.11). The detection limits do vary, and in 1995 the highest detection limit was greater than any detected concentration. Twenty-five percent of the 155 fish tissue samples had concentrations of PCBs above the detection limits, with concentrations ranging from 0.049 to 0.59 ppm. The highest level was observed in 1985 at the Basin. The maximum observed concentrations have decreased over time. When the PCB concentrations are normalized by weight in order to make comparison between sampling years more meaningful, the decrease in the maximum normalized concentrations is even more pronounced. No conclusions should be drawn from the high normalized values for 1981. These numbers are simply the detection limit divided by the weight of the fish and indicate that the fish were small and the detection limit was not.

Figure 10.11 PCBs in Town Lake Fish (1981-1998)

PCBs by Year



Number of Samples above and below Detection Limit



Normalized PCBs by Year

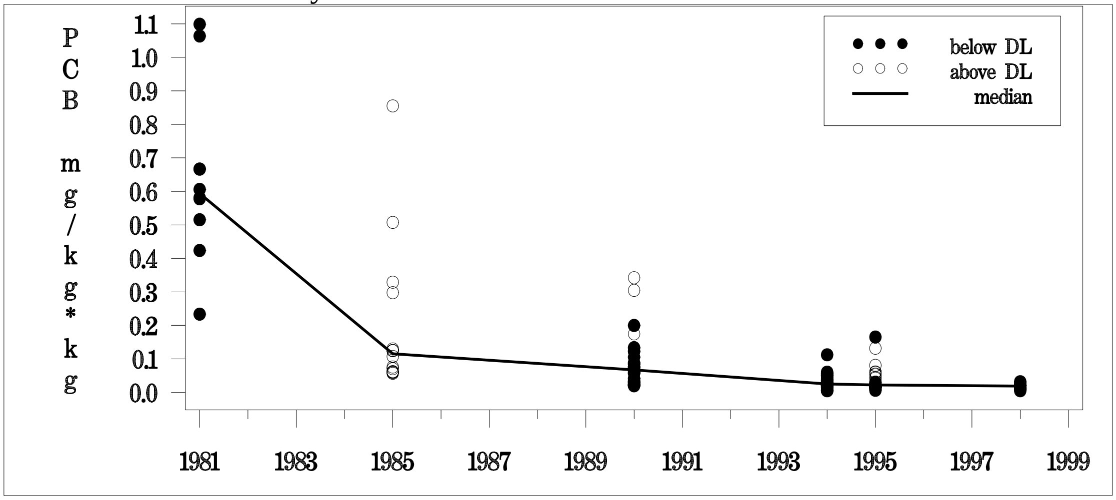
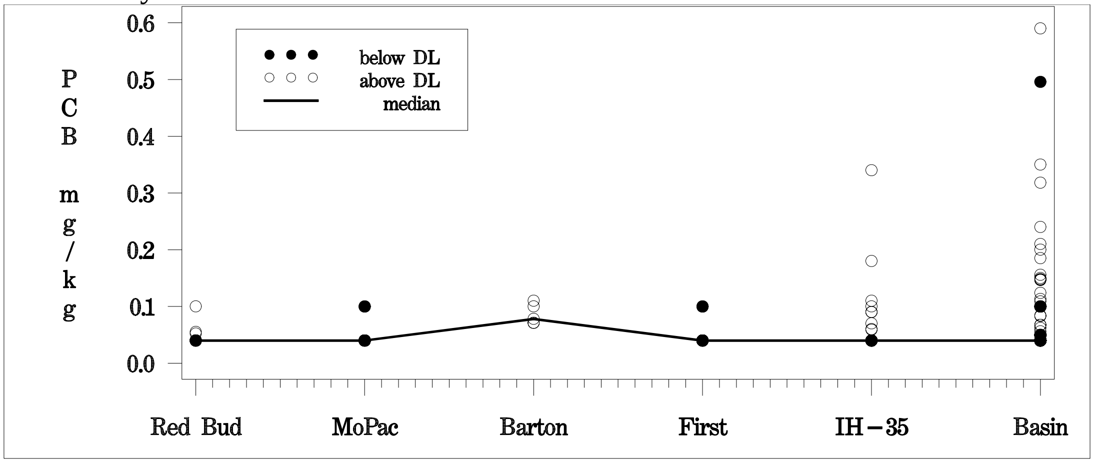
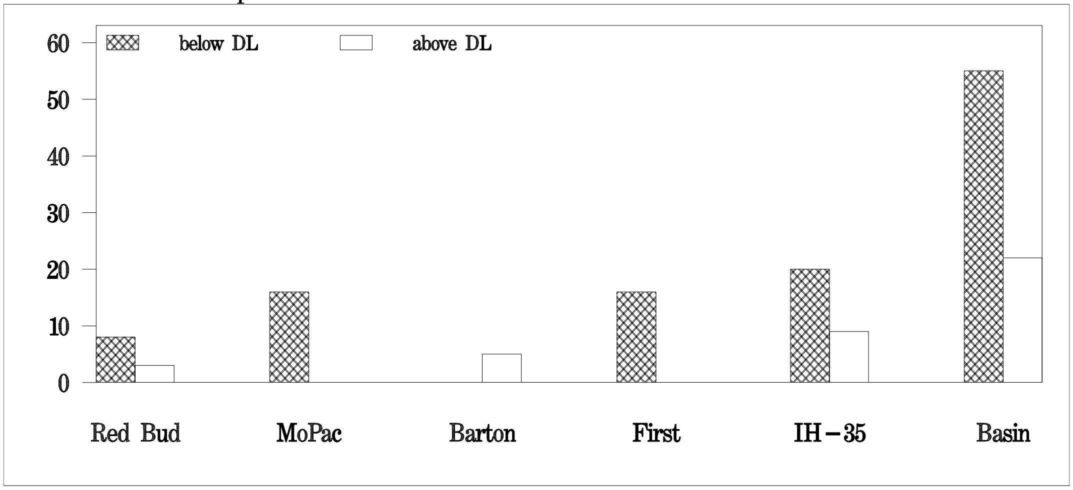


Figure 10.11 (continued) PCBs in Town Lake Fish (1981-1998)

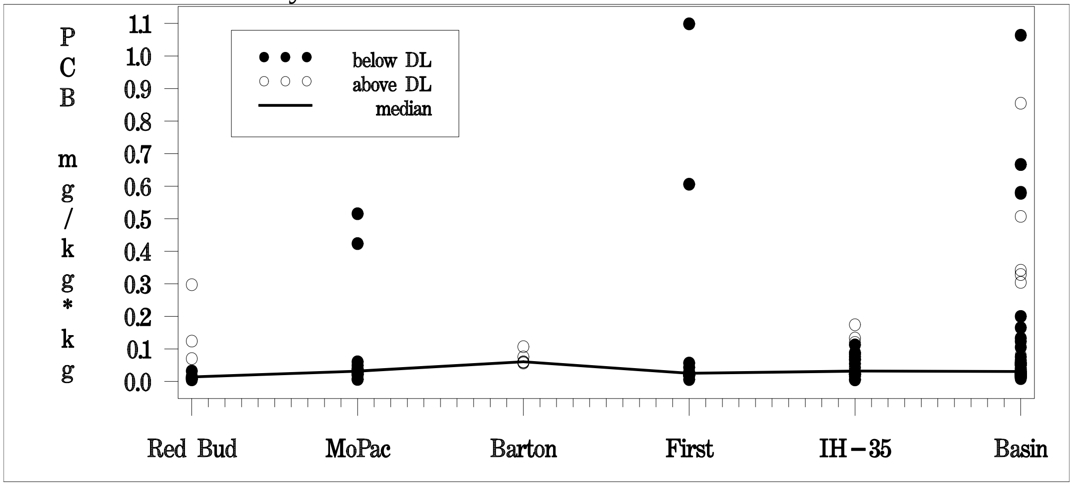
PCBs by Location



Number of Samples above and below Detection Limit



Normalized PCBs by Location

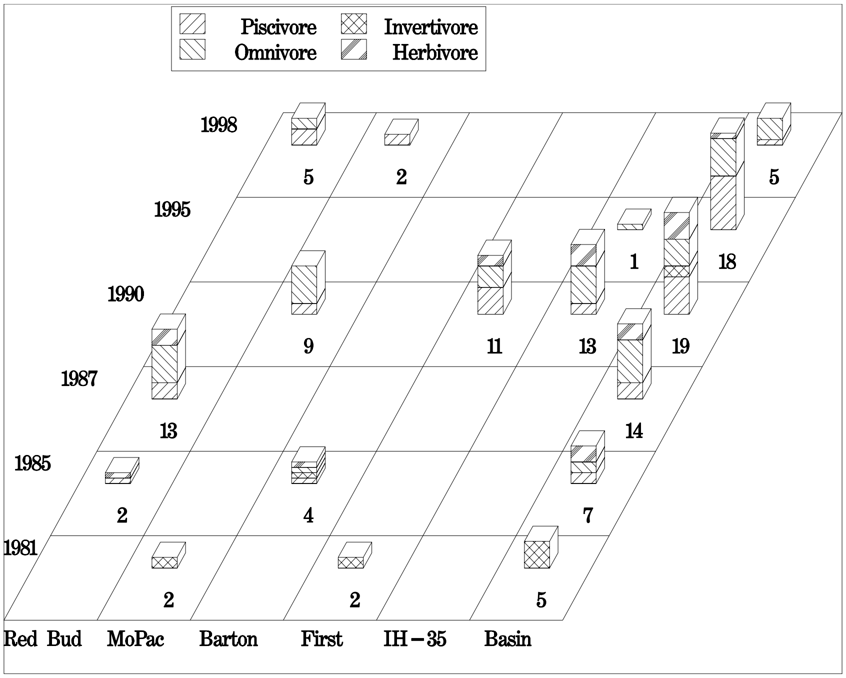


10.4.4 Metals

Only three metals -- mercury, zinc, and copper -- had sufficient data above the detection limits for meaningful analysis. Trends over time for these three metals will be discussed. Five other metals -- lead, chromium, arsenic, selenium, and cadmium -- had concentrations that were mostly below detection limits or were sampled infrequently, thus presentation of median values for these metals over time would be merely a history of lab detection limits. Plots of the data for these metals, however, are presented without substantive inferences being drawn about changes in fish tissue concentrations over time.

The number of mercury samples for each year, location, and fish feeding group (Figure 10.12) again highlight the unbalanced sample design. The Basin was the only site at which fish were sampled in each of the study years. Additionally, the types of fish that were captured differed from year to year. Almost all fish captured in 1985 were invertivores, for example, though none of the fish were invertivores in the 1995 and 1998 studies.

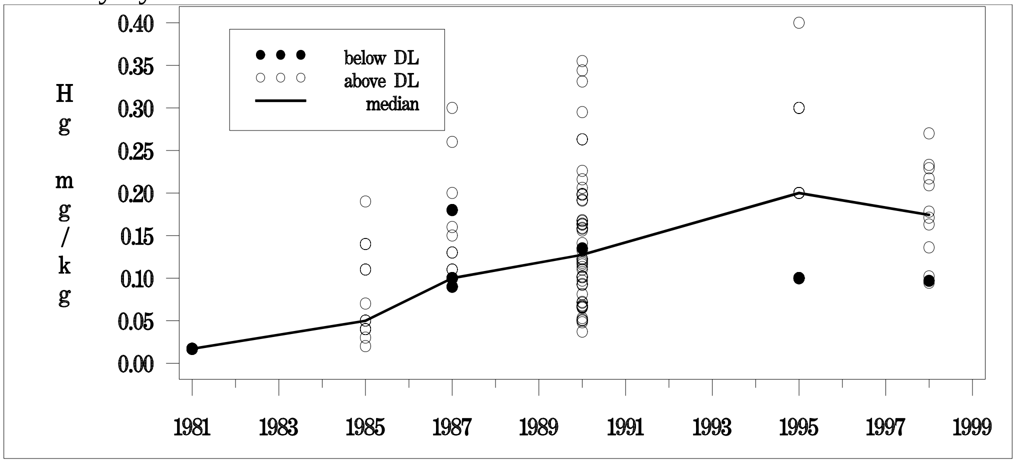
Figure 10.12 Mercury in Town Lake Fish and Number of Samples for Each Year, Location and Feeding Group (1981-1998)



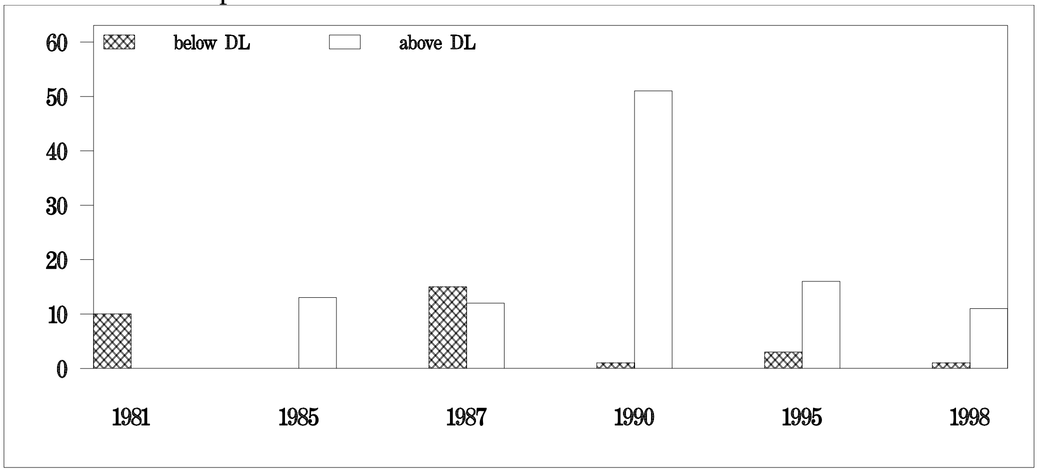
Seventy-seven percent of the 133 fish tissue concentrations were above the detection limits (Figure 10.13), with concentrations ranging from 0.02 to 0.4 ppm. The highest level was observed in 1995 at the Basin. Mercury does not follow the pattern of the majority of other parameters, as maximum mercury concentration have been steadily increasing rather than decreasing. When mercury concentrations are normalized by fish weight, however, levels peak in the middle of the time period for all the fish feeding groups.

Figure 10.13 Mercury in Town Lake Fish (1981-1998)

Mercury by Year



Number of Samples above and below Detection Limit



Normalized Mercury by Year

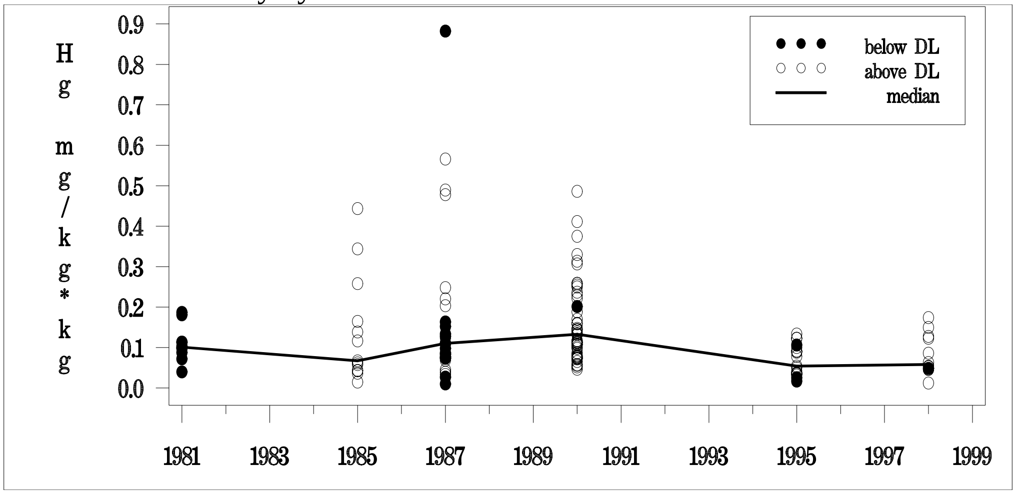
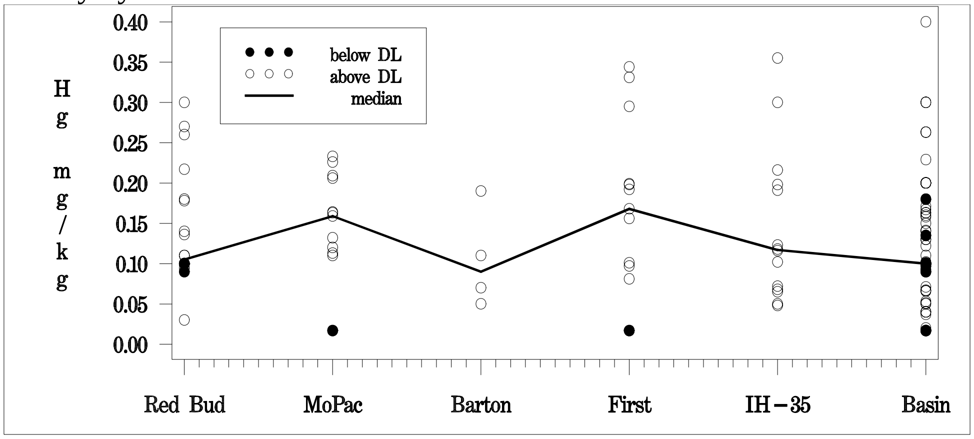
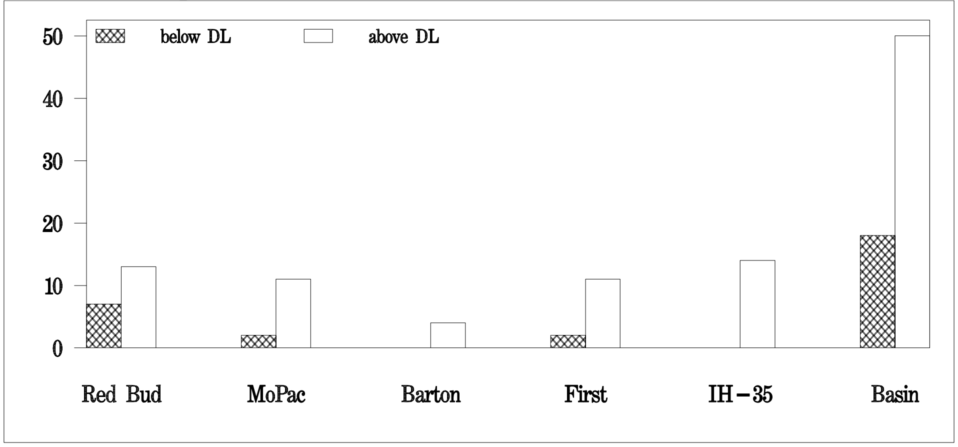


Figure 10.13 (continued) Mercury in Town Lake Fish (1981-1998)

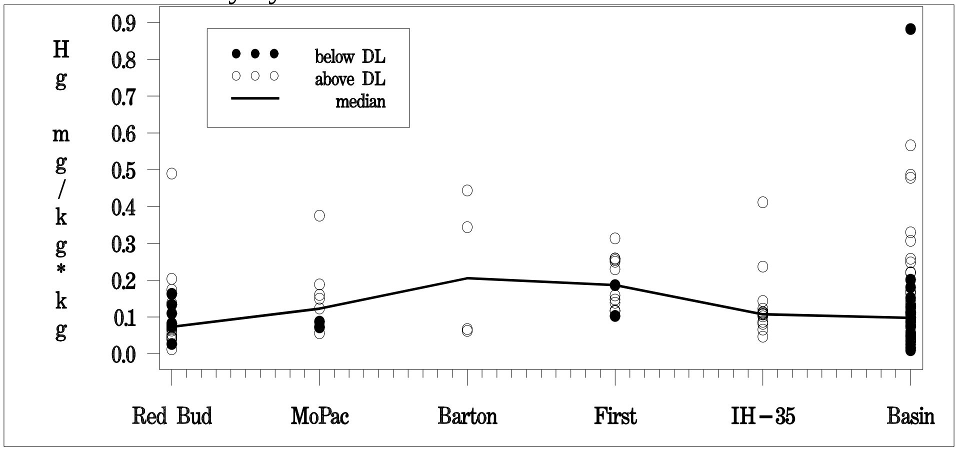
Mercury by Location



Number of Samples above and below Detection Limit



Normalized Mercury by Location



In January 2001, the USEPA announced a new reference dose for methylmercury of $1x10^{-4}$ mg/Kg-day and recommended that all mercury in fish should be assumed to be methylmercury (USEPA 2001). The recommended monthly fish consumption limits for methylmercury in fish based on USEPA default values for risk assessment parameters for the fish sampled from Town Lake in 1998 were calculated (Table 10.6). Twelve fish were analyzed for mercury and only one had mercury levels below a detection limit of 0.097 mg/Kg. Consumption limits have been calculated as the number of allowable 8-ounce fish meals per month for a 72 Kg adult based on the ranges of methylmercury in the consumed fish tissue.

Table 10.6 Monthly Fish Consumption Limits for Methylmercury

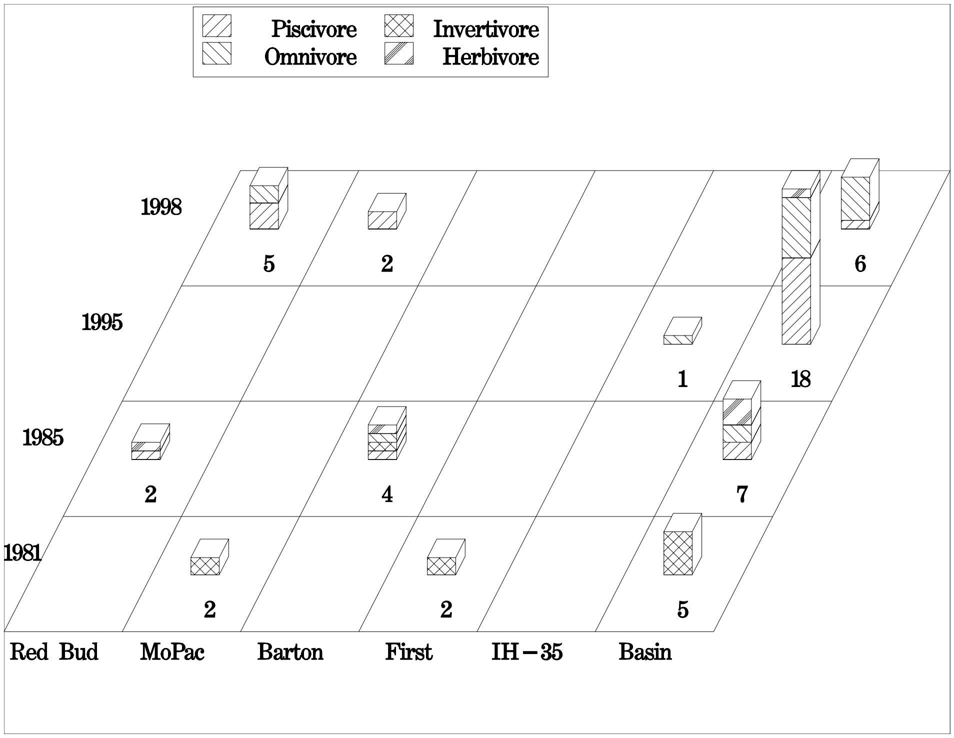
1998 Town Lake Fish (% in Category)	Risk-Based Consumption Limit (8oz fish meals/month)	Non-cancer health endpoints (Fish tissue concentrations in mg/Kg wet weight)
17%	8	0.08 to 0.12
67%	4	0.12 to 0.24
8%	3	0.24 to 0.32

from USEPA 2001

While the State of Texas has not yet adopted federal criteria, the prudent adult will eat no more than four 8-ounce fish meals from Town Lake per month. Additionally, the USEPA announced a new methylmercury Fish Tissue Residue Criterion of 0.3 mg/Kg fish. This represents the concentration in fish tissue that should not be exceeded based on a total fish and shellfish consumption-weighted rate of 4 ounces of fish per week. In 1995, 21 percent of the fish, including largemouth bass, flathead catfish, and freshwater drum, had mercury concentrations of at least 3 mg/Kg. In 1998; however, none of the fish tissue levels were above the 0.3 mg/kg level.

The number of zinc samples in fish tissue for each year, location, and fish feeding group were examined (Figure 10.14).

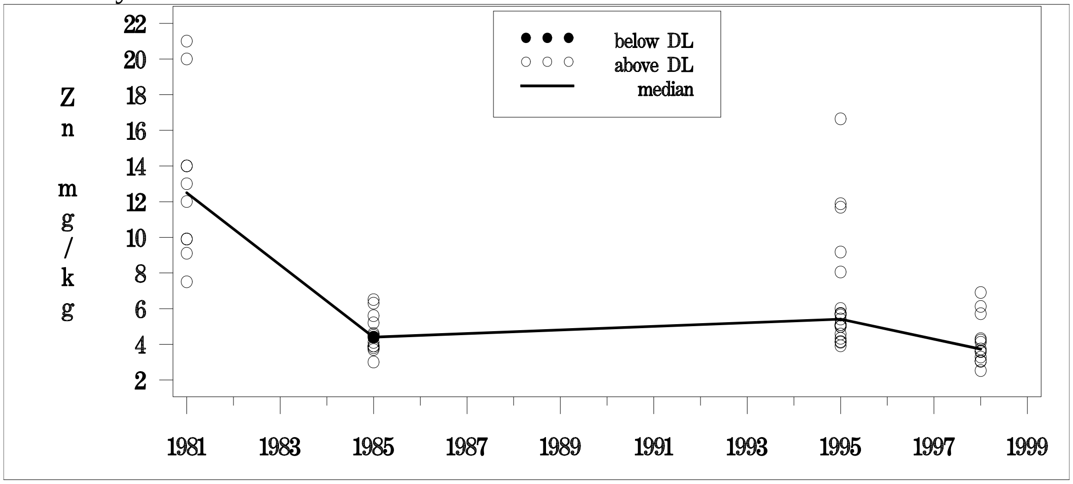
Figure 10.14 Zinc in Town Lake Fish and Number of Samples for each Year, Location and Feeding Group (1981-1998)



Zinc tissue levels were determined in 1981, 1985, 1995, and 1998. All but one of the 55 fish tissue samples had concentrations above the detection limits (Figure 10.15), with concentrations ranging from 2.5 to 21.0 ppm. The highest concentration was observed in 1981 at MoPac. Maximum concentrations decreased in 1985, increased in 1995, and then decreased again in 1998. When the concentrations were normalized, the typical pattern of decreasing maximum and median concentrations becomes apparent. The change from 1985 to 1998 is minimal, implying that normalized zinc concentrations may be stable in Town Lake fish.

Figure 10.15 Zinc in Town Lake Fish (1981-1998)

Zinc by Year



Number of Samples above and below Detection Limit

Normalized Zinc by Year

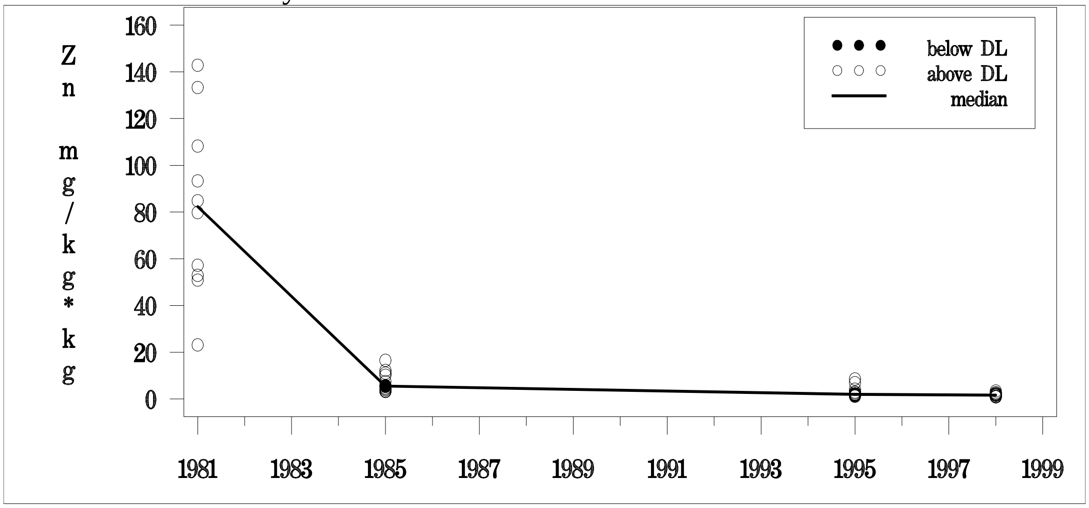
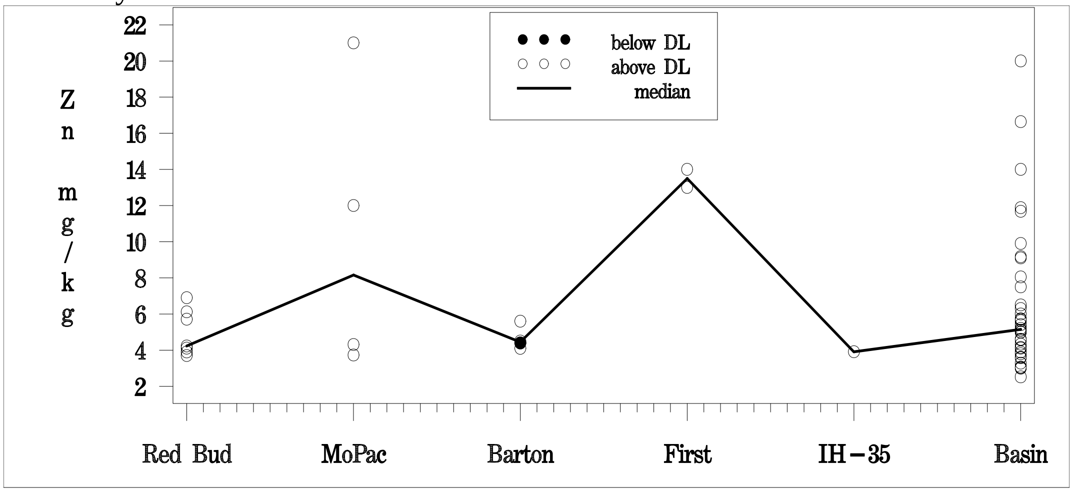


Figure 10.15 (continued) Zinc in Town Lake Fish (1981-1998)

Zinc by Location



Number of Samples above and below Detection Limit

Normalized Zinc by Location

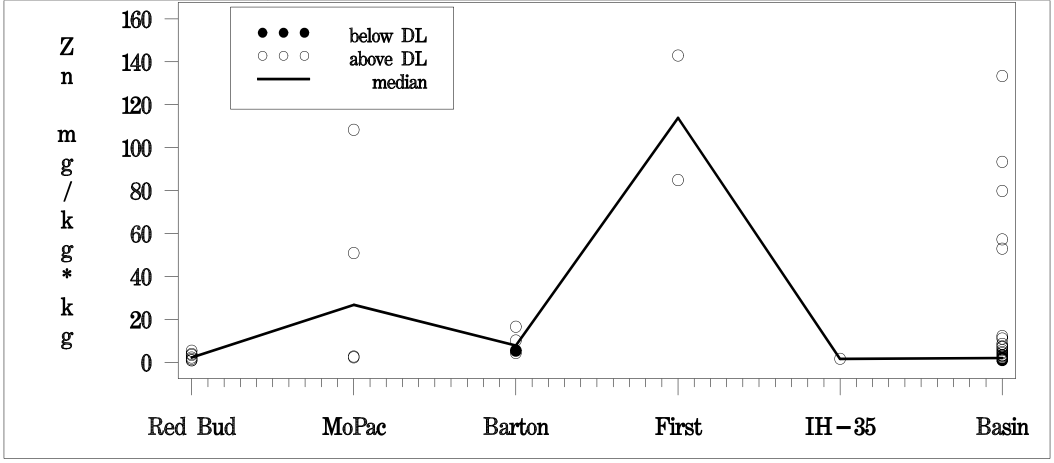
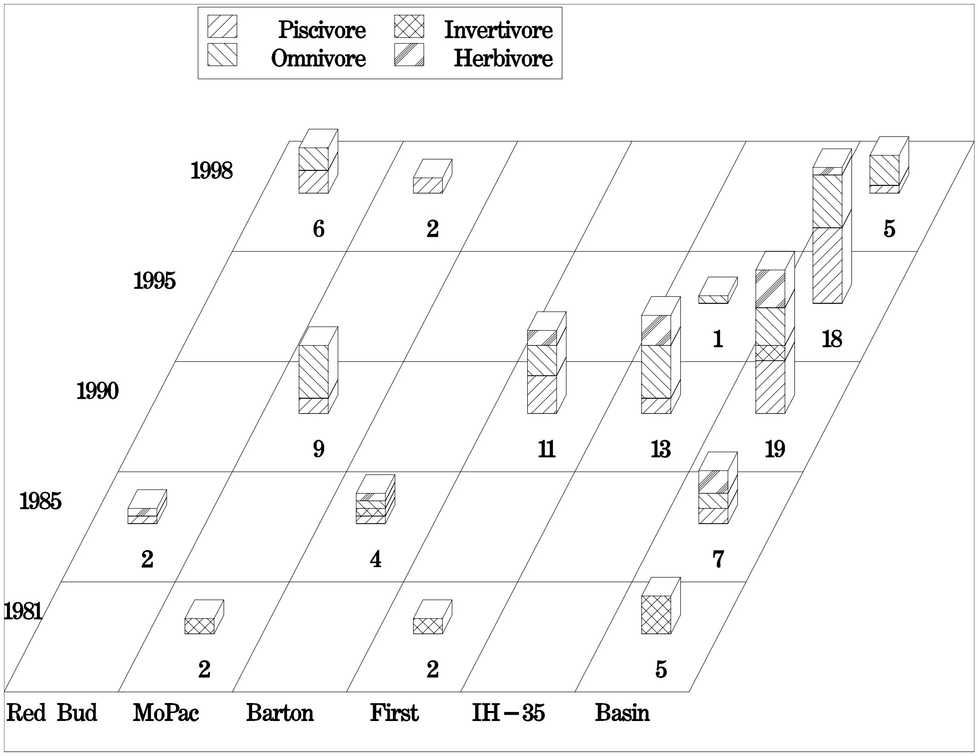


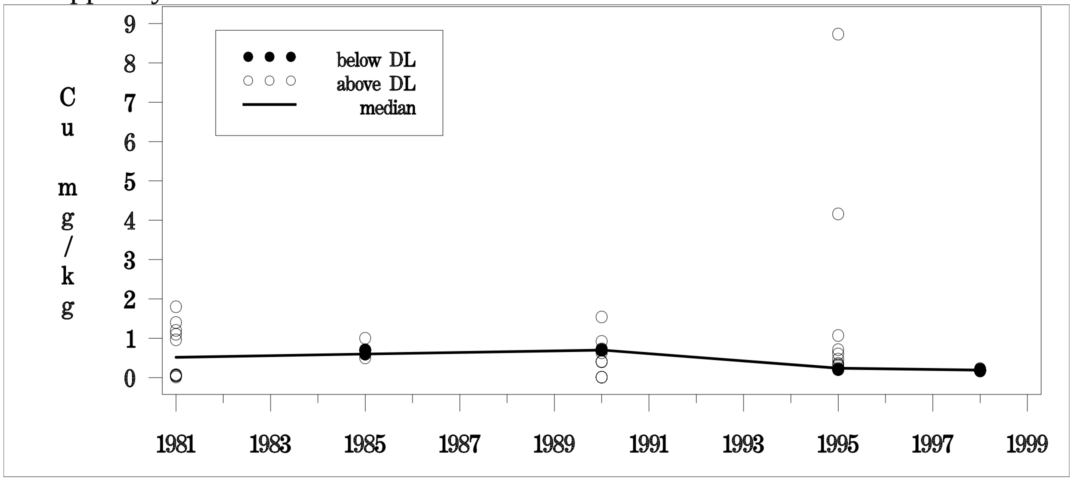
Figure 10.16 Copper in Town Lake Fish and Number of Samples for each Year, Location and Feeding Group (1981-1998)



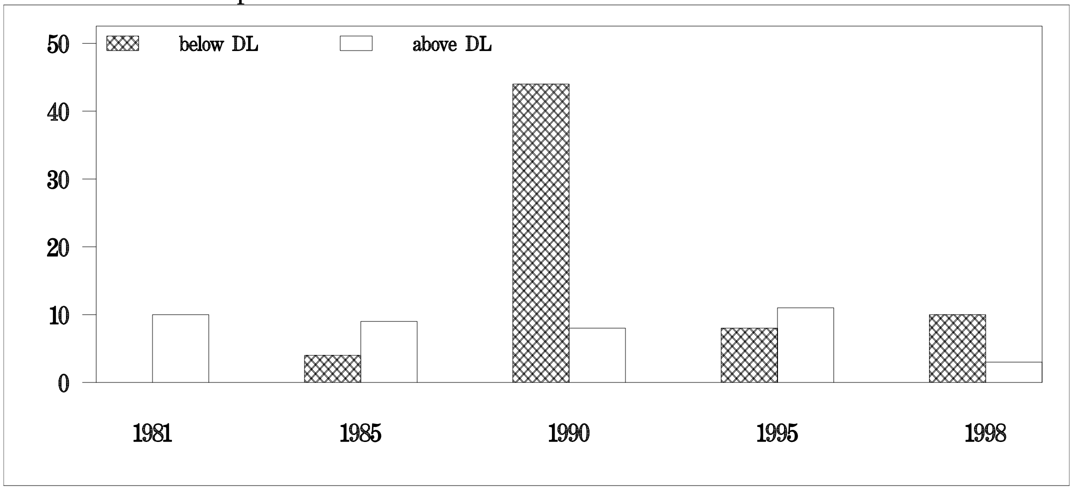
Forty-one percent of the 107 fish tissue samples had copper concentrations above detection limits (Figure 10.17), with concentrations ranging from 0.01 to 8.7 ppm. The highest levels were observed in 1995 at the Basin. The normalized concentrations, however, were highest in 1981, remained approximately the same from 1985 to 1995, and then decreased in 1998.

Figure 10.17 Copper in Town Lake Fish (1981-1998)

Copper by Year



Number of Samples above and below Detection Limit



Normalized Copper by Year

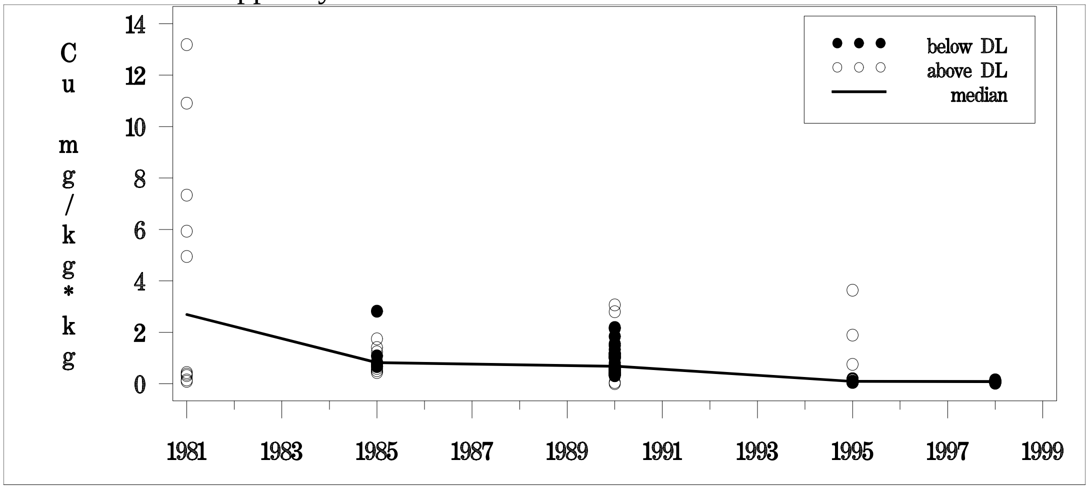
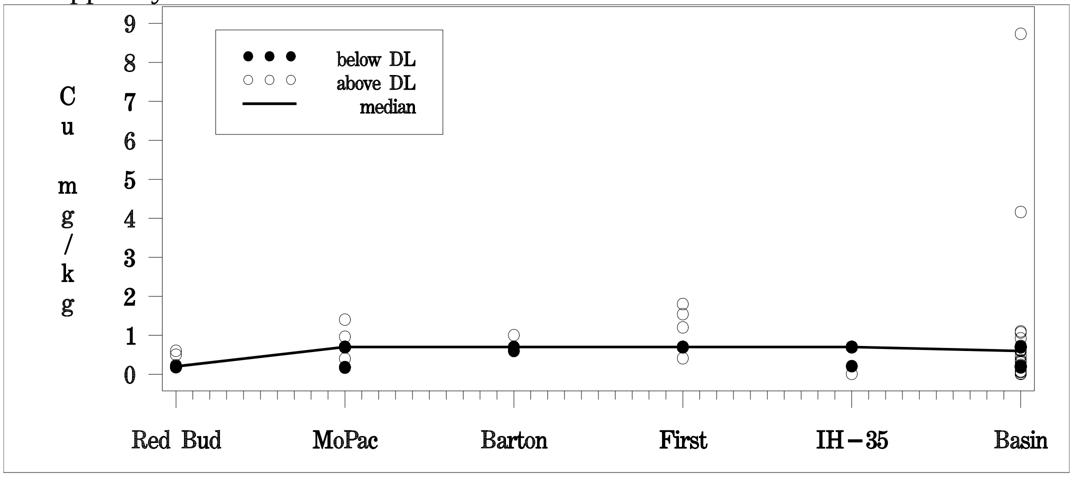
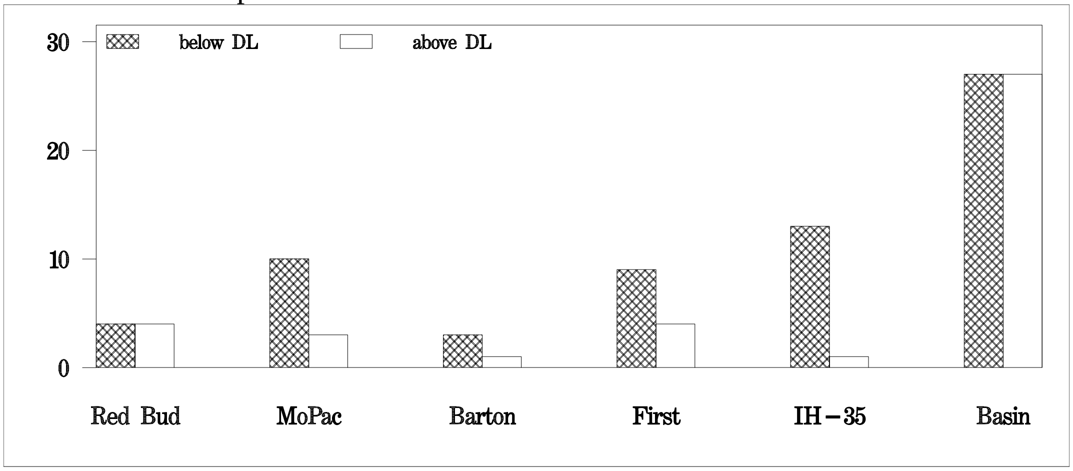


Figure 10.17 (continued) Copper in Town Lake Fish (1981-1998)

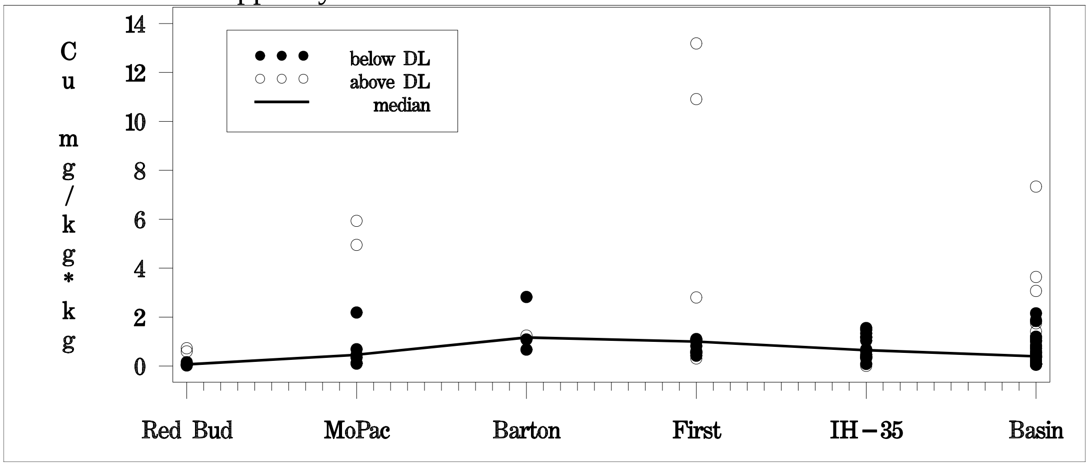
Copper by Location



Number of Samples above and below Detection Limit



Normalized Copper by Location



Only 15 percent of the 121 fish tissue concentrations were above the detection limits for lead (Figure 10.18), with concentrations ranging from 0.10 to 2.2 ppm. The highest lead levels were observed in 1990 at First Street. Lead may display a time pattern similar to that of mercury, which peaks in the middle of the time period, but the small number of data points above detection limit and the change in the detection limit over time make conclusions unsupportable.

Only 32 percent of the 66 fish tissue concentrations of chromium were above the detection limits (Figure 10.18), with concentrations ranging from 0.22 to 1.0 ppm. The highest level was observed in 1987 at Red Bud. The large number of samples with concentration below a relatively high detection limit in 1990 makes conclusions untenable.

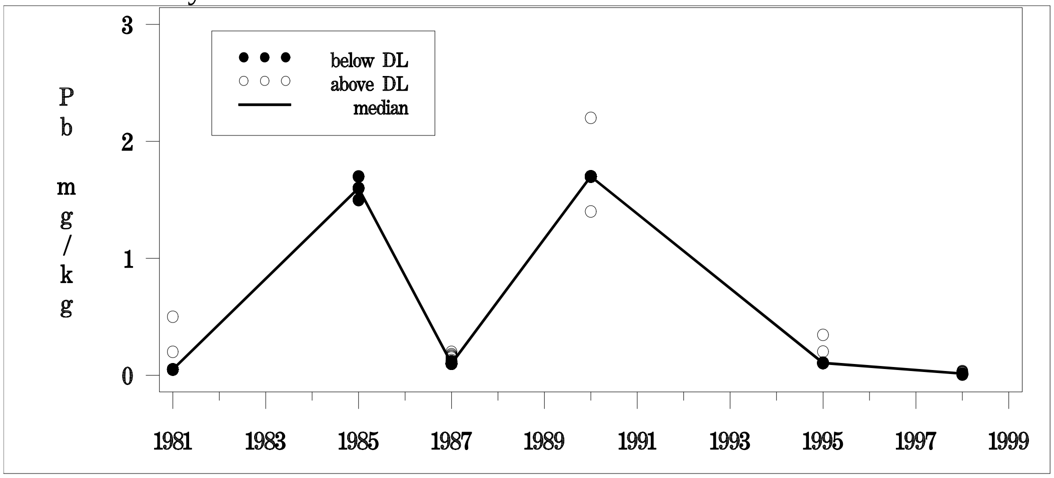
Only 16 percent of the 69 fish tissue concentrations for arsenic were above the detection limits (Figure 10.19), with concentrations ranging from 0.025 to 0.340 ppm. The highest levels were observed in 1987 at Red Bud. Arsenic may display a time pattern similar to that of mercury and lead, which peaks in the middle of the time period, but again the small number of data points above detection limit and the change in the detection limit over time make conclusions unsupportable.

Selenium tissue levels were determined in only two years: 1990 and 1998. Approximately 63 percent of the 32 fish tissue concentrations were above detection limits for selenium (Figure 10.19), with concentrations ranging from 0.13 to 0.49 ppm. The levels were lower in 1998 than in 1990. The highest level was observed in 1990 at First Street.

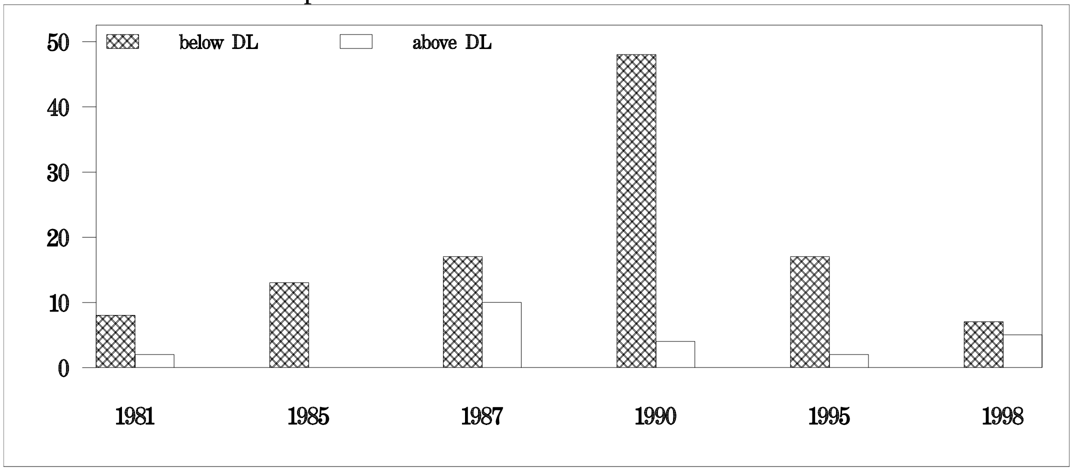
Cadmium tissue levels were above the detection limit in only two years: 1981 and 1998. Approximately 30 percent of the 56 fish tissue concentrations of cadmium were above the detection limits (Figure 10.20), with concentrations ranging from 0.0005 to 0.021 ppm. The levels were similar in 1981 and 1998. The highest level was observed at Red Bud in 1998.

Figure 10.18 Lead and Chromium in Town Lake Fish (1981-1998)

Lead by Year



Number of Samples above and below Detection Limit



Normalized Lead by Year

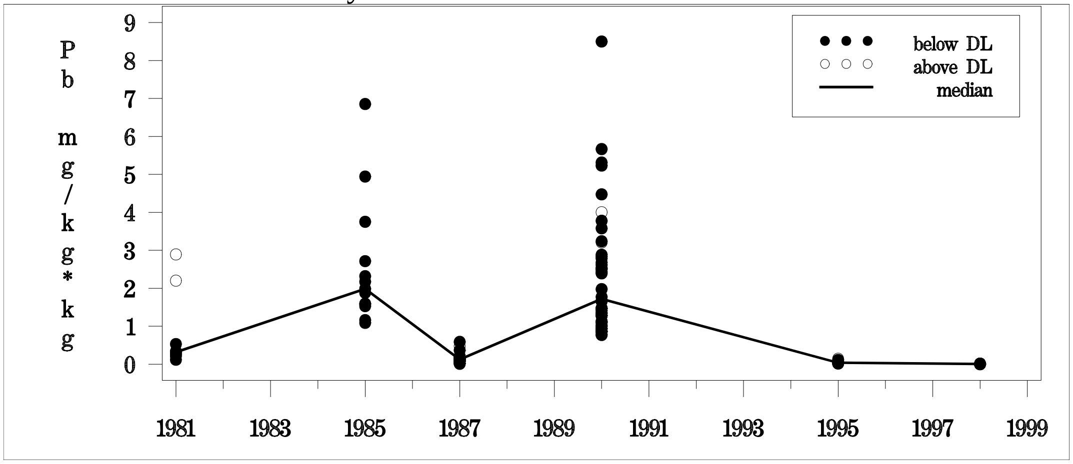
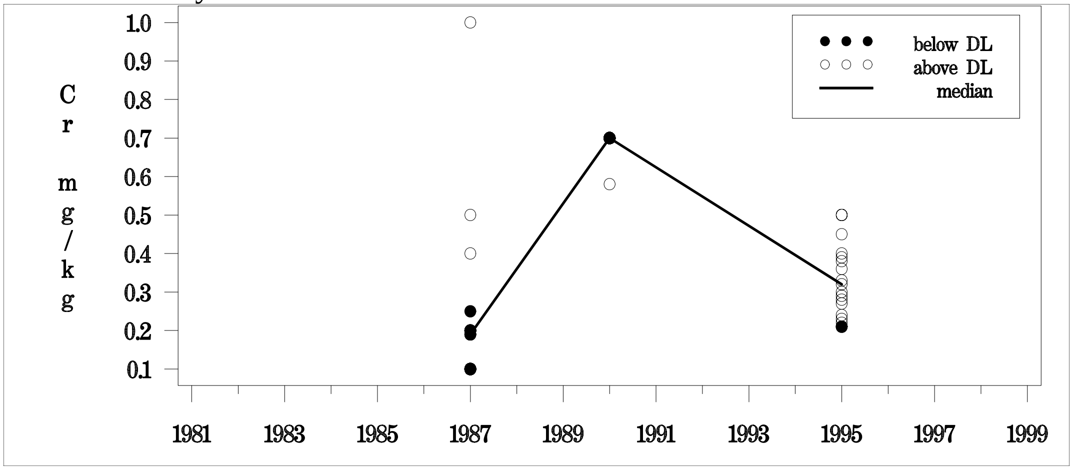


Figure 10.18 (continued) Lead and Chromium in Town Lake Fish (1981-1998)

Chromium by Year



Number of Samples above and below Detection Limit

Normalized Chromium by Year

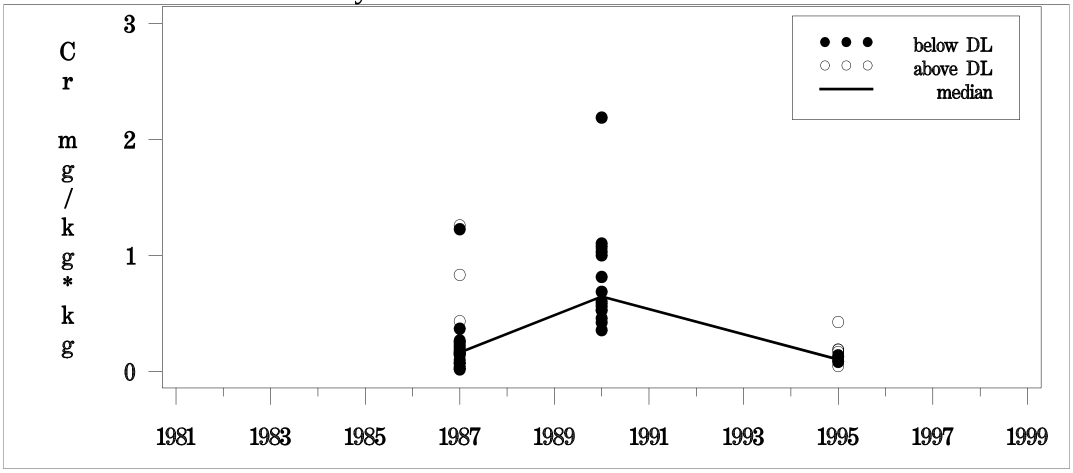
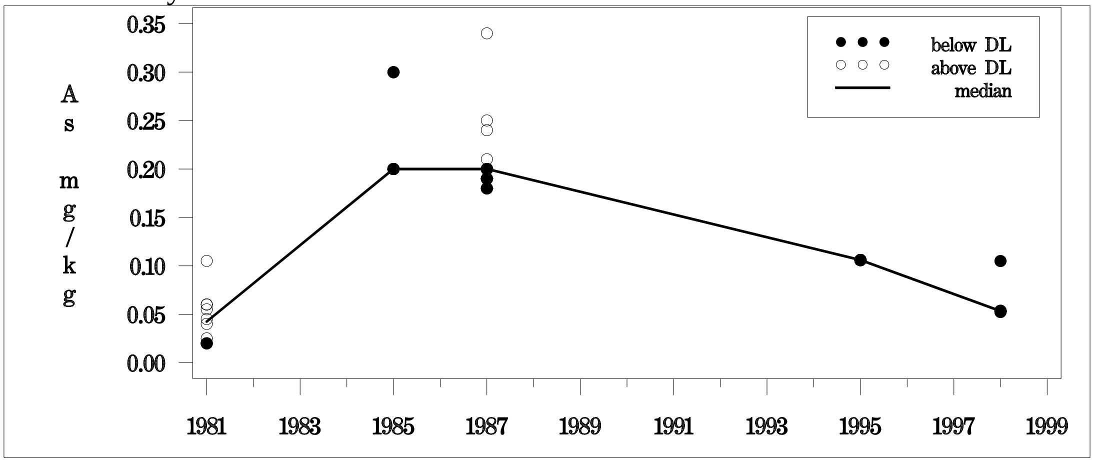
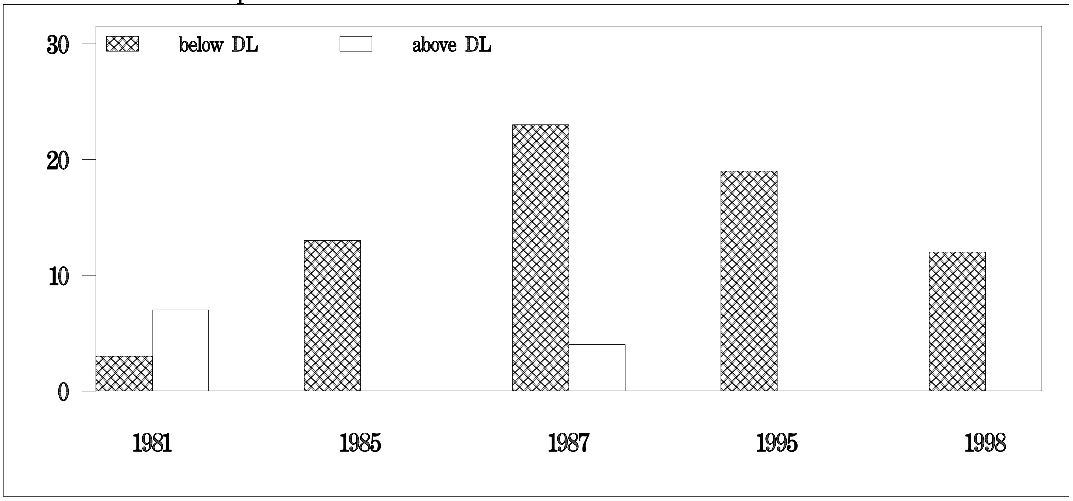


Figure 10.19 Arsenic and Selenium in Town Lake Fish (1981-1998)

Arsenic by Year



Number of Samples above and below Detection Limit



Normalized Arsenic by Year

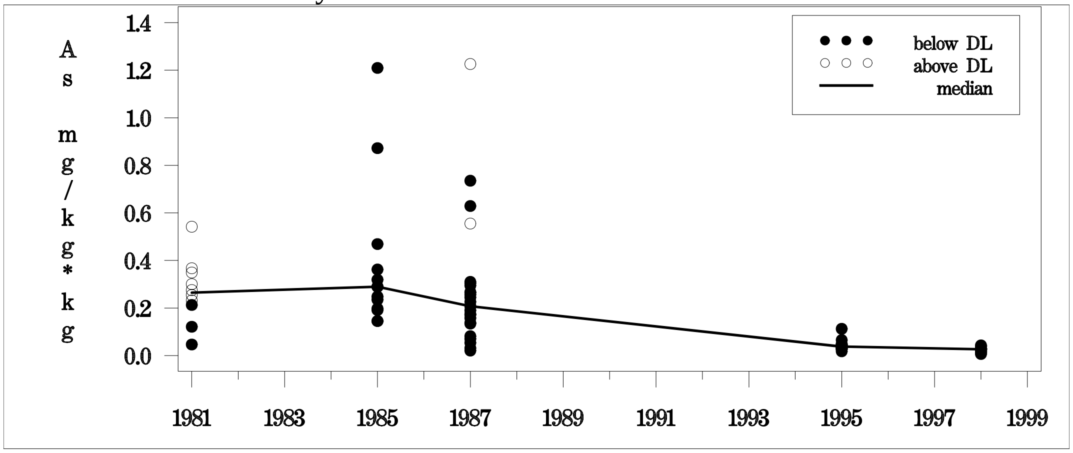
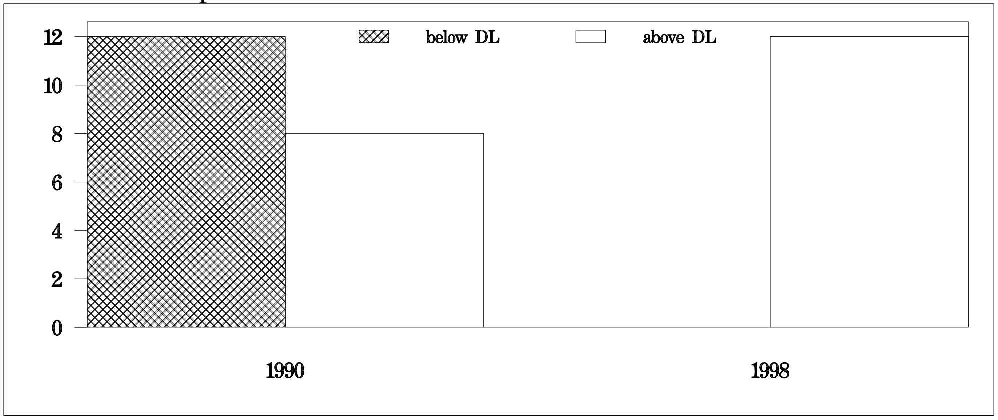


Figure 10.19 (continued) Arsenic and Selenium in Town Lake Fish (1981-1998)

Selenium by Year

Number of Samples above and below Detection Limit



Normalized Selenium by Year

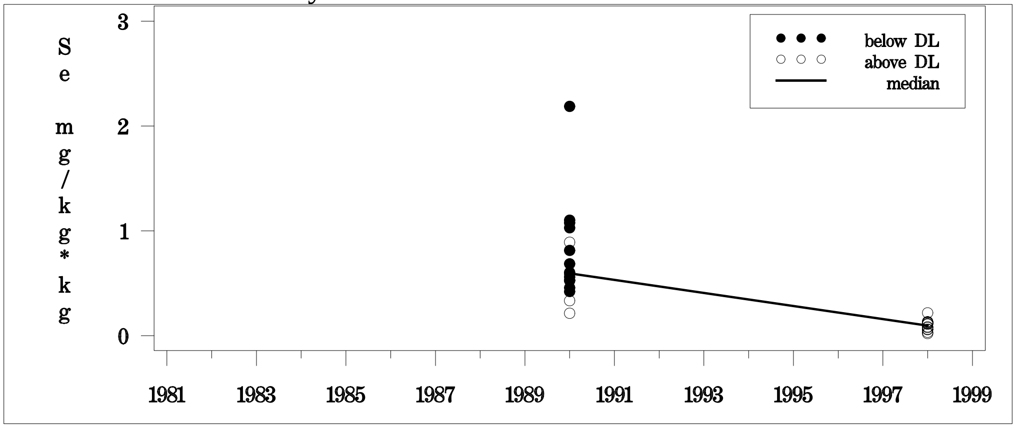
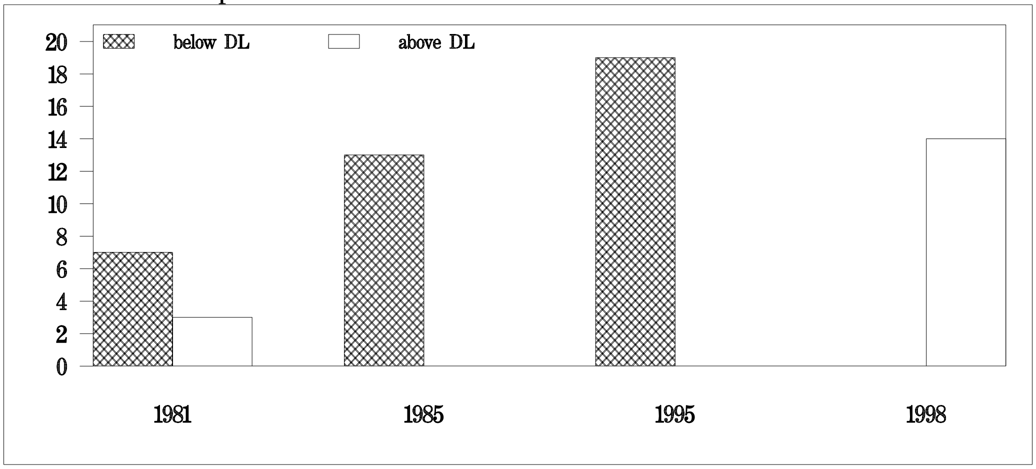


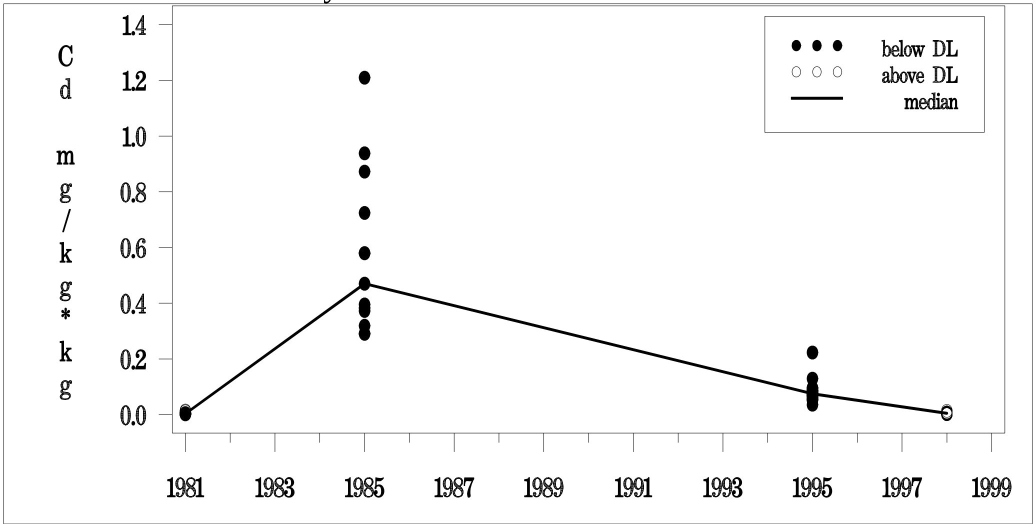
Figure 10.20 Cadmium in Town Lake Fish (1981-1998)

Cadmium by Year

Number of Samples above and below Detection Limit



Normalized Cadmium by Year



10.5 Summary of Results

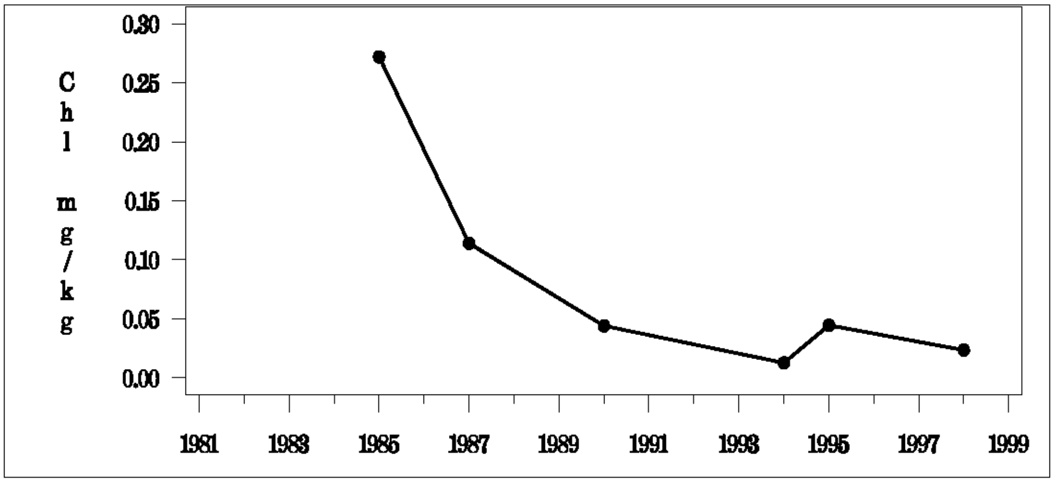
Fish tissue concentrations were normalized (divided) by the weight of the fish for trend evaluations. The concentration medians were calculated for each year for which data were available. The parameters included chlordane; PCBs; the sum of DDT, DDD, and DDE; copper; mercury; and zinc. The change in median concentration over time was assessed (Figure 10.21). All the parameters except mercury have their highest concentration in the first year they were measured, followed by a substantial drop at the succeeding measurement. Only mercury displays a different pattern from the other parameters, with peaks in the middle of the time period rather than at the beginning. After the drop, the decline is more gradual or even essentially level. However, the averaged concentrations of chlordane, the sum of DDT, DDD, and DDE, and PCBs in 1995 were still high enough to require a fish consumption advisory. The overall declining trend in toxins in fish tissue reached low enough levels in 1998 to support lifting of the TDH Fish Consumption Advisory on October 26, 1999 (TDH 1999).

The fish were split into feeding groups in order to examine the effect of diet on changes in tissue concentrations over time using normalized median fish tissue concentrations by group (Figure 10.22). The four fish feeding groups are the piscivores, omnivores, benthic invertivores and herbivores. The ranking of the four feeding groups does not change if non-normalized median concentrations are analyzed. The fish that eat benthic macroinvertebrates usually had the highest median concentrations of pesticides, PCBs, and metals in their tissue. The next highest concentrations were typically found in the herbivores. Gizzard shad were the only herbivores sampled, and the high concentrations observed in gizzard shad tissue may be the result of high oil content and their frequent bottom feeding. Fish in the herbivore and invertivore groups, including shad and sunfish, comprise about half of the fish population and were not sampled at all in 1998. The 1998 study resulted in lifting the fishing ban and met TDH requirements for representation of consumption patterns. Tissue concentrations of pollutants are typically higher in these groups than in the piscivore and omnnivore feeding groups that were included in the 1998 analysis. While shad are not typically eaten by people, sunfish may be. It is likely but not certain that concentrations in these types of fish are below levels of concern.

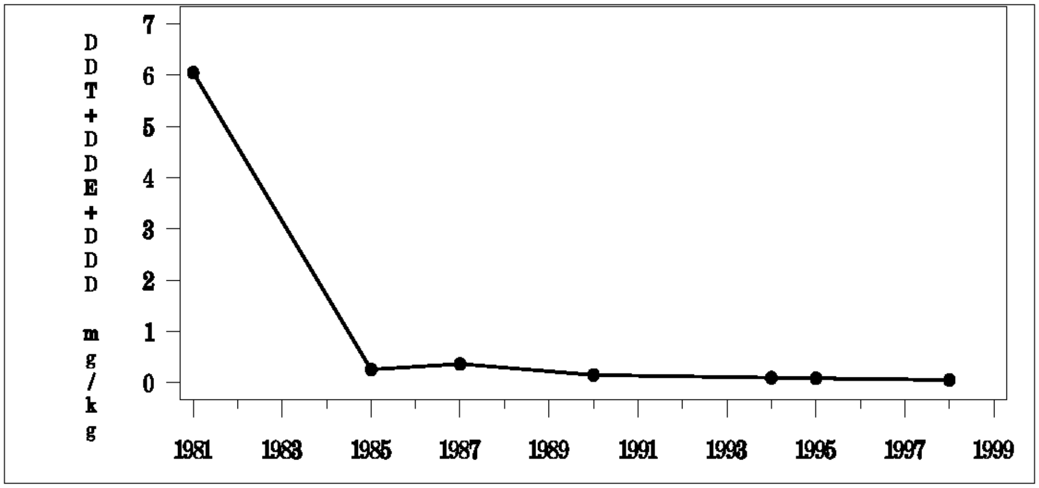
Piscivores and omnivores displayed the lowest normalized concentrations. The median metals concentrations were slightly higher in the piscivores than the omnivores, though concentrations of pesticides and PCBs were approximately the same between these two groups.

Figure 10.21 Normalized Median Concentrations in Town Lake

Chlordane



DDT + DDE + DDD



PCBs

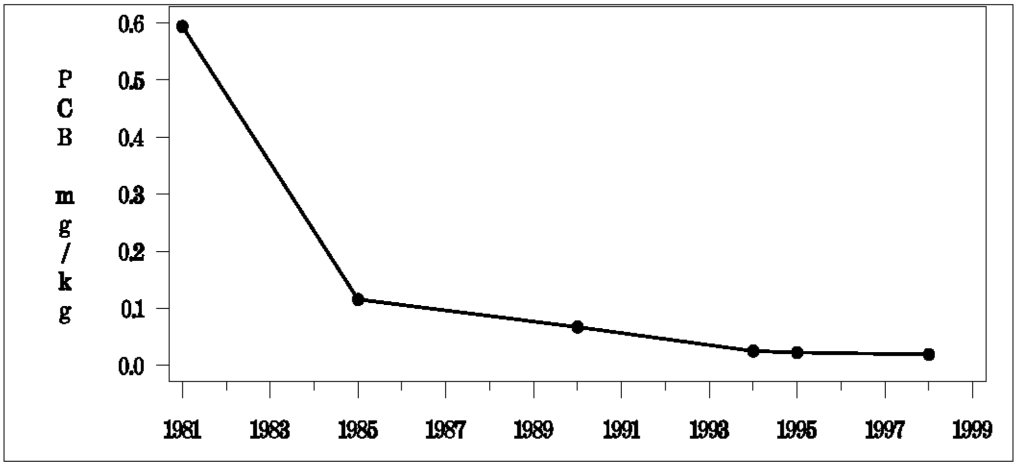
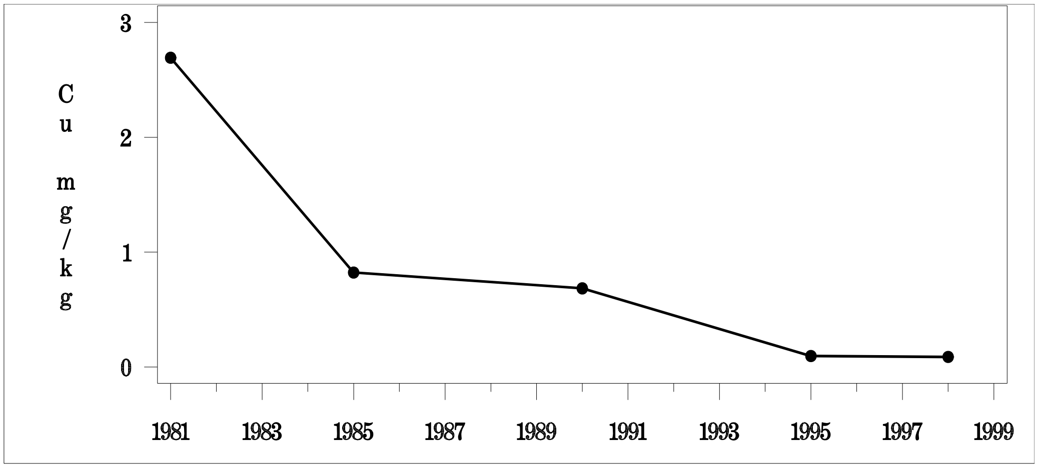


Figure 10.21 (continued) Normalized Median Concentrations in Town Lake

Copper

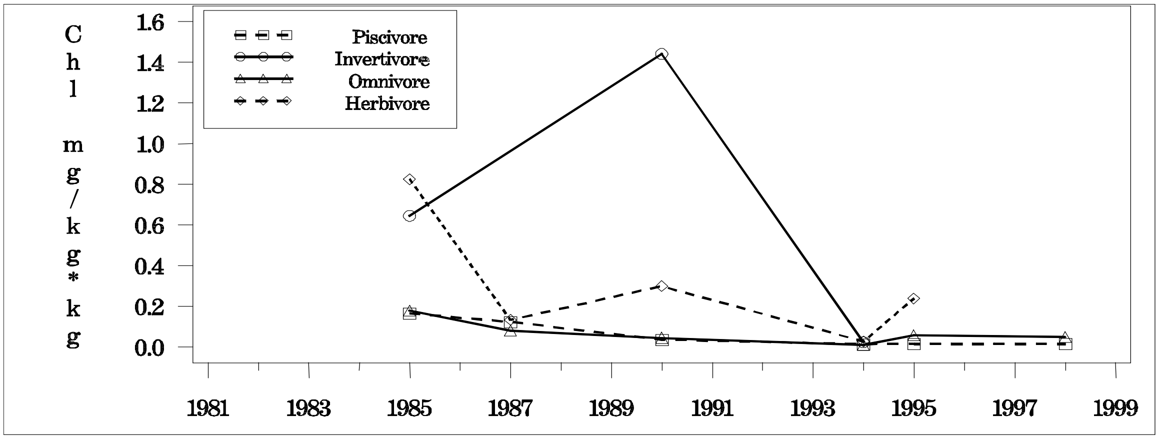


Mercury

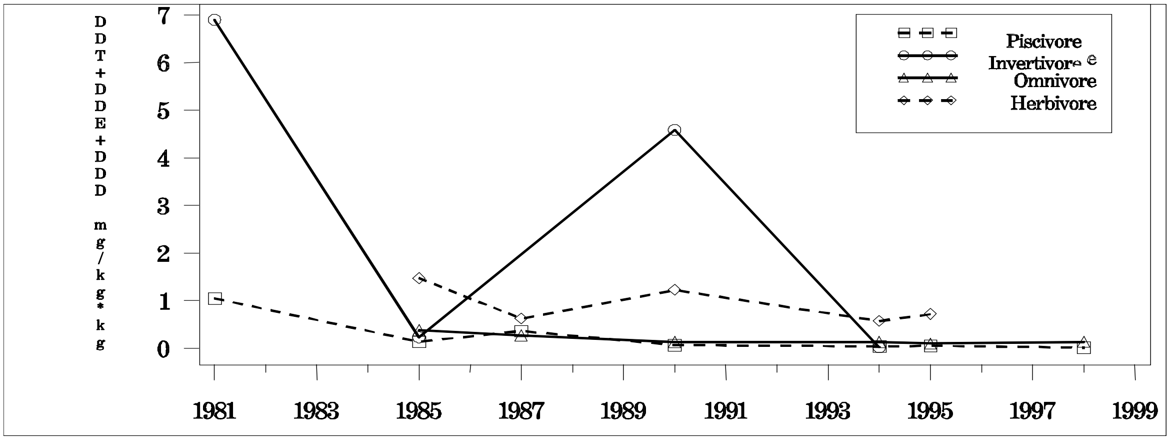
Zinc

Figure 10.22 Normalized Median Concentrations by Feeding Group in Town Lake Fish

Chlordane



DDT + DDE + DDD



PCBs

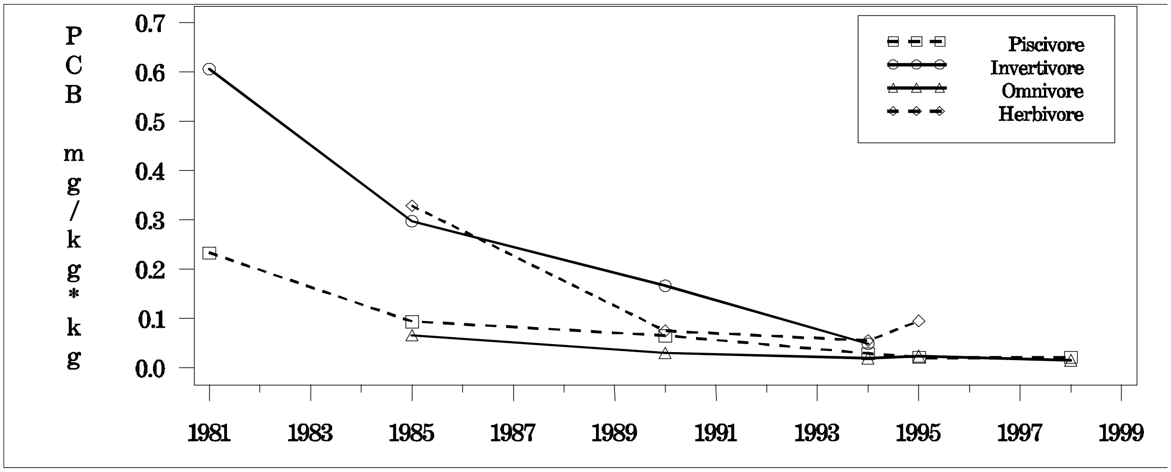
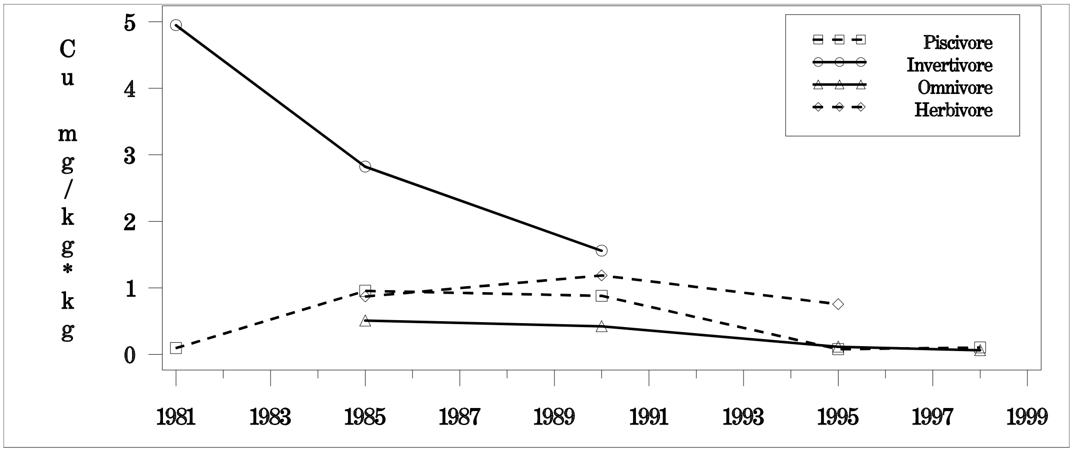
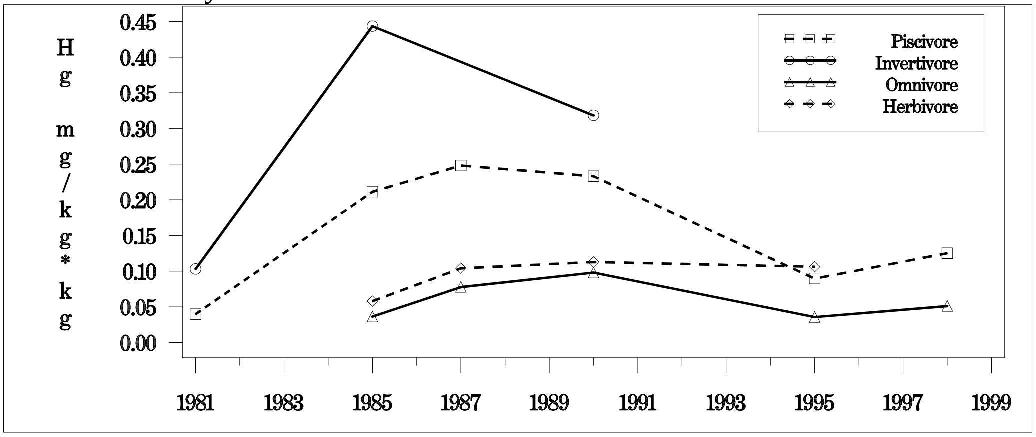


Figure 10.22 (continued) Normalized Median Concentrations by Feeding Group in Town Lake Fish

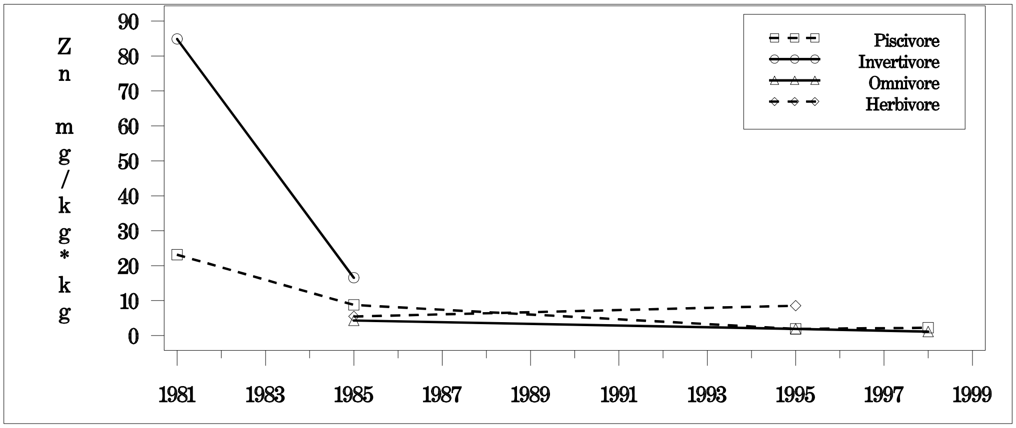
Copper



Mercury



Zinc



11.0 VISUAL INDEX OF POLLUTION

Trash and debris have been indicated as a problem since the first Town Lake Report (COA 1992a). Removal or amelioration of that trash and debris has also been a goal since that time. This goal to reduce visual pollution and enhance the recreational activities associated with Town Lake remains in the new Watershed Protection Master Plan (COA 2001b).

11.1 Index Development and Goals

The Visual Index of Pollution (VIP) was first implemented in April 1994 to provide a periodic measure of COA litter control performance by documenting visible trash on the shores of Town Lake. An increase or decrease in the amount of trash along these waterways can indicate the usefulness of several methods of trash abatement currently used by COA, such as trash booms and inlet filters.

The VIP is currently used as part of the Watershed Engineering and Field Operation Division (WEFOD) performance measure for trash and debris abatement. The original WEFOD goal for the index was to have a 10 percent decrease in scores each year. The VIP was one of 11 scoring factors used to calculate the problem severity score for Town Lake in the Watershed Protection Master Plan (COA 2001b). The plan included Town Lake as one of the receiving waters incorporated into the water quality problem area scoring system used to prioritize watersheds. The lake was broken into two segments, Upper Town Lake and Lower Town Lake. The upper segment provides water for the Green Water Treatment Plant, a source of Austin's municipal water supply. A goal of excellent (overall score of 1) was set for both segments.

The index was originally designed as a photometric one, using photos taken quarterly at the same sites and evaluated by volunteers to determine whether trash and debris were accumulating over time. Variable quality of the photographs presented some problems, including viewer difficulty in distinguishing between trash and other objects, such as rocks and waterfowl. Additionally, the photos covered only a portion of the shoreline. After five years of surveying, it became apparent that certain litter-prone areas were not being accurately assessed or targeted for clean up.

The April 1999 photometric index (PI) results were invalidated because volunteers had problems distinguishing between litter and other objects in more than 30 percent of the slides. This prompted a review of several litter indices, and the method was revised based on Keep America Beautiful's draft Litter Index, an on-site assessment that has shown validity and reproducibility in preliminary pilots. The Watershed Protection Department's Business Plan was amended to include a new short-term target using the revised method: maintaining an annual lake-wide average score of no greater than 2. Since a new target was set when the on-site assessment was implemented, methods and results have been separated by assessment type.

11.2 Photometric Index

The Photometric Index was used from 1994 to 1999. This method consisted of photographing selected portions of the Town Lake shoreline on a quarterly basis and a subsequent evaluation of the photos by volunteers to designate the trash and debris coverage.

The first set of slides was taken in April 1994, establishing baseline data prior to the beginning of trash abatement measures. From April 1995 through April 1999, slides were taken quarterly.

11.2.1 Methods

Seventy sites along the lakeshore were chosen for the index, based on at least one of the following criteria: 1) above or below creek deltas where the inflow of trash may occur, 2) at public access points to the lake or 3) in an alcove where trash floating downstream may accumulate. Easily recognizable landmarks were included in the slides and each site was photographed similarly to its previous photo so that each set could be compared from survey to survey.

At least five volunteers were asked to view the slides and rate each site on a scale of 1 to 5, with 1 being little or no litter, and 5 being a large amount of litter. To facilitate consistency among volunteers, slides with assigned rankings were shown prior to each survey. To document variability among groups of volunteers, one set of slides (April 1995) was shown with each new set and the variations in rankings were documented. These are listed as quality control (QC) averages and help explain some differences in yearly scores, since they are measures of each group's perception of the same set of slides.

11.2.2 Results

Average scores and percentage reduction or increase for each fiscal year (October survey of one year; January, April, and July surveys of the next) were calculated (Table 11.1). Data include the PI scores only. The following datasets were incomplete: 1994-1995 January, 1997-1998 October (missing), and 1998-1999 April.

Table 11.1 Average Annual VIP Scores

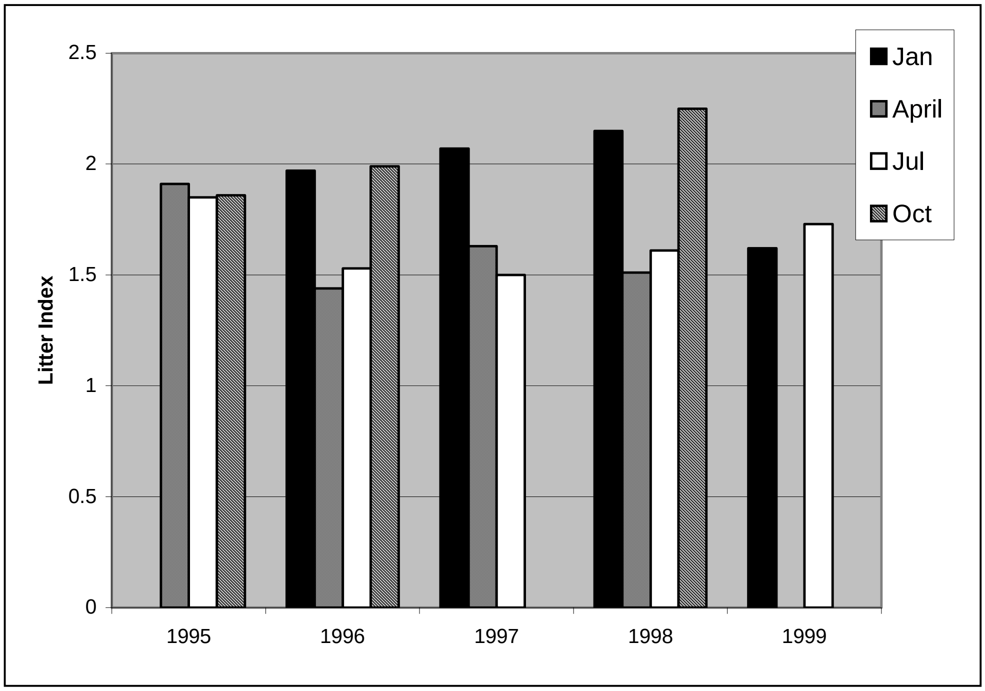
Date	VIP Score	% change from previous year	QC avg.(4/95)
Baseline 1994	2.53		
FY 1994-1995	1.90	24 % decrease	
FY 1995-1996	1.70	12 % decrease	1.99
FY 1996-1997	1.80	5.5 % increase	2.17
FY 1997-1998	1.76	2.2 % decrease	2.12
FY 1998-1999	1.87	6.25 % increase	2.34

Increases in annual scores were influenced by a variety of factors, including missing data, increases in QC averages and recent rainfall. The increase between the fiscal year 1995-1996 average and the fiscal year 1996-1997 average can be explained in part by the increase in QC average. The April 1997 survey was conducted three days after a 2.41-inch rainfall. The run-off associated with this rain event could have increased trash inflow to Town Lake from all urban creeks. The April 1997 score was 13 percent higher than that of April 1996, possibly an indirect result of the rain event. Although these data were useful in documenting storm impacts, subsequent surveys were not conducted within one week of rainfall events greater than one inch.

The increase from FY 1997-1998 to 1998-1999 could also be attributed to the 10 percent increase in QC score. Both years were incomplete datasets, with October 1997 (statistically higher) and April 1999 (statistically lower) scores either missing or invalidated. The absence of the higher score from one and the lower score from the other could have resulted in a wider discrepancy between the two averages.

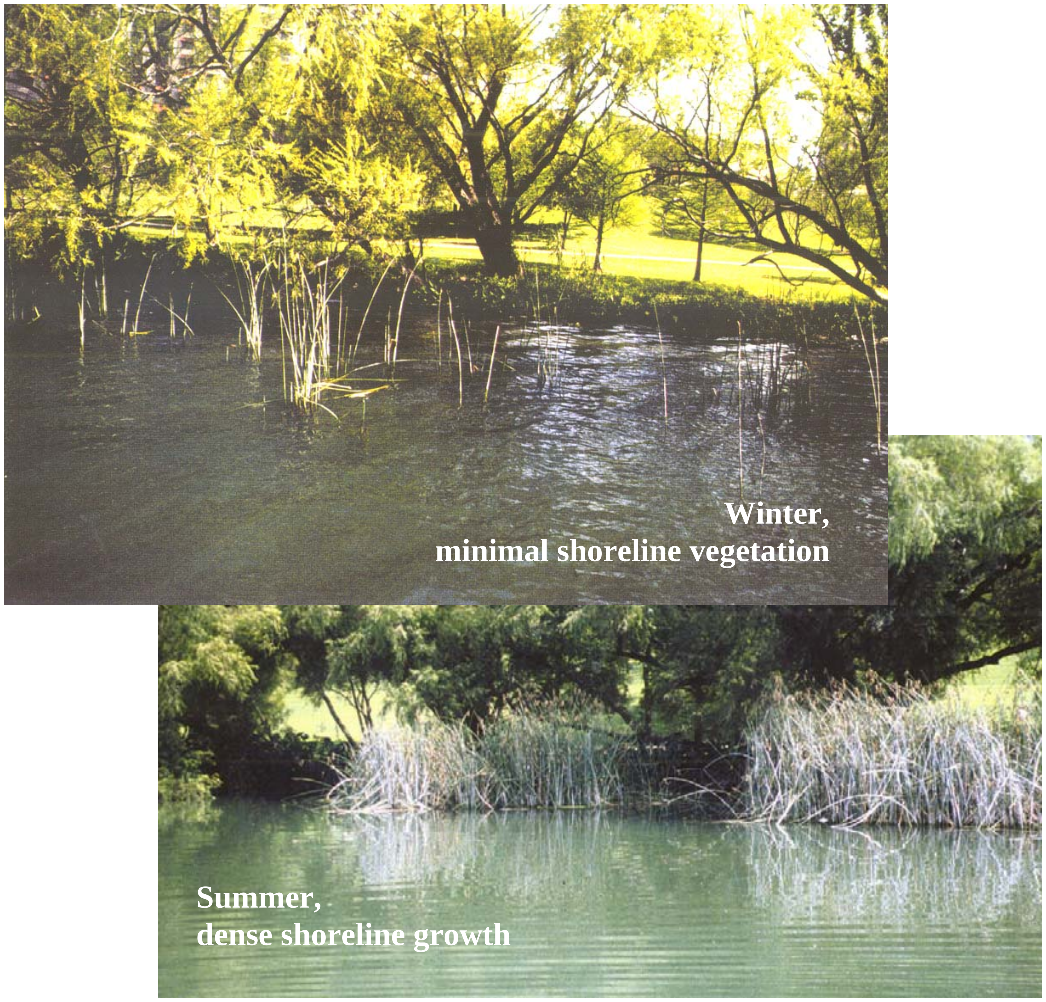
Seasonal scores for all years show trends for improvement (decreasing scores) in April and July and increases in scores in October and January. Analysis of variance indicates that the difference in the groupings of April-July and October-January is highly significant (p=0.001). The mean of the October-January group was significantly higher (2.018) than the mean of the April-July group (1.621). Duncan's Multiple Range Test also confirmed October-January as significantly higher than April- July. January significantly increased (p=0.0479) in scores over time, indicating that the winter season is possibly receiving an increase in the influx of trash into Town Lake (Figure 11.1).

Figure 11.1 VIP Seasonal Scores Using PI



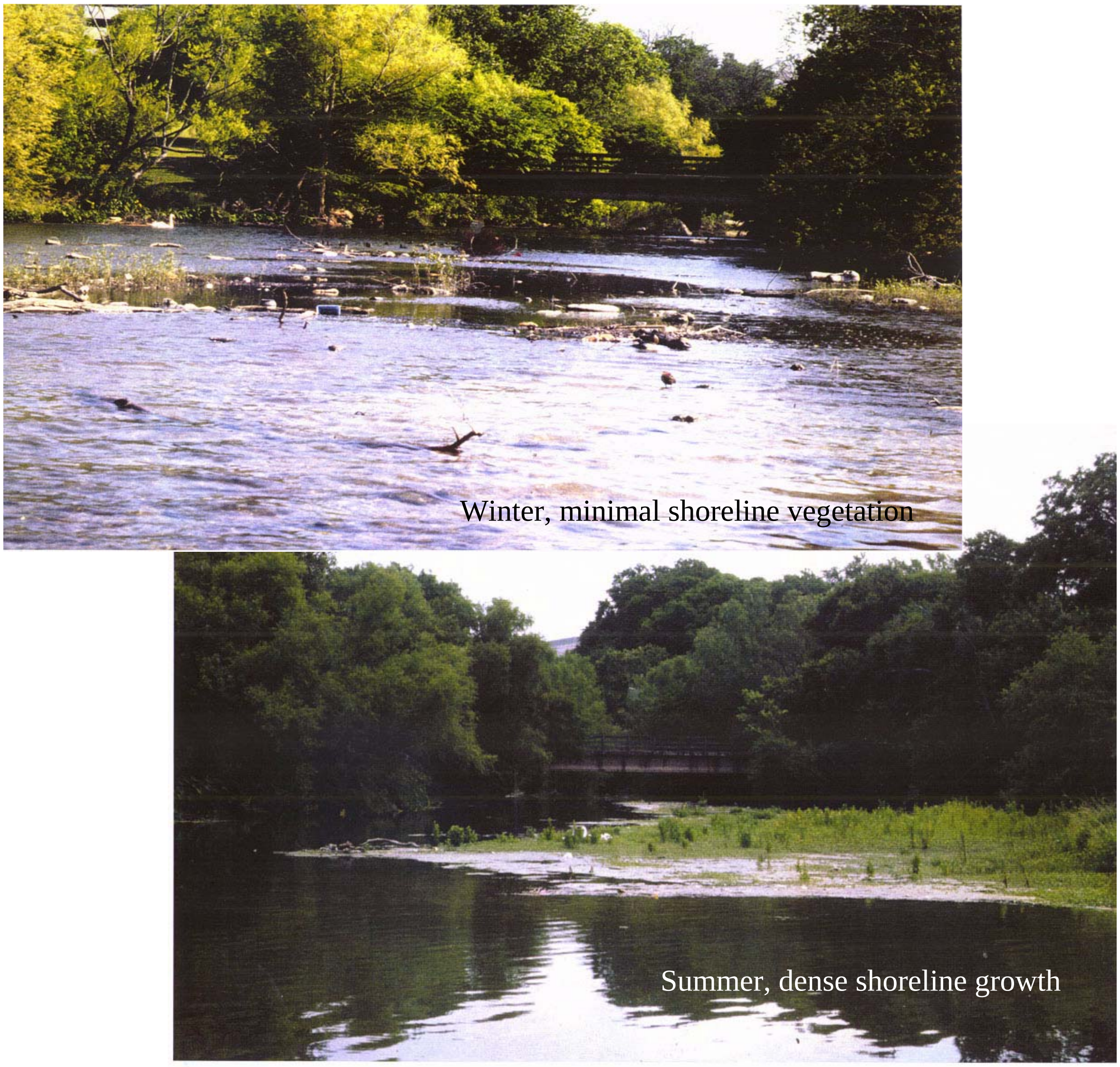
Lower scores in April and July possibly reflect the increase in shoreline vegetation during the spring and summer months as floatable trash becomes hidden by overhanging tree branches and emergent vegetation. Subsequent loss of vegetation in fall and winter months exposes the shoreline, revealing previously hidden trash and potentially causing the higher scores observed in October and January.

Growth of both elephant ear (*Colocassia esculenta*) and native bulrushes (*Scirpus validus*) on the shoreline of Town Lake appears to have increased substantially over the last five years. Elephant ears are exotics and are known to choke out growth of native rushes, which are the preferred habitat of many fish and macroinvertebrates. The following photographs illustrate how increases in vegetation substantially improve the visual aesthetics of the shoreline.



Winter,
minimal shoreline vegetation

Summer,
dense shoreline growth



Winter, minimal shoreline vegetation

Summer, dense shoreline growth

11.3 On-Site Assessment

Due in part to the invalid April 1999 scores, a new assessment instrument was developed based in part on the Keep America Beautiful (KAB) Litter Index, currently being piloted in a number of affiliates around the country (Porter 1999a.) Preliminary statistical tests from these pilots indicate the Litter Index to be valid and reproducible. (Porter 1999b).

Objectives for the new methodology include:

- Provide a visual assessment of trash along waterways that can be quantified for use in prioritizing clean-up efforts along Town Lake.
- Provide a tool to measure the progress of clean up efforts, with an annual lake-wide score of 2.0 or below as the current target.
- Provide new information related to the nature and location of the trash/debris (manmade versus natural debris, shoreline versus in water) and some measure of litter type (plastics versus other) that can be used to target public education efforts.

The main advantages to new method are:

- On-site assessment provides a more accurate indication of trash accumulation.
- Sites are continuous rather than separated, ensuring evaluation of the entire assessed lakeshore and allowing for targeted clean up efforts of problem areas.
- The area near Longhorn Dam known as the Basin, not part of the original study design, has been added to the assessment. Much of this shoreline is parkland, with a high level of public access and visibility.

11.3.1 Methods

The assessed area of the lakeshore is divided into 42 contiguous sites or sub-areas. At each of these, measurements are conducted along a longitudinal reach of the shoreline between two distinct points. Scoring categories range from 1 to 4, with 1 representing from zero to 25 percent litter cover and 4 being 75 to 100 percent litter cover. These categories are based on KAB Litter Index descriptors as well as percent cover modified from the Daubenmire cover classes (BLM 1996).

For each reach, additional categories for litter type and location are noted:

- Man-generated (trash) versus natural material (brush, tree limbs, etc.)
- In the water versus on the bank
- Plastics versus other

Average percent litter cover scores are calculated for each sub-area, as well as an overall average for each sampling date and an average annual score for the entire lake. This annual score is used by the WEFOD to measure the effectiveness of their ongoing clean-up efforts, with the current target being an average annual score below 2. Additionally, sub-area scores are being used to help target litter-prone areas for cleanup. Results from the remaining categories can be used to help focus public education efforts in specific watersheds or for specific behaviors (lakeshore littering, etc.).

11.3.2 Results

The scores for the on-site assessment are presented in Table 11.2

Table 11.2 On-Site Assessment VIP Scores

Fiscal Year	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Yearly Avg
2000-2001	1.99	1.69	1.36	1.85	1.72
1999-2000	1.78	1.86	1.53	1.54	1.68
1998-1999	*	*	*	1.92	NA

* indicates only PI measured during this period

As with the PI, there is a noticeable decline in scores during the warmer months when bank-side vegetation is high and trash is less noticeable. Weather can also affect the scores. The FY 2000-2001 Oct-Dec assessment was not conducted until December 2000 due to weather extremes. A series of heavy storms in October postponed the assessment, as the protocol includes a five-day post-rain event delay to allow some cleanup. Soon after the rain events, an extensive algae bloom in November pre-empted staff and watercraft time. The assessment was conducted in December when a majority of streambank vegetation was dormant, potentially explaining the somewhat elevated scores compared to those measured in October. The higher value in FY 2000-2001 Jul-Sep could be attributed in part to weather as extremely heavy rainfalls three weeks prior to the September survey brought extraordinary amounts of debris in to the lake.

Increased debris removal activity can positively affect scores, as is evidenced by the FY 2000-2001 Jan-Mar score. Use of the new assessment allowed for identification of specific problem areas missing from the PI, and this information was conveyed to the debris removal staff. By March 2001, there was a noticeable visual improvement in many areas with chronic debris problems. This translated to a substantially lower score (1.69) for a time of year in which dormant vegetation typically allows for much higher scores.

11.3.3 Comparison of Indices

The added assessment areas and increased visual accuracy inherent in the new on-site method has the potential to cause an increase in scores (Table 11.3). This was demonstrated by July 1999 scores, when slides for the PI were taken simultaneously with the on-site assessment and the PI score was 12 percent lower than the on-site score. Since that assessment, seasonal values from the on-site method have been lower than PI seasonal averages, and averages for each of the two years available with the on-site assessment are within the range of those from the PI.

Table 11.3 Comparison of Photometric and On-Site (shaded) Indices

<table>
<tr><th>Fiscal Year</th><th>Oct-Dec</th><th>Jan-Mar</th><th>Apr-Jun</th><th colspan="2">Jul-Sep</th><th>Yearly Average</th></tr>
<tr><td>2000-2001</td><td>1.99</td><td>1.69</td><td>1.36</td><td colspan="2">1.85</td><td>1.72</td></tr>
<tr><td>1999-2000</td><td>1.78</td><td>1.86</td><td>1.53</td><td colspan="2">1.54</td><td>1.68</td></tr>
<tr><td>1998-1999</td><td>2.25</td><td>1.62</td><td>Not valid</td><td>1.73</td><td>1.92</td><td>1.87</td></tr>
<tr><td>1997-1998</td><td>NA</td><td>2.15</td><td>1.51</td><td colspan="2">1.61</td><td>1.76</td></tr>
<tr><td>1996-1997</td><td>1.99</td><td>2.05</td><td>1.63</td><td colspan="2">1.50</td><td>1.80</td></tr>
<tr><td>1995-1996</td><td>1.86</td><td>1.97</td><td>1.44</td><td colspan="2">1.53</td><td>1.70</td></tr>
<tr><td>1994-1995</td><td></td><td>NA</td><td>1.91</td><td colspan="2">1.89</td><td>1.90</td></tr>
<tr><td>PI Average</td><td>2.03</td><td>1.95</td><td>1.62</td><td colspan="2">1.63</td><td>1.81</td></tr>
</table>

Another aspect of the on-site method that has the possibility for altering values is the shift in scale. With the on-site method, the scale is from 1 to 4, in keeping with KAB and also to allow litter estimates based on units of 25 percent of total coverage. The PI scale was from 1 to 5, so shortening the scale could decrease overall scores. However, “5” represented extremely large amounts of litter, and in examining the PI scores, this value was used only 118 out of 4,501 times (2.6 percent). It is not anticipated that the new scale will affect scores to a great degree. Even with the potential for some change in scores, the on-site assessment has already provided valuable new information regarding trash abatement efforts and the current score target of 2 or below is still considered an appropriate one.

11.4 Trash Abatement on Town Lake

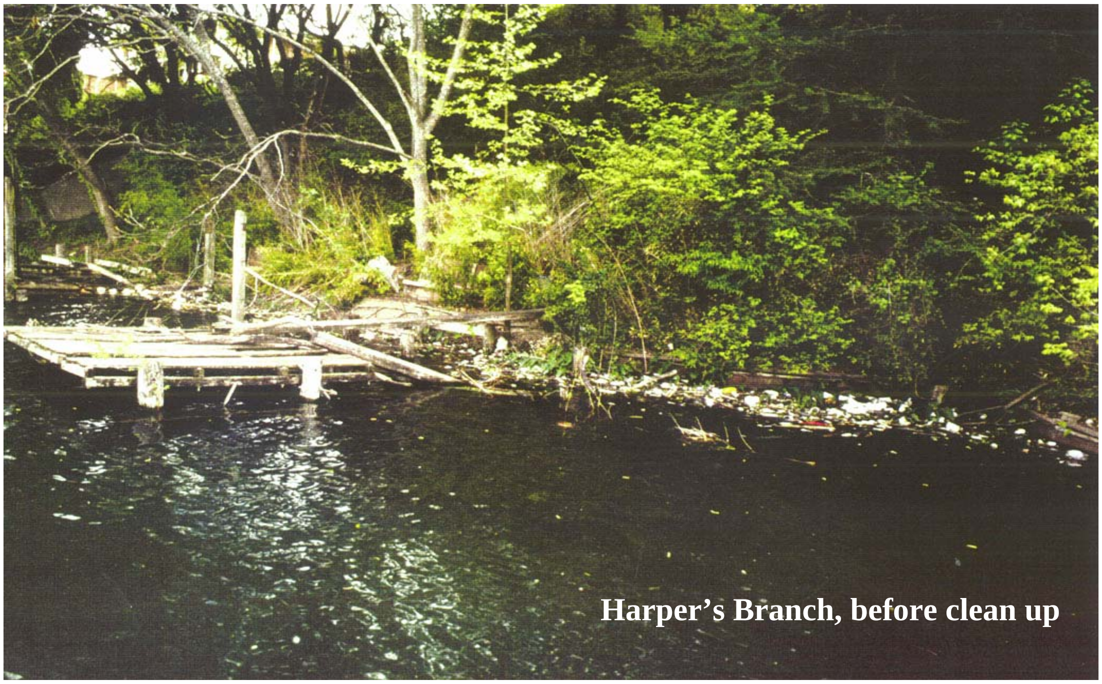
Since 1994, WEFOD trash abatement efforts have increased significantly. Booms have been installed near the mouths of Shoal and West Bouldin creeks to prevent floating trash from entering Town Lake. Inlet filters have been installed in several downtown and residential neighborhoods to stop trash at the source. A skimmer boat was employed in April 1996 to collect trash and floating debris directly from the surface of Town Lake. Increased manpower has been devoted to the manual collection of trash directly from the shoreline. Table 11.4 shows total amounts of trash removed from Town Lake for the past four fiscal years.

Table 11.4 Trash Removed from Town Lake

Type of Trash (tons)	**FY 1995-96**	**FY 1996-97**	**FY 1997-98**	**FY 1998-1999**	**FY 1999-00**
Wet Debris (from lake)	79.3	166.6	208.0	189.2	204.8
Trash from Booms	17.4	31.2	10.5	8.1	20.0
Total	96.7	197.8	218.5	197.3	224.8

The amount of trash removed increased 51 percent between FY 1995-1996 to FY 1996-1997 and 10 percent the next fiscal year. Target for FY 1998-1999 was removal of a total of 180 tons/year and that goal was surpassed by 17.3 tons, for a total of 197.3 tons.

All 12 of the PI sites receiving a score of 4 and above have shown various levels of improvement since 1995. The majority of these sites are located on the south shore near IH-35 and Riverside Drive. A concentrated effort by WEFOD to clean this area of shoreline manually has resulted in less trash accumulation and generally improved scores. The following set of photographs illustrates manual clean up and repair efforts downstream of the mouth of Harper's Branch.



Harper’s Branch, before clean up

Harper’s Branch, after clean up

Implementation of the on-site assessment has already resulted in direct improvement to the visual quality of the lakeshore. By March 2001, improvements were noticeable in areas with chronic debris problems that were not previously measured by the PI. It is anticipated that this type of improvement will continue, as the on-site assessment provides a more effective measurement of visual quality of Town Lake. In addition, staff conducting the assessments are working more closely with WEFOD staff to pinpoint areas of concern.

11.5 Conclusion

Scores for the VIP have consistently decreased from the original baseline in 1994. This reduction in scores reflects increased COA efforts to maintain Town Lake as both aesthetically pleasing and aquatically healthy. WEFOD has consistently increased the amount of trash removed from the lake over four of the last five fiscal years.

Scores have consistently remained below the target set by the Watershed Protection Department's Business Plan of an overall score of 2. The Master Plan set a goal of 1 for both segments of the lake, and this long-term goal as related to the current target should be re-evaluated at some point in the future.

The new on-site assessment tool enables COA to better quantify how litter impacts the aesthetic features of Town Lake and to target efforts to better protect those features. The VIP can serve as a useful community education tool for promoting trash reduction efforts in many areas of Austin, especially those urban drainages affecting Town Lake.

Ongoing improvement efforts include providing WEFOD staff with a map of Town Lake marked with the segments assessed by VIP and quarterly scores for each area, along with average area and overall lake scores. Scores on the most recent version of this map mirror the areas receiving calls from citizens regarding trash and debris. In the future, the VIP should provide an even more accurate picture of problem areas and the effectiveness of current abatement methods, allowing for more targeted clean-up efforts.

12.0 CONCLUSIONS

This update of the 1992 Town Lake diagnostic study (COA 1992a) included the current status of water quality with data analyzed through the year 2000 and a summary of measures taken to reduce pollution from urban runoff since 1990. Major conclusions drawn from these analyses are included below.

Watershed Protection Update

- A major change to watershed regulations affecting Town Lake was the Urban Watersheds Ordinance implemented by the City in 1991. This ordinance provides water quality protection through requirements for buffers, structural water quality controls. and protection of critical environmental features.
- A minimum flow (MDF) policy was put in place by the Lower Colorado River Authority (LCRA) in 1992. This policy beneficially impacted water quality in a number of ways indicated by data collected during this period.
- Programmatic measures such as education efforts and routine shoreline trash and debris cleanups, as well as construction of water quality control structures, have been implemented by the City during this period. While it is difficult to determine specific contributions of these efforts in maintaining Town Lake water quality, program performance measures indicate their benefits.

Town Lake Water Quality

- The water quality impacts from Austin's urbanized landscape were observable 10 years ago, and analysis of monitoring data collected since then presents further evidence of degradation.
- Measurements of turbidity, chlorophyll-*a* and some nutrients increase in the downstream direction.
- During storms, the levels of many constituents and bacteria are elevated downstream of the most urbanized watersheds, exhibiting temporal effects of urban inputs.

- Given a specific combination of dam releases and storm events, slight, though statistically significant increasing trends are observed for total Kjedahl Nitrogen (TKN), temperature, chlorophyll *a*, and dissolved copper.
- A few parameters, including ammonia and dissolved lead, appear to be improving during the recent past.
- Levels of nitrate as well as fecal coliform counts have a percentage of screening level exceedances that may indicate a concern using TNRCC assessment procedures.

Town Lake Algae Blooms

- Conditions contributing to the trophic status of Town Lake have remained relatively unchanged, with new analyses indicating oligotrophic and mesotrophic conditions during most of the year. Eutrophic levels, however, are observed during most years for short periods of time.
- Some of the water quality parameters measured seem to suggest the potential for worsening algae conditions, but results were not consistent for similar parameters.
- During fall 2000, the algal counts remained high for twice as long as the previous longest period, and although the overall counts do not show a significant trend, the maximum chlorophyll-*a* concentrations have been increasing over time.
- Using TNRCC screening levels (TNRCC 2000), Town Lake has exceeded criteria for chlorophyll-*a* in six of the last seven years in at least 5 percent of samples. It is unfortunate that the highest algal levels are located adjacent to the City's drinking water intake.
- Decreases in dissolved oxygen (DO) may indicate a potential concern. In particular, the frequency and duration of near-anoxic conditions at the deepest downstream area of the lake are increasing over time.
- One clam kill was observed in September 1996, and bottom DO was 0.25 mg/L at the Lamar Street bridge where the majority of the clams were found dead following the kill. Potential causes of the abnormally low DO include an influx of organic debris and nutrients in stormwater, subsequent algal growth and atypically low releases from Tom Miller Dam (235 ft^3/s on August 31).

- Although LCRA did put into effect their latest Minimum Daily Flow (MDF) policy in 1992, even the 100 ft^3/s flow required under non-drought conditions may be insufficient to maintain the desired minimum DO concentrations under post-storm, non-release conditions.

Groundwater Impacts on Town Lake

- The significance of non-urban inflows also remains critical to the condition in Town Lake, particularly during non-storm conditions. The influences of Barton Creek and Barton Springs, particularly the introduction of elevated groundwater nitrates, are demonstrated spatially with increases in the lake below the influxes.
- Additionally, when the annual average discharge of Barton Springs drops below 30 ft^3/s, Town Lake's annual percentages of nitrate values exceeding TNRCC screening levels are lowest. Therefore, maintaining the quality of Town Lake continues to depend upon maintaining the quality and quantity of water from this source as well as Lake Austin.
- Tracing in the Barton Springs segment of the Edwards Aquifer (BSEA) has demonstrated surprisingly rapid travel times, which emphasize that impacts on the non-urban watersheds may be transmitted to Town Lake with little opportunity for attenuation.

Upstream Impacts on Town Lake

- During release conditions, flows in Town Lake are dominated by Lake Austin water. The water quality in Lake Austin is characterized by higher mean values of TKN, solids and plankton than are found in Town Lake, but most concentrations are inversely related to flow.
- In general, cleaner water is released to Town Lake. Lake Austin may also be changing its patterns of algal levels, which may have an effect on Town Lake as well. Overall, the forecast for changes in water quality for Town Lake is unclear. Evaluations of probable future scenarios are discussed in Volume II, where modeling examines conditions and limiting nutrients in greater detail.

Sediment Accumulation

- Over the majority of the lake area, sedimentation appears to be offset by scouring events that transport the sediment downstream. A volumetric survey in 1999 indicated no net sedimentation in the lake system since 1992.
- Sediment deposition was estimated by the USGS coring in a backwater area in the downstream basin of the lake at a local rate of 0.98 inches/year.
- Comparisons using aerial photography also indicate little change in deltaic formations at creek mouths since 1951.
- The impacts of sediment within the lake are seen as clarity decreases and turbidity increases in the downstream direction.
- A slight, though statistically significant decreasing trend in clarity was observed during this monitoring period.

Sediment Quality

- Sediment samples from Town Lake document the long-term effects of anthropogenic emissions and the recovery of a system from persistent legacy pollutants. New analyses of Town Lake sediment toxin concentrations confirm some of the analyses conducted in the original 1992 Town Lake Report.
- Many toxic constituents in the sediment remain at levels of concern and, in addition, continue to move from upland sources to the receiving water body. Some decreases in restricted chemicals are seen, although the levels of these restricted constituents are still higher relative to sediment quality guidelines (SQGs) than observed metal concentrations, which are continuing inputs.
- Many lake samples had concentrations for some metals, particularly for cadmium and lead, which exceeded at least one screening level.
- Zinc and other metals showed a fairly strong spatial pattern through the lake, increasing downstream with highest levels below the most urban watersheds at First Street, Congress, and IH-35. These urban watersheds are the source of these pollutants as demonstrated by the high levels detected in sediment collected from water quality control structures capturing runoff from urbanized areas.

- Most metal concentrations are decreasing slightly over the period of record. While control measures put in place may be promoting this improvement, sediments are also impacted by severe flood events that may re-suspend and flush older deposited sediments downstream.
- The organochlorine pesticides still show concentrations over SQGs, with chlordane and DDE (the breakdown product of DDT which persists the longest) most prevalent in recent years.
- The presence of these banned pesticides in water quality control structures indicates their continued transport from older upland soils to Town Lake. Decreasing trends for DDTs and chlordane were significant, as is expected with their discontinued use.
- PCB medians above detection limits have been seen only in water quality control structures, where they are the highest, and in Town Lake sediments. Similar to pesticides, PCBs are apparently still at levels of concern and are still being input into the receiving water system.
- Although levels of concern are not yet reflected in Town Lake sediments, detections of PAHs in the creeks, water quality control structures, and in suspended particulates indicate cause for concern.

Fish Tissue Studies

- Since the 1992 Town Lake Report, fish tissue analyses have been conducted in three years, 1994, 1995, and 1998, resulting in the removal of the fish consumption advisory in October 1999. The removal of this advisory accomplished a primary goal for Town Lake.

- Parallel to results seen for sediment toxins, the maximum detected organochlorine pesticide concentrations in fish tissue have been decreasing over time, although some still have concentrations above the FDA action levels.

- Recent metal concentrations in fish tissue have not shown continued decreases after 1985, contrary to sediment results. Maximum mercury concentrations, in fact, have been steadily increasing rather then decreasing, although when normalized by fish weight they peak in the middle of the time period and none of the fish tissue metal levels in 1998 were above USEPA Fish Tissue Residue Criteria.

- If using a new reference dose for mercury for fish consumption, announced by USEPA in January 2001, a monthly consumption limit for Town Lake fish would be required. State criteria, however, have not yet been revised.

Trash and Debris

- The impact of trash and floatable debris as a form of visible pollution has been recognized since the 1992 Town Lake Report, which identified a reduction goal.
- The Visual Index of Pollution (VIP) was implemented in April 1994 to provide a periodic measure of the City of Austin's litter control performance by documenting visible trash on the shores of Town Lake.
- The scores have consistently decreased from the original baseline in 1994 (a decrease indicating a reduction in visual trash and debris); however, the consistent increase in the amount of trash removed from the lake during four of the last five fiscal years has shown an overall increase in effectiveness of this program.

Master Planning and Future Lake Protection

- Some signs of continued degradation emphasize the difficulty in treating runoff from new development and increased traffic.
- The City has undertaken the task of applying the most efficient management practices for water quality control, while also addressing the contributing problems of increased flood flows and eroding creek banks by developing Phase I of a Watershed Protection Master Plan in 2001.
- This plan revisited the goals for Town Lake using the model described in Volume II of this report and projections of future development with current regulations.
- In developing the master plan, City staff examined the potential problem areas that may impact Town Lake's designated uses: aquatic life use, non-contact recreation, and public water supply. Staff devised strategies and watershed-specific goals to address algae

blooms by controlling nutrient loads, sediment toxin loads, sedimentation, and trash debris.

- The Master Plan recommends solutions to address problems, prioritized citywide and in conjunction with flood and erosion solutions.
- As these solutions are implemented, new goals for Town Lake will be to maintain existing loads to the lake, maintain similar algae bloom conditions and to attain excellent aesthetic conditions.
- Continuing lake monitoring as recommended in this report will determine if Austin is able to achieve its goals and preserve Town Lake as a beneficial natural resource.

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TOWN LAKE REPORT
VOLUME II
TABLE OF CONTENTS

VOLUME II

List of Figures and Tables

FIGURES

TABLES

1.0 TOWN LAKE MODEL

Since the Town Lake Report (COA 1992), algal blooms have continued to be a problem in Town Lake. During the intervening years, both higher maximum algal cell counts during blooms and longer periods with mid-level counts have occurred. Low dissolved oxygen (DO) levels are occurring with greater frequency.

The City of Austin (COA) initiated a master planning process in the Watershed Protection Department (see discussion in Volume I, Section 2). As part of the analysis of problems and solutions, a tool was needed to predict the effects of development on the water quality problems of Town Lake. Also the ability to determine the impacts of the solutions proposed in the master plan on Town Lake water quality was necessary.

A predictive model with both hydrodynamic and water quality capabilities was selected for application to Town Lake, the Water Quality Analysis Simulation Program (WASP). This program is designed to help users "interpret and predict water quality responses to natural phenomena and man-made pollution for various pollution management decisions" (USEPA 1988). WASP has a hydrodynamic component and two water quality components. One of the water quality components deals with conventional water quality problems including eutrophication; the other deals with toxic pollution involving organic chemicals, metals, and sediment contamination. While the water quality problems dealt with in this report are conventional, problems in Town Lake also include toxic sediments and the resulting contamination of the fish populations. WASP was selected for its ability to address both types of problems.

The following discussion contains a brief account of the available water quality data in Town Lake as it relates to eutrophication and algae blooms. Section 4 contains the analysis of the complete water quality data set. The calibrations of the hydrodynamic and water quality (conventional) portions of the WASP model are then presented. Three different time periods were modeled. First, a short period of rapid change was modeled with several storms and an algal bloom. Second, an entire year was modeled for average conditions with gradual changes. The third period modeled was a bloom in 2000, used to assess the validity of the model. Finally the model was used to make projections based on future land use and revise master plan goals for Town Lake. The results of this assessment are presented.

Model Data

Data that have been collected in the Town Lake watershed and used in the modeling process are described below. Flow has been measured in the Town Lake watershed by the U.S. Geological Survey (USGS) at four locations. One spring site, two tributary sites and one river site below Town Lake are gaged. In addition, historical Tom Miller Dam releases are available from LCRA. The locations of the gage sites are shown in Figure 1.1. Water quality data are also collected several times a year at the USGS flow monitoring sites.

Recent water quality monitoring in Town Lake, which is related to the lake's trophic status, falls into two main categories: 1) routine monthly sampling and 2) bloom sampling, which includes daily (weekday) phytoplankton counts. Both the routine monthly and the bloom sampling are carried out at multiple locations and depths in the lake, but the algae counts are from a single spot in Town Lake, with two additional sites in Lake Austin (water treatment plant intakes). The sampling locations are displayed in Figure 7.1. The current sampling protocols for monthly and bloom sampling, including the parameter lists, are included in Volume I, Section 4.1.1. The algae bloom for which the most complete data set is available occurred in fall 1994. These data and data from the routine monthly sampling for 1995 were used for model calibration.

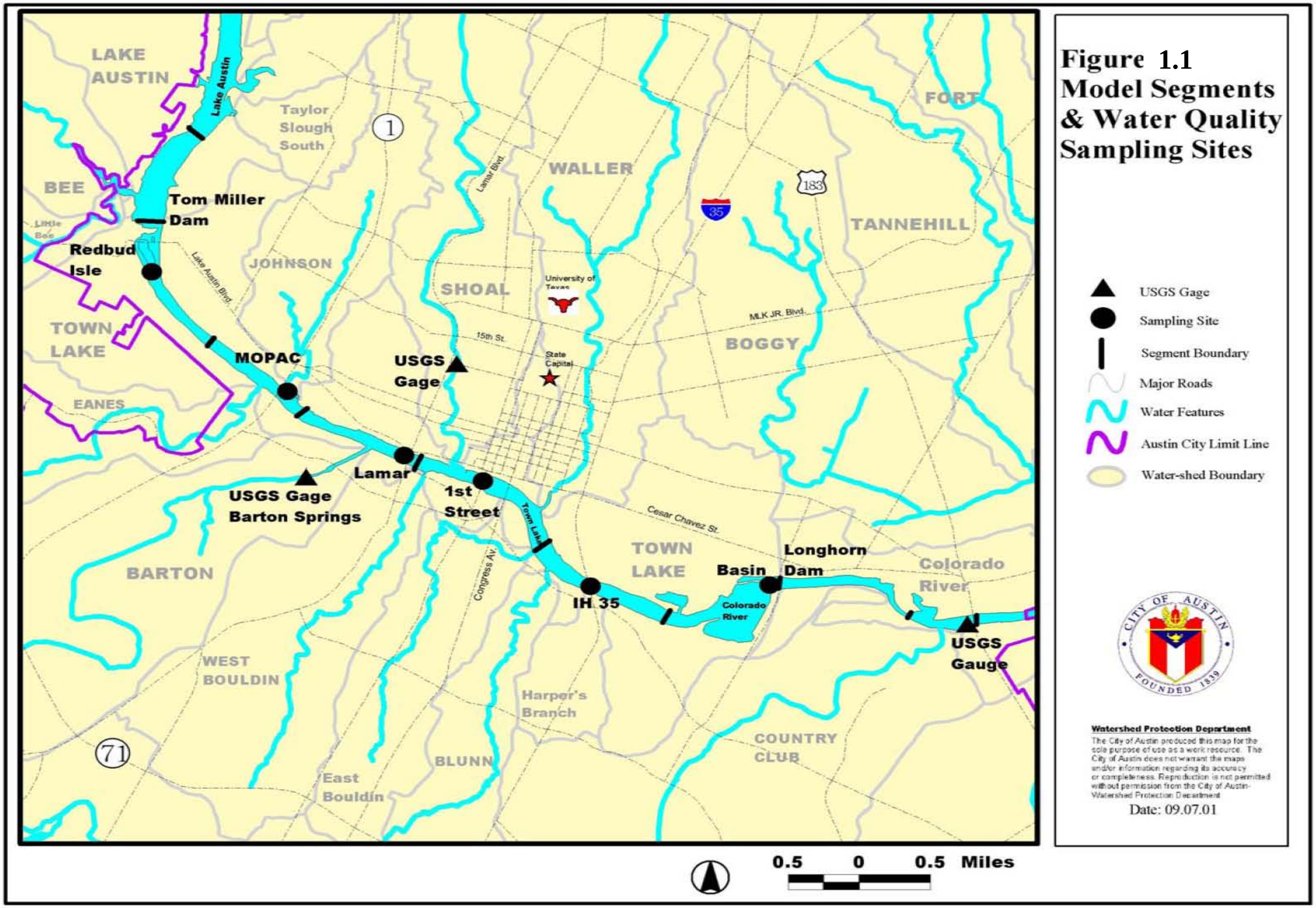


Figure 1.1 Model Segments & Water Quality Sampling Sites

Watershed Protection Department

Date: 09.07.01

2.0 HYDRODYNAMIC MODEL

The WASP4 hydrodynamic model DYNHYD5 (USEPA 1988) simulates the movement of water. It solves the one-dimensional equations of continuity and momentum for a channel-junction computational network. The model predicts water velocity and flow for channels, and water heads and volume for junctions. These values are averaged over time and stored for use by the water quality model. The channel-junction network for Town Lake, the model inputs, and model calibration are described in this chapter. Model junctions will be called segments for the rest of this report.

2.1 Model Network

Town Lake was divided up into 6 segments (junctions) of equal length with the midpoints of the model segments connected by model channels. The number of in-lake segments was based on the location of the water quality sampling locations in Town Lake and the need for model stability. One segment was added above Tom Miller Dam and two below Longhorn Dam in order to incorporate the measured flows at Tom Miller Dam and at the USGS monitoring site 1.4 miles downstream of Longhorn Dam. Figure 2.1 shows a schematic diagram of the hydrodynamic model with the model segments and the tributaries entering each segment. The dimensions of the model channels and segments are also given in Tables 2.1 and 2.2. These channels and segments are shaped like rectangular boxes and their dimensions are averages of the actual lake dimensions. The creeks flowing into each segment are identified in this figure along with the location of the adjacent land areas that drain directly into Town Lake rather than into a creek.

Figure 2.2 Hydrodynamic Model Diagram

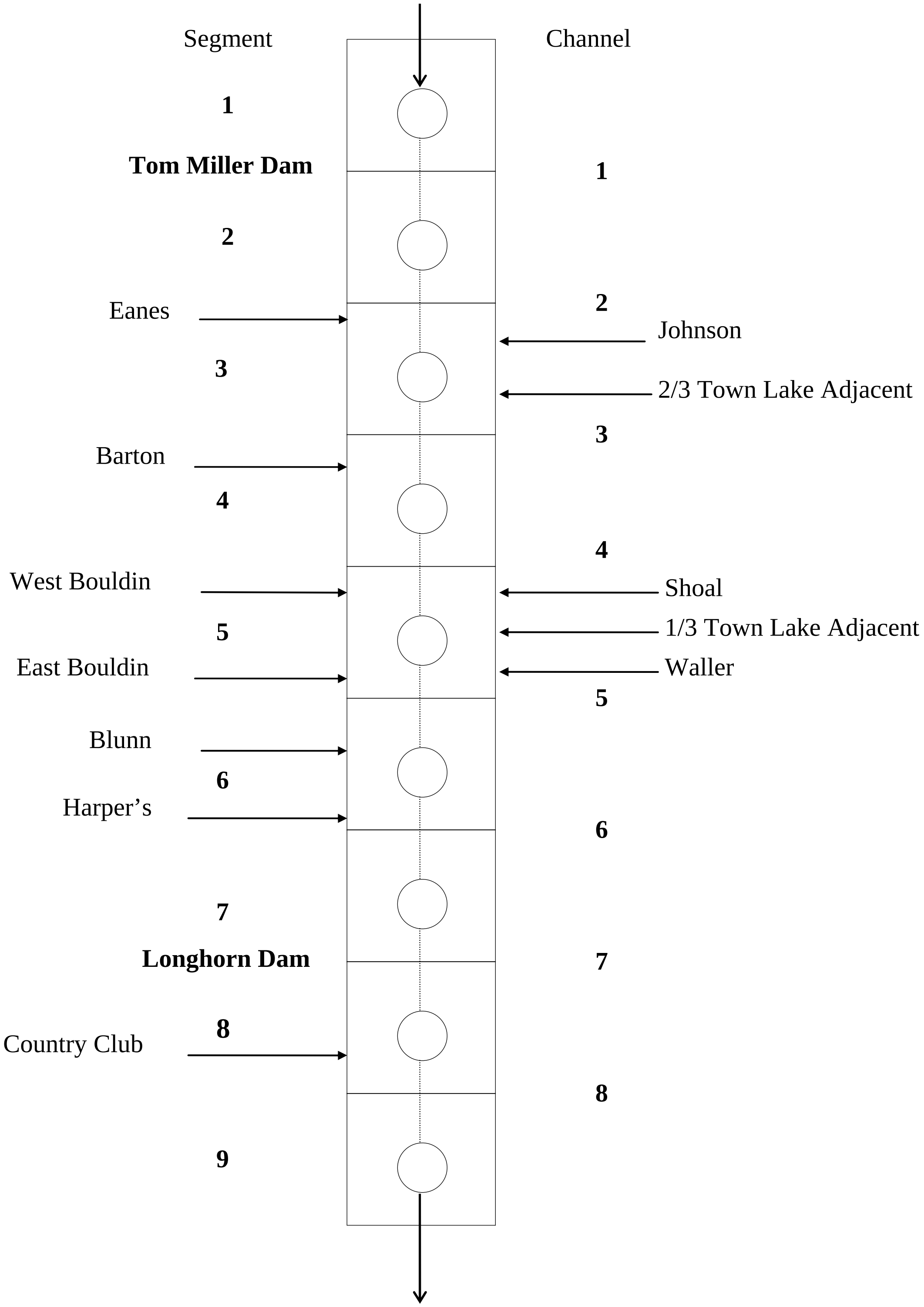


Table 2.1 Channel Characteristics

Channel Number	Length in Meters	Width in Meters	Depth in Meters
1	1609	144	3
2	1609	144	3
3	1609	172	3.4
4	1609	160	3.3
5	1609	230	4.2
6	1609	260	5.5
7	1609	144	3
8	650	80	1.5

Table 2.2 Segment Characteristics

Segment Number	Surface Area in Square Meters
1 Upstream of Town Miller Dam	233,486
2 Red Bud Isle	233,486
3 MoPac	246,946
4 Lamar	220,720
5 First	296,609
6 I-35	325,874
7 Basin	604,852
8 Downstream of Longhorn Dam	233,486
9 Colorado River	52,000

2.2 Model Inputs

In order to run the hydrodynamic model, information pertaining to the modeled waterbody must be supplied. Some of this information is observed, some is estimated, and some is chosen to aid in model calibration. Model inputs include:

- Shape of model channels and segments (Tables 2.1 and 2.2)
- Channel direction: Angle from North
- Manning’s roughness coefficient: 0.05 for all channels

- Time step: One minute
- Constant inflows: Calibration adjustment - see discussion
- Variable inflows - Observed: Tom Miller Dam releases, Barton Springs, Barton Creek (Loop 360), Shoal Creek
- Variable inflows - Estimated: Johnson Creek, Barton Creek below Loop 360, Waller Creek, East and West Bouldin creeks, Blunn Creek, Harper's Branch, Country Club Creek, and the Town Lake adjacent areas.
- Variable Outflow - Observed: Colorado River 1.4 miles downstream of Longhorn Dam

The hydrodynamic model was run for two very different types of scenarios requiring changes in some of the input information. The bloom simulation modeled rapidly changing flows during storm events and subsequent algae blooms. The annual simulation modeled yearly flow conditions using monthly average data. Additional details about the inflows and outflows are described below.

Constant Inflows

The sum of all the measured and estimated variable inflows is less than the gaged outflow for each time period that has been modeled. This discrepancy in the water balance has been noted in previous studies (COA 1992). In-lake springs, leakage from Tom Miller Dam, and discrepancies between the reported and actual discharge from Tom Miller Dam are among the potential causes for this water balance problem. An estimate was made, for each time period modeled, of the quantity of flow needed to alleviate this problem. Tom Miller releases and Barton Springs flow were subtracted from the flow at the USGS station downstream of Longhorn Dam during periods with no flow from Barton Creek or Shoal Creek. The difference was added to the model flows as a constant inflow at Tom Miller Dam and averaged 1.3 m^3/s (46 cfs) during the late fall simulations and 8.9 m^3/s (314 cfs) during the summer simulation.

Variable Inflows

For the bloom simulations, 15-minute flow data was used. However, only 100 different flow values could be input due to array size limitations in the computer program. Visual smoothing was done if necessary to reduce the number of data points. Daily average data were used for the annual simulations. Hourly and daily releases from Tom Miller Dam were obtained from LCRA. Data from USGS gages were used for Shoal Creek, Barton Creek (at Loop 360), and Barton Springs. Inflows from other urban creeks and from the area adjacent to Town Lake were estimated from the Shoal Creek record. Shoal Creek flows were multiplied by the ratio of watershed areas. This method means that differences in watersheds such as percent impervious cover, soil type, and baseflow characteristics are ignored. The flows coming into the same segment were lumped and are related to Shoal Creek flows as follows:

- Johnson, Eanes + 2/3 Town Lake Adjacent = Shoal Creek flow * 0.74
- Barton Creek Urban Inflow - downstream of Loop 360 = Shoal Creek flow * 0.24
- Waller, East and West Bouldin, 1/3 Town Lake Adjacent = Shoal Creek flow * 0.98
- Blunn and Harper’s = Shoal Creek flow * 0.26
- Country Club = Shoal Creek flow * 0.42

Variable Outflow

For the bloom simulations, 15-minute flow data from the USGS gage 1.4 miles downstream of Longhorn Dam were used. Data smoothing was done if necessary. Use of daily average flows for the annual simulations was attempted, but model instability occurred. For periods with intense storms that took place during the evening hours, the model was unstable due to the difference in the daily average flows at the upstream and downstream gages. This instability does not occur when 15-minute data are used. However, the annual simulations were not intended to model the details of storm or bloom events. Thus, for the annual simulations the downstream outflow was set equal to the total of the upstream inflows.

3.0 HYDRODYNAMIC CALIBRATION

3.1 Calibration Procedure

Model predicted flows were compared to the observed flows at USGS gages for four bloom periods. After a satisfactory fit was obtained for August 1991 data, the model was rerun for November 1991 data. For this time period the fit appeared satisfactory. However, when the model was run with data from fall 1994, the fit was no longer sufficient to proceed. The flows in 1994 were much lower than during either monitoring period in 1991, and differences in the fit that had appeared insignificant at higher flows were now much more pronounced. Model segmentation below Longhorn Dam was adjusted until the fit was again judged adequate. The final bloom period in fall 2000 also occurred during very low flows. Model-predicted flows were very similar to observed flows, confirming the choices for model segmentation selected for the 1994 bloom.

Flow data alone are insufficient to completely calibrate the hydrodynamic model. However, neither velocity nor dye data were available. To check the reasonableness of model output, channel velocities were predicted for various classes of flow in Town Lake. The predicted velocities are presented in Table 3.1 and were determined to be within appropriate ranges. Thus, the partial calibration was deemed adequate until additional data can be obtained. Since the model is not completely calibrated, hypothetical flow scenarios should be interpreted with caution. However, observed flow conditions could be used with various pollutant load scenarios.

Table 3.1 Predicted Velocities in Town Lake

		Predicted Channel Velocities (fps)				
Flow Type	**Flow (cfs)**	**Channel 2**	**Channel 3**	**Channel 4**	**Channel 5**	**Channel 6**
Flood	36000	5.6	4.8	6.3	3.9	2.6
Typical release	3100	0.64	0.49	0.55	0.3	0.2
No release, typical creek flow	550	0.105	0.082	0.098	0.052	0.036
Very low flow	70	0.005	0.004	0.013	0.007	0.005

Details of the 1994 and 2000 bloom simulations and the 1995 annual simulation are presented below.

3.2 1994 Bloom Simulation

The movement of water in Town Lake from October 13, 1994, to November 3, 1994, was simulated. During this time period, releases from the upstream reservoir decreased from the high summer irrigation levels to typically minimal winter levels. Several major storm events occurred and an algae bloom was observed. This combination of events is typical of our fall bloom season and thus is appropriate for modeling. The daily average releases from Tom Miller Dam and the daily average rainfall for this time period are presented in Figure 3.1. The measured flows in Barton Creek (Loop 360), Shoal Creek, and Barton Springs are shown in Figure 3.2. These flows are the basis for all the local flow inputs to the hydrodynamic model. The hourly release data from Tom Miller Dam are compared to the 15-minute USGS gauged flow below Longhorn Dam in Figure 3.3. These measurements function as upstream and downstream boundary conditions. The estimated constant inflow for this time period is 1.2 m^3/s (42.4 cfs). Figure 3.4 compares the predicted and observed flows at the downstream end of the model. The input file for this simulation is in Appendix A.

Figure 3.1 Rainfall and Tom Miller Dam Releases - Daily Averages

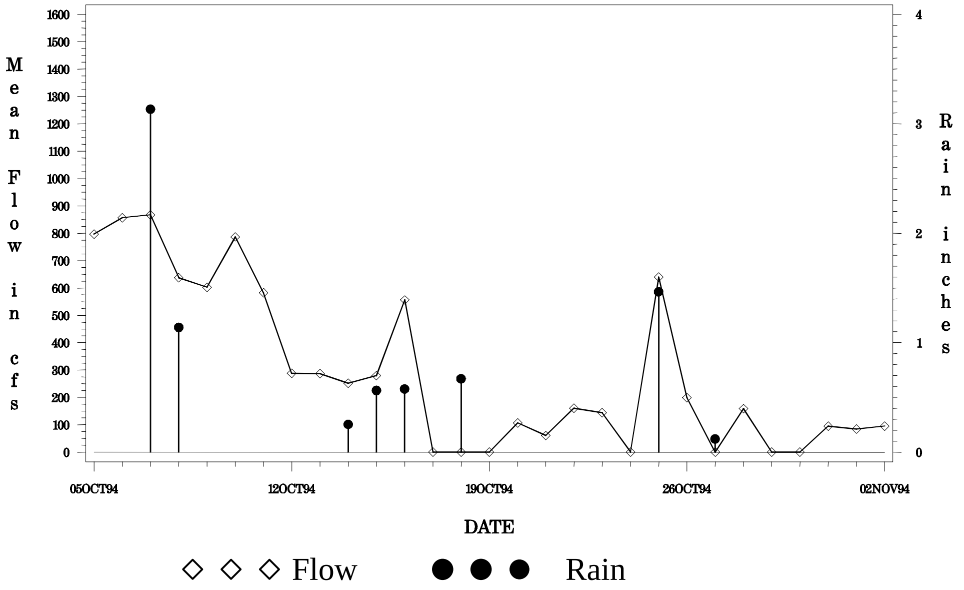


Figure 3.2 Shoal Creek, Barton Creek and Barton Springs Flows

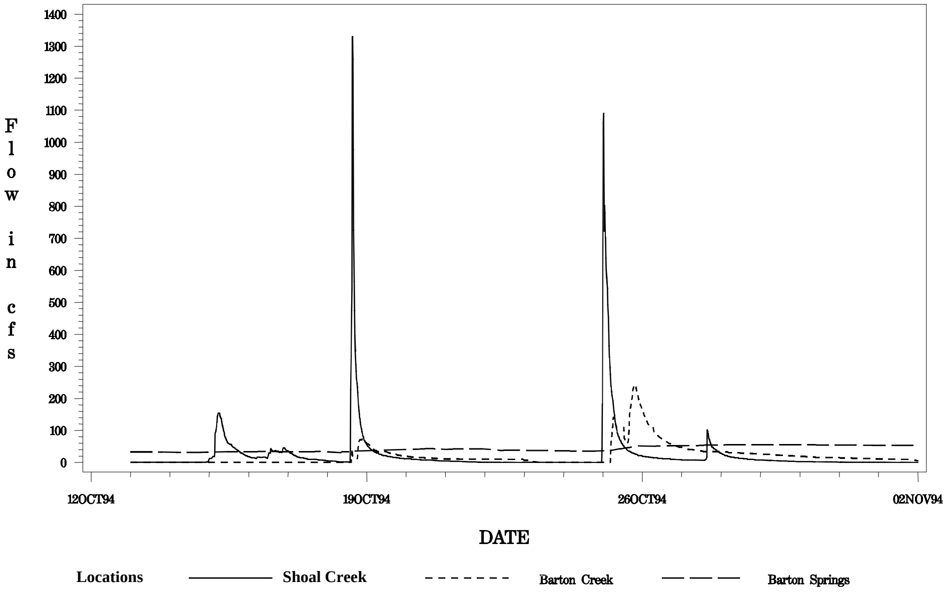


Figure 3.3 Hourly Releases from Tom Miller Dam versus 15-minute Flow Data at the USGS gage below Longhorn Dam

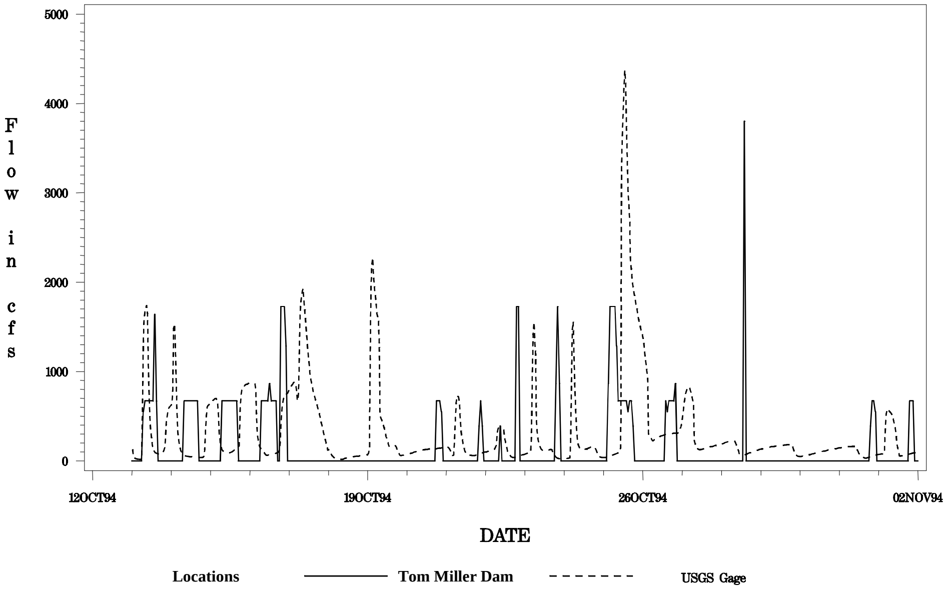
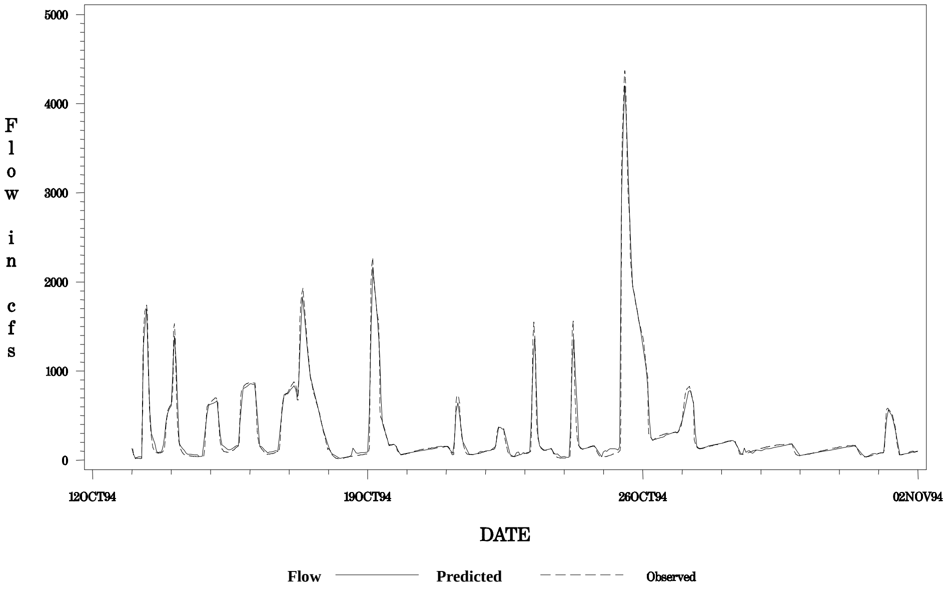


Figure 3.4 Model Predicted Flow Compared to Observed Flow at the USGS Gage



3.3 1995 Annual Simulation

The movement of water in Town Lake from January 1, 1995, to December 31, 1995, was simulated. Annual flows and rainfall for 1995 were close to average (Table 3.2). Annual flows from Barton Creek, Barton Springs, and Shoal Creek were close to average with Tom Miller Dam releases somewhat below average. The number of algal blooms was also normal, although the largest bloom occurred during the spring rather than the fall when the largest blooms most frequently occur. Thus, 1995 was deemed appropriate for modeling.

Table 3.2 Comparison of 1995 Data with Average Annual Data

Location	1995	Annual Average (Period of Record)
Colorado River below Longhorn Dam	1211cfs	1959cfs
Barton Creek Flow	41.3cfs	45.1cfs
Barton Springs Flows	65.8cfs	63.5cfs
Shoal Creek Flow	9.58cfs	8.01cfs
Total Rainfall at Airport	34in	32.6in

Monthly average data were used for all flows. The monthly average flows in Barton Creek (Loop 360), Shoal Creek, and Barton Springs are shown in Figure 3.5. These flows are the basis for all the local flow inputs to the hydrodynamic model. The monthly release data from Tom Miller Dam is plotted in Figure 3.6 along with monthly average rainfall. The downstream boundary flow condition is set equal to the sum of the upstream and local inflows. The constant inflow used for this time period is 1.2 m^3/s (42.4 cfs). This number was not determined from 1995 data, but is a typical low-flow period estimate. The low-flow estimate was used for the entire year, since the model is more sensitive during the low-flow period.

Figure 3.7 compares the predicted and observed flows at the downstream end of the model. The predicted flows are based on monthly averages and thus are much smoother than the observed values. The input file for this simulation is in A.

Figure 3.5 Shoal Creek, Barton Creek and Barton Springs Flows

1995 Monthly Averages

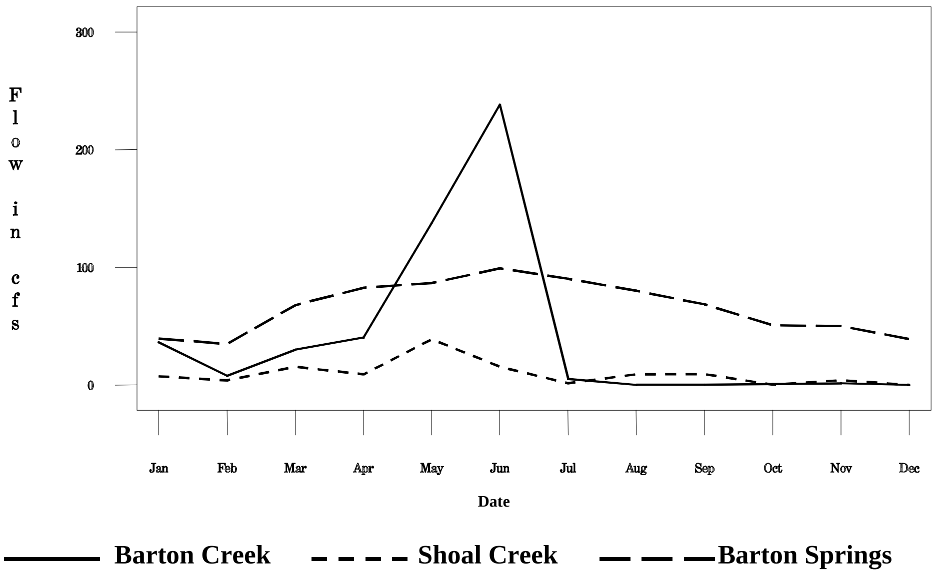


Figure 3.6 Rainfall and Tom Miller Dam Releases - Monthly Averages

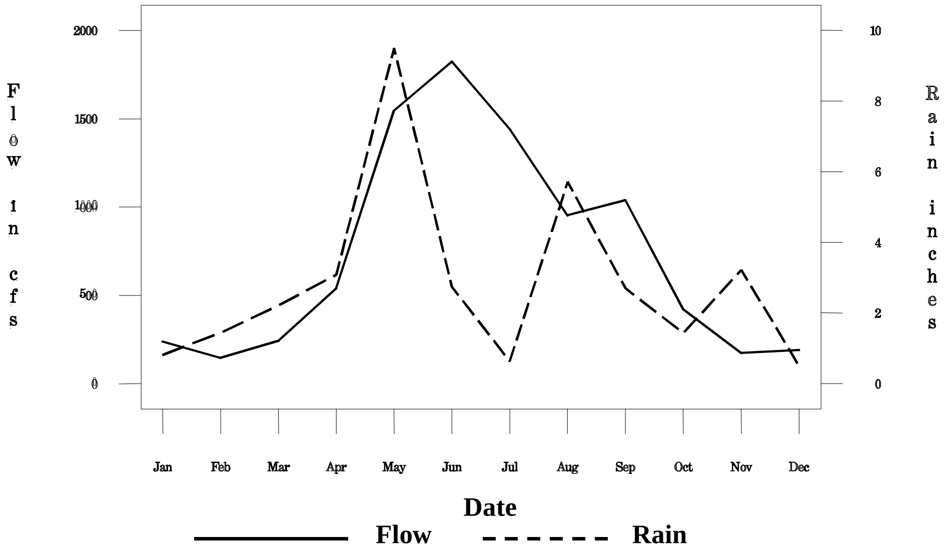
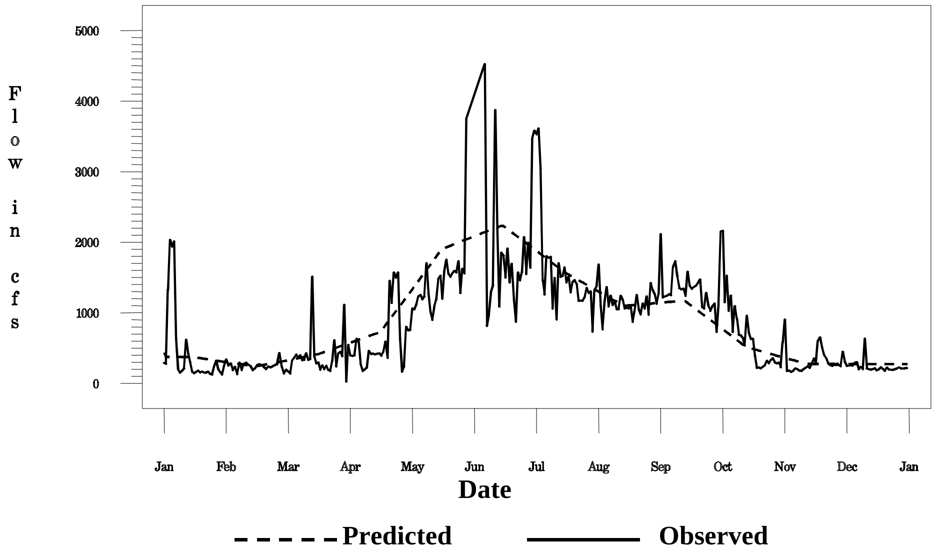


Figure 3.7 Model Predicted Flow Compared to Observed Flow at the USGS Gage



3.4 2000 Bloom Simulation

The movement of water in Town Lake from October 13, 2000, to November 6, 2000, was simulated. During this time period, releases from the upstream reservoir were the lowest observed in recent years. Periods with no upstream inflow included one six-day interval, one four-day interval and four two-day intervals. Four lengthy storm events occurred with measurable rainfall lasting three, four, five, and eight days. Algal counts increased gradually and remained high for a two-week period. The daily average releases from Tom Miller Dam and the daily average rainfall for this time period are presented in Figure 3.8. The measured flows in Barton Creek (Loop 360), Shoal Creek, and Barton Springs are shown in Figure 3.9. These flows are the basis for all the local flow inputs to the hydrodynamic model. The hourly release data from Tom Miller Dam is compared to the 15-minute USGS gauged flow below Longhorn Dam in Figure 3.10. These function as upstream and downstream boundary conditions. The estimated constant inflow for this time period is 1.2 m^3/s (42.4 cfs). Figure 3.11 compares the predicted and observed flows at the downstream end of the model. The input file for this simulation is in Appendix A.

Figure 3.8 Rainfall and Tom Miller Dam Releases - Daily Averages

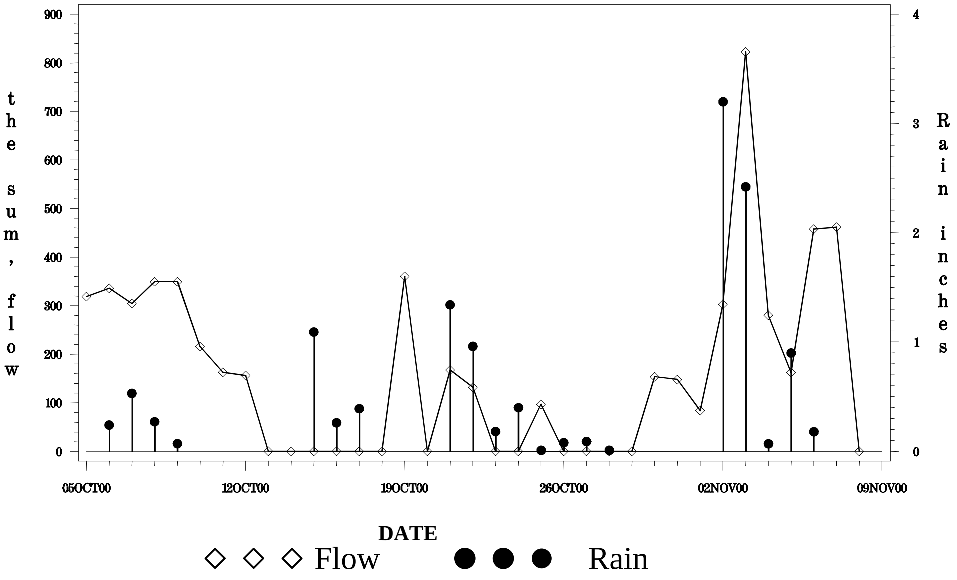


Figure 3.9 Shoal Creek, Barton Creek and Barton Springs Flows

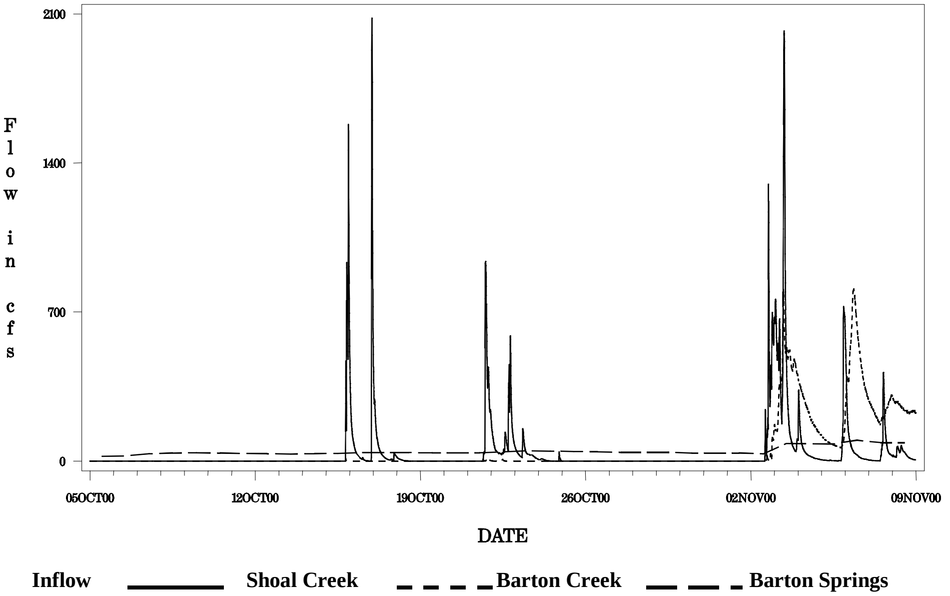


Figure 3.10 Hourly Releases from Tom Miller Dam versus 15-Minute Flow Data at the USGS Gage Below Longhorn Dam

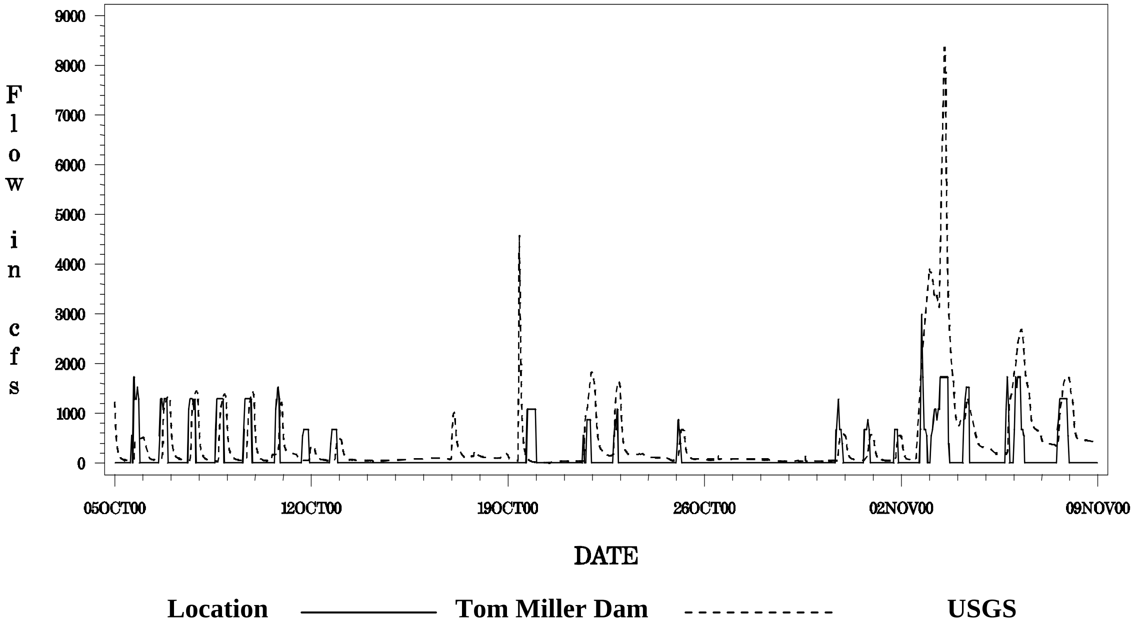
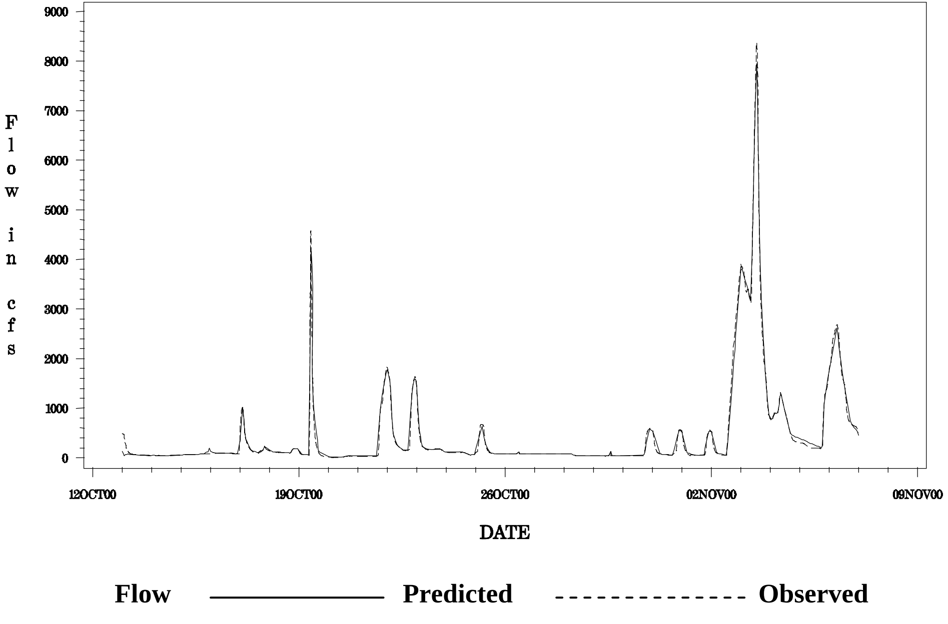


Figure 3.11 Model Predicted Flow Compared to Observed Flow at the USGS Gage



4.0 WATER QUALITY MODEL

EUTRO4, the eutrophication portion of the WASP4 program (USEPA 1988), is a dynamic, compartment-modeling program for aquatic systems that simulates the movement and interaction of constituents within the water and is based on the principle of conservation of mass. The mass balance equations for the constituents account for direct and diffuse loading, advective and dispersive transport, and physical, chemical, and biological transformation. Model inputs include information on:

- model segmentation,
- advective and dispersive transport,
- boundary conditions,
- point and diffuse loads,
- kinetic parameters, constants, temporal and spatial functions, and
- initial concentrations.

The water quality constituents that are modeled include:

- Ammonia,
- Nitrate,
- Organic Nitrogen,
- Orthophosphate,
- Organic Phosphorus,
- Chlorophyll *a*,
- Biological Oxygen Demand (BOD), and
- Dissolved Oxygen (DO).

Two different types of simulations were run. Two periods were modeled with daily data and rapidly changing conditions during fall 1994 and fall 2000. The entire year of 1995 was also simulated using monthly average conditions. These simulations are called the bloom and annual models respectively. When differences in model inputs occur for these two types of simulations they are discussed separately. The input files for the bloom and annual simulations are included in Appendix A. The model inputs for the water quality modeling of Town Lake are described in the following section.

4.1 Segmentation

Water quality modeling was done for the segments of the hydrodynamic model in Town Lake. Six segments corresponding to the hydrodynamic segments 2 through 7 (Figures 1.1 and 2.1) were evaluated. These segments are referred to by the name of the water quality sampling site that is in the segment. Beginning at the upstream end and proceeding downstream, the segments are called Red Bud, MoPac, Lamar, First, I-35, and Basin. These segments are equal in length and are approximately one mile long.

4.2 Transport

The advective and dispersive transport of water is determined by the hydrodynamic model and is averaged over the one-hour time step of the water quality model. The transport values determined from the 1994 and 2000 bloom simulations (Section 7.3.4) and the 1995 annual simulation (Section 7.3.3) were used for water quality modeling.

4.3 Boundary Conditions

The ideal upstream boundary conditions would be obtained just above Tom Miller Dam in Lake Austin. During the 2000 bloom, data were collected in Lake Austin at the LCRA boat dock approximately 700 feet upstream of Tom Miller Dam and used for the upstream boundary conditions, with the exceptions of dissolved oxygen and chlorophyll *a* concentrations. Since the location of water withdrawal from Lake Austin is at the bottom of the lake, dissolved oxygen levels were set to 75 percent of the surface water levels and chlorophyll *a* levels were set to zero. Measurements at depth while the turbines are operating need to be taken to confirm these two modifications to surface data. However, no data were available from this location in 1994 and 1995. During the 1994 bloom simulation period, almost no data were available for the simulated constituents anywhere in Lake Austin. During the 1995 annual simulation, some data were available from other agencies but they were not taken near the dam and did not correlate well with the data from the upstream end of Town Lake at Red Bud Isle. Therefore, observed concentrations from the Red Bud site were used for the upstream boundary conditions in 1994 and 1995, with some modifications and exceptions.

For the 1994 bloom period, observed concentrations from start and end of the time period from the Red Bud site were used for ammonia, nitrate, orthophosphate, and dissolved oxygen. Concentrations during the height of the bloom were not used, since they represent local effects, not changes due to upstream concentration changes. Instead, linear interpolation between pre- and post-bloom data points was used. Observed concentrations from the Red Bud site were used for organic nitrogen. The observed increase in organic nitrogen at the end of the bloom period could be due to either storm runoff into Lake Austin or algal death. Storm runoff was assumed to be the predominant factor and the boundary concentration was set to the observed high value for the day of the storm. No data were available for BOD; therefore, storm concentrations were set to 1.5 mg/L, non-storm concentrations to 0.5 mg/L as good background values**.** Chlorophyll *a* was set to 1.0 μg/L and organic phosphorus was set to 0.003 mg/L. The BOD, chlorophyll *a*, and organic phosphorus estimates were based on historical Lake Austin levels.

For the 1995 annual simulation, monthly average concentrations from the Red Bud site were used except for orthophosphate and chlorophyll *a*. For these two parameters, the boundary conditions were set equal to ½ of the observed Red Bud concentrations, since local conditions were estimated to increase these parameter concentrations over the Lake Austin levels. No data were available at Red Bud for BOD. Concentrations were set to 0.5 mg/L based on historical Lake Austin levels.

The downstream boundary conditions were set equal to the concentrations at the Basin, at the downstream end of Town Lake. No data were available for BOD; therefore, storm concentrations were set equal to 1.5 mg/L, and non-storm concentrations to 0.5 mg/L for the 1994 bloom period and to 0.5 mg/L for the annual and 2000 bloom simulations. These values were based on historical Town Lake data, since no water quality data were available from below Longhorn Dam. These downstream boundary conditions have almost no effect on Town Lake concentrations.

4.4 Loads

Load Source

No point source loads of pollutants are made to Town Lake from authorized wastewater treatment plant discharges, municipal or industrial. All loads are diffuse and enter the lake either through creek flow or as direct runoff from land adjacent to Town Lake. The vast majority of the water entering the lake from the local creeks is storm flow. Very little baseflow occurs in our highly urbanized creeks. The location of the local creeks and the segment into which they flow are identified in Figures 1.1 and 2.1. Eanes Creek, Johnson Creek, and 2/3 of the area adjacent to Town Lake flow into the MoPac segment. Barton Creek and Barton Springs discharge in the Lamar segment. Shoal Creek, Waller Creek, West Bouldin Creek, East Bouldin Creek, and the remaining 1/3 of the area adjacent to Town Lake all flow into the First Street segment. Blunn Creek and Harper's Branch add diffuse loads to the I-35 segment.

Load Quantity

The load for each of the constituents was set equal to the incoming flow times the concentration in the flow. The constituent concentrations for Barton Springs are taken from USGS data (USGS 1996; USGS 1997). The concentrations for Barton Creek at Loop 360 and Shoal Creek are taken from the report: Characterization of Stormwater Pollution for the Austin, Texas Area (COA 1997 (draft)). The volume weighted mean concentration values for stormwater runoff are used since the majority of the inflow is stormwater. Shoal Creek concentrations are used for all the remaining creeks, including the stretch of Barton Creek below Loop 360. Information on chlorophyll *a* levels was not available, so the concentration was set to a minimal value for the 1994 bloom period and to zero for the annual and 2000 bloom simulations. The pollutant concentrations used for calculating the load are shown in Table 4.1. The impact of creek pollutant loads on lake concentrations is much more pronounced when upstream inflows are minimal. Stormwater runoff accounted for 42 percent of the water during the bloom of 1994, 34 percent during the year 1995 and 59 percent during the 2000 bloom.

The annual local loads to Town Lake determined by this method were compared with the annual loads reported in the Diagnostic Study of Water Quality Conditions in Town Lake (COA 1992) and the current annual loads estimated by Center for Research in Water Resources (Dartiguenave 1997). The calculated loads were approximately equal to previous estimates except for total phosphorus load, which was higher than the other load estimates for Town Lake. To reduce the estimated annual WASP4 loads to the same level as reported in the Diagnostic Study of Water Quality Conditions in Town Lake, the WASP4 orthophosphate and organic phosphorus loads were multiplied by 0.75 for the annual simulation and for the 2000 bloom simulation as well.

Table 4.1 Pollutant Concentrations for Load Calculations

	Pollutant Concentrations for Loading Estimates (mg/L)		
Constituent	**Barton Springs**	**Barton Creek**	**Shoal Creek**
Ammonia (NH3)	0.15	0.07	0.175
Nitrate	1.5	0.34	0.6
Orthophosphate	0.01	0.04	0.2
Chlorophyll *a*	0.0001 or 0	0.0001 or 0	0.0001 or 0
Biological Oxygen Demand	0.3	4	12
Dissolved Oxygen	6	9	9
Organic Nitrogen (TKN-NH3)	0.185	1.7	3
Organic Phosphorus (TP-PO4)	0.005	0.12	0.8
Total Kjeldahl Nitrogen (TKN)	0.2	1.8	3.13
Total Phosphorus (TP)	0.015	0.16	1

4.5 Kinetic Parameters and Constants

The parameters and constants that were used in these simulations are listed below in Table 4.2. Many of these parameters were taken from literature values. Additional local studies would improve the estimates for some of these parameters.

Table 4.2 Model Parameters and Constants

Ammonia nitrification

	Nitrification rate at 20° C	0.1/d
	Temperature coefficient	1.08
	Half-saturation constant for nitrification-oxygen limitation	2.0 mg/L
Nitrate Denitrification		
	Denitrification rate at 20° C	0.10/d
	Temperature coefficient	1.08
	Half-saturation constant for denitrification-oxygen limitation	0.1 mg/L
Phytoplankton		
Growth	Maximum growth rate at 20°C	Bloom: 3.5/d Annual: 3.0/d
	Temperature Coefficient	1.08
Light	Light formulation	Smith’s (USGS)
	Maximum quantum yield constant	720 mg C/mole photons
	Chlorophyll extinction coefficient	0.017 (mg chla/m^3)$^{-1}$/m
Nutrients	Half-saturation constraint for nitrogen for phytoplankton growth	0.25 mg/L
	Half-saturation constant for phosphorus for phytoplankton growth	0.001 mg/L
	Nutrient limitation option	Multiplicative
	Phosphorus to carbon ratio in phytoplankton	0.025 mg P/mg C
	Nitrogen to carbon ratio in phytoplankton	0.250 mg N/mg C
	Half-saturation constant for mineralization	0.0 mg/L
	Carbon to chlorophyll ratio in phytoplankton	50 mg C/mg chla
Death	Endogenous respiration rate at 20^{o} C	0.125/d
	Temperature coefficient for respiration	1.045
	Non-predatory phytoplankton death rate	0.044/d
	Grazing rate of zooplankton on phytoplankton	0.0/d
	Fraction of dead and respired phytoplankton nitrogen recycled to organic nitrogen	0.5

Table 4.2 (cont.) Model Parameters and Constants

Biological Oxygen Demand		
	BOD deoxygenation rate at 20^{o} C	0.40/d

	Temperature coefficient for deoxygenation rate	1.05
	Half-saturation constant for BOD deoxygenation rate	0.4 mg/L
Dissolved Oxygen		
	Oxygen to carbon ratio in phytoplankton	2.67 mg O2/mg C
Organic Nitrogen		
	Total organic nitrogen mineralization rate at 20^o C	0.03/d
	Temperature coefficient for nitrogen mineralization rate	1.08
Organic Phosphorus		
	Dissolved organic phosphorus mineralization rate at 20^o C	0.22/d
	Particulate organic phosphorus mineralization rate at 20° C	0.05/d
	Temperature coefficient for phosphorus mineralization rate	1.08

4.6 Temporal and Spatial Functions

Temporal functions change with the date in the simulations and spatial functions vary from one segment to another. Solar radiation and wind vary with time alone. Sediment oxygen demand and the flux of ammonia and phosphate from the sediment to the water column vary spatially. Water temperature and the extinction coefficients for the attenuation of light in the water column vary with both space and time.

Incoming solar radiation was determined from the date, the latitude, and the Austin-area daily cloud cover. Wind at the water surface was set to half of daily average wind speed at 10 m above ground at the Austin airport. The spatially varying sediment-water interaction parameters and their values are shown in Table 4.3.

Table 4.3 Spatial Functions - Sediment Water Interactions

	Segment					
Parameter	**Red Bud**	**MoPac**	**Lamar**	**First**	**I-35**	**Basin**

Sediment oxygen demand (g/m^2-day)	0.1	0.1	0.5	1	2	4.9
Ammonia flux (sediment to water) (mg/m^{2}day)	1	1	1	1	2	2
Phosphate flux (sediment to water) (g/m^2-day)	1	1	1	1	1	1

Temperatures were averaged over depth within a segment. Monthly averages were used for the annual simulation. Linear interpolation was used for days between sampling dates for the bloom simulations, and the mid-month dates for the annual simulation. For one date during the bloom simulation, October 26, 1994, an independent estimate was made for temperature levels. A storm had occurred, the previous observation was pre-storm, and lake temperatures frequently drop abruptly during storms. Using linear interpolation in this case seemed inappropriate.

The light extinction coefficients were estimated from the secchi disk data using the formula, n = 1.7/(secchi disk depth(m)). Following a large storm on October 25, 1994, no data were obtained for several days. On October 26, 1994, one day after the storm, the secchi disk depths were set equal to the observed depths on October 19, 1994, which was one day after a smaller storm. The exception to this estimate was at the Basin. Secchi disk depth at this location was set equal to the observed secchi disk depth at First Street the previous day, since during the storm the algae-laden water from the First Street segment was assumed to dictate subsequent Basin clarity under these conditions.

5.0 MODEL CALIBRATION - 1994 BLOOM

The water quality model was calibrated using data from the bloom period in fall 1994. Parameters that were varied during the calibration procedure included the upstream boundary conditions for organic nitrogen and chlorophyll *a*, four growth parameters, three nutrient parameters, and three other parameters. The growth parameters varied were extinction coefficients, the growth rate, the temperature coefficient for the growth rate, and the water column temperature. The nutrient parameters varied were the half-saturation constant for nitrogen for phytoplankton growth, the half-saturation constant for phosphorus for phytoplankton growth, and the nutrient limitation option. The other parameters varied included the death rate, the carbon to chlorophyll ratio in phytoplankton and the sediment water interaction parameters. The selected parameter values were listed in the previous section.

Model-predicted values were compared to observed values for chlorophyll *a*, nutrients, and dissolved oxygen. Model-predicted nutrient limitations were determined from these results. Light and temperature values were plotted. Chlorophyll *a* data were plotted against nutrient, dissolved oxygen, light, temperature, flow, and rainfall data. These plots are shown below, along with comments on the model fit and the data comparisons.

The model predicts an average value for an entire segment; however, the calibration data were collected at different depths at a single site within the segment. Chlorophyll *a* was collected at the surface. Nutrients were collected at the surface and at the bottom. Temperature and dissolved oxygen were collected at one-meter intervals from top to bottom. Surface and bottom concentrations are plotted in the graphs. For some dates, replicate values were available and are plotted. Multiple observations for which the concentrations are equal are displayed as a single point.

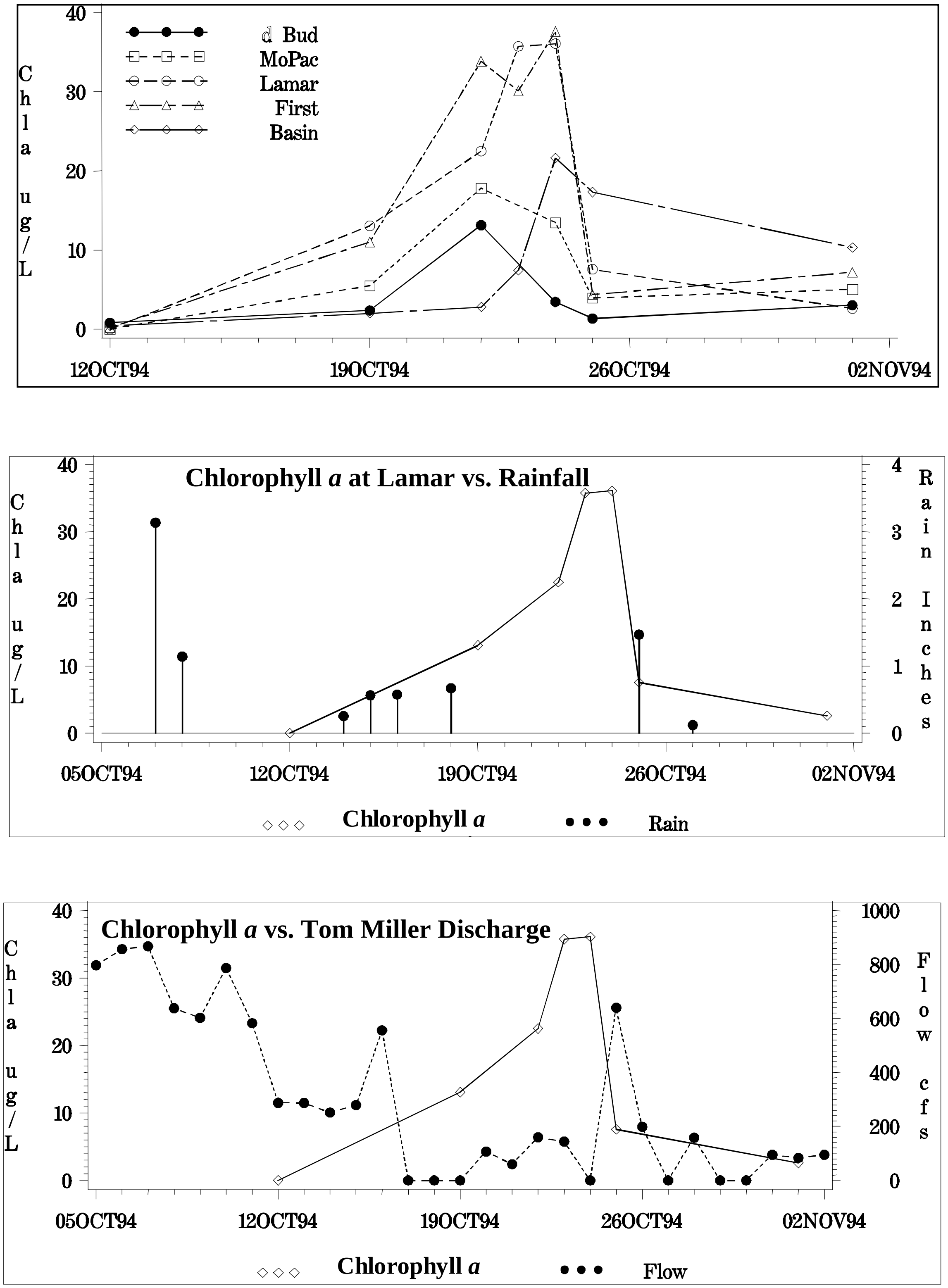
The modeled concentrations may decrease to zero but observed values will not drop below the laboratory detection limits. Observed concentrations that were below the detection limit were plotted at the detection limit. The detection limits vary with date and laboratory used for water chemistry.

5.1 Chlorophyll *a*

Chlorophyll *a* is an aggregate measure of the phytoplankton population or biomass for calibration purposes. The chlorophyll *a* levels in Town Lake from October 12, 1994, to November 2, 1994, are plotted in Figure 5.1. The levels are minimal at the start of the period. Chlorophyll *a* increases to very high levels for Town Lake and then drops abruptly. Figure 5.1 also shows the relationships between rainfall and Lake Austin discharges and Town Lake chlorophyll *a*. Town Lake blooms typically occur on calm, sunny days when flows are low and the water is clear, several days after storms that add nutrients to the lake, and this event was no exception. The bloom ends on a day with heavy rainfall and increased flow. An influx of stormwater increases the turbidity of the lake and decreases the surface temperatures at this time of year. Therefore, conditions are no longer optimal for algal growth. Increased flow also decreases the residence time in the lake and moves some of the algal population downstream, thereby ending the bloom.

The pattern for chlorophyll *a* levels is similar for the four upstream segments of the lake; however, the pattern in the downstream segment is quite different. The high levels appear later in the event and do not decrease as abruptly following the storm as in the other segments. This segment (Basin) is not as uniform as the other segments in its physical characteristics. It has both deep holes and shallow areas with reduced flow. The predictions for this area are, in general, considerably worse than for the rest of the lake.

Figure 5.1 Town Lake Chlorophyll *a*



Model Predictions

The fit between the data and the model predictions (Figure 5.2), is fairly good at Lamar and First, but the predicted values are too high at Red Bud, MoPac, and the Basin. Subsequent runs varying calibration parameters did not produce good fits at both the middle and upper segments. If the fit was good at the upper stretch of the lake, the predicted values were too low in the middle stretch. A good fit in the middle resulted in predicted values that were too high in the upper stretch. Predicted chlorophyll *a* values increase too soon at Longhorn Dam. The model population in all the segments does not drop low enough following the October 25 storm. The predicted values are too high in all the segments at the end of the run.

5.2 Nutrients

Nitrate - Data

Nitrate levels are fairly constant prior to the bloom (Figure 5.3). They dip during the height of the bloom and then increase toward the end of the period as flow from Barton Springs, a source of high nitrates, becomes a larger portion of the water in the lake. Levels in the Basin display a different pattern from the rest of the lake, remaining almost constant throughout. In Figure 5.3, chlorophyll *a* is plotted versus nitrate concentrations in the middle and downstream end of the lake. Nitrate values decrease during the bloom at Lamar, but no apparent relationship exists between nitrate and chlorophyll *a* values at the Basin. This lack of correlation indicates that phytoplankton growth could be limited by nitrate concentrations in the middle of the lake, but not at the downstream end. Water samples taken in the middle of the lake are sometimes not well-mixed lake water, but instead predominately Barton Springs discharge.

Nitrate - Model Predictions

Model predictions and observed values exhibit similar patterns except at the Basin (Figure 5.4). The predicted values are lower than the observed levels during the bloom. The modeled concentrations do not match the first dip in observed values at Lamar and First Street. The predicted levels at the Basin at the end of the run drop to zero. This is due to an excess in predicted phytoplankton (Figure 5.2). The observed minimums are higher than the predicted minimums. The predicted levels are below the laboratory detection limits and are close to zero.

Figure 5.2 Town Lake Chlorophyll *a* - Predicted vs Observed, 1994

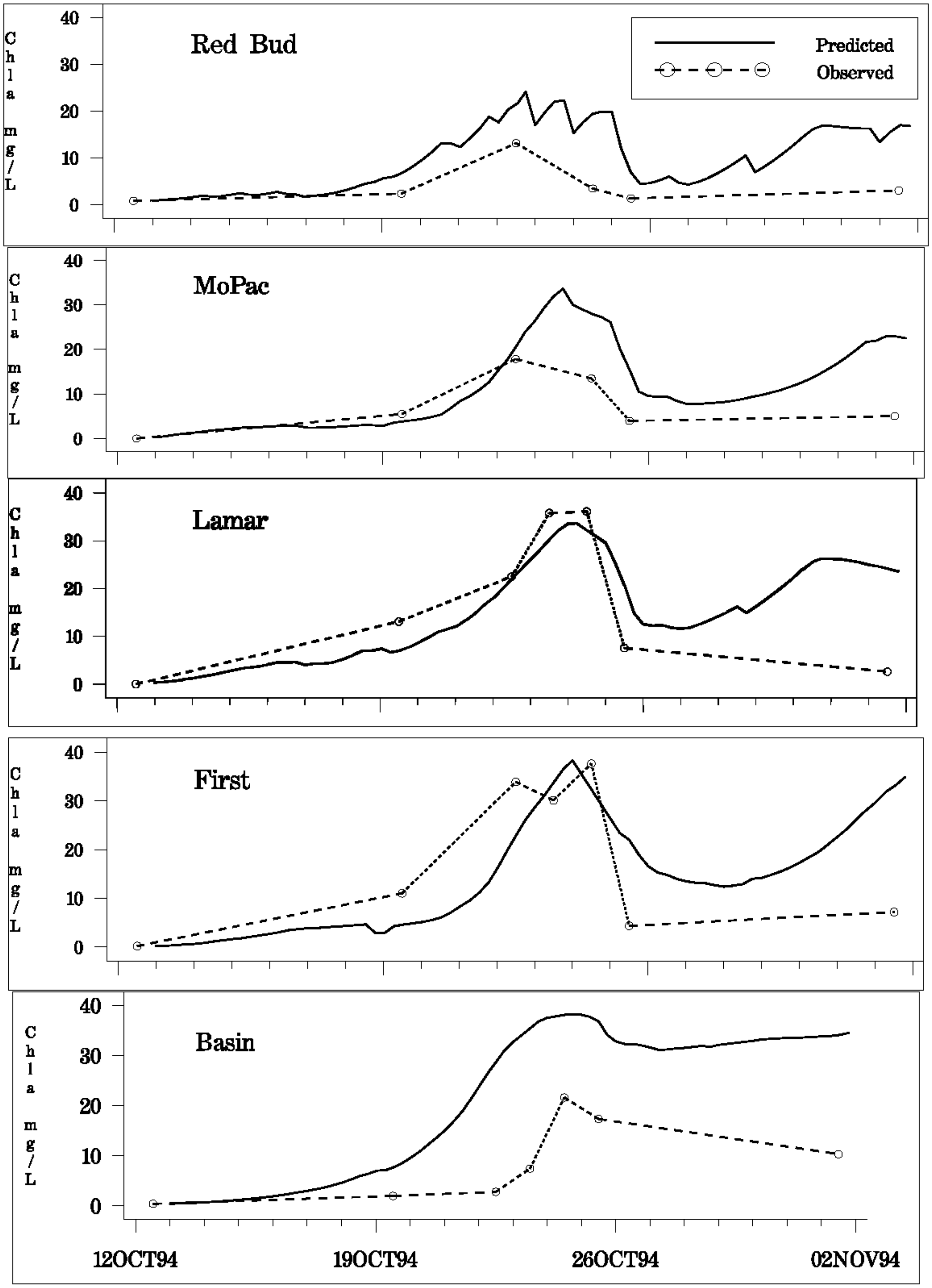
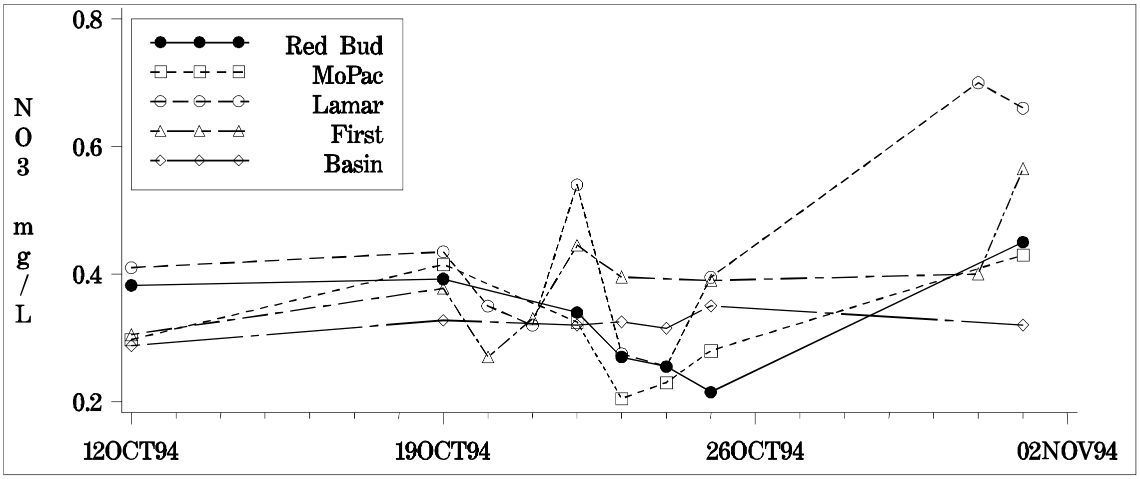
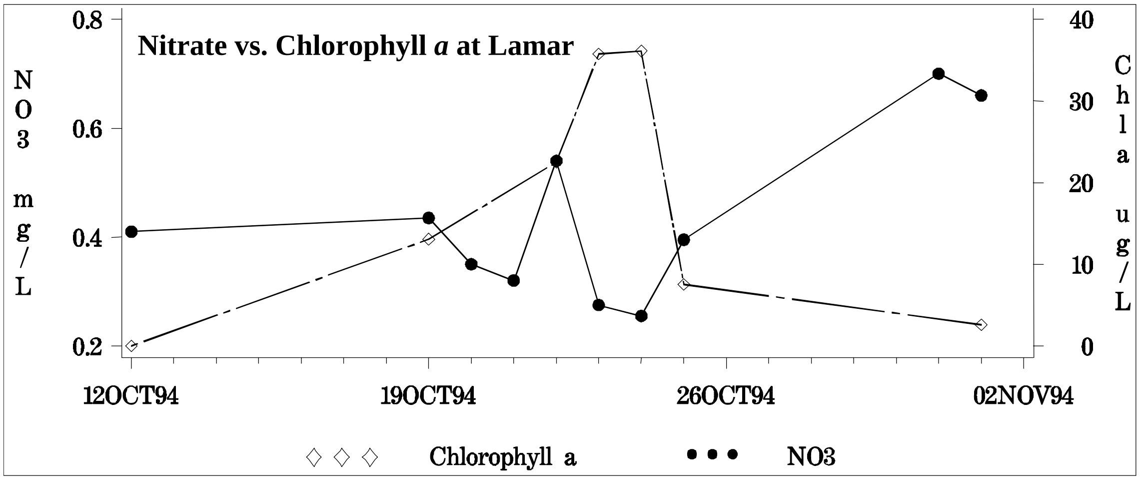


Figure 5.3 Town Lake Nitrates, October 1994





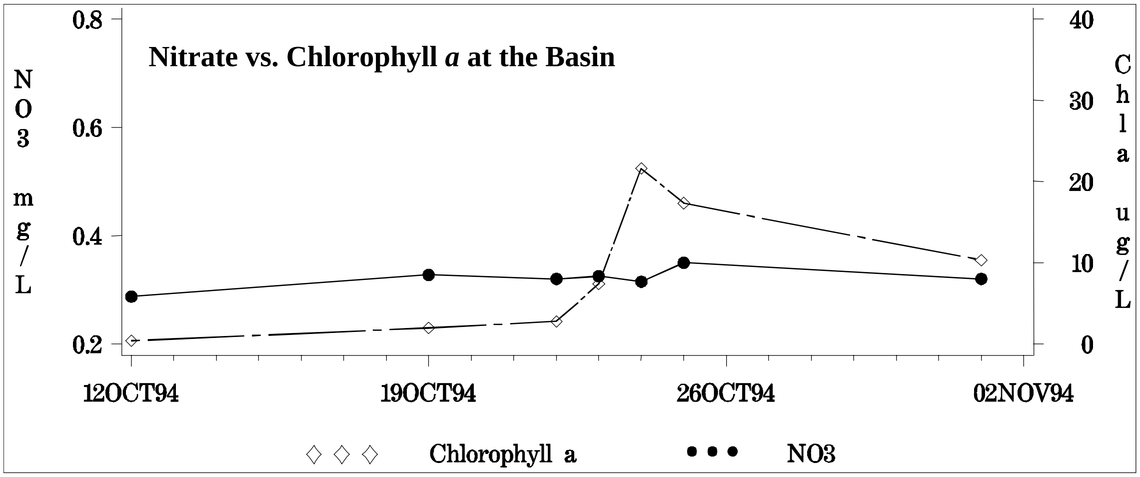
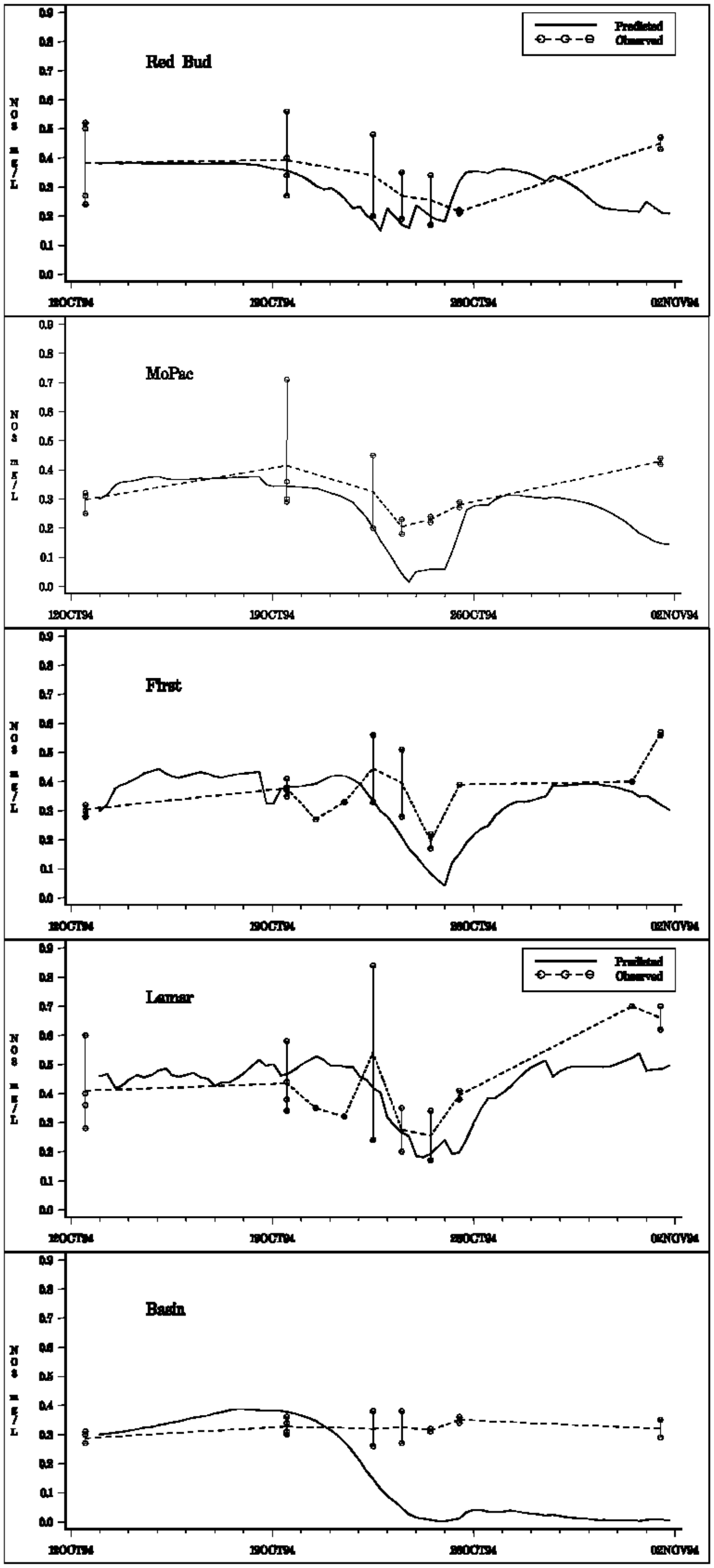


Figure 5.4 Town Lake Nitrate - Predicted vs Observed, 1994



Orthophosphate - Data

Orthophosphate levels increase prior to the bloom (Figure 5.5) except at Red Bud. This increase is likely due to the influence of first-flush stormwater runoff (see rainfall and flow in Figure 5.1). Concentrations plummet to the detection limit during the height of the bloom, and then rebound in the center of the lake with a fresh influx of stormwater and the end of the high phytoplankton concentrations. In Figure 5.5, chlorophyll *a* is plotted versus orthophosphate concentrations in the middle and downstream end of the lake. The impact of high phytoplankton concentrations on orthophosphate levels is apparent in both areas of the lake. These plots indicate that orthophosphorus is a major factor in nutrient limitation for phytoplankton in Town Lake.

Orthophosphate - Model Predictions

The overall pattern of the model predictions is similar to the pattern of the sample data (Figure 5.6). However, the details of the fit are not as good as desired. The timing and magnitude of the major changes are somewhat different. The predicted values do not drop as soon as the observed values at Lamar and First Street. The simulated concentrations drop below the detection limits during the bloom. The observed values are at the detection limit so the quality of the fit cannot be determined. The predicted levels of orthophosphorus do not increase enough in the middle of the lake following the storms that ends the bloom. Finally, the modeled concentrations at the end of the run drop to zero. This is due to an excess in model-predicted phytoplankton.

Ammonia - Data

Ammonia concentrations are similar in most segments of the lake (Figure 5.7). They decrease at the beginning of the modeled time period, decrease again during the bloom, and then increase some after the end of the bloom. The concentrations at the Basin are markedly different, however, both in quantity and pattern. The average concentration increases prior to the bloom, decreases at the height of the bloom and then shows a major increase as the bloom starts to decrease (Figure 5.7). The high average concentration reflects the high levels found at the bottom of the Basin in water with low dissolved oxygen concentrations.

Figure 5.5 Town Lake Orthophosphate, October 1994

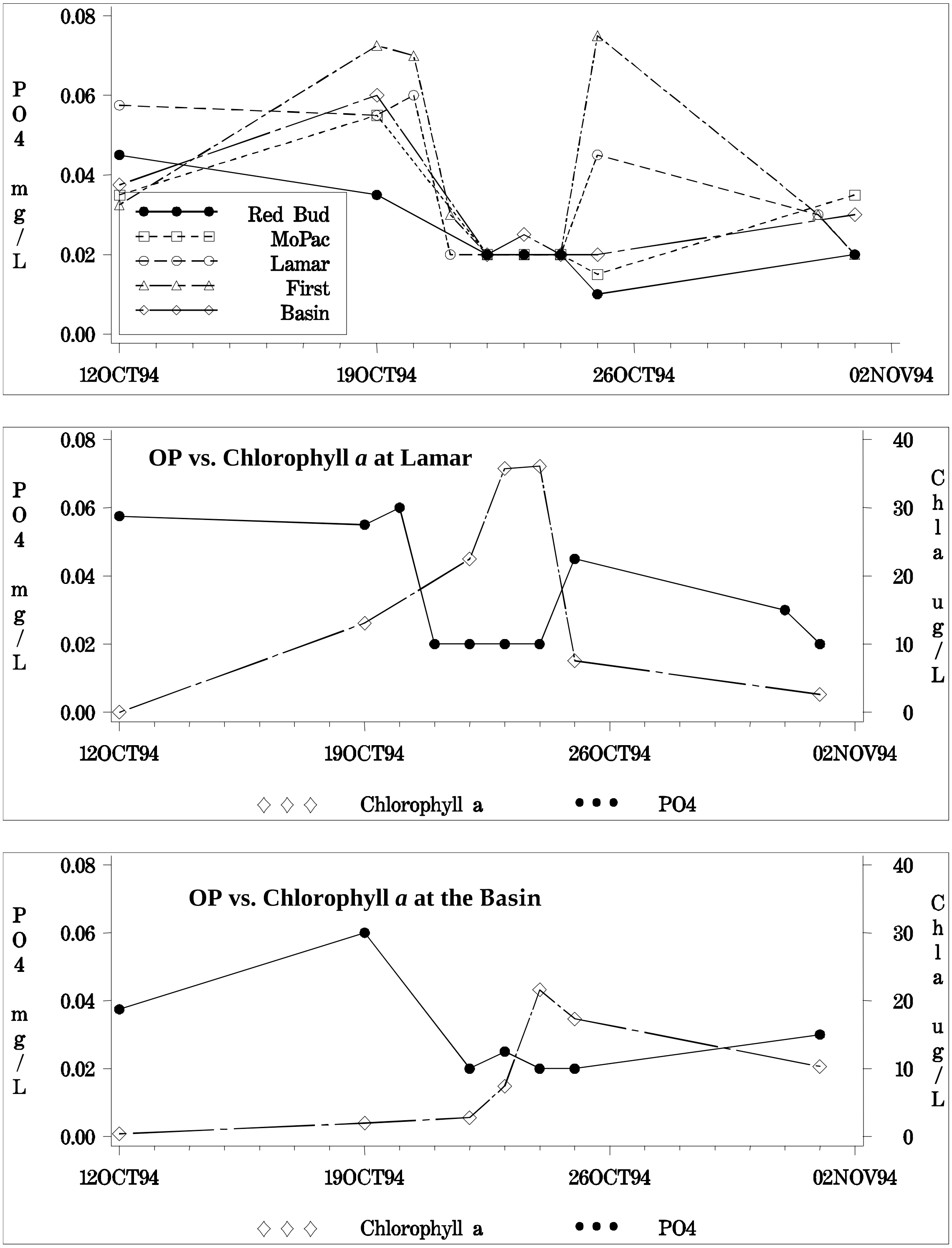


Figure 5.6 Town Lake Orthophosphate - Predicted vs Observed, 1994

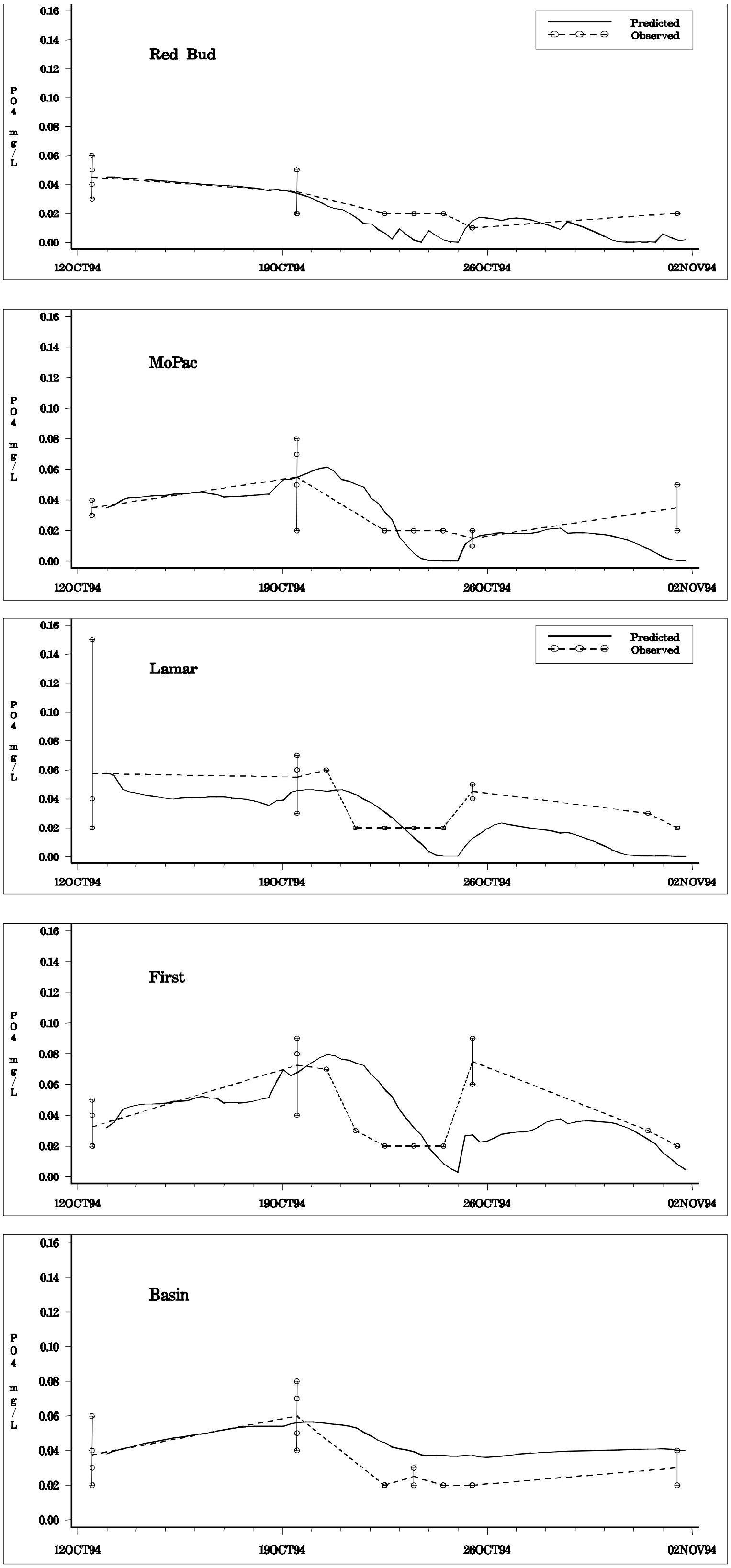
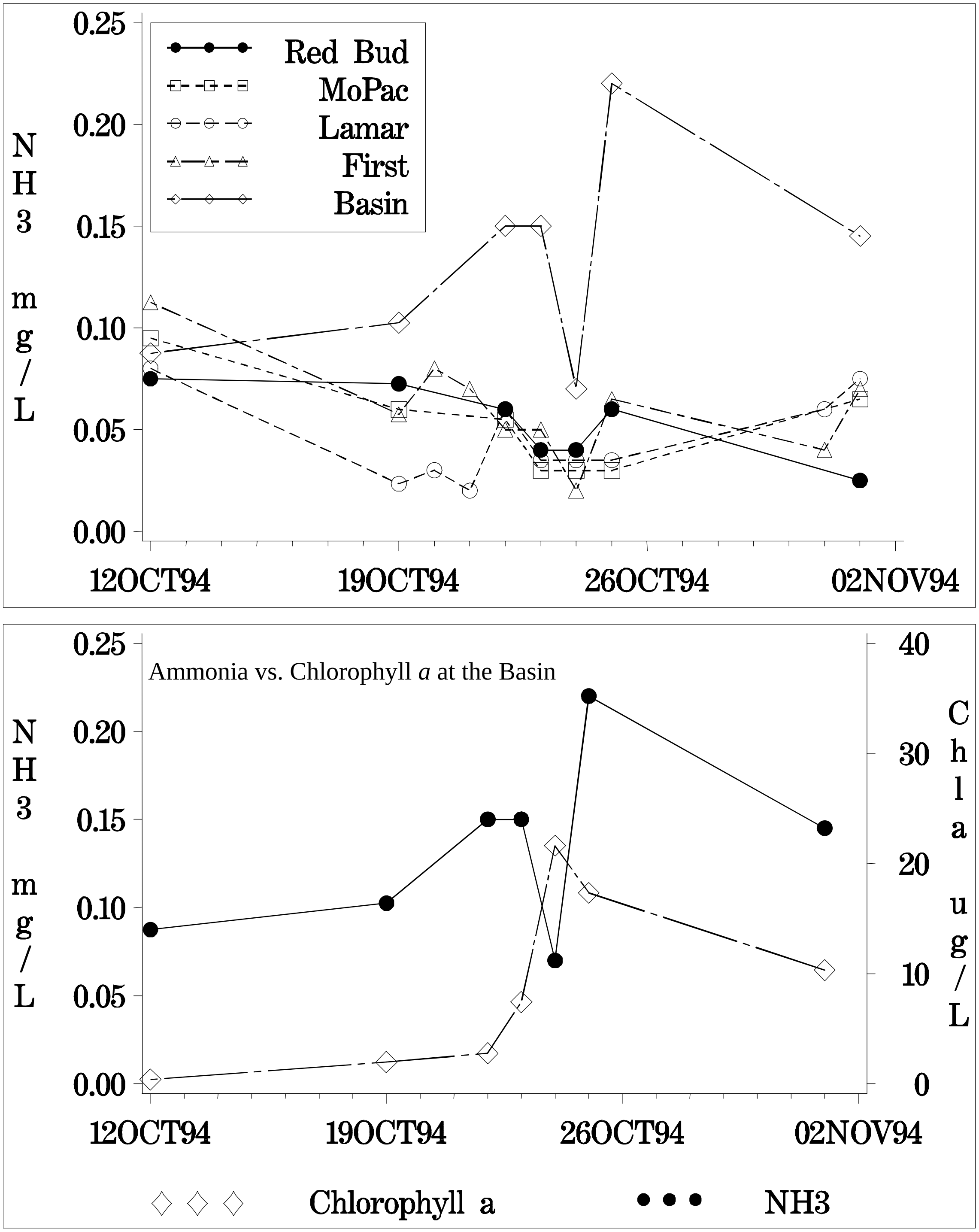


Figure 5.7 Town Lake Ammonia, October 1994



Ammonia - Model Predictions

Model predictions match observed data fairly well except at the Basin, where they are inconsistent with observed data (Figure 5.8). The predicted values are too low in all segments during the bloom. The modeled concentrations, in all segments, drop too low at the end of the run. This occurrence may be due to an excess in model-predicted phytoplankton. The simulated values at the Basin are much too low, and do not show the observed relationship between chlorophyll *a* and ammonia.

Organic Nitrogen - Data

Organic nitrogen levels remain fairly constant until after the bloom, when they increase abruptly (Figure 5.9). A week later levels were low again. No samples were collected during the week following the date with the high levels; therefore, no information on the pattern or rate of decrease in the concentrations is available.

Organic Nitrogen - Model Predictions

Model predictions match observed data fairly well at the upstream end of the lake, with less of a fit downstream. The model predicts increases in organic nitrogen with the small storms that precede the bloom, but the data show only one large increase - with the large storm that ends the bloom. Model predictions remain higher after the end of the bloom that the data indicate.

Organic Phosphorus - Data and Model Predictions

Organic phosphorus is a calculated value from the difference in total phosphorus and orthophosphorus. One or both of the values are frequently at or near the detection limit. Plots of the calculated values are thus unreliable and comparison with predicted values is not beneficial. Predicted and observed values remain within the same range.

Nutrient Limitation - Data

Phytoplankton appears to be nutrient limited in Town Lake. The observed higher levels of chlorophyll *a* at Lamar and First appear to indicate increased growth due to increased nutrients from storm water and from Barton Springs. Nitrate levels drop during the bloom, but not to the detection limit and not in all segments, implying that nitrogen is not the primary limiting nutrient. The match between increased levels of phytoplankton and the decreases in orthophosphate appears to indicate that phosphorus is the primary limiting factor.

Figure 5.8 Town Lake Ammonia - Predicted vs Observed, 1994

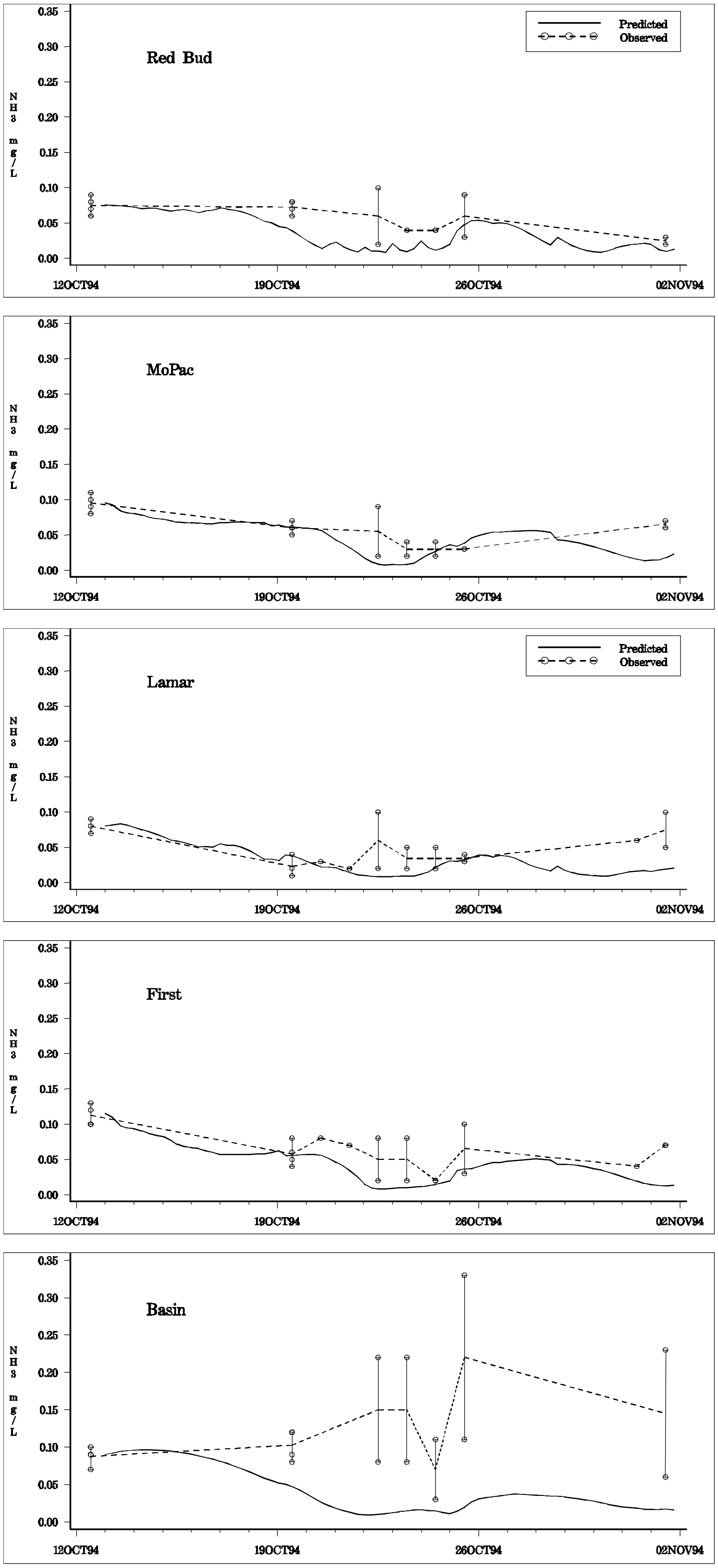
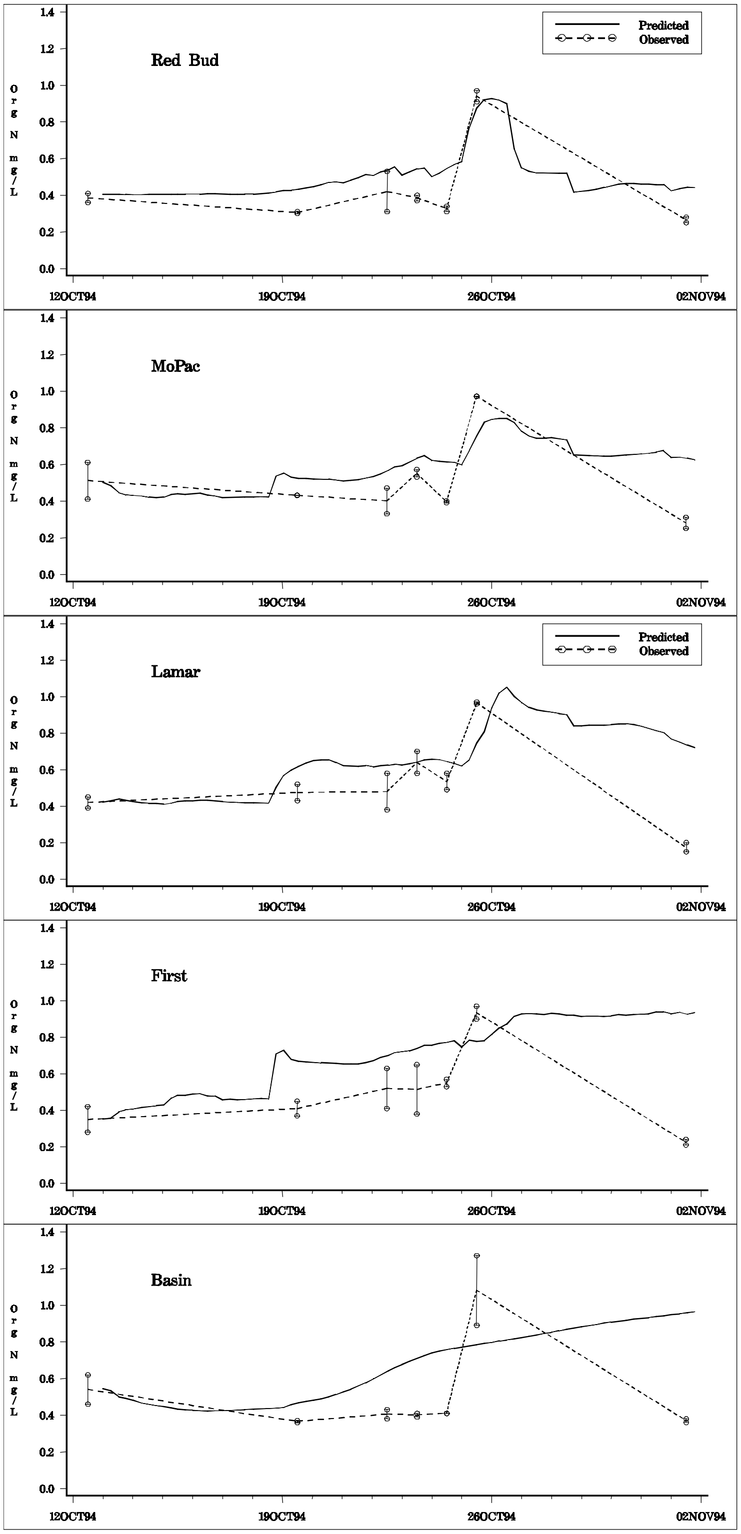


Figure 5.9 Town Lake Organic Nitrogen - Predicted vs Observed, 1994



Nutrient Limitation - Model Predictions

The model predicts that phytoplankton are limited by phosphorus at Red Bud, limited by both nitrogen and phosphorus at MoPac with the phosphorus limitation predominating, limited by phosphorus at Lamar, almost no nutrient limitation at First Street, and nitrogen-limited at the Basin. These predictions match the implications of the data, with the exception of the nitrogen limitation at the Basin. At this location, the simulation result is due to the model overprediction of phytoplankton at the Basin and thus should be disregarded. The data definitely do not support nitrogen limitation at the Basin.

5.3 Light, Temperature and Dissolved Oxygen

Light - Data

Light limitation plays an important role in regulating in phytoplankton growth. The light extinction coefficients were estimated from secchi disk data. The relationship between chlorophyll *a* levels and secchi disk depth is shown in Figure 5.10. Secchi disk depths, and thus light levels, are increasing during the start of the bloom except at Lamar. The start of the bloom is a period of low flow (no inflow from Lake Austin) following several days of light rain. The increase in visibility in the lake during this period may be necessary for an algal bloom to occur. As the bloom increases, the secchi disk depths start to decrease, but the big decrease in the depths is due to storm runoff.

Temperature - Data

Temperature is another important factor in algal growth. The average temperatures in the lake are shown in Figure 5.11. Temperatures were increasing in the lake prior to and during the bloom. The relationship between chlorophyll *a* concentrations and temperatures in the middle and downstream end of the lake are also shown in Figure 5.11. At First Street, temperature and phytoplankton levels vary jointly, but no apparent correlation exists between the two at the Basin. Mean lake temperatures were input to the model except for the period following the storm of October 25. The difference in the observed temperatures and the model temperatures is shown in Figure 5.12. The surface temperatures were considerable higher than the segment mean temperatures during the bloom period. Most algal growth is assumed to take place near the surface. Using the lower mean temperatures reduces the predicted model growth rate. However, many other rates in the model are also affected by temperature and are occurring throughout the water column.

Figure 5.10 Town Lake Secchi Disk Depths vs Chlorophyll *a*

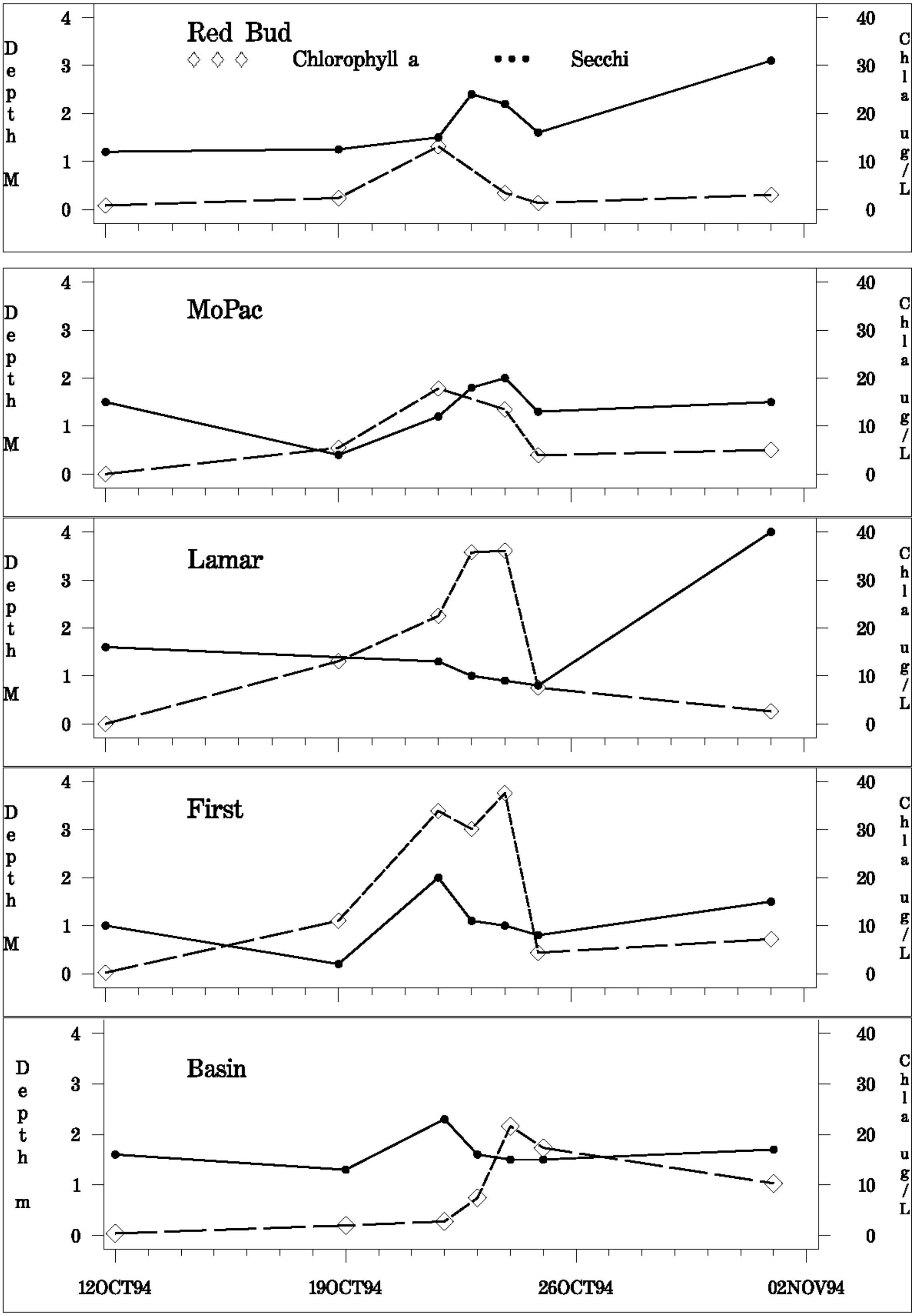


Figure 5.11 Town Lake Temperature

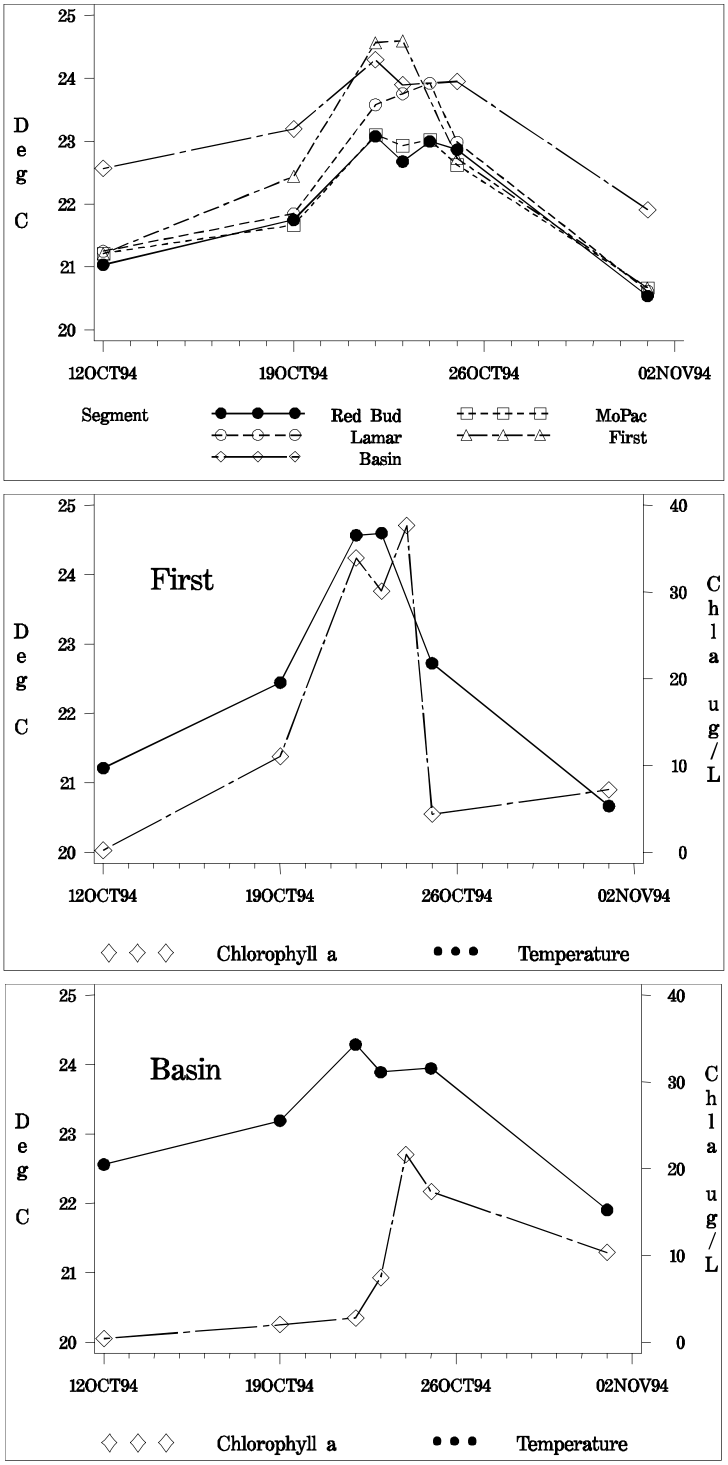
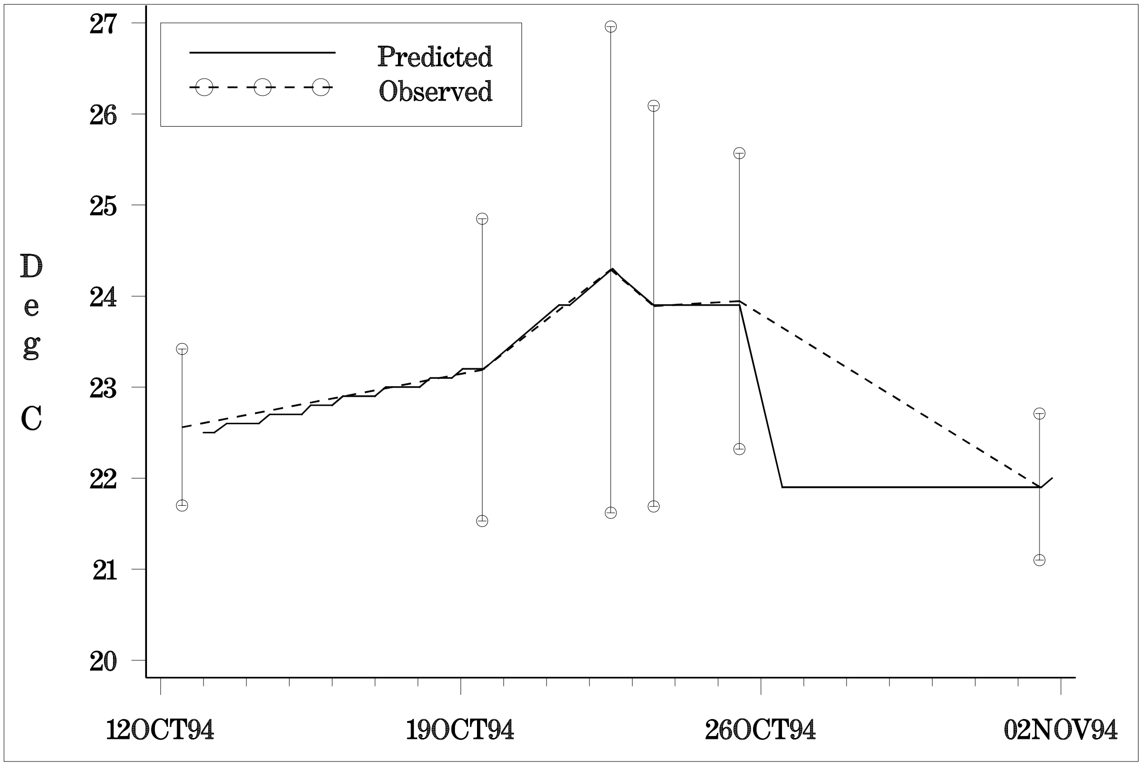


Figure 5.12 Town Lake Temperature - Predicted vs Observed, Basin



Dissolved Oxygen - Data

Dissolved oxygen data show a strong difference between the top and bottom layers of the lake (Figure 5.13). During the bloom, surface concentrations increase while bottom concentrations decrease. Figure 5.13 also shows the relationship between surface and bottom dissolved oxygen concentrations and chlorophyll *a* levels at Lamar.

Dissolved Oxygen - Model Predictions

Model predictions show the same pattern as observed data but the simulated concentrations are too high during the bloom periods (Figure 5.14). The modeled values match the observed surface dissolved oxygen concentrations better than they do the average of the surface and bottom concentrations. These high predicted levels are due in part to the high prediction values for algae. The simulated concentrations are also too high at the end of the run, due to excess predicted algae.

Figure 5.13 Town Lake Dissolved Oxygen

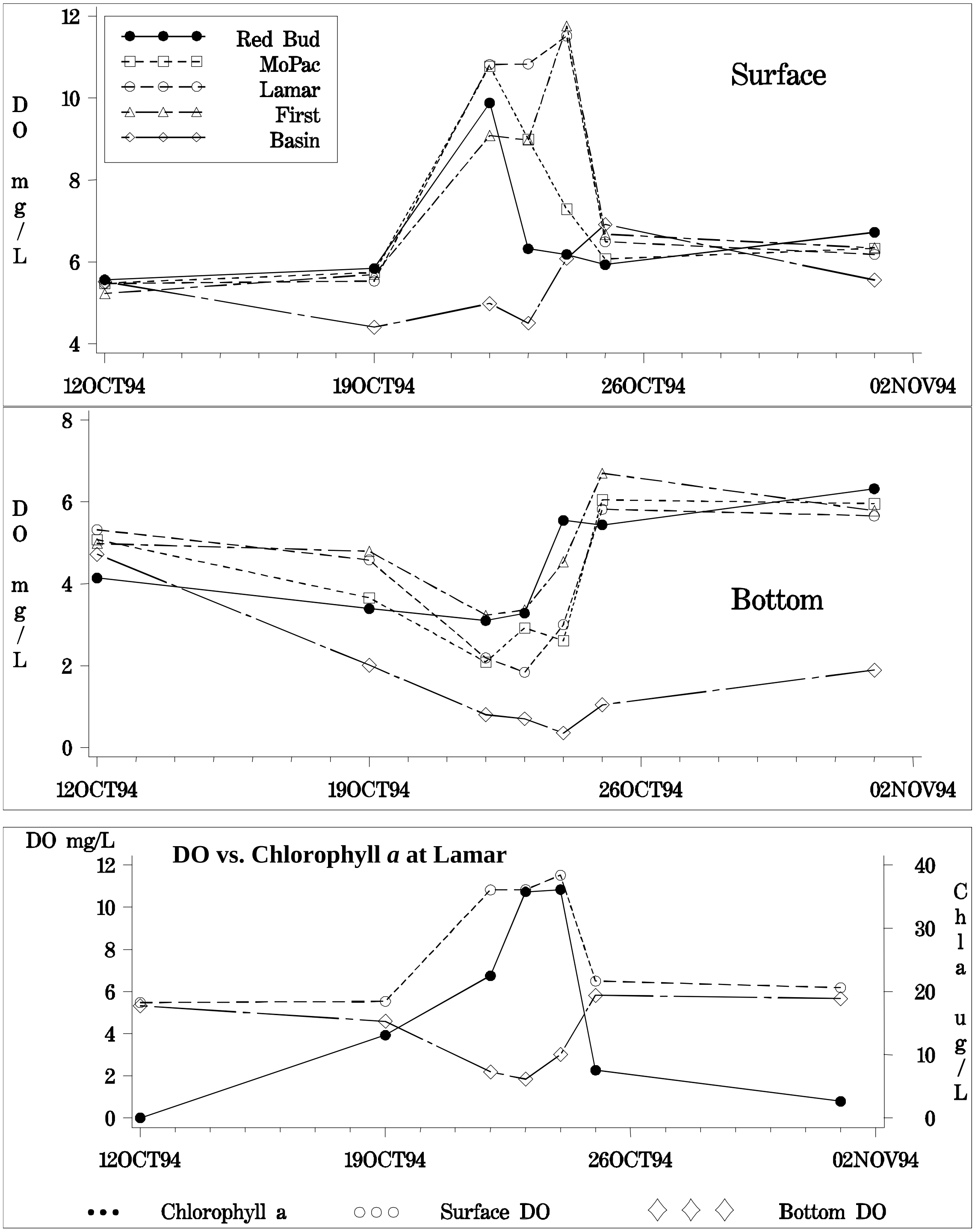
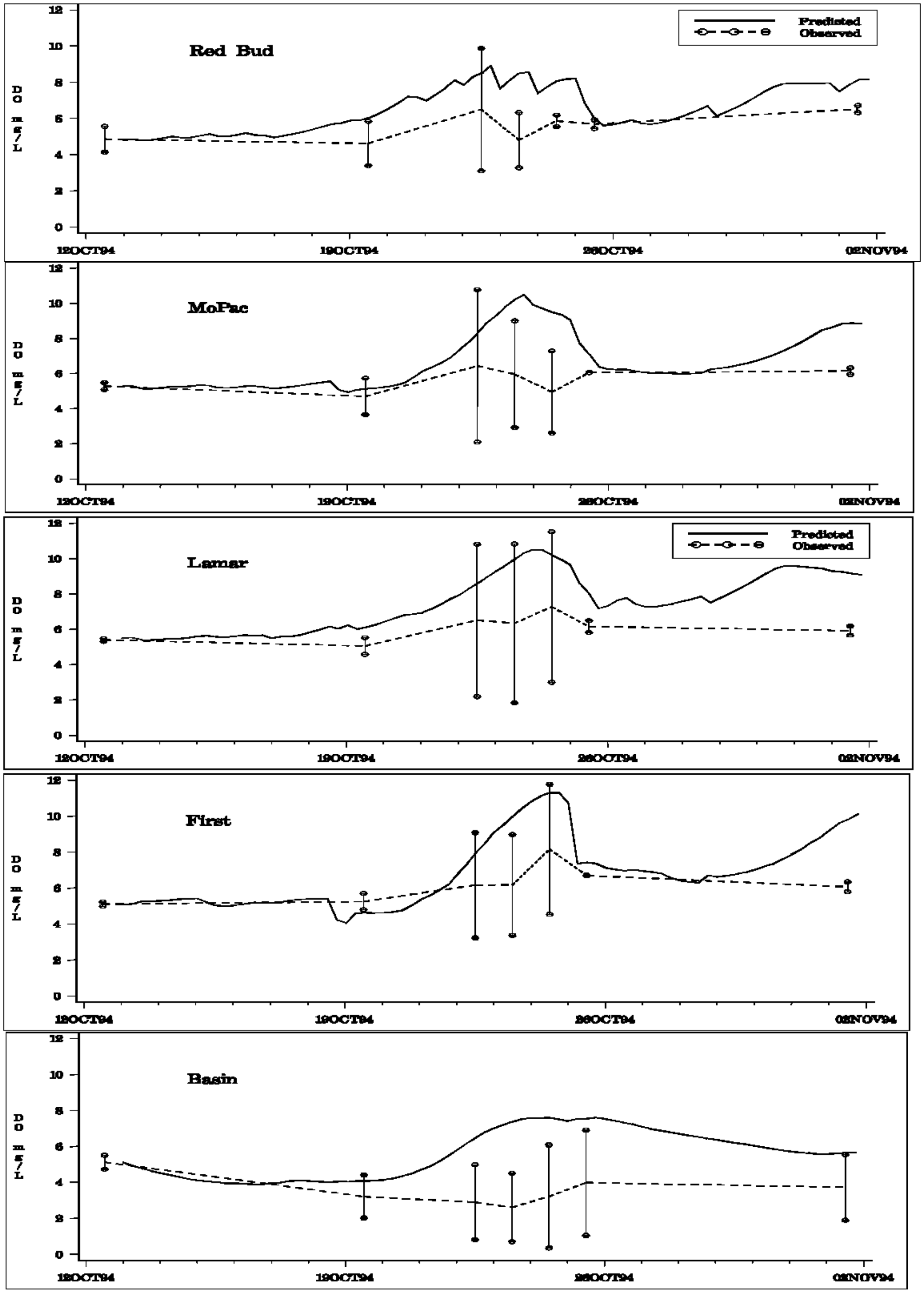


Figure 5.14 Town Lake Dissolved Oxygen - Predicted vs Observed



5.4 Conclusions

The model fit was reasonably good for most parameters at most locations and thus was deemed acceptable. Many parameters were varied in the endeavor to produce the best possible fit and the selected set produced the most desirable overall result.

Several results are pertinent in applying the model to other time periods. The maximum growth rate of 3.5/day for phytoplankton is quite high when compared to literature values, although it is less than the maximum growth rate estimated from cell counts in Town Lake. It is possible that the highest growth rates estimated from daily cell counts may be in error. The cell count includes both live and dead cells. The count could be strongly affected by a patchy algal distribution. This growth rate is high enough to produce a simulated bloom from an initial phytoplankton level of essentially zero. Therefore, this growth rate should not be used for projections unless initial chlorophyll *a* levels are such that a bloom is a possibility. The growth rate used for the annual simulation (to be discussed in the next section) was 3.0/day rather than 3.5/day.

The model fit was best in the center of the lake. The center of the lake receives the most local storm inflow and is the area of the lake from which drinking water is withdrawn. Therefore, the model fit in the center of the lake was of greater importance than the model fit at either end. The model fit at the Basin is the worst and little weight should be given to model predictions in this segment.

In order to simulate well the observed phytoplankton levels in the middle of the lake, the model overpredicts chlorophyll *a* levels in the rest of the lake. Some factor that is not adequately accounted for must affect the central part of the lake. Potential factors include the nutrient levels input from Shoal, Barton, East and West Bouldin, and Waller Creeks; increased clarity in the water due to Barton Springs inflow; the effects of urban baseflow; and the warmer surface temperatures.

The model tracks the bloom fairly well, but then predicts the start of another bloom at the end of the simulated time period. This second bloom did not occur in the lake. The exact mix of factors necessary to start a bloom or to prevent one in Town Lake has not been determined through model evaluations or biological evaluations. Experience indicates that blooms can occur on calm, warm, sunny days with little flow from Lake Austin, several days after a storm, but this does not always happen. Therefore, model predictions of blooms need to be treated as possibilities rather than certainties.

6.0 1995 ANNUAL SIMULATION

The WASP4 model was calibrated by predicting the dynamics of an individual bloom. In addition to increasing understanding of the factors contributing to phytoplankton blooms, the impact of variations in annual loads on lake phytoplankton levels were required for planning purposes. To achieve this end, annual simulations were needed. Although model validation is not yet complete, the model calibrated on a bloom period was applied to an entire year.

A few changes in model input were necessary from the bloom to the annual simulation. These changes are discussed in detail in section 7.2. Model parameters remain the same except for the phytoplankton maximum growth rate, which changes from 3.5/day to 2.5/day. Model loads and temporal functions are monthly averages rather than individual data points.

Model usage also changes with the switch from modeling blooms to simulating annual periods. It is not possible, from a model using monthly average inputs, to predict individual booms and their magnitude or the number of blooms that might occur during the year. Blooms occur due to a very specific combination of factors - clear, calm days, high temperatures, low flows, and excess nutrients. When using monthly average values, time periods are predicted during which, if the daily conditions are all appropriate, blooms might occur, and the potential average magnitude of such blooms.

Model-predicted values were compared to observed values for chlorophyll *a*, nutrients, and dissolved oxygen. Model-predicted nutrient limitations were displayed. Light and temperature values were plotted. These plots are shown below, along with comments on the model fit and the data comparisons. Short-term changes in lake concentrations due to storm or bloom events would not be matched by model predictions, which are based only on changes in monthly average levels.

6.1 Chlorophyll *a*

Chlorophyll *a* levels in 1995 were unusual in that the period of highest concentrations occurred in the spring rather than the fall (Figure 6.1). In the fall, chlorophyll *a* concentrations reached bloom levels only at the Basin. The model predicts two potential bloom periods, one in the spring and one in the fall, with the potential chlorophyll *a* concentration being higher in the spring than in the fall (Figure 6.2). This result agrees with the data and is significant in that the largest blooms in the lake typically occur during the fall. Conditions were different from the usual in 1995, and the model predicts the unusual pattern.

The model also predicts an increase in phytoplankton levels during the summer in the lower end of the lake. Sampling was not conducted often during summer 1995, making it difficult to compare predicted to observed during that season. The model under-predicts bloom concentrations at Lamar and First, and over-predicts at MoPac and the Basin. This result matches the prediction patterns for the 1994 bloom simulation. The timing of the predicted bloom periods and observed blooms is off on occasion. This discrepancy is to be expected since average monthly conditions were used in the model. However, the overall fit was deemed adequate.

Figure 6.1 Town Lake Chlorophyll *a*, 1995

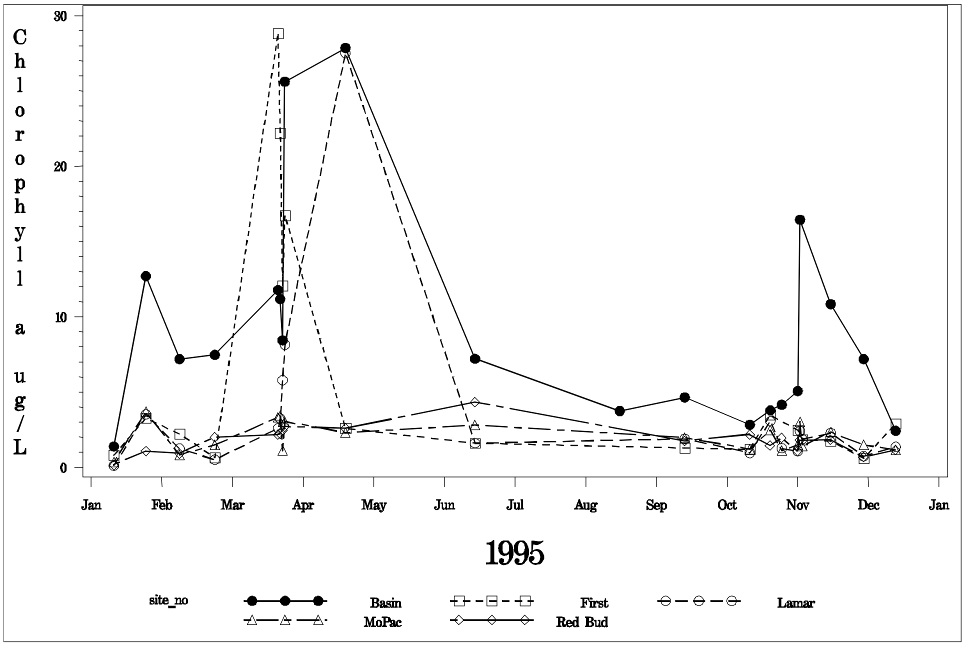
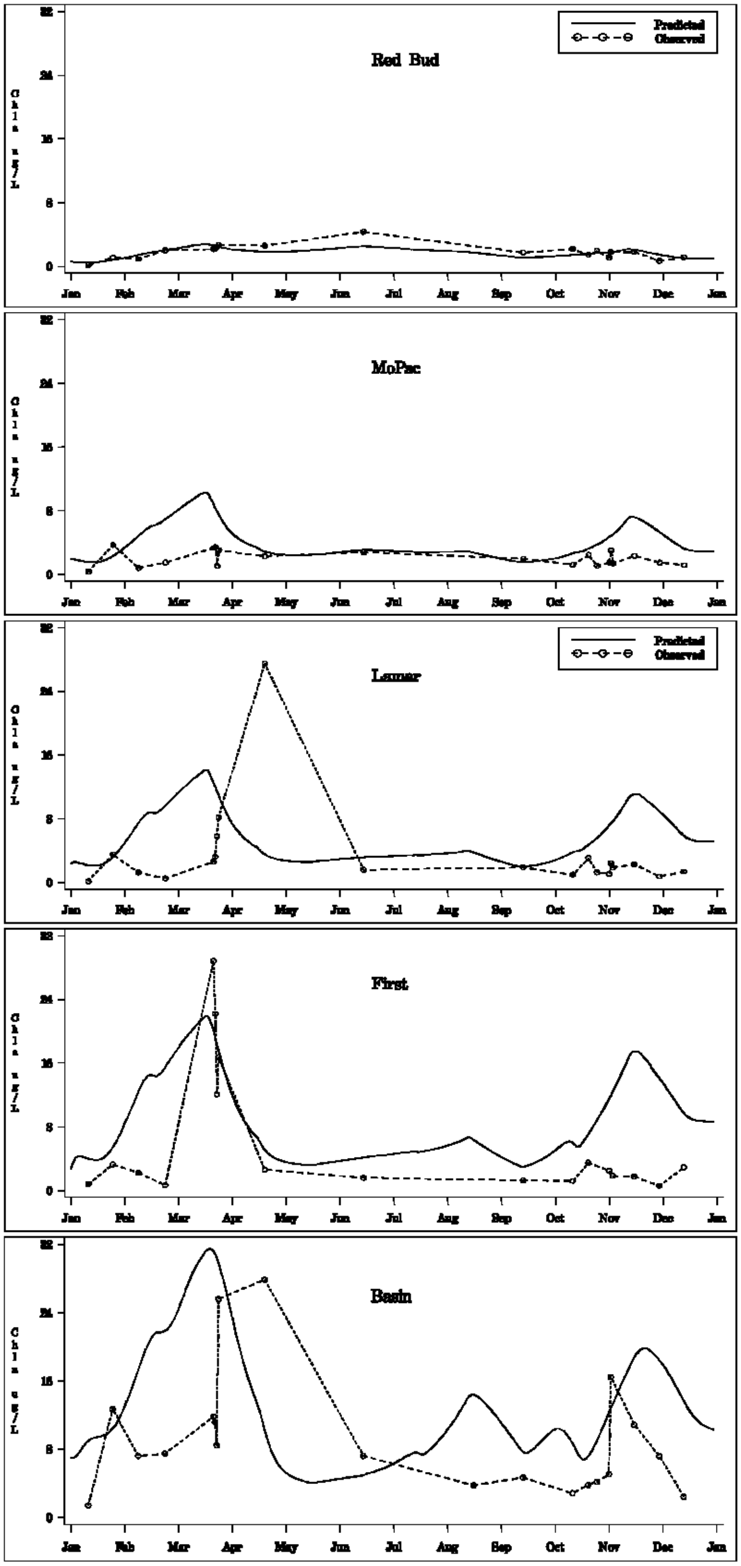


Figure 6.2 Town Lake Chlorophyll *a* – Predicted vs Observed, 1995



6.2 Nutrients

Nitrate

Town Lake nitrate levels are higher during the winter low-flow season when spring flow, which is high in nitrates, is a sizable proportion of the water in the lake. The highest nitrate levels are typically observed downstream of Barton Creek, but during 1995 higher levels were also found in bottom samples from Red Bud (Figure 6.3). To account for this result, staff hydrogeologists have speculated the possibility of spring flow into Town Lake in this segment under high aquifer levels.

Model predictions match observed levels fairly well from January through October, but do not increase as fast as observed levels following the decrease in discharge from Tom Miller Dam (Figure 6.4). However, model predictions of phytoplankton levels were too high during the fall, resulting in model under-prediction of nitrate concentrations. The fit is the worst at the Basin.

Figure 6.3 Town Lake Nitrate, 1995

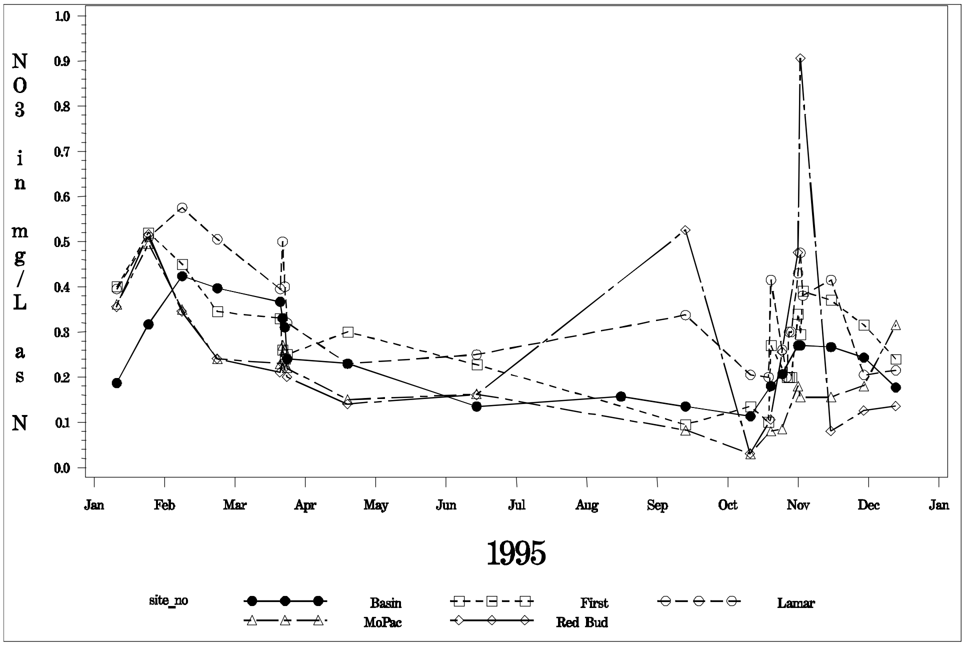
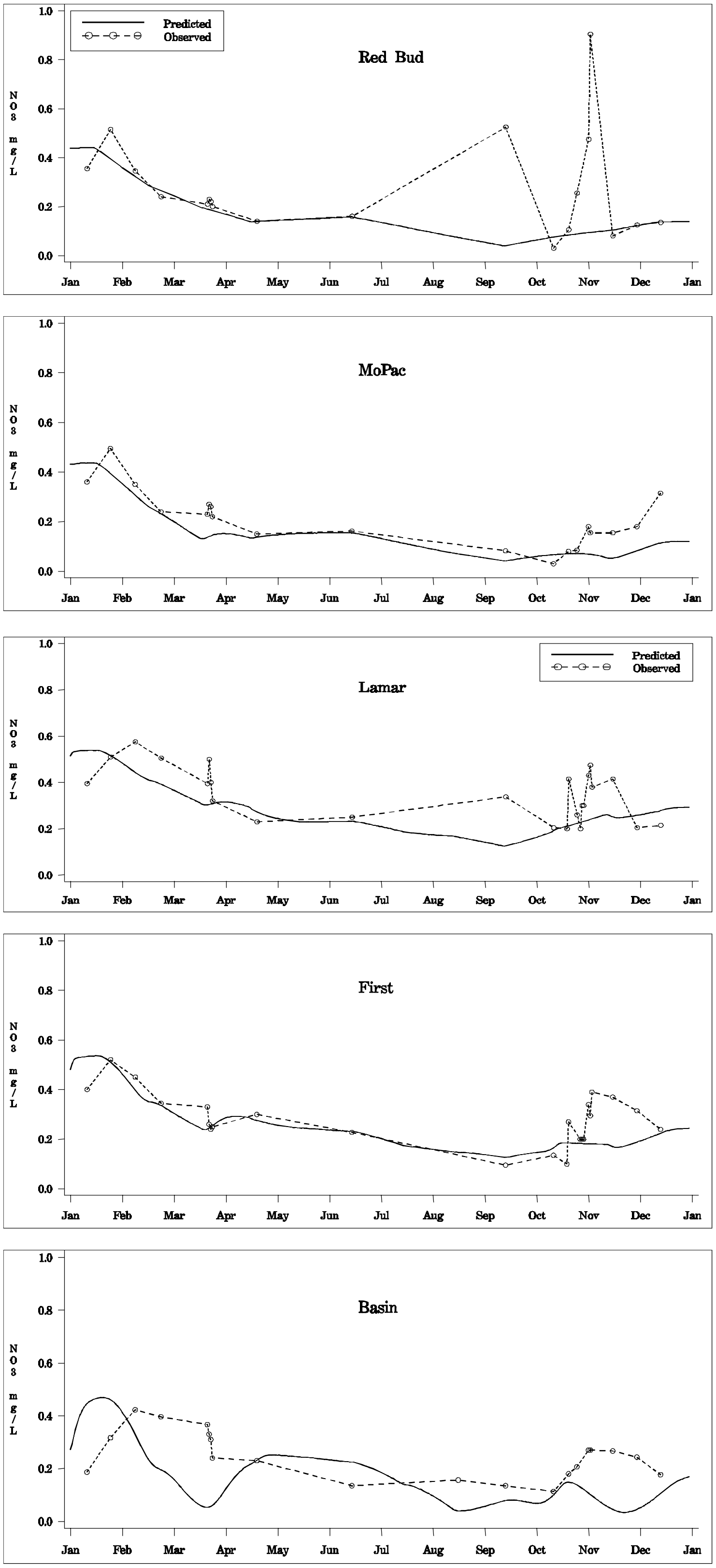


Figure 6.4 Town Lake Nitrate – Predicted vs Observed, 1995



Orthophosphate

Orthophosphate concentrations are at or near the detection limit for most of the year (Figure 6.5). Model predictions are usually less than the observed concentrations (Figure 6.6). The model fit is not particularly good, although the observed and predicted concentrations are similar in range of values.

Figure 6.5 Town Lake Orthophosphate, 1995

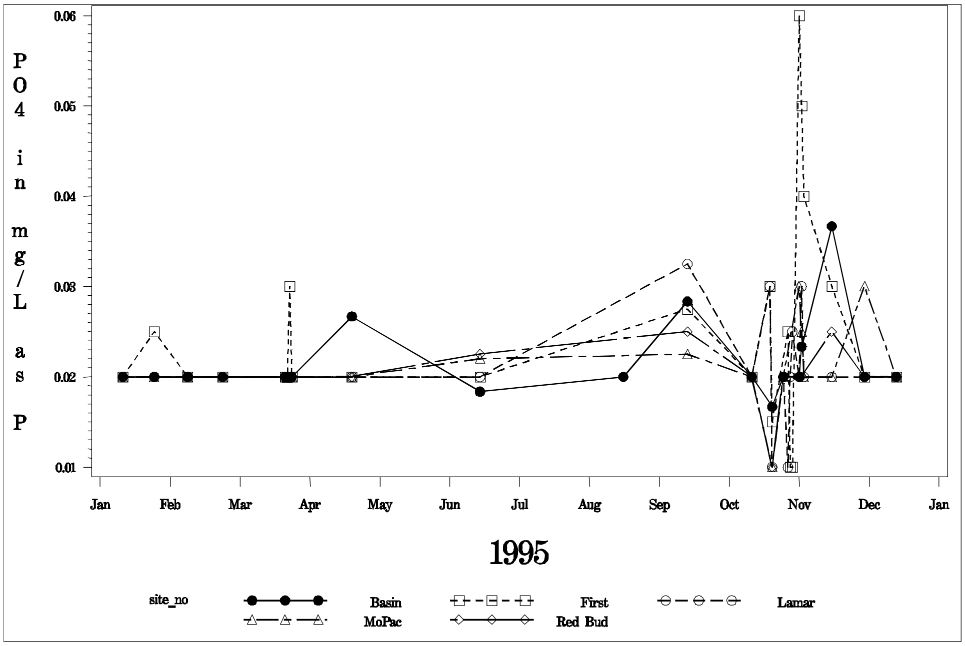
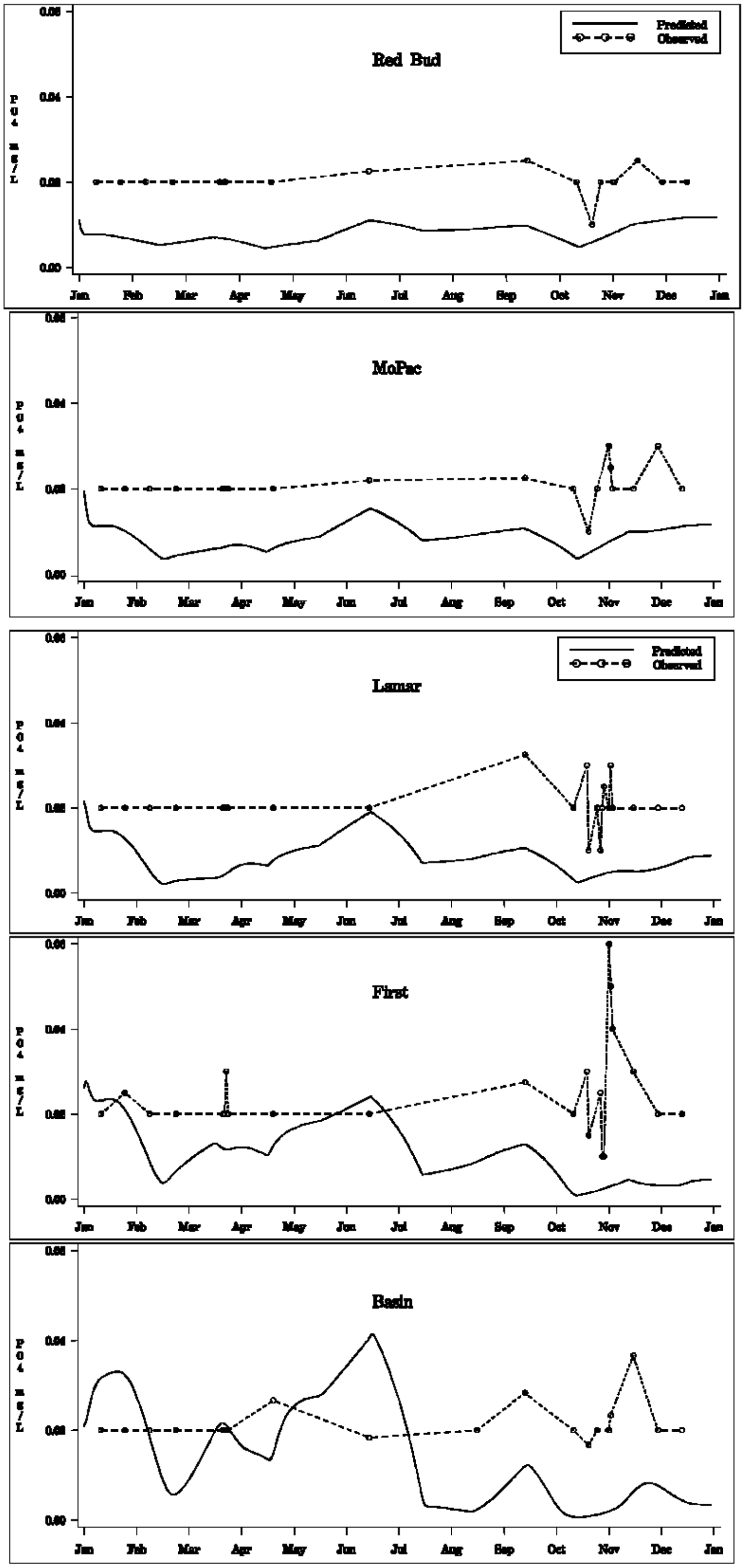


Figure 6.6 Town Lake Orthophosphate – Predicted vs. Observed, 1995



Ammonia

Ammonia concentrations peak during the spring months when the chlorophyll *a* concentrations also peaked (Figure 6.7). The model predictions are reasonably close to the observed levels except that the model does not match the abrupt changes found in the data (Figure 6.8). However, the model inputs are monthly averages and therefore should not show rapid changes within a month.

Figure 6.7 Town Lake Ammonia, 1995

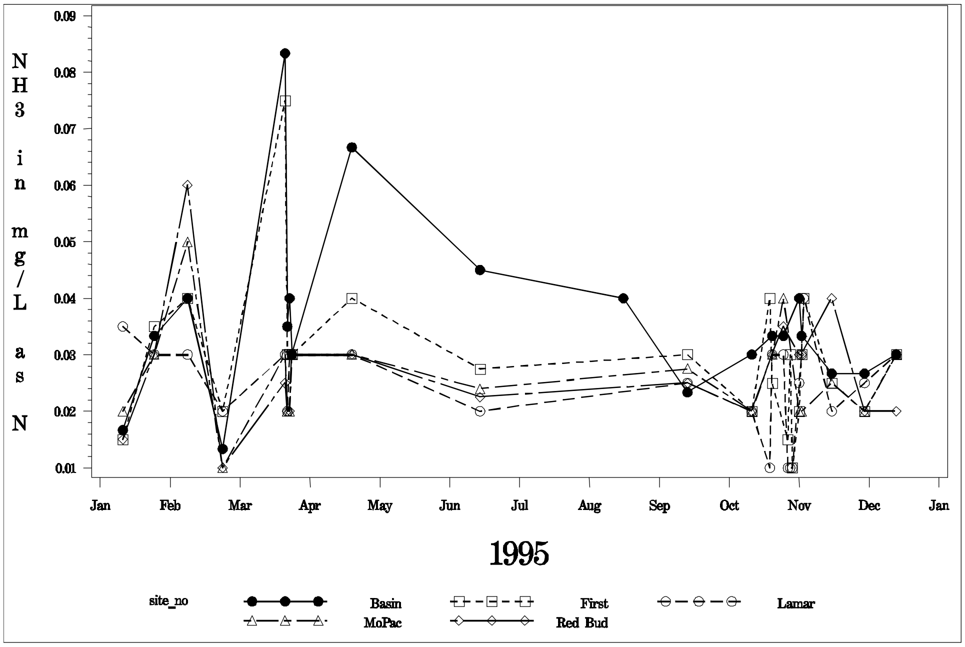
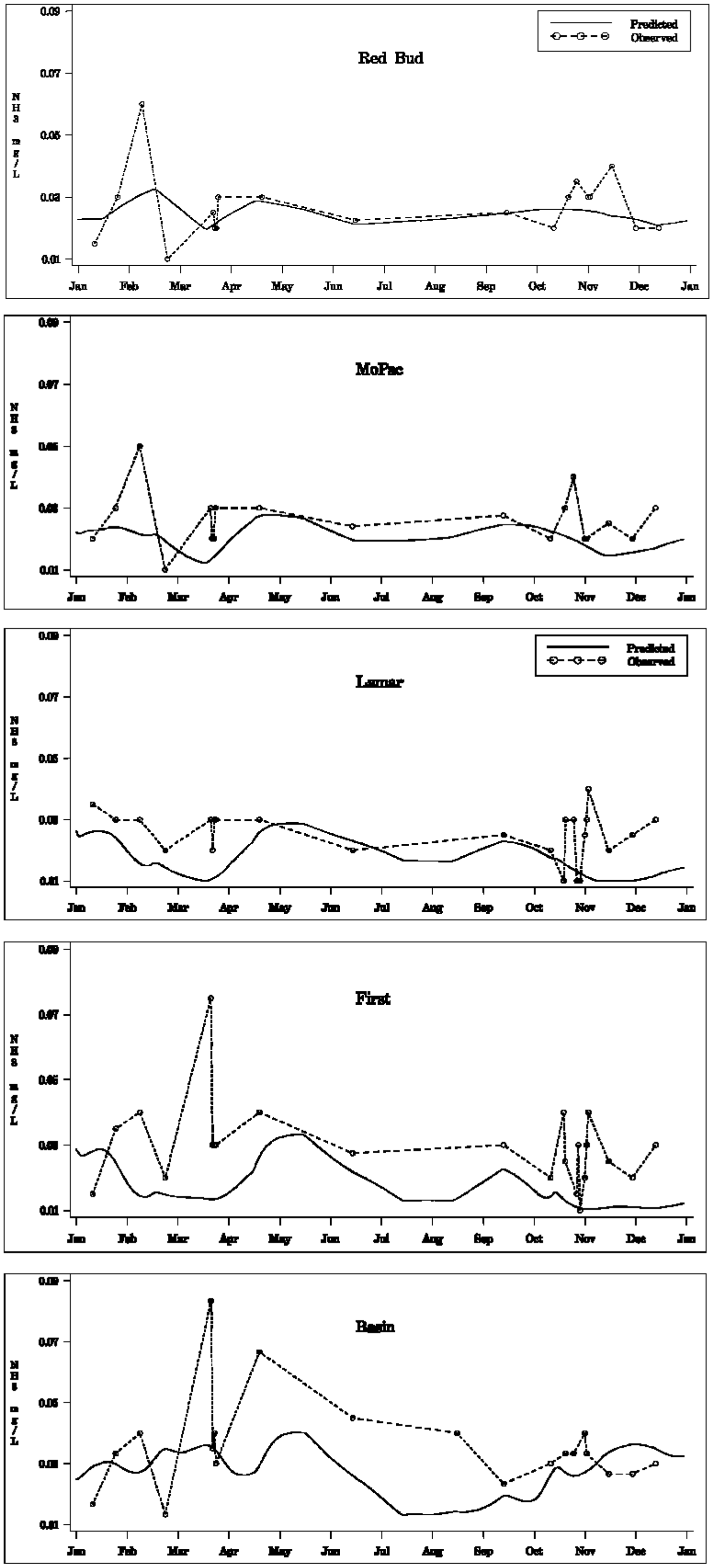


Figure 6.8 Town Lake Ammonia – Predicted vs Observed, 1995



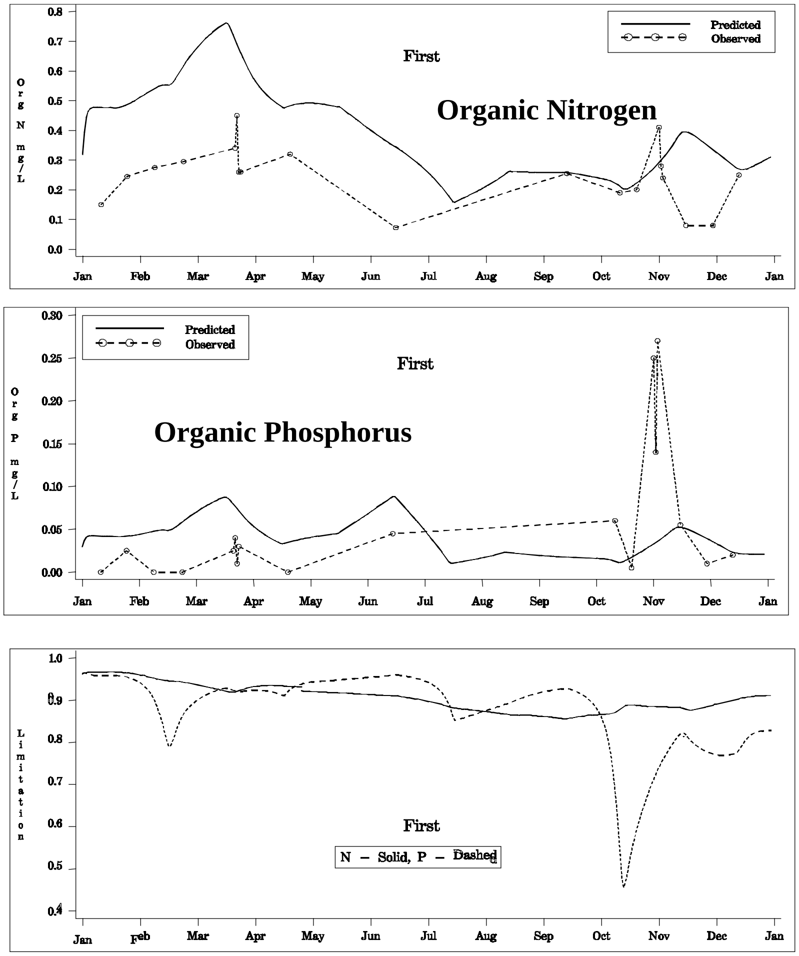
Organic Nitrogen and Phosphorus

The fit between observed and predicted is reasonably good for both organic nitrogen and organic phosphorus. As usual, the fit is worse at the Basin and the model does not match the rapid changes seen in the data. Model predictions for organic nitrogen are somewhat high during the first half of the year. Predicted versus observed concentrations at First Street are shown in Figure 6.9. The rest of the segments show similar patterns.

Nutrient Limitation

The model predicts that phosphorus is the more important limiting nutrient. Nutrient limitation for 1995 at First Street is shown in the bottom graph in Figure 6.9.

Figure 6.9 Organic Nitrogen and Phosphorus – Predicted vs Observed, 1995



6.3 Light, Temperature and Dissolved Oxygen

Light

Water clarity was measured in the lake using a secchi disk. The water is generally clearer during low-flow conditions that occur from mid-October to mid-March (6.10). In general, the upper portion of the lake was less turbid than the downstream portion in 1995. Storms and algal booms affect the visibility in the lake at any season.

Temperature

Average temperatures in all segments follow a similar pattern (Figure 6.11). Temperatures at First Street and the Basin are slightly higher than in the upstream half of the lake for much of the modeled period.

Figure 6.10 Town Lake Secchi Depth, 1995

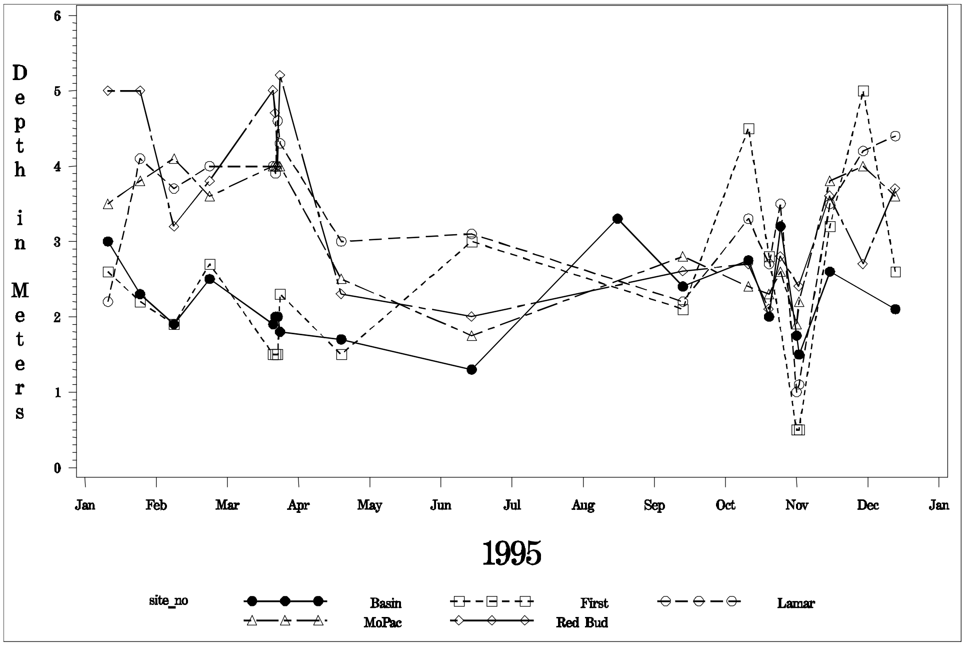
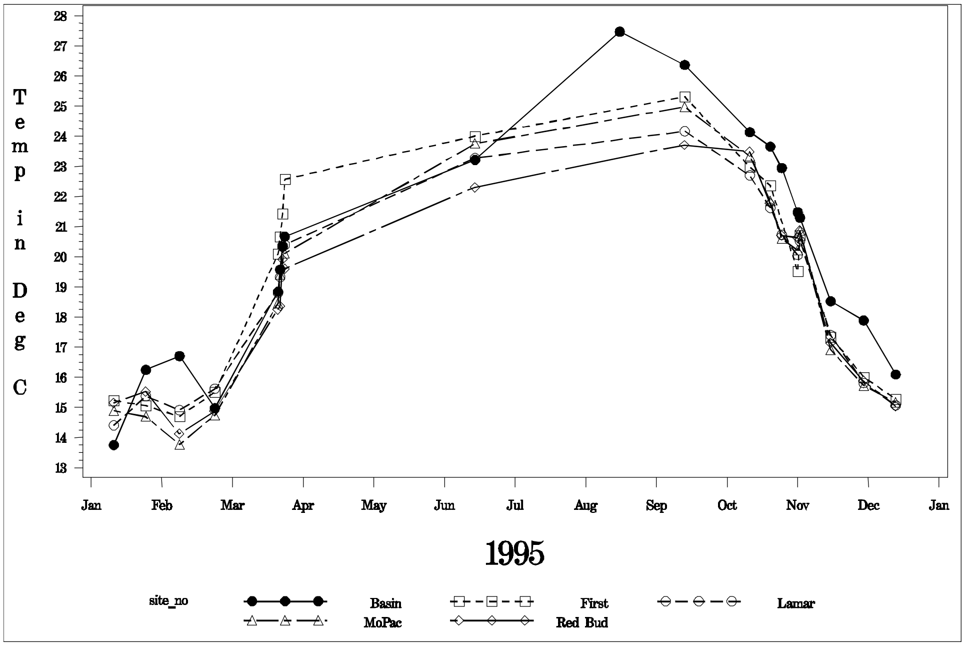


Figure 6.11 Town Lake Temperature, 1995



Dissolved Oxygen

Dissolved oxygen concentrations peak in the winter and early spring (Figure 6.12). The lowest average concentrations occur at the end of the summer. During increases in phytoplankton concentrations, average dissolved oxygen levels drop, although the surface concentrations typically increase. Oxygen stratification is rare in Town Lake and usually lasts for only a short period of time. The model fit to the average observed values is very good for dissolved oxygen, although rapid changes due to bloom or storm conditions are not predicted. Figure 6.13 shows a typical fit between predicted and observed average dissolved oxygen concentrations.

Figure 6.12 Town Lake Dissolved Oxygen, 1995

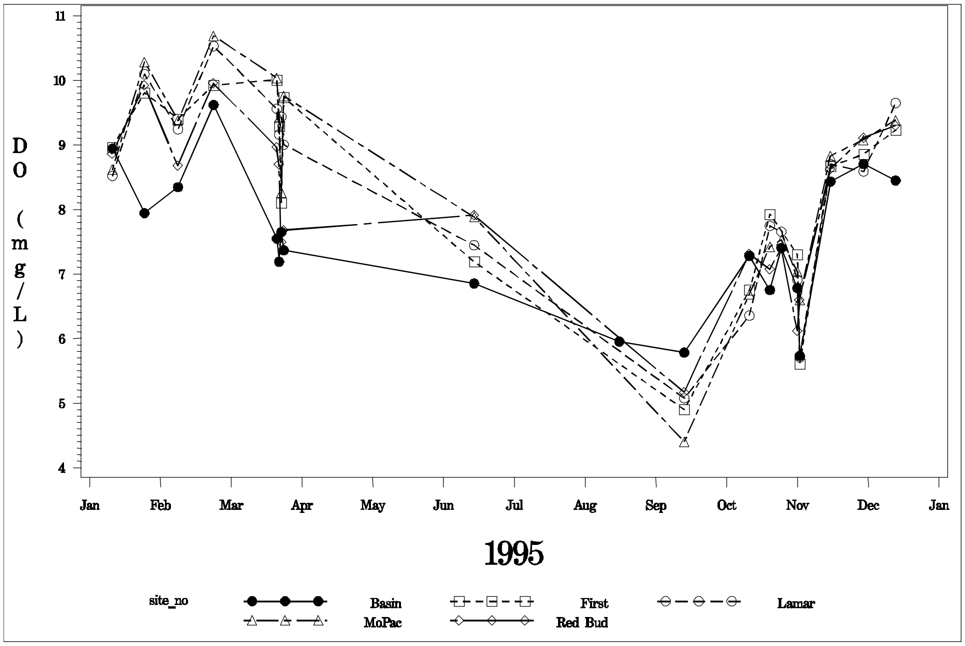
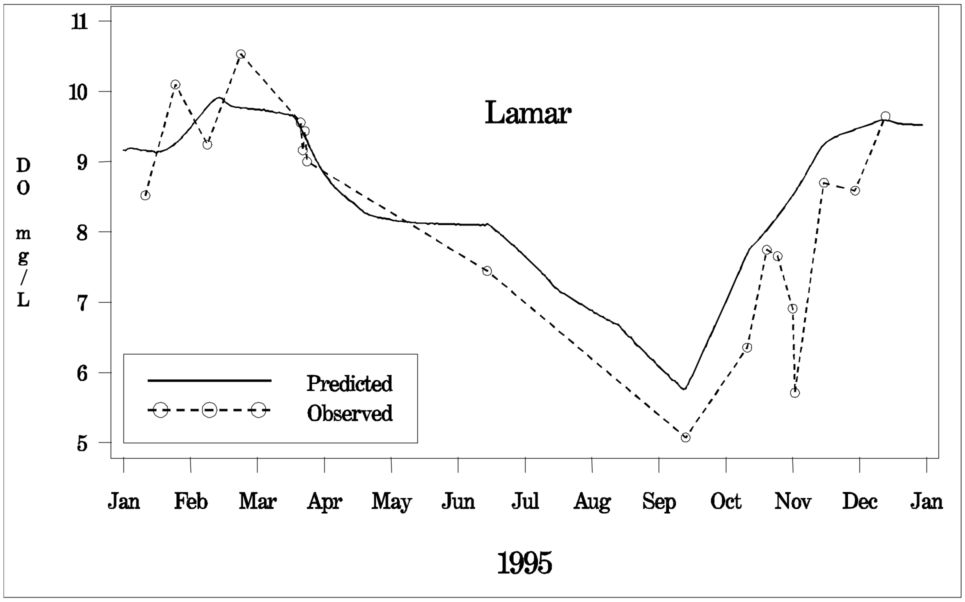


Figure 6.13 Town Lake Dissolved Oxygen - Predicted vs Observed, 1995



6.4 Conclusions

The model fit was judged to be adequate. The ability of the model to predict an unusual temporal pattern in phytoplankton levels was viewed as confirming the model calibration. This successful application of a model calibrated on a bloom period to an entire year could be viewed as model validation, and suggests that the model is functioning appropriately. The annual model could be used to assess relative changes in lake phytoplankton concentrations due to changes in pollutant loadings. The model could also be used to assess changes in the durations of the periods during which blooms might occur if pollutant loading changes. When using monthly average values as input, the only things that can be predicted are time periods that blooms might occur, if the daily conditions are all appropriate, and the potential average magnitude of such blooms.

7.0 MODEL VALIDATION - 2000 BLOOM

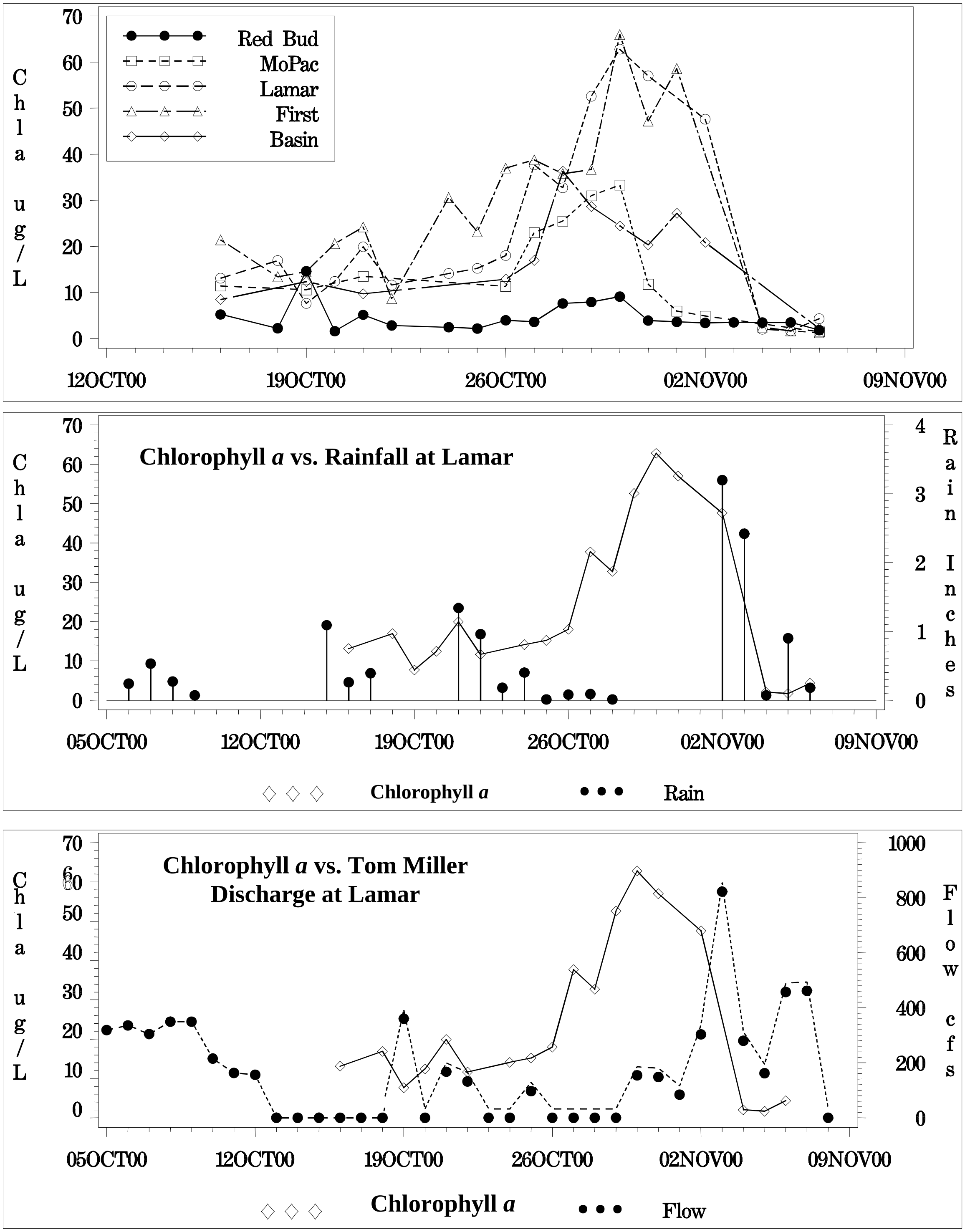
Model validation was attempted using data from the bloom period in the fall of 2000. Model-predicted values were compared to observed values for chlorophyll *a*, nutrients, and dissolved oxygen. Model-predicted nutrient limitations were displayed. Light and temperature values were plotted. Chlorophyll *a* data were plotted against nutrients, dissolved oxygen, light, temperature, flow, and rainfall data. These plots are shown below, along with comments on the model fit and the data comparisons.

7.1 Chlorophyll *a*

Data

The chlorophyll *a* levels in Town Lake from October 16, 2000, to November 6, 2000, are plotted in Figure 7.1. The bloom, based on algal counts, was underway three days before sampling was initiated. Chlorophyll *a* increased slowly to the highest level ever observed in Town Lake, stayed high for an unprecedented eight days, and then dropped abruptly following heavy rainfall and increased flow. Figure 7.1 also shows the relationships between rainfall and Lake Austin discharges and Town Lake chlorophyll *a*. This bloom was different from previous blooms in several ways. During most blooms, the algal counts increase abruptly. In 2000, the increase was gradual. The maximum level of 66 μg/L was much higher than the previous maximum of 38 μg/L in 1994. Levels above 30 μg/L were maintained for eight days. In 1994, levels remained high for only two or three days. Measurable rainfall occurred eight days in a row during the bloom although the maximum chlorophyll *a* levels occurred as usual after the rainfall ceased.

Figure 7.1 Town Lake Chlorophyll *a*, Fall 2000



Model Predictions

The fit between the data and the model predictions (Figure 7.2), is fairly good at First and Red Bud. The predicted values at MoPac, Lamar and First are too high early in the bloom, and the predicted values are not high enough during the later part of the bloom. Predicted concentrations at the Basin increase too soon and remain high too long with an abrupt decrease rather than the observed slow one. Some of the difference between observed and predicted values is no doubt due to the use of a constant stormwater pollutant concentration for several consecutive storm events. Storm data are notoriously variable, but data were not available for stormwater runoff concentrations during the 2000 bloom. Some of the difference may be due to problems in model predictions of nutrient levels.

7.2 Nutrients

Nitrate - Data

Nitrate levels remain at a fairly constant low level prior to and during the bloom (Figure 7.3). A slight dip occurs at the height of the bloom at all sites except Red Bud. During this period, without increased algal consumption, the nitrate levels would have been increasing in the middle and lower portions of the lake due to the decrease in inflows from upstream and the increase in influence of Barton Springs concentrations. Nitrates do increase abruptly at the end of the bloom.

Levels of nitrates at Red Bud are abnormally high. A small spring at the lake bottom at Red Bud appears to be discharging significantly during this event. The plotted points are the average of the surface and bottom values. However, at Red Bud, the high nitrates are restricted to the very deepest water and the depth average is much closer to the surface concentration. The two data points above 1 mg/L at Lamar and First are most likely samples of Barton Springs water not yet mixed in with the rest of the lake water. No bottom samples were taken on those days. In Figure 7.3, chlorophyll *a* is plotted versus nitrate concentrations in the middle and downstream end of the lake.

Figure 7.2 Town Lake Chlorophyll *a* – Predicted vs Observed, Fall 2000

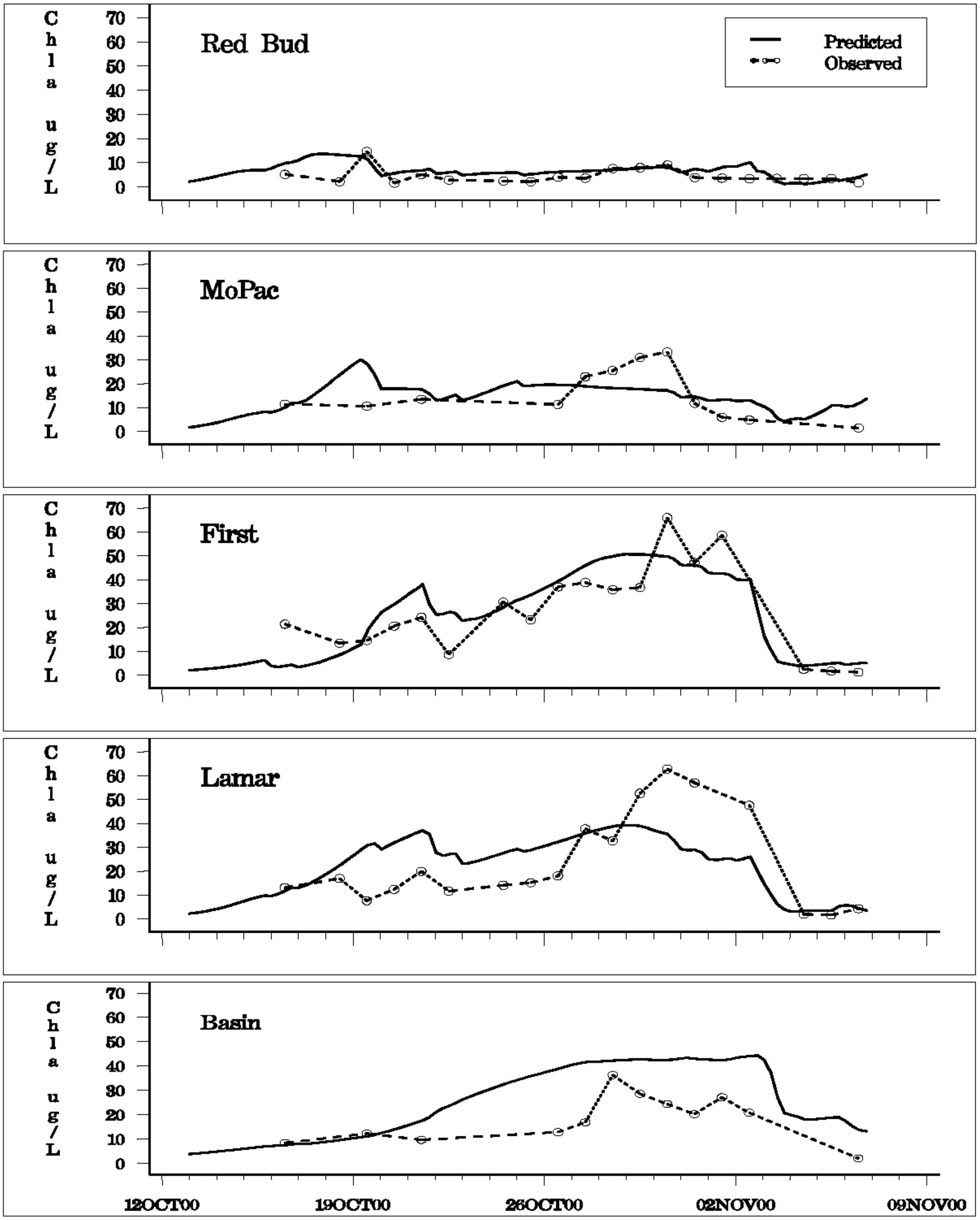
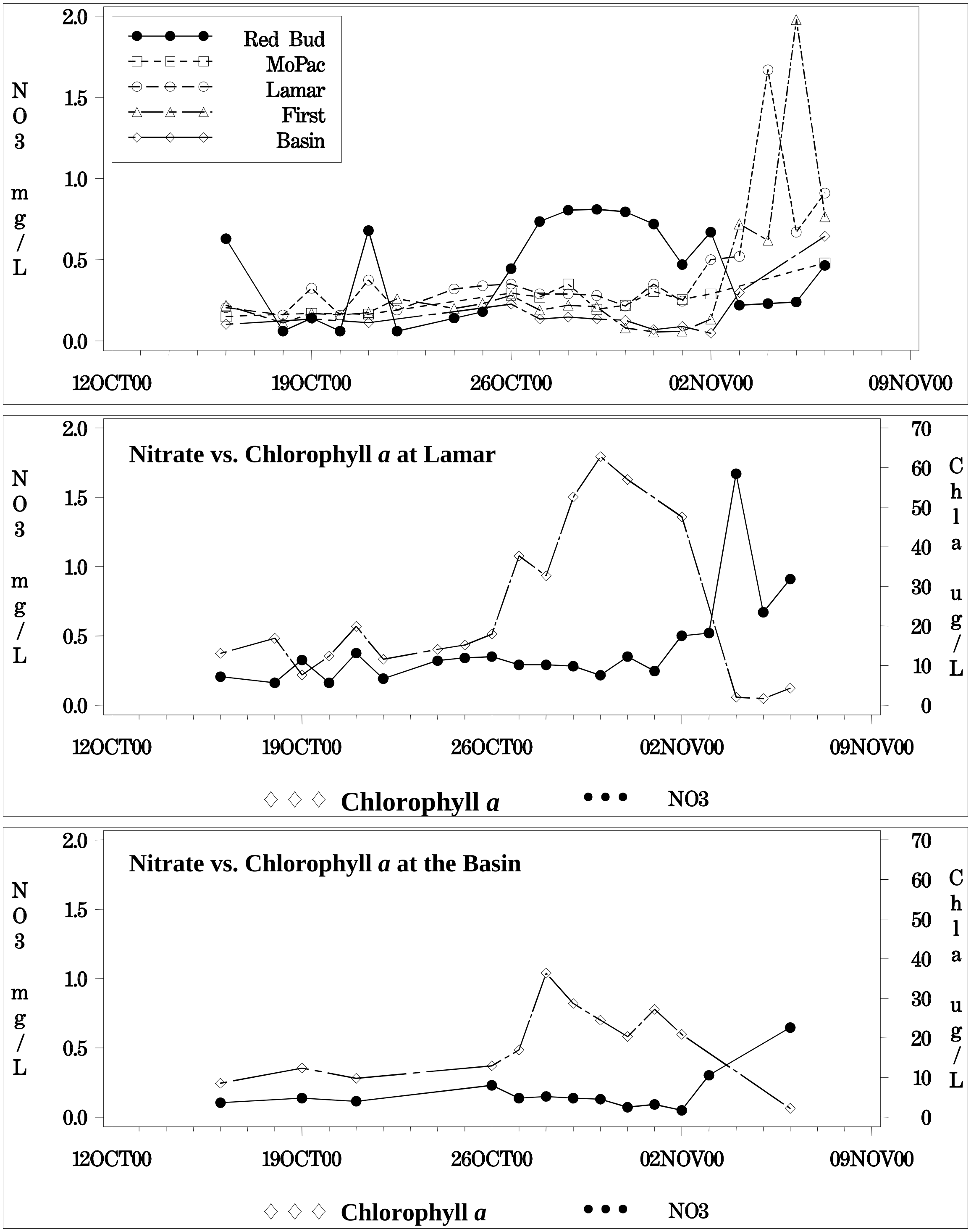


Figure 7.3 Town Lake Nitrate, Fall 2000



Nitrate - Model Predictions

Model predictions and observed values exhibit similar patterns (Figure 7.4). The predicted values at Lamar and First match observed values well. At Red Bud, MoPac, and the Basin, the predicted values are consistently lower than the observed levels. The predicted values are also lower than the nitrate detection limit, which is exceeded only three times: once at the Basin and twice at First. Apparently, model predictions of phytoplankton consumption of nitrate are in excess of actual consumption levels.

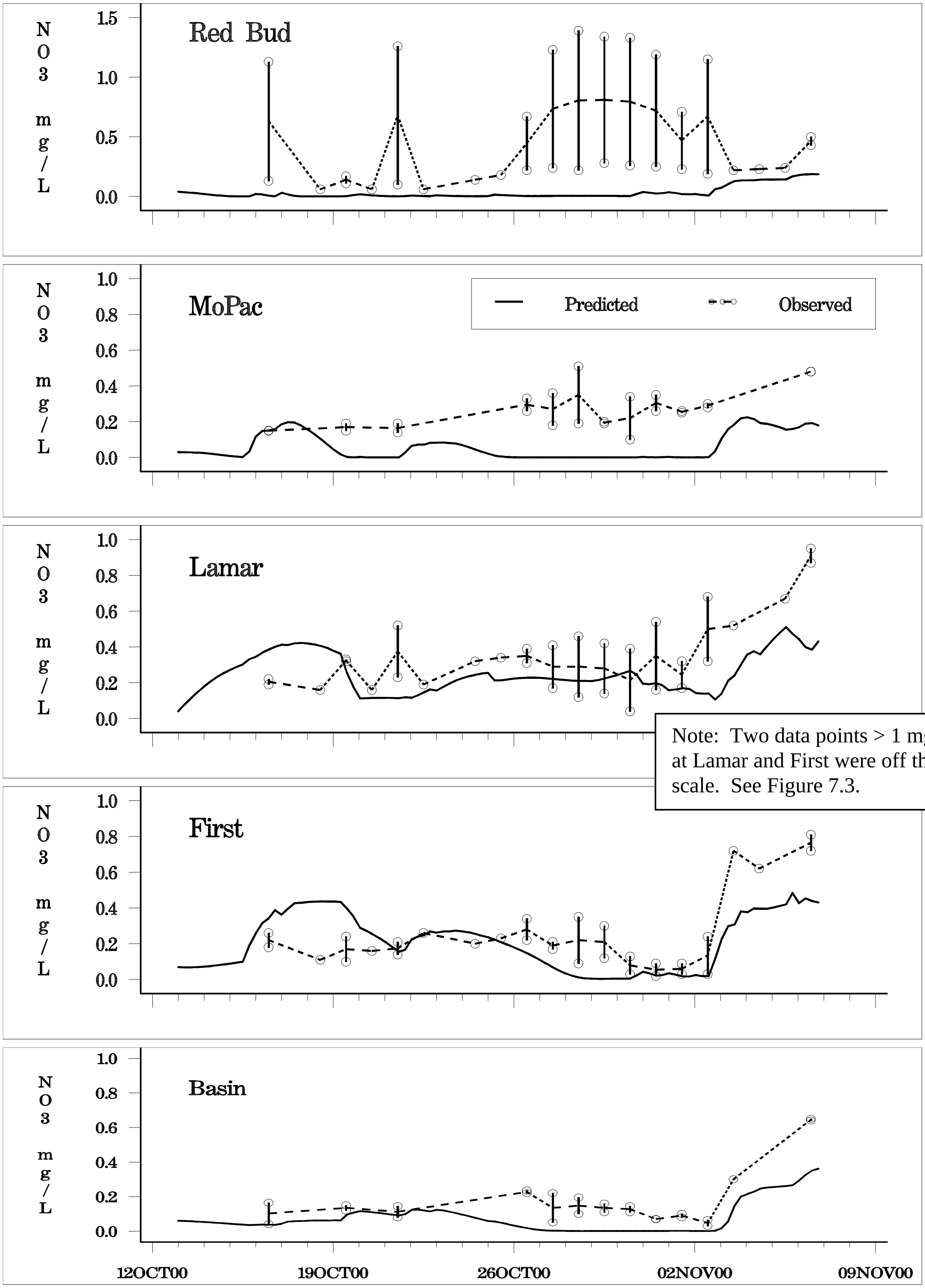
Orthophosphate (PO4) - Data

Orthophosphate levels are typically at the detection limit of 0.02 mg/L, with occasional higher values due most likely to stormwater loads (Figure 7.5). Also in Figure 7.5, chlorophyll *a* is plotted versus orthophosphate concentrations in the middle and downstream end of the lake. The high phytoplankton levels are probably responsible for keeping orthophosphate levels at the detection limit in spite of the frequent rainfall during the period.

Orthophosphate - Model Predictions

Model predictions are close to observed data only at Lamar and Red Bud. Otherwise, model predictions are much higher than the observed values (Figure 7.6). Observed orthophosphate concentrations decrease rapidly during algal blooms. The decrease occurs at rates higher than the modeled drop in concentrations in 1994 or 2000. Additional study is needed to determine the reasons for this. Possible reasons include a higher phosphorus-to-carbon ratio than modeled, or luxury uptake of phosphorus.

Figure 7.4 Town Lake Nitrate – Predicted vs Observed, Fall 2000



Note: Two data points > 1 mg/L at Lamar and First were off the scale. See Figure 7.3.

Figure 7.5 Town Lake Orthophosphate, Fall 2000

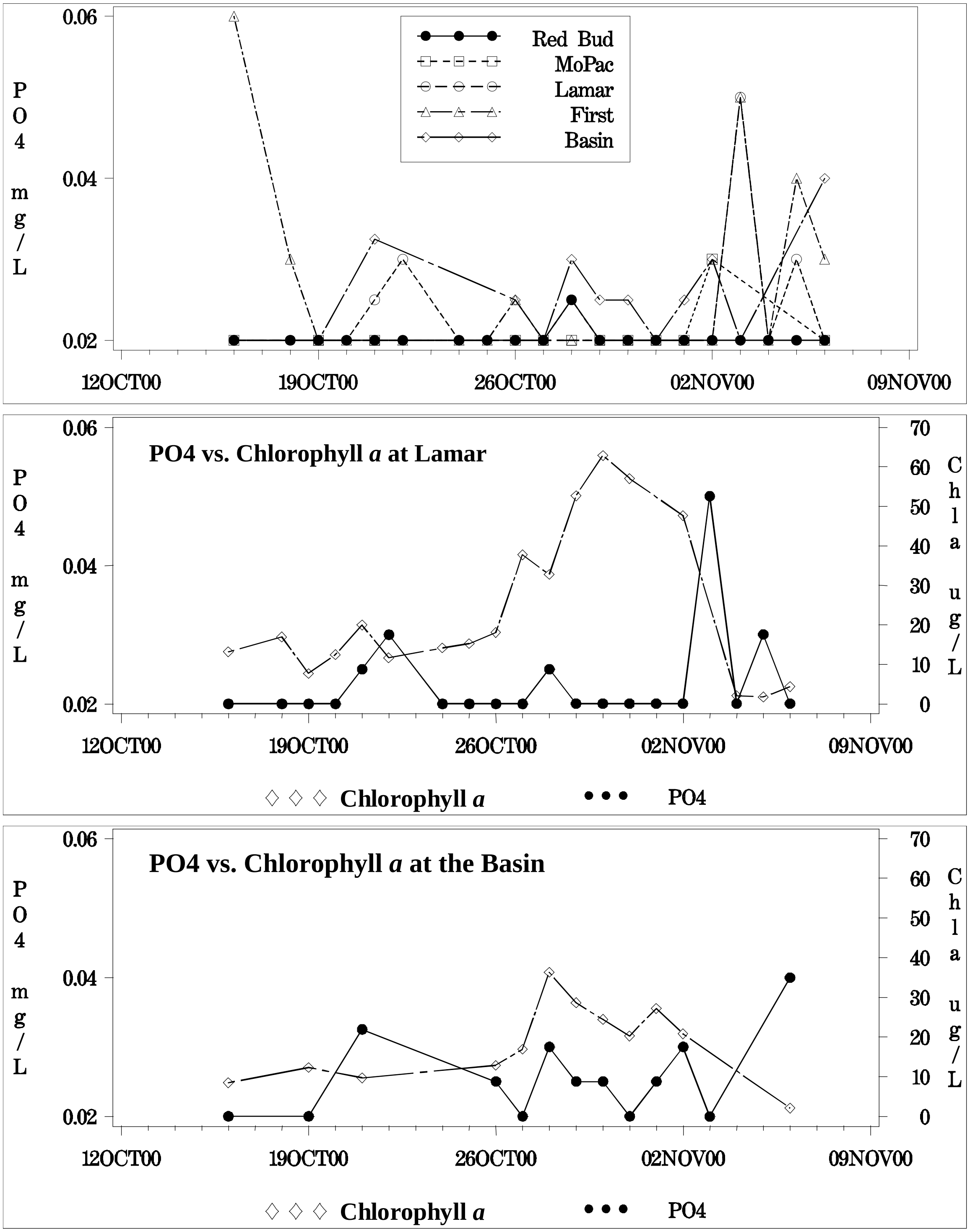
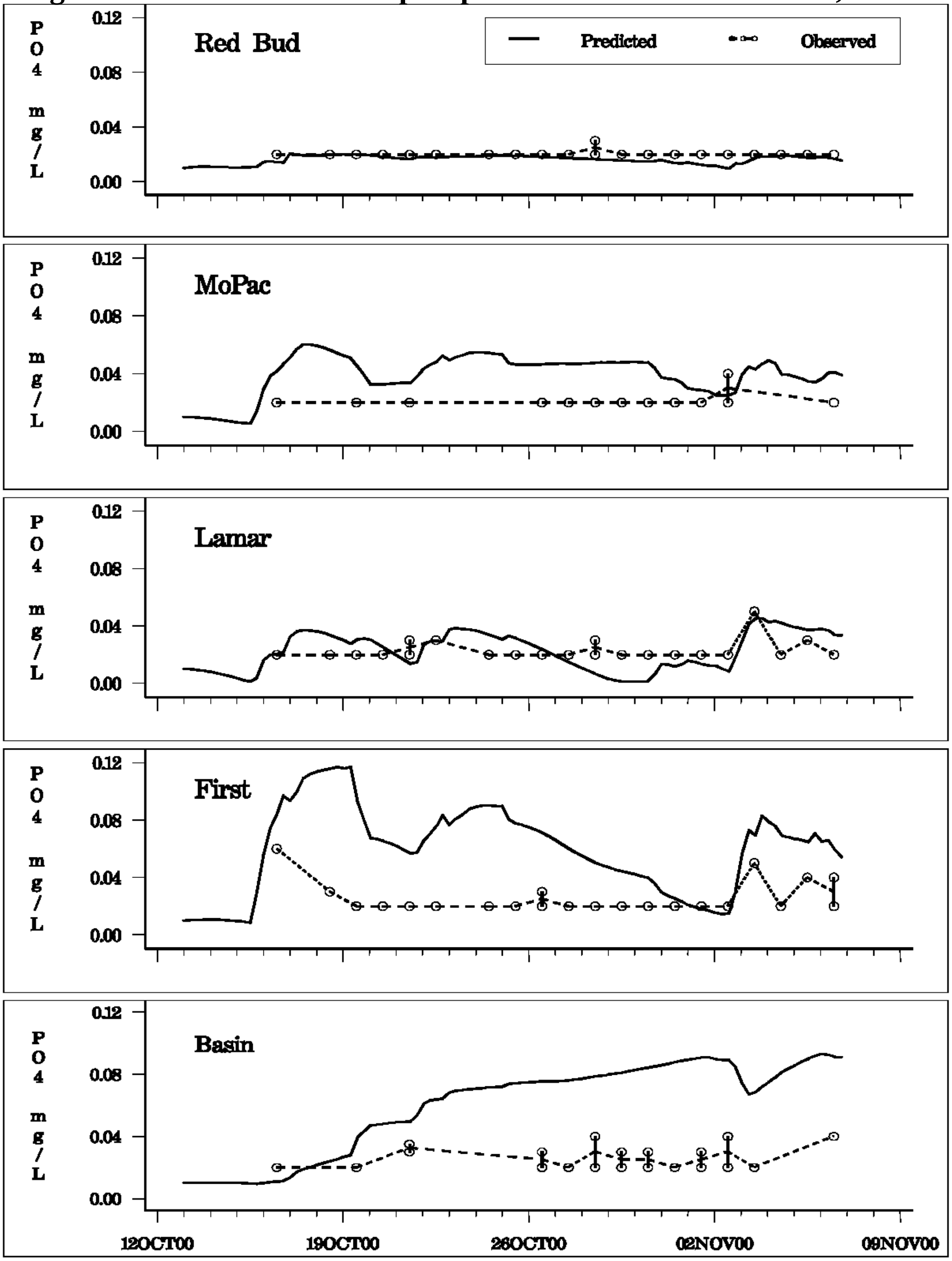


Figure 7.6 Town Lake Orthophosphate Predicted vs Observed, Fall 2000



Ammonia - Data

Ammonia concentrations remain low at Red Bud and MoPac (Figure 7.7). At Lamar and First, the concentrations peak both at the beginning of the period and during the bloom. First also has a peak at the end of the bloom. At the Basin, the values are generally higher than in the rest of the lake and exhibit considerable variation. The highest ammonia values are found at depth at Lamar and the Basin, the two locations with the lowest dissolved oxygen concentrations. In Figure 7.7, chlorophyll *a* is plotted versus ammonia concentrations in the middle and downstream end of the lake.

Ammonia - Model Predictions

Model predictions remain fairly low throughout the period. The predictions match observed data fairly well except at the Basin and Lamar, where they match the surface data rather than the segment average over depth (Figure 7.8). The model assumes uniformly mixed segments. This assumption is usually correct; however, some stratification occurs at the Basin and at Lamar.

Organic Nitrogen and Phosphorus

Organic nitrogen levels show increases during the height of the bloom (Figure 7.9). No apparent relationship exists between observed organic nitrogen levels and stormwater runoff amounts. Organic nitrogen concentrations are usually well mixed in the lake except at the Basin, where the concentrations are highest at the bottom. Model predictions, however, are driven by the high stormwater runoff loads and are consistently too high (Figure 7.10). The shape of the pattern is also inconsistent with this data set. Predicted levels dip during the height of the bloom while the observed concentrations peak. At the Basin, predicted levels increase steadily, unlike the observed concentrations.

Organic phosphorus concentrations show some increases during the height of the bloom (Figure 7.9). As with organic nitrogen, predicted concentrations are too high, are driven by rainfall, and decrease rather than increase during the bloom (Figure 7.11). Predicted levels also increase steadily at the Basin, without the settling indicated by the data. Model segment configuration as a rectangular channel with uniform velocities matches lake characteristics fairly well except in the Basin, where the shape is not rectangular and the velocities are not constant. This could result in the discrepancy in particulate phosphorus predictions.

Figure 7.7 Town Lake Ammonia, Fall 2000

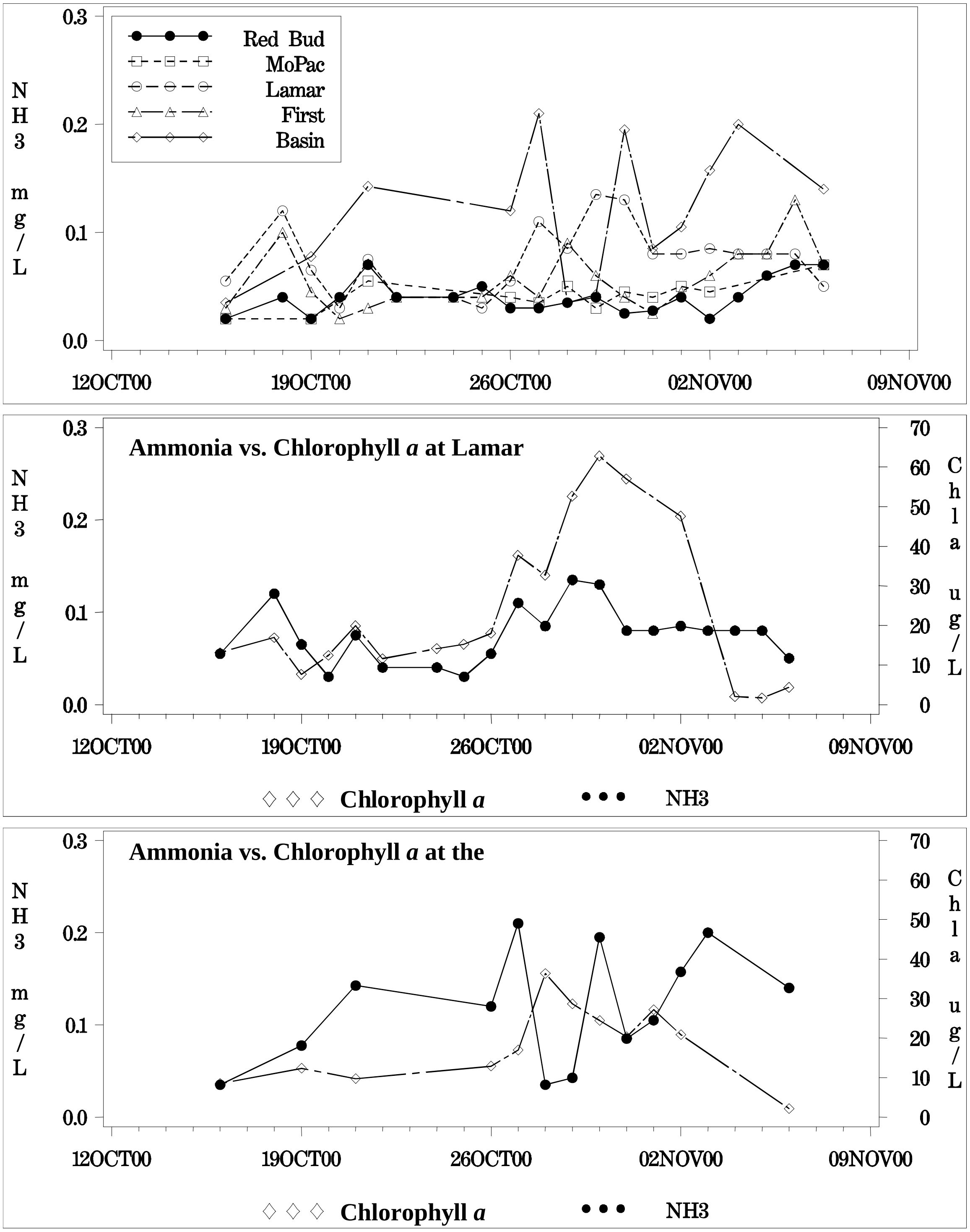


Figure 7.8 Town Lake Ammonia Predicted vs Observed, Fall 2000

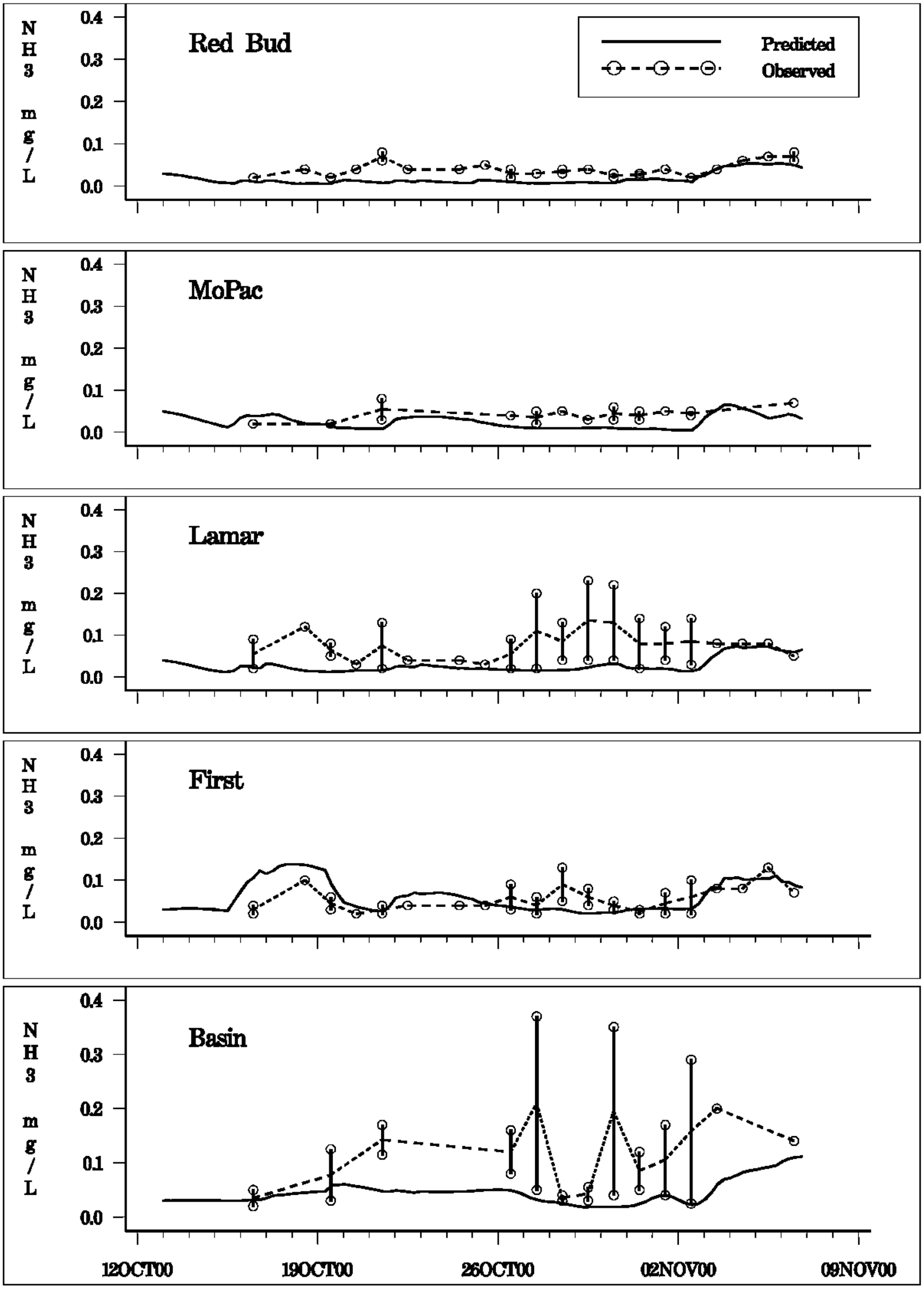


Figure 7.9 Town Lake Organic Nitrogen and Phosphorus, Fall 2000

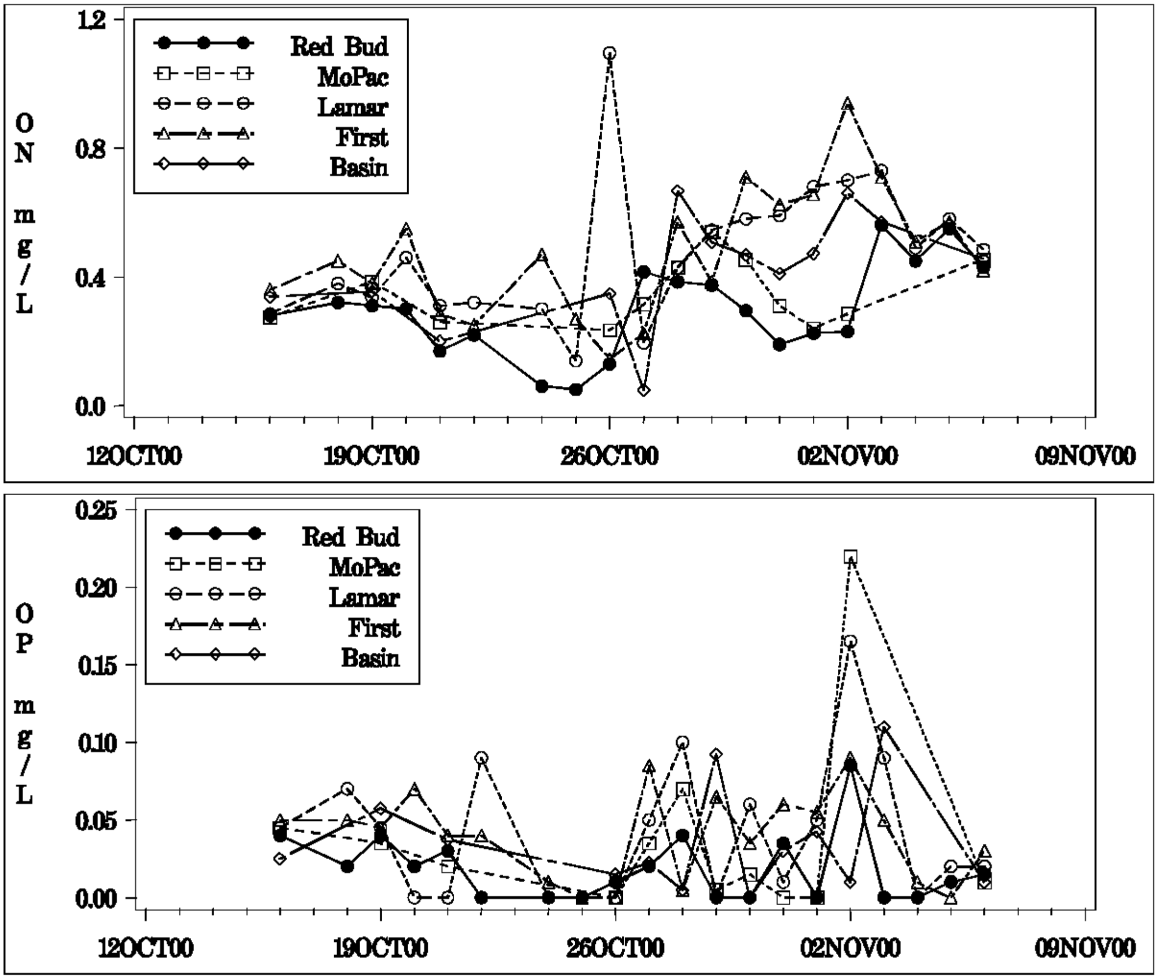


Figure 7.10 Organic Nitrogen – Predicted vs Observed, Fall 2000

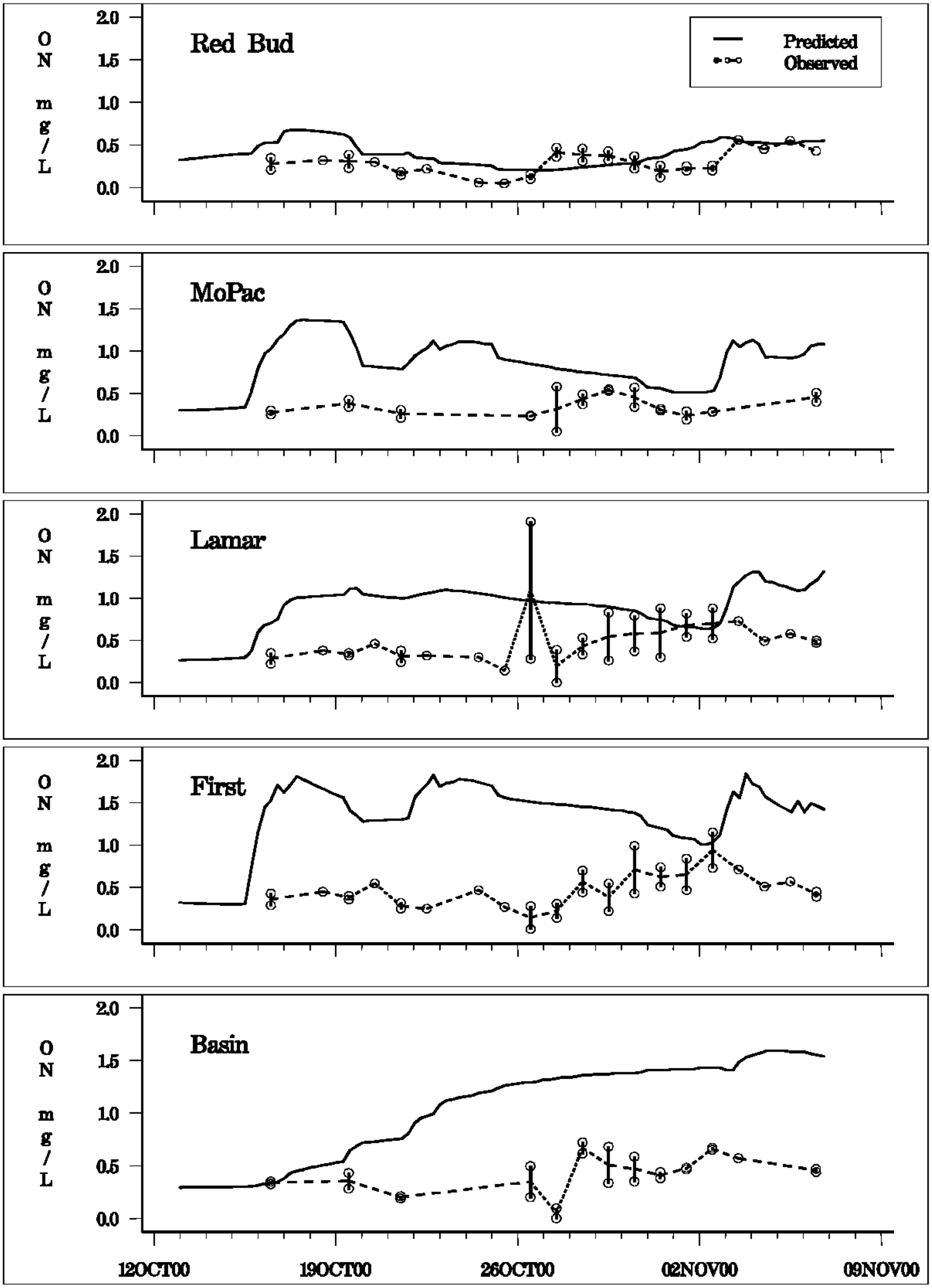
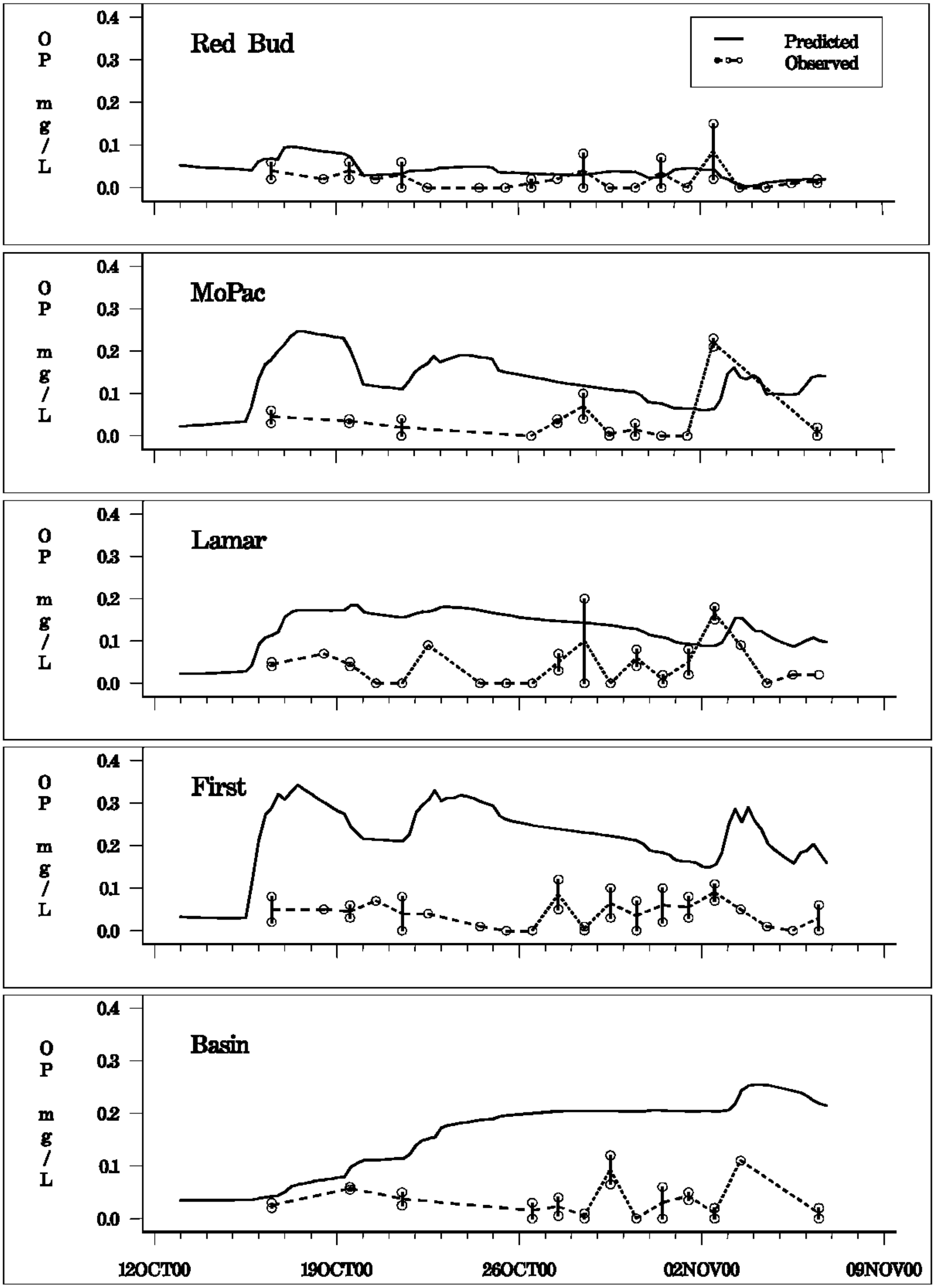


Figure 7.11 Organic Phosphorus – Predicted vs Observed, Fall 2000



Nutrient Limitation - Data

Phytoplankton growth appears to be nutrient limited in Town Lake. The observed higher levels of chlorophyll *a* at Lamar and First seem to indicate increased growth due to increased nutrients from storm water and from Barton Springs. Both nitrate and orthophosphate remain fairly level during the bloom. Without algal consumption, nutrient levels would have been expected to increase during this period due to stormwater runoff and the increased influence of Barton Springs inflow. Both nutrients appear to be limiting during the 2000 bloom, while during the bloom of 1994, only phosphorus appeared to be limiting growth.

Nutrient Limitation - Model Predictions

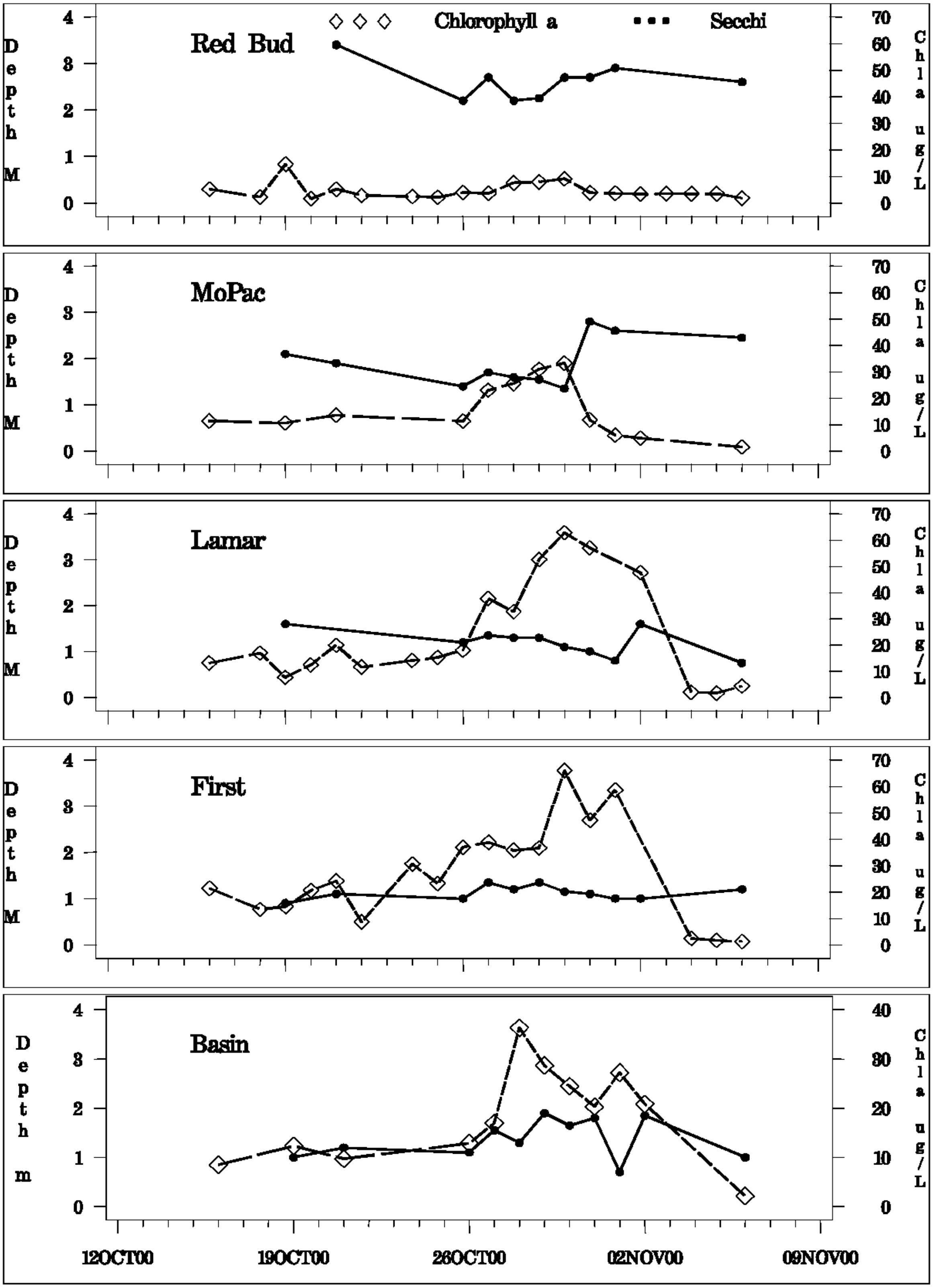
The model predicts that phytoplankton growth is limited by nitrogen at all sites except Lamar. At First and the Basin, the limitation is only during the height of the bloom, whereas at Red Bud and MoPac growth in nitrogen limited most of the time. Model growth is limited by phosphorus only at Lamar, and only for two brief periods. These predictions only partly match the implications of the data. The data indicate that both nutrients are growth-limiting.

7.3 Light, Temperature and Dissolved Oxygen

Light - Data

Light limitation plays an important role in regulating phytoplankton growth. The light extinction coefficient was estimated from secchi disk data. The relationship between chlorophyll *a* levels and secchi disk depth is shown in Figure 7.12. Unlike the 1994 bloom, a relationship between light levels and phytoplankton growth is not apparent from these plots. Abnormally high cloud cover with associated precipitation occurred during much of the bloom. Most of the observed blooms occur during calm, clear weather. Decreased light due to cloud cover, increased turbidity due to stormwater, and self-shading due to the size of the bloom produced fairly uniform light levels, particularly at First and Lamar, where the bloom was the strongest. Therefore, changes in the bloom were driven by other limiting variables rather than by light availability.

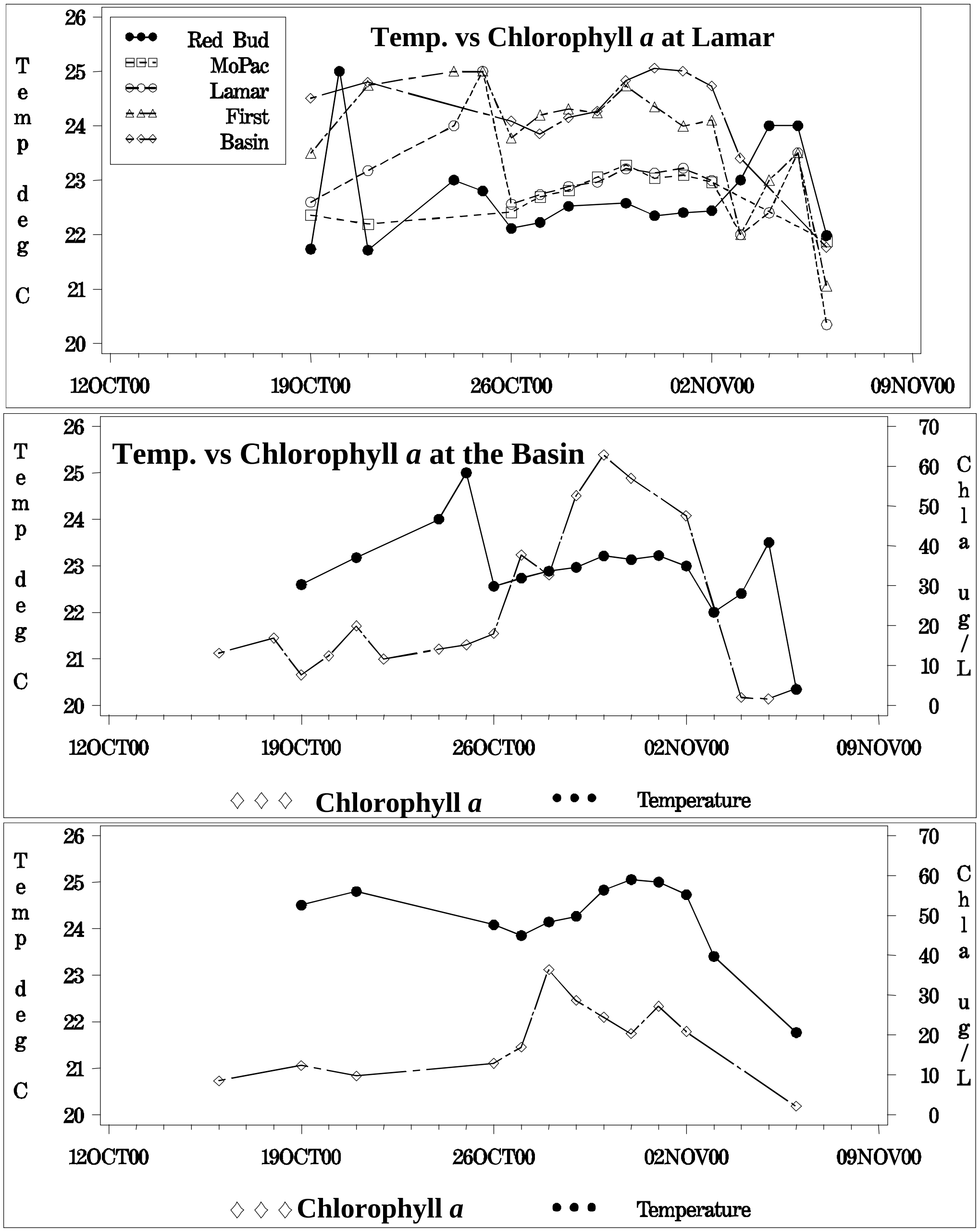
Figure 7.12 Town Lake Secchi Disk Depth vs Chlorophyll *a*, Fall 2000



Temperature - Data

Temperature is another important factor in algal growth. The average temperatures in the lake are shown in Figure 7.13. Temperatures were high during the entire bloom period. The relationship between chlorophyll *a* concentrations and temperatures in the middle and downstream end of the lake are also shown in Figure 7.13. No apparent correlation exists between temperature and chlorophyll *a*, indicating that the temperatures remain high enough at all times for sustained algal growth.

Figure 7.13 Town Lake Temperature, Fall 2000



Dissolved Oxygen - Data

Dissolved oxygen data show a strong difference between the top and bottom layers of the lake (Figure 7.14). During the bloom, surface concentrations increase while bottom concentrations decrease. Figure 7.15 shows the relationship between surface and bottom dissolved oxygen concentrations and chlorophyll *a* levels at Lamar and at the Basin.

Figure 7.14 Town Lake Surface and Bottom Dissolved Oxygen, Fall 2000

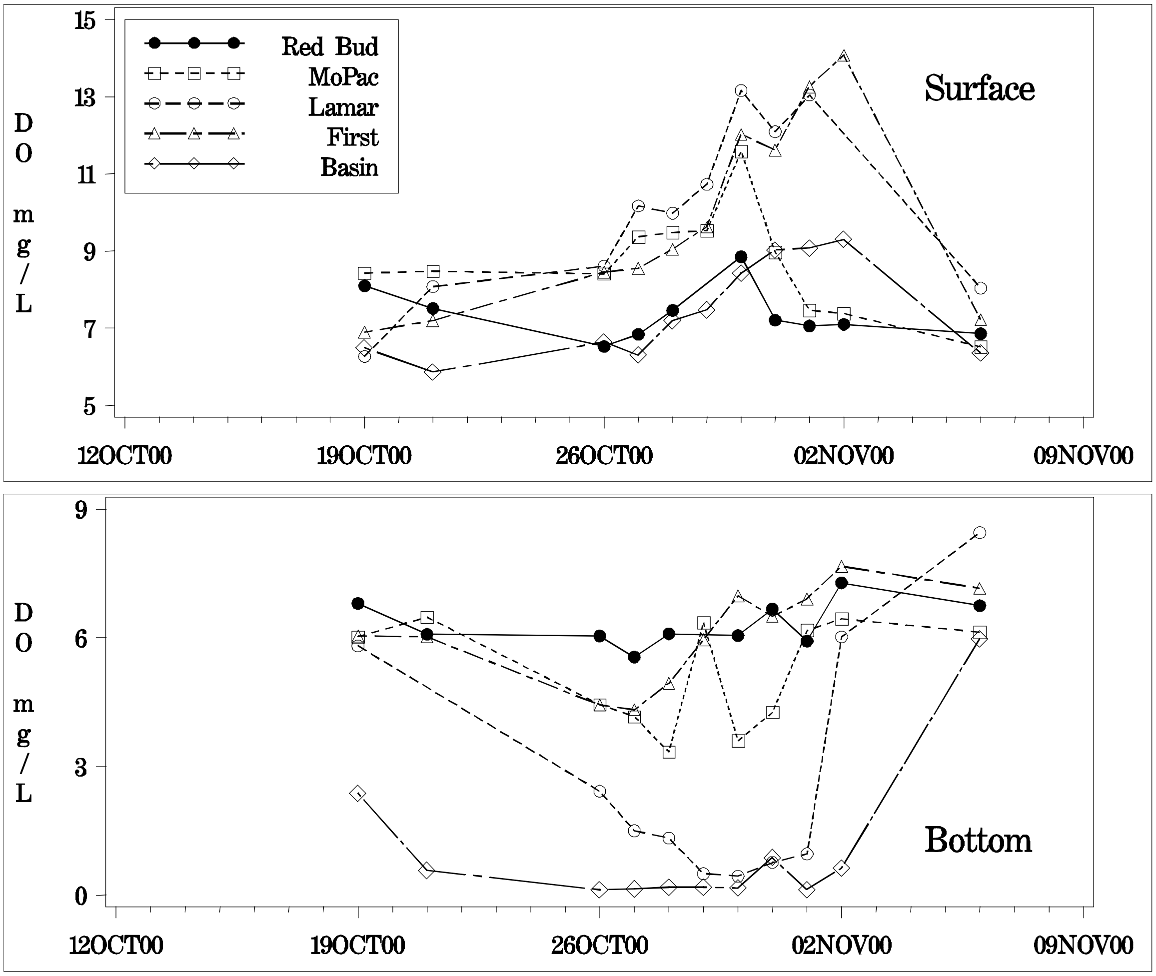
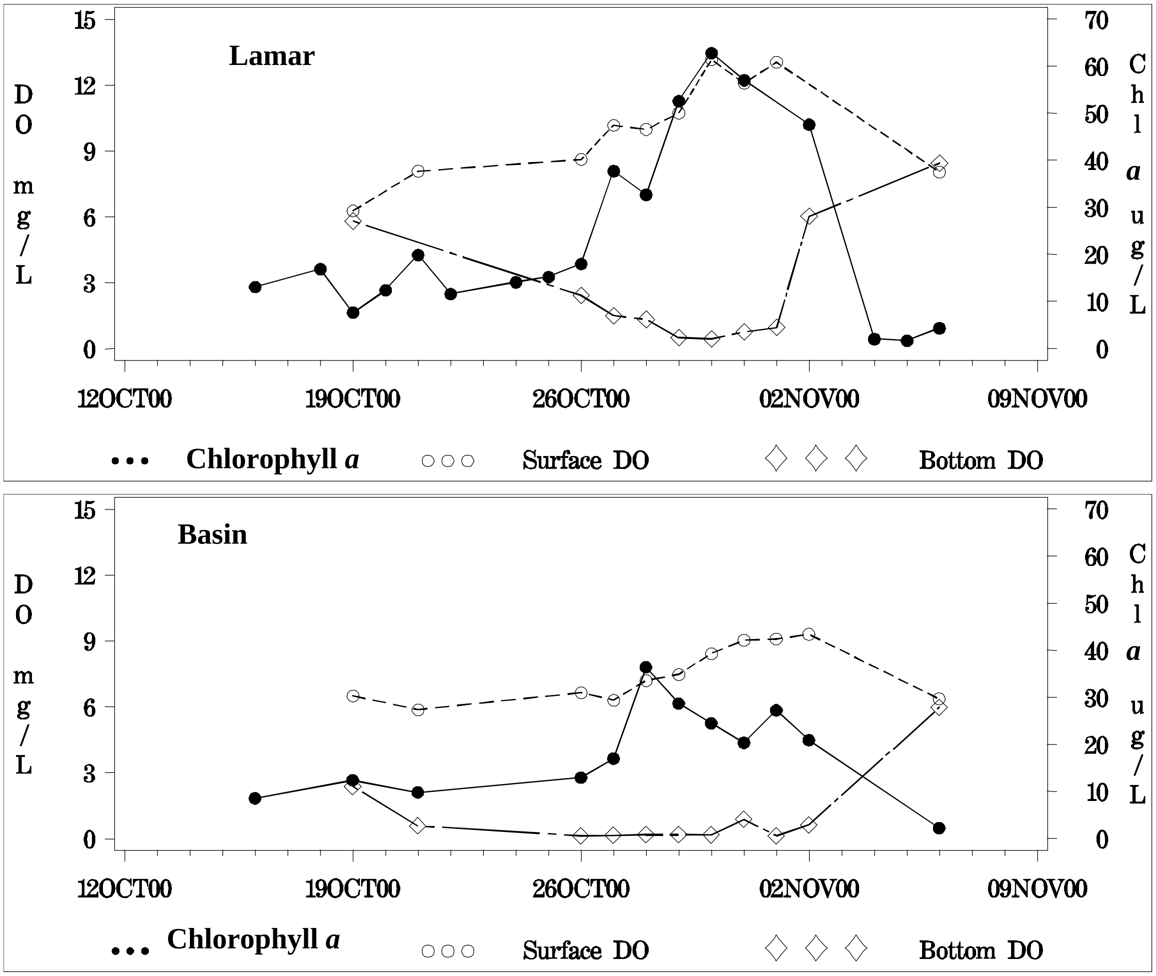


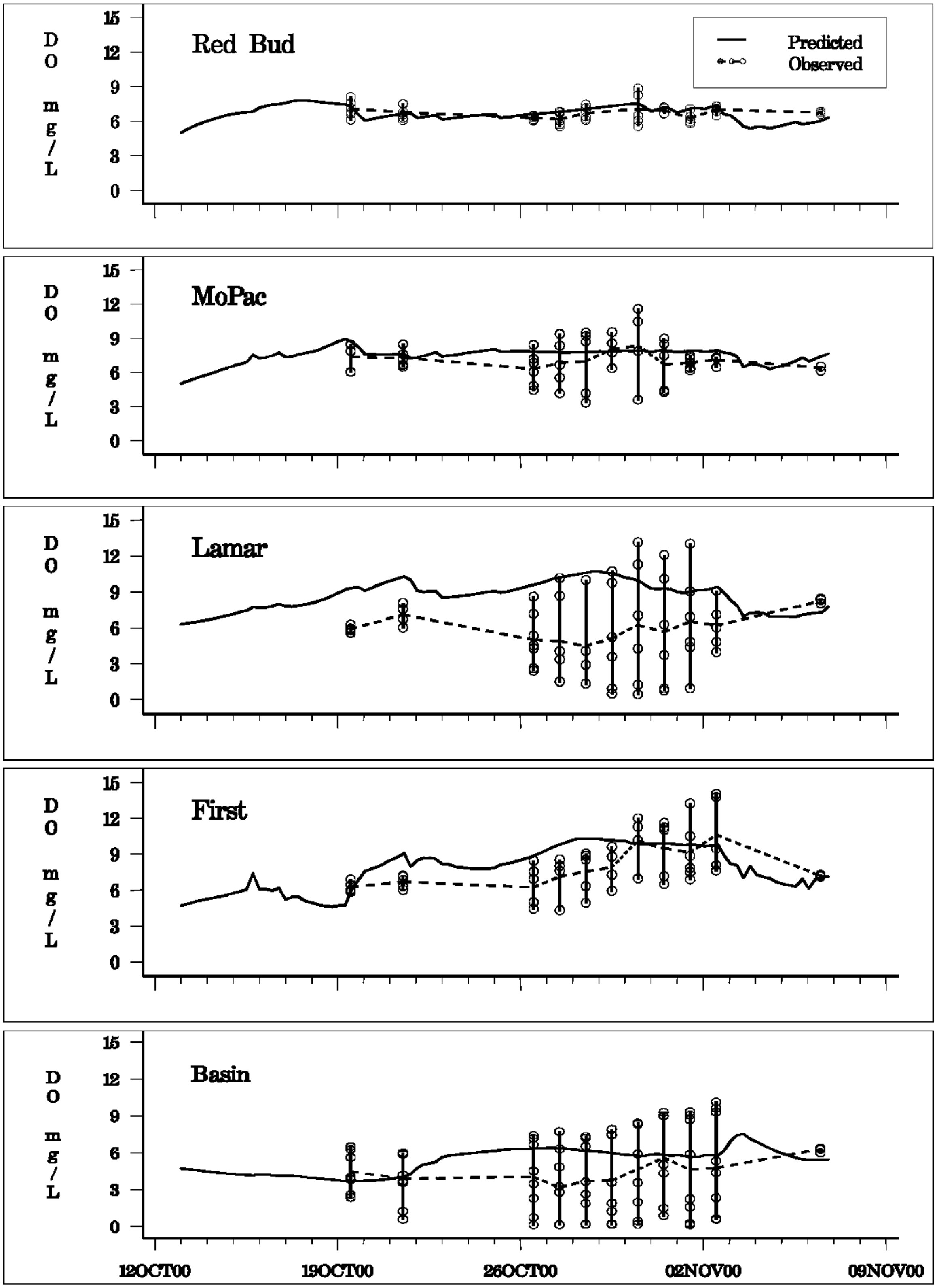
Figure 7.15 Dissolved Oxygen vs Chlorophyll *a*, Fall 2000



Dissolved Oxygen - Model Predictions

Model predictions are fairly close to observed values except at Lamar (Figure 7.16). At Lamar the predicted values are too high until after the bloom. Predicted levels are also high at First and the Basin for several days prior to the peak of the bloom. These high predicted levels may be due in part to the high prediction values for algae.

Figure 7.16 Town Lake Dissolved Oxygen – Predicted vs Observed, Fall 2000



7.4 Conclusions

The model fit seems acceptable for chlorophyll *a*, nitrate, and ammonia. However, the fit for orthophosphate, organic phosphorus, and organic nitrogen was not acceptable. Predicted concentrations for all three were too high and were driven by predicted stormwater loads from creeks. No data were collected in the creeks during this period. The loads were predicted from average storm concentrations, and are unlikely to be the same as the actual stormwater concentrations given the high variance in stormwater quality data.

The orthophosphate data indicate a relationship to storm events, but the observed concentrations are lower than the predicted values, and drop immediately to the detection limit. The mean storm concentration is likely inadequately described, but additional problems also contribute to this discrepancy. The abrupt drop to very low levels indicates either faster algal consumption than modeled or removal from the system by adsorption to soil particles and settling. Decreasing model loads, which are equivalent to either the predicted concentration being too high or to immediate adsorption and settling, do not improve the fit. Instead, the predicted chlorophyll *a* levels become much too low. Faster consumption, if it could be modeled, might well improve the fit for both the 1994 and the 2000 bloom simulations. Variation of model parameters thus far has not resulted in faster orthophosphate removal by algae.

The organic phosphorus and nitrogen data do not appear to be related to storm events. Most organic matter in stormwater runoff may settle prior to reaching the lake. The organic phosphorus and nitrogen concentrations show increases during the peak of the bloom. The lake concentrations of organic matter may be primarily the result of algal death rather than stormwater loads.

Both organic phosphorus and nitrogen-observed concentrations are well mixed in all the lake segments except at the Basin, where bottom concentrations are higher. This result indicates more settling of organic matter in the Basin than in the rest of the lake. Settling is not incorporated in the model as it is currently configured. This explains some of the divergence between the predicted and observed organic phosphorus and nitrogen concentrations, particularly at the Basin. In an attempt to improve the fit, the model was configured to include settling. However, the rate of settling in the model is determined by segment velocity. Predicted velocities are uniform in each segment and are based on the modeled shape, which is rectangular. This matches actual conditions quite well in Town Lake except at the Basin, which is not rectangular and has more variation in velocity than the other segments due to its shape. When settling was modeled, organic matter settled fairly uniformly throughout the lake, rather than just at the basin. Since this result does not agree with the observed data, the model was returned to its original configuration.

Since the understanding of nutrients and their relationship to algal blooms is clearly incomplete, this model simulation cannot be viewed as a final validation of the model. Additional work is recommended on several fronts, including stormwater loads to the lake, the settling of organic matter, and the rates of algal consumption of orthophosphate. However, prediction of the size and extent of the bloom in the center of the lake was quite good. Hence the model can be viewed as partially validated and may still be useful in planning level estimates.

8.0 MODEL APPLICATIONS – MASTER PLAN GOALS

The model was used to assess Town Lake goals related to algae blooms. As described in Section 2, the goals were revised based in part on model confirmation of the feasibility of maintaining the status quo in the face of increased watershed development, and to confirm that reducing the number of blooms in the lake would be very difficult to achieve through structural water quality control retrofits alone.

To determine the current status of the lake with respect to algae blooms, both algae counts and chlorophyll *a* levels were plotted for 1993-1996 (Figures 8.1 and 8.2). The annual pattern for algal count data and chlorophyll *a* data is similar, although little correlation in daily values is present. One reason for inconsistencies may be that counts are made daily, whereas chlorophyll *a* is infrequently measured due to analytical cost. The relationship between trophic state, chlorophyll *a* concentrations, and algal counts, as described in Section 5, are shown in Table 8.1.

Table 8.1 Relationship between Phytoplankton Measures and Trophic State

trophic state	oligotrophic	mesotrophic	eutrophic	"high algae" appearance	hyper-eutrophic
chlorophyll *a*	<4 ug/L	4-10 ug/L	10-25 ug/L	approx. 17 ug/L	>25
algae counts	<2,000	2,000-15,000	>15,000		

Based on the 15,000 cells/mL count, Town Lake has been averaging between one and two blooms per year in recent years. The major bloom period is fall. The number of blooms per year and the number of periods in which the blooms occurred in recent years were discussed in Section 5.

Figure 8.1 Town Lake Chlorophyll *a*, 1993 to 1996

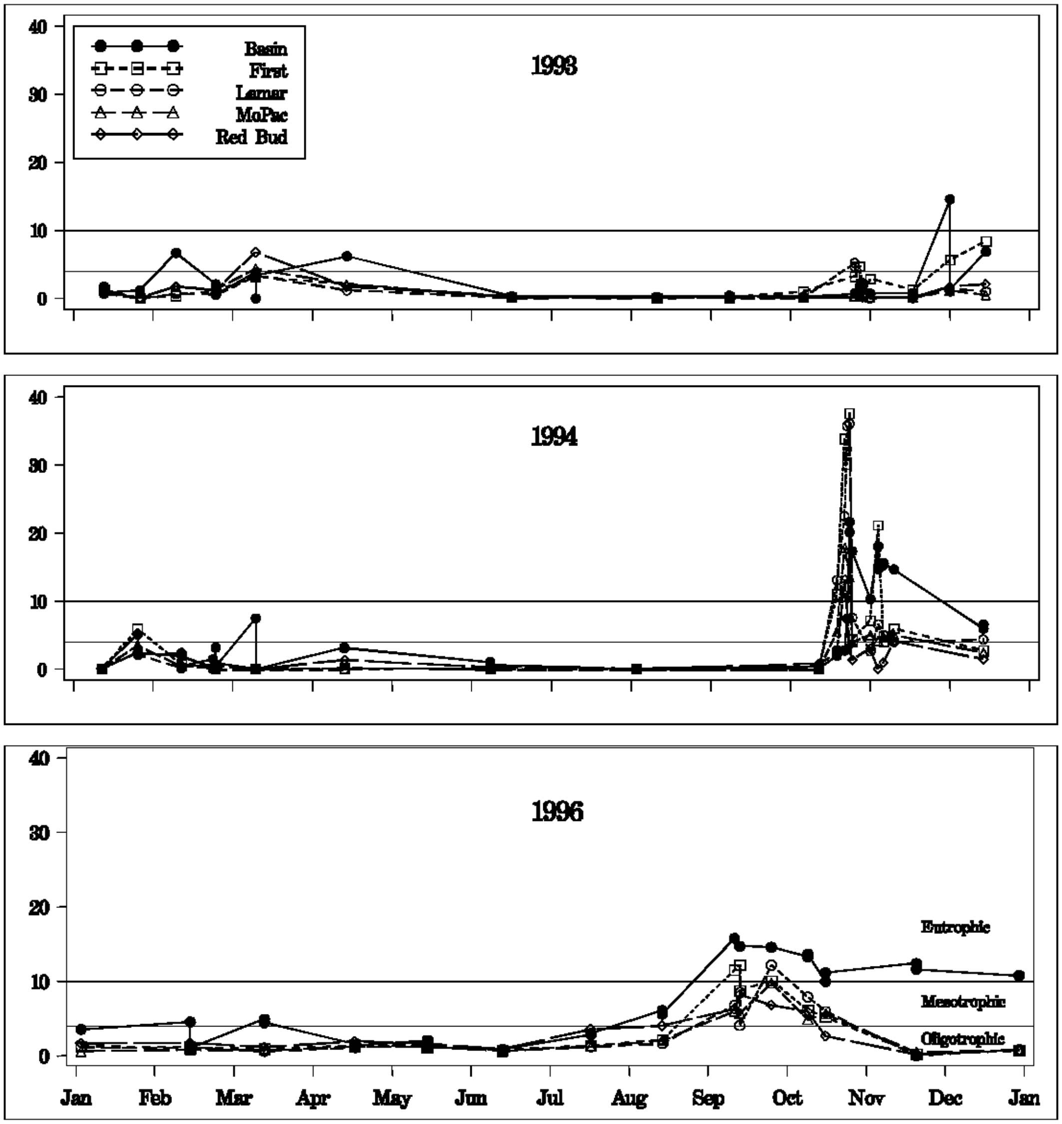
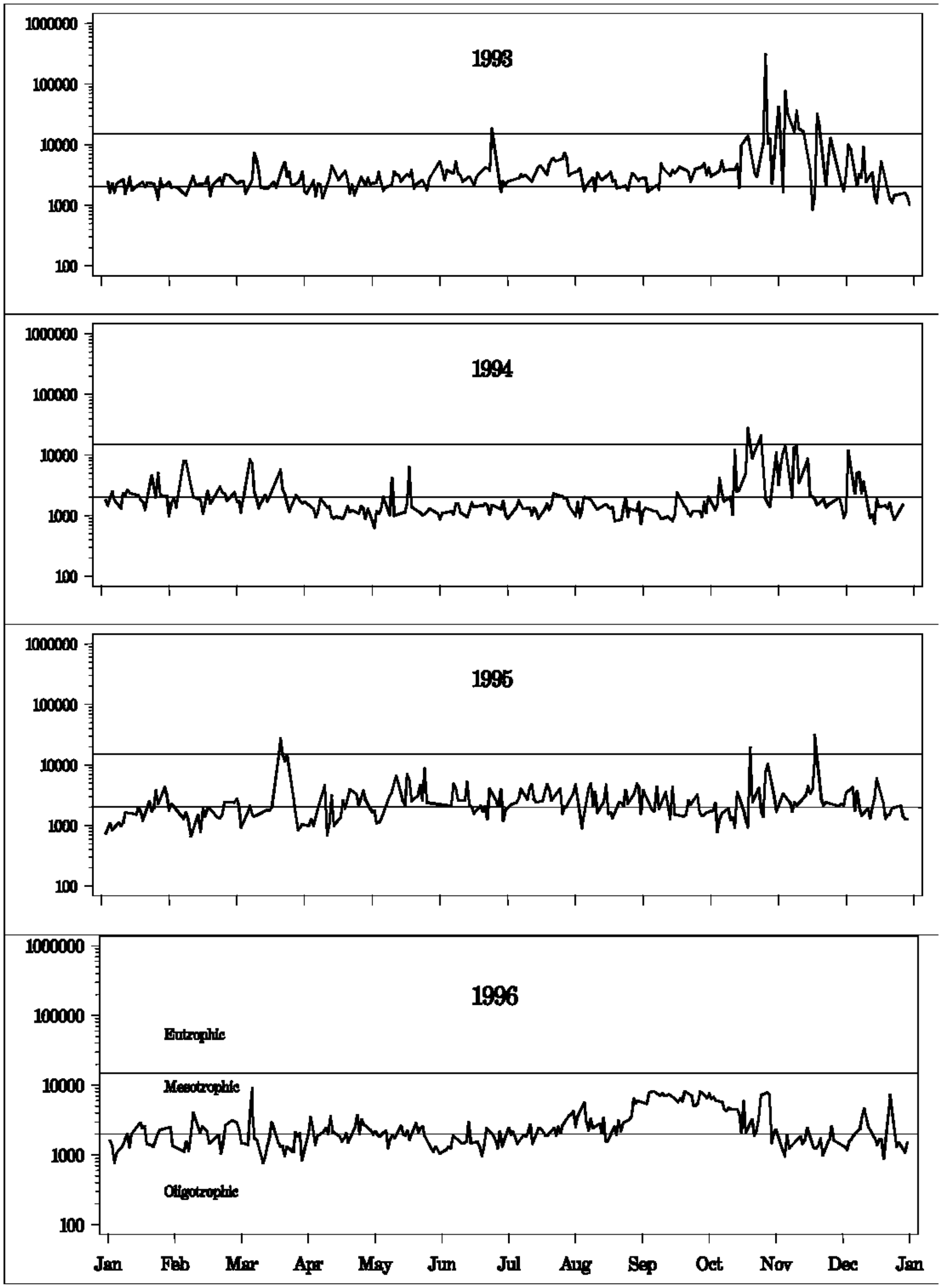


Figure 8.2 Town Lake Phytoplankton (cells/mL), 1993 to 1996



Since the algae counts are taken much more frequently than chlorophyll *a* concentrations, algae blooms were determined from the counts. In the model, however, the chlorophyll *a* concentrations are used to estimate whether or not a bloom might occur. If the predicted chlorophyll *a* concentration is greater than 10 μg/L, then according to the model it is possible for a bloom to occur. Model estimated maximum chlorophyll *a* levels during the 1995 bloom periods are listed in Table 8.2.

Table 8.2 Predicted maximum chlorophyll *a* levels during the 1995 bloom periods

Segment	**Red Bud**	**MoPac**	**Lamar**	**First**	**Basin**
Spring	3	10	14	22	30
Fall	2	6	11	18	20

To determine the impacts of load changes on chlorophyll *a* levels, the model for the 1995 period was run with different loads for the urban creeks. Loads were set at 25 percent and 150 percent of the current loads. At 25 percent the loads did not reduce the number of potential bloom periods to one for all sections of Town Lake. Load reductions below 25 percent of current were determined to be infeasible due to the reported limited opportunities found for water quality control retrofits, implying that a goal of one bloom per year is probably not achievable. Increasing the loads by 50 percent added a third potential bloom period during the late summer at the downstream end, which is undesirable. Therefore, it was decided that a goal of maintaining the current number of blooms at the current level of severity was appropriate.

The goal of maintaining the current status of the lake in terms of nutrient input was evaluated as well. With increased development, increases in loads from the upstream reservoirs is likely. In order to offset these increases, reductions must be made in the stormwater loads from the urban streams. The model was used to estimate the size of the reductions that might be needed. Upstream boundary conditions were increased to match the estimated loads in the year 2040 (COA 2001b). The percentage increase from 1995 conditions was estimated from the Center for Research in Water Resources' (CRWR) work on current (approx. 1995 as described in Section 2) and future (2040) loads into Lake Austin at Bull Creek and predicted population changes in the Lake Austin watershed (Dartiguenave 1997). This increase was approximately 40 percent for most parameters. Input for local loads into Town Lake were reduced from the current estimated amount to determine how much local load reduction would be needed to offset the predicted increase in loadings from Lake Austin and upstream. Approximately a 25 percent decrease in local loads was needed to offset the increased loading from upstream during the non-release season when the water in Lake Austin is affected primarily by local loads. A 25 percent decrease in local stormwater loads may be possible, although difficult, to achieve. Thus the model confirmed that the goal of maintaining the current total load to Town Lake for nutrients is feasible.

Dissolved oxygen levels in Lake Austin were not changed for these scenarios, nor were they considered in the bloom goal setting process. If dissolved oxygen levels decrease in Lake Austin in the future, a small bloom in Town Lake could cause dissolved oxygen in Town Lake to drop to levels of concern. It may then be necessary to decrease the maximum acceptable chlorophyll *a* levels in Town Lake.

9.0 CONCLUSIONS

Causes of Blooms

From water quality data analysis it is evident that blooms typically occur when the days leading up to the bloom are unusually warm, sunny, and very calm, with minimal flow through the lake. The water is usually clear, without the increased turbidity that lingers after storms. However, the 2000 bloom demonstrates that each bloom is unique. During this bloom, flow was even lower than usual, but skies were overcast rather than sunny. Frequent storms provided additional nutrients and light availability was of secondary importance. While sample data indicate that phosphorus is usually the major limiting nutrient in Town Lake, the 2000 bloom demonstrates that nitrogen can also be limiting during very large blooms.

Potential Uses for the Model

The model could be used to predict the effects of land use changes or BMP implementation on water quality in Town Lake for periods when the hydrodynamics of the system are known. To predict short-term, rapid changes, the bloom version should be used. If long-term monthly average changes are of interest, the annual version should be run. Since the WASP model was developed to address seasonal dynamics rather than short-term bloom dynamics, more confidence should be put in seasonal predictions than in bloom predictions.

Limitations of the model

The model has been used to predict the impact of changes, due to master plan implementation, in nutrient loading on the phytoplankton levels in the lake. However, the implementation of the City’s master plan solutions may affect the quantity of water as well as the quality. Since the hydrodynamic model was not calibrated to velocity or dye data, hypothetical flow scenarios should not be used. Therefore, the model cannot be used to predict the effects of those master plan solutions that produce changes in water quantity, such as modified flood detention regulations or baseflow augmentation.

The annual model uses monthly average inputs to predict monthly average results. In Town Lake the extremes are frequently of greater interest than average values. Algae blooms, for example, result from a combination of extremes: low wind speed, high temperature, low flow, low cloud cover, and high nutrient concentrations. Average concentrations predicted by the model should be used in conjunction with estimates of the concentration variance.

Further Studies Needed

In order to improve the model, further investigations should be made. Town Lake velocities are estimated and have not been confirmed by observation. Dye studies or other methods of measuring velocity would allow refinement of the hydrodynamic portion of the model. The model could then be applied to different flow scenarios as well as to hypothetical loadings.

The inability of the model to accurately predict the magnitude of the chlorophyll *a* concentrations in both the middle of the lake and at the ends of the lake should be investigated. Major factors in phytoplankton growth include light and temperature. It is possible that the amount of available light or the impact of temperature on local algal growth rates is not accurately represented. Light availability and algal bioassay equipment would be necessary to investigate the relationship between temperature and growth rates.

Additional data of several types would assist in refining and verifying the Town Lake model. Measurements of dissolved oxygen and chlorophyll *a* concentrations at the turbine intakes in Lake Austin would be needed to confirm the assumptions that no chlorophyll *a* is provided from the bottom of the lake, and that dissolved oxygen levels are 75 percent of surface concentrations

Additional data on stormwater loads would be useful, particularly for periods with low inflow from Lake Austin. Measurements taken at the creek mouths for orthophosphate, organic nitrogen, and organic phosphorus could help determine how much of these constituents actually reach the lake. Determination of the ratios of nitrogen and phosphorus to carbon in phytoplankton biomass could also help fine tune the model. Finally, as factors from the model processes are examined, more data would be necessary for additional validation for both bloom and annual simulations.

10.0 REFERENCES

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APPENDIX A INPUT FILES FOR DYNHYD AND WASP

Sample DYNHYD5 Input File for a Bloom Simulation

```
C:\Wasp4\Bloom\Oct94\doctbest.inp
TOWN LAKE HYDRAULICS inflow=Tom M.+1.2 cms(42cfs),BS=obs, BC=obs+Shoal*.24
10/13-11/03/94, jun3=sh*.74 jun5=sh*1.98 jun6=sh*.26, CountryClub=shoal*42
   NJ   NC NCYC DELT ICRD     START       END
    9    8 0000  60.    5    1 0000   22 0000
***** B: PRINTOUT CONTROL DATA *********************************************
       0.0      1.00    8
    1    2    3    4    5    6    7    8    9
***** C: SUMMARY CONTROL DATA **********************************************
    2    1 0000 24.0   60   30
***** D: JUNCTION DATA *****************************************************
    1      10.0   233486.       7.4    1    0
    2      10.0   233486.       7.4    1    2
    3      10.0   246946.       6.5    2    3
    4      10.0   220720.       6.8    3    4
    5      10.0   296609.       6.7    4    5
    6      10.0   325874.       4.9    5    6
    7      10.0   604852.       4.1    6    7
    8      10.0   233486.       7.0    7    8
    9      10.0    52000.       8.5    8    0
***** E: CHANNEL DATA *****************************************************
    1    1609.0     144.0       3.0     135.0     0.050      .020    2    1
    2    1609.0     144.0       3.0     135.0     0.050      .020    3    2
    3    1609.0     172.0       3.4     120.0     0.050      .020    4    3
    4    1609.0     160.0       3.3     105.0     0.050      .020    5    4
    5    1609.0     230.0       4.2     150.0     0.050      .020    6    5
    6    1609.0     260.0       5.5      90.0     0.050      .020    7    6
    7    1609.0     144.0       3.0      90.0     0.080      .020    8    7
    8     650.0      80.0       1.5      90.0     0.080      .020    9    8
***** F: CONSTANT INFLOWS *************************************************
    1
         1      -1.2
***** VARIABLE INFLOWS ****************************************************
    9
         1        83                                           Tom Miller
    1  0 0       .00    1  7 0    -15.58    1  8 0    -18.97    1 13 0-18.97
    1 14 0    -46.44    1 15 0    -18.97    1 16 0       .00    2  7 0   .00
    2  8 0    -18.97    2 16 0    -18.97    2 17 0       .00    3  6 0   .00
    3  7 0    -18.97    3 16 0    -18.97    3 17 0       .00    4  6 0   .00
    4  7 0    -18.97    4 11 0    -18.97    4 12 0    -24.50    4 13 0-18.97
    4 16 0    -18.97    4 17 0       .00    4 18 0       .00    4 19 0-48.85
    4 21 0    -48.85    4 22 0    -36.39    4 23 0       .00    8 17 0   .00
    8 18 0    -18.97    8 20 0    -18.97    8 21 0    -15.58    8 22 0   .00
    9 19 0       .00    9 20 0    -11.04    9 21 0    -18.97    9 22 0-11.04
    9 23 0       .00   10  8 0       .00   10  9 0    -11.04   10 10 0   .00
   10 18 0       .00   10 19 0    -48.85   10 20 0    -48.85   10 21 0   .00
   11 18 0       .00   11 19 0    -24.50   11 20 0    -48.85   11 21 0-24.50
```

```
  11 22 0       .00   13  2 0       .00   13  3 0    -24.50   13  4 0-48.85
  13  7 0    -48.85   13  8 0    -36.39   13  9 0    -18.97   13 17 0-18.97
13 18 0    -11.04   13 19 0       .00   14 13 0       .00   14 14 0-18.97
14 19 0    -18.97   14 20 0    -24.50   14 21 0       .00   16 13 0   .00
16 14 0   -107.62   16 15 0       .00   19 18 0       .00   19 19 0-11.04
19 20 0    -18.97   19 21 0    -18.97   19 22 0    -15.58   19 23 0   .00
20 18 0       .00   20 19 0    -18.97   20 21 0    -18.97   20 22 0   .00
21 18 0       .00   21 19 0    -11.04   21 20 0    -18.97   21 21 0-18.97
21 22 0    -15.58   21 23 0       .00   22  0 0       .00
      3        70               Johnson, Eanes, 2/3 TL adj = Shoal *.74
 1  0 0       .00    2 22 0       .00    2 2215      -.01    2 2315  -.03
 3  015      -.25    3  315      -.38    3  530     -3.23    3  615 -3.23
 3  715     -2.87    3  830     -2.16    3 10 0     -1.53    3 1215 -1.19
 3 1430     -1.01    3 1745      -.73    3 2315      -.38    4  5 0  -.29
 4 1145      -.25    4 1330      -.90    4 2215      -.88    5  145  -.61
 5  445      -.42    5  915      -.29    5 12 0      -.20    5 2045  -.14
 6 1030      -.02    6 1345      -.01    6 1515    -27.87    6 1530-26.41
 6 16 0    -15.19    6 1645     -8.28    6 1745     -5.45    6 19 0 -3.63
 6 1945     -2.89    6 2045     -2.18    6 2145     -1.68    7  015 -1.09
 7  6 0      -.61    7 1145      -.42    8  545      -.19    8 1830  -.10
 9  330      -.06   10 13 0       .00   12 2315       .00   13  030-22.84
13  1 0    -16.81   13  2 0    -12.60   13  315     -9.49   13  415 -6.22
13  530     -4.38   13  715     -2.89   13  915     -1.76   13 11 0 -1.38
13 1230     -1.09   13 1430      -.84   13 1815      -.61   13 2115  -.46
14  615      -.31   14 1515      -.23   15  9 0      -.13   15 15 0  -.20
15 1530     -2.12   15 18 0     -1.11   16  215      -.46   17  5 0  -.12
18  0 0      -.05   18 2045      -.02   19  715      -.01   20  4 0   .00
21  215       .00   22  0 0       .00
      4        14                                   Barton Springs
 1  0 0      -.93    6 13 0      -.93    6 15 0      -.99    8  8 0 -1.16
 8  9 0     -1.19    9 22 0     -1.19   10  9 0     -1.05   12 19 0  -.99
13  2 0     -1.02   13 21 0     -1.44   15  8 0     -1.47   16  3 0 -1.56
18  9 0     -1.56   22  0 0     -1.47
      4        70      Barton Creek Urban (below Loop 360) = Shoal*.24
 1  0 0       .00    2 22 0       .00    2 2215       .00    2 2315  -.01
 3  015      -.08    3  315      -.12    3  530     -1.05    3  615 -1.05
 3  715      -.93    3  830      -.70    3 10 0      -.50    3 1215  -.39
 3 1430      -.33    3 1745      -.24    3 2315      -.12    4  5 0  -.10
 4 1145      -.08    4 1330      -.29    4 2215      -.29    5  145  -.20
 5  445      -.14    5  915      -.10    5 12 0      -.06    5 2045  -.05
 6 1030      -.01    6 1345       .00    6 1515     -9.04    6 1530 -8.56
 6 16 0     -4.93    6 1645     -2.68    6 1745     -1.77    6 19 0 -1.18
 6 1945      -.94    6 2045      -.71    6 2145      -.54    7  015  -.35
 7  6 0      -.20    7 1145      -.14    8  545      -.06    8 1830  -.03
 9  330      -.02   10 13 0       .00   12 2315       .00   13  030 -7.41
13  1 0     -5.45   13  2 0     -4.08   13  315     -3.08   13  415 -2.02
13  530     -1.42   13  715      -.94   13  915      -.57   13 11 0  -.45
13 1230      -.35   13 1430      -.27   13 1815      -.20   13 2115  -.15
14  615      -.10   14 1515      -.07   15  9 0      -.04   15 15 0  -.06
15 1530      -.69   15 18 0      -.36   16  215      -.15   17  5 0  -.04
```

```
  18  0 0      -.02   18 2045      -.01   19  715       .00   20  4 0   .00
  21  215       .00   22  0 0       .00
      4        47                             Barton Creek Loop 360
 1  0 0       .00    6 1430       .00    6 15 0     -1.16    6 1530  -.40
 6 1815      -.31    6 1930     -1.93    6 2130     -2.10    7  415 -1.13
 7  6 0      -.96    7 1145      -.96    7 1630      -.71    7 22 0  -.57
 8  715      -.42    9  815      -.28   10 2330      -.25   11  145  -.20
11  415      -.15   11  545      -.08   11  915       .00   13  430   .00
13  530     -2.35   13  630     -4.02   13  830     -3.09   13 1245 -3.09
13 13 0     -2.12   13 15 0     -1.67   13 1645     -4.81   13 19 0 -6.85
13 1945     -6.85   13 2045     -6.26   13 2230     -5.32   14  015 -4.50
14  215     -3.88   14  5 0     -3.09   14  8 0     -2.58   14 1015 -2.27
14 1245     -1.98   14 1615     -1.67   14 2115     -1.42   15  5 0 -1.13
16 1030      -.85   17 21 0      -.57   20  745      -.28   20 22 0  -.20
20 23 0      -.15   21  3 0      -.11   22  0 0      -.11
      5        70     Shoal, Waller, E&W Bouldin, 1/3 TL adj = Shoal*1.98
 1  0 0       .00    2 22 0       .00    2 2215      -.02    2 2315  -.07
 3  015      -.67    3  315     -1.01    3  530     -8.64    3  615 -8.64
 3  715     -7.68    3  830     -5.78    3 10 0     -4.09    3 1215 -3.20
 3 1430     -2.69    3 1745     -1.96    3 2315     -1.01    4  5 0  -.79
 4 1145      -.67    4 1330     -2.41    4 2215     -2.36    5  145 -1.63
 5  445     -1.12    5  915      -.79    5 12 0      -.53    5 2045  -.39
 6 1030      -.05    6 1345      -.04    6 1515    -74.58    6 1530-70.65
 6 16 0    -40.65    6 1645    -22.15    6 1745    -14.58    6 19 0 -9.70
 6 1945     -7.74    6 2045     -5.83    6 2145     -4.49    7  015 -2.92
 7  6 0     -1.63    7 1145     -1.12    8  545      -.50    8 1830  -.28
 9  330      -.17   10 13 0       .00   12 2315       .00   13  030-61.12
13  1 0    -44.97   13  2 0    -33.70   13  315    -25.40   13  415-16.65
13  530    -11.72   13  715     -7.74   13  915     -4.71   13 11 0 -3.70
13 1230     -2.92   13 1430     -2.24   13 1815     -1.63   13 2115 -1.23
14  615      -.84   14 1515      -.62   15  9 0      -.36   15 15 0  -.53
15 1530     -5.66   15 18 0     -2.97   16  215     -1.23   17  5 0  -.33
18  0 0      -.13   18 2045      -.05   19  715      -.02   20  4 0   .00
21  215       .00   22  0 0       .00
      6        70                           Blunn, Harpers = Shoal*.26
 1  0 0       .00    2 22 0       .00    2 2215       .00    2 2315  -.01
 3  015      -.09    3  315      -.13    3  530     -1.13    3  615 -1.13
 3  715     -1.01    3  830      -.76    3 10 0      -.54    3 1215  -.42
 3 1430      -.35    3 1745      -.26    3 2315      -.13    4  5 0  -.10
 4 1145      -.09    4 1330      -.32    4 2215      -.31    5  145  -.21
 5  445      -.15    5  915      -.10    5 12 0      -.07    5 2045  -.05
 6 1030      -.01    6 1345       .00    6 1515     -9.79    6 1530 -9.28
 6 16 0     -5.34    6 1645     -2.91    6 1745     -1.91    6 19 0 -1.27
 6 1945     -1.02    6 2045      -.77    6 2145      -.59    7  015  -.38
 7  6 0      -.21    7 1145      -.15    8  545      -.07    8 1830  -.04
 9  330      -.02   10 13 0       .00   12 2315       .00   13  030 -8.03
13  1 0     -5.91   13  2 0     -4.43   13  315     -3.34   13  415 -2.19
13  530     -1.54   13  715     -1.02   13  915      -.62   13 11 0  -.49
13 1230      -.38   13 1430      -.29   13 1815      -.21   13 2115  -.16
14  615      -.11   14 1515      -.08   15  9 0      -.05   15 15 0  -.07
```

```
    15 1530      -.74   15 18 0      -.39   16  215      -.16   17  5 0  -.04
    18  0 0      -.02   18 2045      -.01   19  715       .00   20  4 0   .00
   21  215       .00   22  0 0       .00
         8        70                         Country Club = Shoal*.42
    1  0 0       .00    2 22 0       .00    2 2215       .00    2 2315  -.01
    3  015      -.14    3  315      -.21    3  530     -1.83    3  615 -1.83
    3  715     -1.63    3  830     -1.23    3 10 0      -.87    3 1215  -.68
    3 1430      -.57    3 1745      -.42    3 2315      -.21    4  5 0  -.17
    4 1145      -.14    4 1330      -.51    4 2215      -.50    5  145  -.34
    5  445      -.24    5  915      -.17    5 12 0      -.11    5 2045  -.08
    6 1030      -.01    6 1345      -.01    6 1515    -15.82    6 1530-14.99
    6 16 0     -8.62    6 1645     -4.70    6 1745     -3.09    6 19 0 -2.06
    6 1945     -1.64    6 2045     -1.24    6 2145      -.95    7  015  -.62
    7  6 0      -.34    7 1145      -.24    8  545      -.11    8 1830  -.06
    9  330      -.04   10 13 0       .00   12 2315       .00   13  030-12.96
   13  1 0     -9.54   13  2 0     -7.15   13  315     -5.39   13  415 -3.53
   13  530     -2.49   13  715     -1.64   13  915     -1.00   13 11 0  -.79
   13 1230      -.62   13 1430      -.48   13 1815      -.34   13 2115  -.26
   14  615      -.18   14 1515      -.13   15  9 0      -.08   15 15 0  -.11
   15 1530     -1.20   15 18 0      -.63   16  215      -.26   17  5 0  -.07
   18  0 0      -.03   18 2045      -.01   19  715       .00   20  4 0   .00
   21  215       .00   22  0 0       .00
         9       100                                      Montopolis
    1  0 0      3.60    1  130       .96    1  6 0       .57    1  7 0 38.23
    1  9 0     49.28    1 1030     21.07    1 1130      9.23    1 15 0  2.41
    1 1830      2.46    1 22 0     15.75    2  030     18.18    2  130 41.91
    2  230     38.23    2  5 0      5.24    2  930      1.50    2 19 0  1.10
    2 2230     17.56    3  4 0     19.14    3  630      4.39    3 1130  2.58
    3 17 0      4.53    3 1930     22.77    4  0 0     24.70    4  3 0 24.53
    4  6 0      4.39    4 11 0      1.84    4 17 0      2.63    4 21 0 20.11
    5  330     24.33    5  530     19.14    5  8 0     53.81    5 1230 28.24
    5 2030     10.28    6  130      2.24    6  7 0       .48    7  030  2.46
    7  3 0     64.29    7  7 0     37.38    7  830     12.94    7 13 0  4.62
    7 1630      5.07    7 20 0      1.70    8  3 0      2.46    9  030  4.39
    9  430      1.84    9  630     20.59    9 10 0      6.00    9 14 0  1.81
    9 1630      1.76   10  3 0      3.17   10  6 0      4.30   10  8 0 10.51
   10 11 0      9.94   10 15 0      1.81   10 17 0      1.13   11  330  2.63
   11  530     43.90   11  630     33.98   11  730      9.57   11  9 0  4.67
   11 1130      3.12   11 16 0      3.65   11 1930       .96   12  330   .96
   12  530     44.18   12  9 0      4.53   12 11 0      3.51   12 1830  4.53
   12 23 0      1.10   13  9 0      2.52   13 1030      4.08   13 11 0 92.04
   13 13 0    123.76   13 1730     57.21   13 2230     42.48   14  230 28.32
   14  430      7.65   14  6 0      6.34   14 2130      8.81   15  0 0 12.55
   15  430     23.45   15  7 0     18.18   15  830      4.76   15 1030  3.60
   16  730      6.34   16 12 0      1.84   17 19 0      5.15   18  0 0  1.42
   19  930      4.62   19 1530       .96   20  3 0      2.41   20  530 16.48
   20  830     14.16   20 13 0      1.59   21  130      2.95   21  430 15.58
   21  630     14.73   21  930      2.69   21 12 0      2.10   22  0 0  2.95
***** SEAWARD BOUNDARY DATA ***********************************************
    0
```

```
 ***** WIND DATA ************************************************************
     0
***** Junction Geometry Data **********************************************
    0
***** Channel Geometry Data ***********************************************
    0
***** Evap/Precip. Data ***************************************************
    0
***** MAP TO WASP4  *******************************************************
    0    8
    1    0
    2    1
    3    2
    4    3
    5    4
    6    5
    7    6
    8    7
    9    0
```

Sample DYNHYD5 Input File for an Annual Simulation

```
C:\Wasp4\Bloom\year95\dmon95.inp
TOWN LAKE HYDRAULICS inflow=Tom M.+1.2 cms(42cfs),BS=obs, BC=obs+Shoal*.24
1/1/95-12/31/95, jun3=sh*.74 jun5=sh*1.98 jun6=sh*.26, CountryClub=shoal*42
   NJ   NC NCYC DELT ICRD     START       END
    9    8 0000 120.    5    1 0000  365 0000
***** B: PRINTOUT CONTROL DATA *********************************************
        0.     24.00    8
    1    2    3    4    5    6    7    8    9
***** C: SUMMARY CONTROL DATA **********************************************
    2    1 0000 24.0   60   30
***** D: JUNCTION DATA *****************************************************
    1      10.0   233486.       7.4    1    0
    2      10.0   233486.       7.4    1    2
    3      10.0   246946.       6.5    2    3
    4      10.0   220720.       6.8    3    4
    5      10.0   296609.       6.7    4    5
    6      10.0   325874.       4.9    5    6
    7      10.0   604852.       4.1    6    7
    8      10.0   233486.       7.0    7    8
    9      10.0    52000.       8.5    8    0
***** E: CHANNEL DATA *****************************************************
    1    1609.0     144.0       3.0     135.0     0.050      .020    2    1
    2    1609.0     144.0       3.0     135.0     0.050      .020    3    2
    3    1609.0     172.0       3.4     120.0     0.050      .020    4    3
    4    1609.0     160.0       3.3     105.0     0.050      .020    5    4
    5    1609.0     230.0       4.2     150.0     0.050      .020    6    5
    6    1609.0     260.0       5.5      90.0     0.050      .020    7    6
    7    1609.0     144.0       3.0      90.0     0.080      .020    8    7
    8     650.0      80.0       1.5      90.0     0.080      .020    9    8
***** F: CONSTANT INFLOWS *************************************************
    1
         1      -1.2
***** VARIABLE INFLOWS ****************************************************
    7
         1        14                                         Tom Miller
    0 12 0     -6.70   15 12 0     -6.70   45 12 0     -4.11   75 12 0   -6.81
  105 12 0    -15.27  135 12 0    -43.75  165 12 0    -51.60  195 12 0  -40.76
  225 12 0    -26.97  255 12 0    -29.39  285 12 0    -11.88  315 12 0   -4.90
  345 12 0     -5.37  365 12 0     -5.37
         3        14              Johnson, Eanes, 2/3 TL adj = Shoal *.74
    0 12 0     -0.15   15 12 0     -0.15   45 12 0     -0.08   75 12 0   -0.32
  105 12 0     -0.19  135 12 0     -0.81  165 12 0     -0.33  195 12 0   -0.03
  225 12 0     -0.19  255 12 0     -0.19  285 12 0     -0.00  315 12 0   -0.08
  345 12 0     -0.00  365 12 0     -0.00
         4        14          BS + BC Loop 360 +BC Urban(below 360)=Sh*.24
    0 12 0     -2.19   15 12 0     -2.19   45 12 0     -1.23   75 12 0   -2.87
  105 12 0     -3.54  135 12 0     -6.61  165 12 0     -9.66  195 12 0   -2.71
  225 12 0     -2.33  255 12 0     -2.00  285 12 0     -1.46  315 12 0   -1.48
```

```
   345 12 0     -1.10  365 12 0     -1.10
          5        14     Shoal, Waller, E&W Bouldin, 1/3 TL adj = Shoal*1.98
    0 12 0     -0.26   15 12 0     -0.26   45 12 0     -0.17   75 12 0   -0.50
  105 12 0     -0.31  135 12 0     -1.15  165 12 0     -0.50  195 12 0   -0.10
  225 12 0     -0.32  255 12 0     -0.32  285 12 0     -0.06  315 12 0   -0.17
  345 12 0     -0.06  365 12 0     -0.06
        6        14                           Blunn, Harpers = Shoal*.26
    0 12 0     -0.05   15 12 0     -0.05   45 12 0     -0.03   75 12 0   -0.11
  105 12 0     -0.07  135 12 0     -0.29  165 12 0     -0.11  195 12 0   -0.01
  225 12 0     -0.07  255 12 0     -0.07  285 12 0     -0.00  315 12 0   -0.03
  345 12 0     -0.00  365 12 0     -0.00
        8        14                          Country Club = Shoal*.42
    0 12 0     -0.09   15 12 0     -0.09   45 12 0     -0.05   75 12 0   -0.18
  105 12 0     -0.11  135 12 0     -0.46  165 12 0     -0.19  195 12 0   -0.02
  225 12 0     -0.11  255 12 0     -0.11  285 12 0     -0.00  315 12 0   -0.05
  345 12 0     -0.00  365 12 0     -0.00
        9        14   Estimated Montopolis (set = inflow sum - not measured)
    0 12 0     10.64   15 12 0     10.64   45 12 0      6.87   75 12 0   12.01
  105 12 0     20.69  135 12 0     54.27  165 12 0     63.59  195 12 0   44.83
  225 12 0     31.19  255 12 0     33.29  285 12 0     14.61  315 12 0    7.91
  345 12 0      7.73  365 12 0      7.73
***** SEAWARD BOUNDARY DATA ***********************************************
    0
***** WIND DATA ***********************************************************
    0
***** Junction Geometry Data **********************************************
    0
***** Channel Geometry Data ***********************************************
    0
***** Evap/Precip. Data ***************************************************
    0
***** MAP TO WASP4  *******************************************************
    0    8
    1    0
    2    1
    3    2
    4    3
    5    4
    6    5
    7    6
    8    7
    9    0
```

EUTRO4 Input File of the 1994 Bloom Simulation

```
TOWN LAKE C:\wasp4\o94.inp 21 day run - october 13 to nov 3, 1994
EUTROPHICATION PROBLEM - FLOW FROM DYNHYD - doctmat.inp (more inflows)
NSEG NSYS ICRD MFLG IDMP NSLN INTY ADFC   DD HHMM       A:MODEL OPTIONS
   6   08    0    1    3    0    0  0.0    1 0000
   1    2    3    4    5    6
   1
  .041667       21.
   1
     0.25       21.
   0    0    0    0    0    0    0    0
   1    0    +    *    +    *    +    *    +    *    +    *    B:EXCHANGES
   1     1.000       1.0       1.0            (surface water)
   5
     432.     1609.    1    2
     585.     1609.    2    3
     528.     1609.    3    4
     996.     1609.    4    5
    1430.     1609.    5    6
   2
 1.00E-04        0.  1.00E-04       23.
   0    0    0    0    0    0    0    0
   2    0      23.0    +    *    +    *    +    *    +    *    C: VOLUMES
   1.0000       1.0
        1         7         1   608063.        1.       0.4        1.       0.6
        2         8         1   864381.        1.       0.4        1.       0.6
        3         9         1   706304.        1.       0.4        1.       0.6
        4        10         1   978810.        1.       0.4        1.       0.6
        5        11         1  1661957.        1.       0.4        1.       0.6
        6        12         1  3568627.        1.       0.4        1.       0.6
   3    1 doctMAT.hyd                      +    *    +    *    D: FLOWS
   0    0    0    0    0    0    0    0
        2                                                  E:BOUNDARIES
      1.0       1.0
   1    4                                            **** System 1  - NH3 mg/L
    0.075        .0     0.075        7.     0.060       13.     0.030     22.
   6    4
     0.09        .0      0.10        7.     0.210       13.     0.120     22.
        2                                            **** System 2  - NO3 mg/L
      1.0       1.0
   1    2
     0.38        .0      0.38       22.
   6    2
     0.30        .0      0.35       22.
```

```
      2                                            **** System 3 - OPO4 mg/L
    1.0       1.0
1    4
 0.045        .0     0.035        7.     0.020       13.     0.030    22.
6    4
 0.038        .0     0.055        7.      0.02       13.      0.03    22.
     2                                            **** System 4  CHLa ug/L
   1.0       1.0
1    6
   1.0        .0       1.0      11.       1.0       12.       1.0    13.
   1.0      13.5       1.0       22.
6    6
   0.5        .0       2.0       11.      20.0       12.       15.    13.
   10.      13.5       10.       22.
     2                                            **** System 5  - BOD mg/L
   1.0       1.0
1    6
  0.50        .0      0.50       11.       1.5       12.       1.5    13.
  0.50      13.5      0.50       22.
6    6
  0.50        .0      0.50       11.       1.5       12.       0.5    13.
  0.50      13.5      0.50       22.
     2                                            **** System 6 - DO  mg/L
   1.0       1.0
1    2
   4.5        .0       5.5       22.
6    2
   5.1        .0       4.0       22.
     2                                            **** System 7  - ON  mg/L
   1.0       1.0
1    6
  0.40        .0      0.40       11.      0.95       12.      0.95    13.
  0.30      13.5      0.30       22.
6    6
  0.54        .0      0.45       11.       1.5       12.       1.5    13.
   0.4      13.5       0.3       22.
     2                                            **** System 8 - OP  mg/L
   1.0       1.0
1    2
 0.003        .0     0.003       22.
6    2
 0.025        .0      .025       22.
```

```
       4                                                F:  LOADS
     1.0       1.0
2   32                                                  NH3
   .00       .00       .90      2.01     11.75      2.23      7.83      2.35
  3.69      2.60       .90      3.49      3.24      3.56      2.24      4.07
   .00      5.57       .00      5.60    101.15      5.63     10.52      5.82
  6.49      5.90      3.92      6.01      1.57      6.49       .67      7.30
   .11      8.34       .00     10.24       .00     11.97     82.91     12.02
 22.38     12.19     13.43     12.27      2.80     12.63      2.01     12.79
  1.01     13.43       .56     14.21       .67     14.63      7.72     14.65
  1.68     15.09       .11     17.86       .00     21.00       .00     22.00
3   32
  1.21       .00      1.50      2.01      5.02      2.23      3.75      2.35
  2.40      2.60      1.50      3.49      2.26      3.56      1.93      4.07
  1.21      5.57      1.21      5.60     41.10      5.63     16.37      5.82
 16.09      5.90     12.53      6.01      7.60      6.49      4.26      7.30
  3.27      8.34      1.82     10.24      1.30     11.97     28.20     12.02
  8.62     12.19     30.09     12.27     12.69     12.63     43.90     12.79
 15.95     13.43      8.92     14.21      8.39     14.63     10.62     14.65
  8.19     15.09      4.94     17.86      2.57     21.00      2.57     22.00
4   32                                                  NH3
   .00       .00      2.40      2.01     31.43      2.23     20.96      2.35
  9.88      2.60      2.40      3.49      8.68      3.56      5.99      4.07
   .00      5.57       .00      5.60    270.64      5.63     28.14      5.82
 17.36      5.90     10.48      6.01      4.19      6.49      1.80      7.30
   .30      8.34       .00     10.24       .00     11.97    221.84     12.02
 59.88     12.19     35.93     12.27      7.48     12.63      5.39     12.79
  2.69     13.43      1.50     14.21      1.80     14.63     20.66     14.65
  4.49     15.09       .30     17.86       .00     21.00       .00     22.00
5   32                                                     NH3
   .00       .00       .31      2.01      4.13      2.23      2.75      2.35
  1.30      2.60       .31      3.49      1.14      3.56       .79      4.07
   .00      5.57       .00      5.60     35.54      5.63      3.70      5.82
  2.28      5.90      1.38      6.01       .55      6.49       .24      7.30
   .04      8.34       .00     10.24       .00     11.97     29.13     12.02
  7.86     12.19      4.72     12.27       .98     12.63       .71     12.79
   .35     13.43       .20     14.21       .24     14.63      2.71     14.65
   .59     15.09       .04     17.86       .00     21.00       .00     22.00
     4                                                  NO3
   1.0       1.0
2   32                                                  NO3
   .00       .00      3.07      2.01     40.28      2.23     26.85      2.35
 12.66      2.60      3.07      3.49     11.12      3.56      7.67      4.07
   .00      5.57       .00      5.60    346.79      5.63     36.06      5.82
 22.25      5.90     13.43      6.01      5.37      6.49      2.30      7.30
   .38      8.34       .00     10.24       .00     11.97    284.26     12.02
 76.72     12.19     46.03     12.27      9.59     12.63      6.91     12.79
  3.45     13.43      1.92     14.21      2.30     14.63     26.47     14.65
  5.75     15.09       .38     17.86       .00     21.00       .00     22.00
```

```
  3   32
  120.53       .00    121.52      2.01    133.59      2.23    129.24      2.35
124.63      2.60    121.52      3.49    124.14      3.56    123.02      4.07
120.53      5.57    120.53      5.60    274.85      5.63    196.69      5.82
197.21      5.90    181.13      6.01    158.25      6.49    163.42      7.30
162.57      8.34    135.84     10.24    129.60     11.97    223.09     12.02
160.96     12.19    275.58     12.27    220.65     12.63    384.91     12.79
257.02     13.43    224.33     14.21    225.40     14.63    232.95     14.65
231.36     15.09    213.81     17.86    193.74     21.00    193.74     22.00
4   32                                                  NO3
   .00       .00      8.21      2.01    107.78      2.23     71.85      2.35
 33.87      2.60      8.21      3.49     29.77      3.56     20.53      4.07
   .00      5.57       .00      5.60    927.89      5.63     96.48      5.82
 59.53      5.90     35.93      6.01     14.37      6.49      6.16      7.30
  1.03      8.34       .00     10.24       .00     11.97    760.59     12.02
205.29     12.19    123.17     12.27     25.66     12.63     18.48     12.79
  9.24     13.43      5.13     14.21      6.16     14.63     70.82     14.65
 15.40     15.09      1.03     17.86       .00     21.00       .00     22.00
5   32                                                        NO3
   .00       .00      1.08      2.01     14.15      2.23      9.43      2.35
  4.45      2.60      1.08      3.49      3.91      3.56      2.70      4.07
   .00      5.57       .00      5.60    121.84      5.63     12.67      5.82
  7.82      5.90      4.72      6.01      1.89      6.49       .81      7.30
   .13      8.34       .00     10.24       .00     11.97     99.87     12.02
 26.96     12.19     16.17     12.27      3.37     12.63      2.43     12.79
  1.21     13.43       .67     14.21       .81     14.63      9.30     14.65
  2.02     15.09       .13     17.86       .00     21.00       .00     22.00
     4                                                  PO4
   1.0       1.0
2   32                                                  PO4
   .00       .00      1.02      2.01     13.43      2.23      8.95      2.35
  4.22      2.60      1.02      3.49      3.71      3.56      2.56      4.07
   .00      5.57       .00      5.60    115.60      5.63     12.02      5.82
  7.42      5.90      4.48      6.01      1.79      6.49       .77      7.30
   .13      8.34       .00     10.24       .00     11.97     94.75     12.02
 25.57     12.19     15.34     12.27      3.20     12.63      2.30     12.79
  1.15     13.43       .64     14.21       .77     14.63      8.82     14.65
  1.92     15.09       .13     17.86       .00     21.00       .00     22.00
3   32
   .80       .00      1.14      2.01      5.16      2.23      3.71      2.35
  2.17      2.60      1.14      3.49      2.01      3.56      1.63      4.07
   .80      5.57       .80      5.60     42.36      5.63     11.42      5.82
 10.52      5.90      8.01      6.01      4.75      6.49      2.70      7.30
  2.04      8.34      1.17     10.24       .86     11.97     31.60     12.02
  9.20     12.19     19.82     12.27      7.93     12.63     25.63     12.79
  9.48     13.43      5.38     14.21      5.10     14.63      7.68     14.65
  5.18     15.09      3.03     17.86      1.65     21.00      1.65     22.00
```

```
  4   32                                                      PO4
     .00       .00      2.74      2.01     35.93      2.23     23.95      2.35
  11.29      2.60      2.74      3.49      9.92      3.56      6.84      4.07
    .00      5.57       .00      5.60    309.30      5.63     32.16      5.82
  19.84      5.90     11.98      6.01      4.79      6.49      2.05      7.30
    .34      8.34       .00     10.24       .00     11.97    253.53     12.02
  68.43     12.19     41.06     12.27      8.55     12.63      6.16     12.79
   3.08     13.43      1.71     14.21      2.05     14.63     23.61     14.65
   5.13     15.09       .34     17.86       .00     21.00       .00     22.00
5   32                                                              PO4
    .00       .00       .36      2.01      4.72      2.23      3.14      2.35
   1.48      2.60       .36      3.49      1.30      3.56       .90      4.07
    .00      5.57       .00      5.60     40.61      5.63      4.22      5.82
   2.61      5.90      1.57      6.01       .63      6.49       .27      7.30
    .04      8.34       .00     10.24       .00     11.97     33.29     12.02
   8.99     12.19      5.39     12.27      1.12     12.63       .81     12.79
    .40     13.43       .22     14.21       .27     14.63      3.10     14.65
    .67     15.09       .04     17.86       .00     21.00       .00     22.00
      4                                                CHLA
    1.0       1.0
2   32                                                 CHLA
    .00       .00       .51      2.01      6.71      2.23      4.48      2.35
   2.11      2.60       .51      3.49      1.85      3.56      1.28      4.07
    .00      5.57       .00      5.60     57.80      5.63      6.01      5.82
   3.71      5.90      2.24      6.01       .90      6.49       .38      7.30
    .06      8.34       .00     10.24       .00     11.97     47.38     12.02
  12.79     12.19      7.67     12.27      1.60     12.63      1.15     12.79
    .58     13.43       .32     14.21       .38     14.63      4.41     14.65
    .96     15.09       .06     17.86       .00     21.00       .00     22.00
3   32
   8.04       .00      8.20      2.01     10.21      2.23      9.49      2.35
   8.72      2.60      8.20      3.49      8.64      3.56      8.45      4.07
   8.04      5.57      8.04      5.60     37.32      5.63     27.18      5.82
  27.90      5.90     23.54      6.01     17.14      6.49     13.78      7.30
  12.72      8.34      9.59     10.24      8.64     11.97     24.09     12.02
  13.22     12.19     46.73     12.27     26.18     12.63     71.65     12.79
  32.41     13.43     22.57     14.21     21.98     14.63     23.20     14.65
  21.82     15.09     17.47     17.86     13.65     21.00     13.65     22.00
4   32                                                 CHLA
    .00       .00      1.37      2.01     17.96      2.23     11.98      2.35
   5.65      2.60      1.37      3.49      4.96      3.56      3.42      4.07
    .00      5.57       .00      5.60    154.65      5.63     16.08      5.82
   9.92      5.90      5.99      6.01      2.40      6.49      1.03      7.30
    .17      8.34       .00     10.24       .00     11.97    126.76     12.02
  34.21     12.19     20.53     12.27      4.28     12.63      3.08     12.79
   1.54     13.43       .86     14.21      1.03     14.63     11.80     14.65
   2.57     15.09       .17     17.86       .00     21.00       .00     22.00
```

```
      5   32                                                             CHLA
         .00       .00       .18      2.01      2.36      2.23      1.57      2.35
       .74      2.60       .18      3.49       .65      3.56       .45      4.07
       .00      5.57       .00      5.60     20.31      5.63      2.11      5.82
      1.30      5.90       .79      6.01       .31      6.49       .13      7.30
       .02      8.34       .00     10.24       .00     11.97     16.65     12.02
      4.49     12.19      2.70     12.27       .56     12.63       .40     12.79
       .20     13.43       .11     14.21       .13     14.63      1.55     14.65
       .34     15.09       .02     17.86       .00     21.00       .00     22.00
         4                                                  CBOD
       1.0       1.0
    2   32                                                  CBOD
       .00       .00     61.38      2.01    805.59      2.23    537.06      2.35
    253.19      2.60     61.38      3.49    222.50      3.56    153.45      4.07
       .00      5.57       .00      5.60   6935.78      5.63    721.20      5.82
    444.99      5.90    268.53      6.01    107.41      6.49     46.03      7.30
      7.67      8.34       .00     10.24       .00     11.97   5685.19     12.02
   1534.46     12.19    920.68     12.27    191.81     12.63    138.10     12.79
     69.05     13.43     38.36     14.21     46.03     14.63    529.39     14.65
    115.08     15.09      7.67     17.86       .00     21.00       .00     22.00
    3   32
     24.11       .00     44.01      2.01    285.38      2.23    198.29      2.35
    106.22      2.60     44.01      3.49     96.27      3.56     73.87      4.07
     24.11      5.57     24.11      5.60   2676.00      5.63    926.57      5.82
    895.74      5.90    682.99      6.01    392.27      6.49    190.15      7.30
    130.10      8.34     54.35     10.24     25.92     11.97   1870.02     12.02
    524.88     12.19   1716.42     12.27    673.06     12.63   2448.44     12.79
    844.75     13.43    441.07     14.21    409.78     14.63    563.09     14.65
    399.17     15.09    208.29     17.86     76.12     21.00     76.12     22.00
    4   32                                                  CBOD
       .00       .00    164.23      2.01   2155.51      2.23   1437.00      2.35
    677.45      2.60    164.23      3.49    595.33      3.56    410.57      4.07
       .00      5.57       .00      5.60  18557.89      5.63   1929.69      5.82
   1190.66      5.90    718.50      6.01    287.40      6.49    123.17      7.30
     20.53      8.34       .00     10.24       .00     11.97  15211.72     12.02
   4105.73     12.19   2463.44     12.27    513.22     12.63    369.52     12.79
    184.76     13.43    102.64     14.21    123.17     14.63   1416.48     14.65
    307.93     15.09     20.53     17.86       .00     21.00       .00     22.00
    5   32                                                      CBOD
       .00       .00     21.57      2.01    283.05      2.23    188.70      2.35
     88.96      2.60     21.57      3.49     78.17      3.56     53.91      4.07
       .00      5.57       .00      5.60   2436.89      5.63    253.39      5.82
    156.35      5.90     94.35      6.01     37.74      6.49     16.17      7.30
      2.70      8.34       .00     10.24       .00     11.97   1997.50     12.02
    539.14     12.19    323.48     12.27     67.39     12.63     48.52     12.79
     24.26     13.43     13.48     14.21     16.17     14.63    186.00     14.65
     40.44     15.09      2.70     17.86       .00     21.00       .00     22.00
```

```
           4                                                  DO
         1.0       1.0
    2   32                                                  DO
       .00       .00     46.03      2.01    604.20      2.23    402.80      2.35
    189.89      2.60     46.03      3.49    166.87      3.56    115.08      4.07
       .00      5.57       .00      5.60   5201.83      5.63    540.90      5.82
    333.75      5.90    201.40      6.01     80.56      6.49     34.53      7.30
      5.75      8.34       .00     10.24       .00     11.97   4263.89     12.02
   1150.85     12.19    690.51     12.27    143.86     12.63    103.58     12.79
     51.79     13.43     28.77     14.21     34.53     14.63    397.04     14.65
     86.31     15.09      5.75     17.86       .00     21.00       .00     22.00
    3   32
    482.11       .00    497.04      2.01    678.07      2.23    612.75      2.35
    543.70      2.60    497.04      3.49    536.23      3.56    519.44      4.07
    482.11      5.57    482.11      5.60   3102.31      5.63   2189.41      5.82
   2254.42      5.90   1861.57      6.01   1285.84      6.49    939.13      7.30
    836.49      8.34    596.16     10.24    518.40     11.97   1906.47     12.02
    917.57     12.19   3920.14     12.27   2019.17     12.63   6085.91     12.79
   2538.81     13.43   1650.07     14.21   1589.73     14.63   1699.52     14.65
   1559.87     15.09   1173.45     17.86    847.58     21.00    847.58     22.00
    4   32                                                  DO
       .00       .00    123.17      2.01   1616.63      2.23   1077.75      2.35
    508.08      2.60    123.17      3.49    446.50      3.56    307.93      4.07
       .00      5.57       .00      5.60  13918.42      5.63   1447.27      5.82
    893.00      5.90    538.88      6.01    215.55      6.49     92.38      7.30
     15.40      8.34       .00     10.24       .00     11.97  11408.79     12.02
   3079.30     12.19   1847.58     12.27    384.91     12.63    277.14     12.79
    138.57     13.43     76.98     14.21     92.38     14.63   1062.36     14.65
    230.95     15.09     15.40     17.86       .00     21.00       .00     22.00
    5   32                                                          DO
       .00       .00     16.17      2.01    212.28      2.23    141.52      2.35
     66.72      2.60     16.17      3.49     58.63      3.56     40.44      4.07
       .00      5.57       .00      5.60   1827.67      5.63    190.05      5.82
    117.26      5.90     70.76      6.01     28.30      6.49     12.13      7.30
      2.02      8.34       .00     10.24       .00     11.97   1498.12     12.02
    404.35     12.19    242.61     12.27     50.54     12.63     36.39     12.79
     18.20     13.43     10.11     14.21     12.13     14.63    139.50     14.65
     30.33     15.09      2.02     17.86       .00     21.00       .00     22.00
         4                                                  ON
       1.0       1.0
    2   32                                                  ON
       .00       .00     15.34      2.01    201.40      2.23    134.27      2.35
     63.30      2.60     15.34      3.49     55.62      3.56     38.36      4.07
       .00      5.57       .00      5.60   1733.94      5.63    180.30      5.82
    111.25      5.90     67.13      6.01     26.85      6.49     11.51      7.30
      1.92      8.34       .00     10.24       .00     11.97   1421.30     12.02
    383.62     12.19    230.17     12.27     47.95     12.63     34.53     12.79
     17.26     13.43      9.59     14.21     11.51     14.63    132.35     14.65
     28.77     15.09      1.92     17.86       .00     21.00       .00     22.00
```

```
      3   32
       14.87       .00     19.84      2.01     80.18      2.23     58.41      2.35
     35.39      2.60     19.84      3.49     32.91      3.56     27.31      4.07
     14.87      5.57     14.87      5.60    748.57      5.63    357.78      5.82
    360.35      5.90    279.95      6.01    165.54      6.49     83.96      7.30
     60.77      8.34     28.21     10.24     15.98     11.97    477.11     12.02
    141.20     12.19    682.69     12.27    281.62     12.63   1039.70     12.79
    362.35     13.43    192.58     14.21    178.99     14.63    216.72     14.65
    170.86     15.09     95.74     17.86     39.65     21.00     39.65     22.00
    4   32                                                  ON
       .00       .00     41.06      2.01    538.88      2.23    359.25      2.35
    169.36      2.60     41.06      3.49    148.83      3.56    102.64      4.07
       .00      5.57       .00      5.60   4639.47      5.63    482.42      5.82
    297.67      5.90    179.63      6.01     71.85      6.49     30.79      7.30
      5.13      8.34       .00     10.24       .00     11.97   3802.93     12.02
   1026.43     12.19    615.86     12.27    128.30     12.63     92.38     12.79
     46.19     13.43     25.66     14.21     30.79     14.63    354.12     14.65
     76.98     15.09      5.13     17.86       .00     21.00       .00     22.00
    5   32                                                            ON
       .00       .00      5.39      2.01     70.76      2.23     47.17      2.35
     22.24      2.60      5.39      3.49     19.54      3.56     13.48      4.07
       .00      5.57       .00      5.60    609.22      5.63     63.35      5.82
     39.09      5.90     23.59      6.01      9.43      6.49      4.04      7.30
       .67      8.34       .00     10.24       .00     11.97    499.37     12.02
    134.78     12.19     80.87     12.27     16.85     12.63     12.13     12.79
      6.07     13.43      3.37     14.21      4.04     14.63     46.50     14.65
     10.11     15.09       .67     17.86       .00     21.00       .00     22.00
         4                                                  OP
       1.0       1.0
    2   32                                                  OP
       .00       .00      4.09      2.01     53.71      2.23     35.80      2.35
     16.88      2.60      4.09      3.49     14.83      3.56     10.23      4.07
       .00      5.57       .00      5.60    462.39      5.63     48.08      5.82
     29.67      5.90     17.90      6.01      7.16      6.49      3.07      7.30
       .51      8.34       .00     10.24       .00     11.97    379.01     12.02
    102.30     12.19     61.38     12.27     12.79     12.63      9.21     12.79
      4.60     13.43      2.56     14.21      3.07     14.63     35.29     14.65
      7.67     15.09       .51     17.86       .00     21.00       .00     22.00
    3   32
       .40       .00      1.73      2.01     17.82      2.23     12.01      2.35
      5.88      2.60      1.73      3.49      5.21      3.56      3.72      4.07
       .40      5.57       .40      5.60    162.42      5.63     36.03      5.82
     31.82      5.90     23.34      6.01     12.70      6.49      5.85      7.30
      3.58      8.34      1.27     10.24       .43     11.97    123.36     12.02
     33.63     12.19     62.06     12.27     22.02     12.63     74.61     12.79
     25.66     13.43     13.18     14.21     12.32     14.63     22.67     14.65
     12.80     15.09      5.81     17.86      1.78     21.00      1.78     22.00
```

```
      4   32                                                  OP
           .00       .00     10.95      2.01    143.70      2.23     95.80      2.35
     45.16      2.60     10.95      3.49     39.69      3.56     27.37      4.07
       .00      5.57       .00      5.60   1237.19      5.63    128.65      5.82
     79.38      5.90     47.90      6.01     19.16      6.49      8.21      7.30
      1.37      8.34       .00     10.24       .00     11.97   1014.11     12.02
    273.72     12.19    164.23     12.27     34.21     12.63     24.63     12.79
     12.32     13.43      6.84     14.21      8.21     14.63     94.43     14.65
     20.53     15.09      1.37     17.86       .00     21.00       .00     22.00
    5   32                                                              OP
       .00       .00      1.44      2.01     18.87      2.23     12.58      2.35
      5.93      2.60      1.44      3.49      5.21      3.56      3.59      4.07
       .00      5.57       .00      5.60    162.46      5.63     16.89      5.82
     10.42      5.90      6.29      6.01      2.52      6.49      1.08      7.30
       .18      8.34       .00     10.24       .00     11.97    133.17     12.02
     35.94     12.19     21.57     12.27      4.49     12.63      3.23     12.79
      1.62     13.43       .90     14.21      1.08     14.63     12.40     14.65
      2.70     15.09       .18     17.86       .00     21.00       .00     22.00
         0                                              (NPS LOADS)
         7    +    *    +    *    +    *    +    *    +    *    G: PARAMETERS
TMPSG    3       1.0TMPFN    4       1.0 KESG    5       1.0 KEFN    6       1.0
 FNH4    7       1.0 FPO4    8       1.0  SOD    9       1.0
         1
TMPSG    3       1.0TMPFN    4       4.0 KESG    5       1.0 KEFN    6       5.0
 FNH4    7       1.0 FPO4    8       1.0  SOD    9       0.1
         2
TMPSG    3       1.0TMPFN    4       4.0 KESG    5       1.0 KEFN    6       4.0
 FNH4    7       1.0 FPO4    8       1.0  SOD    9       0.1
         3
TMPSG    3       1.0TMPFN    4       3.0 KESG    5       1.0 KEFN    6       3.0
 FNH4    7       1.0 FPO4    8       1.0  SOD    9       0.5
         4
TMPSG    3       1.0TMPFN    4       2.0 KESG    5       1.0 KEFN    6       2.0
 FNH4    7       1.0 FPO4    8       1.0  SOD    9       1.0
         5
TMPSG    3       1.0TMPFN    4       2.0 KESG    5       1.0 KEFN    6       2.0
 FNH4    7       2.0 FPO4    8       1.0  SOD    9       2.0
         6
TMPSG    3       1.0TMPFN    4       1.0 KESG    5       1.0 KEFN    6       1.
 FNH4    7       2.0 FPO4    8       1.0  SOD    9       4.0
    +    *    +    *    +    *    +    *    +    *    +    *    H: CONSTANTS
GLOBALS            0
NH3                1
nitrificat         3
    K1320C        11      0.15    K1320T        12      1.08
      KNIT        13       2.0
NO3                1
denitrif           3
     K140C        21      0.10     K140T        22      1.08
      KNO3        23      0.10
```

```
  PO4                0
  PHYT               4
growth             2
       K1C        41       3.5       K1T        42      1.08
light              3
    LGHTSW        43       1.0    PHIMAX        44      720.
       XKC        45     0.017
nutrients          6
     KMNG1        48     0.025     KMPG1        49     0.001
      NCRB        58      0.25      PCRB        57     0.025
      CCHL        46       50.    NUTLIM        54         1
death              4
      K1RC        50     0.125      K1RT        51     1.045
       K1D        52     0.044       FON        95      0.50
CBOD               1
deoxygenat         3
       KDC        71      0.40       KDT        72      1.05
      KBOD        75       0.4
DO                 1
ratio              1
      OCRB        81      2.67
ON                 1
mineralize         2
    K1013C        91     0.030    K1013T        92      1.08
OP                 1
mineralize         2
      K58C       100      0.22      K58T       101      1.08
        15                                                  I:TIME  FUNCTIONS
TEMP1    9    1                                                       basin
      22.5         0      23.2       6.5      24.3       9.5      23.9      10.5
      23.9      11.5      23.9      12.5      21.9      13.5      21.9      19.5
      22.5        22
TEMP2    9    2                                                        first
      21.2         0      22.4       6.5      24.6       9.5      24.6      10.5
      25.0      11.5      22.7      12.5      20.7      13.5      20.7      19.5
      22.1        22
TEMP3    9    3                                                        lamar
      21.2         0      21.8       6.5      23.6       9.5      23.8      10.5
      24.0      11.5      23.0      12.5      20.6      13.5      20.6      19.5
      21.6        22
TEMP4    9    4                                                        redbud
      21.0         0      21.7       6.5      23.1       9.5      22.7      10.5
      22.8      11.5      22.9      12.5      20.5      13.5      20.5      19.5
      21.4        22
ITOT    15    5
      530.         0      440.         1      440.         5      476.         7
      467.        11      440.        12      467.        13      440.        14
      467.        15      521.        16      467.        17      458.        18
      503.        19      440.        20      440.        22
```

```
     F     3    6
        .482         0      .453        23      .429        47
WIND    13    7
       1.5         0       1.5         3       2.0         4       1.0         6
       1.9         8       1.0         9       1.4        11       2.8        12
       2.3        13       0.8        14       0.7        17       1.6        18
       3.0        22
 KE1     9    8                                                      Basin
      1.06         0      1.31         6      0.74         9      1.06        10
      1.13        11      1.13        12      2.13        13      1.00        19
      0.85        22
 KE2     9    9                                                      First
      1.70         0      5.00         6      0.85         9      1.55        10
      1.70        11      2.13        12      5.00        13      1.13        19
      1.31        22
 KE3     9   10                                                      Lamar
      1.06         0      1.42         6      1.31         9      1.70        10
      1.89        11      2.13        12      1.42        13      0.43        19
      0.81        22
 KE4     9   11                                                      MoPac
      1.13         0      4.25         6      1.42         9      0.94        10
      0.85        11      1.31        12      4.25        13      1.13        19
      0.85        22
 KE5     9   12                                                      Redbud
      1.42         0      1.36         6      1.13         9      0.71        10
      0.77        11      1.06        12      1.36        13      0.55        19
      0.77        22
TFNH4   10   13
      1.00         0      1.00        26      1.00        30      1.00        33
      1.00        57      1.00        83      0.25       114      0.10       142
      0.10       163      0.10       180
TFPO4   10   14
      1.00         0      1.00        26      1.00        30      1.00        33
      1.00        57      1.00        83      0.20       114      0.00       142
      0.00       163      0.00       180
Airtm    2   21
      1.00         0      1.00        26
NH3                                         3  0.0    1.0E08    J:INITIAL CONC.
   1:     0.075       1.0   2:     0.095       1.0  3:      0.08   1.0
   4:     0.115       1.0   5:     0.10        1.0  6:      0.09   1.0
NO3                                         3  0.0    1.0E08
   1:      0.38       1.0   2:      0.30       1.0  3:       0.46  1.0
   4:      0.30       1.0   5:      0.30       1.0  6:       0.30  1.0
PO4                                         3  0.0    1.0E08
   1:   0.045         1.0   2:   0.035         1.0  3:    0.058    1.0
   4:   0.032         1.0   5:   0.036         1.0  6:    0.038    1.0
PHYT                                        4 2.69    1.0E08
   1:      0.80       0.0   2:      0.30       0.0  3:       0.30  0.0
   4:      0.20       0.0   5:      0.30       0.0  6:       0.40  0.0
```

```
  CBOD                                        3  0.0    1.0E08
     1:   0.50          1.0   2:   0.50          1.0  3:    0.50     1.0
   4:   0.50          1.0   5:   0.50          1.0  6:    0.50     1.0
DO                                          3  0.0    1.0E08
   1:       4.8       1.0   2:       5.3       1.0  3:    5.5      1.0
   4:       5.1       1.0   5:       5.1       1.0  6:    5.1      1.0
ON                                          3  0.0    1.0E08
   1:   0.40          1.0   2:   0.50          1.0  3:    0.42     1.0
   4:   0.35          1.0   5:   0.35          1.0  6:    0.54     1.0
OP                                          3  0.0    1.0E08
   1:       .003      1.0   2:     .003        1.0  3:      .050   1.0
   4:       .015      1.0   5:      .020       1.0  6:      .025   1.0
```

EUTRO4 Input File of the 1995 Annual Simulation

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TOWN LAKE  C:\wasp4\EMON95.inp .5*PO4 LA BD, .75*OP,PO4 load, g=3.0 I35 T=Ba
EUTROPHICATION PROBLEM - FLOW FROM DYNHYD - doctmat.inp  ext*2 at I35, Basin
NSEG NSYS ICRD MFLG IDMP NSLN INTY ADFC   DD HHMM       A:MODEL OPTIONS
   6   08    0    1    3    0    0  0.0    1 0000
   1    2    3    4    5    6
   1
  .041667      364.
   1
     1.0      364.
   0    0    0    0    0    0    0    0
   1    0    +    *    +    *    +    *    +    *    +    *    B:EXCHANGES
   1     1.000       1.0       1.0            (surface water)
   5
     432.     1609.    1    2
     585.     1609.    2    3
     528.     1609.    3    4
     996.     1609.    4    5
    1430.     1609.    5    6
   2
 1.00E-04        0.  1.00E-04      365.
   0    0    0    0    0    0    0    0
   2    0     330.0    +    *    +    *    +    *    +    *    C: VOLUMES
   1.0000       1.0
        1         7         1   608063.        1.       0.4        1.       0.6
        2         8         1   864381.        1.       0.4        1.       0.6
        3         9         1   706304.        1.       0.4        1.       0.6
        4        10         1   978810.        1.       0.4        1.       0.6
        5        11         1  1661957.        1.       0.4        1.       0.6
        6        12         1  3568627.        1.       0.4        1.       0.6
   3    1 DMON95.HYD                        +    *    +    *    D: FLOWS
   0    0    0    0    0    0    0    0
        2                                                 E:BOUNDARIES
      1.0       1.0
   1   14                                         **** System 1  - NH3 mg/L
     .023        0.      .023       15.      .035       45.      .024      75.
     .030      105.      .027      135.      .023      165.      .024     195.
     .025      225.      .025      255.      .028      285.      .030     315.
     .020      345.      .020      365.
   6   14
     .025        0.      .025       15.      .027       45.      .053      75.
     .067      105.      .056      135.      .045      165.      .042     195.
     .040      225.      .023      255.      .032      285.      .032     315.
     .030      345.      .030      365.
        2                                         **** System 2  - NO3 mg/L
      1.0       1.0
   1   14
     0.44        0.      0.44       15.      0.29       45.      0.21      75.
     0.14      105.      0.15      135.      0.16      165.      0.12     195.
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   0.08      225.      0.04      255.      0.08      285.      0.11    315.
   0.14      345.      0.14      365.
6   14
  0.25        0.      0.25       15.      0.41       45.      0.32     75.
  0.23      105.      0.14      135.      0.14      165.      0.15    195.
  0.15      225.      0.14      255.      0.17      285.      0.26    315.
  0.18      345.      0.18      365.
     2                                            **** System 3 - OPO4 mg/L
   0.5       1.0
1   14
  .015        0.      .015       15.     0.012       45.      .018    75.
  0.01      105.      .013      135.      .017      165.      .018    195.
  .019      225.      .020      255.      .010      285.      .016    315.
  0.02      345.      0.02      365.
6   14
  0.02        0.      0.02       15.      0.02       45.      0.02     75.
  .027      105.      .023      135.      .018      165.      .019    195.
  .020      225.      .028      255.      .019      285.      .025    315.
  0.02      345.      0.02      365.
     2                                            **** System 4  CHLa ug/L
   0.5       1.0
1   14
   0.6        0.       0.6       15.       1.5       45.       2.4     75.
   2.6      105.       3.4      135.       4.3      165.       3.4    195.
   2.6      225.       1.7      255.       1.8      285.       1.7    315.
   1.1      345.       1.1      365.
6   14
   7.0        0.       7.0       15.       7.3       45.      15.0     75.
  27.9      105.      17.9      135.       7.2      165.       5.5    195.
   3.7      225.       4.7      255.       3.6      285.       9.9    315.
   2.4      345.       2.4      365.
     2                                            **** System 5  - BOD mg/L
   1.0       1.0
1   14
  0.50        0.      0.50       15.      0.50       45.      0.50     75.
  0.50      105.      0.50      135.      0.50      165.      0.50    195.
  0.50      225.      0.50      255.      0.50      285.      0.50    315.
  0.50      345.      0.50      365.
6   14
  0.50        0.      0.50       15.      0.50       45.      0.50     75.
  0.50      105.      0.50      135.      0.50      165.      0.50    195.
  0.50      225.      0.50      255.      0.50      285.      0.50    315.
  0.50      345.      0.50      365.
     2                                            **** System 6 - DO  mg/L
   1.0       1.0
1   14
   9.3        0.       9.3       15.       9.4       45.       8.2     75.
   8.1      105.       8.0      135.       7.9      165.       6.9    195.
   6.1      225.       5.2      255.       7.3      285.       7.6    315.
   9.2      345.       9.2      365.
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  6   14
     8.5        0.       8.5       15.       9.0       45.       7.4     75.
   7.2      105.       7.0      135.       6.9      165.       6.4    195.
   5.9      225.       5.8      255.       7.1      285.       7.4    315.
   8.4      345.       8.4      365.
     2                                            **** System 7  - ON  mg/L
   1.0       1.0
1   14
  0.14        0.      0.14       15.      0.31       45.      0.20     75.
  0.28      105.      0.18      135.      0.08      165.      0.11    195.
  0.15      225.      0.18      255.      0.16      285.      0.13    315.
  0.21      345.      0.30      365.
6   14
  0.27        0.      0.27       15.      0.34       45.      0.24     75.
  0.27      105.      0.18      135.      0.10      165.      0.17    195.
  0.23      225.      0.32      255.      0.23      285.      0.21    315.
  0.30      345.      0.30      365.
     2                                            **** System 8 - OP  mg/L
   1.0       1.0
1   14
  .002        0.      .002       15.      .002       45.      .002     75.
  .002      105.      .002      135.      0.09      165.      .002    195.
  .002      225.      .002      255.      .003      285.      .021    315.
  .015      345.      .015      365.
6   14
  .013        0.      .013       15.      .010       45.      .010     75.
  .002      105.      .002      135.      .002      165.      .002    195.
  .002      225.      .002      255.      .016      285.      .073    315.
  .020      345.      .020      365.
     5                                                F:  LOADS
   1.0       1.0
2   14         Johnson, Eanes, 2/3 TL Adj = Shoal*.74            NH3
  2.32         0      2.32        15      1.25        45      4.91      75
  2.88       105     12.27       135      4.94       165      0.46     195
  2.91       225      2.93       255      0.07       285      1.28     315
  0.02       345      0.02       365
3   14         BC Urban = Shoal*0.24, BC at 360                  NH3
  6.93         0      6.93        15      1.73        45      6.71      75
  7.80       105     27.52       135     42.38       165      1.03     195
  0.95       225      0.95       255      0.15       285      0.64     315
  0.01       345      0.01       365
3   14          Barton Springs                                   NH3
  1.44         0      1.44        15      1.28        45      2.49      75
  3.03       105      3.18       135      3.64       165      3.31     195
  2.94       225      2.51       255      1.86       285      1.84     315
  1.43       345      1.43       365
4   14         Shoal, Waller, EW Bouldin, 1/3 TL Adj=Sh*1.98     NH3
  6.21         0      6.21        15      3.35        45     13.14      75
  7.70       105     32.84       135     13.21       165      1.23     195
  7.78       225      7.84       255      0.20       285      3.43     315
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   0.06       345      0.06       365
 5   14          Shoal * 0.26 - Blunn, Harpers                     NH3
  0.81         0      0.81        15      0.44        45      1.73      75
  1.01       105      4.31       135      1.74       165      0.16     195
  1.02       225      1.03       255      0.03       285      0.45     315
  0.01       345      0.01       365
     5                                                  NO3
   1.0       1.0
2   14         Johnson, Eanes, 2/3 TL Adj = Shoal*.74            NO3
  7.95         0      7.95        15      4.29        45     16.84      75
  9.87       105     42.08       135     16.93       165      1.58     195
  9.97       225     10.05       255      0.25       285      4.40     315
  0.07       345      0.07       365
3   14         BC Urban = Shoal*0.24, BC at 360                  NO3
 32.61         0     32.61        15      7.81        45     30.31      75
 36.56       105    127.97       135    203.57       165      4.78     195
  3.25       225      3.27       255      0.70       285      2.52     315
  0.02       345      0.02       365
3   14          Barton Springs                                   NO3
144.44         0    144.44        15    127.67        45    249.10      75
303.16       105    318.13       135    364.09       165    331.27     195
293.74       225    251.41       255    186.00       285    183.51     315
143.02       345    143.02       365
4   14         Shoal, Waller, EW Bouldin, 1/3 TL Adj=Sh*1.98     NO3
 21.28         0     21.28        15     11.47        45     45.06      75
 26.41       105    112.60       135     45.30       165      4.22     195
 26.68       225     26.89       255      0.68       285     11.78     315
  0.19       345      0.19       365
5   14         Shoal * 0.26 - Blunn, Harpers                     NO3
  2.79         0      2.79        15      1.51        45      5.92      75
  3.47       105     14.79       135      5.95       165      0.55     195
  3.50       225      3.53       255      0.09       285      1.55     315
  0.02       345      0.02       365
     5                                                  PO4
  0.75      1.0
2   14         Johnson, Eanes, 2/3 TL Adj = Shoal*.74            PO4
  2.65         0      2.65        15      1.43        45      5.61      75
  3.29       105     14.03       135      5.64       165      0.53     195
  3.32       225      3.35       255      0.08       285      1.47     315
  0.02       345      0.02       365
3   14         BC Urban = Shoal*0.24, BC at 360                  PO4
  4.39         0      4.39        15      1.22        45      4.74      75
  4.99       105     18.00       135     25.13       165      0.67     195
  1.08       225      1.09       255      0.10       285      0.60     315
  0.01       345      0.01       365
3   14          Barton Springs                                   PO4
  0.96         0      0.96        15      0.85        45      1.66      75
  2.02       105      2.12       135      2.43       165      2.21     195
  1.96       225      1.68       255      1.24       285      1.22     315
  0.95       345      0.95       365
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  4   14         Shoal, Waller, EW Bouldin, 1/3 TL Adj=Sh*1.98     PO4
    7.09         0      7.09        15      3.82        45     15.02      75
  8.80       105     37.53       135     15.10       165      1.41     195
  8.89       225      8.96       255      0.23       285      3.93     315
  0.06       345      0.06       365
5   14         Shoal * 0.26 - Blunn, Harpers                    PO4
  0.93         0      0.93        15      0.50        45      1.97      75
  1.16       105      4.93       135      1.98       165      0.18     195
  1.17       225      1.18       255      0.03       285      0.52     315
  0.01       345      0.01       365
     5                                               CHLA
   0.0       1.0
2   14         Johnson, Eanes, 2/3 TL Adj = Shoal*.74           CHLA
  1.33         0      1.33        15      0.71        45      2.81      75
  1.65       105      7.01       135      2.82       165      0.26     195
  1.66       225      1.68       255      0.04       285      0.73     315
  0.01       345      0.01       365
3   14         BC Urban = Shoal*0.24, BC at 360                 CHLA
  9.26         0      9.26        15      2.12        45      8.22      75
 10.35       105     35.90       135     59.17       165      1.34     195
  0.54       225      0.55       255      0.20       285      0.56     315
  0.00       345      0.00       365
3   14          Barton Springs                                  CHLA
  9.63         0      9.63        15      8.51        45     16.61      75
 20.21       105     21.21       135     24.27       165     22.08     195
 19.58       225     16.76       255     12.40       285     12.23     315
  9.53       345      9.53       365
4   14         Shoal, Waller, EW Bouldin, 1/3 TL Adj=Sh*1.98     CHLA
  3.55         0      3.55        15      1.91        45      7.51      75
  4.40       105     18.77       135      7.55       165      0.70     195
  4.45       225      4.48       255      0.11       285      1.96     315
  0.03       345      0.03       365
5   14         Shoal * 0.26 - Blunn, Harpers                    CHLA
  0.47         0      0.47        15      0.25        45      0.99      75
  0.58       105      2.46       135      0.99       165      0.09     195
  0.58       225      0.59       255      0.01       285      0.26     315
  0.00       345      0.00       365
     5                                               CBOD
   1.0       1.0
2   14         Johnson, Eanes, 2/3 TL Adj = Shoal*.74           CBOD
159.04         0    159.04        15     85.76        45    336.83      75
197.43       105    841.62       135    338.62       165     31.58     195
199.44       225    201.01       255      5.05       285     88.02     315
  1.42       345      1.42       365
3   14         BC Urban = Shoal*0.24, BC at 360                 CBOD
404.87         0    404.87        15    103.35        45    401.60      75
456.51       105   1617.90       135   2440.20       165     60.40     195
 64.83       225     65.34       255      8.90       285     41.43     315
  0.46       345      0.46       365
3   14          Barton Springs                                  CBOD
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    28.89         0     28.89        15     25.53        45     49.82      75
    60.63       105     63.63       135     72.82       165     66.25     195
  58.75       225     50.28       255     37.20       285     36.70     315
  28.60       345     28.60       365
 4   14         Shoal, Waller, EW Bouldin, 1/3 TL Adj=Sh*1.98     CBOD
 425.54         0    425.54        15    229.45        45    901.24      75
 528.25       105   2251.91       135    906.03       165     84.49     195
 533.62       225    537.83       255     13.50       285    235.51     315
   3.79       345      3.79       365
 5   14         Shoal * 0.26 - Blunn, Harpers                     CBOD
  55.88         0     55.88        15     30.13        45    118.34      75
  69.37       105    295.71       135    118.97       165     11.09     195
  70.07       225     70.62       255      1.77       285     30.93     315
   0.50       345      0.50       365
      5                                                  DO
    1.0       1.0
 2   14         Johnson, Eanes, 2/3 TL Adj = Shoal*.74            DO
 119.28         0    119.28        15     64.32        45    252.62      75
 148.07       105    631.22       135    253.96       165     23.68     195
 149.58       225    150.75       255      3.78       285     66.02     315
   1.06       345      1.06       365
 3   14         BC Urban = Shoal*0.24, BC at 360                  DO
 833.60         0    833.60        15    190.82        45    739.74      75
 931.09       105   3230.85       135   5325.72       165    120.53     195
  48.85       225     49.23       255     17.57       285     50.41     315
   0.34       345      0.34       365
 3   14          Barton Springs                                   DO
 577.77         0    577.77        15    510.69        45    996.42      75
1212.66       105   1272.52       135   1456.36       165   1325.09     195
1174.96       225   1005.65       255    744.00       285    734.05     315
 572.09       345    572.09       365
 4   14         Shoal, Waller, EW Bouldin, 1/3 TL Adj=Sh*1.98     DO
 319.16         0    319.16        15    172.09        45    675.93      75
 396.19       105   1688.93       135    679.52       165     63.36     195
 400.22       225    403.37       255     10.13       285    176.64     315
   2.84       345      2.84       365
 5   14         Shoal * 0.26 - Blunn, Harpers                           .
  41.91         0     41.91        15     22.60        45     88.76      75
  52.02       105    221.78       135     89.23       165      8.32     195
  52.55       225     52.97       255      1.33       285     23.19     315
   0.37       345      0.37       365
      5                                                  ON
    1.0       1.0
 2   14         Johnson, Eanes, 2/3 TL Adj = Shoal*.74            ON
  39.76         0     39.76        15     21.44        45     84.21      75
  49.36       105    210.41       135     84.65       165      7.89     195
  49.86       225     50.25       255      1.26       285     22.01     315
   0.35       345      0.35       365
 3   14         BC Urban = Shoal*0.24, BC at 360                  ON
 163.04         0    163.04        15     39.06        45    151.56      75
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      182.81       105    639.84       135   1017.87       165     23.88     195
       16.23       225     16.36       255      3.50       285     12.61     315
      0.11       345      0.11       365
    3   14          Barton Springs                                   ON
     17.81         0     17.81        15     15.75        45     30.72      75
     37.39       105     39.24       135     44.90       165     40.86     195
     36.23       225     31.01       255     22.94       285     22.63     315
     17.64       345     17.64       365
    4   14         Shoal, Waller, EW Bouldin, 1/3 TL Adj=Sh*1.98     ON
    106.39         0    106.39        15     57.36        45    225.31      75
    132.06       105    562.98       135    226.51       165     21.12     195
    133.41       225    134.46       255      3.38       285     58.88     315
      0.95       345      0.95       365
    5   14         Shoal * 0.26 - Blunn, Harpers                     ON
     13.97         0     13.97        15      7.53        45     29.59      75
     17.34       105     73.93       135     29.74       165      2.77     195
     17.52       225     17.66       255      0.44       285      7.73     315
      0.12       345      0.12       365
         5                                                  OP
      0.75       1.0
    2   14         Johnson, Eanes, 2/3 TL Adj = Shoal*.74            OP
     10.60         0     10.60        15      5.72        45     22.46      75
     13.16       105     56.11       135     22.57       165      2.11     195
     13.30       225     13.40       255      0.34       285      5.87     315
      0.09       345      0.09       365
    3   14         BC Urban = Shoal*0.24, BC at 360                  OP
     14.04         0     14.04        15      4.12        45     16.05      75
     16.04       105     58.55       135     77.23       165      2.19     195
      4.32       225      4.35       255      0.33       285      2.29     315
      0.03       345      0.03       365
    3   14          Barton Springs                                   OP
      0.48         0      0.48        15      0.43        45      0.83      75
      1.01       105      1.06       135      1.21       165      1.10     195
      0.98       225      0.84       255      0.62       285      0.61     315
      0.48       345      0.48       365
    4   14         Shoal, Waller, EW Bouldin, 1/3 TL Adj=Sh*1.98     OP
     28.37         0     28.37        15     15.30        45     60.08      75
     35.22       105    150.13       135     60.40       165      5.63     195
     35.57       225     35.86       255      0.90       285     15.70     315
      0.25       345      0.25       365
    5   14         Shoal * 0.26 - Blunn, Harpers                     OP
      3.73         0      3.73        15      2.01        45      7.89      75
      4.62       105     19.71       135      7.93       165      0.74     195
      4.67       225      4.71       255      0.12       285      2.06     315
      0.03       345      0.03       365
         0                                              (NPS LOADS)
         7    +    *    +    *    +    *    +    *    +    *    G: PARAMETERS
TMPSG    3       1.0TMPFN    4       1.0 KESG    5       1.0 KEFN    6       1.0
 FNH4    7       1.0 FPO4    8       1.0  SOD    9       1.0
         1
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  TMPSG    3       1.0TMPFN    4       4.0 KESG    5       1.0 KEFN    6       5.0
   FNH4    7       1.0 FPO4    8       1.0  SOD    9       0.1
         2
TMPSG    3       1.0TMPFN    4       4.0 KESG    5       1.0 KEFN    6       4.0
 FNH4    7       1.0 FPO4    8       1.0  SOD    9       0.1
         3
TMPSG    3       1.0TMPFN    4       3.0 KESG    5       1.0 KEFN    6       3.0
 FNH4    7       1.0 FPO4    8       1.0  SOD    9       0.5
         4
TMPSG    3       1.0TMPFN    4       2.0 KESG    5       1.0 KEFN    6       2.0
 FNH4    7       1.0 FPO4    8       1.0  SOD    9       1.0
         5
TMPSG    3       1.0TMPFN    4       2.0 KESG    5       2.0 KEFN    6       1.0
 FNH4    7       2.0 FPO4    8       1.0  SOD    9       2.0
         6
TMPSG    3       1.0TMPFN    4       1.0 KESG    5       2.0 KEFN    6       1.
 FNH4    7       2.0 FPO4    8       1.0  SOD    9       4.0
    +    *    +    *    +    *    +    *    +    *    +    *    H: CONSTANTS
GLOBALS            0
NH3                1
nitrificat         3
    K1320C        11      0.15    K1320T        12      1.08
      KNIT        13       2.0
NO3                1
denitrif           3
     K140C        21      0.10     K140T        22      1.08
      KNO3        23      0.10
PO4                0
PHYT               4
growth             2
       K1C        41       3.0       K1T        42      1.08
light              3
    LGHTSW        43       1.0    PHIMAX        44      720.
       XKC        45     0.017
nutrients          6
     KMNG1        48     0.025     KMPG1        49     0.001
      NCRB        58      0.25      PCRB        57     0.025
      CCHL        46       50.    NUTLIM        54         1
death              4
      K1RC        50     0.125      K1RT        51     1.045
       K1D        52     0.044       FON        95      0.50
CBOD               1
deoxygenat         3
       KDC        71      0.40       KDT        72      1.05
      KBOD        75       0.4
DO                 1
ratio              1
      OCRB        81      2.67
ON                 1
mineralize         2
```

```
      K1013C        91     0.030    K1013T        92      1.08
  OP                 1
mineralize         2
      K58C       100      0.22      K58T       101      1.08
        15                                                  I:TIME  FUNCTIONS
TEMP1   14    1                                                       basin
      14.9        0.      14.9       15.      15.8       45.      19.9       75.
      21.0      105.      22.1      135.      23.2      165.      25.3      195.
      27.5      225.      26.4      255.      23.6      285.      19.8      315.
      16.1      345.      16.1      365.
TEMP2   14    2                                                        first
      15.1        0.      15.1       15.      15.1       45.      21.2       75.
      22.1      105.      23.0      135.      24.0      165.      25.2      195.
      26.5      225.      25.3      255.      22.7      285.      18.3      315.
      15.3      345.      15.3      365.
TEMP3   14    3                                                        lamar
      14.9        0.      14.9       15.      15.3       45.      19.7       75.
      20.9      105.      22.1      135.      23.3      165.      24.4      195.
      25.5      225.      24.2      255.      21.6      285.      18.4      315.
      15.1      345.      15.1      365.
TEMP4   14    4                                                        redbud
      15.3        0.      15.3       15.      14.5       45.      19.0       75.
      20.1      105.      21.2      135.      22.3      165.      23.8      195.
      25.0      225.      23.7      255.      22.0      285.      18.6      315.
      15.0      345.      15.0      365.
ITOT    14    5
     382.0        0.     382.0       15.     445.0       45.     518.0       75.
     644.0      105.     642.0      135.     672.0      165.     707.0      195.
     681.0      225.     579.0      255.     489.0      285.     404.0      315.
     354.0      345.     354.0      365.
   F    14    6
      0.44        0.      0.44       15.      0.47       45.      0.50       75.
      0.54      105.      0.57      135.      0.59      165.      0.58      195.
      0.55      225.      0.52      255.      0.48      285.      0.45      315.
      0.43      345.      0.43      365.
WIND    14    7
       3.8        0.       3.8       15.       3.6       45.       4.5       75.
       3.9      105.       3.8      135.       3.4      165.       3.1      195.
       2.3      225.       2.5      255.       3.1      285.       3.5      315.
       3.7      345.       3.7      365.
 KE1    14    8                                                     Basin
      0.63        0.      0.63       15.      0.77       45.      0.89       75.
      1.00      105.      1.15      135.      1.31      165.      0.91      195.
      0.52      225.      0.71      255.      0.63      285.      0.85      315.
      0.81      345.      0.81      365.
 KE2    14    9                                                     First
      0.71        0.      0.71       15.      0.74       45.      1.00       75.
      1.13      105.      0.85      135.      0.57      165.      0.66      195.
      0.73      225.      0.81      255.      0.46      285.      0.74      315.
      0.65      345.      0.65      365.
```

```
   KE3    14   10                                                      Lamar
        0.53        0.      0.53       15.      0.44       45.      0.40       75.
      0.57      105.      0.56      135.      0.55      165.      0.62      195.
      0.69      225.      0.77      255.      0.53      285.      0.68      315.
      0.39      345.      0.39      365.
 KE4    14   11                                                      MoPac
      0.46        0.      0.46       15.      0.44       45.      0.43       75.
      0.68      105.      0.81      135.      0.94      165.      0.83      195.
      0.72      225.      0.61      255.      0.71      285.      0.57      315.
      0.47      345.      0.47      365.
 KE5    14   12                                                      Redbud
      0.34        0.      0.34       15.      0.49       45.      0.36       75.
      0.74      105.      0.80      135.      0.85      165.      0.91      195.
      0.52      225.      0.71      255.      0.63      285.      0.85      315.
      0.81      345.      0.81      365.
TFNH4   10   13
      1.00         0      1.00        26      1.00        30      1.00        33
      1.00        57      1.00        83      1.00       114      1.00       142
      0.10       163      1.00       365
TFPO4   10   14
      1.00         0      1.00        26      1.00        30      1.00        33
      1.00        57      1.00        83      1.00       114      1.00       142
      1.00       163      1.00       365
Airtm    2   21
      1.00         0      1.00       365
NH3                                         3  0.0    1.0E08    J:INITIAL CONC.
   1:     0.023       1.0   2:     0.025       1.0  3:     0.032   1.0
   4:     0.025       1.0   5:     0.025       1.0  6:      .025   1.0
NO3                                         3  0.0    1.0E08
   1:      0.44       1.0   2:      0.43       1.0  3:       0.45  1.0
   4:      0.46       1.0   5:      0.35       1.0  6:       0.25  1.0
PO4                                         3  0.0    1.0E08
   1:   0.020         1.0   2:   0.023         1.0  3:    0.020    1.0
   4:   0.023         1.0   5:   0.023         1.0  6:    0.020    1.0
PHYT                                        4 2.69    1.0E08
   1:   0.60          0.0   2:   2.00          0.0  3:    1.80     0.0
   4:   2.00          0.0   5:   4.00          0.0  6:    7.00     0.0
CBOD                                        3  0.0    1.0E08
   1:      0.50       1.0   2:      0.50       1.0  3:       0.50  1.0
   4:      0.50       1.0   5:      0.50       1.0  6:       0.50  1.0
DO                                          3  0.0    1.0E08
   1:       9.3       1.0   2:       9.4       1.0  3:    9.3      1.0
   4:       9.4       1.0   5:       9.0       1.0  6:    8.5      1.0
ON                                          3  0.0    1.0E08
   1:   0.14          1.0   2:   0.17          1.0  3:    0.16     1.0
   4:   0.20          1.0   5:   0.24          1.0  6:    0.27     1.0
OP                                          3  0.0    1.0E08
   1:       .002      1.0   2:     .013        1.0  3:      .008   1.0
   4:       .013      1.0   5:     .013        1.0  6:      .013   1.0
```