# LAKESIDE LAKE TMDL
# Nutrients & Associated Parameters

**Arizona Department of Environmental Quality**
**with PBS&J**

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# Table of Contents

1.0 INTRODUCTION

1.1 Description of TMDL Process ..... 1
1.2 Water Quality Standards, 305(b), 303(d) and Impairment ..... 2

2.0 PROJECT BACKGROUND

2.1 Background; 303d Status and Problem Statement ..... 33
2.2 Summary of Lakeside Lake TMDL Goals ..... 5

3.0 LAKE AND WATERSHED OVERVIEW

3.1 Geography ..... 6
3.2 Lake Morphology and Operations ..... 7
3.3 Climate ..... 8
3.4 Land Use ..... 9

4.0 SOURCE WATER QUALITY

4.1 Source Water and Lake Productivity ..... 9
4.2 Reclaimed Water Used in Lakeside Lake ..... 11
4.2.1 Delivery System ..... 11
4.2.2 Water Quality ..... 12
4.3 Storm Water Runoff ..... 15

5.0 LAKE WATER QUALITY: 1998 – 2003

5.1 1998 Data; Observations from 2002 Load Analysis Study ..... 17
5.1.1 Algae (Phytoplankton) ..... 18
5.1.2 Nitrogen ..... 19
5.1.3 Phosphorus ..... 19
5.1.4 Dissolved Oxygen ..... 20
5.1.5 pH ..... 20
5.2 2002-2003 Data; Comparison with 1998 Data for TMDL Analysis ..... 22
5.2.1 Post Aerator Installation ..... 22
5.3 2003 Reclaimed Water Quality Data ..... 29

6.0 MODEL SELECTION, CALIBRATION & SENSITIVITY ANALYSIS

6.1 Model Selection ..... 30
6.2 Model Configuration ..... 30
6.3 Model Calibration ..... 31
6.4 Sensitivity Analysis ..... 31

7.0 MODELING RESULTS

7.1 1998 Baseline Conditions .......... 32
7.2 2002-2003 Data Input for the TMDL Analysis .......... 32
7.3 Comparison Between Measurements and Modeled Results .......... 33
7.4 Evaluation .......... 34

8.0 ORIGINAL 2002 LOAD ANALYSIS

8.1 Alternatives Modeled .......... 35
8.2 Analysis Summary .......... 38
8.3 Review of Initial Test Remedy .......... 38

9.0 UPDATED 2004 LOAD ANALYSIS AND TMDL

9.1 Nutrient Reduction Scenario Evaluations .......... 40
9.1.1 Baseline .......... 40
9.1.2 Management Alternatives .......... 40
9.2 Updated Model Results and Evaluation .......... 43
9.3 Linkage Analysis & Numeric Targets Revisited .......... 44
9.4 TMDL Calculations .......... 45
9.4.1 Phosphorus Loading .......... 46
9.4.2 TMDL for Ortho-phosphorus with MOS .......... 48
9.4.3 Targets for Nitrate, ammonia, Chlorophyll-a, DO, and pH .......... 49

10.0 STAKHOLDER PARTICIPATION

10.1 Lakeside Lake Task Force .......... 51

11.0 TMDL IMPLEMENTATION OVERVIEW

11.1 2 001 Lake Management Manual (LMM) .......... 51
11.2 Initial Load Analysis .......... 52
11.1.1 "Test Period" for aeration remedy .......... 52
11.1.2 Results of the Test Period .......... 52
11.3 TMDL .......... 52
11.2.1 Phosphorus Control Using Alum .......... 53
11.2.2 AZPDES Permit for Discharge of Reclaimed Water .......... 53
11.1.3 Monitoring Plan .......... 53

12. REFERENCES

APPENDIX A: Chapter 3 Figures from Updated Load Analysis Report, PBS&J, 2004
APPENDIX B: Chapter 4 Figures from Updated Load Analysis Report, PBS&J, 2004

## List of Tables


| | | |
|---|---|---|
| 4-1 | Nutrient Levels in Source Water | 9 |
| 4-2 | Trophic State Index | 11 |
| 4-3 | Hydrologic Data | 15 |
| 4-4 | Constituent Concentrations in Runoff | 15 |
| 7-1 | Constituent Concentrations in Reclaimed Water | 32 |
| 8-1 | Management Alternatives Modeled in 2002 | 36 |
| 8-2 | 2002 Model Results with and without aerations | 37 |
| 8-3 | 2002 Load Analysis Summary | 39 |
| 9-1 | TMDL Numeric Targets | 45 |
| 9-2 | OP Loads for Alternatives Modeled | 47 |
| 9-3 | NO3+NO2-N and NH3-N Loads for Alternatives Modeled | 50 |


## List of Figures


| | | |
|---|---|---|
| 2-1 | City of Tucson | 4 |
| 3-1 | Aerial Photo of Lakeside Watershed | 6 |
| 3-2 | Lake Bathymetry and Location of Aerators | 7 |
| 3-3 | Schematic of 2002-installed Aerators | 8 |
| 3-4 | Climatological Factors | 8 |
| 4-1 | Productivity of 7 Lakes in Phoenix & Tucson | 10 |
| 4-2 | Map of Reclaimed Water Distribution System | 12 |
| 4-3 | Variation in Nitrogen Species in Reclaimed Water | 13 |
| 4-4 | Variation in Ortho-phosphate and Alkalinity in Reclaimed Water | 14 |
| 4-5 | Tucson Stormwater Data | 16 |
| 5-1 | Lakeside Lake Sampling Locations | 18 |
| 5-2 | Algal Species Density | 19 |
| 5-3 | Dissolved Oxygen Profiles | 21 |
| 5-4 | pH Profiles | 21 |
| 5-5 | 2002-2003 Chlorophyll-a Data for Site I | 23 |
| 5-6 | 2002-2003 Total Phosphorus Data for Site H | 23 |
| 5-7 | 2002-2003 Algae Species Density for Site I and Site H | 24 |
| 5-8 | 2002-2003 Nitrogen Data for Site I | 25 |
| 5-9 | 2002-2003 Phosphorus Data for Site I | 26 |
| 5-10 | 2002 and 2003 Summer pH Exceedances | 27 |
| 5-11 | 2002 and 2003 Improvements in Summer DO | 28 |
| 5-12 | Summer and Fall 2003 Reclaimed Nutrient Levels | 29 |

# 1.0. INTRODUCTION

## *1.1 Description of TMDL Process*

The goal of the federal Clean Water Act (CWA) is to "protect and preserve the physical, chemical, and biological integrity of the nations waters". This is often termed the "fishable"/"swimmable" goal of the CWA and is understood to mean that a surface water is meeting the designated use standards for fishing and public recreation (including swimming, etc.). Water bodies deemed by default to be capable of supporting fishing and/or swimming in 1975 were assigned aquatic life support criteria. In cases where waters do not meet this goal, Section 303(d) of CWA requires states to develop Total Maximum Daily Loads (TMDLs) for the pollutants causing impairment with oversight from the Environmental Protection Agency (EPA). A TMDL allocates pollution control responsibilities among pollution sources in a watershed, and is the basis for actions taken to restore the chemical, physical, and biological integrity of a waterbody that has been classified as "impaired" for one or more designated uses.

Water quality standards are the criteria established to protect the designated uses of Arizona's waters. When states and local communities identify problems in meeting water quality standards, a TMDL can be part of a plan to remedy water quality problems. If the initial determination that a waterbody supports the "fishable"/"swimmable" goals was incorrect, a state may submit a "delist report" to have the waterbody removed from the impairment list. If one or more of the conditions under 40 CFR 130.10 (The goals of CWA) preclude attainment of uses, the state must conduct a "Designated Use Attainability Study". An EPA approval must be obtained in order to remove a designated use. If uses can potentially be met but require flexibility in one or more surface water quality standards (criteria), a state may pursue "site-specific", "regional" or even "seasonal" standards. This last process is similar to removing a designated use and it also requires adherence to EPA guidelines and EPA approval.

A TMDL represents the total load of a pollutant that can be discharged to a water body on a daily basis and still meet the applicable water quality standard. The TMDL can be expressed as the total mass or quantity that can enter the water body within a unit of time. In most cases, the TMDL determines the allowable pounds per day of a constituent and divides it among the various contributors in the watershed as waste load (i.e., point source discharge) and load (i.e., nonpoint source) allocations. The TMDL must also account for natural background sources, seasonal variation, and provide a margin of safety. For non-point sources such as accelerated erosion or internal nutrient cycling, it may not be feasible or useful to derive a pounds per day figure.

TMDLs must include specific information to be approved by U.S. EPA Region 9. This necessary information can be summarized in the following 8 elements:

**Plan to meet State Surface Water Quality Standards:** The TMDL includes a study and a plan for the specific water and pollutants that must be addressed to ensure that applicable water quality standards are attained.

**Describe quantified water quality goals, targets, or endpoints:** The TMDL must establish numeric endpoints for the water quality standards, including beneficial uses to be protected, as a result of implementing the TMDL. This often requires an interpretation that clearly describes the linkage(s) between factors impacting water quality standards.

**Analyze/account for all sources of pollutants.** All significant pollutant sources are described, including the magnitude and location of sources.

**Describe the linkage between water quality endpoints and pollutants of concern.** The TMDL must explain the relationship between the numeric targets and the pollutants of concern. In other words, the recommended pollutant load allocations must be less than or equal to the total loading capacity of the receiving water and still meet water quality criteria.

**Develop a margin of safety (MOS) that considers uncertainties, seasonal variations, and critical conditions.** The TMDL must describe and quantify any uncertainties regarding the ability of the plan to meet water quality standards that have been addressed. The plan must consider these issues in its recommended pollution reduction targets with a quantifiable MOS.

**Assign allocations to point sources, non point sources, and background sources.** Allocations are quantitative and refer to the respective loads allowed from each source contributing to the pollutant of concern. The allocations will become part of the permit conditions where an NPDES permit is needed.

**Provide implementation recommendations for pollutant reduction actions and a monitoring plan.** The TMDL should provide a specific process and schedule for achieving pollutant reduction targets. A monitoring plan should also be included, especially where management actions will be phased in over time. Results from monitoring will be used to assess the validity of the pollutant reduction goals.

**Include an appropriate level of public involvement in the TMDL process.** This is usually met by publishing public notice of the TMDL, circulating the TMDL for public comment, and holding public meetings in local communities. Public involvement must be documented in the state's TMDL submittal to EPA Region 9.

### *1.2 Water Quality Standards, 305(b), 303(d), and Impairment*

Water quality standards for surface waters are reviewed and revised by states every three years as criteria are refined. These criteria, or threshold levels, are developed for various potential pollutants based on the particular designated uses of a water body and the degree of exposure or risk to humans, animals, and plants. Standards may be numeric or narrative, meaning they can be numbers, ranges of numbers, or narrative descriptions. Arizona's Surface Water Quality Standards contain both numeric and narrative criteria.

Every two years, each state must submit an accounting of how well their water bodies are meeting their standards. This report is known as the Water Quality Assessment Report or "305(b) Report", after the section of the Clean Water Act (CWA), requiring a report to Congress. Waters are classified as "attaining" their uses, "threatened" (waters that are currently meeting standards but may be impaired, and "impaired" according to the number and nature of criteria violations. Based on the 305(b) Assessment Report, the state generates a list of impaired waters from a review of threatened and impaired categories (A.R.S. Title § 49-232 through 234; A.A.C. Title 18, Chapter 11, Article 6). The list is referred to as the Water Quality Limited List or "303(d) List", after the relevant CWA section. Waters on this list require a TMDL.

# 2.0 PROJECT BACKGROUND

## *2.1 Background; 303d Status and Problem Statement*

Lakeside Lake (LSL) is a 13-acre urban impoundment along Atterbury Wash in Tucson, Arizona (Figure 2-1). Originally a storm water retention basin, the impoundment was engineered in 1985 to become a public park feature and recreational fishery. The original source water was groundwater supplied by an adjacent well, along with periodic storm inputs from Atterbury Wash. The Groundwater Management Act of 1980 established the Tucson metropolitan area as one of a few Active Management Areas (AMAs) in Arizona. AMAs were created to protect and conserve groundwater, requiring among other things, the need to prove a 100-yr water supply for new growth. In 1987, the Legislature enacted a law restricting the use of surface water or potable groundwater in artificial lakes and ponds in Active Management Areas (AMAs). The Arizona Department of Water Resources (ADWR) regulations require that a new lake cannot exceed 12,320 sq. ft., the size of an Olympic-sized pool, unless filled with reclaimed or poor quality groundwater. As a result, the City of Tucson began discharging reclaimed water to LSL in 1990.

As part of an urban recreation park, the lake is managed by the Tucson Parks & Recreation Department (Parks & Rec). LSL became an urban fishery prior to it's expansion in 1985. By 1986 it was officially added to the Arizona Game & Fish Department's (AGFD) Urban Fishing Program. AGFD initially stocked trout year-round at LSL. However, declining conditions led to AGFD to stock trout only in the cooler months and catfish and other warm-water species in the summer months. In spite of periodic water quality problems, the lake has been a very popular fishing hole.

With reclaimed nutrient levels that are orders of magnitude greater than groundwater levels, LSL has become increasingly eutrophic over the years. These conditions have resulted in noxious algal blooms, high pH, low dissolved oxygen (DO), limited stocking, and periodic fish kills. A marked decline in water quality and several fish kills since the early 1990s led to citizen complaints and increased attention on the part of the City of Tucson (City), Arizona Game & Fish Department (AGFD), the University of Arizona, and the Arizona Department of Environmental Quality (ADEQ). In 1992, the City installed an aeration system of PVC piping on the bottom of the lake. Air pumped from a compressor on-shore, through the pre-piping, was meant to improve water quality and alleviate stress to fishes.

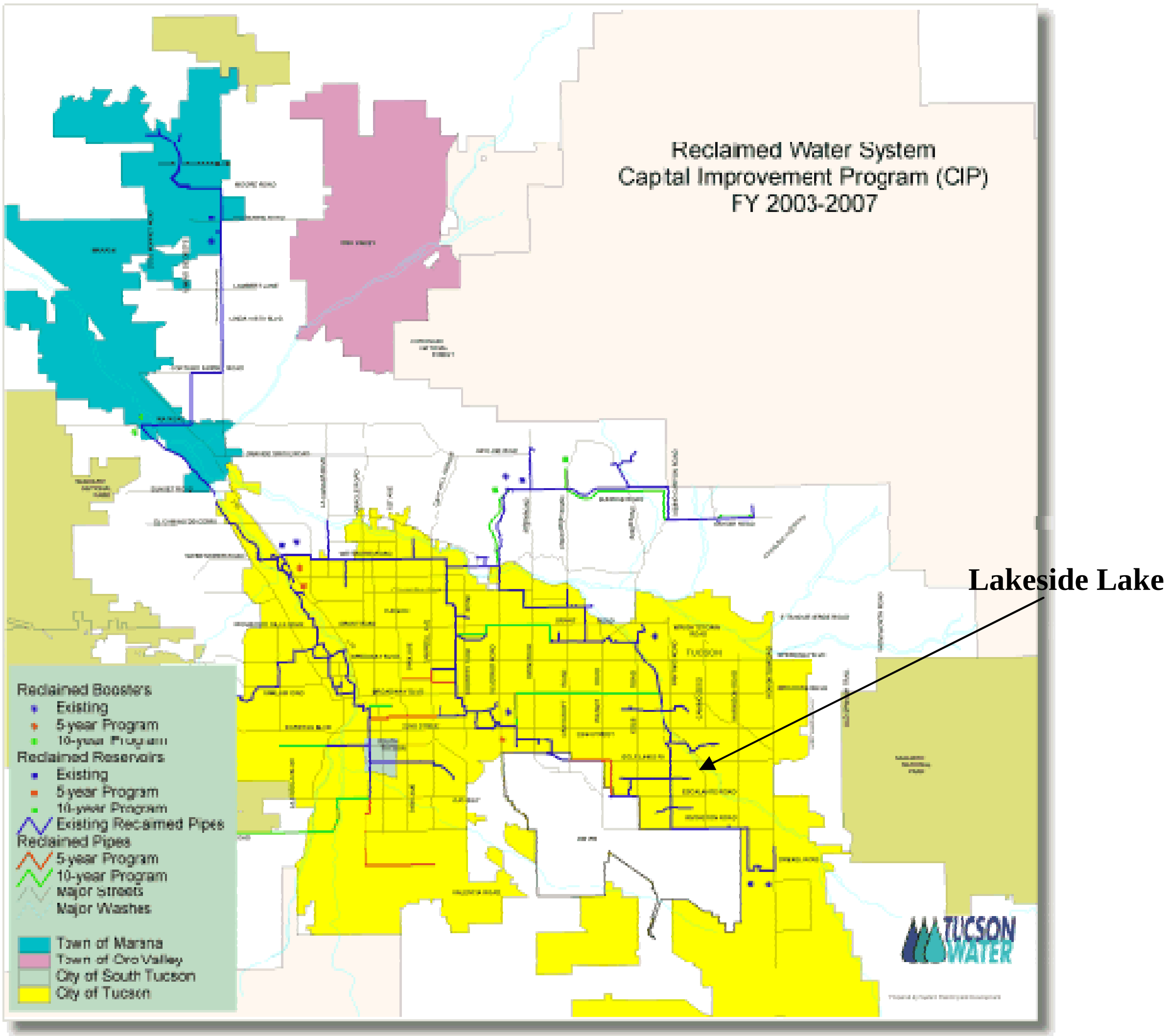


**Figure 2-1 City of Tucson (www.ci.tucson.az.us)**

Because LSL was constructed within the natural drainage of Atterbury Wash, it was listed as a "water of the state" in the 1996 Surface Water Quality Standards (A.A.C. R18-11, Appendix B). As part of an urban recreation park, LSL is designated for the following uses under Title 18, Chapter 11 of the Arizona Administrative Code: Aquatic and Wildlife - warm water fishery ("A&Ww"), Partial Body Contact ("PBC"), and Fish Consumption ("FC"). The City received a Reuse Permit in 1983 for watering the park with reclaimed water, but did not begin using this source of water for the lake until 1990. By 1992, the City was notified of the need to apply for a NPDES Permit, which they did in 1996.

By 1997, the City and the Arizona Department of Environmental Quality (ADEQ) had begun the NPDES application process. The water quality in LSL continued to decline and a temporary hold was placed on the NPDES process in order to allow collection and evaluation of data from LSL. Two year-long studies were initiated in 1998: one by the City of Tucson and a separate collaboration between ADEQ and AGFD. Data generated from these studies were used to develop the load analysis report completed in 2002 by PBS&J. Subsequently, assessment of data from 1998, 2002, and 2003 has resulted in a listing of impairment for high pH, low DO, ammonia, and narrative nutrient violations (Draft 2004 303(d) Report).

The numeric standards of particular relevance to this TMDL include portions of R18-11-109: pH in a range of 6.5 SU to 9.0 SU (all year, all portions of the water column); dissolved oxygen no lower than 6.0 mg/L or 90% saturation within the top 1 meter of the water column; an ammonia standard based upon pH and temperature; and a narrative standard (R18-11-108 A.6) which in relevant part reads:

> *Surface waters shall be free from pollutants in amounts or combinations that ...cause the growth of algae or aquatic ants that inhibit or prohibit the habitation, growth, or propagation of other aquatic life or that impair recreational uses…*

## *2.2 Summary of LSL TMDL Goals*

Due to assessed water quality standards violations and the requirement for a NPDES permit, a Load Analysis Model was constructed to 1) test a management strategy that was expected to gain a better understanding of seasonal constraints to the ecosystem, 2) test the ability of a newly installed aeration system in mitigating water quality standards exceedances, 3) effectively build monitoring and management plans for the lake and watershed, and 4) evaluate the need to consider site-specific, seasonal, or designated use criteria changes. Generally, changes in standards or the establishment of site-specific standards are the result of ongoing science-based investigations or changes in toxicity criteria from EPA. Changes in designated uses and standards are part of the surface water standards triennial review process and are subject to public review. Standards are not changed to bring the waterbody into compliance, but must be based on existing uses, technical and economic feasibility, and natural conditions (40 C.F.R. 131.10).

The LSL TMDL has incorporated data collected post-installation of the new aerator (2002-2003). The TMDL refines the load analysis model and establishes numeric load reductions for nitrate, ammonia, and phosphorus. Target endpoints will be measured in the lake itself and shall: 1) not exceed a threshold of 50 *u*g/L chlorophyll-a during peak growing season (April-October), and 2) meet the DO, pH, and ammonia numeric criteria for a warm water fishery. The implementation plan will be an NPDES permit condition and will require active management of LSL to meet these endpoints.

# 3.0 LAKE AND WATERSHED OVERVIEW

## *3.1 Geography*

The impoundment that later became LSL was originally a storm water detention and stock tank at the intersection of Kinnison Wash and Atterbury Wash. Atterbury Wash originates in open land leased by the City to Davis Monthan Air Force Base. From the eastern boundary of Davis Monthan Air Force Base, it flows north and reaches the lake about 4 miles downstream, then continues another half mile or so to its confluence with Pantano Wash. The present-day configuration routes Kinnison Wash around the lake and downstream of the dam. While both washes are ephemeral, the 12-sq mi. Atterbury watershed is largely undeveloped on its south end (Figure 3.1), whereas Kinnison Wash flows through residential neighborhoods. LSL is now part of an urban park with picnic ramadas and a fishing dock.

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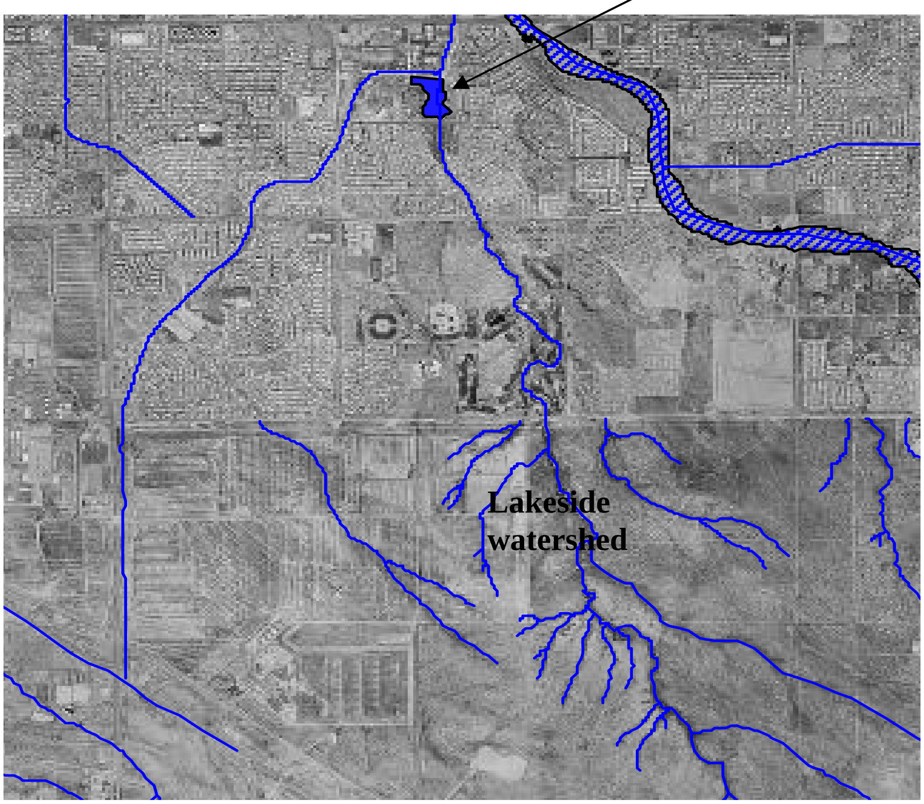
**Lakeside Lake**




**Figures 3-1 Aerial Photo of Lakeside Lake and Watershed (USGS, 1992)**

### *3.2 Lake Morphology and Operations*

From the bathymetry measurements taken in January of 2002, LSL is approximately 13 surface acres, has a maximum depth of 28 feet, an average depth of 12 feet, and a capacity of about 150 acre-feet. In 1986 when the lake was reconstructed, the maximum depth was reported as 35 feet with a capacity of 14 surface acres. The discrepancy is assumed to reflect sedimentation. LSL is lined with soil cement and has a concrete shelf extending three feet from the shore. The spillway is located at the northeast end of the lake. Lake level fluctuations led the City to begin supplementing groundwater and runoff with reclaimed water; since 1990, up to 45,000 gallons per day (gpd) of reclaimed water have been added through a submerged pipe to the northern cell to maintain the water level (Figure 3.2)

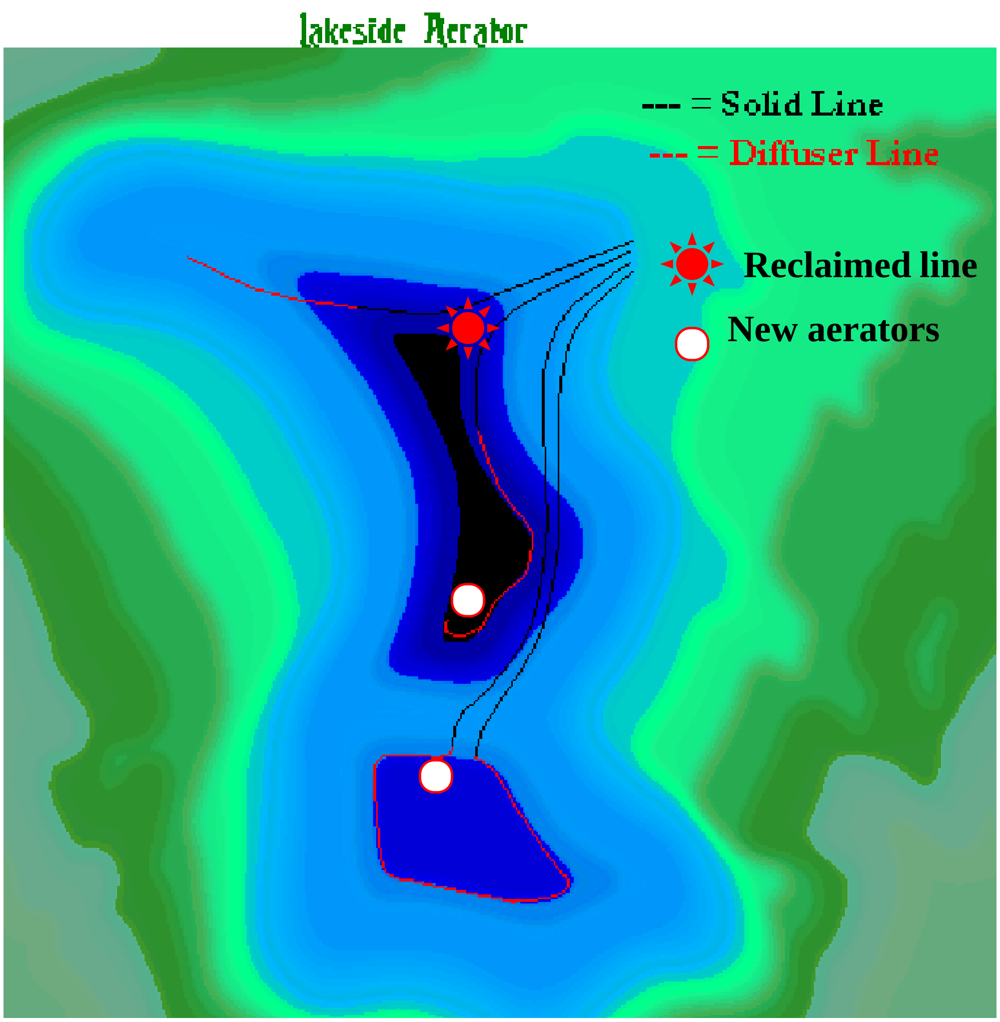



**Figure 3-2. Location of 1992 Air Diffusers, Reclaimed Line, and the Two Aerators Installed at Lakeside Lake in 2002 (Bathymetry Map from Walker, 1999)**

Figure 3-3 shows the configuration of the two new aerators installed in 2002.

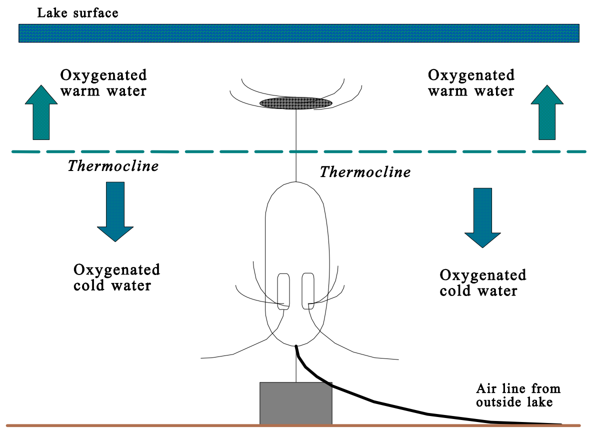



**Figure 3-3. Schematic of 2002-Installed Aeration System**

### *3.3 Climate*

The City of Tucson is located within the Basin and Range province in southern Arizona at an elevation of 2500 feet asl. The area receives an annual average of 12 inches of precipitation. Figure 3-4 shows the cyclical pattern of precipitation, with the majority of the rain falling either in late summer/early fall or winter storms.

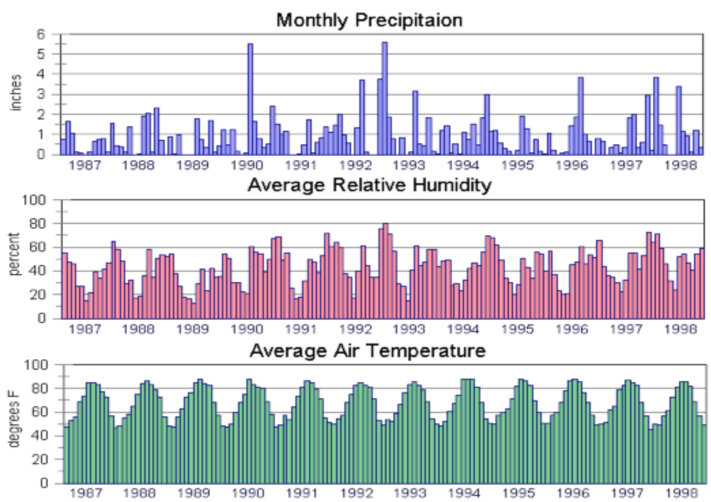



**Figure 3-4. Climatological Factors, National Weather Service**

### *3.4 Land Use*

As part of a Tucson city park, access to LSL is open to the public. The area immediately surrounding and downstream of the lake is primarily residential and commercial. A short distance upstream of the lake along Atterbury Wash is a larger park, Lincoln Regional Park and Golf Course.

## 4.0 SOURCE WATER QUALITY

### *4.1 Source Water & Lake Productivity*

As mentioned, groundwater was delivered to LSL for a number of years to maintain adequate levels. Although use of groundwater has been severely curtailed in recent years, there are still some lakes in Tucson where it is still the primary source of water, e.g., Kennedy Lake. Several water quality parameters affect the character and productivity of small urban lakes. Studies indicate nutrient supply is the most crucial factor. Table 4-1 summarizes key nutrient values inherent in the three potential sources of water for LSL: City of Tucson groundwater data, Central Arizona Project (CAP) water from the Colorado River, and reclaimed water. Reclaimed water consists of secondary-treated effluent from the Pima County Wastewater Management District (WWMD) Roger Road Wastewater Treatment Plant which receives additional filtration and chlorination at the City's Reclaimed Water Production Facility before distribution through the reclaimed system. In times of high demand, water from the Sweetwater Recharge Project may also be added to the reclaimed system for delivery.

**Table 4-1. Nutrient Levels in Source Water (City of Tucson)**

| Parameter | Range in CAP Water | Range in Tucson Groundwater | Range in Tucson Reclaimed Water |
|---|---|---|---|
| Nitrate - N | 0.2 mg/L | 0.5 - 6 mg/L | 2 - 8.5 mg/L |
| Ammonia - N | 0.062 mg/L | not reported | 8 mg/L |
| Total Kjeldahl nitrogen | not reported | not reported | not reported |
| Ortho-phosphorus | 0.011 mg/L | <0.22 mg/L | 0.3 - 3.5 mg/L |
| Total phosphorus | <0.02 mg/L | not reported | not reported |

Nutrient levels in CAP water are in the range that may be limiting to algal growth, but in general, most surface water and groundwater sources in Arizona have nutrient levels that promote algae growth in rapidly cycling, relatively small urban lakes. Source water nutrient differences suggest there is a continuum in productivity between small urban impoundments. This continuum is also related to lake size, age, configuration, water retention time, and to what degree there may be storm water or other non-point source inflows.

ADEQ has found there is no "one size fits all" assessment for urban lakes. This point was underscored in the joint ADEQ/AGFD Urban Lake Study in 1998 of seven urban lakes in

Tucson and Phoenix. Figure 4-1 shows the variability in productivity using the Trophic State Index (TSI) between two groundwater-supplied lakes [Chaparral ("CH") and Kennedy ("KN")], two reclaimed water-supplied lakes [Lakeside ("LA") and Silverbell ("SI")], and three lakes supplied with surface water from the Salt River Project (SRP) canal system [Papago (" PA"), Cortez ("CO"), and Alvord (" AL")]. There is an apparent trend from lower trophic values (SRP water) to higher trophic values (reclaimed water). The TSI was calculated using Brezonick's method, as shown in Table 4-2.

**Figure 4-1. Productivity of 7 Urban Lakes (data from AGFD, 1998)**

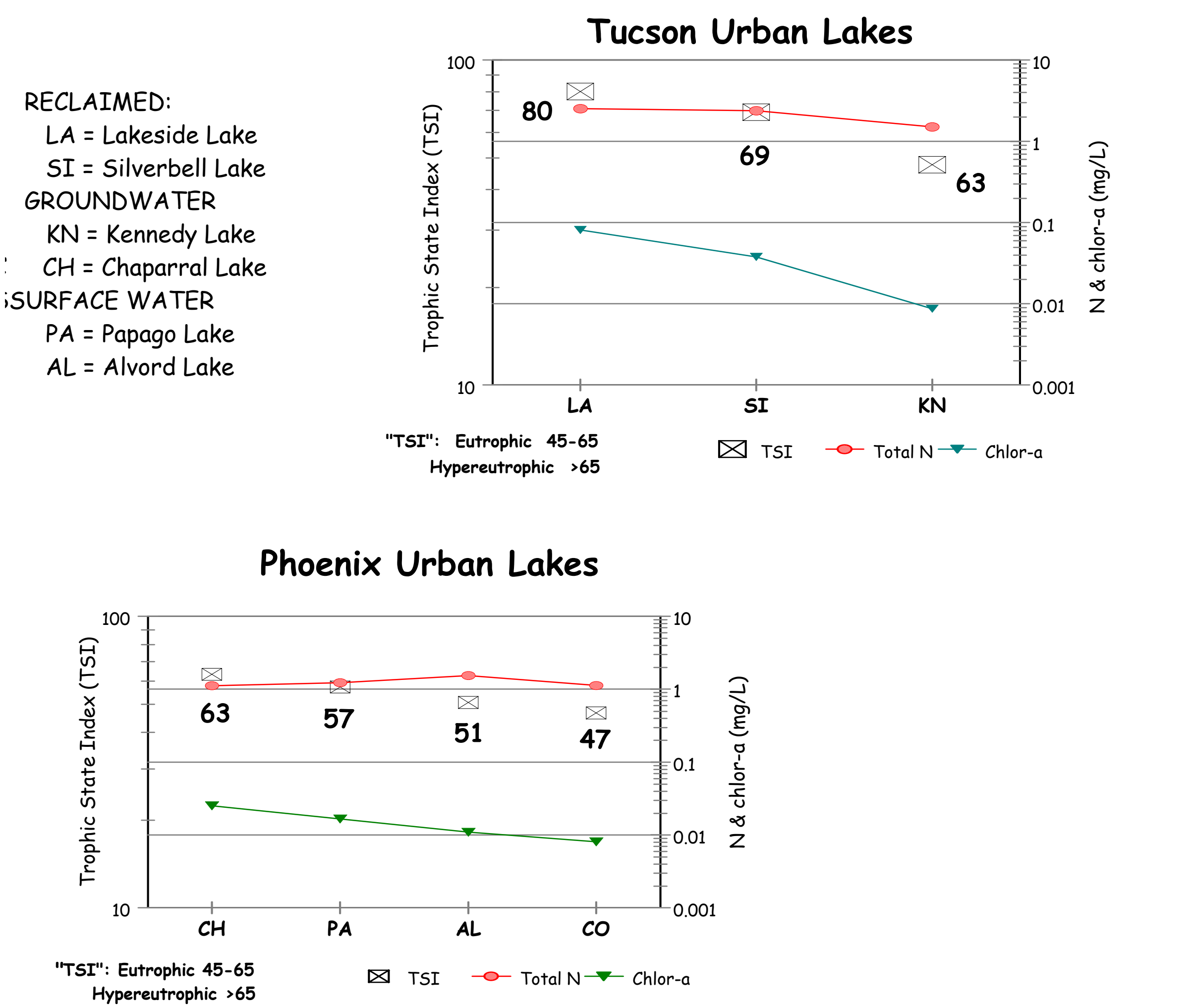


**Table 4-2 Trophic State Index (Brezonick, 1984)**

| TSI | Trophic State | Chlor-a (ug/L) | SD (m) | Total P (ug/L) | | Total N (mg/L) | |
|---|---|---|---|---|---|---|---|
| | | | | P-lim | N&P-lim | N-lim | N&P-lim |
| <30 | Oligotrophic | <5 | >3 | <10 | <13 | <.25 | <.28 |
| 30-45 | Mesotrophic | 5-12 | 1.2-3 | 10-20 | 13-35 | .25-.65 | .28-.75 |
| 45-65 | Eutrophic | 12-20 | .6-1.2 | 20-35 | 35-65 | .65-1.1 | .75-1.2 |
| >65 | Hypereutrophic | >20 | <.6 | >35 | >65 | >1.1 | >1.2 |

## *4.2 Reclaimed Water Used in LSL*

### 4.2.1 Delivery System

The City of Tucson has one of the largest community reclaimed water systems in the United States. The reclaimed water system began operation in 1984 with a golf course and the University of Arizona (U of A) Farms as the first customers. Currently, Tucson Water delivers reclaimed water to nearly 400 sites, including: 13 golf courses, 32 parks, 35 schools (the U of A and Pima County included), and more than 300 single family homes. From the Pima County WWMD Roger Road Wastewater Treatment Plant, the City routes secondary treated effluent through their nearby Reclaimed Water Production Facility. After filtering and disinfecting the reclaimed water, it is stored in a reservoir until it is pumped through its own system of pipes and reservoirs to customers throughout the Tucson region. Figure 4-2 shows a map of the distribution system in relationship to LSL. (WERC web site)

Currently, over eight percent of Tucson Water’s total demand is met with reclaimed water. Future projections anticipate 15 percent of the total demand will be met with reclaimed water. The reclaimed water system includes more than 85 miles of pipeline and five reservoirs with a combined storage capacity of 15 million gallons. In 2001, over 3.4 billion gallons of reclaimed water were delivered to customers, enough to supply more than 90,000 people for a year.

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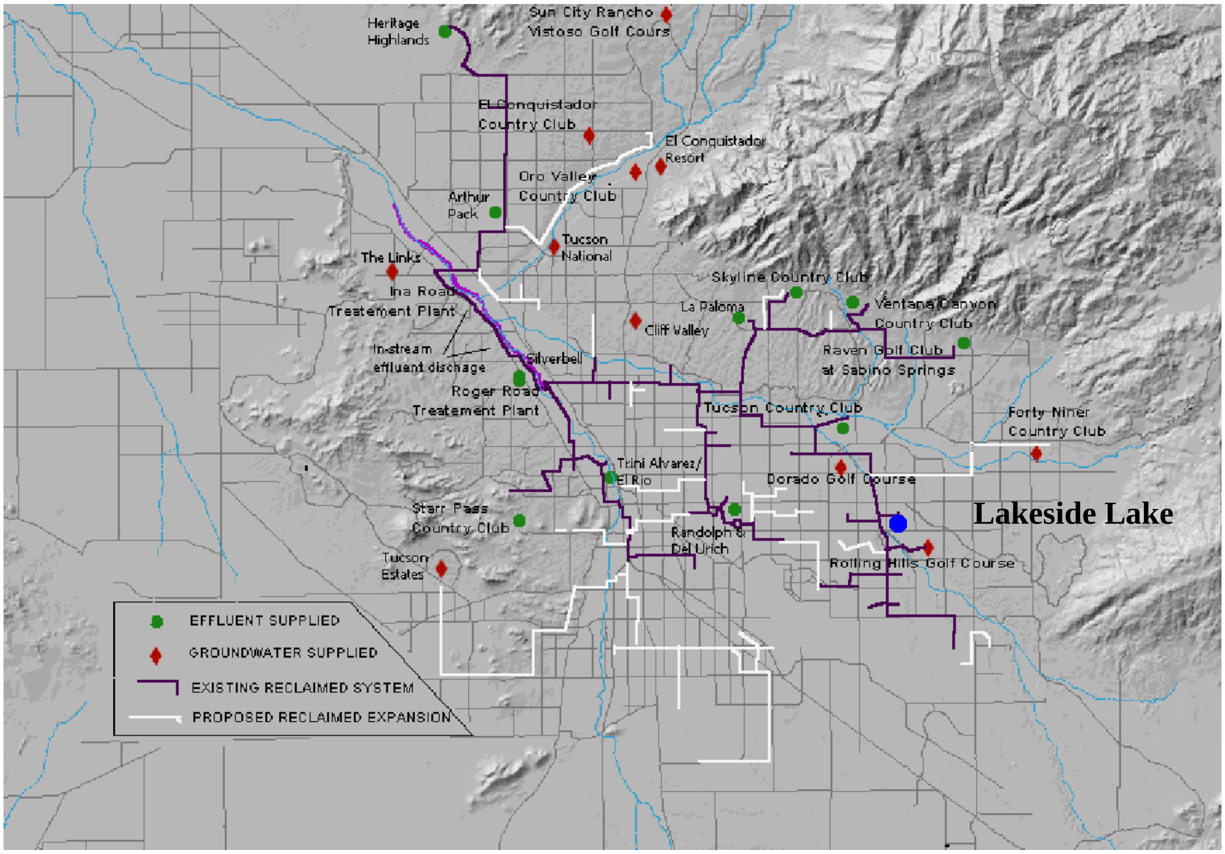



**Figure 4-2. Map of Reclaimed Water Distribution System (City of Tucson)**

### 4.2.2. Water Quality

The high levels and significant variations in reclaimed water nutrients are particularly relevant to the development of this TMDL, given the large quantity of reclaimed water that is added to the lake daily. In 1997, 1998, and 1999, nitrite-nitrogen varied from 2 to 8.3 mg/L, at least an order of magnitude higher than what would potentially limit primary production. Of particular concern, ammonia nitrogen was usually above 6 mg/L with some measurements as high as 16 mg/L. In the presence of high water temperature and pH, unionized ammonia can be toxic or lethal to fish and other aquatic organisms, even at levels of 0.02 mg/L. Figures 4-3 and 4-4 (from PBS&J, 2002) show the variability in $NO_3$-N, $NH_3$-N, alkalinity, and ortho-phosphate from January 1997 to June 1999. During the same time period, orthophosphate in reclaimed water varied from 0.3 mg/L to 3.5 mg/L. As with nitrogen, a value of 0.3 mg/L for ortho-phosphorus is an order of magnitude above that considered limiting for algae growth.

**Figure 4-3 Variation in Nitrogen Species in Reclaimed Water (PBS&J, 2002)**

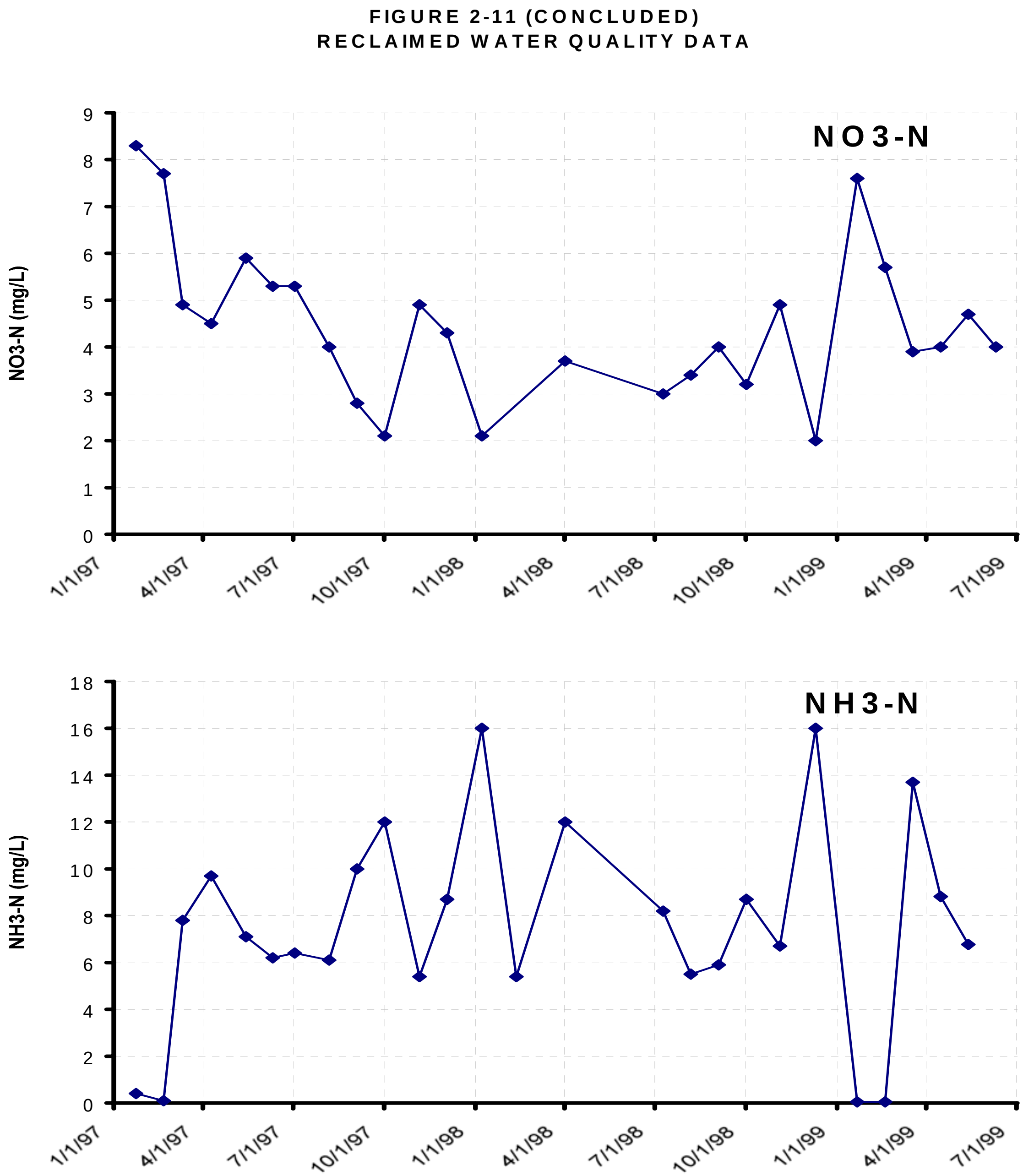
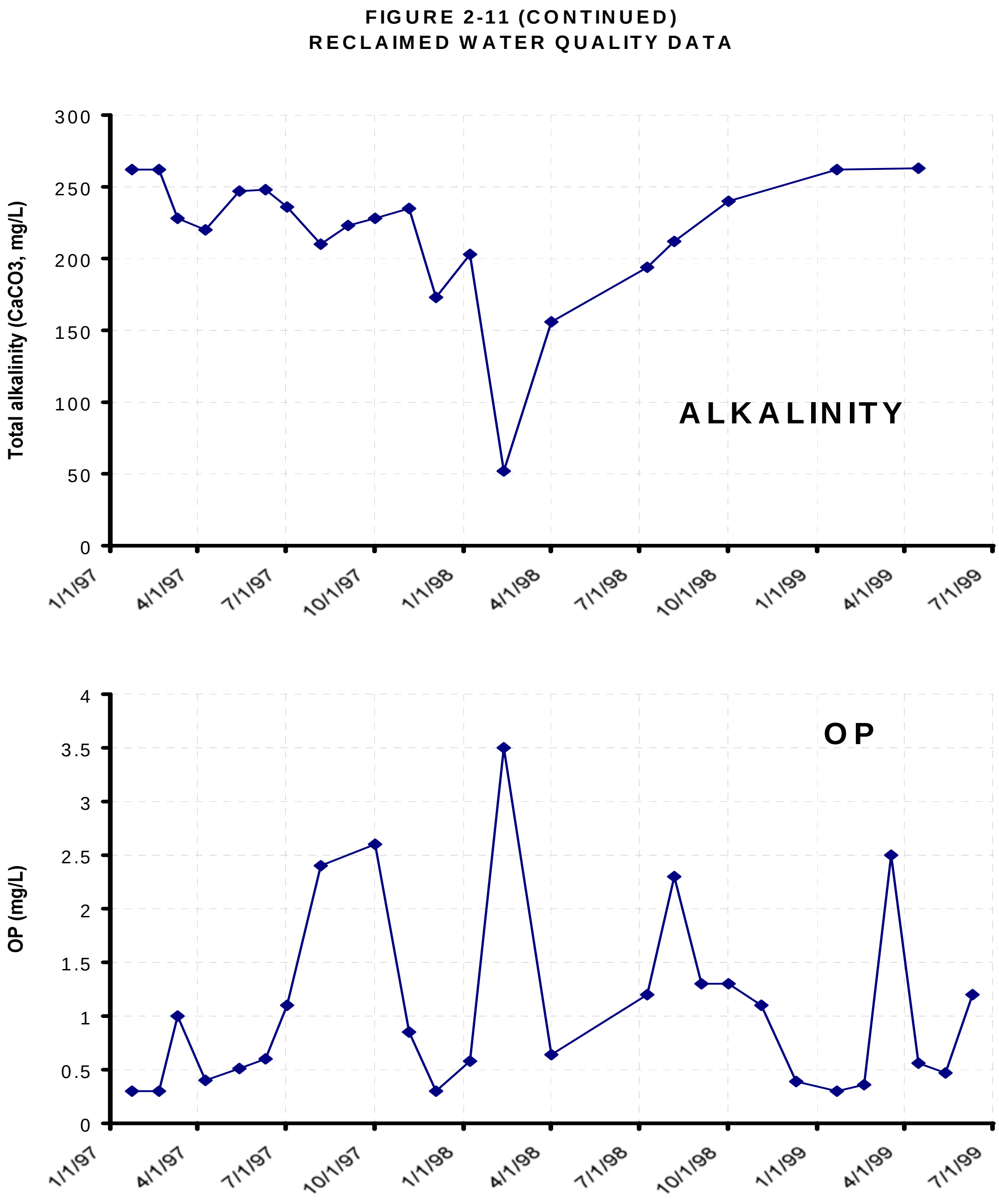


**Figure 4-4 Variation in Ortho-phosphate and Alkalinity in Reclaimed Water (City of Tucson)**



## 4.3 *Stormwater Runoff*

There are no runoff water quality data for Atterbury Wash, as the wash is dry most of the time and no storm sampling has been performed. The US Geological Survey (USGS) had a stream flow gage on Kinnison Wash just upstream of LSL, however, gaged flow data were available only from 10/1/75 to 9/30/83. Historic records show there is considerable year-to-year variation and 1982 appears to have been an unusually wet year. The total runoff volume from March 1976 to February 1983, by season, is shown in Table 4-3 below. Data on monthly precipitation, annual reclaimed water used, and average wash flow were used in modeling.

**Table 4-3 Hydrologic Data (USGS)**

| | Total runoff volume by season (ac-ft) Mar 1976 to Feb 1983 |
|---|---|
| Spring (Mar, Apr, May) | 94 |
| Summer (Jun, Jul, Aug) | 338 |
| Fall (Sep, Oct, Nov) | 433 |
| Winter (Dec, Jan, Feb) | 321 |

To get an indication of the possible range of constituent concentrations in runoff in a local setting, data from the City of Tucson storm water monitoring program were utilized and coupled with the available flow data. The average results of selected parameters from 1996 to 2001 are summarized in Table 4-4.

**Table 4-4 Constituent Concentrations in Runoff (City of Tucson)**

CONSTITUENT CONCENTRATIONS IN RUNOFF
(mg/L)

| | TDS | TISS[1] | OP | NH3-N | NO2+NO3-N | LDOM[2] | LPOM[3] | DO |
|---|---|---|---|---|---|---|---|---|
| Before 7/15/98 | 160 | 130 | 0.05 | 0.1 | 0.2 | 10 | 10 | 7 |
| From 7/15/98 | 80 | 130 | 0.05 | 0.1 | 0.2 | 10 | 10 | 7 |

[1] Total inorganic suspended solids
[2] Labile dissolved organic matter
[3] Labile particulate organic matter

There were no measurements of $NH_3$-N and OP but these can be inferred or estimated from the TKN and TP data. As is typical with surface water, there is a broad range or high variability in the runoff concentrations. Due to the relatively undeveloped nature of the contributing watershed, concentrations of total suspended solids (TSS) and particulate nutrients might be expected to vary in direct relation to the intensity of the runoff event and the time period in between events. It appears there has been significant input of TSS to LSL, evidenced by an apparent decline in bottom elevation since 1986, as noted in Section 1.4.

The Storm water Monitoring Program targets specific land use types to characterize water quality during storm events. For example, Figure 4-5 presents nitrogen water quality data by commercial, industrial, single family residential, multi-family residential, and mixed use (commercial, single and multi-family) land uses. The solid bar in each plot shows the average of the data for that land use. The vertical line indicates the range of values that lie outside the $75^{th}$ quartile.

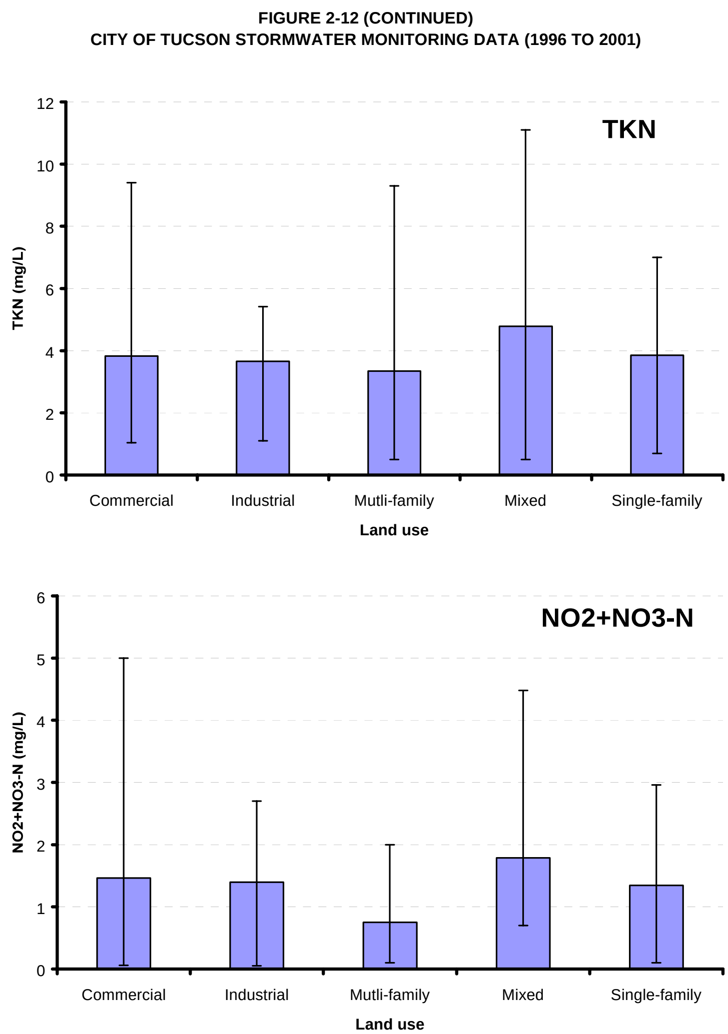



**Figure 4-5 Tucson Storm Water Data (1996-2001)**

# 5.0 LAKE WATER QUALITY: 1998 - 2003

## 5*.1 1998 Data; Observations from 2002 Load Analysis Study*

To address the water quality concerns in LSL, two studies were conducted in 1998 that involved sampling in the lake. The "Urban Lakes Study" resulted from an Intra-agency Service Agreement (ISA) between the Arizona Department of Environmental Quality and the Arizona Game and Fish. This study was undertaken as part of the Arizona Urban Fishing Lake Limnological Characterization Program (UFLLCP). A second study was performed for the City of Tucson by Sweetwater Environmental Consulting and Lake Management (SECLM). These two studies are the primary data sources for the water quality modeling of LSL.

The sampling locations for the two studies, Sites A to I, are shown in Figure 5-1. All stations were sampled under the UFLLCP, however, efforts were concentrated at Sites H and I. Only field measurements of surface water were taken at the other sites. Only sites A, H, and I were sampled by SECLM. Data from the two studies were combined for the load analysis. A summary review of the data is discussed below.

LSL's conductivity and total dissolved solids (TDS) levels reflect the pattern associated with reclaimed source water except when the flushing effect of heavy monsoon inflows from Atterbury Wash provided dilution in July 1998. In this case, the conductivity dropped from about 600 to about 300 micromohs/cm, and TDS dropped from about 300 mg/L to about 150 mg/L. TDS data showed higher values in the southern cell (H), as would be expected in dry weather when the only input was reclaimed water at the northern end.

As would be expected given storm inputs, TSS and turbidity data showed increases after the July 1998 runoff event. Based on available data, there appears to be a positive correlation between the TSS and chlorophyll-a and an inverse relationship between TSS and Secchi depth. The data did not show the usual strong correlation between chlorophyll-a and algal biomass. There is a need for a higher resolution in data collection; this is a recommendation for the TMDL implementation plan.

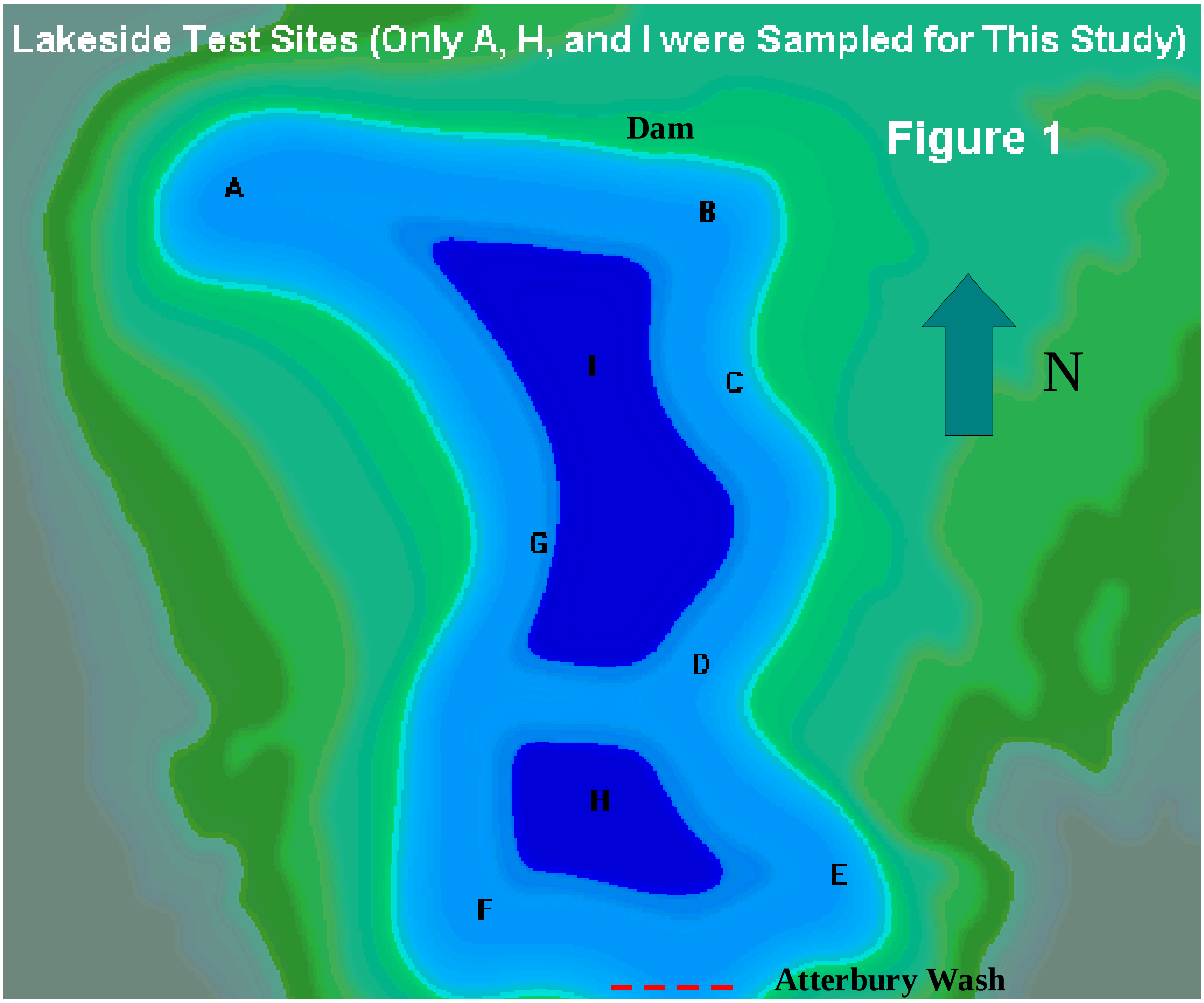



**Figure 5-1 Lakeside Lake Sampling Locations (Walker, 1999)**

### 5.1.1 Algae (phytoplankton)

The general pattern for phytoplankton analysis is the same for both studies. There is a single peak in the algae density in June. Chlorophyta (green algae) appears to be the dominant species at times, but Cyanophyta (blue-greens) were the dominant algae in the June algal bloom and Cryptophyta (greens) were dominant in winter (Figure 5-2, PBS&J, 2002). The observed peak in June biomass, when Cyanophyta were dominant, cannot be correlated to a corresponding peak in chlorophyll-a, because chlorophyll was not analyzed in June. The fact that chlorophyll was only analyzed four times in the UFLLCP study, and often at different times than the SECLM algae counts were done, the correlation is not as strong as expected ($R^2 = 0.45$).

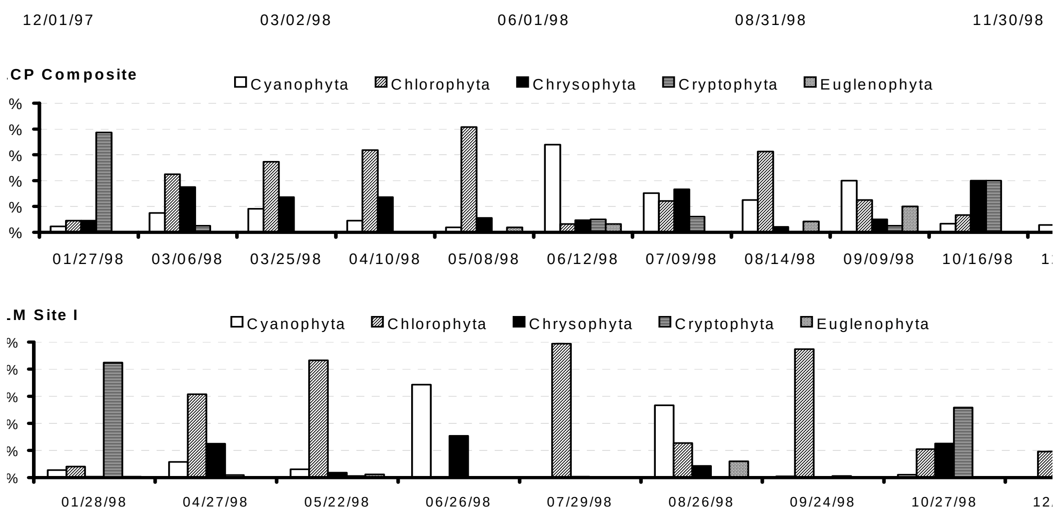



**Figure 5-2 Lakeside Lake Algae Measurements ( 12/97-12/98)**

### 5.1.2 Nitrogen

Nitrogen data show Kjeldahl nitrogen (TKN) values around 2 mg/L in the first half of the year, and then dropping to about 1 mg/L in the second half. Most of the change can be attributed to a reduction in the ammonia nitrogen ($NH_3$-N), a preferred food source for algae. Nitrate nitrogen ($NO_3$-N) was detected in the lake during the spring, but dropped to below detection levels for most of the second half of the year. These data do not suggest any limitations of algae growth by lack of nitrogen. A commonly cited value in the literature for nitrogen limitation in lakes is 0.08 mg/L as nitrate-nitrogen (NO3-N) or a ratio of nitrogen to phosphorus (N:P) < 7 (Burch and Sly, 1982)

### 5.1.3 Phosphorus

Phosphorus species analyzed differed between the two studies. However, most crucial to nutrient limitation, ortho-phosphorus values (300-3500 ppb) were well above the 5 ppb level thought to be limiting for algae growth. The two studies were consistent in showing a slow decline in total phosphorus (TP) values over the sample year, possibly due to plant uptake and phosphorus settling out of the photic zone.

### 5.1.4 Dissolved Oxygen (DO)

There were wide fluctuations of DO during the year, with super-saturation observed in late January and late March at the surface and complete depletion of oxygen in the lower part of the lake in summer as well as occasionally in spring. Most of the time lake sites and depths did not show much difference; the few differences observed are thought to reflect relative inflow or aeration effects.

The configuration and operation of the old aeration system did not allow the lake to naturally stratify. As a result, there has been a continuous percolation of nutrients and organic matter from the lower water column into the upper layers, promoting optimum conditions for growth of algae year-round. In a lake that is producing a large biomass of algae year-round, there is also continuous die-off/decomposition, perpetuating a high biological oxygen demand (BOD). High internal BOD results in less buffering capacity, leading to periods of acute oxygen shortage. This cycle can be precarious on a diel basis and serious following storms, resulting in severe DO “crashes” and establishing conditions for fish kills.

Dissolved oxygen at LSL in 1998 ranged between 0 and 14 mg/L, depending on depth. Figure 5-3 (from PBS&J, 2002) shows the seasonal pattern of dissolved oxygen at LSL in 1998. Note the relative lack of thermal/density stratification as evidenced in the homogenous vertical profiles. Oxygen levels below 5 mg/L can be stressful for fish and oxygen levels below 3 mg/L can be lethal. The near absence of oxygen produced a fish kill in July of that year.

### 5.1.5 pH

For pH, no significant difference seems to exist between sites. Arizona has adopted a pH standard for the aquatic and wildlife use as a range: 6.5 standard units (SU) to 9.0 SU. Most of the time, the pH in LSL varied between 7 and 9, occasionally exceeding the upper standard of 9 SU. A pH in excess of 9 SU can be stressful for fish. In addition, high pH in combination with high water temperature becomes potentially toxic because it promotes higher levels of unionized ammonia. The following graphs (Figure 5-4: PBS&J, 2002) show the fluctuations in summer water column pH. Note the spike in pH during the first week of July 1998; this condition preceded the drop in dissolved oxygen the following week.

In 1998, pH in LSL fluctuated throughout the year; though not reaching 10 SU, as it had been reported in the early 1990's. In 1998, higher pH values correspond to higher algal biomass, which indicate that there may be several algal bloom ‘seasons’ in this system.

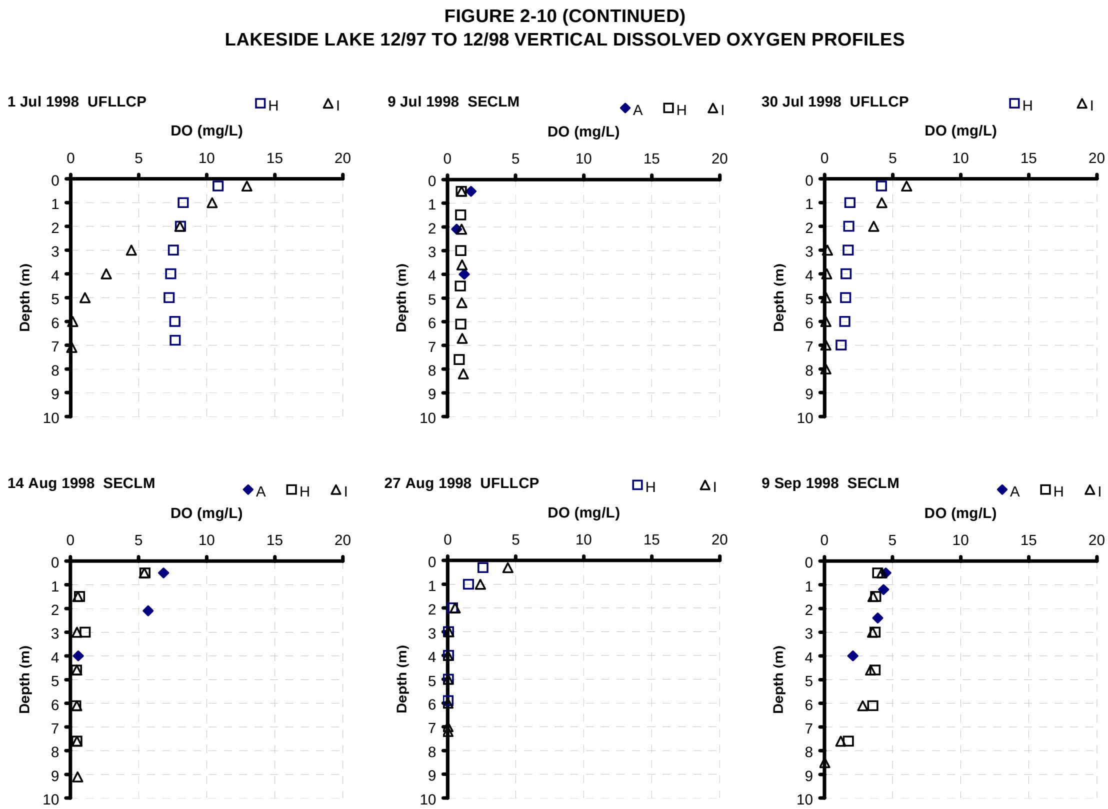



**Figure 5-3 Dissolved Oxygen Profiles (AGFD, 2000; Walker, 1999)**

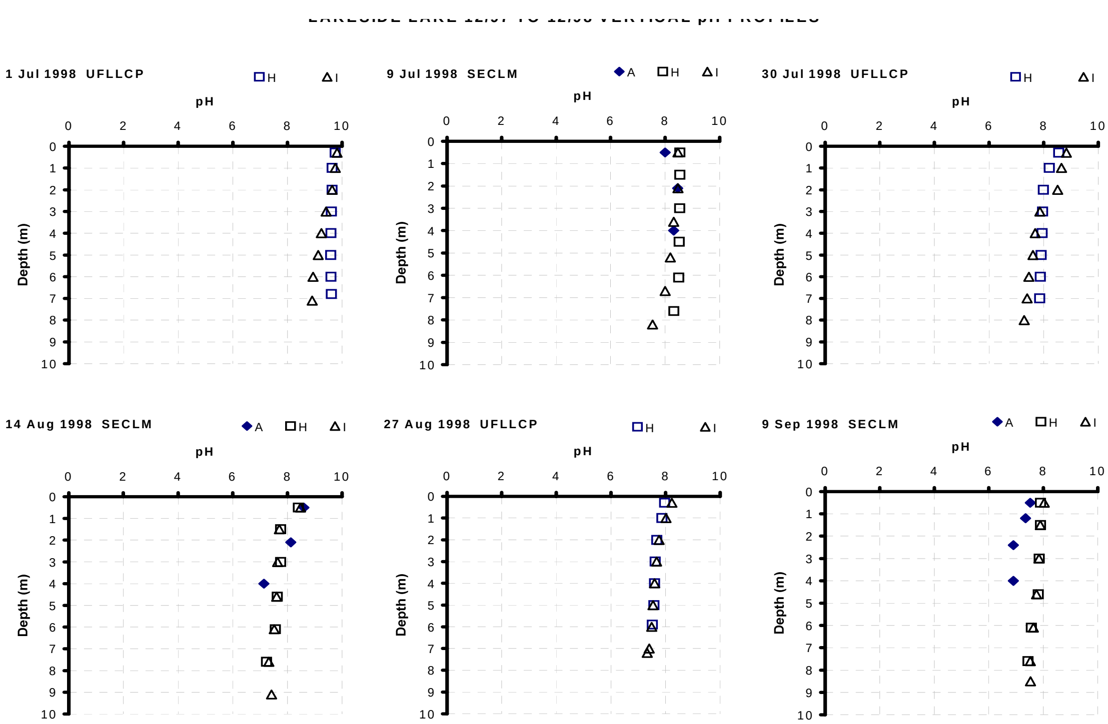



**Figure 5-4 pH Profiles (AGFD, 2000; Walker, 1999)**

## 5.2 *2002-2003 Data; Comparison with 1998 Data for TMDL Analysis*

### 5.2.1 Post Aerator Installation

A new aeration system was installed in LSL in June 2002. The City reported that the system ran at 15–20% capacity between September 2002 and May 2003, and at 100% capacity after June 2003. A leak in the aeration line was discovered in late February 2003 and repaired by June 2003. According to City staff, supply of reclaimed water was turned off between February 27, 2003 and June 25, 2003 to lower the water level for repair work.

Additional data were collected after completion of the Load Analysis Study. This monitoring was conducted to evaluate the condition of the lake after installation of the new aeration system. Data were collected from the lake between July 2002 and December 2003, with more frequent sampling during the summer and early fall. There was also one sampling event in early April 2002. Reclaimed water from the line feeding LSL was sampled six times between July and October 2003 (see Section 6-3). Wash monitoring was planned, however runoff events were not sampled due to their extreme flashiness. In general, there was little variation in water quality between the two main lake sites (H & I).

Similar to the 1998 data, it is apparent that significant runoff events occurred in July of each year, resulting in a significant drop of both conductivity and TDS. Between August 2002 and July 2003, the conductivity and TDS increased steadily, reflecting drought conditions. The conductivity was over 1000 uS and TDS was over 600 mg/L in early July 2003 before dilution by runoff. These values are significantly higher than those measured during the same period in 1998 (about 600 uS and 300 mg/L, respectively). The level of dissolved salts in the lake was close to that of the reclaimed water.

The turbidity values on August 12, 2002 were exceptionally high (over 300 NTU) but the corresponding TSS values were relatively low. Several reasons could account for this. For example, it was possible that the flows brought in dissolved, colored, organic material such as lignins, tannins, humic and fluvic acids, constituents that increase turbidity but not suspended solids. In general, the surface TSS and turbidity appear to be at a similar level as those in 1998.

The highest chlorophyll-a value in the 1998 data was 83 µg/L, whereas in 2002, the new data show a peak chlorophyll a value of 120 µg/L at Site I (Figure 5-5) and 174 µg/L at Site H). Just following this peak, when the algae began to die, total phosphorus also peaked (Figure 5-6). In 2003, the peak occurred in August and was substantially lower in magnitude, about 60 µg/L at both sites. Total phosphorus did not show as high a peak either, perhaps due to stepped up aeration causing faster decomposition and settling. Associated secchi depths varied between 0.2 to 0.9 m. The relationship between Secchi depth and chlorophyll-a seems to suggest an inverse but noisy relationship between the two parameters, similar to that in the 1998 data, except this time there are higher values of chlorophyll-a.

**Figure 5-5 2002-2003 Chlorophyll-a Data for Site I**

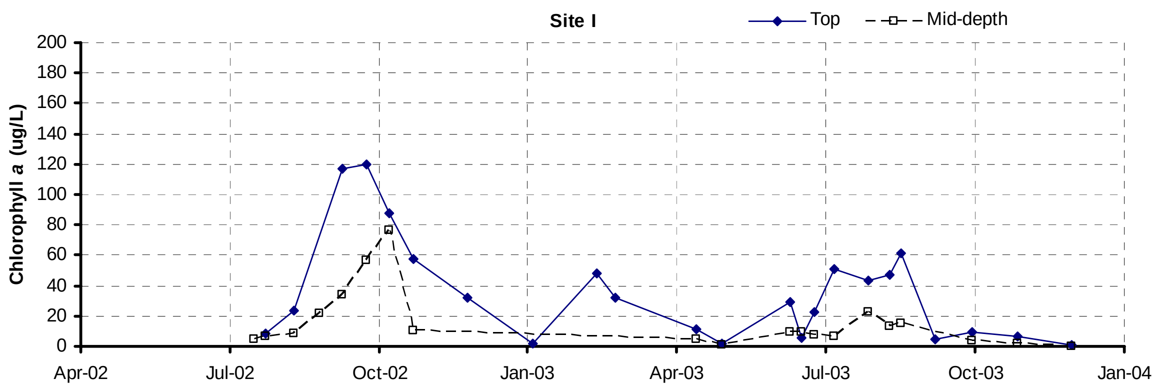
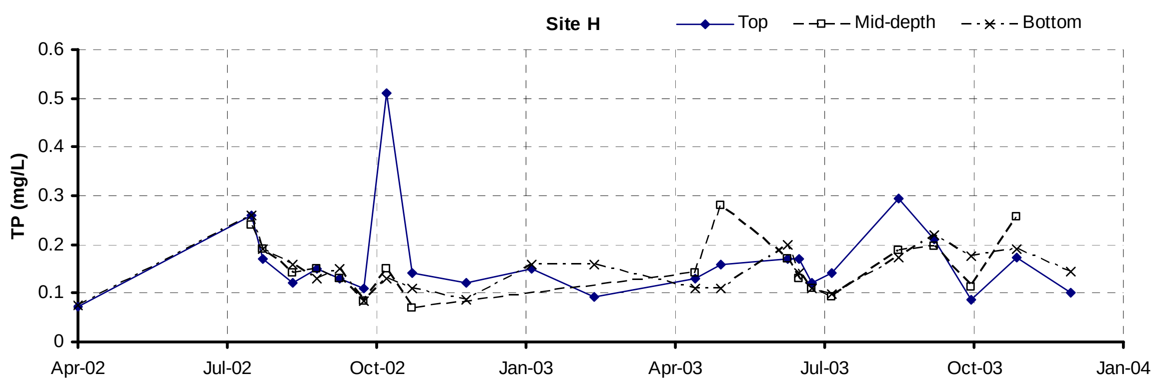
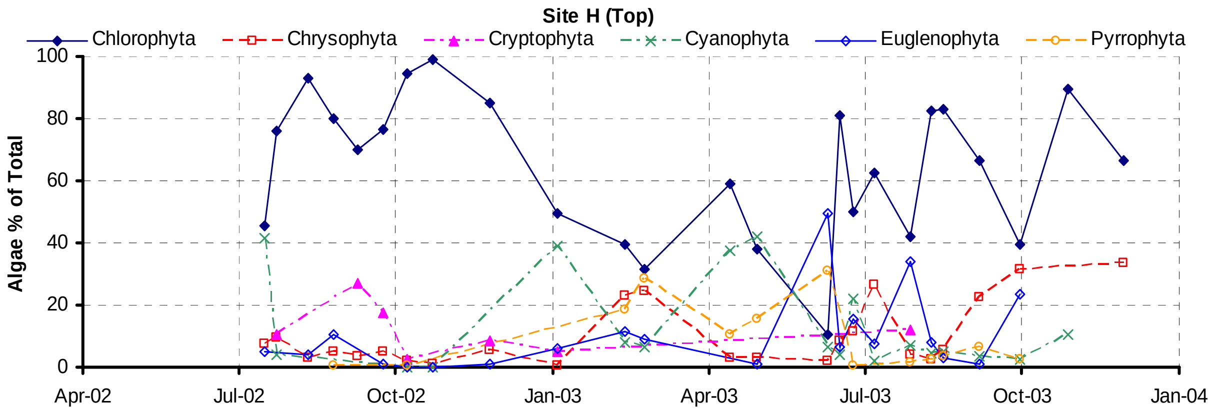



**Figure 5-6 2002-2003 Total Phosphorus Data for Site H**




The algae density data by type are shown in Figure5-7. The data track very well with the chlorophyll a data for the top depth. With a few exceptions, Chlorophyta (green algae) appears to be the dominant species throughout the monitoring period. This is somewhat different than the 1998 data in which Cyanophyta (blue/green algae) was dominant in a June algal bloom and Cryptophyta was dominant in winter. Nevertheless, the dominance of Chlorophyta seems to decrease somewhat in 2003 compared with 2002. Part of the TMDL implementation will be to manage the lake to minimize the presence of blue-green algae.



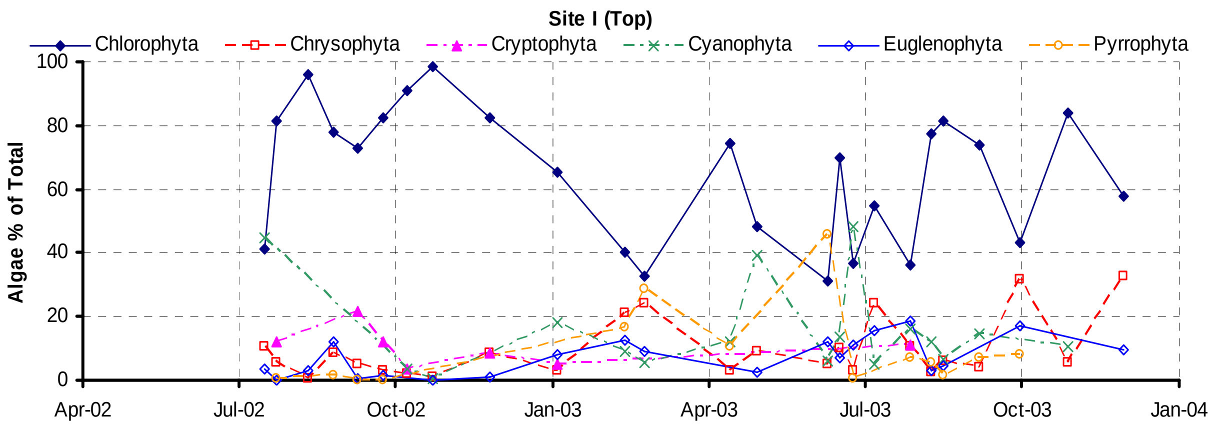
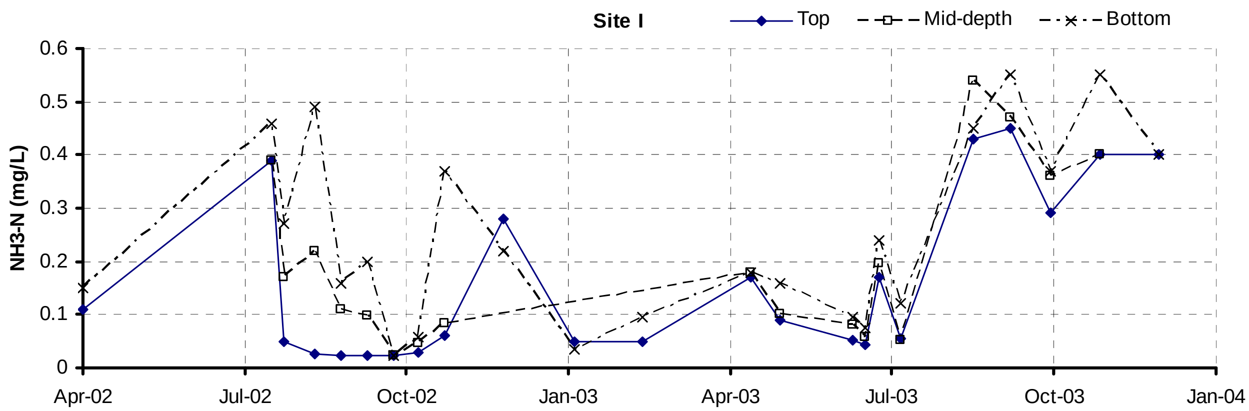



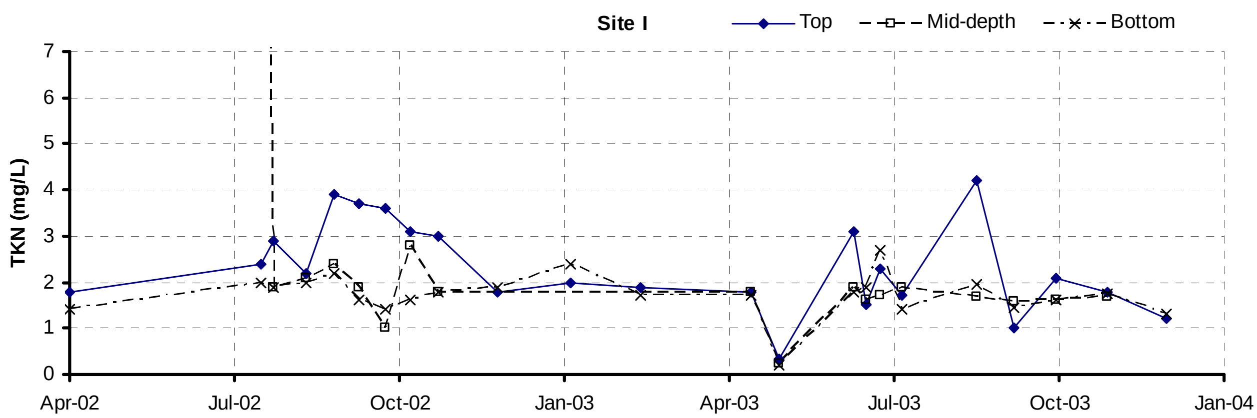

**Figure 5-7 2002-2003 Algae Species Data for Site I and Site H**

Figure 5-8 shows the ammonia nitrogen (NH3-N), total Kjeldahl nitrogen (TKN), and nitrate-nitrite nitrogen (NO3+NO2-N), respectively, for Site I. The TKN was more or less at the 2 mg/L level with occasional deviations. The NH3-N data fluctuate between a few hundredth of a mg/L to about 0.5 mg/L. There are significant fluctuations in the NO3+NO2-N levels in the lake. As in the 1998 data, the recent data again show that the lake has a large excess of nitrogen.

NH3 Data




TKN Data




NO2/NO3 Data

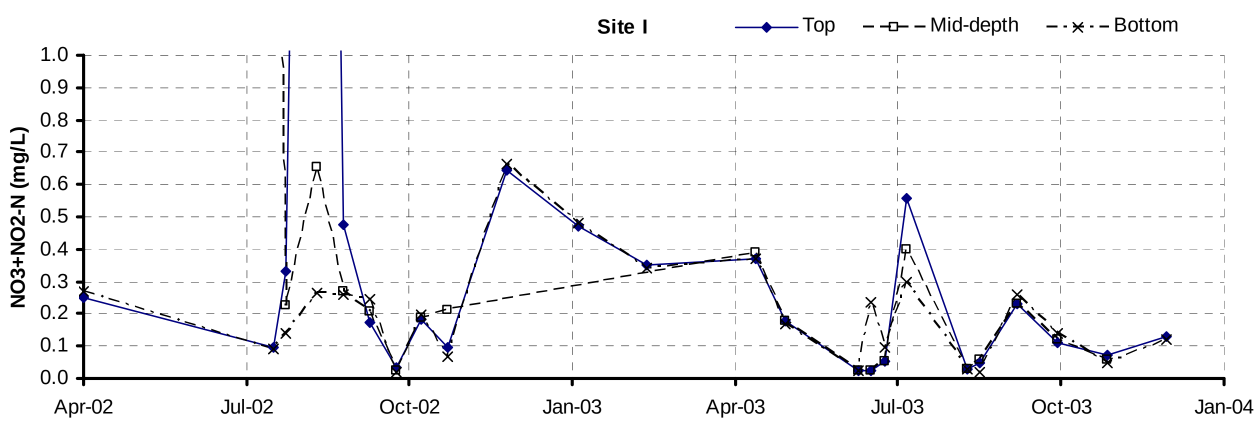
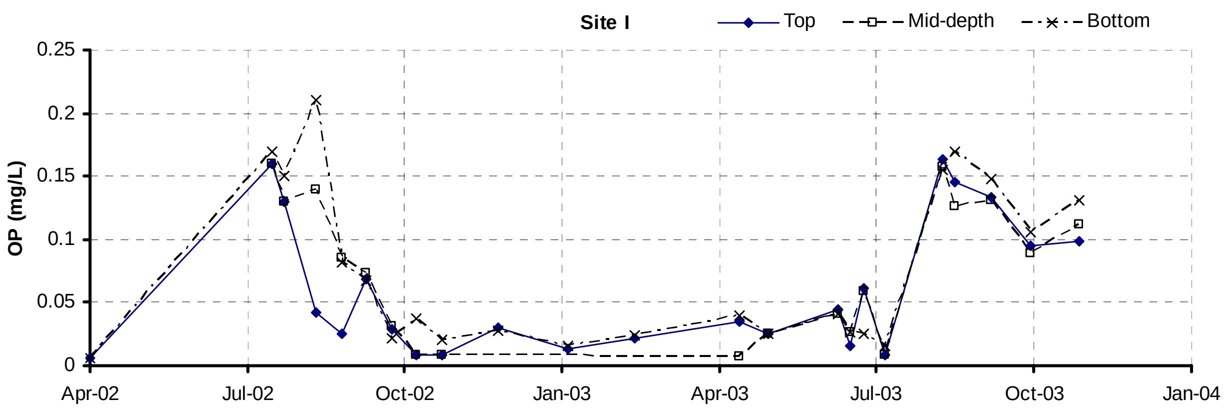



**Figure 5-8 2002-2003 Nitrogen Data for Site I**

Figure 5-9 shows the orthophosphate (OP) and total phosphorus (TP), respectively for Site I. There was a general decline in OP during fall 2002 reaching a minimum in early October, corresponding somewhat to the peak in chlorophyll a. Apparently the OP was taken up by the algae. After the algal bloom, the OP level increased somewhat but was still at relatively low level, until a significant increase occurred between early July and August. The increase was probably due to the resumed supply of the nutrient-rich reclaimed water and nutrients introduced by the runoff that caused the sharp drop in conductivity and TDS. Other than a few occasional spikes, the TP level was typically between 0.1 to 0.2 mg/L. Site H phosphorus data are similar except for an influx from Atterbury Wash in October of 2002.



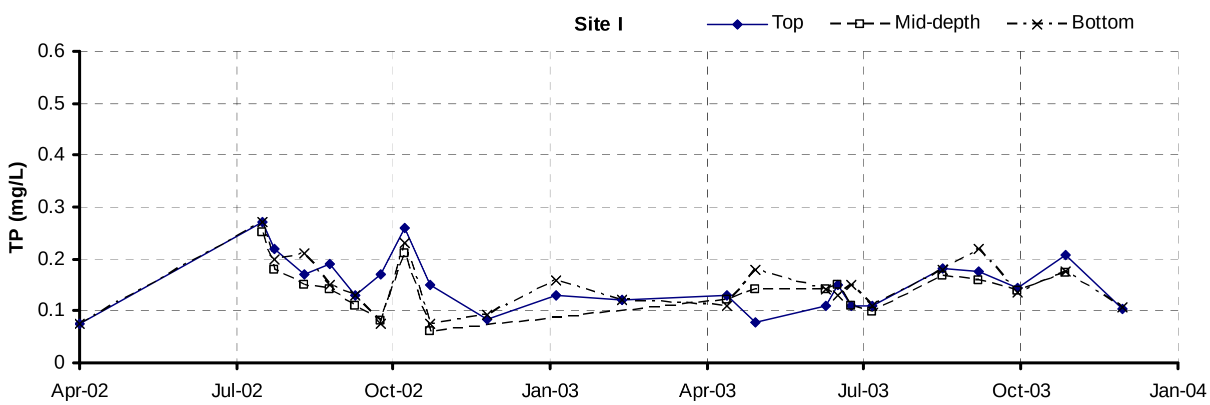




**Figure 5-9 2002-2003 Phosphorus Data for Site I**

Water temperature profiles of the two sites are almost identical. Except for slightly warmer temperatures near the surface, there was essentially no stratification. Summer pH profiles for site H and site I were also almost identical. The values varied between 7 and 9, occasionally exceeding the standard of 9 at the surface (Figure 5-10).

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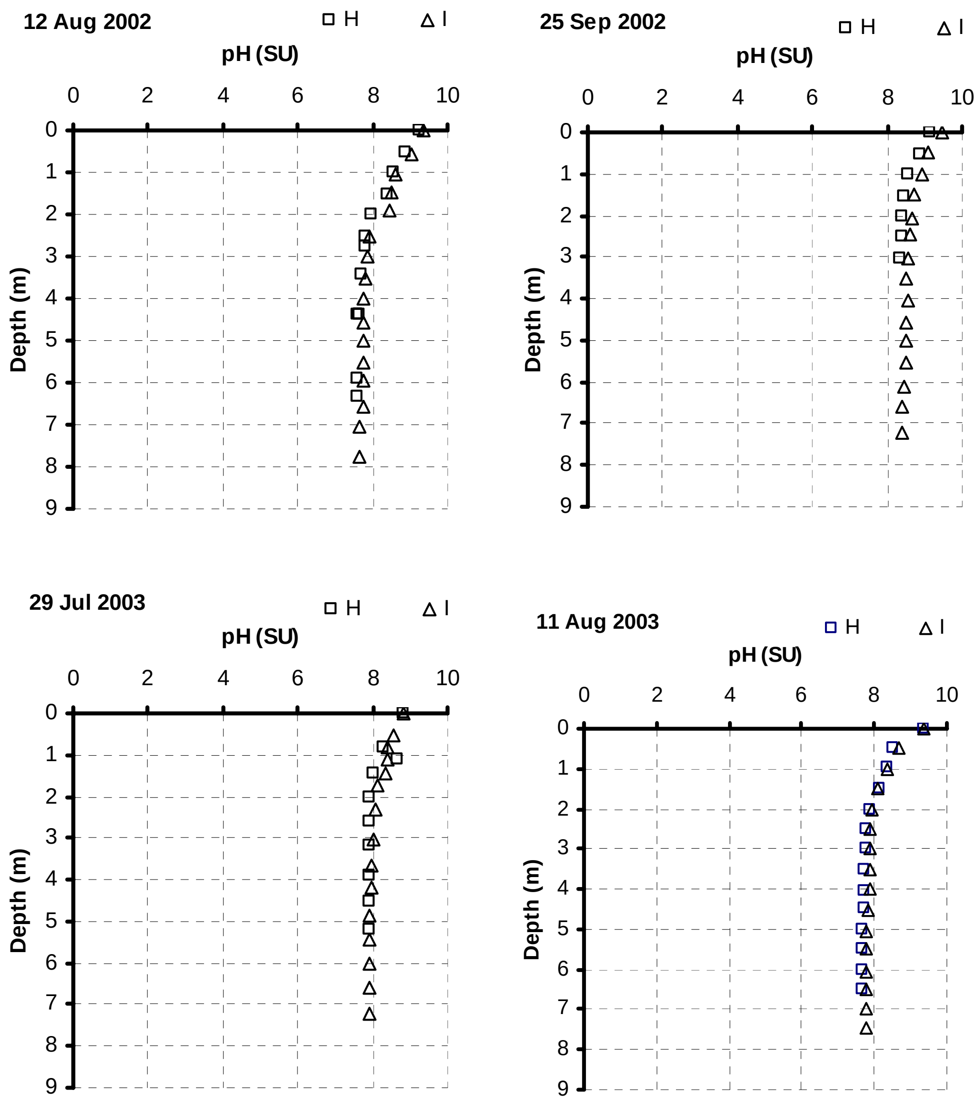


**Figure 5-10 2002 and 2003 Summer pH Exceedances**

The DO data were also similar at the two sites. The only time that the DO in the lower part of the lake was close to zero was on August 12, 2002. On the other sampling dates, the DO was at least close to or above 2 mg/L (Figure 5-11). This was significantly different than the situation in 1998. The 1998 data showed complete depletion of oxygen in the lower part of the lake in summer and occasionally in spring. Apparently, the new aeration system was able to keep the lake aerobic. From late July to October 2002 and July to August 2003, supersaturation was observed in the surface of the lake. This observation agrees with the high chlorophyll-a levels during these two periods.

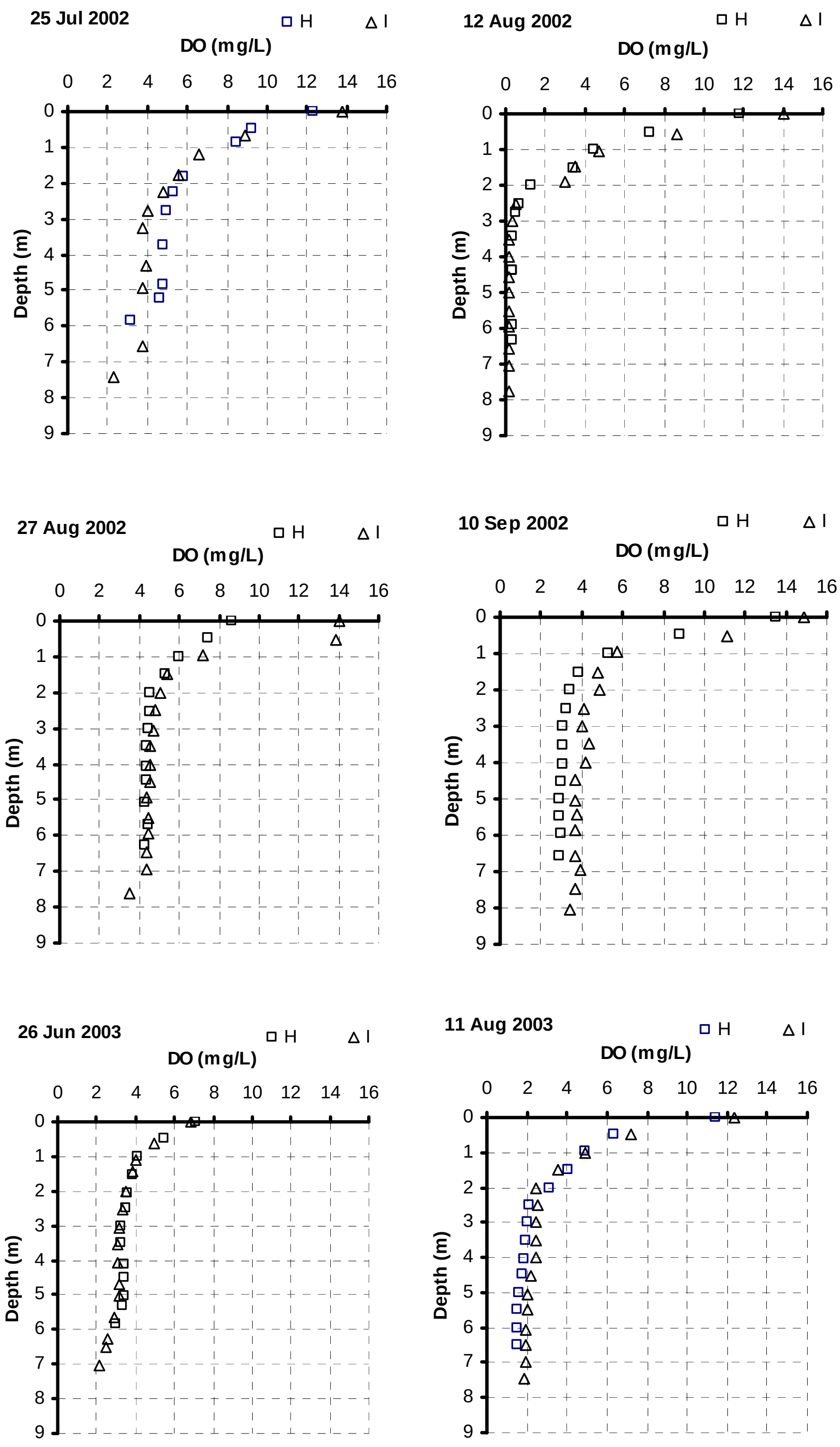


**Figure 5-11 2002 and 2003 Improvement in Summer DO**

### *5.3 2003 Reclaimed Water Quality Data*

Reclaimed water sampling was done in summer and early fall of 2003 when the temperature of the water was relatively high (up to 35 degrees Celsius). The pH was slightly above 7. The DO values were mostly about 2 or 3 mg/L. It should be noted that DO was not depleted in the long pipeline between the reclaimed water plant and the lake. The conductivity was between 1100 and 1200 uS. The data again show that the nutrient levels of the reclaimed water are very high for use as lake makeup water. The phosphorus in the reclaimed water appears to be mainly orthophosphate (Figure 5-12).

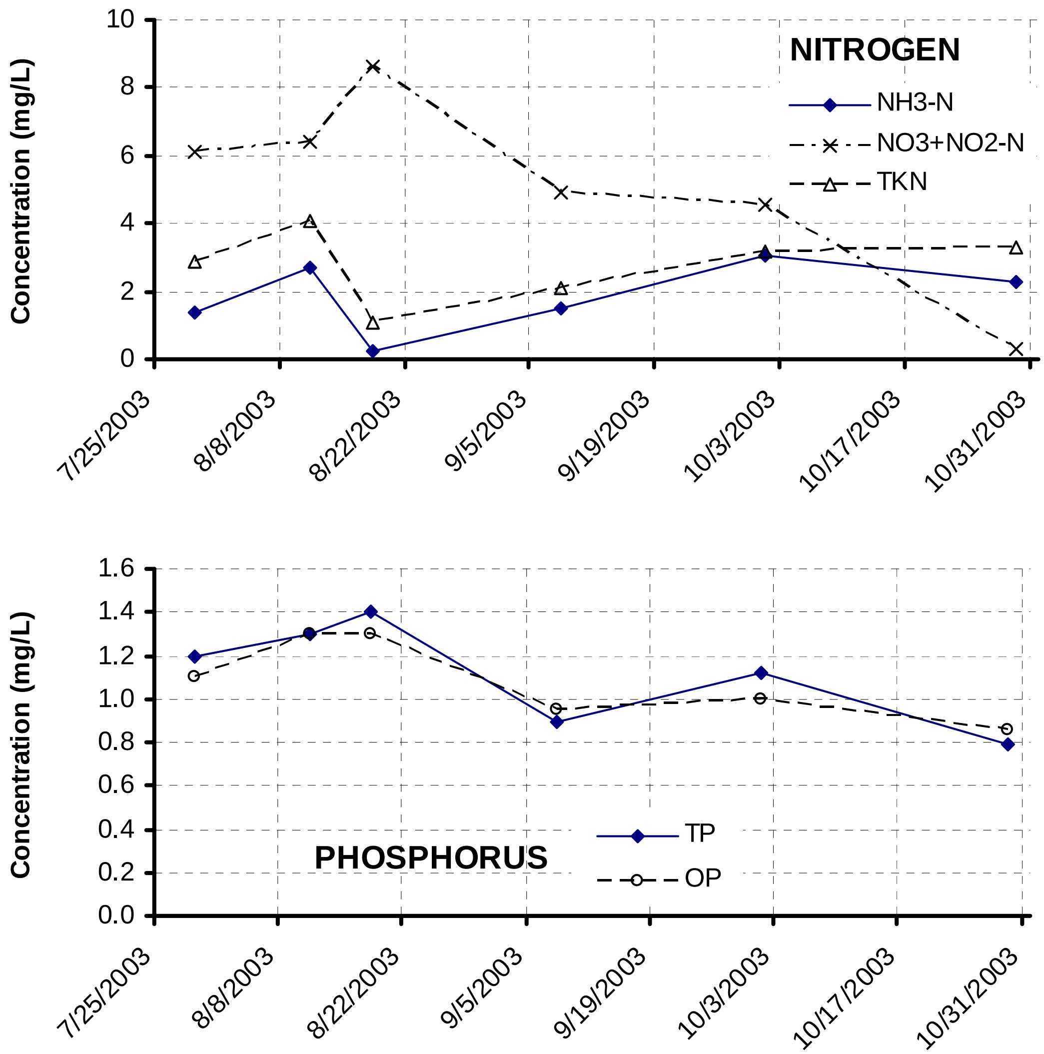


**Figure 5-12 Summer & Fall 2003 Reclaimed Nutrient Levels**

# 6.0. MODEL SELECTION, CALIBRATION & SENSITIVITY ANALYSIS

## *6.1 Model Selection*

PBS&J was tasked with selecting an appropriate modeling approach for a nutrient load analysis at LSL. Various models were reviewed and their respective assets and limitations evaluated. The following criteria were used in the model selection.

- Able to perform time-varying simulation.
- Able to simulate the dynamics of nutrients, dissolved oxygen, pH, and phytoplankton under high nutrient loading.
- Able to perform transport and mixing in vertical direction.
- In public domain.
- Has detailed documentation.
- Has proven record in lake applications.

The options were narrowed to two: WASP and CE-QUAL-W2. WASP was eliminated based on the difficulty in linking it with another hydrodynamic program, which was needed for storm water inputs. CE-QUAL-W2 version 3.0 was chosen as the receiving water model for LSL. This two-dimensional, longitudinal/vertical, hydrodynamic and water quality model was linked to HEC-1 for routing of storm water to the lake. This model combination was used both for the initial load analysis study and the recent TMDL.

## *6.2 Model Configuration*

Model geometry was based on bathymetric data obtained by the ADEQ Lakes Program in January 2002. The lake was divided into two longitudinal segments representing the north and south cells of the lake. Horizontally, the lake was divided into eight 1-meter (3.3 ft) layers. The model assumed water quality conditions to be uniform within each layer (but not between layers).

Meteorological data were obtained from the Tucson International Airport, the National Climatic Data Center and from Pima County Flood Control District. Evaporation was estimated by the model based on the meteorological data. Depending on temperature, humidity and wind speed, evaporation averages about a third of an inch per day and peaks at substantially higher rates. Direct precipitation is small compared with runoff and does not have a significant effect on model results. Therefore, direct precipitation was not modeled. Discharge data at the outlet were not available, but spills were calculated by the model in runoff events.

For the load analysis study, seepage was assumed to be negligible since the lake has a soil cement liner. However, a subsequent study was performed and the lake was found to have a seepage rate of 0.0884 to 0.1122 acre-ft/day (Willis, 2004a).

Reclaimed water use, based on monthly data, was calculated to be 45,000 gal/day and assumed to be constant over the month. The data suggest that nutrient levels are high but there are significant variations with no definite trends. Hence for the purpose of the calibration, representative values were used (refer back to Table 4-3). Constituent concentrations in runoff were taken from available data supplied by the City of Tucson Storm water Program for other urban areas, though all areas were more developed than the Atterbury Wash watershed (refer back to Table 4-4)

Very little information was available on the original aeration system installed in 1992. The description provided by the City of Tucson stated that the system was made up of perforated PVC pipe, acting as a diffuse line on the bottom of each of the two cells. Air was supplied from a compressor outside the lake, however, no information was available regarding the air flow rate or when the aerator was on. In order to model the artificial aeration, the model code was modified to include an oxygen supply in the bottom layer. In CE-QUAL-W2, coefficients for calculating the vertical eddy viscosity and diffusivity are built-in and are not parameters generally adjusted. However, in this case, in order to account for the increased vertical mixing due to the artificial aeration, the code was modified to increase the vertical eddy viscosity and diffusivity. When modeling the lake without artificial aeration, the bottom oxygen supply was turned off and the original algorithm for calculating eddy viscosity and diffusivity was used. Similar adjustments were made in order to model the increased mixing provided by the subsequent aeration system installed in 2002.

## *6.3 Model Calibration*

The model was calibrated to both the 1998 and the 2002–2003 data sets. The 1998 calibration is basically unchanged except for some adjustments made to accommodate the new model code and to be consistent with the new data. The most dramatic difference between the two data sets was the much higher chlorophyll-a concentrations observed in the fall of 2002 extending into 2003 than was seen in 1998. The reason for the much higher chlorophyll a concentrations is not known. There is a large excess of nutrients in both periods so nutrient levels do not provide an explanation.

The main difference between the two periods was believed to be the greater mixing energy of the new aerator. The effect was implemented through a lower algae and particulate organic matter settling rate. The original model calibration was modified to reflect more accumulation of oxygen demanding material in the sediment and slightly different ratios of algae, P, and N content relative to chlorophyll-a.

## *6.4 Sensitivity Analysis*

A sensitivity analysis was performed to assess the uncertainty associated with the model predictions. Individual model parameters were increased or decreased, one at a time, to evaluate their effects on the model output. Input conditions were also varied to investigate their effects. The evaluation was based on changes in the chlorophyll a level since this is one of the key water quality indicators. The analysis was done with aeration, but the conclusion would be similar without aeration, as dissolved oxygen concentration was not considered to be a good candidate for this sensitivity analysis. Interpretation of results was complicated by the limited information on the aerator.

A summary of the sensitivity analysis shows the model is most sensitive (reactive) to the maximum algal growth rate and the light extinction coefficient due to algae. The model is least sensitive to the nutrient concentrations, and coefficients that relate concentration to algal growth. The reason for this phenomenon is that there is a great excess of nutrients so that algal growth in the lake is light limited rather than nutrient limited for the entire year. Even completely removing the nutrients in runoff or reclaimed water does not appear to be sufficient to affect results in the short term. However, over time these kinds of dramatic changes in source water would have a marked effect on water quality.

# 7.0 MODELING RESULTS:

## *7.1 Initial Load Analysis*

The 1998 monthly rainfall data (Tucson International Airport) used by PBS&J showed a total annual rainfall of 13.62 inches, slightly higher than the long-term average annual of 12.00 inches for the Tucson area. Therefore, 1998 was assumed to be a wetter than average year. Inflows from Atterbury Wash were adjusted relative to gage records and reflect the average annual inflow for the period of record, or 154 ac-ft. Water quality data used to represent baseline conditions were averages of those collected in the two 1998 studies.

Without aeration, the simulated chlorophyll-a concentrations in the surface layer reached a peak of 107 *u*g/L. There was significant daily fluctuation in DO and pH frequently exceeded 9 SU between May and July. Simulation showed DO dropping in late July to 2 mg/L just one meter below the lake surface to essentially 0 at depth.

With the original air diffuser system, the model simulated chlorophyll-a at 64 *u*g/L, with a dampened swing in DO and pH. This simulation assumed optimal functionality of the system, but this had not been the case for some time. The model simulated improvements to DO and pH but underestimated projected chlorophyll-a peaks.

## *7.2 2002-2003 Data Input for the Updated (TMDL) Load Analysis*

Unlike 1998, the amount of reclaimed water used in the 2002 to 2003 period was not available, therefore the originally-provided inputs from 1994 to 2001 were used by default, except for the time period between February 27, 2003 and June 25, 2003. For this period, the City of Tucson reported that there was no reclaimed water added due to a need to draw the lake down for aerator repairs. Reclaimed water quality was sampled six times between July 2003 and October 2003. Reclaimed water nutrient concentrations for the 2002-2003 period were revised according to Table 7-1.

**Table 7-1 Constituent Concentrations* in Reclaimed Water for 2002–2003 Simulation**

| TDS | TISS [1] | OP | $NH_3$-N | $NO_3$+$NO_2$-N | LDOM[2] | DO |
|---|---|---|---|---|---|---|
| 750 | 5 | 1 | 2 | 5 | 20 | 3 |

[1] Total inorganic suspended solids * mg/L

[2] Labile dissolved organic matter

No water quality or flow data were collected from Atterbury Wash in 2002 or 2003. Like the first load analysis, Atterbury Wash runoff was first estimated based on a relationship between rainfall and flow. Starting with this relationship, the runoff volume was adjusted to provide a better agreement between modeled and measured TDS concentrations in the lake and water surface elevations. Elevations were derived from the maximum depths recorded for sample events. Runoff concentrations were the same as previously modeled.

Lake level survey data were collected by The City from April 6, 2004 to May 25, 2004. These data were used by Arroyo Engineering to conduct a leakage analysis. Arroyo concluded that the seepage rate was 0.0884 - 0.1122 acre-ft/day (Willis, 2004a). Therefore, an average value of 0.1 ac-ft/day was used in revised model calibrations.

Very little information was available on the new aerator. The modeling effort was begun assuming aerator configuration to be the same as in the initial Load Analysis model. Preliminary model results show some stratification in the lake whereas the data indicated that there was little or no stratification during that period. To better reflect the greater power of the new aerator and to better match observed data, the vertical mixing rates were increased.

### *7.3 Comparison between Measurements and Modeled Results*

This section summarizes and compares data and model results for both the 1998 and 2002–2003 periods. Referenced figures can be found in the updated in Appendix A taken from the updated “Lakeside Lake Nutrient Load Analysis”, PBJ&J, December 2004.

Each parameter had both periods represented, but as noted above, there are some major differences in the two data sets. Part of these differences can be attributed to the differences in laboratory procedures and reporting levels employed for the two data sets, and part is apparently due to the physical changes induced by the new aerator. The only difference in the modeling setup for the two periods was the changes in the settling rates for algae and particulate organic matter.

TDS concentrations and alkalinity, both conservative substances in CE-QUAL-W2, were used to assist in the water balance calibration along with water surface (Figures 3-1 and 3-2). As mentioned above, the “observed” water surface elevations were estimated from depth measurements of the deepest samples during sampling. The depths should not be regarded as completely accurate measurements of the water surface elevations, but were used to give an indication of the water levels. The agreement between model results and observations appears to be acceptable given the uncertainties in the input data.

Measurements and model results of chlorophyll-a and TSS for the two periods were compared in Figures 3-4 and 3-5, respectively. Due to unknown reasons, very low levels of chlorophyll-a were observed in July 2002 when the conditions should be favorable for algae growth. Therefore, this month was not modeled and the simulation began in mid August 2002. There are a number of discrepancies between the modeled chlorophyll-a and the observations. For example, the model does not produce the unusually large bloom in September–October 2002, and it does not reflect the low concentrations in October 2003. Due to the many factors affecting chlorophyll-a levels, this parameter is difficult to predict. Moreover, there are limitations in the model such as using a constant algal biomass to chlorophyll-a ratio whereas this ratio is known to be different for different algal species and is also known to vary over time for a given species. Nevertheless, the model gives results that are considered generally representative of LSL during two fairly different periods.

Figures 3-6 to 3-10 show the nutrient concentrations. The $NH_3$-N concentrations in Figure 3-6 are significantly lower in 2002–2003 than in 1998. One reason is possibly less sediment release of $NH_3$-N since the DO data show that with the new aerator the lake bottom was seldom anoxic. Another reason is that with lower DO levels in 1998, the rate of nitrification could have been lower than it was in 2002–2003. In the recalibration process, the nitrification rate was increased to lower the model results of $NH_3$-N. The 1998 $NH_3$-N concentrations are under-predicted by the model for part of the year, and the details of the concentration changes are not tracked well, but there is general agreement between the model and the concentration ranges during both periods.

The NO3+NO2-N data levels in the two data sets appear to be in the same range. The model tracks reasonably well, but does not match the zero values in the latter half of 1998. This may be because the model does not reduce the nitrification rate when DO levels are low. The model results of TKN in Figure 3-8 seem to match reasonably well for both periods.

The TP results in Figure 3-9 appear to follow the general trend of the data, although they appear slightly low for most of the 2002–2003 period. With OP in Figure 3-10, there is a reasonable tracking of the 2002–2003 data but poor agreement with the 1998 data in the later part of the year. Much of the problem appears to be with 1998 data, as the “zero” results do not appear to be correct. The model shows very low values in spring and early summer 2003. This is probably a result of the model simulating the OP taken up by the relatively abundant algae in that period.

Figures 3-11 to 3-13 show the measured and modeled vertical profiles for temperature, DO and pH. Since the data show that there is little variation between the northern and southern cells, only results for the northern cell are shown. There is good agreement between measured and modeled temperatures. With pH, the model results depend on the assumed values of alkalinity and total inorganic carbon in the runoff and reclaimed water. The overall agreement between measurements and model results appear to be acceptable.

The revised model was applied to the data set employed in Phase I. Figures 3-14 to 3-16 show the vertical profiles for the 1998 simulation. In general, the results of the recalibrated model appear to have the same level of agreement with observations as the previous model.

### *7.4 Calibration Discussion*

While the model does not match all parameters all the time, it does seem to cover most parameters most of the time. Given that it is simulating some very high and dynamic plankton levels with a strong excess of nutrients, and with many aspects of the input data that are only estimated values, we believe the model provides a reasonable and useful approximation of the system.

Once the model was calibrated, simulations of alternatives that will achieve water quality criteria were performed. The particular criteria under consideration are to meet the $NH_3$-N concentration required to avoid toxicity, and to meet a chlorophyll-a level that would be low enough to avoid anoxic conditions, even if the aerator were unable to maintain a sufficient concentration of DO in the water column.

# 8.0 ORIGINAL 2002 LOAD ANALYSIS

## *8.1 Alternatives Modeled*

Input parameters for the alternatives modeled are summarized in Table 8-1, taken from PBS&J, 2002. For each of the first five alternatives, simulation was performed without aeration and with the original aerator. Table 8-2, also from PBS&J, 2002, shows a summary of modeled alternatives applied to the northern cell. Without aeration, each alternative offered no lasting improvement above baseline conditions for chlorophyll-a or pH, with the exception of lower pH in CAP water. Also without aeration, all scenarios still show varying degrees of oxygen depletion in the surface layer, not meeting the standard of 6 mg/L up to 10% of the time. A lack of aeration also predicts unacceptable levels of unionized ammonia.

For air diffusion in combination with BNR, alum, or algaecide, the model predicted that chlorophyll-a could be maintained at about 65 *u*g/L (still in the hypereutrophic range). However, with only the original diffuser, all scenarios showed 10-20% of the days with a daily minimum DO in the surface layer below 6 mg/L. The CAP and new aerator scenarios predicted DO > 4 mg/L almost everywhere except for 1 mg/L at the bottom, and generally above 5 mg/L in the photic zone.

# Table 8-1 Management Alternatives Modeled for 2002 Lakeside Lake Load Analysis

**LAKESIDE LAKE MANAGEMENT ALTERNATIVES**

| Scenario | Concentrations in makeup water (mg/L) | | | | | | | | | Concentrations in runoff (mg/L) | | | | | | | | | | Remark |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TDS | TISS [1] | OP | NH3-N | NO2+ NO3-N | LDOM [2] | DO | TIC [3] | ALK [4] | TDS | TISS [1] | OP | NH3-N | NO2+ NO3-N | LDOM [2] | LPOM [5] | DO | TIC [3] | ALK [4] | |
| Baseline | 600 | 5 | 1 | 8 | 3 | 20 | 0 | 50 | 200 | 160 | 130 | 0.05 | 0.1 | 0.2 | 10 | 10 | 7 | 30 | 100 | |
| Reclaimed water with biological nutrient removal | 600 | 5 | 0.4 | 6 | 2 | 15 | 0 | 50 | 200 | 160 | 130 | 0.05 | 0.1 | 0.2 | 10 | 10 | 7 | 30 | 100 | |
| Wetland in the Wash | 600 | 5 | 0.25 | 1 | 1 | 5 | 0 | 50 | 200 | 160 | 130 | 0.05 | 0.1 | 0.2 | 10 | 10 | 7 | 30 | 100 | |
| Low nutrient water makeup (CAP water) | 600 | 2 | 0.01 | 0.01 | 0.2 | 2 | 8 | 50 | 140 | 160 | 130 | 0.05 | 0.1 | 0.2 | 10 | 10 | 7 | 30 | 100 | |
| Lake alum treatment | 600 | 5 | 1 | 8 | 3 | 20 | 0 | 50 | 200 | 160 | 130 | 0.05 | 0.1 | 0.2 | 10 | 10 | 7 | 30 | 100 | Applied alum at beginning of each month, assumed 30% removal of algae and 80% removal of OP. |
| Lake algaecide treatment | 600 | 5 | 1 | 8 | 3 | 20 | 0 | 50 | 200 | 160 | 130 | 0.05 | 0.1 | 0.2 | 10 | 10 | 7 | 30 | 100 | Applied algaecide and re-start simulation with initial chlorophyll a of 10 ug/L. |
| New aerator | 600 | 5 | 1 | 8 | 3 | 20 | 0 | 50 | 200 | 160 | 130 | 0.05 | 0.1 | 0.2 | 10 | 10 | 7 | 30 | 100 | Mixing in upper part of lake and oxygen supply in lower part of lake. |
| Well water | 322 | | <0.24 | | 1.8 | | | | 130 | | | | | | | | | | | Average values provided by City of Tucson. This scenario not simulated. See Section 5.3.5. |

[1] TISS Total inorganic suspended solids.
[2] LDOM Labile dissolved organic matter.
[3] TIC Total inorganic carbon.
[4] ALK Alkalinity

Table 8-2 2002 Model Results with and without Aeration

| Scenario | Without aeration | | | | | | | With aeration (existing aerator except for new aerator alternative) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Peak daily average chl a conc (ug/L) | Percentage of days | | | | | | Peak daily average chl a conc (ug/L) | Percentage of days | | | | | |
| | | Daily max pH > 9 | Daily min DO in surface layer < 6 mg/L | Daily min DO in surface layer < 4 mg/L | Daily min DO in 4th layer < 4 mg/L | Daily min DO in bottom layer < 1 mg/L | Daily max unionized NH3-N in surface layer > 0.02 mg/L | | Daily max pH > 9 | Daily min DO in surface layer < 6 mg/L | Daily min DO in surface layer < 4 mg/L | Daily min DO in 4th layer < 4 mg/L | Daily min DO in bottom layer < 1 mg/L | Daily max unionized NH3-N in surface layer > 0.02 mg/L |
| Baseline | 109 | 28% | 9% | 0% | 94% | 100% | 100% | 65 | 0% | 19% | 0% | 21% | 22% | 100% |
| Reclaimed water with biological nutrient removal | 109 | 33% | 9% | 0% | 94% | 100% | 100% | 65 | 0% | 19% | 0% | 17% | 16% | 100% |
| Wetland in the Wash | 109 | 38% | 7% | 0% | 93% | 100% | 100% | 56 | 0% | 14% | 0% | 8% | 13% | 88% |
| Low nutrient water makeup (CAP water) | 90 | 2% | 5% | 0% | 93% | 100% | 99% | 42 | 0% | 10% | 0% | 0% | 0% | 34% |
| Lake alum treatment | 104 | 45% | 9% | 0% | 93% | 100% | 100% | 66 | 0% | 17% | 0% | 12% | 15% | 100% |
| Lake algaecide treatment | 96 | 29% | 8% | 0% | 94% | 100% | 100% | 64 | 0% | 17% | 0% | 10% | 10% | 100% |
| New aerator | | | | | | | | 54 | 0% | 6% | 0% | 0% | 0% | 100% |

Note:
Period of simulation is from April through September, total of 183 days.

### *8.2 Analysis Summary*

Table 8-3 shows the annual nutrient loads in makeup water and runoff for the baseline and each of the alternatives. The loads were calculated based on the concentrations and the annual volumes of makeup water and runoff in the model for the average baseline year. The loads in the runoff for all the alternatives were the same as those in the baseline. It can be seen that with the baseline alternative, the reclaimed water load was dominant. In the alum, algaecide, and new aerator alternatives, the lake would continue to receive reclaimed water. Therefore, the loads in the makeup water were the same as those in the baseline. In the BNR and wetland alternatives, a portion of the nutrients in the reclaimed water were removed. The CAP water alternative had the lowest loads in the makeup water.

Based on available storm water data, the CAP water alternative was the only alternative for which the runoff loads are higher than the makeup water loads. It should be noted that this analysis was based on a relatively wet year, i.e., runoff contributions were above average in 1998. The impact of a series of dry years on lake water quality would mean that more reclaimed water would be added to maintain lake volume, thus affecting loading outcomes. This point was moot, as the CAP alternative was not seriously considered due to financial and logistic constraints.

Another potentially important source of nutrients for algal growth was lake sediment. Sediment contribution of nutrients was simulated in two ways in the model. When DO in the overlying water was below 0.1 mg/L, phosphorus and ammonia were assumed to be released at a constant rate. When the bottom water was aerobic, the decay of organic matter accumulated in the sediment was assumed to contribute nutrients but at a much reduced rate. The annual loads of $NH_3$-N and OP released from the sediment under anoxic conditions (non-aerated) were about 390 kg/yr and 50 kg/yr respectively. Under aerobic conditions, the annual loads of $NH_3$-N and OP contributed by decay of organic sediment were about 70 kg/yr and 3 kg/yr respectively, significantly lower than the loads in the reclaimed water.

### *8.3 Review of Initial Test Remedy*

ADEQ and the City of Tucson agreed to test the effects of the new aeration system for at least one year. Installation of the new aerators occurred in June 2002 and in-lake monitoring began in July 2002. Monitoring was conducted bi-weekly through the summer and fall and weekly during the following spring and summer (2003).

EPA Region IX supported the improved aeration system for improving low dissolved oxygen in the lake, but did not approve the initial Load Analysis Study as a TMDL. EPA directed ADEQ to revisit the analysis and derive actual nutrient load reductions to attain water quality standards. The remainder of this document discusses updates to the Load Analysis, additional alternatives considered and modeled, actual load reductions for phosphorus in reclaimed water, and quantitative load allocations for both phosphorus and nitrogen, which will become conditions of AZPDES approval.

## Table 8-3 2002 Load Analysis Summary

**Loads in kg/year**

| Scenario | OP | | NH3-N | | NO2+NO3-N | | LDOM [1] | |
|---|---|---|---|---|---|---|---|---|
| | Makeup | Runoff | Makeup | Runoff | Makeup | Runoff | Makeup | Runoff |
| Baseline | 46.7 | 9.3 | 373.5 | 18.6 | 140.1 | 37.2 | 933.7 | 1860.0 |
| | *56.0* | | *392.1* | | *177.3* | | *2793.7* | |
| Reclaimed water with biological nutrient removal | 18.7 | 9.3 | 280.1 | 18.6 | 93.4 | 37.2 | 700.3 | 1860.0 |
| | *28.0* | | *298.7* | | *130.6* | | *2560.3* | |
| Wetland in the Wash | 11.7 | 9.3 | 46.7 | 18.6 | 46.7 | 37.2 | 233.4 | 1860.0 |
| | *21.0* | | *65.3* | | *83.9* | | *2093.4* | |
| Low nutrient water makeup (CAP water) | 0.5 | 9.3 | 0.5 | 18.6 | 9.3 | 37.2 | 93.4 | 1860.0 |
| | *9.8* | | *19.1* | | *46.5* | | *1953.4* | |
| Lake alum treatment | 46.7 | 9.3 | 373.5 | 18.6 | 140.1 | 37.2 | 933.7 | 1860.0 |
| | *56.0* | | *392.1* | | *177.3* | | *2793.7* | |
| Lake algaecide treatment | 46.7 | 9.3 | 373.5 | 18.6 | 140.1 | 37.2 | 933.7 | 1860.0 |
| | *56.0* | | *392.1* | | *177.3* | | *2793.7* | |
| New aerator | 46.7 | 9.3 | 373.5 | 18.6 | 140.1 | 37.2 | 933.7 | 1860.0 |
| | *56.0* | | *392.1* | | *177.3* | | *2793.7* | |

**Loads in lbs/day**

| Scenario | OP | | NH3-N | | NO2+NO3-N | | LDOM [1] | |
|---|---|---|---|---|---|---|---|---|
| | Makeup | Runoff | Makeup | Runoff | Makeup | Runoff | Makeup | Runoff |
| Baseline | 0.28 | 0.06 | 2.25 | 0.11 | 0.84 | 0.22 | 5.63 | 11.21 |
| | *0.34* | | *2.36* | | *1.07* | | *16.84* | |
| Reclaimed water with biological nutrient removal | 0.11 | 0.06 | 1.69 | 0.11 | 0.56 | 0.22 | 4.22 | 11.21 |
| | *0.17* | | *1.80* | | *0.79* | | *15.43* | |
| Wetland in the Wash | 0.07 | 0.06 | 0.28 | 0.11 | 0.28 | 0.22 | 1.41 | 11.21 |
| | *0.13* | | *0.39* | | *0.51* | | *12.62* | |
| Low nutrient water makeup (CAP water) | 0.00 | 0.06 | 0.00 | 0.11 | 0.06 | 0.22 | 0.56 | 11.21 |
| | *0.06* | | *0.11* | | *0.28* | | *11.77* | |
| Lake alum treatment | 0.28 | 0.06 | 2.25 | 0.11 | 0.84 | 0.22 | 5.63 | 11.21 |
| | *0.34* | | *2.36* | | *1.07* | | *16.84* | |
| Lake algaecide treatment | 0.28 | 0.06 | 2.25 | 0.11 | 0.84 | 0.22 | 5.63 | 11.21 |
| | *0.34* | | *2.36* | | *1.07* | | *16.84* | |
| New aerator | 0.28 | 0.06 | 2.25 | 0.11 | 0.84 | 0.22 | 5.63 | 11.21 |
| | *0.34* | | *2.36* | | *1.07* | | *16.84* | |

[1] LDOM Labile dissolved organic matter.
[2] LPOM Labile particulate organic matter.
[3] Concentrations are shown in Table 5-4.
[4] Annual volume of makeup water is 37.8 ac-ft.
[5] Annual volume of runoff is 150.6 ac-ft.
[6] Italicized value is sum of loads in makeup water and runoff

# 9.0 UPDATED 2004 LOAD ANALYSIS AND TMDL

## *9.1 Nutrient Reduction Scenario Evaluations*

With the model calibrated to a reasonable degree to both 1998 and 2002–2003 data, three broad areas of nutrient removal were evaluated: P removal from reclaimed water, use of groundwater, and alum treatment of the lake. Within the category of treatment of the reclaimed water, four levels of treatment and cost were considered. All scenarios were simulated with the new aeration system in operation.

### 9.1.1 Baseline

The baseline condition established in the initial Load Analysis was used for comparison of the various nutrient reduction scenarios. The baseline approximates the long-term average rainfall pattern for the area. In the initial Load Analysis, the annual runoff volume used was 150.6 ac-ft. This was approximately the average annual runoff of the flow record between 1976 and 1982 at the USGS gage 09485390 that is no longer in service.

For the subsequent analysis, the City provided clarification that the old USGS gauge was actually positioned on Kinnison Wash, which confluences with Atterbury Wash just downstream of Lakeside and drains only 4.97 sq. miles as opposed to Atterbury Wash, which drains over 12 square miles. The baseline average annual storm inflow has been revised based on water balance data from 1993 to 1999 to 70 ac-ft. The estimate was based on assuming the lake did not overflow. Considering that some overflow probably occurred during that time, the 70 ac-ft as an average value may be low but is at least reasonable given estimates for reclaimed inflow to Lakeside: 29.8 to 45 acre-ft. A daily input rate for each month was calculated based on the monthly volume and assumed to be constant over the month.

The baseline weather includes summer monsoon rains, but does not include major runoff events. As recently as August 2004, a large runoff event introduced a substantial amount of sediment and oxygen demanding material. The runoff oxygen demand load, combined with reduced light transmission and photosynthesis, resulted in very low lake DO levels and a fish kill. This special situation is not part of the baseline simulations, but is discussed in the next section.

### 9.1.2 Management Alternatives

This section briefly describes the alternatives considered. The next section presents model results for these alternatives. In modeling the following cases, the phosphorus concentrations in the reclaimed water input was changed to the values discussed for each, while concentrations of the other parameters were kept the same as in the baseline.

**P Removal from Reclaimed Water (Scenario 1)**
Current TP levels in the reclaimed water are in the 1–2 mg/L range, much of this in the dissolved bioavailable form. A package plant that doses with an alum-polymer, provides mixing and time for coagulation to occur, and then filters out the floc or particulate matter, could be expected to remove a large percentage of the P. Alum addition converts soluble P into an insoluble salt that can be removed by settling or filtration.

Design details include 1) the dosage rate of alum and polymer, 2) what type of filter to use, and 3) disposal of the filter backwash. These details can be expected to control the performance of the small plant. Following are options provided for regulatory review and consideration:

- The first level of treatment **(Scenario 1a**) would involve a modest alum dose rate and use of sand filters. A TP concentration of 0.2 mg/L is a level commonly achieved in domestic wastewater treatment that should be workable as a target for on-site treatment. However, the operational challenges of managing a small facility in intermittent use should not be ignored. For the purpose of modeling, all the 0.2 mg/L of TP was assumed to be in the dissolved form (modeled as ortho-phosphorus or "OP")**.**

- A reasonably good level of TP removal should be achieved with considerably less investment and operational expense with a modest alum dosing applied to the reclaimed water followed by an opportunity for floc formation before the water is introduced to the lake. This option would be somewhat less effective than installation of a package plant treatment with filtration. Based on that judgment, a TP target level of 0.4 mg/L was assumed in the reclaimed water for this option **(Scenario 1b)**. The main advantage would be that the cost of filtering and sludge disposal could be avoided**.**

- A greater level of TP removal **(Scenario 1c**) can be achieved with a higher dosage of alum and use of microfiltration. A high level of filtration that yields essentially no particulate matter will limit the TP to that in the dissolved form. The practical limit for alum removal of dissolved P is about 0.02 mg/L. Adding this level of solids removal would add markedly to the operational cost, but has been reported to achieve a TP level of 0.02 mg/L .

- The ultimate level of treatment **(Scenario 1d)** would be reverse osmosis, where essentially all dissolved solids are removed yielding a high quality water. Essentially, this would produce water without TP, but the cost has been estimated to be on the order of $1,000-$2,000 per ac-ft; or $50,000-$100,000 a year. This estimate may still be low as there is no specific allowance for the pre-treatment that would be needed with a wastewater source, and the remote location and intermittent operation would also add to costs.

**Replace Reclaimed Water with Groundwater (Scenario 2)**

This alternative is relatively simple. According to the City of Tucson, up to 50 gallons per minute (2.16 MG or 6.6 acre-ft/month) of groundwater can be obtained from a local well. This would be generally sufficient to support the lake level in winter months, but would need to be supplemented with reclaimed water at times of high demand in the summer months. The TP concentration of this groundwater is not known with confidence. Limited testing with an analytical testing method sufficient to provide meaningful results, suggested a concentration of approximately 0.014 mg/L would result from use of the well. The dollar cost of operating the well is not known, but is presumably fairly minor. A bigger concern will be the issue of consistency with groundwater protection requirements.

In modeling this case, the amount of groundwater used was assumed to be the same as the amount of reclaimed water used in the baseline. Concentrations of various parameters were replaced with values from groundwater data supplied by the City of Tucson. The phosphorus level was input at 0.014 mg/L in the dissolved form.

**Alum Treatment of Lake (Scenario 3)**

Reducing P levels in the lake can be achieved with in-lake alum application and allowing the coagulated material to settle to the bottom. This would have the advantage of being able to respond to P coming in via runoff and also be able to address P in the reclaimed water. However, it may not be as efficient as applying the same amount of alum to the reclaimed water. The P in the lake is at a much lower concentration than the reclaimed water and much of the alum would be consumed in flocculating other substances. A direct application can produce a one-time reduction in P, but would have limited long-term effect.

**Scenario 3a** would involve a yearly application of alum at an assumed rate of 10 mg/L for the lake at some time in the summer. The actual application concentration would have to be determined through laboratory testing. For this scenario, it is assumed that at this dose rate 80% of the available P and 30% of the existing phytoplankton will be removed from the lake water column. The amount of alum involved to dose the entire lake to 10 mg/L is not inconsequential. The lake volume of 150 ac-ft or 49 million gallons would require 490 gallons of powdered aluminum sulfate or almost 1000 gallons if the liquid form was applied (liquid alum consists of only about 50% aluminum sulfate). Due to extensive mixing required to dissolve powdered alum, liquid alum is generally preferred for this type of application. At an approximate cost of $3/gallon ($150/55-gallon drum, Bay Chemicals, 2004), this might not be a prohibitive cost each year. However, the labor costs for applying the material by boat may be more significant.

Another option **(Scenario 3b)** is to apply alum to the lake as needed taking advantage of the water circulation provided by the new aerator. New alum piping can be placed parallel to the existing air pipes and alum fed to each diffuser for mixing in the lake. The new aeration system consists of a large air compressor on shore that feeds separate surface and bottom units in both the north and south compartments of the lake.

A major challenge for this option will be to estimate the effect of a specific dose rate and control mechanism, and then translate that into a removal process in the model. Because alum will act to flocculate many things, including plankton cells and runoff material introduced from Atterbury Wash, it is almost impossible to predict how much of the available P would be removed by a given dose of alum at any one time. It is likely that the only practical way to proceed will be with an initial series of laboratory “jar tests” that are used to determine an application rate that achieves the best results at the lowest cost. After the selected amount is applied, monitoring would be needed to assess effects and determine when additional application might be needed.

### *9.2 Updated Model Results and Evaluation*

For each scenario, the model was run for several years with identical input data repeating every year until an equilibrium condition was reached. Equilibrium was assumed when there was no significant difference between results of two consecutive years. Usually equilibrium was reached in the second or third year of simulation. Results in the third year of simulation are presented later for each alternative. In this way, results are compared on the same basis (Figures from the updated Load Analysis Study, PBS&J, 2004, Appendix B).

Figure 4-1 shows the midday model results of chlorophyll-a for the baseline and scenarios 1a, 1b, 1c, 1d and 2. If the target for chlorophyll-a is 50 µg/L, it appears that alum treatment resulting in TP of 0.2 mg/L in the reclaimed water will accomplish this target and there is not much to gain reducing the TP to very low level. Using groundwater will also result in chlorophyll-a concentration below 50 µg/L. The 1b alternative of simply adding alum to the reclaimed water and allowing settling to occur in the lake (assumed concentration of 0.4 mg/L) also meets the target but with a smaller margin.

Figure 4-2 shows the OP concentrations for the baseline. Year to year variation could be significant, but with the conditions modeled, OP is already very low between mid March and mid July. Apparently the OP from the reclaimed water is taken up by the algae and the concentration in the lake remains low in this situation. An alum treatment of the lake would not be useful during this period. Therefore, the alum treatment was applied in mid August.

It was assumed that this treatment would reduce the OP in the lake by 80% and the algae by 30%. Figure 4-3 shows the results of Scenarios 3a. Compared to the baseline, the alum treatment removes the peak in chlorophyll-a between late August and early September. The chlorophyll-a level in the rest of the year is also lower, but not to a large degree. By July and early August of the following year, the chlorophyll-a level is essentially the same as the baseline. The model results illustrate that the treatment is effective in the short term, but has very limited long-term effect. No attempt was made to model Scenario 3b due to uncertainties in the removal process as discussed above. However, it is reasonable to assume that having the ability to dose with alum as needed (in the lake) at a fairly modest cost will allow more accurate control of lake conditions. This could include dosing immediately after a large runoff event or when bloom conditions are encountered. Greater control should translate to an overall improvement in water quality.

Another concern for LSL is ammonia toxicity. The acute and chronic criteria for total ammonia (in mg N/L) are given in 18 A.A.C. 11, Article 1, Appendix A, Table 24 and 25, respectively. The acute criteria depend on pH and the chronic criteria depend on both pH and water temperature. Figure 4-4 shows the NH3-N model results at midday and the corresponding chronic criteria calculated from the modeled pH and water temperature. All the results are below chronic criteria. Since acute criteria are higher than chronic, the results are also below acute criteria.

### *9.3 Linkage Analysis & Numeric Targets Revisited*

Developing detailed design or cost information was not part of the study scope of work, but a brief discussion has been provided. It appears that the least expensive option would be alum addition to the reclaimed water stream, with provision for mixing prior to introduction to the lake. The overall effectiveness is not known and laboratory testing would be needed as part of design work. However, with an assumed reduction in the reclaimed water concentration down to 0.4 mg/L, the target of 50 µg/L chlorophyll-a under baseline conditions would be potentially achievable.

Treating the reclaimed water to higher levels or use of groundwater (at the assumed concentration based on a single observation) would all appear to be effective but at a much higher cost. The major limitation for all of the scenarios that only address reclaimed water is that they do not have a provision to deal with short-term and unusual events. While the major P source is now from reclaimed water, runoff events can bring large loads in a short time. The baseline condition was selected to represent typical conditions but does not include large runoff events like that seen in July 2004, or algal blooms like was observed in the fall of 2002. These situations appear to be common enough to be a concern, and may require actions to address the entire lake rather than just the P in the reclaimed water. To address these situations, alternatives 3a or 3b, applying alum to the entire lake, would be required.

Comparing scheduled yearly operations (3a) with on-demand operation with mixing and distribution provided by the aeration system (3b), there would appear to be a clear advantage for 3b in flexibility and ability to respond and in reduced personnel requirements. There would be a higher initial cost for alum piping and onshore tankage, but this should be recovered quickly with reduced personnel costs and possibly reduced alum usage.

A concern that is sometimes raised with the use of alum is an increase in settling and more rapid accumulation of sediment in the lake. In LSL this should not be a concern because almost all of the solids that enter the lake are already removed by settling**.** Only in very large runoff events are solids carried out of the lake. To the extent that alum reduces the amount of plankton produced, there may actually be a reduction in the amount of organic matter that settles to the bottom.

Another concern is toxicity. While alum itself is not particularly toxic, it is acidic and can lower the pH if sufficient alkalinity is not present. This should not be a concern as LSL waters appear to have substantial alkalinity at this time. If it becomes a concern it may be necessary to compliment alum with a source of alkalinity such as lime or sodium hydroxide. A related point is aluminum toxicity. Some states have numerical criteria for aluminum that might pose a limitation on its use. However, Arizona does not currently have a criterion for aluminum.

The numeric targets for this TMDL are listed in Table 9-1 below and express both numeric criteria and narrative thresholds. Apart from ammonia-nitrogen, other nitrogen species are not specifically called out as thresholds but will be incorporated in the TMDL monitoring plan.

**Table 9-1 TMDL Numeric Target Endpoints**

| TARGET | TYPE of TARGET | THRESHOLD |
|---|---|---|
| Dissolved oxygen | Numeric | 6.0 mg/L within top meter |
| Dissolved oxygen | Narrative nutrient | 2.0 mg/L at depth; positive ORP |
| pH | Numeric | 6.5-9.0 S.U. at all depths/all times |
| Reclaimed NH3-N | TMDL | 2 mg/L |
| In-lake ammonia | Numeric | pH & temperature-based |
| Reclaimed NO2+NO3-N | TMDL | 5 mg/L |
| In-lake nitrate | None | NA |
| Chlorophyll-a | Narrative nutrient | 50 ug/L peak, April-October |
| Reclaimed total phosphorus | TMDL | 0.4 mg/L |
| In-lake ortho-phosphorus | TMDL | 0.009 mg/L peak, April-October |

## *9.4*

## *TMDL Calculations*

The previous section indicates that it would be possible to reduce significantly the peak chlorophyll-a concentrations by removing P chemically from either the reclaimed water or from the lake itself. This section puts the alternatives on a load basis and provides the recommended TMDL for Total and Ortho-phosphorus. Nitrogen loads, DO levels, and the case of reclassifying LSL as effluent-dependent water (EDW) are also discussed.

Table 9-2 provides a summary of the annual OP loads to the lake for an average year and also for wet and dry years. The flow record between 1976 and 1982 at the USGS gage 09485390 were used to identify the wet and dry years, which are 1982 and 1979, respectively. The runoff volumes to LSL were estimated by applying a factor of 0.47 to the annual flow volume recorded at the USGS gage. (Refer back to Section 5.1 for a discussion of the runoff to LSL.) The average, wet, and dry makeup water loads were selected from the period when reclaimed water use data were available, 1993–2000. Because the data periods for the two inflow sources do not overlap, the values are not necessarily consistent. For example, with a wet year total runoff of 168 ac-ft, the need for reclaimed water could have been smaller (if the runoff was well distributed through the year) or larger (if the runoff all occurred in one event and it was dry for the rest of the year).

The loads are presented for each scenario evaluated. The annual alum application (3a) alternative is estimated to remove 80% of the OP in the lake at the time of application. Sediment release of OP is not considered in this analysis because one of the effects of the new aeration system has been to maintain DO in bottom waters most of the time.

### 9.4.1 Phosphorus Loading

The objective of this section is to make an initial effort needed to address the allowable P load using the TMDL allocation equation:

$$TMDL = WLA + LA + MOS$$

where TMDL is the load of P that can be accommodated and still meet the water quality targets or criteria: chlorophyll-a of 50 ug/L, minimum dissolved oxygen of 2 mg/L, pH between 6.5 and 9.0 S.U., and ammonia levels below the chronic toxicity value based on pH and temperature. WLA is the waste load allocation for point sources, LA is the load allocation considering background and non-point sources, and MOS is the margin of safety. From Table 10-2, the makeup water is the WLA term and runoff is the LA term. The unknown is the MOS to be applied.

Alternative 1b will be used for estimating the TMDL. The total load for the average year would be 0.139 lb/day (sum of makeup water load of 0.113 lb/day and runoff load of 0.026 lb/day). There is an implicit MOS due to the conservative assumption of using the maximum annual volume of reclaimed water in the simulation and the fact that the simulation results show the chlorophyll-a level is lower than the target of 50 mg/L.

Table 9-2 OP Loads for Alternatives (PBS&J, 2004)

**Average year**

| Alternatives | Makeup water (37.9 ac-ft/yr) | | Runoff (70 ac-ft/yr) | | |
|---|---|---|---|---|---|
| | OP conc (mg/L) | OP load (lb/day) | OP conc (mg/L) | OP load (lb/day) | Total load (lbs/day) |
| Baseline | 1 | 0.282 | 0.05 | 0.026 | |
| 1a | 0.2 | 0.056 | 0.05 | 0.026 | |
| **1b** | **0.4** | **0.113** | 0.05 | **0.026** | **0.139** |
| 1c | 0.02 | 0.006 | 0.05 | 0.026 | |
| 1d | 0 | 0.000 | 0.05 | 0.026 | |
| 2 | 0.014 | 0.004 | 0.05 | 0.026 | |
| 3a | 1 | 0.282 | 0.05 | **0.026** | |

**Amount of OP removed with one-shot alum treatment of lake (80%)** **8.8 lb**

**Wet year**

| Alternatives | Makeup water (29.8 ac-ft/yr) | | Runoff (168 ac-ft/yr) | | |
|---|---|---|---|---|---|
| | OP conc (mg/L) | OP load (lb/day) | OP conc (mg/L) | OP load (lb/day) | Total load (lb/day) |
| Baseline | 1 | 0.222 | 0.05 | 0.063 | |
| 1a | 0.2 | 0.044 | 0.05 | 0.063 | |
| **1b** | **0.4** | **0.089** | 0.05 | 0.063 | **0.152** |
| 1c | 0.02 | 0.004 | 0.05 | 0.063 | |
| 1d | 0 | 0.000 | 0.05 | 0.063 | |
| 2 | 0.014 | 0.003 | 0.05 | 0.063 | |
| 3a | 1 | 0.222 | 0.05 | **0.063** | |

**Dry Year**

| Alternatives | Makeup water (45.0 ac-ft/yr) | | Runoff (19.5 ac-ft/yr) | | |
|---|---|---|---|---|---|
| | OP conc (mg/L) | OP load (lb/day) | OP conc (mg/L) | OP load (lb/day) | Total load |
| Baseline | 1 | 0.335 | 0.05 | 0.007 | |
| 1a | 0.2 | 0.067 | 0.05 | 0.007 | |
| **1b** | **0.4** | **0.134** | 0.05 | 0.007 | **0.141** |
| 1c | 0.02 | 0.007 | 0.05 | 0.007 | |
| 1d | 0 | 0.000 | 0.05 | 0.007 | |
| 2 | 0.014 | 0.005 | 0.05 | 0.007 | |
| 3a | 1 | 0.335 | 0.05 | **0.007** | |

The other higher levels of makeup water treatment or groundwater use also meet the chlorophyll-a target, but would have a larger MOS because the WLA term is smaller. The simulation of alum addition to the lake alone, does not meet the target level because of the particular assumptions made on removal percentage and the restriction of this scenario to a single application.

The choice of alternatives involves some difficult judgments on where to treat and how to achieve the best results per investment of public funds. While the largest source of OP appears to be the reclaimed makeup water, the runoff load is not inconsequential. Furthermore, there is substantial uncertainty in the runoff load because there is very little historic data regarding this load. The concentration of 0.05 mg/L OP is a default value from the literature. In the Load Analysis, storm water data of TP were available from other parts of the Tucson area, but no OP data. It was assumed that most of the OP was in particulate form not available for algae uptake. Nevertheless, the OP concentration in runoff can be expected to vary significantly with the size of the event. It is likely that alum treatment of the makeup water can achieve the chlorophyll-a target of 50 μg/L most of the time. But it is not likely that simply treating the makeup water will be effective all of the time. Some ability to dose the lake after a significant runoff event or during a bloom would increase the assurance that TMDL targets will be met.

### 9.4.2 TMDL for Ortho-phosphorus, with appropriate MOS based on Modeling

From the model, it appears that all TMDL water quality target goals can be achieved at a reasonable cost using alternative 1b. However, this alternative will not provide an adequate margin of safety (MOS) needed to compensate for occasional upsets. The greatest degree of assurance for ortho-phosphorus loads can be achieved with a combination of alternatives 1b and 3b. Alum addition to the reclaimed water could be employed whenever it was being added to the northern cell, with the amount adjusted upwards when needed during the peak growing season. When runoff events introduce material to the southern cell, or a bloom was occurring, alum could be introduced near one of the aeration units where the mixing provided could be employed beneficially. A series of laboratory jar tests of alum dose requirements will be needed to optimize the design. Based on model results, the MOS for ortho-phosphorus has been calculated as the sum of:

- The difference between the dry year and the avg. year for the WLA (0.134 lbs/day – 0.113 lbs/day = 0.021 lbs/day), and

- The difference between the wet year and the avg. year for the LA (0.063 lbs/day – 0.026 lbs/day = 0.058 lbs/day)

= **MOS of 0.058 lbs/day (approximately 20% modeling error) , therefore:**

**TMDL (P) = 0.113 lbs/day (WLA) + 0.026 lbs/day (LA) + 0.058 lbs/day (MOS)**
**TMDL (P) = 0.197 lbs/day**

### 9.4.3 Targets for Nitrogen, Chlorophyll-a, DO, and pH

The nitrogen load is also contributing to lake productivity and is of particular concern due to potential ammonia toxicity. Table 10-3 provides a summary of the annual bioavailable NH3-N and NO3+NO2-N loads to the lake. Atmospheric nitrogen was not modeled in this project, as these inputs are miniscule compared with nitrogen in reclaimed water. To reduce the nitrogen loads, it would require adding nitrification and denitrification processes either at the treatment plant or in an on-site package plant. Either way, the cost would likely to be significantly higher than the simple alum treatment proposed above. Moreover, since reclaimed water input to the lake is not needed all the time, there would be operational issues with an on-site nitrification/denitrification system. On the other hand, alum could be introduced as needed. The target chlorophyll-a level, DO criteria, and pH criteria could be achieved with phosphorus reduction at a reasonable cost, thus nitrogen treatment per se, is not proposed. The nitrogen component of this TMDL as modeled reflects the following two conditions with no extra reductions.

**Condition #1: use of alum with reclaimed water and runoff (without groundwater**)

**TMDL (NO3+NO2-N) = 1.409 lb/day (WLA) + 0.104 lb/day (LA) + 0.410 lb/day (MOS)***
**TMDL (NO3+NO2-N) = 1.922 lbs/day**
**TMDL (NH3-N) = 0.564 lb/day (WLA) + 0.052 lb/day (LA) + 0.178 lb/day (MOS)***
**TMDL (NH3-N) = 0.794 lbs/day**
*Where MOS = difference between dry and avg. years for WLA + difference between avg. and wet years for LA and reflects modeling error

Or,

**Condition #2**: **use of alum with groundwater, reclaimed water, and runoff**

**TMDL (NO3+NO2-N) = 0.874 lb/day (WLA) + 0.104 lb/day (LA) + 0.309 lb/day (MOS)***
**TMDL (NO3+NO2-N) = 1.287 lbs/day**
**TMDL (NH3-N) = 0.007 lb/day (WLA) + 0.052 lb/day (LA) + 0.074 lb/day (MOS)***
**TMDL (NH3-N) = 0.133 lbs/day**
*Where MOS = difference between dry and avg. years for WLA + difference between avg. and wet years for LA and reflects modeling error

The Water Quality Standards require a minimum DO of 6.0 mg/L within the first meter below the surface. The data and the model results show that with the aerator, this can be achieved most of the time. However, there would still be times that a large runoff event could introduce a large amount of sediment and oxygen demanding material resulting in low DO levels. As discussed above, alternative 3b provides the flexibility to respond to such events in a timely manner.

## Table 9-3 Nitrogen Loads for Alternatives (PBS&J, 2004)

| | Makeup water | | | Runoff | | |
|---|---|---|---|---|---|---|
| | Volume (ac-ft/yr) | NO3+NO2-N Load (lb/day) | NH3-N Load (lb/day) | Volume (ac-ft/yr) | NO3+NO2-N (0.2 mg/L) Load (lb/day) | NH3-N (0.1 mg/L) Load (lb/day) |
| **All alternatives except Groundwater, 5 mg/L NO3+NO2-N and 2 mg/L N** | | | | | | |
| **Dry year** | **45.0** | **1.673** | **0.669** | **20** | **0.029** | **0.014** |
| **Average year** | **37.9** | **1.409** | **0.564** | **70** | **0.104** | **0.052** |
| **Wet year** | **29.8** | **1.108** | **0.443** | **168** | **0.250** | **0.125** |
| **Groundwater, 3.1 mg/L NO3+NO2-N and 0.025 mg/L NH3-N** | | | | | | |
| **Dry year** | **45.0** | **1.037** | **0.008** | **20** | **0.029** | **0.014** |
| **Average year** | **37.9** | **0.874** | **0.007** | **70** | **0.104** | **0.052** |
| **Wet year** | **29.8** | **0.687** | **0.006** | **168** | **0.250** | **0.125** |

# 10.0 STAKEHOLDER PARTICIPATION:

## *10.1 LSL Task Force*

During the initial Load Analysis Study, a series of four stakeholder meetings were held between January and June 2002. This task force was made up of personnel from ADEQ, various departments within the City of Tucson (Water, Transportation/Stormwater, Parks & Recreation, and the Mayor's Office), Pima County Wastewater, Pima County Department of Environmental Quality, Pima Association of Governments, Aquatic Consulting & Testing, Inc., the University of Arizona, and the AZ Game and Fish Department Urban Lakes Program. Task Force sessions allowed participants to be involved in problem identification, review of water quality endpoints, model development, and choice of preferred alternatives. Modeling of alternatives was perceived to be a value-added contribution to baseline discussions and cost-benefits analysis.

The Task Force was reconvened in the Spring of 2004 for review of the updated model. The group met two times initially and continued to play a core role in two additional public meetings.

# 11.0 IMPLEMENTATION OVERVIEW

## *11.1 2001 Lake Management Manual*

The City of Tucson hired Aquatic Consulting & Testing, Inc. (ACT) to complete a lake management manual (The Manual) for all of its urban lakes. The document, released in June 2001, outlined what is known about various urban lakes in the Tucson area and offered a list of monitoring and management options for each one. The Manual summarized water quality concerns at LSL, citing high nutrient load, turbid storm water, and insufficient aeration as the primary factors leading to crashes in DO; elevated pH and ammonia; and, very high algal biomass. The Manual also included proposed lake water quality goals, management activities, and monitoring schedules (field and lab) for each Tucson urban lake considered. Several treatment options and cost estimates were offered for LSL (a "no action" option was not among them):

Long-term options

- tertiary treatment of wastewater effluent
- wetlands for effluent: 50% reduction in nitrogen and 20-50% reduction in phosphorus
- use of well water or alternate source of water, e.g., CAP water
- treat stormwater runoff to remove TSS/settleable solids...using settling ponds
- constructed wetlands in wash using a membrane curtain designed to remove some nutrients and solids
- dredge lake every "x" number of years

Less costly short-term options

- upgrade lake aeration system
- treat with alum to remove P

- treat with algaecides prior to bloom period (April/May)
- manage lake level...drop during spring to minimize filamentous algae growth
- improve access (better ramp) during fish stocking to improve fish survival

The Manual presented the concept of tracking lake water quality over time through use of a "Report Card" or matrix of indicators that would be useful in gaging decline or improvements. An example of such a report card has also been instituted at Tempe Town Lake in the metro Phoenix area (see Appendix A). This matrix concept is expected to become part of TMDL implementation plan.

## *11.2 Initial Load Analysis*

### 11.2.1 "Test Period" for Aeration Remedy

The test period for the two aerators installed in June of 2002 was set at one and a half years. Demonstration of remedy success was to be standards attainment with no more than a 10% violation rate for each of the standards of concern (DO; pH; ammonia toxicity; narrative standard). In addition, there were to be no significant fish kills.

ADEQ and the City agreed on an initial start-up period for optimization of the new aeration system. It was thought that this period would be no more than a couple of months. However, as discussed, with changes in air flow and the need for repairs, stabilization of operation did not occur until June of 2003. Monitoring data collected from June 2002 to December 2003 provided the new data set for updating the model.

### 11.2.2 Results of the Test Period

With the new aeration system, water quality improvements were achieved at Lakeside in terms of overall levels of dissolved oxygen in the water column. However, increased agitation and vertical mixing had the effect of stimulating greater algal productivity, resulting in increased chlorophyll-a levels, as well as continued pH and ammonia violations at the lake surface. Water quality assessment still showed greater than 10% standards violations. As a result, EPA informed ADEQ that an actual nutrient load reduction would be needed. The TMDL was initiated in the spring of 2004.

## *11.3 TMDL*

### 11.3.1 Phosphorus Control Using Alum

Based on model results, ADEQ recommends a two-prong approach for alum application at Lakeside Lake. A dosing system is to be installed at the side of the lake for the purpose of treating reclaimed source water. This system will most likely be sited within the enclosure that houses the aeration pumps for security and access to the reclaimed line. There should be sufficient room to construct a contact chamber prior to discharge to the lake. The amount of alum used, the contact time, and the frequency of dosing will have to be established through bench testing. The City will be responsible for completing these tests in a timely manner, which is the first step toward design of an appropriate and efficient treatment system.

A second system is to be installed that can directly disperse alum throughout the lake. The purpose of this system will be to treat wash inputs and to provide back up treatment when needed. System design would be most efficient if the alum could be dispensed so as to take advantage of the agitation from the two large aerators. Bench testing will also be required to determine the optimum dose rate to lake water. The costs for these systems will not be realized until the bench tests are completed. The City may be eligible to receive grant assistance toward installation and operation of these systems.

### 11.3.2 AZPDES Permit for Discharge of Reclaimed Water

The City will reopen formal permit negotiations with AZPDES staff. ADEQ Permit staff will coordinate with ADEQ TMDL staff and Region IX EPA to integrate the TMDL into the AZPDES permit. The permit will address all aspects of reclaimed water discharge to Lakeside Lake. The AZPDES permit will contain reclaimed water monitoring, however, TMDL compliance monitoring will be conducted in-lake, requiring provisions for a mixing zone.

### 11.3.3 Monitoring Plan

The critical period for TMDL compliance corresponds to the summer months and the peak growing season for algae (April/May – September/October). When evaporation is greatest, supplemental water is needed, and monsoon events are likely. The City will work with ADEQ to develop and implement a comprehensive lake monitoring plan to capture seasonal transitions and provide the data necessary to assess compliance with this TMDL. The City may pursue reclassification of Lakeside Lake to “Effluent Dependent” (defined in A.A.C. 18-11) only through petition within a Triennial Review. Such an action would require a Use Attainability Analysis and must meet both federal and state requirements.

## 12.0 REFERENCES

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Ward, G.H. and Benaman, J. 1999b. Models for TMDL Application in Texas Watercourses (Draft report).

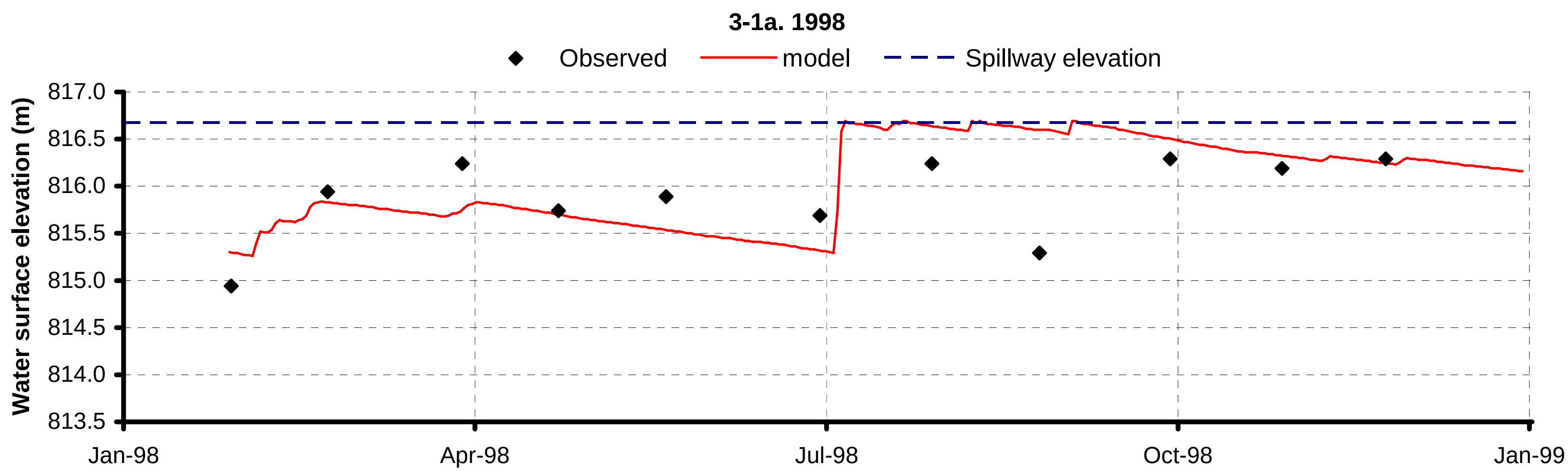
Ward, G.H. and Benaman, J. 1999a. A Survey and Review of Modeling for TMDL Application in Texas Watercourses (Draft report).

Water Resource Research Center (WERC) web site: http://ag.arizona.edu/AZWATER/

# APPENDIX A:

Chapter 3 Figures from Updated Load Analysis Report, PBS&J, 2004

**FIGURE 3-1**
**COMPARISON BETWEEN MODELED AND OBSERVED WATER SURFACE ELEVATIONS**



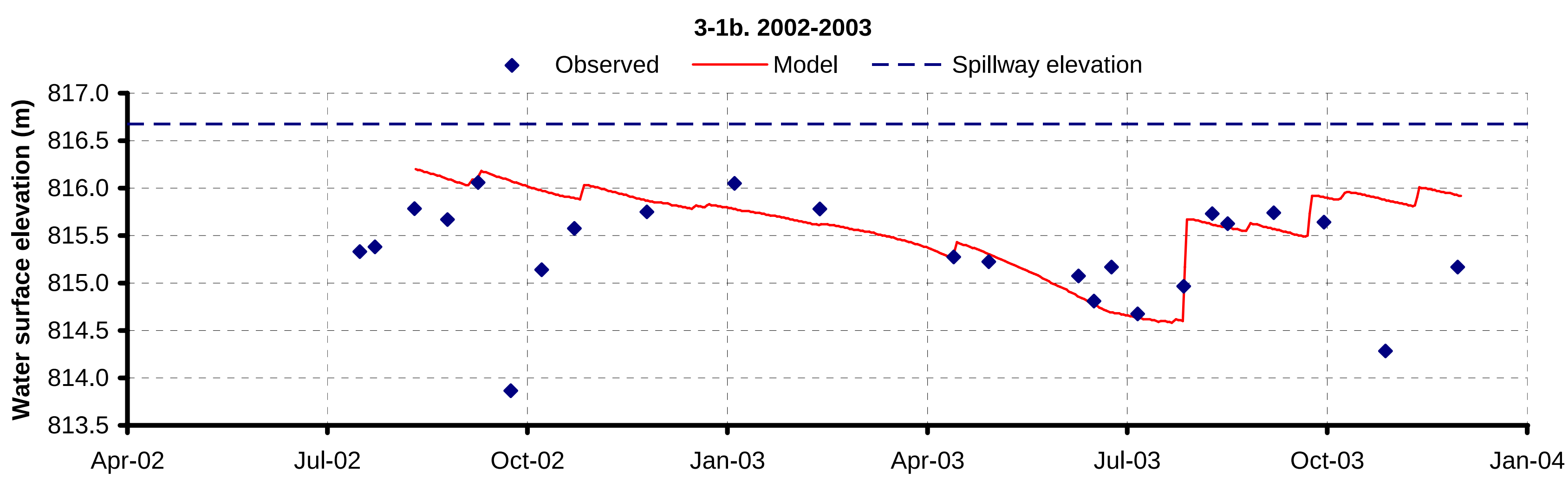
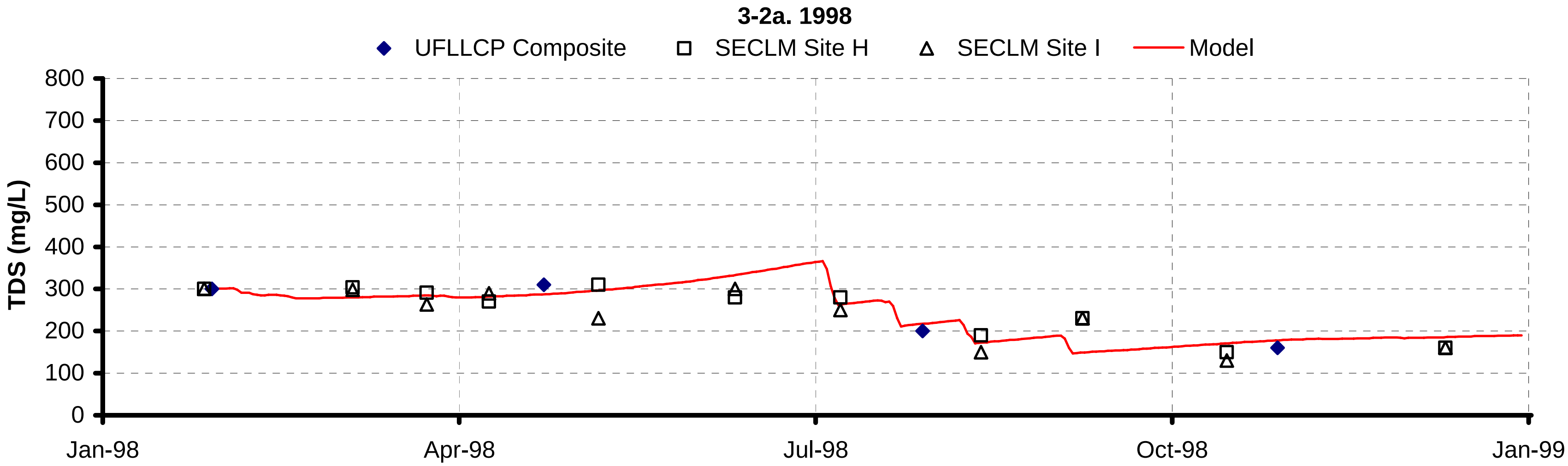



**FIGURE 3-2**
**COMPARISON BETWEEN SURFACE MEASUREMENTS AND MODEL RESULTS OF TDS**



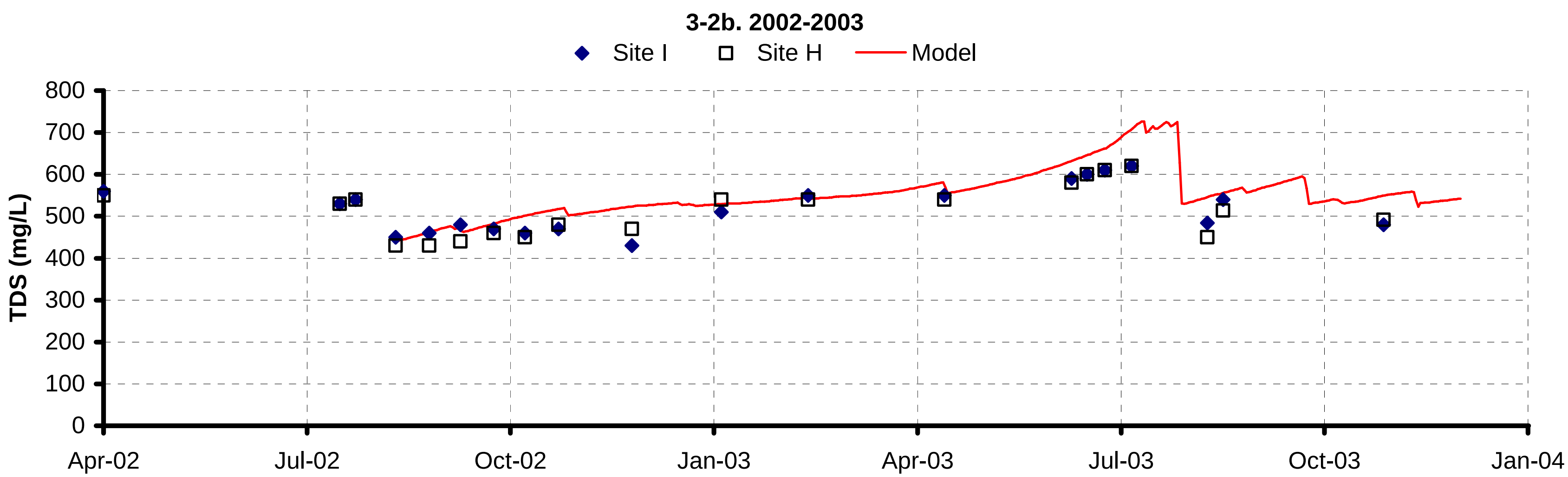
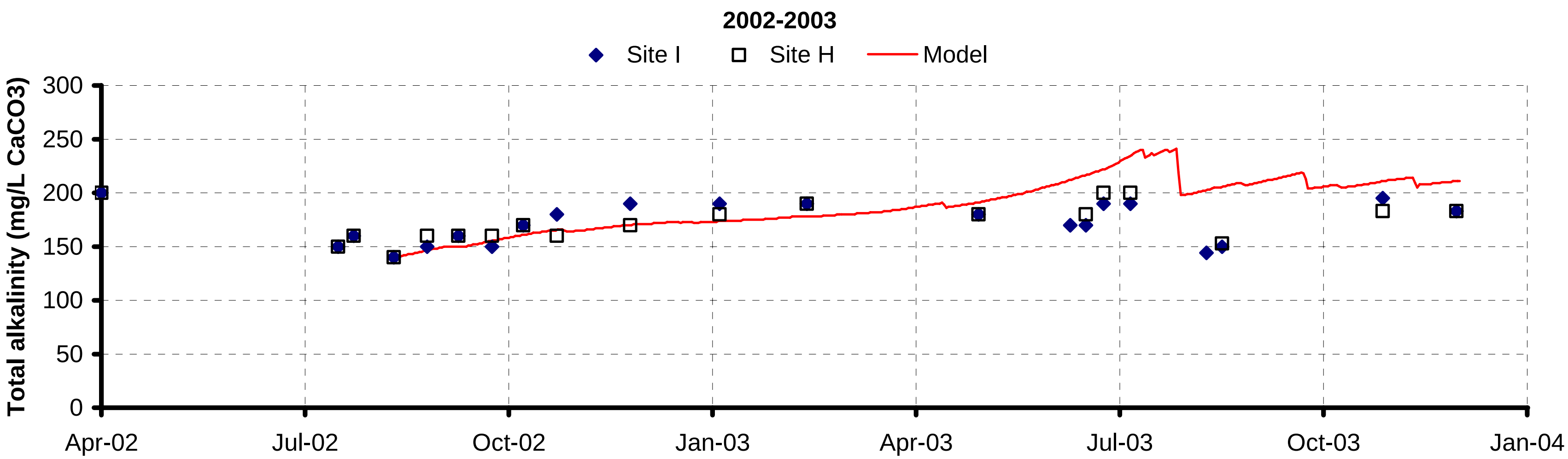
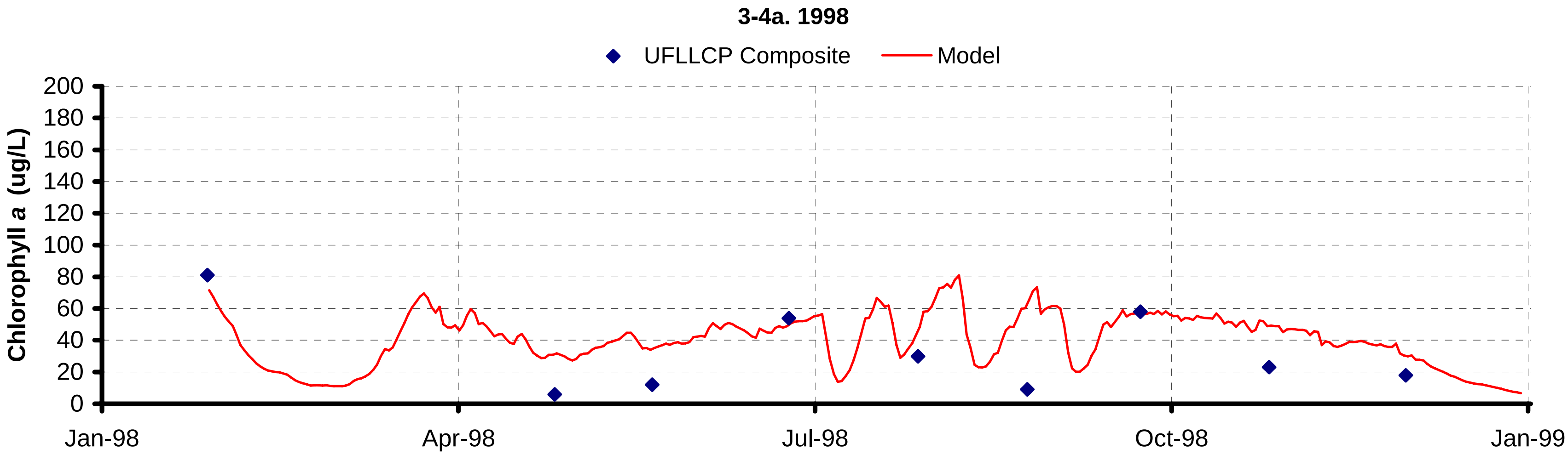



**FIGURE 3-3**
**COMPARISON BETWEEN SURFACE MEASUREMENTS AND MODEL RESULTS OF TOTAL ALKALINITY**




The 1998 period has very few alkalinity data.

**FIGURE 3-4**
**COMPARISON BETWEEN SURFACE MEASUREMENTS AND MODEL RESULTS OF CHLOROPHYLL *A***



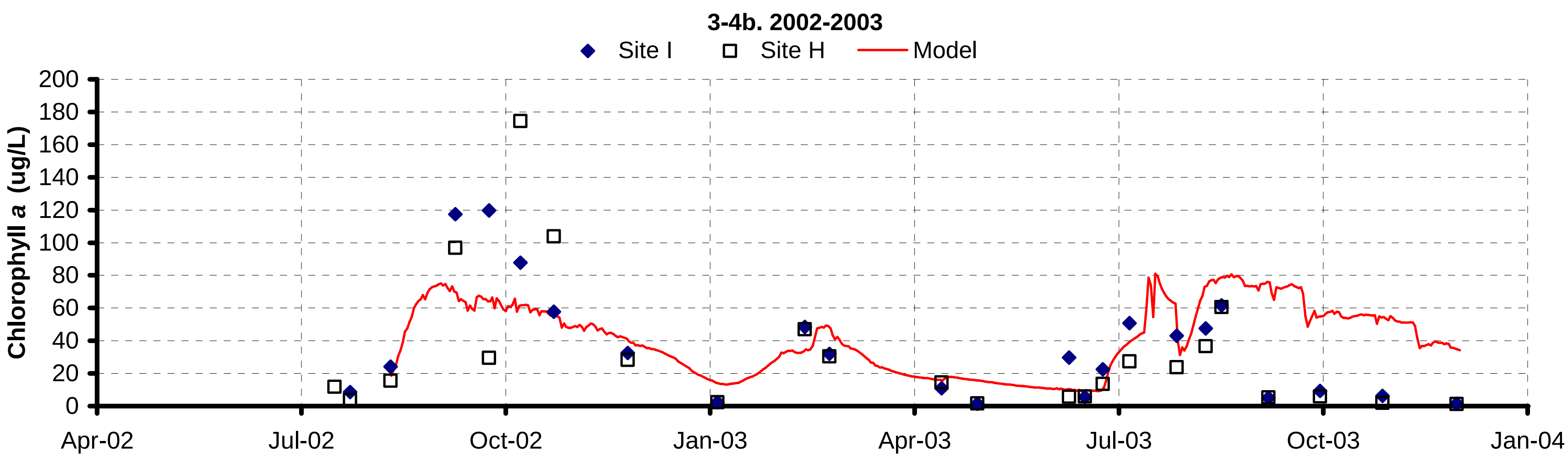
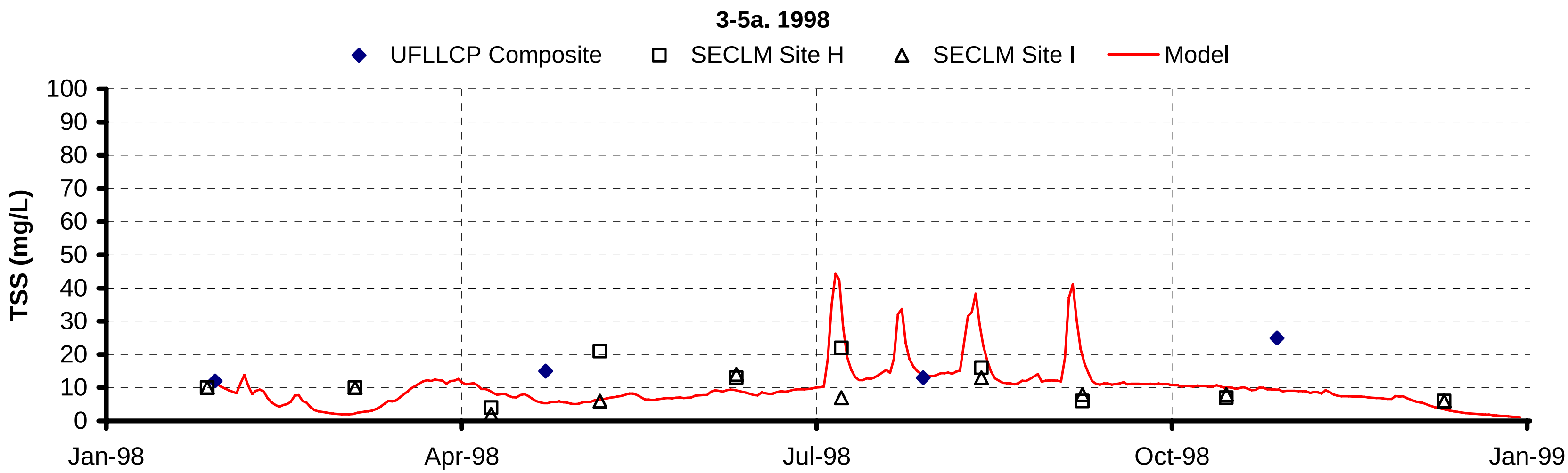



**FIGURE 3-5**
**COMPARISON BETWEEN SURFACE MEASUREMENTS AND MODEL RESULTS OF TSS**



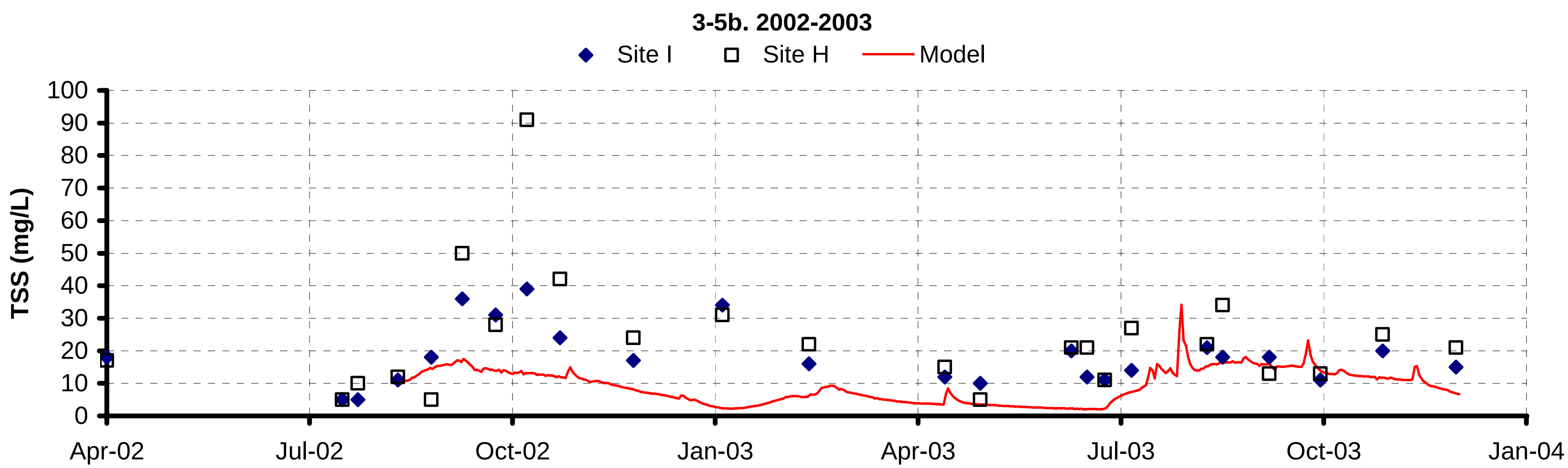
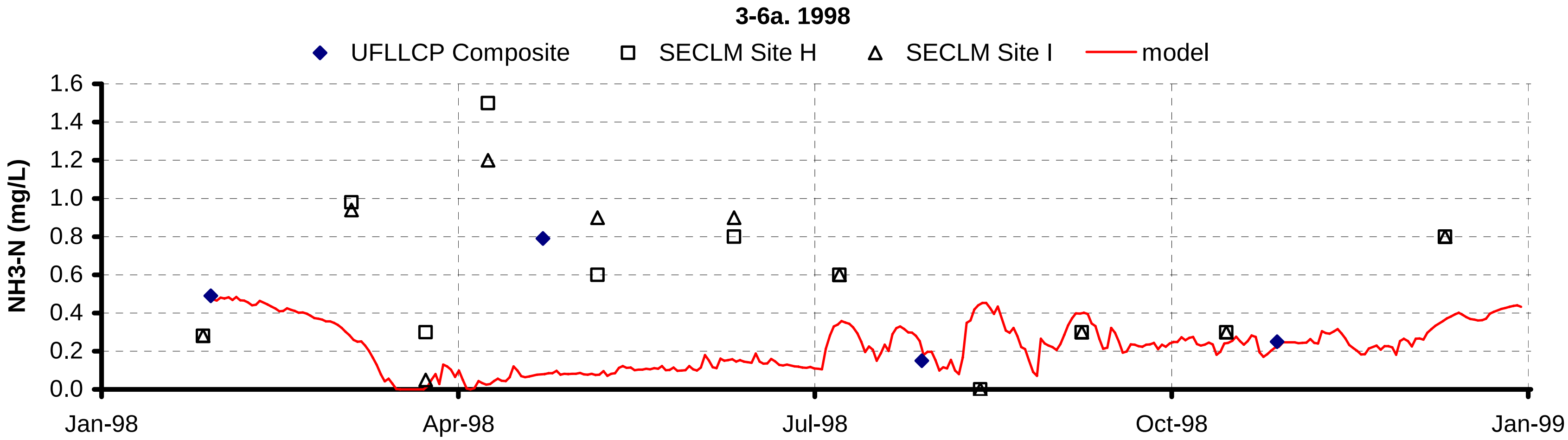



**FIGURE 3-6**
**COMPARISON BETWEEN SURFACE MEASUREMENTS AND MODEL RESULTS OF NH3-N**



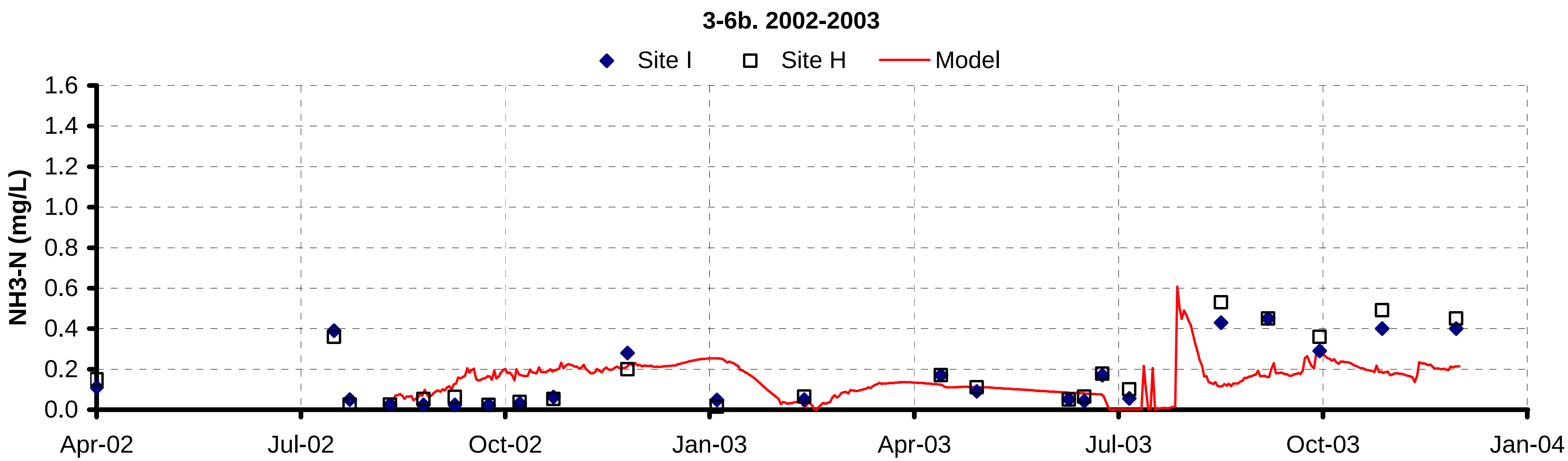
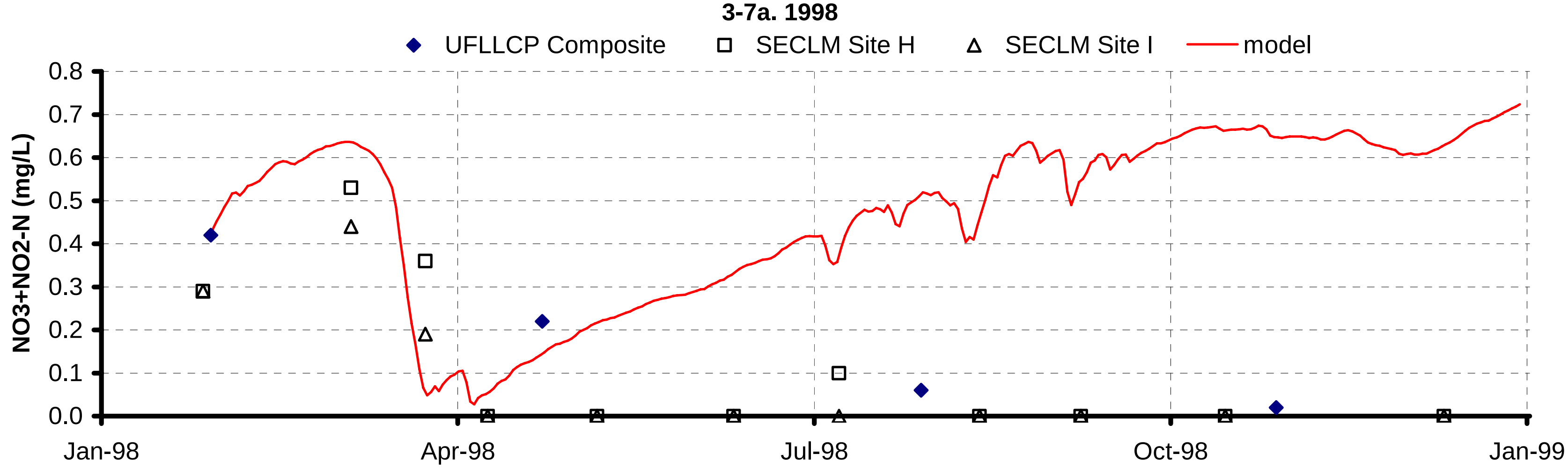



**FIGURE 3-7**
**COMPARISON BETWEEN SURFACE MEASUREMENTS AND MODEL RESULTS OF NO3+NO2-N**



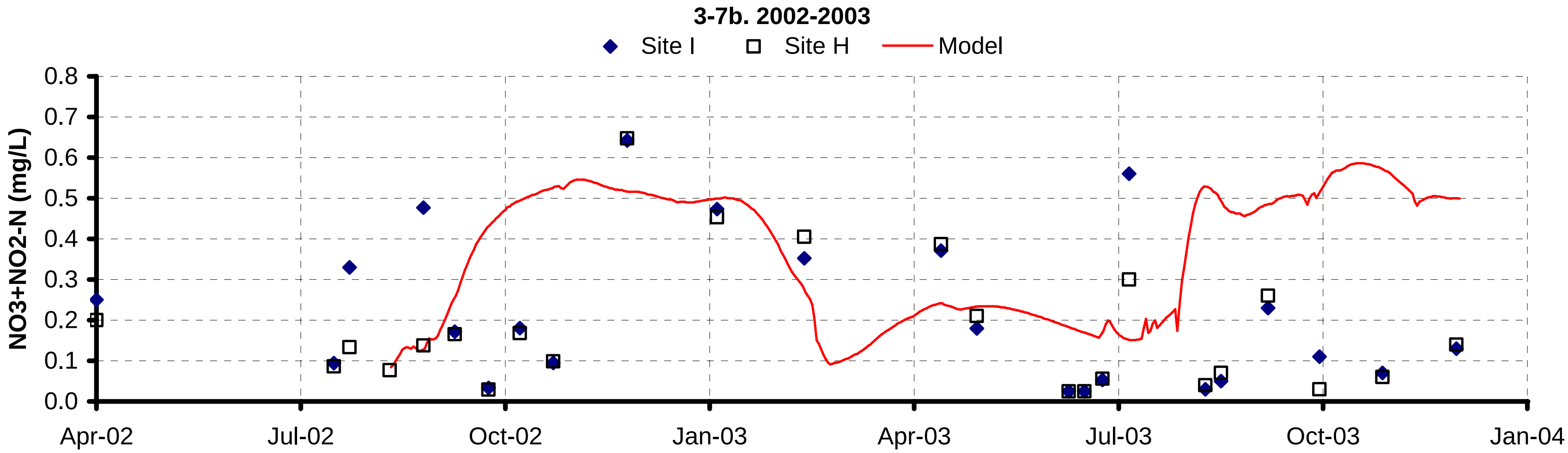
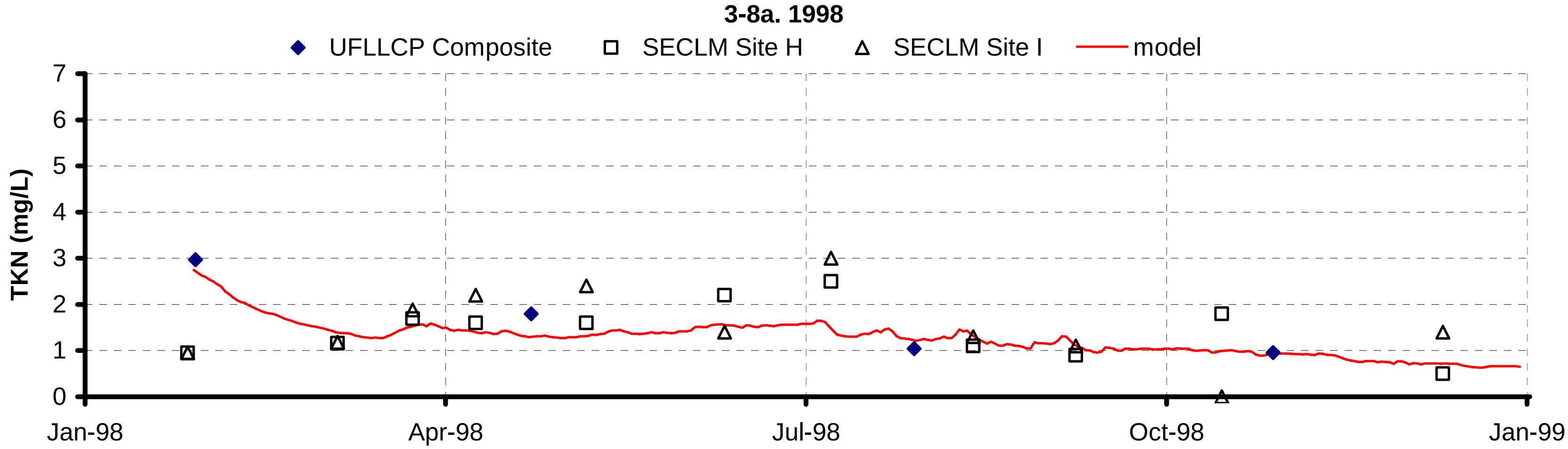



**FIGURE 3-8**
**COMPARISON BETWEEN SURFACE MEASUREMENTS AND MODEL RESULTS OF TKN**



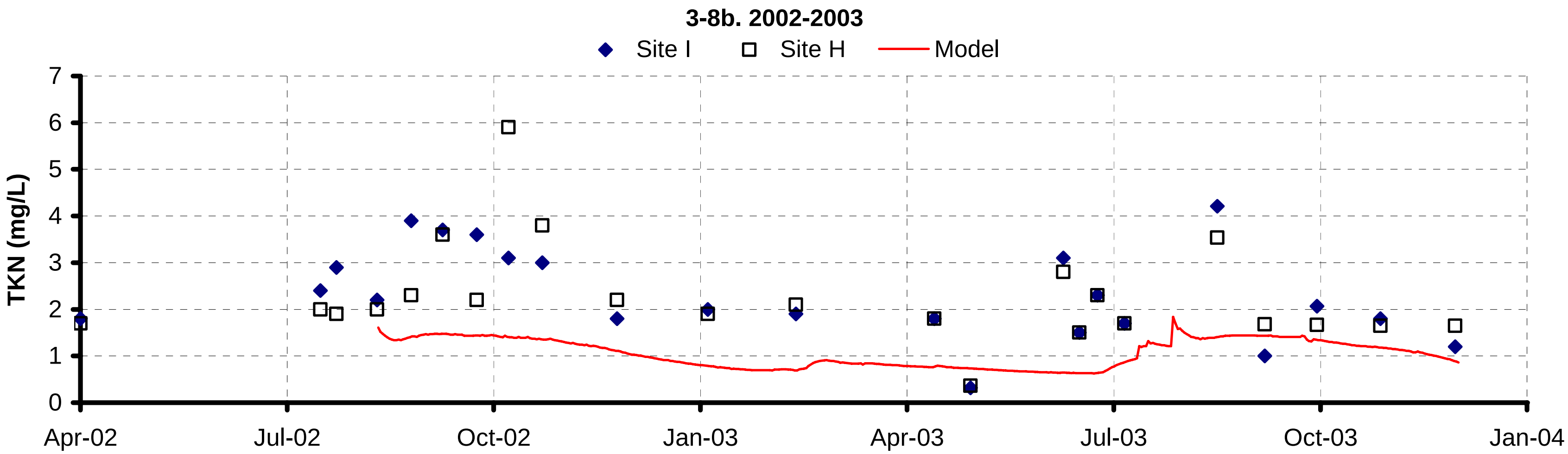
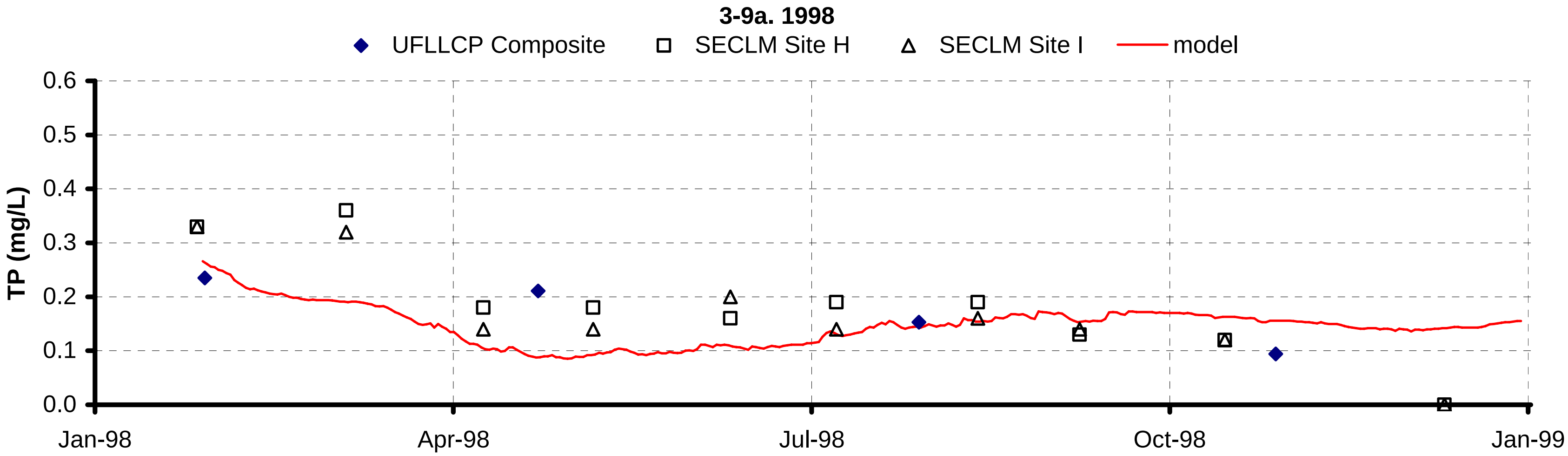



**FIGURE 3-9**
**COMPARISON BETWEEN SURFACE MEASUREMENTS AND MODEL RESULTS OF TP**



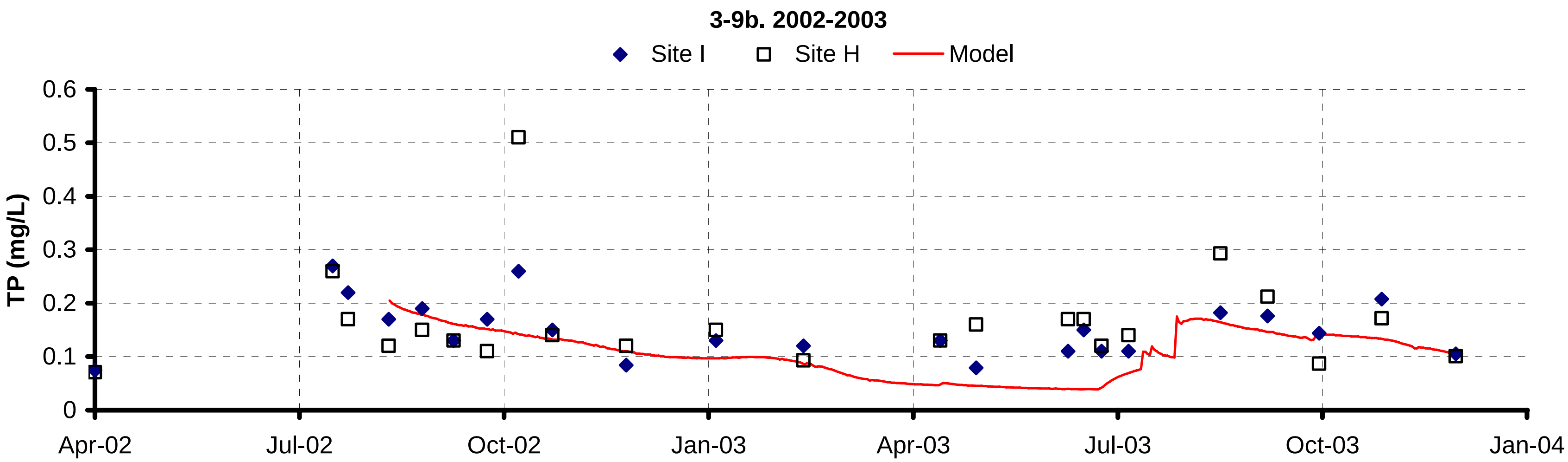
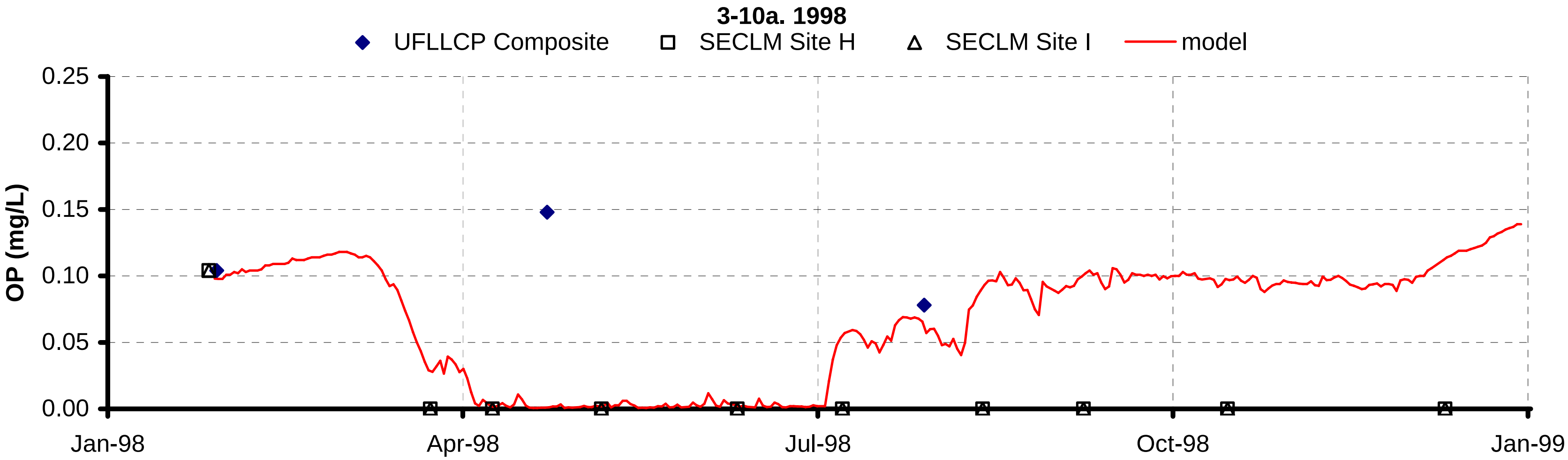
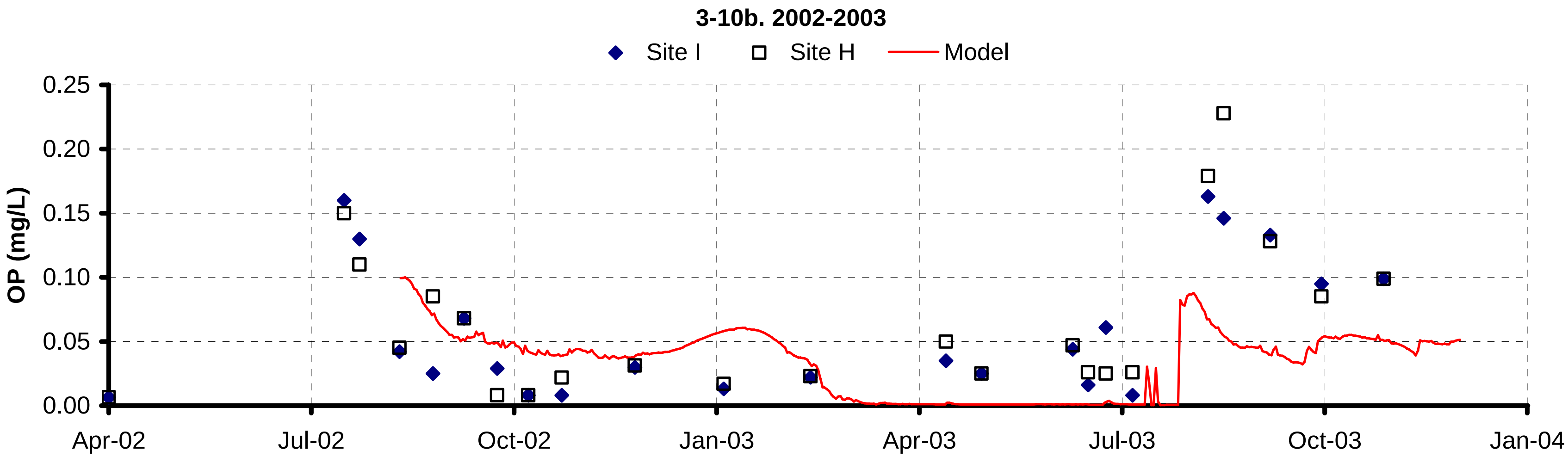



**FIGURE 3-10**
**COMPARISON BETWEEN SURFACE MEASUREMENTS AND MODEL RESULTS OF OP**



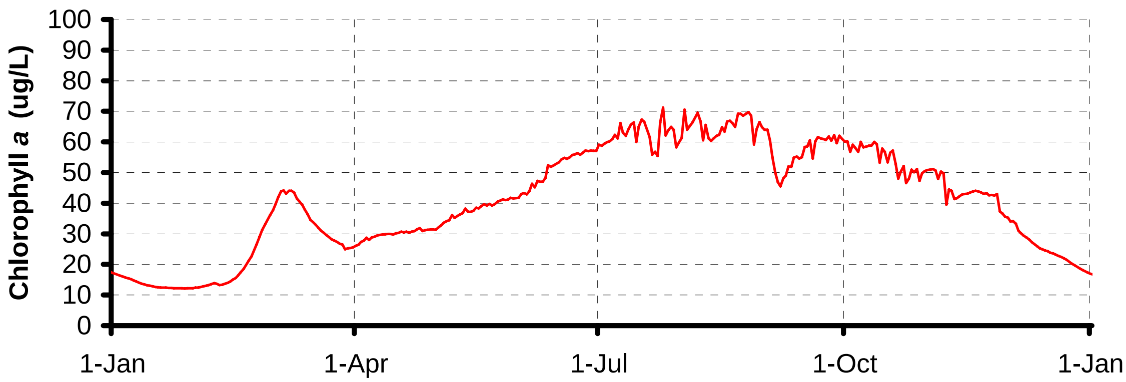



# APPENDIX B:

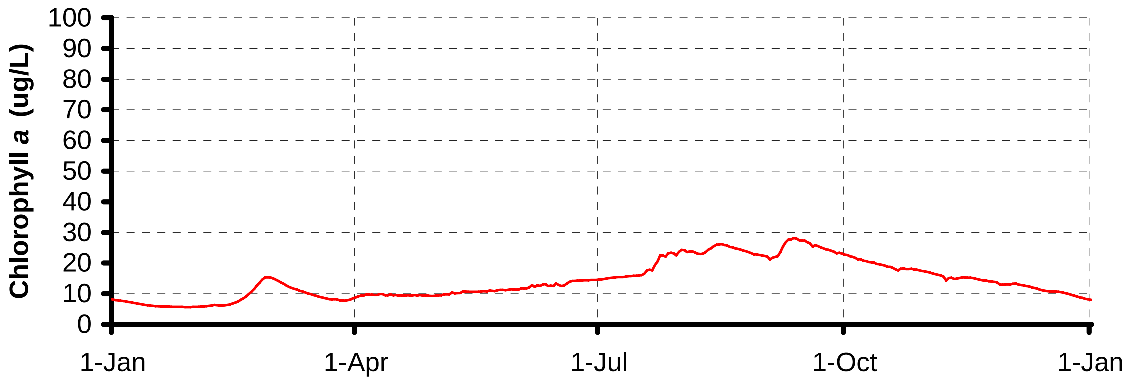
## Chapter 4 Figures from Updated Load Analysis Report, PBS&J, 2004

**FIGURE 4-1**
**MODEL RESULTS OF CHLOROPHYLL a**

**Baseline, TP=1 mg/L**




**Scenario 1a - P removal from reclaimed water, TP=0.2 mg/L**




**Scenario 1b - P removal from reclaimed water, TP=0.4 mg/L**

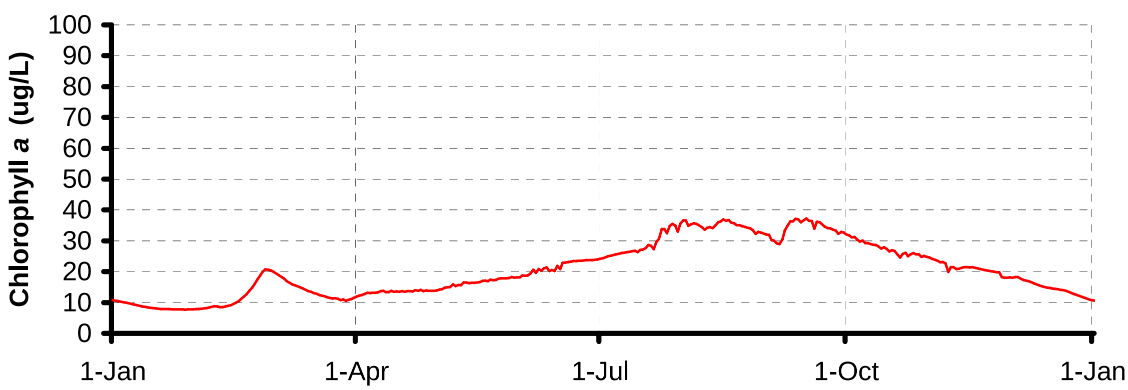
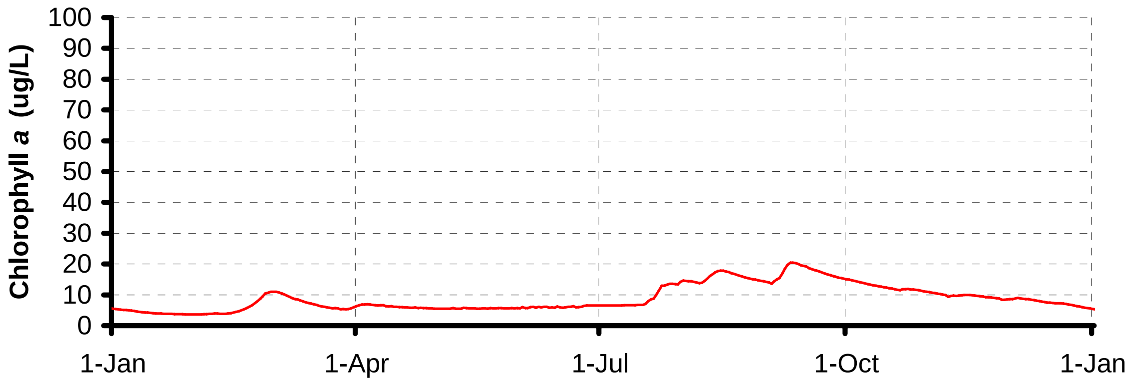
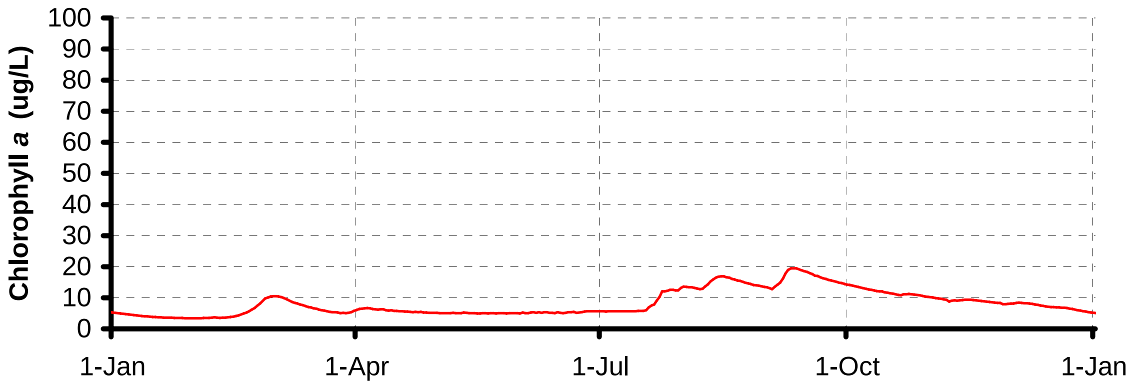


**FIGURE 4-1 (CONCLUDED)**
**MODEL RESULTS OF CHLOROPHYLL a**

**Scenario 1c - P removal from reclaimed water, TP=0.02 mg/L**




**Scenario 1d - P removal from reclaimed water, TP=0.0 mg/L**




**Scenario 2 - Groundwater, TP=0.014 mg/L**

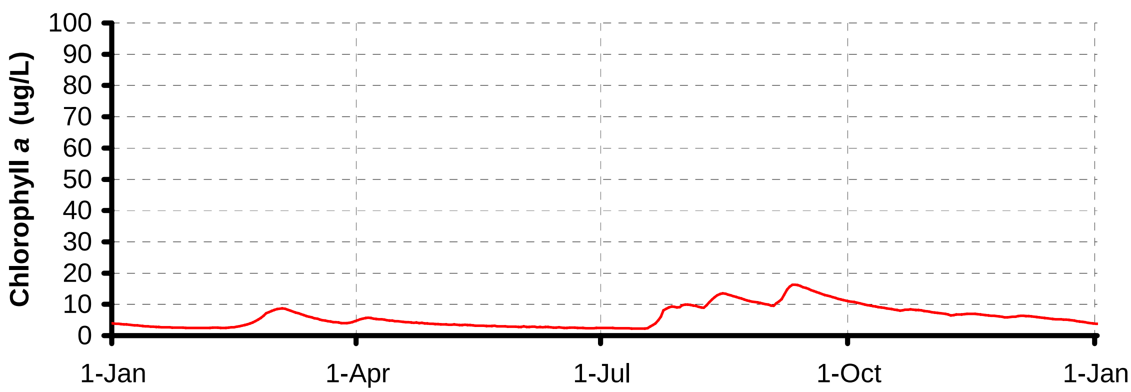


**FIGURE 4-2**
**MODEL RESULTS OF OP**

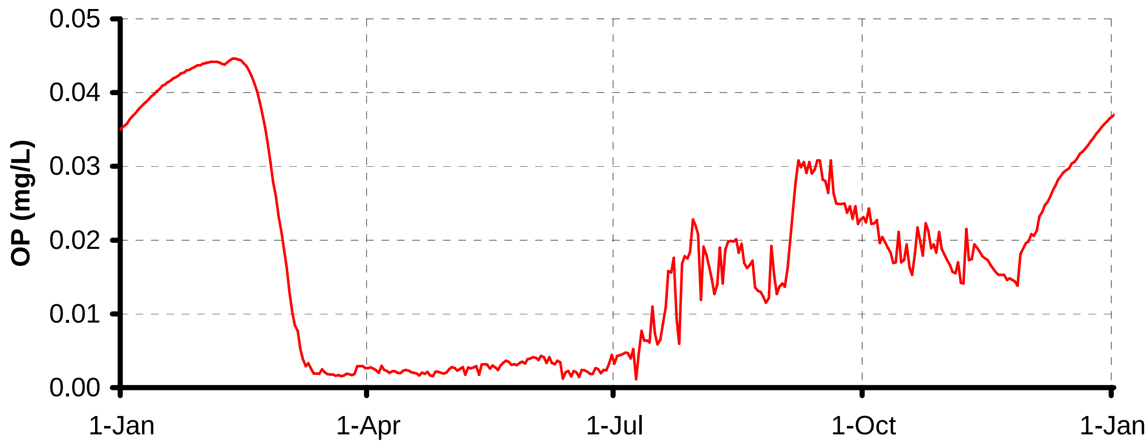
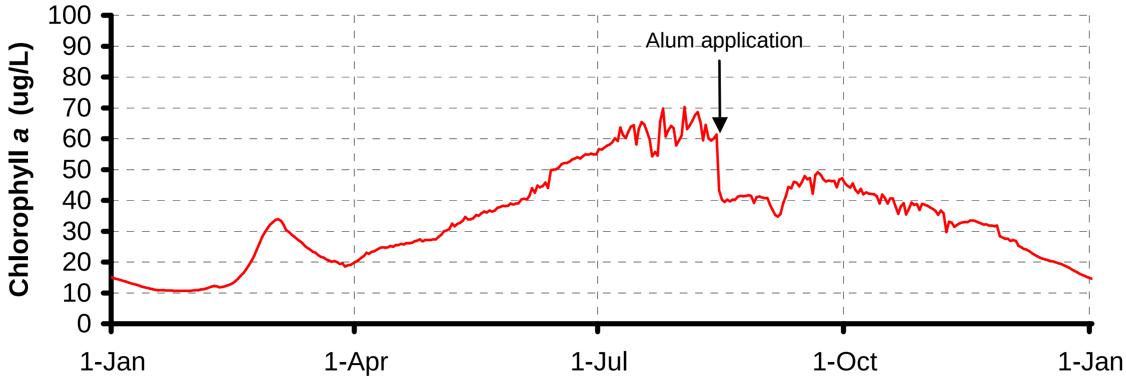


**FIGURE 4-3**
**MODEL RESULTS OF SCENARIO 3A**



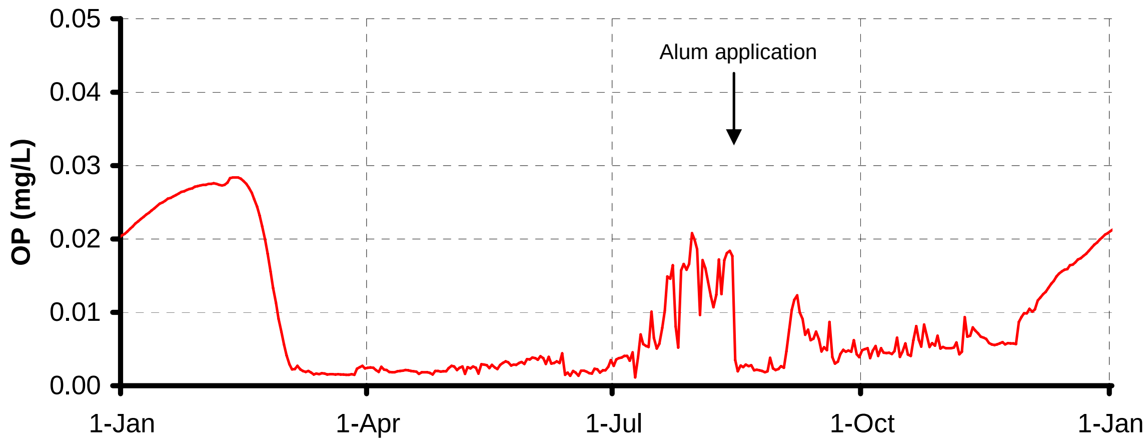



**FIGURE 4-4**
**MODEL RESULTS OF $NH_3$-N**

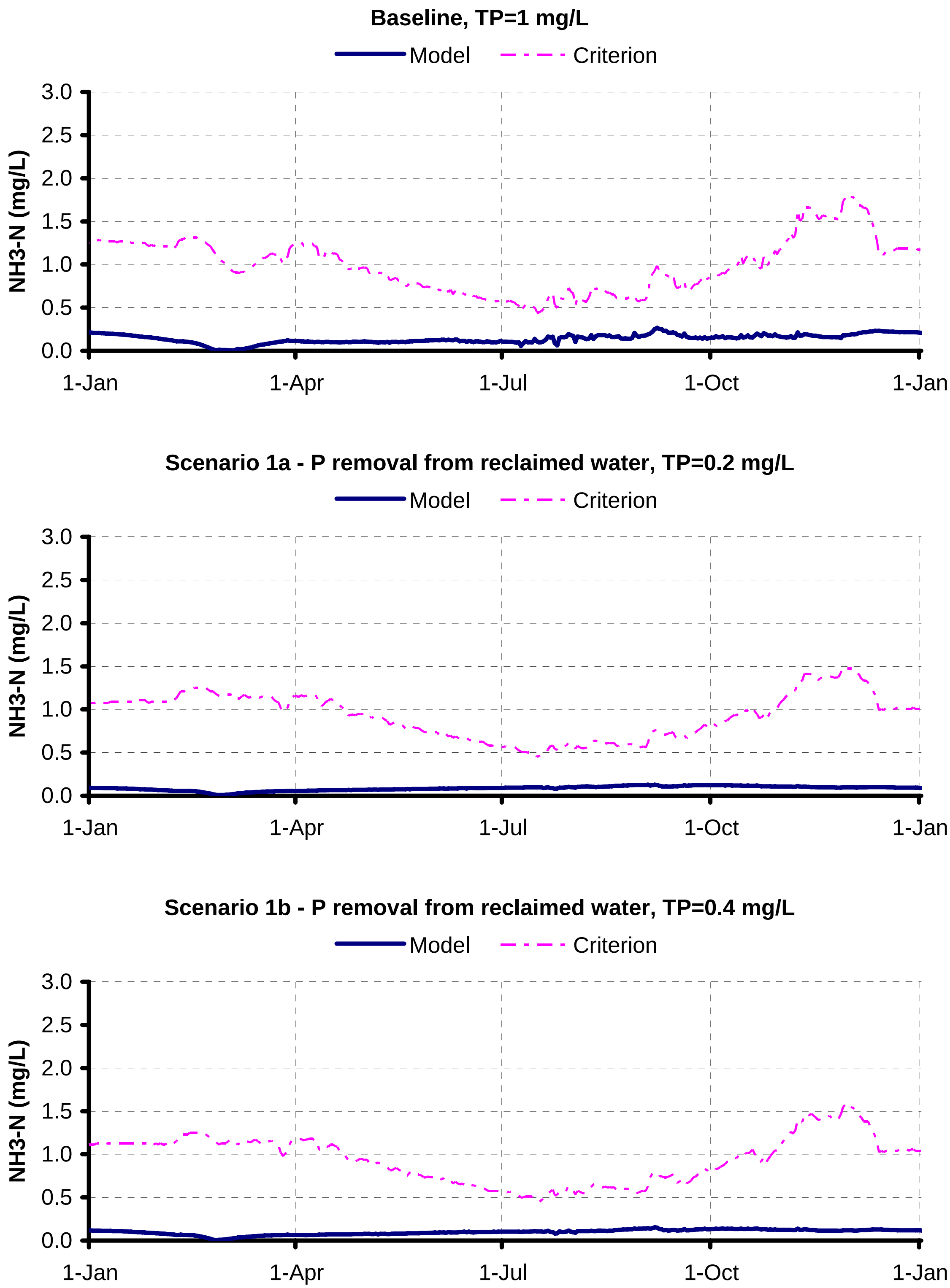
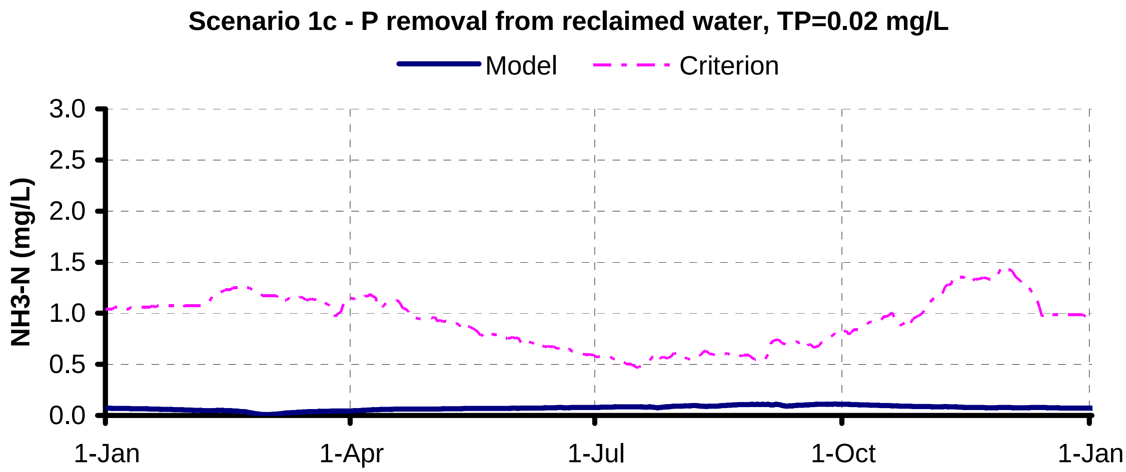
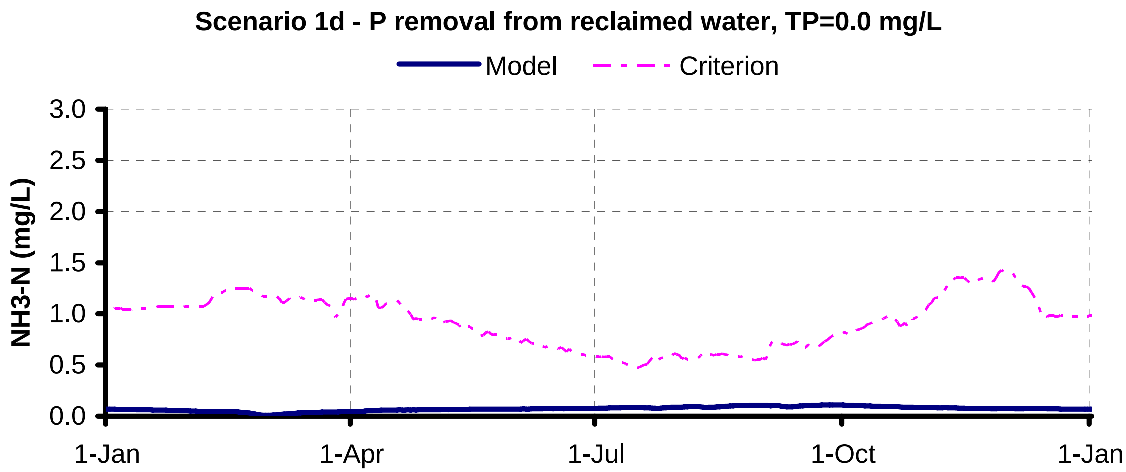


**FIGURE 4-4 (CONTINUED)**
**MODEL RESULTS OF $NH_3$-N**



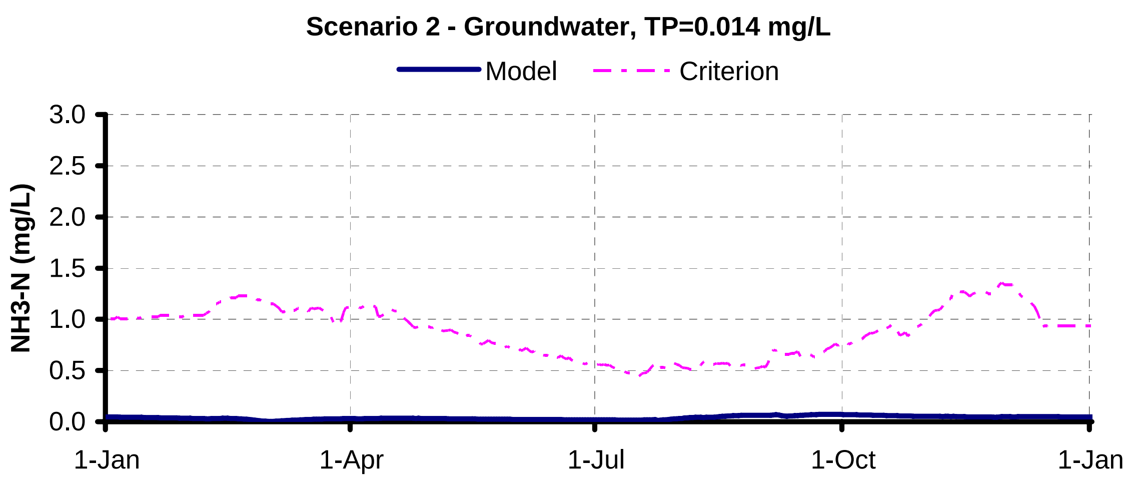



**FIGURE 4-4 (CONCLUDED)**
**MODEL RESULTS OF $NH_3$-N**