FINAL

FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION

South West DISTRICT • Tampa Bay Tributaries Basin

TMDL Report

Nutrient TMDL for Lake Hunter

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Chapter 1: INTRODUCTION

1.1 Purpose of Report

This report presents the TMDL for nutrients for Lake Hunter (Lake) in the Hillsborough River Basin (Figure 2.1). The Lake was verified as impaired by nutrients using the methodology in the Identification of Impaired Surface Waters Rule (IWR, Rule 62-303, Florida Administrative Code), and was included on the Verified List of impaired waters for the Hillsborough River Basin that was adopted by Secretarial Order on May 27, 2004. The TMDL establishes the allowable loadings to the Lake that would restore the waterbody so that it meets its applicable water quality criteria for nutrients.

1.2 Identification of Waterbody

Lake Hunter is located inside the City of Lakeland, Polk County, Florida, at Latitude 28^{o} 02” 06’ and Longitude 81o 58” 00’ (Figure 1.1). The estimated annual average surface area of the Lake is less than 100 acres, with an average depth of six feet. The entire surface water drainage basin of the Lake is approximately 0.8 square miles. The topographic elevation of the water surface is near 160 feet NGVD. There are no tributaries flowing into the Lake, although there are a number of stormwater outfalls that discharge runoff from the basin into the Lake. Additionally, stormwater discharges from two other lakes (Lakes Beulah and Wire) are piped into Lake Hunter (Figure 1.1).

For assessment purposes, the Department has divided the Hillsborough River Basin into water assessment polygons with a unique waterbody identification (WBID) number for each watershed or stream reach. The Lake has been given the WBID number of 1543.

1.3 Background Information

The TMDL Report for the Lake is part of the implementation of the Florida Department of Environmental Protection’s (Department) watershed management approach for restoring and protecting water resources and addressing Total Maximum Daily Load (TMDL) Program requirements. The watershed approach, which is implemented using a cyclical management process that rotates through the state’s fifty-two river basins over a five-year cycle, provides a framework for implementing the requirements of the 1972 federal Clean Water Act and the 1999 Florida Watershed Restoration Act (Chapter 99-223, Laws of Florida).

A TMDL represents the maximum amount of a given pollutant that a waterbody can assimilate and still meet the waterbody’s designated uses. A waterbody that does not meet its designated uses is defined as impaired. TMDLs must be developed and implemented for each of the state’s impaired waters, unless the impairment is documented to be a naturally occurring condition that cannot be abated by a TMDL or unless a management plan already in place is expected to correct the problem.

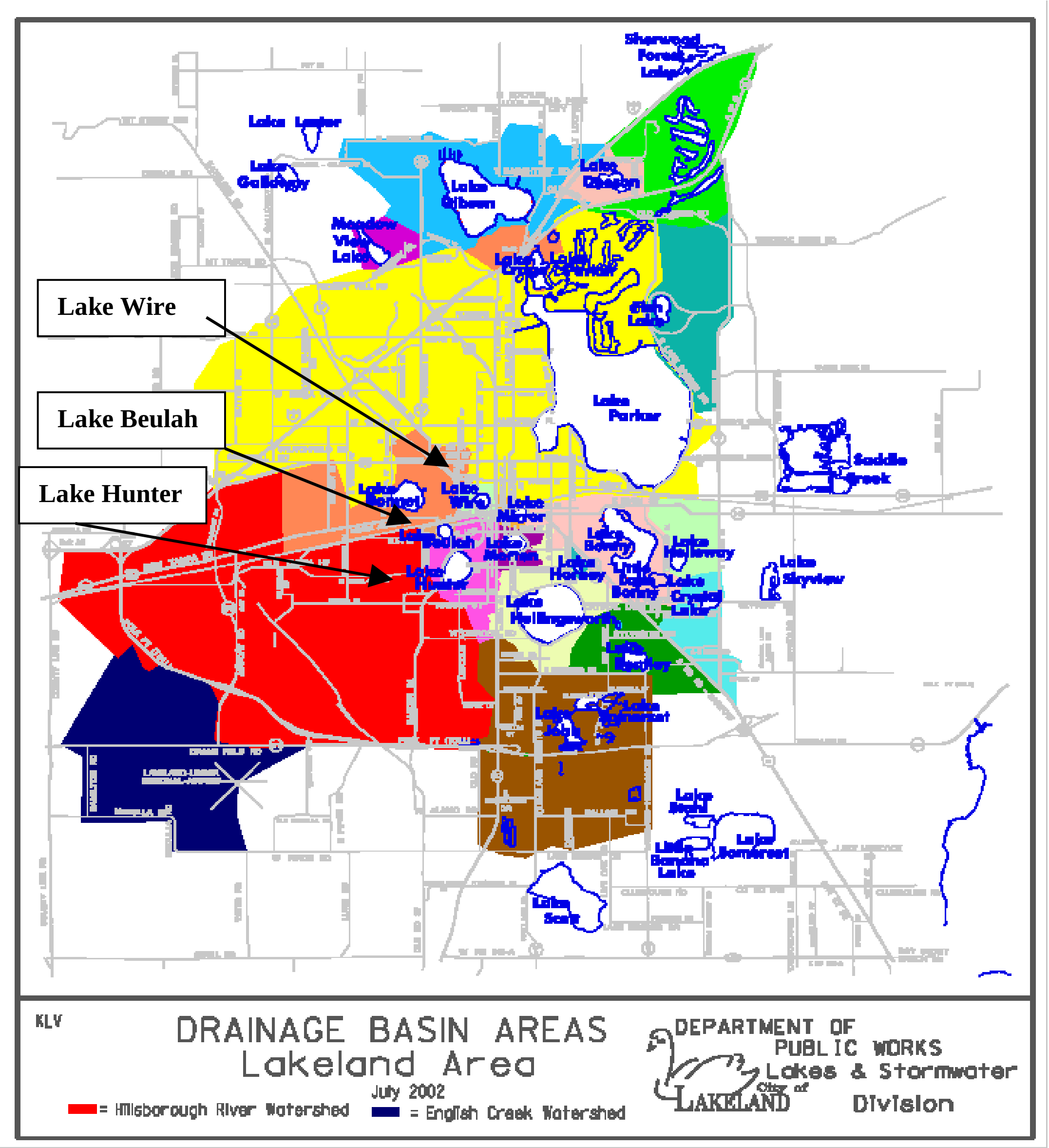


Figure 1.1: Lakeland area with drainage basins of the lakes including Lakes Hunter WBID 1543, Wire, and Beulah.

The development and implementation of a Basin Management Action Plan, or B-MAP, to reduce the amount of pollutants that caused the impairment will follow this TMDL Report. These activities will depend heavily on the active participation of the water management district, local governments, businesses, and other stakeholders. The Department will work with these organizations and individuals to undertake or continue reductions in the discharge of pollutants and achieve the established TMDLs for the impaired Lake.

Chapter 2: STATEMENT OF WATER QUALITY PROBLEM

2.1 Legislative and RuleMaking History

Section 303(d) of the federal Clean Water Act requires states to submit to the EPA a list of surface waters that do not meet applicable water quality standards (impaired waters) and establish a TMDL for each pollutant causing the impairment of the listed waters on a schedule. The Department has developed such lists, commonly referred to as 303(d) lists, since 1992. The list of impaired waters in each basin, referred to as the Verified List, is also required by the Florid Watershed Restoration Act (Subsection 403.067[4)] Florida Statutes [F.S.]), and the state's 303(d) list is amended annually to include basin updates.

Florida's 1998 303(d) list included 21 waterbodies in the Hillsborough River Basin. However, the FWRA (Section 403.067, F.S.) stated that all previous Florida 303(d) lists were for planning purposes only and directed the Department to develop, and adopt by rule, a new science-based methodology to identify impaired waters. After a long rule-making process, the Environmental Regulation Commission adopted the new methodology as Chapter 62-303, Florida Administrative Code (F.A.C.) (Identification of Impaired Surface Waters Rule, or IWR), in April 2001.

2.2 Information on Verified Impairment

The Department used the IWR to assess water quality impairments in the Lake Hunter watershed and verified that the Lake was impaired for nutrients. Lake Hunter was verified as impaired based on elevated annual average Trophic State Index (TSI) values over the verification period (the Verified Period for the Group 2 basins is from January 1, 1996 to June 30, 2003). The TSI is calculated based on concentrations of TP, TN, and Chl a as follows:

$\mathrm{CHLA}_{TSI} = 16.8 + 14.4 * \mathrm{LN}(\mathrm{Chl}\ a)$ Chl *a* in µg/L
$\mathrm{TN}_{TSI} = 56 + 19.8 * \mathrm{LN}(N)$ N in mg/L
$\mathrm{TN2}_{TSI} = 10 * [5.96 + 2.15 * \mathrm{LN}(N + 0.0001)]$
$\mathrm{TP}_{TSI} = 18.6 * \mathrm{LN}(P * 1000) – 18.4$ P in mg/L
$\mathrm{TP2}_{TSI} = 10 * [2.36 * \mathrm{LN}(P * 1000) – 2.38]$

If $N/P > 30$, *then* $\mathrm{NUTR}_{TSI} = \mathrm{TP2}_{TSI}$
If $N/P < 10$, *then* $\mathrm{NUTR}_{TSI} = \mathrm{TN2}_{TSI}$
if $10 < N/P < 30$, *then* $\mathrm{NUTR}_{TSI} = (\mathrm{TP}_{TSI} + \mathrm{TN}_{TSI})/2$

$\mathrm{TSI} = (\mathrm{CHLA}_{TSI} + \mathrm{NUTR}_{TSI})/2$ (TSI has no units)

The following analysis of the eutrophication-related data for Lake Hunter used all of the available data from 1988 – 2002 for which records of TP, TN, and Chl a were sufficient to calculate annual average conditions. To calculate the TSI for a given year, there must be at least one sample in each season of the year. This caused the elimination of the years 1988, 1989, 1990, and 1995 from the analysis of TSI for Lake Hunter. Additionally, as the verified period ends in the middle of 2003, annual averages were not determined for 2003.

Annual average TSI values exceeded the IWR threshold level of 60 in all of the years with sufficient data (Figure 2.5), and averaged 79.7 over the period. Exceeding 60 in any one year of the verified period would have been sufficient to determine the Lake was impaired for nutrients.

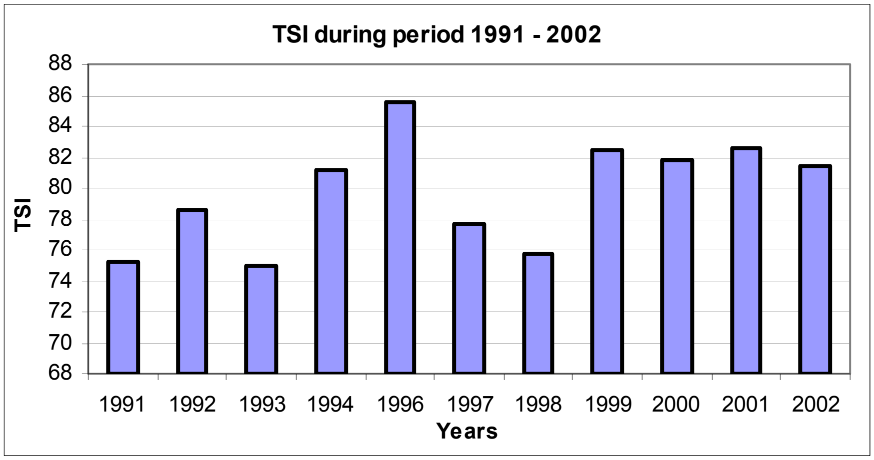


Figure 2.1. TSI for Lake Hunter calculated from annual average concentrations of TP, TN, and Chl a.

Temporal trends in individual constituents of the TSI were examined using plots of the annual average concentrations and 2 point moving average of total phosphorous (TP), total nitrogen (TN), and chlorophyll a (Chl a) (Figures 2.2, 2.3, and 2.4). From the late 1980's through 1994, TN and TP concentrations appear fairly stable. However, both TN and TP concentrations began to increase starting in 1994. For Chl a, the 1990's appear to be a period of gradually increasing concentrations.

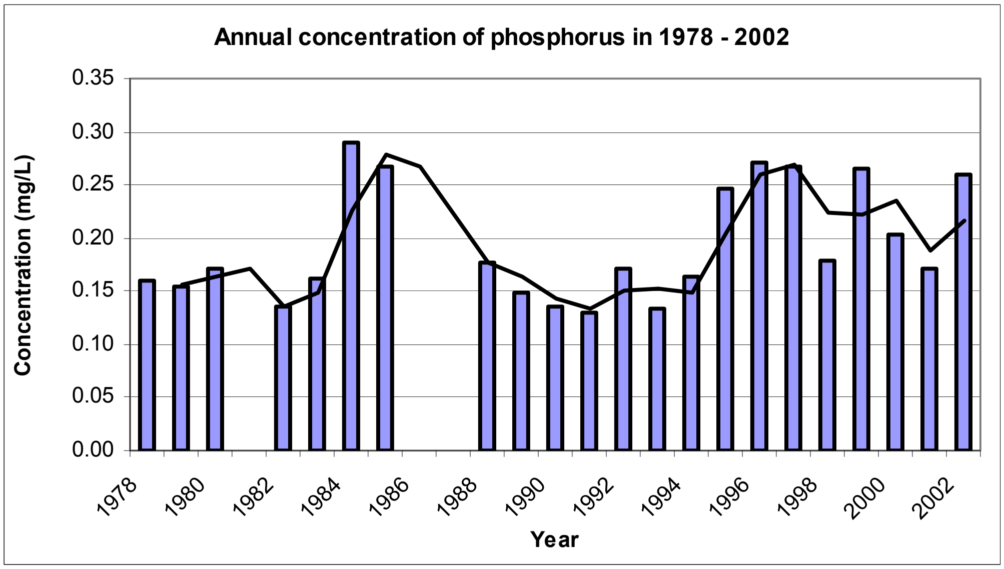


Figure 2.2. Level of phosphorus in Lake Hunter during past 25 years.

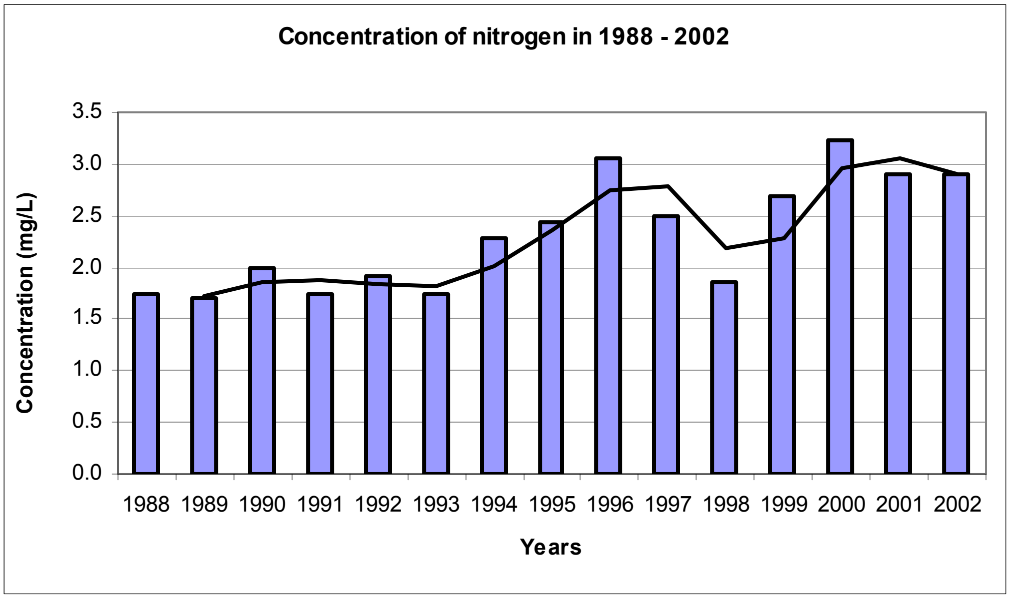


Figure 2.3. Level of nitrogen in Lake Hunter during past 15 years.

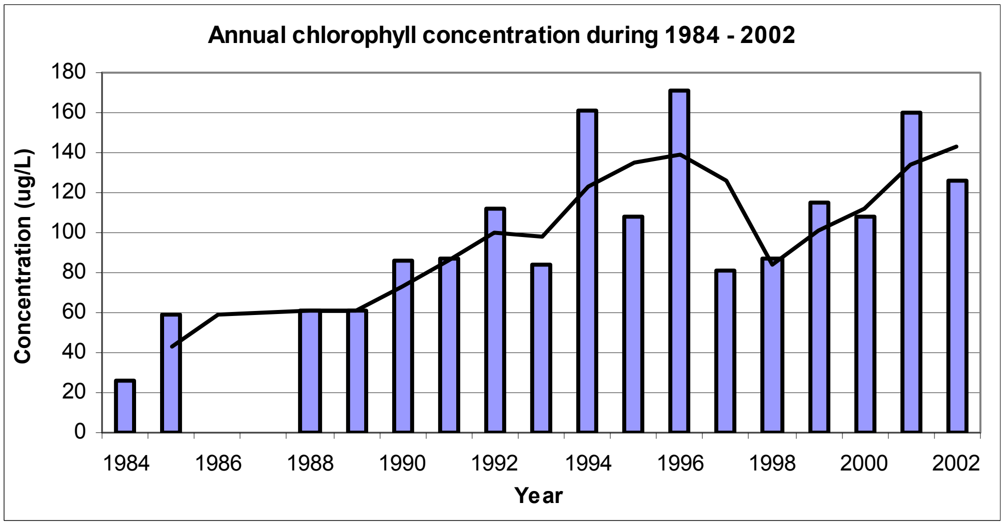


Figure 2.4. Chlorophyll a measured in Lake Hunter during past 19 years.

Chapter 3. DESCRIPTION OF APPLICABLE WATER QUALITY STANDARDS AND TARGETS

3.1 Classification of the Waterbody and Criteria Applicable to the TMDL

Florida's surface water is protected for five designated use classifications, as follows:

Class I	**Potable water supplies**
Class II	**Shellfish propagation or harvesting**
Class III	**Recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife**
Class IV	**Agricultural water supplies**
Class V	**Navigation, utility, and industrial use (there are no state waters currently in this class)**

Lake Hunter is classified as a Class III freshwater body, with a designated use of recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife. The Class III water quality criterion applicable to the observed impairment is the narrative nutrient criterion [Rule 62-302.530(48)(b), FAC].

3.2 Interpretation of the Narrative Nutrient Criterion

Florida's nutrient criterion is narrative only — nutrient concentrations of a body of water shall not be altered so as to cause an imbalance in natural populations of aquatic flora or fauna. Accordingly, a nutrient-related target was needed to represent levels at which an imbalance in flora or fauna is expected to occur. While the IWR provides a threshold for nutrient impairment for lakes based on annual average TSI levels, these thresholds are not standards and need not be used as the nutrient-related water quality target for TMDLs. In fact, in recognition that the IWR thresholds were developed using statewide average conditions, the IWR (Subsection 62-303.450, F.A.C.) specifically allows the use of alternative, site-specific thresholds that more accurately reflect conditions beyond which an imbalance in flora or fauna occurs in the waterbody.

The TSI originally developed by R. E. Carlson (1977) was calculated based on Secchi depth, chlorophyll concentration, and total phosphorus concentration and was used to describe a lake's trophic state. Carlson's TSI was developed based on the assumption that the lakes were all phosphorus limited. In Florida, because the local geology produced a phosphorus rich soil, nitrogen can be the sole or co-limiting factor for phytoplankton population in some lakes. In addition, because of the existence of dark-water lakes in the state, using Secchi depth as an index to represent lake trophic state can produce misleading results. Therefore, the TSI was revised to be based on Chl a, total nitrogen, and total phosphorus concentrations.

The Florida-specific TSI was determined based on the analysis of data from 313 Florida lakes. The index was adjusted so that a Chl a concentration of 20 ug/L was equal to a TSI value of 60. A TSI of 60 was then set as the threshold for nutrient impairment for most lakes (for those with a color higher than 40 platinum cobalt units) because, generally, the phytoplankton may switch to communities dominated by blue-green algae at Chl a levels above 20 ug/L. These blue-green algae are often an unfavorable food source to zooplankton and many other aquatic animals. Some blue-green algae may even produce toxins, which could be harmful to fish and other animals. In addition, excessive growth of phytoplankton and the subsequent death of these algae may consume large quantities of dissolved oxygen and result in anaerobic condition in lakes, which makes conditions in the impacted lake unfavorable for fish and other wildlife. All of these processes may negatively impact the health and balance of native fauna and flora.

Because of the amazing diversity and productivity of Florida lakes, some lakes have a natural background TSI that is different from 60. In recognition of this natural variation, the IWR allows for the use of a lower TSI (40) in very clear lakes, a higher TSI if paleolimnological data indicate the lake was naturally above 60, and the development of site-specific thresholds that better represent the levels at which nutrient impairment occurs. For this study, the Florida Department of Environmental Protection (DEP) used modeling to estimate the natural background TSI by setting land uses to natural or forested land, and then compared the resulting TSI to the IWR thresholds. If the natural background TSI can be determined, then an increase of 5 TSI units above natural background will be used as the water quality target for the TMDL. Otherwise, the IWR threshold TSI of 60 will be established as the target for TMDL development.

Chapter 4: DETERMINATION OF CURRENT LOADING

4.1 Overview

The external load assessment was intended to determine the loading characteristics of the various sources of pollutants to the Lake. Assessing the external load entailed assessing land use patterns and rainfall to determine the volume, concentration, timing, location, and underlying nature of the nonpoint and atmospheric sources of nutrients to the Lake.

4.2 Types of Sources

An important part of the TMDL analysis is the identification of pollutant source categories, source subcategories, or individual sources of the pollutant of concern in the watershed and the amount of pollutant loading contributed by each of these sources. Sources are broadly classified as either “point sources” or “nonpoint sources.” Historically, the term point sources has meant discharges to surface waters that typically have a continuous flow via a discernable, confined, and discrete conveyance, such as a pipe. Domestic and industrial wastewater treatment facilities (WWTFs) are examples of traditional point sources. In contrast, the term “nonpoint sources” was used to describe intermittent, rainfall driven, diffuse sources of pollution associated with everyday human activities, including runoff from urban land uses, agriculture, silviculture, and mining; discharges from failing septic systems; and atmospheric deposition.

However, the 1987 amendments to the Clean Water Act redefined certain nonpoint sources of pollution as point sources subject to regulation under the EPA’s National Pollutant Discharge Elimination Program (NPDES). These nonpoint sources included certain urban stormwater discharges, including those from local government master drainage systems, construction sites over five acres, and a wide variety of industries (see **Appendix A** for background information on the federal and state stormwater programs).

To be consistent with Clean Water Act definitions, the term “point source” will be used to describe traditional point sources (such as domestic and industrial wastewater discharges) and stormwater systems requiring an NPDES stormwater permit when allocating pollutant load reductions required by a TMDL (see Section 6.1). However, the methodologies used to estimate nonpoint source loads do not distinguish between NPDES stormwater discharges and non-NPDES stormwater discharges, and as such, this source assessment section does not make any distinction between the two types of stormwater.

4.3 Potential Sources of Nutrients in the Lake Hunter Watershed

Point Sources

There are no permitted wastewater treatment facilities that discharge nutrient loads into the Lake.

Municipal Separate Storm Sewer System Permittees

Within the Lake Hunter Basin, the stormwater systems owned and operated by local governments and the Florida Department of Transportation within the City of Lakeland are covered by an NPDES MS4 permit. Several other local governments in the basin have also applied for coverage under the Phase 2 NPDES MS4 permit.

Land Uses and Nonpoint Sources

Unlike traditional point source effluent loads, nonpoint source loads enter at so many locations and exhibit such large temporal variation that a direct monitoring approach is often infeasible. For this project, all nonpoint sources were evaluated by use of a watershed and lake modeling approach. Table 4.1 shows the acreage of the various land use categories examined. Figure 4.1 shows the drainage basin of the Lake and the spatial distribution of the land uses shown in Table 4.1. The predominate land coverage is Medium density Residential (59%) with general Urban second (27.3%) and Transportation, Communication, and Utilities following at 9.1 percent. The 93.4 acres of the Lake itself were not included as part of the watershed in Table 4.1.

Table 4.1: Land Cover Distribution

CODE	LANDUSE	ACRES
1000	Urban and Built-Up	167.07
	Low Density Residential	0.00
	Medium Density Residential	360.96
	High Density Residential	11.72
2000	Agriculture	0.00
3000	Rangeland	0.00
4000	Forest	3.42
5000	Water	0.00
6000	Wetlands	12.84
7000	Barren Land	0.00
8000	Transportation, Communications, and Utilities	55.45
TOTAL SUB-WATERSHED ACRES:		611.44

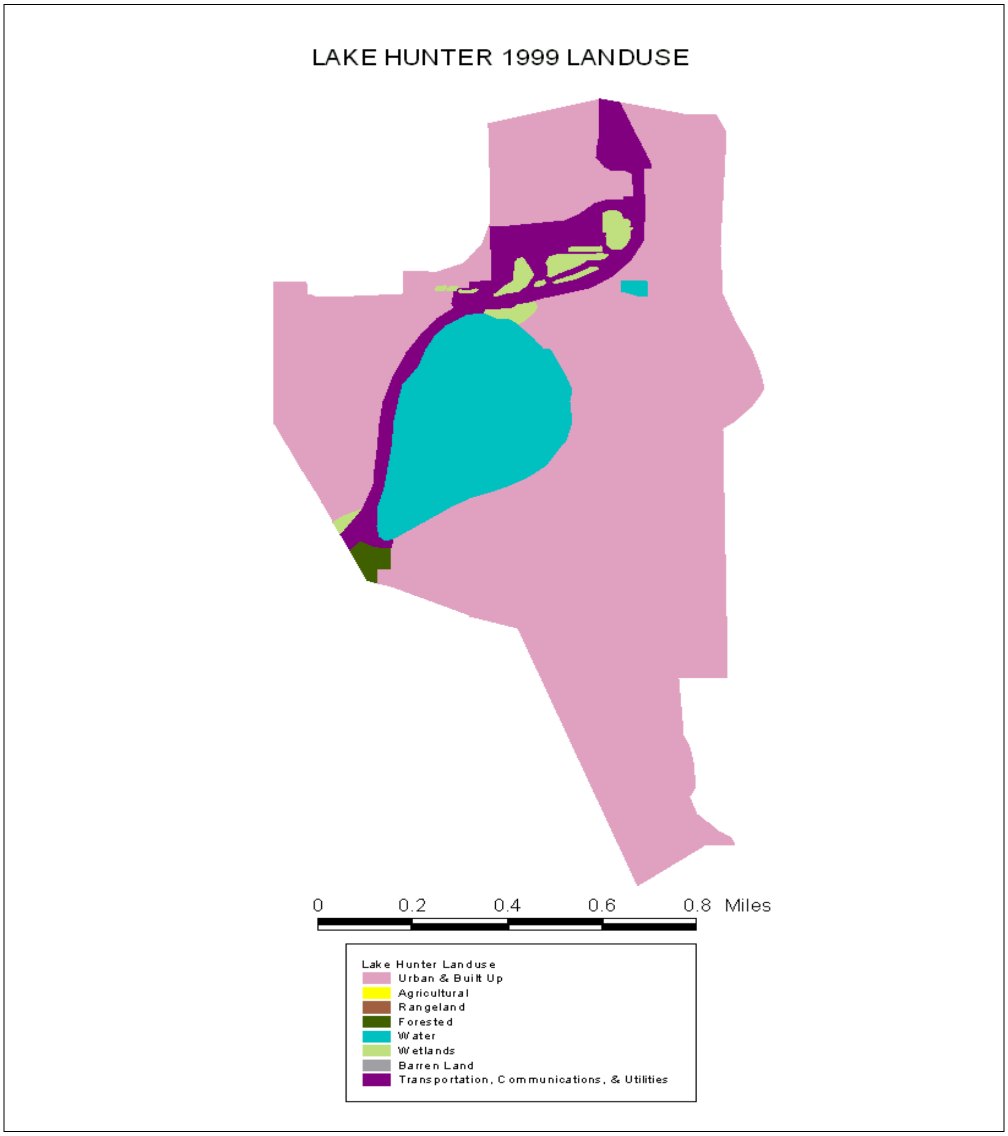


Figure 4.1. Map of drainage basin of Lake Hunter and land uses

4.4 Modeling of Nonpoint Sources

A spreadsheet model based on the governing equations contained in the Watershed Assessment Model (WMM) was used to estimate loading from nonpoint sources (except septic tanks). For the evaluation of septic tanks, the methods of Douglas Haith, Ross Mandel, and Ray Shyan Wu [1] were used. It was assumed that the effluent from septic systems infiltrates into the soil and enters the shallow saturated zone. Effluent nitrogen is converted to nitrate, and except for removal by plant uptake, the nitrogen is transported to the receiving water by groundwater discharge. Conversely, phosphate in the effluent is adsorbed and retained by the soil and hence does not reach the lake. The nitrogen load to groundwater in a month (m) as (kg) is:

$$N_m = 0.001\, a_m\, d_m(e - u_m) \qquad (1)$$

Where:

$\mathbf{a_m}$ = population served by septic tanks,
$\mathbf{d_m}$ = number of days in month m,
e = per capita daily nutrient load in septic tank effluent (assumed 12 g/day), and
$\mathbf{u_m}$ = per capita daily nutrient uptake by plants in month m (assumed 1.6 g/d during growing season and zero during non-growing season).

It was assumed that there are seven months of growing season in Florida. The City of Lakeland provided the estimates of the number of septic tanks. It was further assumed that the average household has four persons.

As noted previously, the governing equations from the Watershed Management Model (WMM) were incorporated into a spreadsheet model for use in the Lake Hunter Basin to estimate TN and TP loading. Development of the WMM model was originally funded by DEP under contract to Camp Dresser and McKee (CDM). The equations in the WMM are designed to estimate annual or seasonal pollutant loadings from a given watershed and evaluate the effect of watershed management strategies on water quality (WMM User's Manual: 1998). The fundamental assumption of the equations is that the stormwater runoff from any given land use is in direct proportion to annual rainfall and is dictated by the portion of the land use category that is impervious and the runoff coefficients of both pervious and impervious area.

The governing equation is:

$$(1) \qquad R_L = [C_p + (C_I - C_p)\, IMP_L] * I$$

Where:

R_L = total average annual surface runoff from land use L (in/yr);
IMP_L = fractional imperviousness of land use L;
I = long-term average annual precipitation (in/yr);
C_P = pervious area runoff coefficient; and
C_I = impervious area runoff coefficient.

The equation estimates pollutant loadings based on nonpoint pollution loading factors (expressed as lbs/ac/yr) that vary by land use and the percent imperviousness associated with each land use. The pollution loading factor M_L is computed for each land use, L. by the following equation:

$$(2) \qquad M_L = EMC_L * R_L * K$$

Where:

M_L = loading factor for land use L (lbs/ac/yr);
EMC_L = event mean concentration of runoff from land use L (mg/L); EMC varies by land use and pollutant;
R_L = total average annual surface runoff from land use L computed from Equation (1) (in/yr); and

K = 0.2266, a unit conversion constant.

Data required include:

- Area of all the land use categories and the area served by septic tanks
- Percent impervious area of each land use category
- EMC for each pollutant type and land use category
- Percent EMC of each pollutant type that is in suspended form
- Annual precipitation, and
- Point source flows and pollutant concentrations.

Calibration is normally conducted on both runoff quantity and quality. This was a two-step procedure since the water quality calibration is a function of the predicted runoff volumes. Calibration of water quantity is usually achieved through adjusting the pervious and impervious area runoff coefficients. Typical ranges of runoff coefficients are 0.05 – 0.30 for pervious area (WMM User's Manual: 1998) and 0.85 – 1.0 for impervious area (Linsley and Franziani, 1979). After the water quantity calibration, water quality should be calibrated by adjusting the pollutant delivery ratio – the percent quantity of pollutant in the surface runoff that is eventually delivered to the destination waterbody.

Atmospheric Deposition

Rainfall records for the watershed were taken from the NOAA database, CIRRUS. The rainfall station used was located in Lakeland, FL. (UCAN: 4017, COOP: 084797). In 2000, the rainfall station was relocated to the Lakeland Linder Regional Airport. This resulted in a few months of missing data. These rainfall data gaps were filled by taking records from the weather station in Plant City, located about eight miles from the Lake. Annual rainfall averages 54.48 inches, with values ranging from 38.26 inches to 67.13 inches over the period under study (Table 4.2).

Evaporation rate data were primarily obtained from a University of Florida Experimental Station about 15 miles northeast of the Lake. Some gaps were filled by data obtained from the Archibald Biological Station, located southeast of Lake Hunter. The available data were Class A pan evaporation data. Class A Pan's have the following characteristics: 4 foot diameter, 10 inches deep, well-ventilated (bottom raised 10 inches off the ground), and filled an eight inch depth. The "Pan" is undoubtedly the most widely used evaporation instrument today. However, hydrologists and scientists are generally interested in the evaporation rate over land or from an open water body like a lake. The pan evaporation rate should be adjusted to estimate the actual evaporation from land or open water due to pan boundary effects (greater radiant energy intercepted by the side wall and shallow bottom of the pan) and a lower water vapor pressure in the air above the land than in the air above a lake's surface. For these reasons, evaporation from an open water surface (E) is often estimated from the pan evaporation (E_p) as : $E = KE_p$, where K is the pan coefficient. This adjustment of the measured pan rate was incorporated into this study. The average Pan coefficient for the United States is 0.7 [2]. For Lake Hunter, the value of 0.8 followed the estimate of 0.81 for Lake Okeechobee, Florida. Annual evaporation rates varied from 54.72 inches to 63.52 inches (Table 4.2).

Wet deposition data were obtained from the Polk County Natural Resource Division, Bartow, Florida. The data were collected at a station located at Lake Cannon in the Winter Haven Chain of Lakes, around 10 miles east of Lake Hunter. The nearly 40 TN and 40 TP rainfall samples collected during 1988 – 2002 averaged 0.680 and 0.026 mg/L, respectively.

Sediment Flux

For calculation of the sedimentation rate, the Vollenweider model described in [5] and two W. Walker models included in the Bathtub model [6] were considered. After reviewing a report by Knight on improvement of water quality in South Florida wetlands [7] (primarily due to sedimentation) the second order Walker models for phosphorus and nitrogen sedimentation were selected. In the case of phosphorus;

$$C_p = [(1 + 4\ a\ c_f\ C_{po}\ \tau)^{0.5} - 1]/\ (2\ a\ c_f\ \tau) \qquad (3)$$

Where:

C_{po} is the phosphorus concentration for incoming water,
τ is residence time,
c_f is a calibration factor, and
a is the intercept of the phosphorus sedimentation term, in this case

$$0.17\ Q_s\ /\ (Q_s + 13) \qquad (4)$$

Symbol Q_s stands for the surface overflow rate, defined as the discharge from the lake per one unit of surface area.

The sedimentation of sediment-attached nitrogen was estimated by an equation similar to Eq. (3). However, this time the intercept of the nitrogen sedimentation term was

$$0.0045\ Q_s\ /\ (Q_s + 7.2) \qquad (5)$$

In this report, the term *internal recycling* refers to internally derived phosphorus. The most important source comes from bottom sediments that release phosphorus when the surrounding area goes anoxic. Additionally, in relatively shallow prairie reservoirs, phosphorus is recycled from bottom sediments from circular eddies generated by wind. Yousef reported that a 75-hp boat motor could re-suspend fine clay sediments to a depth of over 10 feet [8]. However, re-suspension may be negligible in Lake Hunter because the amount of accumulated sediments in the lake were reduced by a lake drawdown in 1983. The total drawdown of the Lake, conducted by the Division of Freshwater Fisheries of the Florida Fish and Wildlife Conservation Commission, exposed the bottom sediments through the spring of 1984. Bottom sediments were removed, followed by chemical treatment and mechanic removal of cattails [8].

The annual-average phosphorus concentration and turbidity of lake water usually drops during the years following this type of treatment. For example, when nutrient-rich sediments were removed from Lake Trummen in Sweden, the total phosphorus concentration dropped sharply and remained fairly stable for at least 18 years [9]. However, a similar lowering of the phosphorus concentration and turbidity did not take place in Lake Hunter, as shown in Figures 2.2 and 4.2.

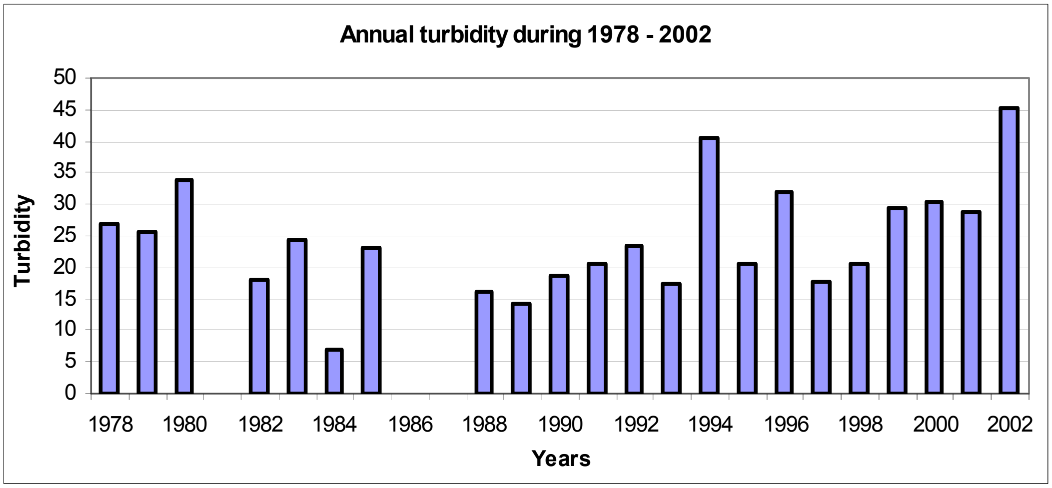


Figure 4.2 Turbidity in Lake Hunter during 1978 - 2002

Water Budget: Flows and Volumes

An essential part of the analysis of a water body is a water budget and mass balance for each year. The water budget for Lake Hunter was formulated as

Point and nonpoint source inflow + groundwater flow + precipitation = outflow + evaporation + change of volume

While there are no NPDES facilities that discharge wastewater within the Lake Hunter watershed, the City of Lakeland, Division of Lakes & Stormwater staff provided information that two other lakes, Beulah and Wire, discharge stormwater through pipes into Lake Hunter. In this analysis, those lakes were evaluated as point sources in developing the water budget.

Discharge from Lake Hunter

Lake Hunter discharges through a double gate into an unnamed creek. Although the discharge flows were never recorded, the Public Works Department for the City has limited monitoring data for the opening of the gates (adjustments) during the period 1997 – 2003. Using these data, a statistical approach was used to establish a relationship between water stages in the Lake and the flow through the outfall structure. The records of water stage in the Lake were matched with the available records of the gates' adjustments. The discharge from the gate was simulated by equation (Eq.) 2 [3]:

$$Q = C\,a\,L\,(2\,g\,h)^{0.5} \qquad (2)$$

Where:I

a is the height of an opening,
L is the width of the opening,
g is the gravitational constant,
h is the hydraulic head on the center of the opening, and
C is the coefficient of discharge.

During the calculations, it was allowed that **C** varied with the depth of the opening and the hydraulic head. From Eq. (2) the discharge, **Q,** can be estimated knowing the water level in the lake, height of the opening of the gate, and the dimensions of the gate. For the double gate in Lake Hunter, the calculated flow through a single gate was doubled, disregarding any mutual influence of both gates.

The Public Works Department provided nearly 450 records of the water stage in Lake Hunter during the years 1988 – 2002, but with only 55 records of the gates' adjustments. Moreover, prior to October 1997, a double weir was in place instead of the double gate present now. Given the situation, the estimate of historical outflows from the Lake may not be very accurate. The principal assumption of this portion of the analysis was that, whether the water was discharged through weirs or gates, the City's objective to maintain a specific, safe water stage in the Lake remained the same. Therefore, over a long time span such as a year, the total volume of water expected to be discharged depended more on the inflows to the Lake rather than on the method of discharge from the Lake.

To estimate the complete outflows from the record of 450 water stages (*with only 55 records of adjustments* of the gates or weirs), an approximate relationship between stages, some other easily measured parameters, and the known (or assumed) outflows needed to be developed. After some experimentation, it was found that the outflows correlate reasonably well with water stages, the amount of rain in a given day, and the sum of rainfall during the 13 prior days. The total rainfall that occurred during the previous two weeks was included into the estimation of the daily outflow. The gate adjustments, provided by the Public Works Department, were not consistently recorded during the early years. However, with time, the recordings showed a more systematic two-week schedule. Therefore, for the majority of outflows, the rainfall aggregated from the previous 13 days and the current day encompassed practically *all* rainfall recorded at the Lake. In other words, the sum of the rain (1+ 13 days) was related to the predominant time span of the records of adjustments (two week intervals). The least-square technique available with the software As-Easy-As provided the coefficients of polynomials relating estimated outflows with three independent variables. The coefficient of determination, R^2, was 0.86 (see Figure 4.3).

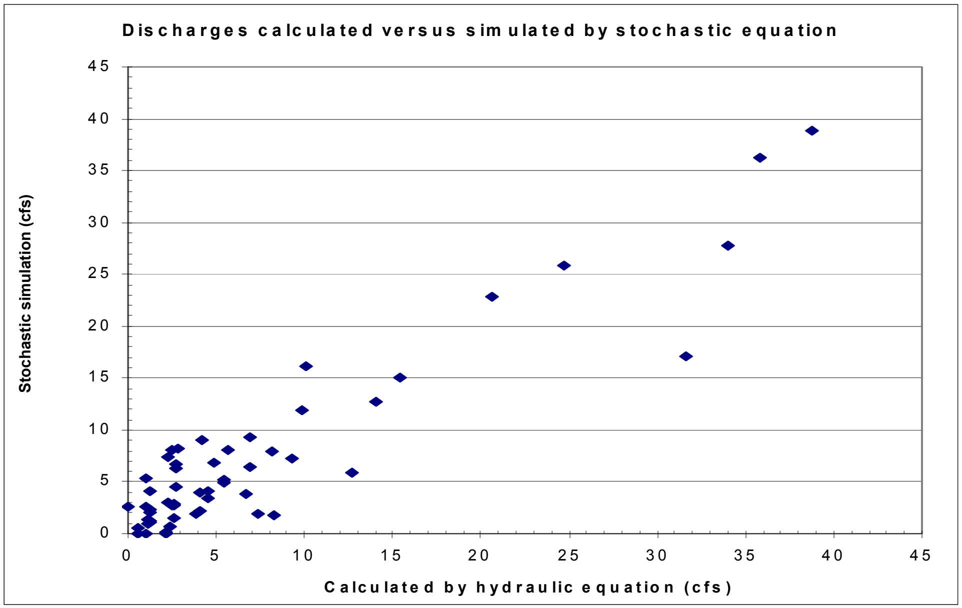


Figure 4.3 Correspondence between outflows calculated from known adjustment of the gates and estimated by regression equation with water stage, rainfall at this day, and total rain in preceding 13 days as independent variables. Ideally, the points should plot along a diagonal.

The regression developed was applied to the complete record of 450 water stages (1988 – 2002) and the record of daily rainfalls to estimate the outflows from Lake Hunter. The calculated outflows were then multiplied by the number of days between consecutive dates (mostly in 14-day intervals) and summed up into annual discharges.

The lack of measured data on the actual outflows during 1988 – 2002 prevented estimating the accuracy of the calculated outflows. The implied accuracy was judged intuitively, plotting outflows and rainfalls and looking for the expected correspondence between both parameters (Figure 4.4). The estimated annual outflows are provided in Table 4.2.

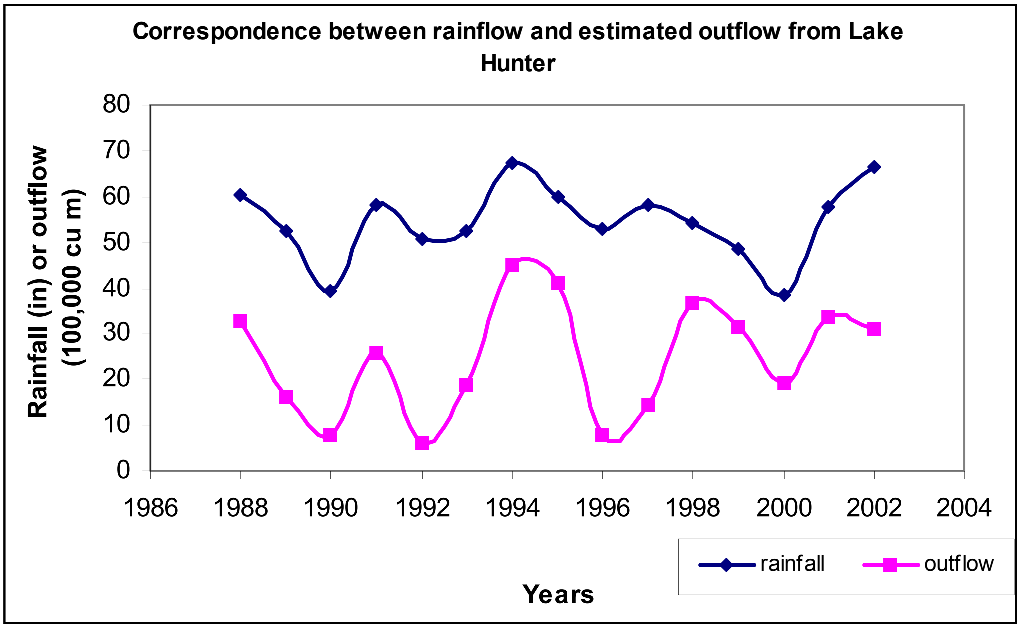


Figure 4.4 Plotted annual rainfalls and outflows from Lake Hunter

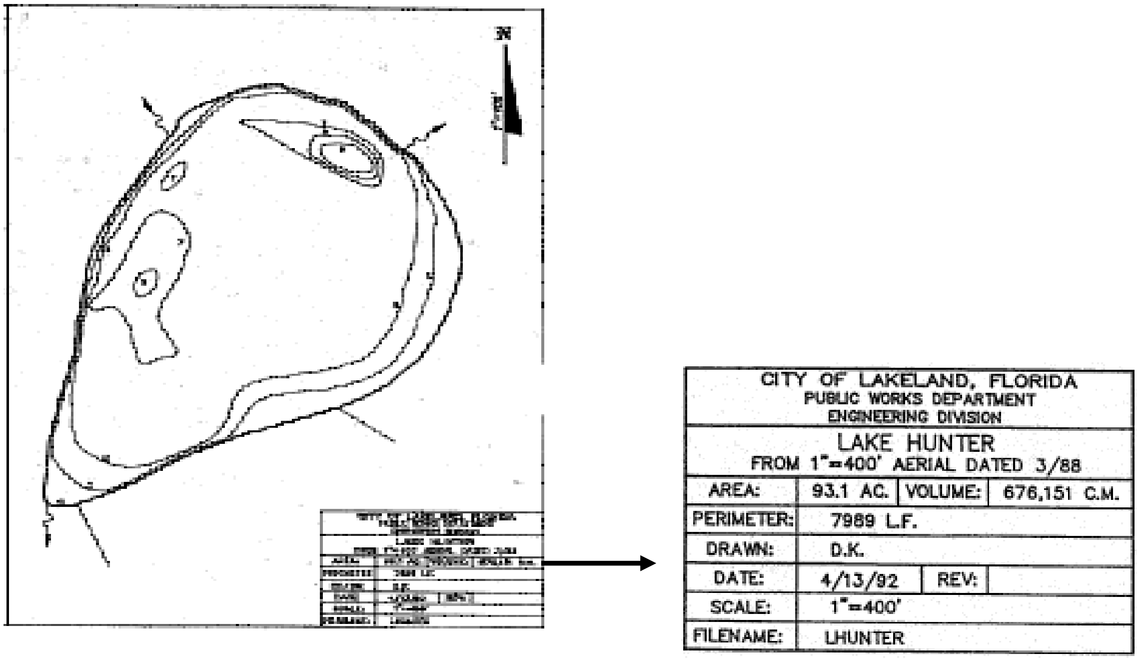
Runoff from Lake Hunter Basin

The other component of the water balance equation is surface runoff volume. The spreadsheet model based on the equations from the WMM was applied to calculate discharges from the mostly residential basin of 611 acres. The runoff coefficients were taken from Harvey Harper [4], complimented by estimates provided by other authors (Haith, [1], and Brown, [15]) wherever it was necessary. The land uses and acreage in the Lake Hunter drainage basin is shown in Figure 4.1 and Table 4.1. Estimates of surface runoff are provided in Table 4.2.

Volume of Water in Lake Hunter

One of the components of the water budget, and a quantity playing a dominant role in the mass balance equation as well, is the volume of water detained in the Lake. The records of water stages during 1988 – 2002 were provided by the Public Works Department, City of Lakeland. However, for the estimate of detained water volume, two pieces of information were still needed: lake morphometry and at least one pair of water stage and water volume measurements as a reference point. This information was taken from the bathymetric map for Lake Hunter (Figure 4.5). The area and volume of Lake Hunter on the day the aerial photo was taken are shown in the lower right corner of the map are. In the records of water stages, it was found that the water level in that month was stabilized at 161.60 feet above see water level.

The scale of the bathymetric map (Figure 4.5) was found by overlapping that map on a cartographic map of the Lake held in the Department's GIS files. Knowing the scale of Figure 4.5, it was possible to calculate the areas inside the contour lines. Analysis of the contour lines assumed a simple dependency of the surface area and volume of the detained water on the depth of the Lake. Two types of volume have been calculated: one is the average volume during a year, and the other is the volume at the end of the year. The latter volume was used to estimate the change of water volume in a given year, which is one component of the water budget equation.



CITY OF LAKELAND, FLORIDA
PUBLIC WORKS DEPARTMENT
ENGINEERING DIVISION
LAKE HUNTER
FROM 1"=400' AERIAL DATED 3/88

AREA:	93.1 AC.	VOLUME:	676,151 C.M.
PERIMETER:	7989 L.F.		
DRAWN:	D.K.		
DATE:	4/13/92	REV:	
SCALE:	1"=400'		
FILENAME:	LHUNTER		

Figure 4.5. Bathymetric map for Lake Hunter with magnified legend to the right

Discharges from Lakes Beulah and Wire

As mentioned previously, Lakes Beulah and Wire occasionally discharge to Lake Hunter via hydraulic structures and underground pipes. The Lakes & Stormwater Division (Department of Public Works, Lakeland, Florida) kept records of water stages and the adjustment of the openings in the hydraulic structures in these two lakes. Lake Wire discharges through a single weir that holds up to three six inch flushboards, and Lake Beulah discharges through a gate. Both structures were redesigned at least once between 1988 and 2002 and were not functional during some periods.

The stormwater discharges from those two lakes constitute major inflows to Lake Hunter. Due to the uncertainty of the data, the estimates of the stormwater contribution of both lakes to Lake Hunter can not currently be verified. However, both of the other drainage basins are of a similar type, mostly medium density residential, are located close to one and another, and are receiving almost the same rainfalls. Additionally, the same objective applies to both lakes: to maintain a certain, safe, water level. The resemblance of one hydrograph to another is the only measure of accuracy that can be applied to the estimates (see Figure 4.6). The estimated cumulative outflows are included in Table 4.2.

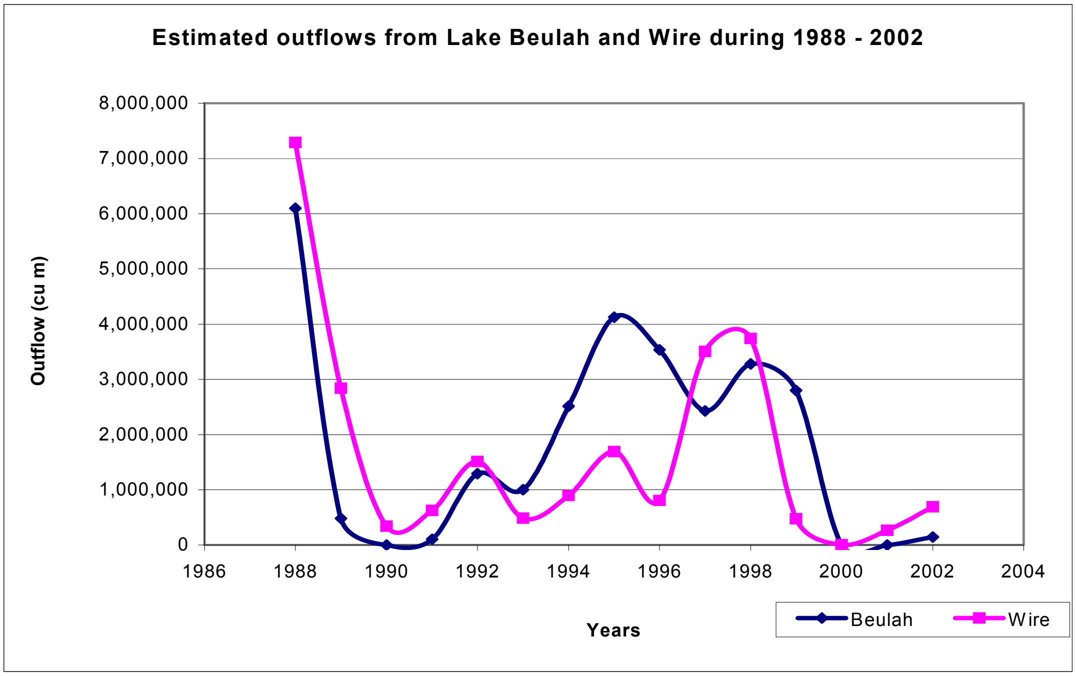


Figure 4.6. Annual discharges from Lake Wire and Beulah estimated from recorded water stages and adjustments.

Other Sources of water: Groundwater

Within the Central Florida area, the surficial aquifer system ranges from 50 to 300 feet in thickness and is composed of unconsolidated sand and clay. The surficial aquifer system is hydrologically separated from the underlying Upper Floridan aquifer by the intermediate confining unit. However, sinkholes and subsidence features often modify and breach the confining unit, thereby diminishing the hydrologic confinement [11].

Groundwater can be a very important component of water sources to lakes in Central Florida. In this mantled karst terrain, unconsolidated sands and clays overlie an irregular limestone surface. The surface is highly permeable, so rainfall quickly percolates through the sands to the water table, favoring groundwater flow over surface water drainage. As a result, 70 percent of Florida’s lakes are seepage lakes, having no natural stream flow into or out of them. Groundwater typically enters a lake in shallow areas near the shore [12].
Data on the groundwater interaction with Lake Hunter were not available. Traditionally, these data are one of the most difficult to collect. The recharge of Lake Hunter by the shallow groundwater aquifer was estimated from the water balance made for the Lake for each year.

The water budget for the Lake was on a negative side (on an annual average basis, more water was lost to the groundwater from the lake than water gained by the lake from the aquifer) mostly due to the substantial water supply from Lakes Wire and Beulah. It appears that accretion to the surficial aquifer is related to the amount of discharge from Lakes Wire and Beulah. When discharges from these other two lakes stop playing a dominant role in the total inflow to Lake Hunter, the groundwater system supplies the Lake with water. When these lakes are discharging to Lake Hunter, the aquifer becomes a 'sink' from the over-supplied Lake Hunter. The cumulative discharges from Lakes Wire and Beulah and accretion to the surficial aquifer are compared in Figure 4.7.

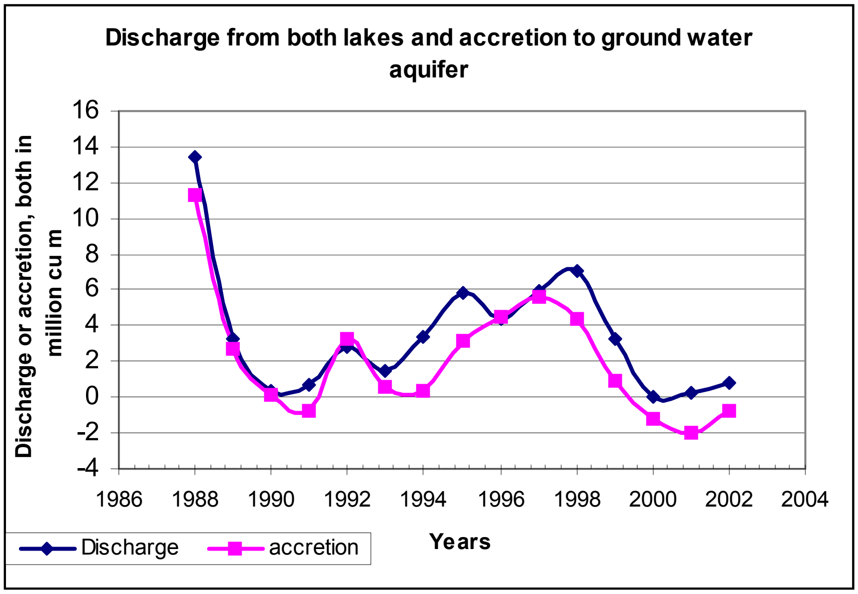


Figure 4.7 Cumulative discharge from Lakes Wire and Beulah with loss to groundwater aquifer. The red line falling below level zero corresponds to groundwater seeping into Lake Hunter.

Year	Rainfall	Evap	Outflow	Surface Runoff	Inflow from Lake Wire & Beulah	Average Volume	Volume at year's end
	in/y	in/y	cu m	Ac- ft	cu m	cu m.	cu m.
							597,311
1988	60.54	60.96	3,265,172	1,001.3	13,388,753	671,643	666,044
1989	52.36	61.84	1,627,951	866.0	3,317,435	637,902	615,549
1990	39.43	62.40	794,500	652.1	339,607	545,978	579,138
1991	58.21	56.80	2,566,142	962.7	732,438	666,958	675,278
1992	50.51	56.24	628,170	835.4	2,798,808	564,129	561,032
1993	52.38	55.12	1,887,566	866.3	1,486,330	609,919	581,406
1994	67.13	54.72	4,496,325	1,110.3	3,410,846	629,888	647,625
1995	60.06	57.12	4,093,349	993.3	5,817,687	659,252	453,772
1996	52.85	57.12	767,620	874.1	4,339,355	590,449	617,834
1997	58.14	61.84	1,437,865	961.6	5,930,325	595,036	638,440
1998	54.41	63.52	3,671,542	899.9	7,021,634	648,457	626,982
1999	48.66	57.84	3,155,802	804.8	3,271,311	669,416	724,027
2000	38.26	58.59	1,910,111	632.8	6,494	638,707	657,977
2001	57.67	57.66	3,381,921	953.8	266,217	666,132	691,477
2002	66.58	56.17	3,104,547	1,101.2	832,367	656,464	626,982

Table 4.2. Rainfall and other data applied to water budget during years 1988 – 2002

It is unlikely that periods during which the shallow groundwater aquifer discharges to Lake Hunter are accidentally coincidental to seasons of reduced rainfall. Comparison of Figure 4.4 with Figure 4.7 shows that periods of net groundwater inflow to the lake or relatively low losses from the Lake to the groundwater corresponds to, or closely follows, annual precipitation that was below average.

The contribution of groundwater to Lake Hunter (Figure 4.8) or Lake Hunter to the shallow aquifer (red line in Figure 4.7) showed large variations over time. Also, the percentage of the groundwater component in the total water supply to Lake Hunter or in the discharge of water from Lake Hunter varied in such a wide range that the average value would not have had practical meaning. The variability of the groundwater component is shown in Figure 4.8.

Year	Ground water (cu m)	Ground water as percent
1988	-11,286,080	--
1989	-2,651,724	--
1990	-179,311	--
1991	*721,902*	*23*
1992	-3,263,913	--
1993	-601,408	--
1994	-329,854	--
1995	-3,136,600	--
1996	-4,417,866	--
1997	-5,643,038	--
1998	-4,290,527	--
1999	-679,050	--
2000	*1,238,178*	*50*
2001	*1,972,624*	*50*
2002	*755,157*	*21*

Table 4.3 Summary of groundwater component. Years in which aquifer discharged to the Lake are underscored. Percent of groundwater is related to total water supplied to Lake.

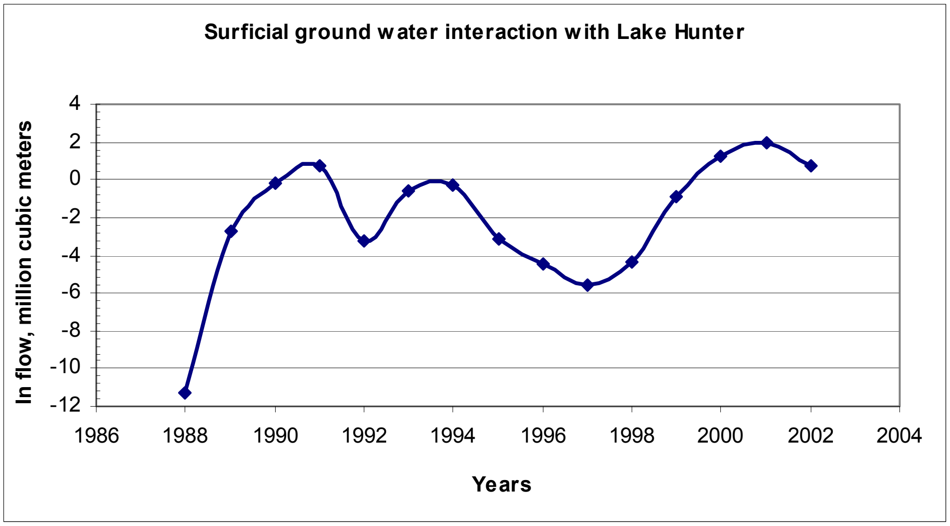


Figure 4.8 Supply of groundwater aquifer by Lake Hunter. The positive volumes refer to seepage of ground water into the Lake.

Water Budget: Mass Calculations

To calculate nutrient loads into and out of the Lake, annual average concentrations for nutrients and chlorophyll a were calculated from the seasonal concentrations of TN, TP, and Chl a. Figures 2.2, 2.3, and 2.4 summarize those data as the annual average concentrations in Lake Hunter. The major sources of nutrients to the Lake are surface runoff from the drainage basin that picks up and transports soil, nutrients, organic matter, toxins, and other pollutants; stormwater discharges from lakes Wire and Beulah; direct rainfall falling onto the Lake's surface; and groundwater inflow to the Lake.

Mass from Lakes Wire and Beulah

A spreadsheet model based on the WMM was used to balance the mass of TP and TN measured in the Lake. The mass balance equation is

Sedimentation – internal load = point and nonpoint source load + groundwater load + rainfall load – export load – increase of suspended mass

The term *Export load* in the mass balance equation is that mass of nutrients that leaves Lake Hunter with the outflow. It is always calculated as a product of outflow volume and the concentration in the Lake.

The last term in the mass balance equation is an *increase of suspended mass*. This term was calculated as the difference between the mass of either nutrient contained in the Lake at the beginning and end of each year.

Water quality data for Lakes Wire and Beulah consisted of a monthly sampling of TP and TN from 1989 – 1991. Beginning in 1992, only one sample per season of both nutrients was collected. Products of the concentrations and outflows during matching months or seasons were aggregated into annual totals.

The combined loads from Lake Wire and Lake Beulah were added into the annual mass balance equation as a point source to Lake Hunter. Missing water quality data for Lakes Wire and Beulah for 1988 eliminated that year from further analysis. See Table 4.4 for results of these mass load calculations.

Mass of TN and TP in kgs pounds**(lbs)** discharged from Lakes Beulah and Wire into Lake Hunter during current conditions:				
	Lake Beulah		Lake Wire	
Year	TN	TP	TN	TP
1996	6,077 **(13,397)**	332 **(732)**	737 **(1,625)**	76 **(168)**
1997	3,570 **(7,870)**	519 **(1,144)**	3,066 **(6,759)**	857 **(1,889)**
1998	2,983 **(6,576)**	597 **(1,316)**	2,553 **(5,628)**	733 **(1,616)**
1999	2,974 **(6,556)**	411 **(906)**	345 **(761)**	71 **(156)**
2000	3 **(6.6)**	0 **(0)**	4 **(8.8)**	1 **(2.2)**
2001	0 **(0)**	0 **(0)**	171 **(377)**	45 **(99)**
2002	222 **(489)**	35 **(77)**	680 **(1,499)**	156 **(344)**
Average	*2,261* **(4,985)**	*271* **(597)**	*1,079* **(2,379)**	*277* **(611)**

Table 4.4 Mass of TN and TP in kgs & pounds (lbs) discharged from Lakes Beulah and Wire into Lake Hunter during current conditions:

Mass from Lake Hunter watershed

The mass of nutrients washed off by surface runoff was estimated using loading functions provided by Harvey Harper for different land uses [4]. It should be noted that the loading function for forest was assumed as 1.09 mg/L for nitrogen and 0.046 mg/L for phosphorus. Those loading function became particularly important during estimation of natural background conditions when all man-made alterations to natural conditions were arbitrarily replaced by forest land use. See Tables 4.5 and 4.6 for results of mass load calculations.

Sources	Current Condition		Natural Background Condition		80% reduction TMDL Condition	
	TN Kgs **(lbs)**	**TP** Kgs **(lbs)**	**TN** kgs **(lbs)**	**TP** kgs **(lbs)**	**TN** kgs **(lbs)**	**TP** kgs **(lbs)**
Lakes Wire and Beulah combined	3,341 **(7,366)**	548 **(1,208)**	0 **(0)**	0 **(0)**	668 **(1,473)**	109 **(240)**
Ground water	503 **(1,109)**	35 **(77)**	252 **(556)**	8 **(18)**	503 **(1,109)**	35 **(77)**
Nonpoint Sources Lake Watershed	2,385 **(5,259)**	349 **(769)**	1,135 **(2,502)**	49 **(108)**	495 **(1,091)**	71 **(157)**
Septic Tanks	340 **(749)**	0 **(0)**	0 **(0)**	0 **(0)**	0 **(0)**	0 **(0)**
Direct Rainfall on Lake	331 **(730)**	13 **(29)**	319 **(703)**	12 **(26)**	331 **(730)**	13 **(29)**
Net internal recycling	1,872 **(4,127)**	0 **(0)**	89 **(196)**	0 **(0)**	137 **(302)**	0 **(0)**

Table 4.5 Load in kgs and lbs from various sources (Current is average for the period 1996 - 2002):

Note: Reduction of load for internal recycling for natural background and the 80% reduction scenarios further increases the implicit margin of safety.

Lake Hunter watershed average nutrients contribution during 1996 - 2002 (in kgs):						
	Current conditions		Background condition		80% reduction	
	TN	TP	TN	TP	TN	TP
Septic Tank	339.7	0.0	0.0	0.0	0.0	0.0
Forest/Rural Open	6.4	0.3	1,118.5	47.3	6.4	0.3
Urban Open	88.8	9.8	0.0	0.0	17.8	2.0
Medium Density	1,633.4	251.1	0.0	0.0	326.7	50.2
High Density	105.8	21.4	0.0	0.0	21.2	4.3
Highway	535.4	64.8	0.0	0.0	107.1	13.0
Wetlands	16.1	1.4	16.1	1.4	16.1	1.4
Sum	*2,725.6*	*348.8*	*1,134.6*	*48.7*	*495.3*	*71.2*
Please note that septic tanks were completely eliminated in 80% reduction alternative,						
And forest and wetlands were not reduced at all						

Table 4.6 Lake Hunter Watershed Loadings by Source Category during 1996 - 2002 (in kgs).

Mass from Ground water

No data on ground water quality was available at the time of this analysis. However, out of the 14 years analyzed, ground water was found to supply Lake Hunter in only four years. For those four years, the nutrient concentrations in ground water were set at values from studies on Lake

Morton by Environmental Research & Design [13]. Lake Morton is a 40.8-acre urban lake located in the central downtown area of the City of Lakeland, less than a mile northeast of Lake Hunter. The project included a detailed study of ground water interaction using seepage meters. This provided an annual estimate of the mass loading from ground water seepage as 57.8 kg of nitrogen and 4.07 kg of phosphorus. Together with the annual ground water seepage estimated as 52.74 ac-ft, the average concentration of nutrients in the groundwater was 0.8885 mg/L of TN and 0.06256 mg/L of TP. These concentrations were used in the analysis of Lake Hunter. See Tables 4.5 and 4.6 for results of mass load calculations.

Annual Water and Mass Balance Results

An annual water balance and mass budget were conducted for the years 1989 through 2002 using the spreadsheet model. The calculated mass entering the Lake was added to the mass residing in the Lake at the beginning of each year and then divided by the total volume of water that entered the Lake. The estimated average concentration of either TP or TN was then reduced by sedimentation, according to Eq.s (3), (4), and (5). No data on sedimentation in Lake Hunter was available during this analysis. Therefore, the calibration coefficient c_f was manually adjusted to match the total calculated mass of nutrients coming into the Lake to the measured data. Figures 4.9 and 4.10 provide insight into the reliability of the modeling effort. Tables 5.2, 4.4, 4.5,and 4.6 contain the mass loading, concentration, and TSI results of the various scenarios.

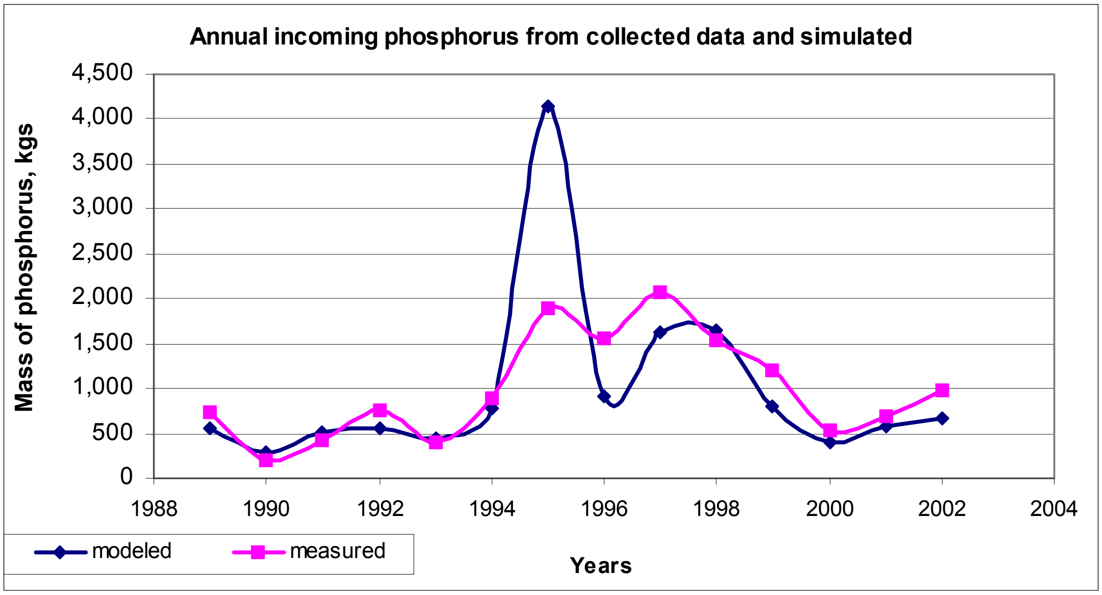


Figure 4.9 Comparison of modeled phosphorus load into Lake Hunter during 1989 – 2002 to the measured load. Average difference is 0.7 kg/year.

In general, the accuracy of the TP load estimates seems to be reasonable. While the model estimates did not match the spike of load in 1995, the high load measured in 1995 is an artifact of the collection method and a storm induced washout from a construction site. According to

City of Lakeland staff, there was a severe rain event (more than 2.0" rain) in August 1995 during the construction of a school near Lake Wire. This rain caused a construction washout, and silt deposits (whitish water discharge) covered almost five acres of the Lake. Because lake samples were only taken quarterly and the sampling corresponded to the month with the spill, this one spill accident impacted the average phosphorus concentration during the entire season preceding the spill and during the following season as well.

The mass of TN coming into Lake Hunter provided a greater challenge. While estimates for 1987 through 1995 were relatively accurate, concentrations measured in the Lake consistently exceeded the model estimates for 1996 through 2002, in spite of applying a separate negative calibration coefficient (**c_f**) for those years. Unless the estimate of loads originating from Lakes Wire and Beulah is erroneous, there is an additional source of nitrogen to Lake Hunter that has yet to be identified. The negative calibration coefficient may reflect net nutrient releases from bottom sediments or fixation of atmospheric nitrogen by blue green algae. A search for algae species composition data from 1989 through 2002 proved to be unsuccessful. The City of Lakeland, Florida Fish & Wildlife Conservation Commission, Southwest Florida Water Management District, and the Polk County Division of Natural Resource were unable to provide any such data.

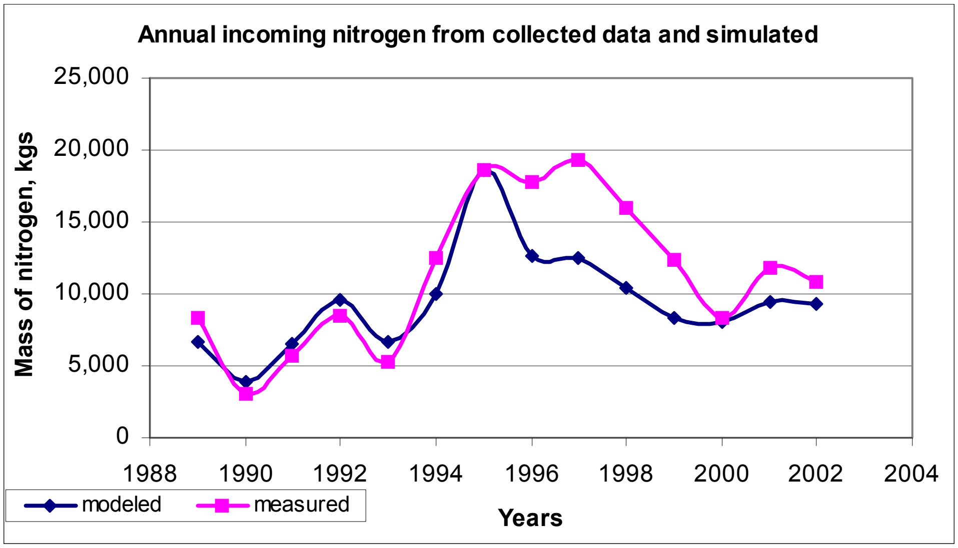


Figure 4.10 Comparison of nitrogen load into Lake Hunter during 1989 – 2002 to the measured load. Average difference is 1,844 kg/year.

Another potential source of nutrients to the Lake that was not included into this analysis could be waterfowl. Lake Hunter is situated inside the City with a recreational park and trail around it, and this park is home to a variety of waterfowl species such as swans, herons, ducks, and geese. The majority of the waterfowl are actively maintained and fed by the City of Lakeland Parks and Recreation Department as well as local residents and park visitors [13]. For nearby Lake Morton (with a surface area less than 50% of Lake Hunter), Environmental Research & Design estimated that waterfowl contributed 776 kg of TN and 156 kg of TP per year load to the lake.

Summary of mass balance in Lake Hunter

The spreadsheet model applied to the Lake Hunter data facilitated calculation of the water balance (volume and mass) for all water incoming and leaving the Lake. Parameter $\mathbf{c_f}$ in Eq. (3) was optimized in the simulation of sedimentation/internal recycling to match the predicted annual average mass of both nutrients with the measured data. The ground water interaction with Lake Hunter was a major missing component of the water budget. The outflow from Lakes Wire, Beulah, and Hunter were estimated from water stages read in two-week or even longer time intervals. Therefore, it was not possible to assure a truly balanced water budget. The mass balance equation revealed a missing nitrogen mass loading to the Lake during the period 1996 –2002 (see Figure 4.10).

From the quantity of missed nutrients, especially of nitrogen, it appears that some source of nitrogen is still unidentified. In addition to the sources already mentioned (birds, bluegreen algae, or internal recycling) there may be unaccounted sources discharging to Lake Hunter. There are a total of 28 pipes that discharge to Lake Hunter. It is the Departments understanding that these are storm drainage systems serving the drainage basin of the Lake. It is possible that some of the pipes may serve municipal areas from outside the drainage basin.

Chapter 5: DETERMINATION OF ASSIMILATIVE CAPACITY

Nutrient enrichment and the resulting problems related to eutrophication tend to be widespread and are frequently manifested far (in both time and space) from their source. Addressing eutrophication involves relating water quality and biological effects (such as photosynthesis, decomposition, and nutrient recycling), as acted upon by hydrodynamic factors (including flow, wind, tide, and salinity) to the timing and magnitude of constituent loads supplied from various categories of pollution sources.

5.1 Critical Conditions

To evaluate nutrient impairment in a lake, a reference condition is needed. For lakes in Florida, the reference condition is represented by the TSI. Lake Hunter was included on the list of impaired waters because at least one annual mean TSI exceeded the IWR threshold during the verified period. For Lake Hunter, the verified threshold was different in different years due to variations in the Lake's color (Figure 5.1). In years with a mean color less than 40, the TSI threshold would be 40. In years with a mean color greater than 40, the TSI threshold would be 60. Since the annual TSIs of Lake Hunter were always greater than 60 (Figure 5.2), the Lake would be listed as impaired regardless of the color. Due to the uncertainty of the appropriate target TSI for development of the TMDL, the Department used modeling to evaluate various background scenarios for the Lake.

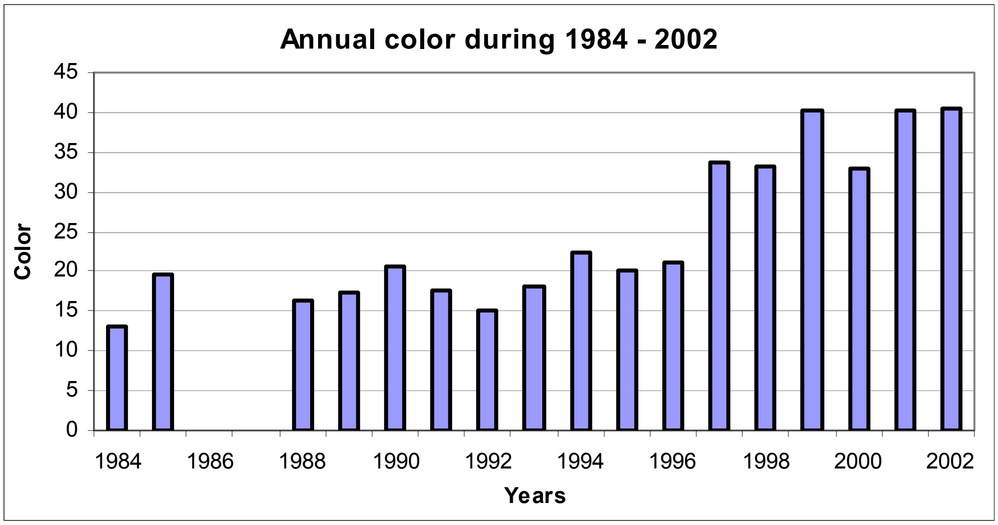


Figure 5.1 Annual-average color in Lake Hunter during years 1984 – 2002

The assimilative capacity should be related to some specific hydro-meteorological condition such as an 'average' during a selected time span or to cover some range of expected variation in these conditions. In this analysis, rather than use average conditions, the Department examined the existing data to determine a set of “critical years” for meteorological conditions. The TSIs from Figure 5.2 were arranged in ascending order: 74.9, 75.3, 75.7, 77.6, 78.6, 81.2, 81.4, 81.8, 82.43, 82.6, 85.6. The lower tenth percentile for this set of numbers is 75.3 (1991), the 50th percentile is 81.2, and 90th percentile is 82.6 (2001). The meteorological conditions of the year 2001 were selected as the “worst case” critical condition (90th percentile worst case TSI for the period 1989 – 2002). The meteorological conditions of 1991 were selected as the “best case” critical condition (10th percentile TSI for the period 1989 – 2002).

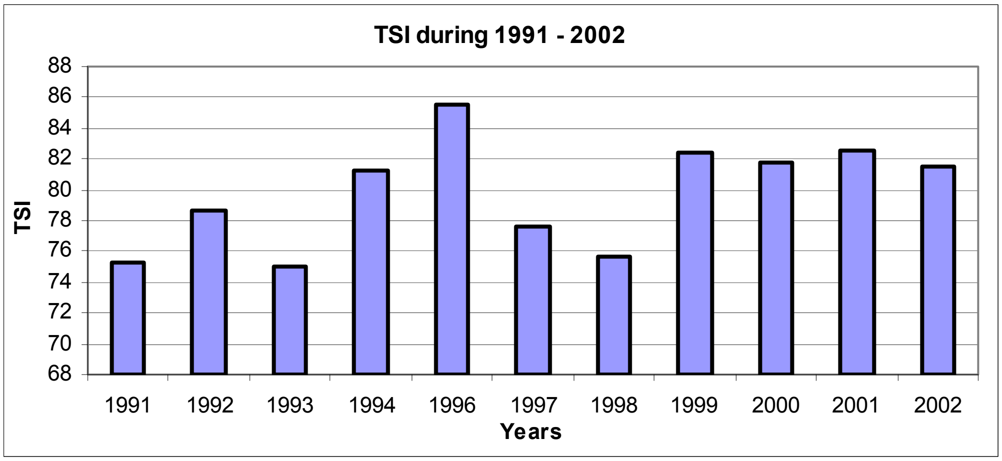


Figure 5.2 Annual-average TSI during years 1991 – 2002. During those years, samples of TN, TP, and Chl a were taken in every season.

5.2 Determination of Natural Background

To evaluate the natural background condition for the Lake, the current land uses listed in Table 4.1 under *urban*, and *transportation* categories were evaluated as *forest,* loading from septic tanks was set at zero, and the connections between Lake Hunter and Lakes Wire and Beulah were eliminated.

Under these background conditions, it is likely that the ground water inflow/outflow to the Lake was different from that of the current condition, which is highly impacted by the roughly 740 thousand cubic meters of water flowing annually from Lakes Wire and Beulah. The removal of this volume of water from Lake Hunter would lower the hydraulic head in the Lake and increase ground water inflow to the Lake.

To estimate the ground water inputs to the lake under background conditions, several relationships were tested, and the total annual inflow to the Lake correlated best with the groundwater component listed in Table 4.3. The approximation function was

$$\text{groundwater inflow to Lake Hunter} = 2.404 - 0.86 * \text{total inflow} \qquad (6)$$

where both inflows are in million cubic meters. Figure 5.3 shows this correlation [coefficient of determination (R^2, was 0.73)].

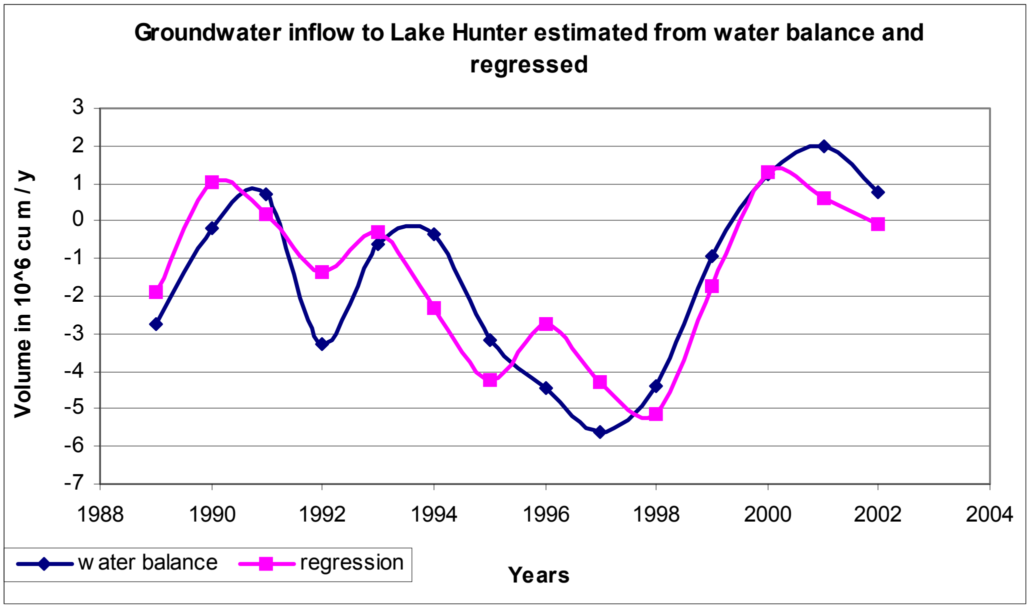


Figure 5.3. Approximation of groundwater component by regression Eq. (6). During most of period 1989 – 2002 Lake Hunter discharged to groundwater aquifer (negative numbers).

Using the same climatological conditions as occurred in 1991 (10th percentile year), the natural background total inflow to Lake Hunter was estimated as 1.636 million cubic meters, and for this inflow Eq. (6) provided the expected groundwater inflow as 891,600 cubic meters. Comparing estimates of the groundwater component for current conditions in 1991, to the natural background estimates, the total groundwater contribution increased by 162,000 cubic meters. The estimate from Eq. (6) suggests that, as expected, the surficial aquifer bled down more abundantly to Lake Hunter before the basin was populated.

Having estimates of inflows from all identified sources, a water budget for the pre-populated Lake was still not complete because the volume of water detained in the Lake and discharges from the Lake were not known. Discharge from the Lake under background conditions is not known because the morphometry of the Lake outlet is not known and discharge is a straight function of depth of water and morphometry of the outlet.

Given the lack of information about the Lake depth and outlet, discharges, water stages, and the volume of detained water were calculated for the natural condition in daily steps until equilibrium was reached in the Lake. The daily inflows were total volumes divided by the number of days in a year. The secondary advantage of such a simulation was the elimination of the influence of not knowing the initial condition of the Lake for volume, depth, and discharge at steady state.

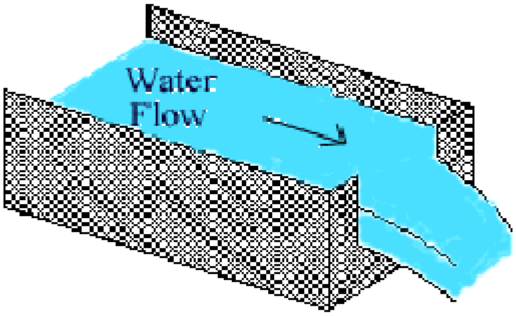


Figure 5.4 Idealization of water discharging from Lake Hunter

The outfall of Lake Hunter in the pre-populated basin was then approximated by a rectangular, top – open orifice, Figure 5.4. The theoretical formula for a stream of water issuing from such an orifice is [3]

$$Q = 2/3 \, L \, h \, (2 \, g \, h)^{0.5} \qquad (7)$$

where

L = width of the opening, m
h = water level above the crest of the orifice, m, and
g = gravitational constant, 9.80665 m^2/s.

In the derivation of Eq. (7) from the Bernoulli energy conservation equation, the energy loss term has been dropped. The convenient way to account for the energy loss and the effect of contraction of the nappe is by introducing a coefficient of discharge, **C**, that is usually close to 0.6, but not necessarily 2/3. For wide orifices, **C** stabilizes near 0.6, and this value was used in the calculation. Steady-state was achieved with the Lake's volume at 195,648 cu m, a depth of 0.91 m, and a discharge of 5,566 cu m/d or two million cu m per year. With reference to the current average condition, the natural background depth of Lake Hunter was about a meter less than current. Possibly, the Lake was shallow most of the time and the groundwater aquifer supplied the Lake in most years.

With the assumption of steady – state, the calculated natural background discharge from the Lake becomes less influenced by the shape and width of the outlet (that were only roughly estimated from available data). However, the volume of detained water depends on the elevation of the outlet. In turn, the residence time varies with the volume of the Lake, and the resident mass of Chl a (and other constituents) through the process of sedimentation may be impacted as well.

Background Mass Balance

Determination of the background condition of the Lake required the mass balance equation to be modified. Outflow from the Lake was assessed by Eq. (7). However, water level above the crest of the orifice, **h**, was not known *a priori*. The water level, h, needed to be approximated for consecutive days until the discharge from the Lake stabilized at a steady-state level. This made the calculation of the discharge for background conditions different from the current condition described in Section 4, and in which the discharge was regressed upon known water stages and antecedent precipitation.

These changes were incorporated into the spreadsheet model and the following mass continuity equation was solved:

Initial mass in lake + mass in rainfall + mass in nonpoint source + mass in ground water inflow – sedimentation = (lake's volume + Vout) X

In this equation, **Vou**t denotes the volume of annual outflow, and **X** is the unknown concentration of TP or TN in Lake Hunter. Since sedimentation is closely related to the concentration in the lake, the unknown was calculated in two steps. First, the estimate of sedimentation was assumed to be zero, and the mass continuity equation solved for concentration **X**. This value was then applied to refine the estimate of sedimentation using W. Walker's [6] algorithm and then to correct the concentration of **X**.

Before the Lake Hunter watershed was developed, groundwater from the surficial aquifer seeped into the Lake more frequently. The quality of this groundwater is not known. As the best approximation, the concentrations established by the U.S. Eutrophication Survey, and quoted in [6], was substituted for the missing data. These data are mean concentrations computed from 12 monthly stream flow samples in watersheds free of point sources. Since such limited sampling is unlikely to capture nutrient fluxes from storm runoff, the stream flow concentrations were used to represent groundwater discharges to streams. For an area in the above survey that was at least 75% forested, the concentration of TP was 0.007 mg/L and the concentration of TN was 0.23 mg/L.

The effect of eliminating Lakes Wire and Beulah, septic tanks, and converting all human landuses to forest, was that the concentration of TP in Lake Hunter dropped from 0.130 mg/L (current) to 0.033 mg/L (natural background). Similarly, the current concentration of TN of 1.750 mg/L dropped to 0.843 mg/L (natural background).

The regression equation of Dr. Reckhow from the EUTROMOD model and five models developed by Dr. Walker were tested against the annual average Chl a concentrations in Lake Hunter. The best fit was a function of TP, TN, turbidity, and flushing rate [6]

$$
\begin{aligned}
Xpn &= \{p^{-2} + [(n - 150)/12]^{-2}\}^{-.05} \\
Bx &= Xpn^{1.33} / 4.31 \qquad (8) \\
G &= Zmix\,(0.14 + 0.0039\,Fs) \\
Chl\ a &= Cc\,Bx / [(1 + 0.025\,Bx\,G)\,(1 + G\,a)]
\end{aligned}
$$

where

Chl a is chlorophyll a concentration in μg/L

p is phosphorus concentration in μg/L
n is nitrogen concentration in μg/L,
Zmix is mean depth of mixed layer, m
a is nonalgal turbidity, m^{-1}, and
Cc is calibration coefficient.

The estimate of nonalgal turbidity was also provided by Walker as

$$a = S^{-1} - 0.025 (\text{Chl } a) \qquad (9)$$

In this equation, **S** is Secchi depth, in m, that was approximated as [6]

$$S = Cs\ 16.2\ Xpn^{-0.79} \qquad (10)$$

With a calibration coefficient **Cs** equal to one, approximation (10) fit the data from Lake Hunter as seen on Figure 5.5.

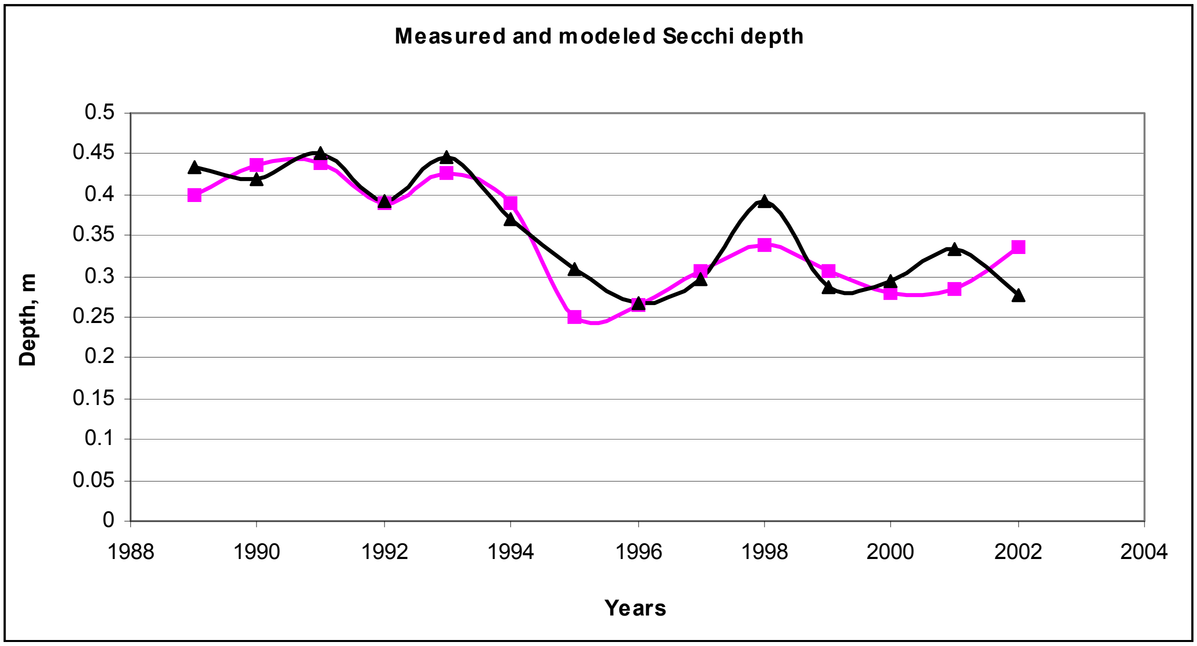


Figure 5.5 Equation (10) fits the data on Secchi depth from Lake Hunter. Pink line connects measured data.

The set of equations (8) – (10) were validated with Chl a data from Lake Hunter, as shown on Figure 5.6. The predicted Chl a concentrations matched data collected during 1991 – 2002 (with 1995 dropped), with the calibration coefficient, **Cc,** equal to 1.6.

Walker's procedure has been used to approximate **Chl a** for the natural background condition. Since the natural background Secchi depth is unknown, the concentration was calculated in iterations until an acceptable fit was obtained.

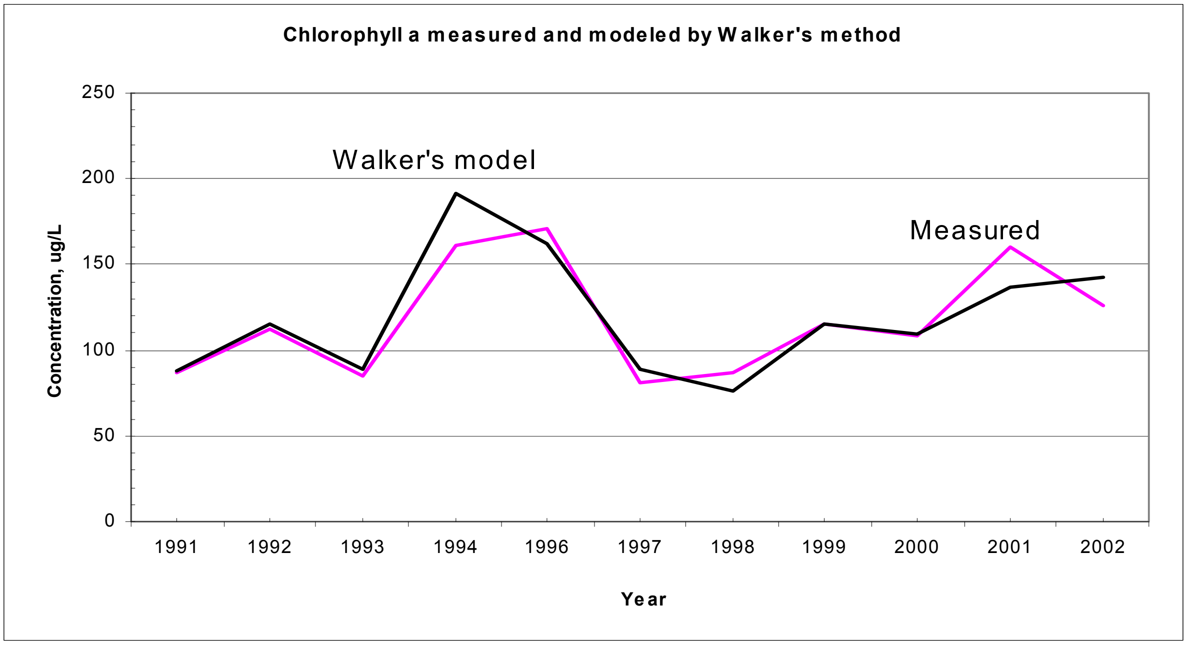


Figure 5.6. Chlorophyll concentration in Lake Hunter approximated by Walker's model

During 1991 – 2002, the range of the TN to TP ratio (N/P) was 9.8 – 16.9. In Florida, a lake is considered nitrogen-limited if the ratio of N/P is less than 10, and phosphorus-limited if the ratio of N/P exceeds 30. According to such a classification, Lake Hunter is neither clearly phosphorus nor nitrogen limited. The correlation of Chl a with either of the nutrients was found to be weak.

Based on the Walker model, the natural background chlorophyll a, TN, TP, and secchi depth were estimated as 28.9 µg/L, 0.843 mg/L, 0.033 mg/L, and 1.14 m, respectively. The resultant estimated natural background TSI for the meteorological conditions of 1991 (lowest 10th percentile TSI in period of record) was equal to **57.4**. For the comparison, and to establish the upper range of TSIs occurring prior to settlement in the basin, a similar analysis was conducted for the year 2001, which coincides with the 90th percentile TSI. For that condition, the estimated concentration of TP in Lake Hunter was 0.033 mg/L, the estimated TN was 0.873 mg/L, the estimated Chl a was 29.2 µg/L, and the estimated TSI was **57.5**. The TSI for 1991 under current conditions is **75.2** and for 2001 is **82.6**. The predicted narrow variation between worst and best case meteorological conditions for background would be expected due to evaluating the land as forest instead of the current residential/urban nature of the watershed. This is primarily related to (1) evaluating all land area as a single landuse, (2) using a lower loading function for forest over residential/urban results in an overall reduction in loadings, and (3) the use of a lower runoff coefficient for forest results in less water and less variation in runoff than use of multiple coefficients for multiple landuses. Both parameters (loading rate and runoff coefficient) are used in multiplication [Eq.'s (1) and (2)]. Therefore, any amount of rain that fell on residential land will cause a greater incremental increase in load than from forested land. In other words, the range in variation of loads (and concentrations in the Lake) coming from a watershed predominated by forest is expected to have a smaller range in variation of those loads than the same rain falling on the watershed if dominated by residential/urban landuse.

The ease of use of the spreadsheet model allowed for the calculation of natural background TN, TP, Chl a, and TSIs for the range of actual meteorological conditions over the period of 1989 – 2002. Those calculations showed moderate variability of all three parameters with the TSIs ranging between 53 and 59 during the 14 years modeled (Figure 5.7). It would appear that in it's natural state, the TSI of the Lake was always well above 40. Mass loading results for natural background are contained in Tables 5.2, 4.4, and 4.6.

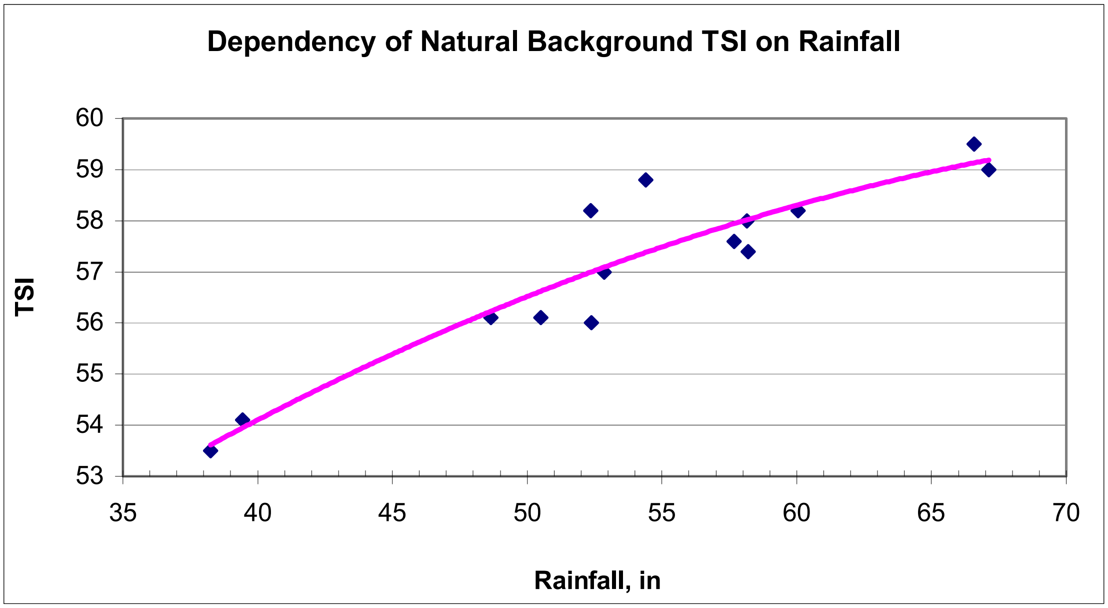


Figure 5.7 Variation of TSI with total annual rainfall in pre-developed basin of Lake Hunter. The TSIs were approximated by polynomial of second order (pink line).

5.3 Determination of Assimilative Capacity

It should be recognized that the direct application of natural background as the target TSI would not allow for any assimilative capacity. The IWR uses as one measure of impairment in lakes, a 10 unit change in TSI from "historical" levels. This 10 unit increase is assumed to represent the transition of a lake from one trophic state (say mesotrophic) to another nutrient enriched condition (eutrophic). The Department has assumed that allowing a 5 unit increase in TSI over the natural background condition would prevent a lake from becoming impaired (changing trophic states) and reserve 5 TSI units to allow for future changes in the basin and as part of the implicit margin of safety in establishing the assimilative capacity. This raises the target TSI for Lake Hunter to **63** (57.6 + 5 rounded).

Determination of Loading Capacity: Scenarios Evaluated

Several scenarios were evaluated in an attempt to determine the load that will meet the target TSI of 63 (Tables 5.2 and 4.4). For the first scenario, the meteorological conditions of 2001 were used as worst case conditions, and the spreadsheet model was run without the discharges from Lakes Wire and Beulah. This condition induced more groundwater into the Lake. This resulted in a moderate drop of the TSI for critical conditions from 82.6 to 76.3. However, in that calculation, the nutrient mass from “unknown” sources was not included. If the loads from “unknown” sources is included, the TSI would rise to 78.7.

The second scenario evaluated consisted of successive simulations in which the concentrations of TN and TP in the various sources of nutrients were reduced. The loading functions of the most influential land uses, i.e. urban open, medium density residential, high density residential, and highways were reduced by 90 percent, the septic tanks were removed, and the inflow from Lakes Wire and Beulah shut off. This lowered the TSI for the critical year (2001) to 61.6 (target TSI equals 63). In another attempt, an 85 percent reduction of the loading functions increased the TSI to 62.9, the target value.

However, there is some uncertainty related to that calculation. Although inflow from both contributing lakes was eliminated in the scenario, the volume and outflow from Lake Hunter was kept the same as estimated for the actual year 2001. There is not enough data to reliably estimate discharge, groundwater inflow, and the detention volume of the Lake at the same time. Therefore, an additional set of simulations was conducted in which the water inflow from both contributing lakes was preserved, but the nutrient content reduced in the same proportion as the watershed loading functions. In these model runs, the water volumes (and whole water budget) was the same as that resulting from the analysis of actual years, only the concentration of nutrients carried by that water was reduced. Trying several reductions, it was determined that an 80 percent reduction of nutrients in discharges from land uses - urban open, medium density residential, high density residential, and highways, and an 80 percent reduction of the loads from the two connected lakes (Wire and Beulah) should lower the nutrient concentrations in Lake Hunter to the required level. This analysis presumed that all the septic tanks in the basin were eliminated (Table 5.1).

Year	TP in lake	TN in lake	Chla in lake	TSI	Unknown Sources P	Unknown Sources N
	mg/L	mg/L	mg/L		Kg	Kg
1989	0.026	0.301	8.3	42.2	169	1,704
1990	0.048	0.567	26.0	56.5	-73	-792
1991	0.051	0.634	29.0	58.1	-90	-836
1992	0.032	0.492	18.0	51.3	204	-1,028
1993	0.037	0.494	19.8	52.5	-34	-1,328
1994	0.034	0.414	15.2	49.5	109	2,434
1996	0.038	0.425	16.4	50.6	653	5,069
1997	0.049	0.328	10.8	43.4	426	6,758
1998	0.043	0.254	5.7	36.1	-105	5,626
1999	0.042	0.357	12.6	45.4	416	4,004
2000	0.061	0.856	39.5	62.6	134	169
2001	0.061	0.871	39.2	62.6	118	2,326
2002	0.059	0.717	33.7	60.4	306	1,587

Table 5.1 Average nutrient concentrations in Lake Hunter and TSI after 80% reduction of strength of surface runoff and discharge from Lake Wire and Beulah.

The resulting estimates of concentrations in Lake Hunter are shown in Table 5.1. All years were calculated in sequence to preserve initial conditions of the Lake at the beginning of each year. A reduction of nutrient concentration by 80 percent should protect the mesotrophic condition of the Lake during all years used in this analysis. The maximum TSI would occur in 2000 and 2001 at the level of 62.6. However, these estimates assume that the unidentified mass of nutrients, tabulated in the last two columns of Table 5.1 are located and eliminated. For example, based on the water budget, during the year 2001, 118 kg of phosphorus and 2,326 kg of nitrogen entered the Lake from “unknown” source(s). This study was unable to assign that mass to any known source of pollution.

Importance of Inflows from Lakes Wire and Beulah

For most of the years during the period 1989 – 2002, loads into Lake Hunter stabilized at a similar level, yet the TSI rose in 1990, 1991, and during the last three years (2000-2002). The simple explanation for that increase was found by comparing the TSI of the Lake to the total inflow from the two northern lakes [Figure 5.8. Note that the scale for the volume discharged from Lakes Wire and Beulah (pink line) is inversed]. For years when the total inflow from Lakes Wire and Beulah was much reduced, the TSI in Lake Hunter jumped above normal. It may not be coincidental that just for the years 1991 and 2000 – 2002, the analysis predicted a net inflow of groundwater into the Lake. This indicates the importance of the inflow of water from both lakes (Wire and Beulah) to provide dilution, elevated stage, and decreased residence time in Lake Hunter. By this evaluation, it is important to keep the volume of the discharge from Beulah and Wire at current levels as a part of any management plan for Lake Hunter. Keeping the water stage in Lake Hunter high should prevent ground water, which is high in nutrients, from entering the Lake. This conclusion is valid as long as the estimated nutrient concentrations in groundwater have not been exaggerated.

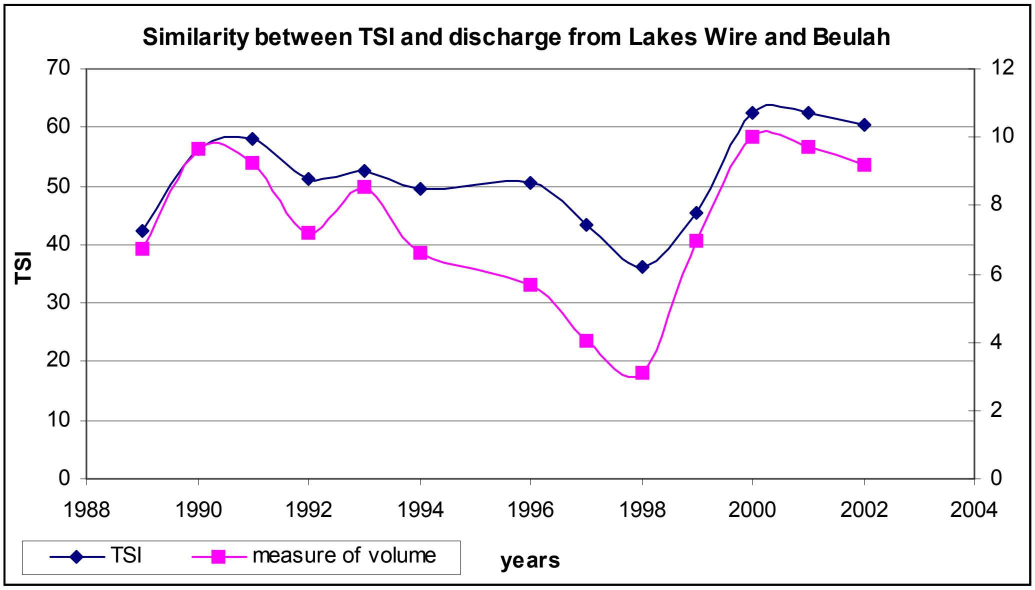


Figure 5.8 Comparison between Lake Hunter TSI and water volume discharging from Lakes Wire and Beulah into Lake Hunter. Note that the scale for the discharges from Lakes Wire and Beulah is inverted

	Average During Verified Period		Year 2001 (worst case)		Year 1991 (best case)	
	Concentration	Mass (kgs) **(lbs)**	Concentration	Mass (kgs) **(lbs)**	Concentration	Mass (kgs) **(lbs)**
Current Condition						
TN (mg/L)	2.113	8,780 **(19,356)**	2.324	7,388 **(16,288)**		
TP (mg/L)	0.173	944 **(2,081)**	0.142	556 **(1,226)**		
Chl a (ug/L)	77.514	346 **(763)**	79.02	270 **(595)**		
TSI	76.8		76.5			
Natural Background						
TN (mg/L)	0.853	1,799 **(3,966)**			0.843	1,824 **(4,021)**
TP (mg/L)	0.032	69 **(152)**			0.033	73 **(161)**
Chl a (ug/L)	28	59 **(130)**			29	62 **(137)**
TSI	57.1				57.5 (58)	
All Sources Reduced 80 %						
TN (mg/L)	0.544	2,135 **(4,707)**	0.871	2,984 **(6,579)**		
TP (mg/L)	0.05	243 **(536)**	0.061	222 **(489)**		
Chl a (ug/L)	22.529	81 **(179)**	39	134 **(295)**		
TSI	55.4		62.6 (63)			

Table 5.2 Summary table providing loads and concentrations in current, natural background, and with 80% reduction in all sources: 1991 is Critical Condition "good" year, 2001 is Critical Condition "worst" year.

Note: The meteorological conditions of 1991 were used for calculating the natural background condition (best case). The year 1991 was one of least impaired years for Lake Hunter (10th percentile year).

Note: The meteorological conditions of 2001 were used for calculating the worst case condition for determining the TMDL for the Lake. These conditions were among those that produced the highest level of impairment (90th percentile year).

Note: All sources reduced equally by 80%, except septic tank loads that were eliminated.

Note: The combination of these conditions (best case background and worst case current) was used as the critical conditions and this added to the implicit margin of safety.

Chapter 6: DETERMINATION OF THE TMDL

6.1 Expression and Allocation of the TMDL

A TMDL can be expressed as the sum of all point source loads (wasteload allocations or WLAs), nonpoint source loads (load allocations or LAs), and an appropriate margin of safety (MOS) that takes into account any uncertainty about the relationship between effluent limitations and water quality:

As mentioned previously, the WLA is broken out into separate subcategories for wastewater discharges and stormwater discharges regulated under the NPDES Program:

$$\textbf{TMDL} \cong \sum \textbf{WLAs}_{\textbf{wastewater}} + \sum \textbf{WLAs}_{\textbf{NPDES Stormwater}} + \sum \textbf{LAs} + \textbf{MOS}$$

It should be noted that the various components of the TMDL equation may not sum up to the value of the TMDL because a) the WLA for NPDES stormwater is typically based on the percent reduction needed for nonpoint sources and is accounted for within the LA, and b) TMDL components can be expressed in different terms [for example, the WLA for stormwater is typically expressed as a percent reduction and the WLA for wastewater is typically expressed as a mass per day].

WLAs for stormwater discharges are typically expressed as “percent reduction” because it is very difficult to quantify the loads from MS4s (given the numerous discharge points) and to distinguish loads from MS4s from other nonpoint sources (given the nature of stormwater transport). The permitting of stormwater discharges is also different than the permitting of most wastewater point sources. Because stormwater discharges cannot be centrally collected, monitored and treated, they are not subject to the same types of effluent limitations as wastewater facilities, and instead are required to meet a performance standard of providing treatment to the “maximum extent practical” through the implementation of Best Management Practices.

This approach is consistent with federal regulations [40 CFR § 130.2(I)], which state that TMDLs can be expressed in terms of mass per time (e.g. pounds per day), toxicity, or **other appropriate measure**. TMDLs for Lake Hunter are expressed in terms of pounds/year and percent reductions, and represent the maximum annual average load of TN and TP the waterbody can assimilate and maintain the Class III nutrient criterion (Table 6.1).

WBID	Parameter	WLA		LA (lbs/year)	MOS	TMDL (lbs/year)	Percent Reduction
		Wastewater (lbs/year)	Stormwater (% reduction)				
1543	TN	NA	80%	6,579	Implicit	6,579	80
1543	TP	NA	80%	489	Implicit	489	80

Table 6.1 TMDL Allocation

6.2 Load Allocation (LA)

The allowable LA is 489 lbs/year for TP and 6,579 lbs/year for TN. This corresponds to reductions from the existing loadings of 80 percent for TN and 80 percent for TP. It should be noted that the LA may include loading from stormwater discharges regulated by the Department and the Water Management District that are not part of the NPDES Stormwater Program (see Appendix A).

6.3 Wasteload Allocation (WLA)

NPDES Wastewater Discharges

The $\text{WLA}_{\text{wastewater}}$ is not applicable because there are no NPDES wastewater facilities present in the Lake Hunter watershed.

NPDES Stormwater Discharges

The wasteload allocation for stormwater discharges is an 80% reduction in loading, which is the required percent reduction in nonpoint sources. It should be noted that the LA may include loading from stormwater discharges regulated by the Department and the Water Management District that are not part of the NPDES Stormwater Program (see Appendix A).

6.4 Margin of Safety (MOS)

Consistent with the recommendations of the Allocation Technical Advisory Committee (Florida Department of Environmental Protection, February 2001), an implicit margin of safety (MOS) was used in the development of this TMDL. An implicit MOS was provided by the conservative decisions associated with a number of modeling assumptions. These include use of event mean concentrations for estimating runoff water quality, estimating the maximum load from septic tanks rather than average loading, use of total rainfall instead of effective rainfall for runoff calculations, use of a probabilistic approach (described in Section 5.1) to determine the worst case meteorological conditions instead of using average rainfall conditions, and the development of a site-specific alternative water quality target that estimates the assimilative capacity.

Chapter 7: NEXT STEPS: IMPLEMENTATION PLAN DEVELOPMENT AND BEYOND

Following adoption of this TMDL by rule, the next step in the TMDL process is to develop an implementation plan for the TMDL, which will be a component of the Basin Management Action Plan for the Trout Lake Basin. This document will be developed in cooperation with local stakeholders and will attempt to reach consensus on more detailed allocations and on how load reductions will be accomplished.

The Basin Management Action Plan (B-MAP) will include:

- Appropriate allocations among the affected parties.
- A description of the load reduction activities to be undertaken.
- Timetables for project implementation and completion.
- Funding mechanisms that may be utilized.
- Any applicable signed agreements.
- Local ordinances defining actions to be taken or prohibited.
- Local water quality standards, permits, or load limitation agreements.
- Monitoring and follow-up measures.

It should be noted that TMDL development and implementation is an iterative process, and this TMDL will be re-evaluated during the BMAP development process and subsequent Watershed Management cycles. The Department acknowledges the uncertainty associated with TMDL development and allocation, particularly in estimates of nonpoint source loads and allocations for NPDES stormwater discharges, and fully expects that it may be further refined or revised over time. If any changes in the estimate of the assimilative capacity AND/OR allocation between point and nonpoint sources are required, the rule adopting this TMDL will be revised, thereby providing a point of entry for interested parties.

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Appendices

Appendix A
Stormwater Regulations

In 1982, Florida became the first state in the country to implement statewide regulations to address the issue of nonpoint source pollution by requiring new development and redevelopment to treat stormwater before it is discharged. The Stormwater Rule, as authorized in Chapter 403, Florida Statutes (F.S.), was established as a technology-based program that relies upon the implementation of BMPs that are designed to achieve a specific level of treatment (i.e., performance standards) as set forth in Chapter 62-40, Florida Administrative Code (F.A.C.).

The rule requires Water Management Districts (WMDs) to establish stormwater pollutant load reduction goals (PLRGs) and adopt them as part of a SWIM plan, other watershed plan, or rule. Stormwater PLRGs are a major component of the load allocation part of a TMDL. To date, stormwater PLRGs have been established for Tampa Bay, Lake Thonotosassa, Winter Haven Chain of Lakes, the Everglades, Lake Okeechobee, and Lake Apopka. No PLRG has been developed for Trout Lake at the time this study was conducted.

In 1987, the U.S. Congress established section 402(p) as part of the Federal Clean Water Act Reauthorization. This section of the law amended the scope of the federal NPDES to designate certain stormwater discharges as “point sources” of pollution. These stormwater discharges include certain discharges that are associated with industrial activities designated by specific Standard Industrial Classification (SIC) codes, construction sites disturbing five or more acres of land, and master drainage systems of local governments with a population above 100,000 [which are better known as “municipal separate storm sewer systems” (MS4s)]. However, because the master drainage systems of most local governments in Florida are interconnected, EPA has implemented Phase 1 of the MS4 permitting program on a county-wide basis, which brings in all cities (incorporated areas), Chapter 298 urban water control districts, and the DOT (Department of Transportation) throughout the 15 counties meeting the population criteria.

An important difference between the federal and the state stormwater permitting programs is that the federal program covers both new and existing discharges while the state program focuses on new discharges. Additionally, Phase 2 of the NPDES stormwater permitting program will expand the need for these permits to construction sites between one and five acres, and to local governments with as few as 10,000 people. These revised rules require that these additional activities obtain permits by 2003. While these urban stormwater discharges are now technically referred to as “point sources” for the purpose of regulation, they are still diffuse sources of pollution that can not be easily collected and treated by a central treatment facility similar to other point sources of pollution, such as domestic and industrial wastewater discharges. The DEP recently accepted delegation from EPA for the stormwater part of the NPDES program. It should be noted that most MS4 permits issued in Florida include a re-opener clause that allows permit revisions to implement TMDLs once they are formally adopted by rule.